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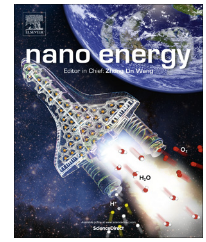

RAPID COMMUNICATION

Functional triboelectric generator as self-powered vibration sensor with contact mode and non-contact mode

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Abstract
We demonstrated a sort of self-powered vibration sensor based on a triboelectric generator (TEG) using triboelectrification and electrostatic induction effects. The as-prepared TEG delivered an output voltage of 34.06 V and short-circuit current density of 22.5 mA/m^2 corresponding to a maximum power density of 0.77 W/m^2, which was capable of driving five LEDs directly and continuously with working frequency of 50 Hz without any rectification circuit or energy storage unit. The vibration sensor has a detection range of 0–500 Hz, and high accuracy. Besides, it could realize detection under non-contact mode, which would protect the device and the detected object in operation. Moreover, the stability and repeatability could also be well retained. The TEG based vibration sensor possessed great potential in machines operation monitoring, process control, and security applications in unreachable and access-denied extreme environments.

Introduction

Scavenging mechanical energy from ambient environment has attracted increasing attention in the past decade not only for achieving self-powered systems [1-6], but also for the needs of worldwide rapid-growing energy consumptions.

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Irregular mechanical energies, such as human body motion, air flows and ocean waves were the most common, diversely presented but usually ignored in our daily life. Various approaches for harvesting mechanical energies have been developed based on electromagnetic [7,8], electrostatics [9-11], and piezoelectrics [12-16]. The triboelectric effect was a universal phenomenon that could generate electrostatic charges when different materials contacted. However, it has always been regarded as an undesirable effect for its potential hazard to electronic systems and public safety. Recently, triboelectric nanogenerator (TENG) [17-20] has been demonstrated to be an extremely simple, powerful and reliable means of harvesting ambient mechanical energy mainly using polymer-based materials.

The mechanism of TEG was based on the coupling between triboelectrification and electrostatic induction [17]. Energy conversion was achieved by periodic contact and separation between surfaces with different polarities of triboelectricity. Potential between two electrodes were induced in responding to the mechanical agitation and thus drive electrons through external load.

Detection of vibration is important for process control, machines monitoring, and security applications for unreachable and access-denied extreme environments [21-23]. Building self-powered systems was an effective and practically applicable method to maintain sustainable and independent operation of sensor networks and mobile electronics without using batteries. Here in this work, a self-powered vibration sensor based on triboelectric generator by harvesting ambient mechanical energy was designed. With a work area of 0.5 cm × 0.5 cm and a vibration frequency of 50 Hz, the electrical output of the sensor achieved a peak voltage of 34.06 V and current density of 22.5 mA/m^2 corresponding to a maximum power density of 0.77 W/m^2 with vibration frequency of 50 Hz. The proposed vibration sensor yielded accurate results in the range of 0–500 Hz, and it could work under non-contact mode which took advantages over vibration sensors based on piezoelectric effect. This work pushed forward an important step toward the practical applications of triboelectric generator as self-powered sensor systems.

Experimental

Firstly, a rectangular (5 cm × 2.5 cm) PTFE (Polytetrafluoroethylene) film with a thickness of 50 μm was washed with acetone, isopropyl, and alcohol, consecutively. It was immersed in alcohol for two hours to eliminate its surface charges before blown dry with nitrogen. Then, a thin layer of Au (100 nm in thickness) was deposited onto the PTFE film by sputter coating as the back electrode. Au-coated PTFE film was adhered to a piece of glass slide to make a flat surface with the uncoated surface exposed. During the operation, the glass slide was fixed on a stationary stage. The vibration frequency and amplitude of the plate could be controlled by adjusting the output frequency and voltage of a function generator, respectively. Finally, the conducting copper wires were connected to the two electrodes as leads for subsequent electric measurement. A digital oscilloscope (DS4052, RIGOL) was used to measure the output voltage and current of the vibration sensor. To measure the mechanical stability and robustness, the whole device was operated at a frequency of 100 Hz for 1000 s (10^5 cycles). All of the measurement was carried out in an ambient environment at room temperature.

Results and discussions

A schematic representation of the experiment setup was shown in Figure 1a. The fabricated triboelectric generator (TEG) was structurally composed of an iron plate and a PTFE film on a glass slide. The iron plate or Al plate served as the contact electrode and contact surface, and was connected to a vibration system. The vibration frequency and amplitude could be controlled by the output frequency and voltage of a function generator, respectively. The glass slide covered by PTFE film (50 μm in thickness) was fixed on a stationary stage. The effective size of the TEG was 0.5 cm × 0.5 cm.

The electricity generation mechanism of the TEG could be described by the coupling between triboelectric effect and electrostatic effect. As schematically depicted in Figure 1b–e, in the initial state where the surfaces of PTFE and Al (or Fe) overlapped and intimately contacted each other (Figure 1b), electrons would be transferred from the metal plate to the PTFE film, according to the difference of triboelectric polarities [24], with the PTFE film negatively charged and the metal plate positively charged with equal charge density. The produced negative charges would be retained on the surfaces of PTFE for an extended period of time due to its insulating property. Since the two charged surfaces were closely contacted, there was no potential drop between the electrodes. When the top plate started to move up-ward (Figure 1c), the opposite triboelectric charges formed a dipole moment due to the air gap, which established an electric potential difference between the contact electrode and the back electrode. Thus a current flowed from the contact electrode to the back electrode was induced in order to balance the potential difference. This process would continue until the top plate reached the highest position where the electrons transferred through the external circuit canceled the potential difference, leaving an equal amount of induced charges on the back electrode (Figure 1d). When the top plate moved downward, an electric potential difference with reversed polarity was generated, making electrons flow in a reversed direction (Figure 1e), which would last until the top plate reached the lowest position where the two charged surfaces were brought into intimately contact (Figure 1b). Therefore, an entire electricity generation cycle would output a cycle of alternating current signal. Figure 1f showed the output voltage during one cycle, from which one could see that an alternating voltage signal was obtained.

To investigate the performance of the fabricated TEG, output voltage and short-circuit current density (J_{sc}) were measured, as shown in Figure 2a and b. With a vibration frequency of 50 Hz, the maximum output voltage and current density were up to 34.06 V and 22.5 mA/m^2. A peak output power density of 0.77 W/m^2 has been achieved and five LEDs were driven directly and continuously with vibration frequency of 50 Hz (Figure S1, Supporting information). To further verify that the output signal was generated by the triboelectric generator, a widely used switching-polarity measurement was also conducted. As shown in Figure 2c,

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