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Proceeding Paper

The Energy Harvesting Performance of a Flexible Triboelectric-Based Electrospun PTFE/PVDF Fibre †

Pattarinee White [1,*], Dmitry Bavykin [2], Mohamed Moshrefi-Torbati [3] and Stephen Beeby [1]

1 Centre for Flexible Electronics and E-Textiles, University of Southampton, Southampton SO17 1BJ, UK
2 Energy Technology Research Group, University of Southampton, Southampton SO17 1BJ, UK
3 Mechatronics Research Group, University of Southampton, Southampton SO17 1BJ, UK
* Correspondence: p.white@soton.ac.uk
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Abstract: A triboelectric power generator/energy harvester is an attractive option for mechanical energy harvesting for smart, wearable applications. This paper reports on the fabrication and evaluation of the energy harvesting performance of Polytetrafluoroethylene/Polyvinylidene Fluoride (PTFE/PVDF) fibre prepared using a one-step electrospinning technique. Different concentrations (0, 1, 2, 3, and 4%wt.) of the 1 µm PTFE powder in the electrospun PVDF fibre were investigated. The electrospun fibre was assembled into a nonwoven fabric mat and tested in the vertical contact separation triboelectric mode by constructing a sandwich structure with electrodes in a book-shaped assembly. The voltage output from the cyclical compressive test for fibres with 4%wt. PTFE in PVDF was five times greater than it was for the 100% PVDF electrospun fibres. The influence of adding nylon fabric as a triboelectric donor material within the assembly was explored. The output of the 4%wt. PTFE/PVDF sample was then tested with and without nylon fabric at different frequencies (3–12 Hz). The results show a further 80% increase in the output voltage with the additional nylon fabric included, and the harvester was able to illuminate up to 95 LEDs.

Keywords: triboelectric; textile energy harvester; electrospinning; electrospun fibre

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1. Introduction

Polytetrafluoroethylene (PTFE) has good thermal stability, and is the most negative triboelectric material listed in the triboelectric series that are used for energy harvesting applications [1]. Increasing the surface area of the PTFE within a triboelectric harvester is one approach to improve the output of the harvester. Previous attempts to prepare PTFE fibre mats using the electrospinning process involve the use of a precursor polymer solution in order to structure the shape of the PTFE. This requires a subsequent thermal treatment to eliminate the precursor polymer and, if it is used in an electrostatic device or to enhance the triboelectric generation, a corona charging process to restore the trapped charge in the PTFE fibre. The PTFE fibres produced in this manner show good energy harvesting performances, but they require two or more steps in the material preparation [2–5]. Electrospun Polyvinylidene Fluoride (PVDF) fibre has been recognised as a high-performance piezoelectric polymer [6], which also exhibits negative triboelectric properties [1]. PTFE and PVDF can be combined during electrospinning, and this avoids the requirement for the precursor polymer and the subsequent additional processes. The use of electrostatically charged electrospun PTFE/PVDF has been demonstrated in air filtration [7], but its energy harvesting performance has not yet been reported.

The combined PTFE/PVDF fibres can be readily assembled into a non-woven textile, allowing the material to be used in various triboelectric operating modes, such as the lateral sliding mode demonstrated by Paosangthong et al. [8]. The fabrication and testing of the energy harvesting performance of PTFE/PVDF fibre is reported.

2. Materials and Methods

2.1. Electrospinning Preparation

The PTFE/PVDF electrospun fibre was produced by mixing PTFE particles (Sigma Aldrich, Dorset, UK, 1 micron particles) in an 18%wt PVDF solution as a polymer carrier for PTFE. The PVDF solution was prepared from PVDF powder (Sigma Aldrich, Dorset, UK, Mw = 534,000) mixed with N-Dimethylformamide (DMF, Sigma Aldrich, Dorset, UK, 99.8%) and acetone (Fisher Scientific, Waltham, MA, USA, 99.6%) at a 7:3 ratio and mixed on a magnetic hotplate stirrer at 60 °C for 4 h. Different concentrations (0, 1, 2, 3, and 4%wt.) of the PTFE particles were added to the PVDF solvent solution and blended using the magnetic stirrer at room temperature for 2 h. The electrospinning process was performed using a blunt tip (21 G) needle. The electrospinning apparatus EC-DIG produced by IME Technologies, Netherlands was used in this study. The distance from the tip to the substrate, the applied voltage, the flow rate, and the rotating drum speed were kept constant at 22 cm, 25 kV, 2 mL/hr, and 150 rpm, respectively, for each concentration. After electrospinning for 90 min, the PTFE/PVDF fibre was collected in the form of a nonwoven fibre mat, as shown in Figure 1a. The energy harvesting performance of the electrospun PTFE/PVDF fibre mats were measured without any further processing steps.

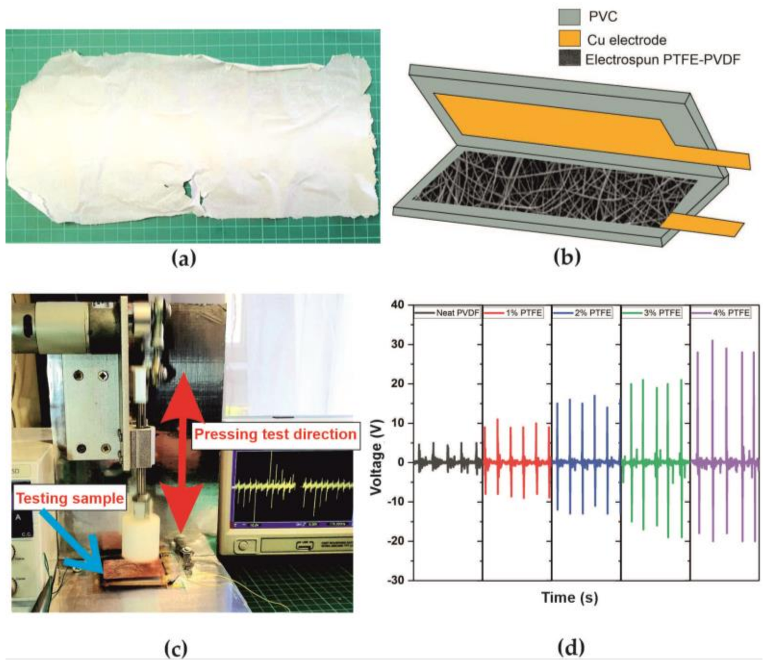

Figure 1. (**a**) PTFE/PVDF fibre mats after the electrospinning process of the 4%wt PTFE in the PVDF sample; (**b**) the schematic of the booked shape assembly for the testing cell PTFE/PVDF fibre sandwich with electrodes; (**c**) the compression test rig; (**d**) voltage output from constantly tapping the booked shape PTFE/PVDF fibre assembly at different PTFE concentrations of 0, 1, 2, 3, and 4%wt., respectively.

2.2. Test Assembly and Protocol

The electrospun PTFE/PVDF fibre mats with each concentration of PTFE (0, 1%, 2%, 3%, and 4%) were cut into 5 × 4 cm samples. Each sample was then assembled in a sandwich structure with Cu electrodes using a folded over (book-shaped) PVC sheet backing, as shown in Figure 1b. This forms a vertical contact separation mode triboelectric harvester. A second generator design with a piece of nylon fabric added to the assembly as a triboelectric donor material was used to explore the addition of this material for the enhancement of the performance of the triboelectric power generator.

A cyclical compression test system using a linear actuator was set up to apply a controlled pressure of 0.5 N/cm^2 at different frequencies (3–12 Hz), as shown in Figure 1c.

The test sample was attached to the oscilloscope to observe the changes in the voltage induced by the periodic mechanical pressure applied by the rig. The capacitor charging experiment was performed using a full-wave bridge rectifier to charge 0.1, 1, 10, and 100 µF capacitors.

3. Results and Discussion

The vertical book-shaped structure was chosen for energy harvesting performance testing as it is a simple structure and could be assembled into a multi-layered device. The highest voltage output from compressing at 5 Hz was found to be 30 V for the 4%wt PTFE, which is five times higher than that of the 100% PVDF sample (6 V), as shown in Figure 1d. This clearly shows that introducing the PTFE particles in the PVDF fibre can improve the performance of triboelectric power generators. The output voltage increases with an increasing percentage of PTFE particles. However, 4% PTFE is the highest amount of polymer content that can be processed via electrospinning because the solution conductivity is not strong enough to produce the electrospun fibre.

The 4% PTFE in the PTFE/PVDF sample was used in the energy harvesting test at different pressing rates of 3–12 Hz. It was found that the output voltage increases with an increasing pressing frequency. The highest output voltage of around 55 V was found at 12 Hz, as shown in Figure 2b. To enhance the energy harvesting performance of the triboelectric power generator, nylon fabric, which exhibits a high positive affinity in the triboelectric material series, was placed on top of the top copper electrode as shown in Figure 2a. The voltage output of the Nylon-PTFE/PVDF device at the different pressing frequencies is shown in Figure 2c. A small improvement in the voltage output was observed with the highest voltage output, which reached at 70 V at 12 Hz.

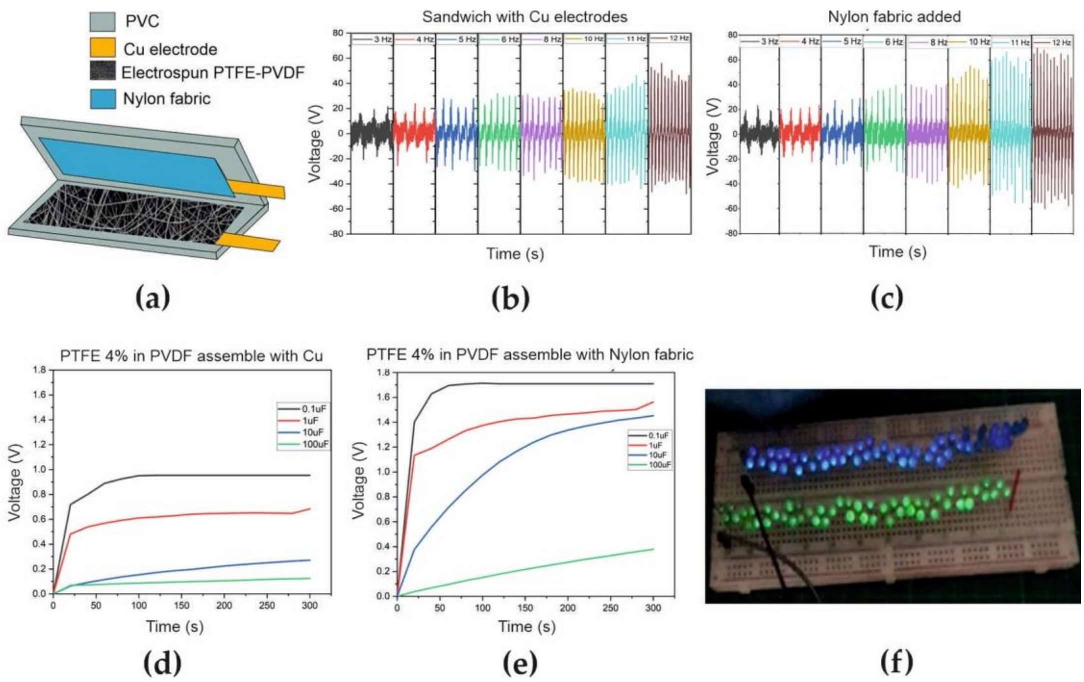

Figure 2. (**a**) The schematic of the improved triboelectric harvester design with added nylon fabric, (**b**) the voltage output of the triboelectric assembly without nylon fabric, (**c**) the voltage output of the triboelectric assembly after introducing nylon fabric, (**d**) the charging profile, voltage vs. time of the PTFE/PVDF fibre device without nylon fabric, (**e**) the charging profile after introducing nylon fabric and (**f**) 95 LED lights were illuminated via tapping the harvester with the PTFE/PVDF electrospun fibres as the acceptor and nylon fabric as the donor material.

The charging experiment was further performed to explore and compare the amounts of energy captured by the device and transferred to the capacitor storage. Devices with and without the nylon fabric were tested at 5 Hz with the different capacitor values, and the results are shown in Figure 2d,e. Overall, the energy stored in the capacitors is higher for the nylon-PTFE/PVDF device, with the amounts of energy stored being 0.15, 1.0, 7.2 and 4.5 µJ for 0.1, 1, 10 and 100 µF, respectively. The maximum energy stored value occurs with the 10 µF capacitor, which nearly reached its maximum capacity in the 300 s charging time. This is 69%, 79%, 94% and 89% larger than those of the device without nylon for 0.1, 1, 10 and 100 µF, respectively. The energy stored in the 100 µF capacitor is less than that of the 10 µF capacitor over the same duration due to the impedance mismatch.

After connecting the optimum harvester structure (4% PTFE with Nylon fabric) to a full-wave bridge rectifier circuit, it was found that 95 LED lights were illuminated when it was compressed at 12 Hz. The charging experiment and illuminating LED light results demonstrate the promising mechanical energy conversion that was achieved with the electrospun PTFE/PVDF fibre mat. The lightweight, flexible, and breathable PTFE/PVDF electrospun fibre could be integrated within clothing as an energy source, whilst remaining comfortable for the user.

4. Conclusions

A flexible Polytetrafluoroethylene (PTFE) fibre was successfully prepared using a one-step electrospinning process using a Polyvinylidene Fluoride (PVDF) solution as a precursor. The energy harvesting performance was first explored using a vertical contact separation mode triboelectric assembly. The electrospun fibres were collected in the form of a non-woven textile mat, which displayed a very promising negative surface potential. The voltage output was increased by a factor of five by adding PTFE to the PVDF electrospun fibre. This was further improved by the addition of a nylon fabric with the triboelectric harvester. The textile harvester was shown to illuminate up to 95 LED lights when it was assembled with nylon fabric as a donor material.

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Conflicts of Interest: The authors declare no conflict of interest.

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