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Research paper

Segmented wind energy harvester based on contact-electrification and as a self-powered flow rate sensor

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ABSTRACT

A single-electrode-based segmented triboelectric nanogenerator (S-TENG) was developed. By utilizing the wind-induced vibration of a fluorinated ethylene propylene (FEP) film between two copper electrodes, the S-TENG delivers an open-circuit voltage up to 36 V and a short-circuit current of 11.8 μA, which can simultaneously light up 20 LEDs and charge capacitors. Moreover, the S-TENG holds linearity between output current and flow rate, revealing its feasibility as a self-powered wind speed sensor. This work demonstrates potential applications of S-TENG in wind energy harvester, self-powered gas sensor, high altitude air navigation.

1. Introduction

Wind energy, as one of the most universal energy sources in nature, contains a gigantic reserve of renewable and green mechanical energy [1]. Making use of this sustainable energy carries immeasurable significance in large-scale electricity generation for public utilities and is considered as an alternative to fossil fuel. In general, the wind motions can be converted into electricity based on electromagnetic [2,3] and piezoelectric effect [4–10]. Given the significantly bulky volume and cost fabrication of electromagnetic generator and low efficiency of piezoelectric nanogenerator, a light weight, cost-effective, scalable, and simple structured harvester is desperately needed to scavenge a variety of wind motions.

Recently, owing to the conjunction between triboelectrification and electrostatic induction, triboelectric nanogenerators (TENGs) have been demonstrated to harvest energy from a varieties of ambient mechanical motions, including human motion [11–14], vibration [15–18], rotating tire [19–21], sound wave [22,23], water wave and rain drops [24–26], which could be a new paradigm toward large scale energy. Through converting mechanical motion into electric signal, TENGs have been extensively utilized to successfully build up robust self-powered sensing systems with superior performance, including but not limited to tactile sensor [27], trajectory sensor [28,29], Mercury ion and ethanol sensors [30,31], and UV detector [32]. In fact, a majority of triboelectric effect based wind harvesters rely on single-electrode-mode [33–35] and contact-separation mode [36–41]. Nevertheless, the inner counteraction dramatically limits output power and device performance of these two modes. Therefore, it is highly desired to develop a novel design of TENG that can effectively inhibit the inner counteraction.

In this article, a newly designed thin film based segmented triboelectric nanogenerator (S-TENG) for scavenging wind energy was developed, which consists of copper (Cu) foils and a fluorinated ethylene propylene (FEP) thin film. Owing to the conjunction between triboelectrification and electrostatic induction, the prepared S-TENGs with a size of 10 cm × 5 cm × 2 cm can deliver an open-circuit voltage up to 36 V and a short-circuit current of 11.8 μA, corresponding to a maximum power output of 114.7 μW at external resistance of 300 MΩ, which is capable of powering tens of light emitting diodes (LEDs) instantaneously and efficiently charging capacitors. Furthermore, the prepared S-TENGs hold prominent linearity between output current and wind speed, unraveling the practicability as a self-powered sensor for detecting real-time wind speed. This work not only pushes forward a significant step toward the realization of large scale energy generation through triboelectrification but also provides a promising approach in self-powered air navigation, self-powered gas sensor, active wind vector sensor.

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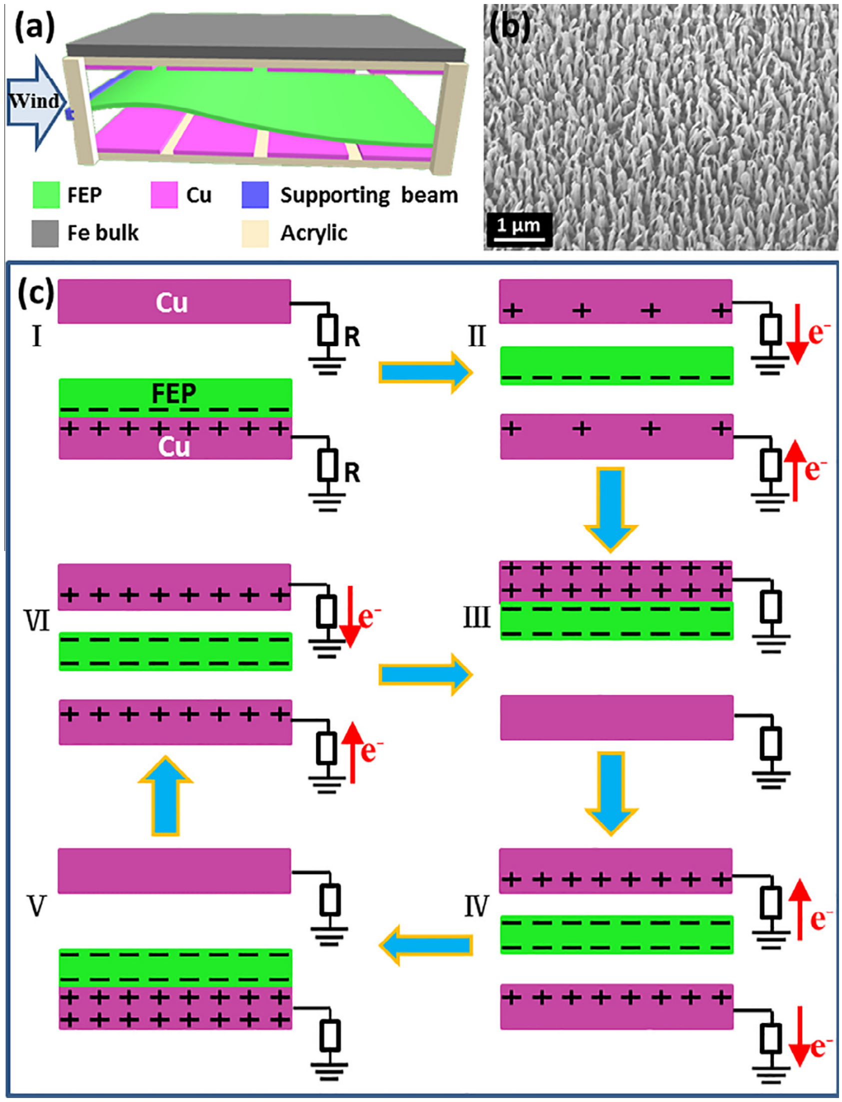

Fig. 1. Single-electrode-based segmented triboelectric nanogenerator (S-TENG). (a) Schematic diagram of the fabricated S-TENG. (b) SEM image of the FEP surface with etched nanowire structure at the tilted view of 30°. (c) Working mechanism of the S-TENG for electricity generation process in a full cycle.

2. Experimental methods

2.1. Fabrication of the S-TENG

The S-TENG is composed of a FEP thin film and two Cu foils as electrode. A 3 mm thick acrylic sheet was cut into rectangle with dimensions of 10 cm × 5 cm by precision laser cutter. A pair of tailored Cu films with a thickness of 35 μm was attached on the surface of two acrylic sheets to form the electrodes. The FEP film with a thickness of 50 μm was fixed to an acrylic supporting beam that had a separation of 1.0 mm away from the underlying electrode. Segmented electrode is realized by cutting the electrode into parallel units with similar size. The electrodes were grounded by lead wires for electric measurement. Nanowires on the surface of FEP were produced by using inductively coupled plasma (ICP) reactive ion etching. The FEP film with a thickness of 50 μm was clean with isopropyl alcohol and deionized water, then blown dry with nitrogen gas. In the etching process, Au particles were deposited by using DC sputter on the FEP surface as a mask. Subsequently, a mixed gas including Ar, O_2, and CF_4 was introduced in the ICP chamber, with corresponding flow rate of 15.0, 10.0, and 30.0 sccm, respectively. The FEP film was etched for 15 s to obtain nanowire structure on the surface. One power source of 400 W was used to yield a large density of plasma, while another 100 W was used to accelerate the plasma ions. Fe bulk was fixed on the top of the acrylic sheet to add the total weight of the device.

2.2. Characterization and electrical measurement of the S-TENG

The morphology and nanostructure of etched FEP film were characterized by Hitachi SU8010 field emission scanning electron microscopy (SEM) operated at 5 kV. The output performance of S-TENG was measured using Stanford Research Systems. Keithley 6514 system electrometer and SR570 low noise current amplifier were used to record the output voltage and current, respectively.

3. Results and discussion

The segmented configuration of the S-TENG is schematically illustrated in Fig. 1a. The copper (Cu) foil plays dual roles of electrode and contact surface. As a triboelectric layer, one end of a fluorinated ethylene propylene (FEP) film is fixed to the supporting beam, leaving the other end free-standing. The air flow vibrates the triboelectrically charged FEP film and periodically changes