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Electrical Power Generation from Randomly-Oriented Electrospun Nanofibrous Nonwoven

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ABSTRACT

In this study, we have demonstrated that randomly-oriented electrospun PVDF nanofiber nonwovens can be used directly as an active layer to generate electrical power with a voltage output as high as 4 volt and current 4 micoramp scales on a small nonwoven piece. This discovery may provide a simple, efficient, cost-effective and flexible solution to self-powering of microelectronics for various purposes.

1. INTRODUCTION

Powering of miniature electronic devices by scavenging small mechanical forces from local environment provides a promising way to run the devices sustainably. For this purpose, electrical power generators from inorganic nanowires have been developed (Wang 2006 and Xu 2010). Inorganic nanowires, however, are typically brittle, and they have to work on a limited strain level. The electrical outputs of the inorganic nanowire-based power-generator are low also, typically in tens of millivolt. Recently, the research has moved onto using polymer nanofibers to harvest mechanical energy. For example, single poly(vinylidene fluoride) (PVDF) nanofibers (Chang 2010) and aligned PVDF nanofiber array (Hansen 2010) have been reported separately to prepare nanogenerators. Despite the improved flexibility of polymer nanofibres, the reported devices are still low in electrical outputs.

In our recent study (Fang 2011), we found that randomly-oriented electrospun PVDF nanofiber nonwovens can be used directly as an active layer for making electrical power generator. The device under mechanical deformation can produce a much improved electrical outputs with a reasonable energy conversion yield. The power generation is stable over a long working period. Here, we report on that the preparation of the nanofiber power generators and their unusual energy conversion performance.

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2. APPROACH

A homogeneous PVDF/DMF (16%, w/v) solution was electrospun into nanofiber nonwoven mat using a conventional electrospinning setup. The power generator device was prepared simply by sandwiching an as-spun PVDF nonwoven membrane between two metal foils.

3. RESULTS AND DISCUSSION

PVDF nanofiber membranes were prepared by an electrospinning setup illustrated in Fig. 1a. The nanofibers have an average diameter of 183±37 nm and show a rough surface (Fig. 1b). The Fourier Transform Infrared (FTIR) spectrum and the X-ray diffraction (XRD) data of the nanofiber membrane and cast PVDF film, shown in Fig. 1c & d, confirm that electrospinning process favors the formation of β phase PVDF crystalline over casting.

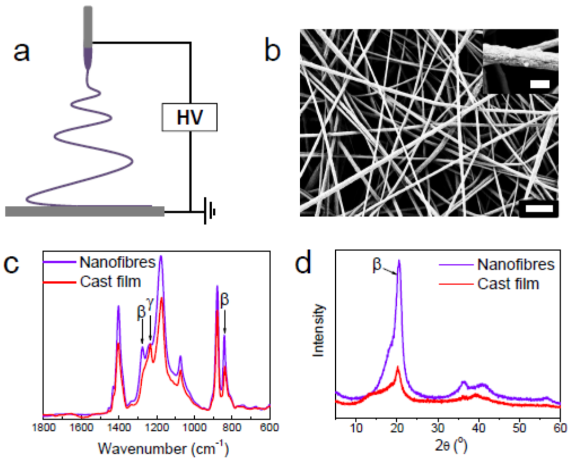

Fig. 1. a) Electrospinning setup, b) SEM images of electrospun PVDF nanofibers (scale bar: 2 μm, inset scale bar: 200 nm). c) FTIR spectra of electrospun PVDF nanofibers and PVDF cast film. d) XRD patterns of electrospun PVDF nanofibers and PVDF cast film.

It was found that the polarity of the outputs was determined by the device side that received the compressive impact and the way to connect with the electrochemistry working station. When the electrode that received the compressive impact was connected to the counter electrode, while the opposite electrode was connected with the working electrode, a positive front output followed by a negative back output was always detected. However, when the connection was reversed, the outputs reversed the polarity.

Fig. 2a shows the structure of the assembled power generator device, it contains an electrospun PVDF nanofibre layer and two thin electrodes. Upon rapidly compressing the device from one side, two pulse voltage outputs with an opposite polarity were generated. The first signal was derived from the compressive deformation of nanofibers within the membrane, while the subsequent opposite output was attributed to the recovery deformation of the compressed nanofiber due to the release of the impact force. Repeatedly impacting the nanofibre membrane led to a continuous alternation of positive and negative voltage signals (Fig. 2b & c), a typical characteristic of AC power.

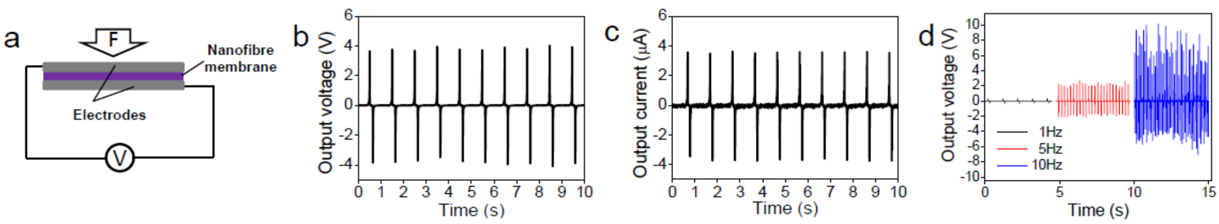

Fig. 2. a) Schematically illustration of the power generation device, b) voltage and c) current outputs of a nanofiber device under a 1 Hz compressive impact (working area, 16 cm^2), d) relationship between impact frequency and the voltage output (working area, 2 cm^2)

Impact frequency is an important factor affecting the electrical outputs. For a nanofiber membrane device with the working area of 2 cm^2, under the compressive impact frequency of 1 Hz, the average peak voltage output was 0.43 V. When the impact frequency was increased to 5 Hz, the voltage output became 1.75 V. Further increasing the frequency to 10 Hz led to the output voltage reaching up to 6.5 V (Fig. 2d). The frequency-dependent voltage output originates from the influence of initial impact speed. For the impact frequency of 1, 5, and 10 Hz, the initial impact speed is 6.8, 34 and 68 mm/s, respectively. Such a high voltage generated by a low initial impact speed is beneficial in harvesting electrical energy from movements of human body.

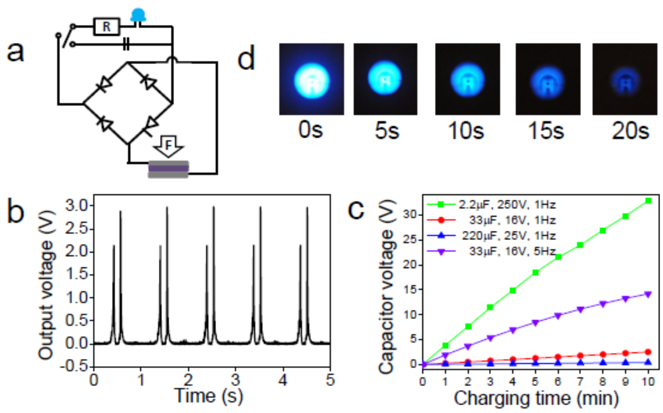

Fig. 3. a) Circuit for charging a capacitor and lighting a LED device, b) DC voltage output rectified from 1 Hz compressive impact of a 16 cm^2 nanofiber membrane, c) voltage ~ charging time relationship for a nanofiber membrane device loaded with different capacitors, d) still frames captured from a video showing the continuous lighting of a blue LED.

To convert the voltage outputs to DC signals, a full wave rectifier bridge was used (Fig. 3a) and the rectified voltage output reached 2.5 V (Fig. 3b). Fig. 3c lists the voltage ~ charging time relationship of a nanofiber device. Increasing the impact frequency increased the charging speed. It took around 1 minute to charge a 2.2 μF capacitor to over 3 V at 1 Hz. The changing time was shortened to 20 seconds when the working frequency increased to 5 Hz. The time needed to charge a 33 μF capacitor to light up a commercial blue LED was about 6 minutes. When a 200 kΩ resistor was used to stabilize the output voltage, the one-time charged capacitor could light the LED for over 20 seconds before complete consumption of the power, as illustrated in Fig. 3d.

CONCLUSION

We have demonstrated a novel fabrication of PVDF nanofiber membrane-based power generating devices that can convert mechanical energy to electrical power with a voltage output as high as 4 volt and current 4 micoramp scales. It may provide a simple, efficient, cost-effective and flexible solution to self-powering of microelectronics for various purposes.

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