

Full paper

Implanting a solid Li-ion battery into a triboelectric nanogenerator for simultaneously scavenging and storing wind energy

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ABSTRACT

Wind energy scavenging and storage usually can be achieved by utilizing two different separated units, such as a triboelectric nanogenerator and a Li-ion battery with need of being periodically charged. Here, we report a new strategy of implanting a flexible solid Li-ion battery (SLB) into a triboelectric nanogenerator (TENG) for simultaneously scavenging and storing wind energy into chemical energy to achieve a self-charging system. The fabricated TENG can deliver an output voltage of about 135 V and an output current of about 12 μA, which can be utilized to effectively charge the SLB in the triboelectric vibration film of TENG. The SLB can be easily charged from 1.5V to 3.5 V in about 55 s by using a transformer and a rectifier to connect the TENG. This research provides a new route of energy scavenging and storage devices for self-charging systems.

1. Introduction

As a method of energy scavenging, TENGs have been extensively utilized to scavenge all forms of mechanical energies [1–8]. Harvesting wind energy not only provides a viable method of producing renewable energy but also opens up a new path for self-powered technology without need of an external power source [9–12]. Nowadays, as a portable energy storage device, Li-ion battery is widely used in all kinds of small electronic devices. It can convert electric energy into chemical energy through driving Li-ions to move between the cathode and anode for accomplishing the electrochemical reactions [13–17]. In order to maintain sustainable operation of electronic devices, the Li-ion batteries have to face the issues of being periodically charged due to limited capacities. Especially, the main drawbacks of the Li-ion batteries are the high cost, possible environmental pollution, and difficulty of replacing battery in remote areas [18]. Moreover, the bottleneck of TENG development is no longer working principle and device structure optimization but has instead shifted toward developing the self-charging systems by integration of the TENG and energy storage devices [19–22]. By using the wind-induced vibrations of an organic triboelectric film, the TENGs can effectively scavenge wind energy in the natural environment. Although simple integrations between TENGs and Li-ion batteries have been investigated [23–25], there has no report about implanting a Li-ion battery into a TENG. The flexible solid Li-ion battery (SLB) may be utilized to realize the

inner hybrid of Li-ion battery and TENG.

Herein, we present a novel strategy of implanting a SLB into a triboelectric fluorinated ethylene propylene (FEP) film of TENG to simultaneously scavenge and store wind energy into chemical energy, so that the TENG and the SLB are hybridized as a single unit. Through the coupling of contact triboelectrification and electrostatic induction, the self-charging system has been achieved due to wind-induced vibrations of the FEP film between the two Cu foils. The fabricated device can generate an output voltage of about 135 V and output current of 12 μA under the wind speed of 24.6 m/s, where the corresponding largest output power is about 0.66 mW under a loading resistance of about 12 MΩ. The output voltage and current of the device after using a transformer are about 9 V and 0.25 mA, which can be utilized to effectively charge the SLB from 1.5V to 3.5 V in about 55 s.

2. Experimental section

2.1. Preparation of Li_{1.3}Al_{0.3}Ti_{1.7}(PO₄)₃

LATP powder was prepared by sol-gel method. The raw materials for LATP synthesis were Li(CH₃COO)·2H₂O, Al(NO₃)₃·9H₂O, Ti(OC₄H₉)₄ and NH₄H₂PO₄, with the stoichiometric ratio Li: Al: Ti: P = 1.3:0.3:1.7:3.0. The typical synthesis process was as follows: Ti(OC₄H₉)₄ was dissolved in a mixed solution of deionized water and

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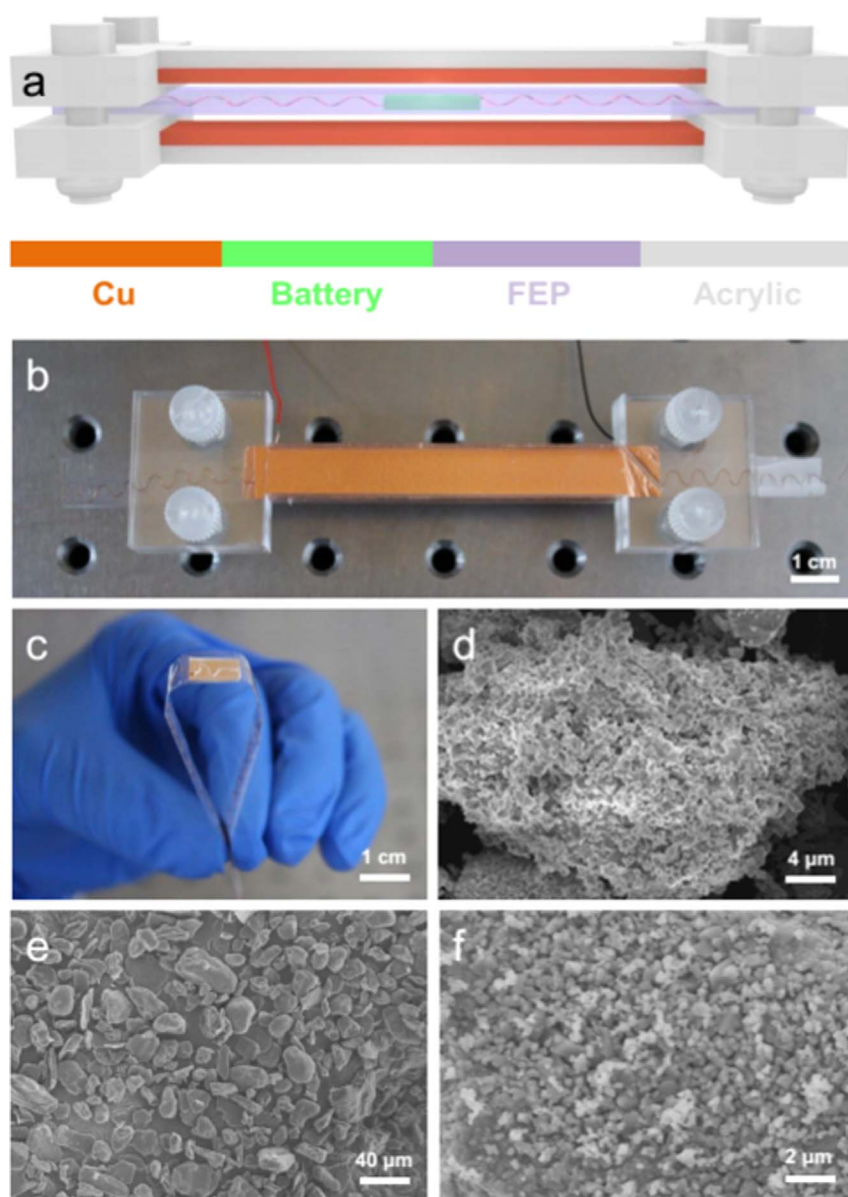


Fig. 1. Detailed structure of the fabricated device. (a) Schematic diagram of the fabricated device. (b) Photograph of the device. (c) Photograph of the solid Li-ion wrapped in FEP film. (d–f) SEM images of LATP (d), graphite (e) and LiMn_2O_4 (f).

concentrated nitric acid in a volume ratio of 4: 1, and the mixture was continuously stirred with a magnetic stirrer to form a homogeneous solution. Then, the CH_3COOLi and $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ were added to the above solution until it is completely dissolved. A certain amount of citric acid as a complexing agent to the solution was prepared to obtain a transparent homogeneous solution, where the molar ratio of citric acid and metal ion is 1.5: 1. The solution's PH value was adjusted to about 5 with aqueous ammonia, and subsequently $\text{NH}_4\text{H}_2\text{PO}_4$ and dispersant ethylene glycol were dissolved in the solution. After a homogeneous solution was obtained, it was heated to remove H_2O at a temperature of 170°C to facilitate the progress of the polymerization and esterification reactions until a gel was formed. Then the obtained gel was dried in a blast oven to obtain a black sample at a temperature of 180°C for 1 h. The sample was calcined in the muffle furnace at 850°C for 5 h at a heating rate of $2^\circ\text{C}/\text{min}$ to obtain LATP powder, and then was grinded in the agate mortar for 30 min.

2.2. Preparation of polyethylene oxide (PEO)-LATP electrolyte membrane

The composite PEO-LATP electrolyte membrane was prepared with the mass ratio among LATP, PEO and bistrifluoromethanesulfonimide

($\text{LiN}(\text{CF}_3\text{SO}_2)_2$) as 8: 2: 1. PEO powder was completely dissolved in acetonitrile, and then LATP and $\text{LiN}(\text{CF}_3\text{SO}_2)_2$ were added into the above solution under continuous stirring until a homogeneous solution was obtained. The mixed solution was poured into a plastic mold and placed on a horizontal tabletop. After natural drying, the membrane was pulled off from the substrate to obtain the PEO-LATP electrolyte membrane.

2.3. Preparation of electrode

The LiMn_2O_4 electrode was prepared in aqueous solution with the mass ratio of LiMn_2O_4 , Polyvinylpyrrolidone (PVP), and acetylene black as 8: 1: 1. The PVP was weighed with an electronic balance into the deionized water to form a 6% solution and stirred for 3 h. The acetylene black was added and stirred for 1 h, and finally LiMn_2O_4 was added and stirred for 8 h. The obtained homogenate evenly coated on aluminum foil thickness of $10\ \mu\text{m}$. The Al foil was placed in an electric blast drying oven, dried at 80°C , and subsequently transferred to a vacuum oven at 80°C for about 24 h to obtain the positive electrode. The preparation of graphite electrode was the same as the LiMn_2O_4 electrode, while the electrode is Cu foil.

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