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RAPID COMMUNICATION

Harvesting energy from automobile brake in contact and non-contact mode by conjunction of triboelectrication and electrostatic-induction processes

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Abstract
Energy harvesting from moving objects and machines in our daily life, such as automobile and train, is quite important for powering portable electronics, sensor systems and high fuel efficiency. Here, we present a disc-based design that simulates the braking system in an automobile for harvesting energy when the braking pads are both in contact and in non-contact modes. The mechanisms for the design are based on a conjunction use of triboelectrification and electrostatic-induction processes. The static non-mobile charges for driving the free electrons are created by triboelectrification when the two discs of opposite tribo-polarities are in direct contact during the braking action. The process for generating electricity in non-contact mode is due to the electrostatic induction of the existing tribo-charges on the insulating pad. Our approach demonstrates an effective means for harvesting energy from a rotating disc structure during both braking and non-braking processes, with potential application in motor cycles, automobiles, and even moving trains.

Introduction

Energy is urgently needed for the sustainable development of human society in the next few decades and even centuries. Renewable energy has attracted a lot of interest due to its large-scale availability, environmental friendly

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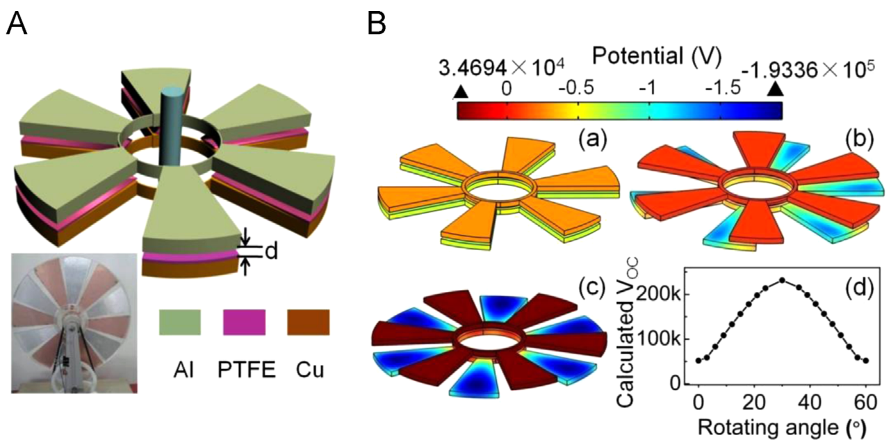

Figure 1 (A) Schematic structure of the disc-based TENG. Inset is a photograph showing the real disc-based TENG. (B) Finite-element simulation of the potential distribution for the discs (d=5 mm) at different relative rotation angles: (a) 0°, (b) 12°, (c) 24°. (d) is the simulated maximum potential difference between PTFE and Al layer as a function of relative rotation angle.

nature and sustainability [1-4]. The most popular green energy is solar energy, wind energy and hydraulic power [5-7]. Take hydraulic energy as an example; it is mainly converted into electricity via the electromagnetic induction process [8] as first discovered by Faraday. This has been the most important approach for mechanical energy conversion. Although piezoelectric effect [9,10] and electrostatic effect [11] have been used for converting mechanical energy into electricity at small scale, their efficiencies are rather low.

Recently, a new and innovative approach based on the triboelectrification effect has been invented for converting small-scale mechanical energy into electricity [12,13]. A triboelectric nanogenerator (TENG) has been demonstrated for harvesting energy in the following modes: contact-separation [14,15], lateral sliding [16,17], and double-electrode or single electrode [18]. Disc-based TENG has been demonstrated based on contact electrification [16], which raises about the wearing of the contact materials with the increase in working load and time. A common characteristic of these modes requires a direct contact of the two materials in order to harvest energy, which may give rise to issues such as durability, life time and stability for the TENG. For example, the continuous friction in the lateral sliding mode disk TENG will produce a large amount of heat and accelerate material depletion, thereby restricting its wide applications. Now let us consider a practical situation such as a disc-based braking system in an automobile. During braking, the brake pads are forced to be in contact with the rotating disc, but in the non-braking situation, for most of the time, the pad may be a bit away from the disc. Although the demonstrated TENG can harvest energy from a disc brake system during tight contact, an approach is missing for the case when the pad is off the disc with minimized friction.

Here, we demonstrate a disc shape TENG that can harvest energy in a brake system during both contact and non-contact modes. In contact mode, the TENG operates in the lateral sliding mode that is dominated by a parallel triboelectrification and electrostatic-induction processes. In non-contact mode, the TENG relies on electrostatic induction for energy harvesting. The conjunction operation of the TENG in the two modes opens a new approach for harvesting energy from a disc-based brake system, with potential applications in motor cycles, automobiles, and even moving trains.

Experimental section

The basic design of the TENG is shown in Figure 1(A). Six fan-shaped Al foils were connected by an annular electrode as an electrode/induction layer. A polytetrafluoroethylene (PTFE, 100 μm-thick) was fabricated to have the same shape as the Al layer. On the backside of the PTFE layer, a 300 nm - thick copper layer was deposited that serves as another electrode. The Al layer was attached to a polymethyl methacrylate (PMMA, 5 mm-thick) disc substrate on one side of the TENG; and the PTFE-Cu layers were attached to another PMMA disc substrate. Both parts can freely rotate with respect to each other in both contact and non-contact modes to simulate the braking and non-braking modes of a brake pad, respectively. The spacing between the Al layer and the PTFE film is defined as d. The switch between electrostatic-induction and triboelectrication can be achieved by adjusting the spacing d. All of the fan-shaped structures have an external diameter of 230 mm, inner diameter of 71 mm and a radial angle of 24°.

Result and discussion

Working mechanism of the TENG

The electric potential distribution in the Al layer and the PTFE layer at different relative rotation angles were first simulated using COMSOL. The triboelectric charge density on the surfaces of Al and PTFE was first set as $\pm 90\ \mu C/m^2$, respectively, and the spacing (d) between the two was set as 5 mm. Figure 1(B) shows the potential distribution on discs at three typical relative rotation angles: 0°, 12° and 24°. The maximum potential drop between the Al and PTFE