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Hybridized nanogenerator for simultaneously scavenging mechanical and thermal energies by electromagnetic-triboelectric-thermoelectric effects

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ABSTRACT

High-efficiency rotation based energy harvesters require simultaneous scavenging of mechanical energy and rotation-induced wasted thermal energy. A hybridized nanogenerator is reported that has an electromagnetic generator (EMG), a triboelectric nanogenerator (TENG), and a thermoelectric generator (ThEG) for simultaneously harvesting mechanical and thermal energies in one process. As driven by the relative rotation motions between two disks, all of the EMG, TENG and ThEG can deliver outputs due to the cooperative operation of electromagnetic, triboelectric, and thermoelectric effects. With increasing the working time of the hybridized nanogenerator, the output power of EMG can be kept in a stable value, and an obvious increase can be seen for the output power of ThEG, while the output power of TENG exhibited a dramatic decrease. By using the power management circuits, all of the EMG, TENG, and ThEG devices can deliver a constant output voltage of 5 V, where the hybridized nanogenerator can produce a pulsed output current peak of about 160 mA. Moreover, the hybridized nanogenerator has been successfully installed in a commercial bicycle to scavenge biomechanical energy for lighting up globe lights and charging up a cell phone.

1. Introduction

Due to the challenges of energy crisis and environmental issues, more and more efforts have been impelled in looking for renewable energies in the environment to realize sustainable development of modern society [1–3]. As one of the most commonly available energies, mechanical energy has been successfully converted into electricity by some energy harvesting devices, such as electromagnetic generators (EMGs) [4,5], piezoelectric nanogenerators [6–8], and triboelectric nanogenerators (TENGs) [9–11]. Among them, TENGs have several obvious advantages of light weight, low cost, and high output power [12–16], which can be utilized to scavenge almost all forms of mechanical energies, where the rotation motions can result in the largest output power of the TENG due to high frequencies [17]. Previous investigation has indicated that a large energy loss exists in the TENG due to the friction induced heat dissipation [18], where the triboelectric effect-induced waste thermal energy can be dramatically increased in the TENG with increasing the working time of the device, especially for the high-speed rotation based TENGs. The using of a thermoelectric generator (ThEG) to scavenge the waste thermal energy is an ideal solution to minimize the energy loss in the TENG. Although the EMG has been integrated in the rotation based TENG to increase the total output power of the device [14,19], there has been no any report about the efficient integration of TENG and ThEG.

Here, we have developed a hybridized nanogenerator that can simultaneously scavenge mechanical and thermal energies due to the cooperative operation of electromagnetic, triboelectric, and thermoelectric effects. Both the EMG and TENG can deliver output voltage/current signals under the relative rotation motions between two disks. Moreover, the triboelectric effect-induced waste thermal energy can be scavenged by using a ThEG. By using the power management circuits, all the EMG, TENG, and ThEG devices can deliver a constant DC output voltage of 5 V, where the output current peak of the hybridized nanogenerator can be up to about 160 mA. Moreover, we also demonstrated that the fabricated hybridized nanogenerator can be installed in a commercial bicycle for scavenging the human motions induced biomechanical energy to drive some electronic devices or charge a cell phone.

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2. Experimental section

2.1. Fabrication of the hybridized nanogenerator

The fabricated hybridized nanogenerator includes an EMG, a TENG and a ThEG. The EMG consists of eight magnets (the diameter of 25 mm and the thickness of 1.8 mm for each one) and the corresponding eight coils (the diameter of 25 mm, the thickness of 1.2 mm, and the coil turns of about 2000), where the eight magnets with a magnetic alternating means have been set in a circular acrylic disk. The TENG includes a layer of radial-arrayed Cu strips as a triboelectric material, a layer of polyamide film (the diameter of 14.5 cm, the thickness of 50 μm) as another triboelectric material, and two sets of complementary radial-arrayed Cu electrodes, where a layer of protection layer was utilized to prevent the oxidation of Cu electrodes. The polyamide film was fixed on the protection layer. The relative rotation motions between the Cu strips and the polyamide film can drive the working of the TENG, resulting in the observed output voltage/current signals. The ThEG is composed of eight thermoelectric units with the dimensions of 4 cm × 4 cm × 0.4 cm with the connection in series. When the TENG is working, the triboelectric effect-induced thermal energy can increase the temperature for one side of ThEG, where the produced temperature difference between the two sides of the ThEG can drive the working of the ThEG.

3. Results and discussion

Fig. 1(a) presents a schematic diagram of the fabricated hybridized nanogenerator, where the device consists of a rotator and a stator. The EMG consists of eight magnets (layer 1) with the magnetic poles in alternating arrangement in an acrylic disk and eight groups of coils (layer 5) in series connection at the corresponding positions of the magnets. The TENG consists of the radially-arrayed sectors (layers 2 and 4) and the triboelectric material (polyamide film) at the middle section (layer 3), where the layer 3 was fixed on the layer 4. The ThEG is fixed in the stator (layer 6) to scavenge the waste thermal energy. Fig. 1(b) shows six optical images of the layers 1–6, indicating that the diameter of the EMG and TENG is about 14.5 cm. As displayed in Fig. 1(c), the photograph of the hybridized nanogenerator illustrates that the hybridized nanogenerator can work under relative rotation motions between the rotator and the stator.

Fig. 2(a) displays the electricity generation process of the EMG under the relative rotation motions between the rotator and the

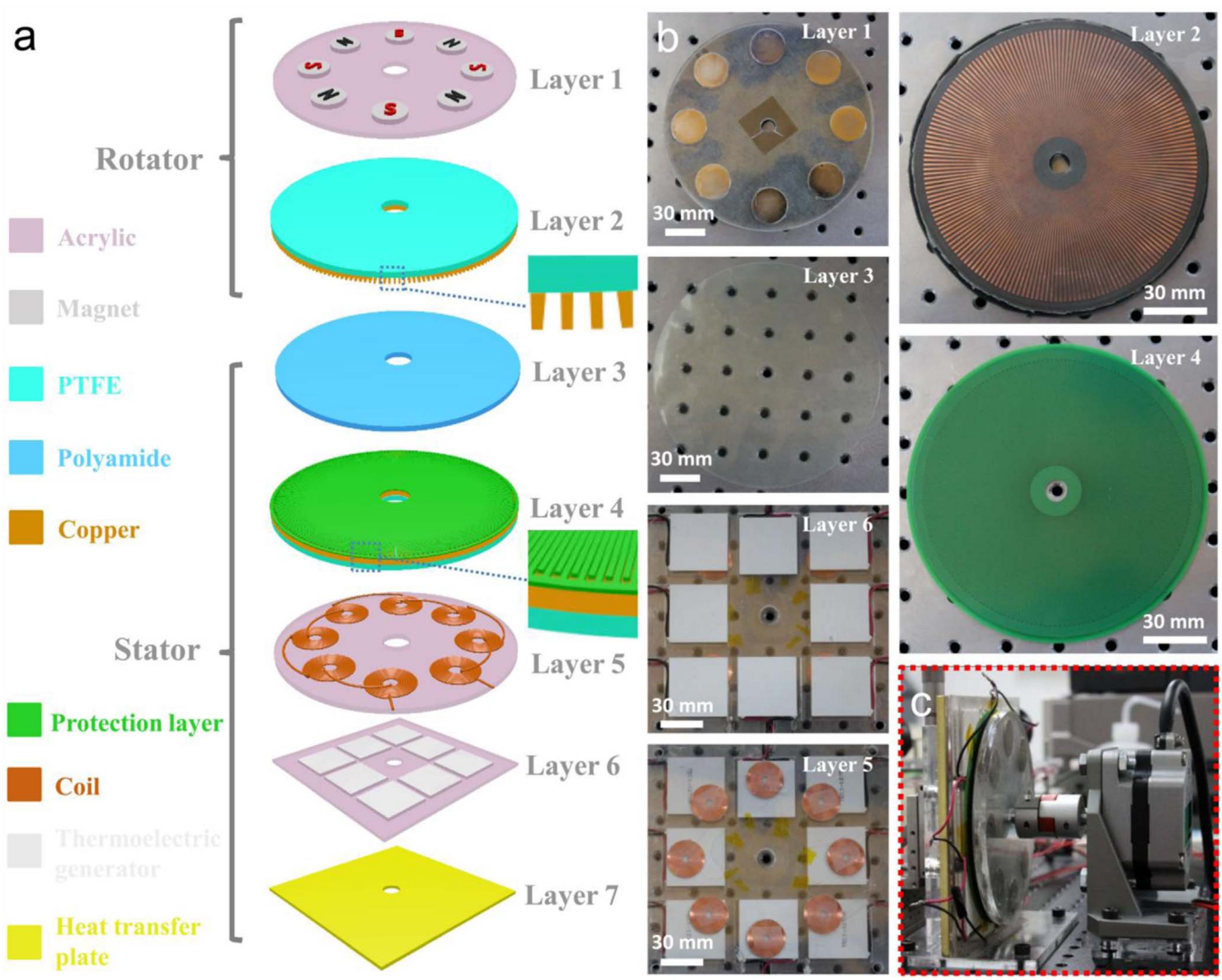

Fig. 1. (a) Schematic diagram of the fabricated hybridized nanogenerator. (b) Photographs of the hybridized nanogenerator with the different layers. (c) Photograph of the hybridized nanogenerator.