Nano Energy (2014) **10**, 37–43

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/nanoenergy

RAPID COMMUNICATION

Enhancing the performance of triboelectric nanogenerator through prior-charge injection and its application on self-powered anticorrosion

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Received 11 July 2014; received in revised form 21 August 2014; accepted 28 August 2014
Available online 6 September 2014

KEYWORDS
Energy harvesting;
Nanogenerator;
Charge injection;
Self-powered system;
Anticorrosion

Abstract
Corrosion is a large damage for industry, infrastructure and transport equipments such as vehicle and freighter. If the energies in environment can be harvested into electricity for the prevention of corrosion, it will be very valuable. Here, we enhanced the property of triboelectric nanogenerator and designed a self-powered anticorrosion system to protect iron from corrosion. Nanostructures fabricated through a simple method and prior-charge injection into the space between the surface of the friction layers and the electrodes were used to greatly enhance the property of triboelectric nanogenerator. The charge density was increased by 48% owing to the nanostructure and further increased by 53% owing to the prior-charge injection process. The output open-circuit voltage reached 1008 V, the short-circuit current density reached 32.1 mA/m^2 and the charge density reached 121 μC/m^2. On the basis of this high performance TENG, we developed a self-powered anticorrosion system to successfully protect a piece of iron sheet soaked in saline water from corrosion.

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http://dx.doi.org/10.1016/j.nanoen.2014.08.017
2211-2855/

Introduction

Nanogenerator (NG) is a kind of energy converter that converts mechanical energy in the environment into electric energy to power some micro/nano devices [1-5]. Recently, triboelectric nanogenerators (TENGs) have attracted much attention for high performance, durable, little maintenance and low cost [6-8]. A general TENG is made of two pieces of flexible substrates covered by materials with different triboelectric characteristics. Triboelectric charges with opposite signs are generated on the surface of the friction layers of the device by triboelectrification, and mechanical movement causes the polarization of the tribocharges, resulting in the output of electric power. So, charge density is one of the most conclusive parameters that determine the performance of a TENG. In previous works, two methods have been used to improve the charge density, using materials easier to gain/loss charges [4] and fabricating micro/nanostructures on the friction layers [5,9]. All their works increased the charge density on the surface of the friction layers and improved the performance of the TENG greatly, exhibiting wide application prospect. However, the long-term development of TENG will be limited by studying on increasing the charge density only on the surface of the friction layers. It is beneficial for enhancing TENG's performance to make full use of all the space, not only the surface but also the space between the surface and the electrodes in TENG. Therefore, we expect that, if charges can be injected into TENG directly, the performance of TENG will be improved significantly.

With the development of TENG, it has been applied in many fields such as sensors [10,11], electronics [12,13] and electrochemistry [14]. When the performance of TENG is enhanced to higher level, it is possible to be further applied in more fields even in engineering field. Materials corrosion is a large problem exists almost in all fields of national economy [15] such as energy, transportation, machinery, chemical industry. Many methods, such as physical anticorrosion [16,17], chemical anticorrosion [18,19] and electrochemical anticorrosion [20,21], have been developed to prevent corrosion. Comparing with other methods, the impressed current cathodic protection [20] is the most durable one because it does not cost other materials, but the constantly electric energy consuming leads to the problem of high energy consumption. Developing a self-powered anticorrosion technology will turn over a new leaf for the field of anticorrosion.

In this paper, we explored a very simple and cheap method to fabricate nanostructures on friction layers, and further introduce a new method which injects charges directly into the space between the surface of the friction layers and the electrodes. The charge density was increased by 48% owing to the nanostructure and further with additional 53% increase owing to the charge injection process. A new TENG with high performance was developed. The open-circuit voltage reached 1008 V and the short-circuit current reached 51.4 μA, corresponding to current density of 32.1 mA/m^2. Furthermore, we demonstrated a self-powered anticorrosion system (SPAS) on the basis of the impressed current cathodic protection using the high performance TENG as the power source. A piece of iron sheet from rusting in simulated seawater was protected successfully. The SPAS exhibits a good prospect to protect materials from rusting with low energy cost.

Material and methods

Preparation of polyamide (Nylon) and Poly (vinylidene fluoride) (PVDF) solutions

2 g Nylon was added into 18 g formic acid in a 50 mL triangular flask. The solution was stirred for 5 min to dissolve Nylon completely. 3.75 g PVDF was added into 8.5 g N.N-dimethylacetamide (DMAC) and 12.75 g acetone in a 50 mL triangular flask. The solution was stirred at 60 °C for 30 min and cooled to room temperature to dissolve PVDF completely. All the reagents above were analytically pure and used without any further purification.

Fabrication of TENG with nanostructures

Nylon and PVDF solutions were spin-coated on two pieces of Polyethylene terephthalate (PET) film, respectively, and Ag electrodes with the size of 4 cm × 4 cm were deposited on the other side of the PET films by magnetron sputtering. The PET films were fixed together at two edges with electrodes outward. The device was heated to 80 °C under bending state and then cooled down to make the device arch-shaped. The thickness of the TENG is 400 μm.

Method of prior-charge injection

The TENG was connected to a high voltage DC power, with the positive end connected with the electrode on the PET sheet with PVDF film, and negative end connected with the other electrode. The device was pressed to make the two films contact with each other and 10 kV (25 V/μm) voltage was applied on the device. After one hour, the device was released and the voltage was removed.

Results and discussion

The performance of TENG before charge injection

Figure 1a sketches the structure of the TENG and Figure 1b shows the TENG's photograph. As explained in previous studies [14], the TENG works on the coupling of contact electrification and electrostatic induction. For our TENG, Nylon and PVDF were selected as the friction because they are low cost, durable and easy to fabricate, meanwhile they have large difference in the ability of trapping electrons. When the TENG was pressed, Nylon film and PVDF film contacted and rubbed against with each other. Electrons transferred from Nylon to PVDF subsequently, which generated positive charge on the surface of Nylon film and negative charge on the surface of PVDF film according to the triboelectric series. As shown in Figure S1, when the device was pressed, the PVDF film with negative charge contacted with Nylon film with positive charge, leading to the potential of the electrode on the substrate with PVDF rise while the potential of other electrode drop. The potential difference between the two electrodes drove the charge flow forward. When the pressure released, the potential of the electrode on the substrate with PVDF dropped while the potential of other electrode raised, leading to the charge flow back.