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Full paper

Magnetically levitated-triboelectric nanogenerator as a self-powered vibration monitoring sensor

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ABSTRACT

This paper presents a magnetically levitated-triboelectric nanogenerator to harvest mechanical energy and detect acceleration of the vibratrion in the surroundings. Based on the effective conjunction of triboelectrification and electromagnetic induction, maximum power density of 3.23 W m^{-3} is obtained at 100 MΩ and 10 m s^{-2} for the triboelectric part, while the electromagnetic part can provide power density of 2.25 W m^{-2} at 1 KΩ and 10 m s^{-2}. The hybridized nanogenerator also exhibits a good stability for the output performance and a good charging performance. This hybridized nanogenerator can light up 40 commercial light-emitting diode bulbs and charge a 470 μF capacitor by using a power management circuit. Furthermore, due to the magnetically-levitated structure, the hybridized nanogenerator has been utilized as a vibrometer. It can clearly detect the vibration with the acceleration less than 30 m s^{-2} and amplitude less than 7.5 mm. This work not only presents a novel approach in the field of mechanical energy harvesting, but also a solid step towards self-powered monitoring technology.

1. Introduction

Sensors for monitoring quantities such as vibrations, temperature, ammonia concentrations, and micro-differential pressure are widely employed in the field of bridge construction and working environment supervision. These devices are convenient aides to work and life, but they also cause an increase in energy demand. Although the power consumption of these devices is low and generally provided by batteries, they are difficult to operate for extended periods of time. By contrast, harvesting energy from the surrounding environment is a promising way to power electronic devices [1–4]. In recent years, electromagnetic, piezoelectric and electrostatic generators have been fabricated to convert mechanical energy into electricity, increasing battery life and reducing the maintenance costs of the monitoring systems.

Recently, the triboelectric nanogenerator (TENG), which couples the effects of contact electrification and electrostatic induction, has been proved to be an effective means of energy harvesting [5–20]. The vertical contact-separation TENG has a high open-circuit voltage, which can be easily achieved. This makes its use convenient in any application requiring high voltage; however, the short-circuit current of the TENG is relatively low, which limits its applications. When the size is reduced, the output will be lower. It has been shown that an effective way to compensate the low short-circuit current of TENGs consists in coupling two or more energy conversion mechanisms [21–30]. Nonetheless, the complicated structure required to complete the conversion still limits their application.

In this work, we demonstrated the use of an magnetically levitated-triboelectric nanogenerator to convert mechanical energy into electricity. The device integrates two TENGs and one electromagnetic generator (EMG). It is worth mentioning that an magnetically levitated generator (MLG) has been put forward. The magnetically levitated component of the hybrid nanogenerator has high efficiency and sensitivity, due to the main magnet that can keep the suspension in the middle-position. The main magnet has two important roles. The first is to move up and down repeatedly, which is essential for the contact-separation between the two friction materials. The second is to change the induced electromotive force in the coils repeatedly and quickly, efficiently converting the mechanical energy to electricity. A characterization of the outputs of the triboelectric and magnetically levitated components has been conducted systematically. It was found that the power generated could instantaneously light up 40 LEDs, indicating that a high output can be obtained. Moreover, owing to the high sensitivity and good recovery performance of the magnetically-

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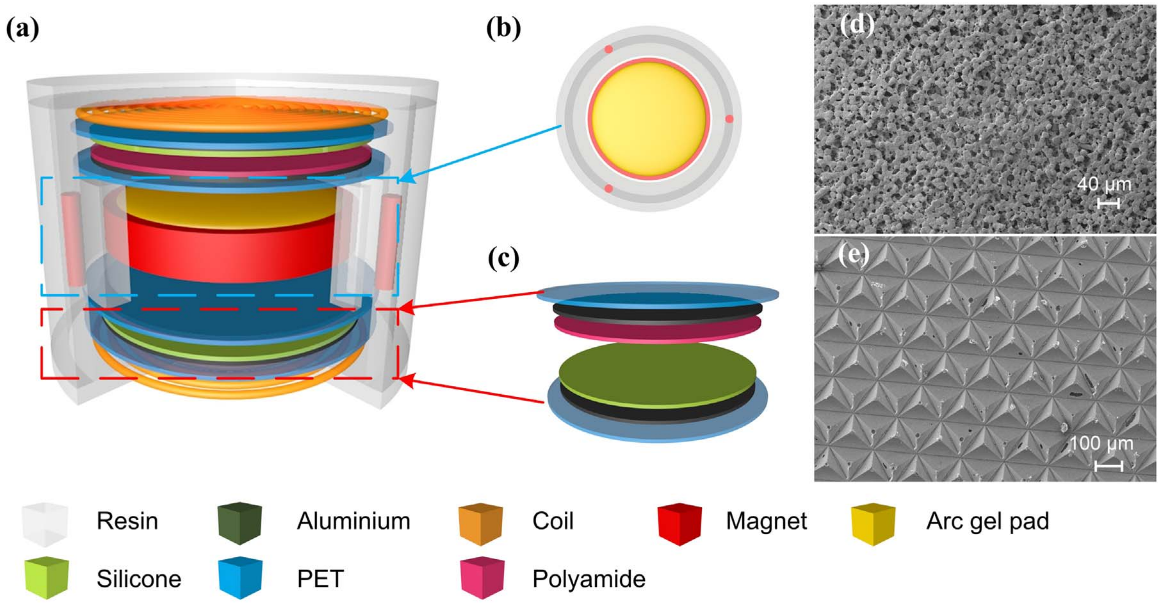

Fig. 1. Magnetically levitated-triboelectric nanogenerator. a) Schematic illustration of the hybrid generator, which consists of two TENGs and one EMG. b) Schematic illustration of the magnetically levitated generator. c) A basic unit of the TENG: one-piece membrane structure consisting of polyamide, aluminium electrode, silicone and polyethylene terephthalate (PET). d) SEM image of nylon membrane. e) SEM image of silicone thin film.

levitated structure, this nanogenerator was also demonstrated as a self-powered vibration monitoring system, which can be mainly employed to detect acceleration. Vibrations characterized by accelerations lower than 30 m s^{-2} and amplitudes below 7.5 mm can be detected. This work not only presents a novel approach in the field of mechanical energy harvesting, but also a solid step towards self-powered monitoring technology.

2. Results and discussion

2.1. Structure of the magnetically levitated-triboelectric nanogenerator

The hybrid generator consists of two TENGs and one EMG, as schematically illustrated in Fig. 1a. Fig. 1b shows the electromagnetic component. Fig. 1c shows one of the TENGs, which consists of a one-

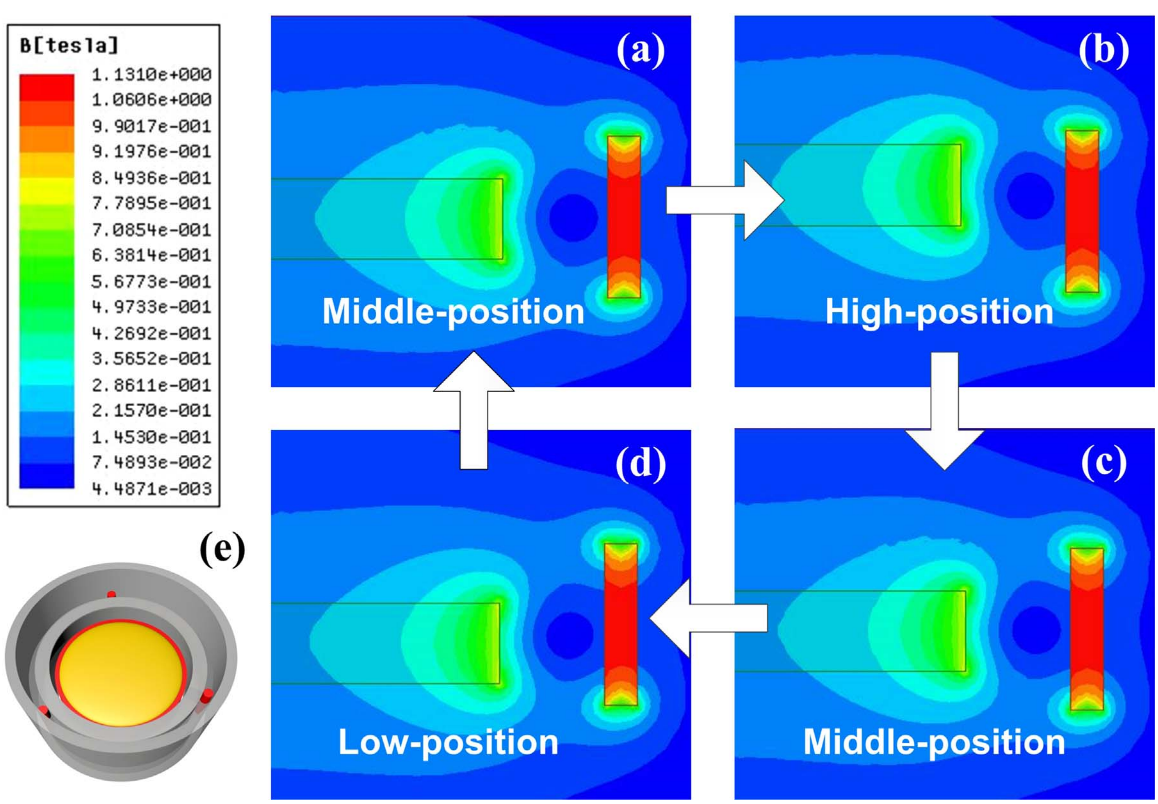

Fig. 2. Finite element simulation of MLG motion. a) Simulation of the magnetic field in the middle-position. b) Simulation of the magnetic field in the high-position. c) Simulation of the magnetic field in the middle-position. d) Simulation of the magnetic field in the low-position. e) 3D layout of the circular magnet and three cylindrical magnets.