

Piezoelectric P(VDF-TrFE) Thick Film Based Micro-power Generator Using Flexible Substrate for Wearable Applications



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Abstract Energy harvesting, non-toxic and flexible sensing capability have attracted enthusiasm for the potential variety of devices in Internet of things (IoT), wearable and biomedical applications. In this paper, usage of non-toxic lead-free piezoelectric material, P(VDF-TrFE) as a polymer piezoelectric material for developing thick-film based flexible piezoelectric micro-power generator. The P(VDF-TrFE) thick film was prepared by solution casting in between of top and bottom electrodes on top of PET substrate. Fabrication and characterization of the P(VDF-TrFE) thick film were examined by EDX, FESEM, XRD and ferroelectric tester. In order to prove the flexible P(VDF-TrFE) piezoelectric micro-power generator applications, a sample of the fabricated P(VDF-TrFE) film was mounted in such way that it directly hit by the blades of a rotating D.C fan. It generated a maximum open-circuit output voltage of 14 V when the D.C fan operated at rotational speed of 20 cps.

Keywords Energy harvesting · P(VDF-TrFE) · Thick film · Wearable applications

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1 Introduction

Nowadays, wearable technology have captured a large market share in latest trending products. Consumers become increasing conscious of their daily activities such as monitoring their health and exercise using wearable devices with Internet of thing capability [1–3]. These flexible electronics consists of sensors, display, and smart system. The consumers also look for wearable devices which are flexible, environmental friendly, comfortable and safe to be worn. Wearable device allows the device to conform to our bodies by seamlessly integration into any attires that we wear. The flexible and wearable devices are stretchable, thus do not constrain and fix to any rigid surface. Currently, most of the wearable devices are powered by bulky batteries with limited lifespan. This problem is overcome by using micro-power generator based on P(VDF-TrFE) polymer piezoelectric thick film.

Poly(vinylidene fluoride trifluoroethylene) [P(VDF-TrFE)] is a high performance polymer piezoelectric materials used in the energy harvesting applications. This P(VDF-TrFE) could be used as sensors, wearable devices, flexible electronic devices, actuators and energy harvester. The polymer piezoelectric materials incur low cost in manufacturing, has mechanical flexibility and low processing temperature. It is an environmentally friendly materials as compared with PZT piezoelectric materials [4–6]. The PVDF material exists in crystalline form of alpha, α -phase and is nonpolar. In order to increase the degree of crystallinity of P(VDF-TrFE), it required hot plate annealing and poling are applied [7, 8].

In this paper, thick-film based P(VDF-TrFE) piezoelectric using solution casting is demonstrated. Then, the P(VDF-TrFE) thick film were examined by EDX, FESEM, XRD and ferroelectric tester. Finally, mechanical tapping on the P(VDF-TrFE) was conducted to prove the piezoelectric response to mechanical energy and the conversion of electrical energy in application of micro-power generator.

2 Experiment Setup

The P(VDF-TrFE) solution was prepared by dissolving P(VDF-TrFE) powders (Kureha, 12.5 wt.%, 75/25 mol%) in dimethylformamide liquid medium (DMF, Sigma Aldrich) by mechanical stirring at room temperature for 12 h. At this point, the solution was drenched in ultrasonic bath for 30 min so that the solution was fully dissolved. The well-mixed P(VDF-TrFE) solution were casted on a flexible substrate, PET which pre-coated bottom electrode and then slow evaporated under infra-red light at 80 °C for 30 min. After that, the samples were cured in oven at 60 °C for 4 h in order to remove unwanted residual solvent. Finally, the P(VDF-TrFE) thick film was sandwiched by top electrode layer (see Fig. 1).

Subsequently, the materials processing and fabrication, the fabricated P(VDF-TrFE) thick film micro-power generator was demonstrated by using finger tapping method (see Fig. 2) for output voltage in open circuit [9].

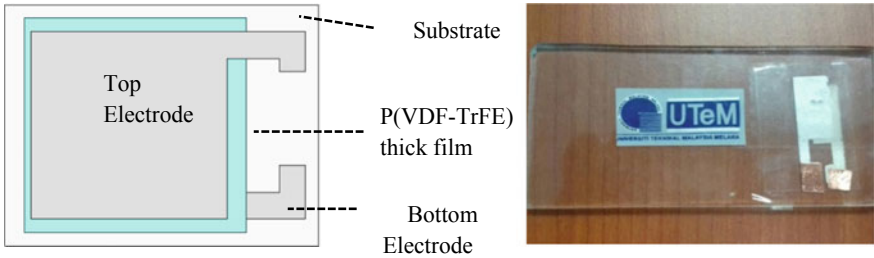


Fig. 1 a Schematic diagram. b Fabricated device

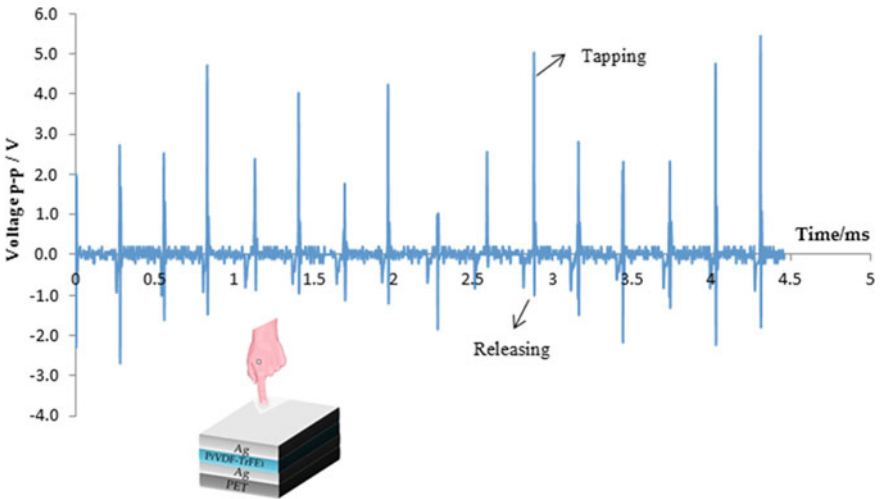


Fig. 2 Peak-to-peak voltage of P(VDF-TrFE) harvester versus tapping time

Due to the simple experiment setup using finger tapping and releasing where the output voltage will be varied from time to time because variable such as force of finger must be controlled so that the output voltage is increasing linearly to the force. To improve the experiment setup, the P(VDF-TrFE) device as attached to the stand of direct current (D.C) fan motor [366B, Mini D.C Fan—MRDIY] (see Fig. 3). The blades of the van act as force variable to tap the edge of the P(VDF-TrFE) device by controlling the speed of the blades using direct current power supply.

P(VDF-TrFE) harvester was attached in the cantilever configuration to a stand located next to a DC electric fan motor. The motor position was adjusted until two of the fan blades were located at same distance from the top and bottom surface of the free end of the P(VDF-TrFE) cantilever. After P(VDF-TrFE) harvester was connected to an oscilloscope (see Fig. 4), the DC electric motor was switched on to rotate the fan blade. Periodical tapping on the P(VDF-TrFE) cantilever were performed by the fan blades every time the blades hitting the cantilever end. The tapping frequency

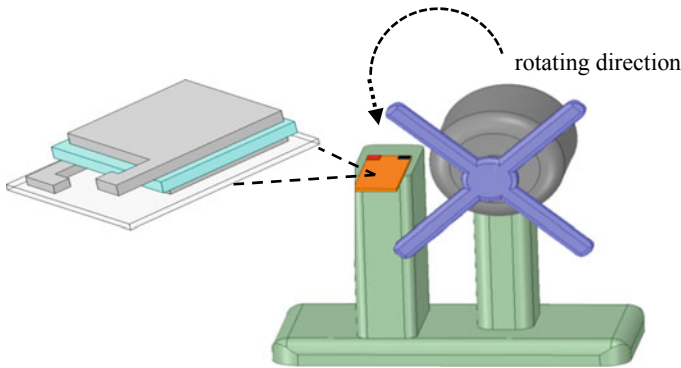


Fig. 3 Experimental setup of force tapping by rotating fan blade



Fig. 4 Voltage (P-P) profile generated by the experimental setup

was controlled by adjusting the motor speed through its power supply [PM3006-2, Digimess]. Speed of the blades were measured by portable digital vibrometer, (PDF-100, Polytec). The current innovation improves the control of tapping force and increases the accuracy of the output voltage measurement.

3 Results and Discussion

Their cross-section were captured using field emission scanning electron microscopy (FESEM, 15 kV accelerating voltage, scanning electron emission mode, Evo.50, Carl Zeis) (see Fig. 5a) where the thickness, 40 μm of P(VDF-TrFE) layer, top and bottom electrodes of thickness, 8 μm on the PET substrate, 175 μm . The distribution of P(VDF-TrFE) harvester elements were determined using Energy-Dispersive Microanalysis (EDS, Oxford Instrument) integrated to Field-Emission Scanning Electron

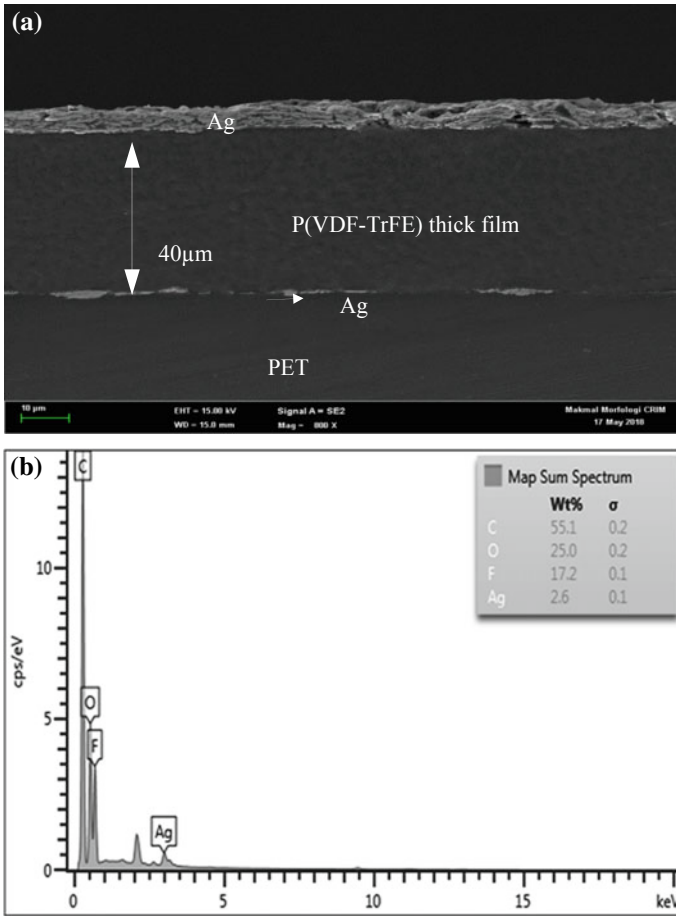


Fig. 5 **a** FESEM micrograph of the electrical harvester structure's cross-section with thickness of 40 μm P(VDF-TrFE) thick film. **b** EDS spectrum elements, P(VDF-TrFE) harvester

Microscope (FESEM, 3 kV accelerating voltage, secondary electron emission mode, Merlin compact-60-25, Carl Zeiss) (see Fig. 5b). The elemental composition F, C, Ag, and O confirmed the presence of P(VDF-TrFE) and Ag polymer electrode on the PET substrate [10].

The XRD peak of fabricated P(VDF-TrFE) thick film (see Fig. 6) appeared at $2\theta = 21.03^\circ$ indicates the presence of β -phase at (110/200) reflection plane [11, 12]. The process temperature for annealing and poling was reported in the previous work [13].

The hysteresis loop of ferroelectric of the P(VDF-TrFE) thick film with thickness of 40 μm and electrode area of 2.99 cm². This measurement was done using Radiant Precision LC II Ferroelectric tester and the result shows the remnant polarization is about 0.093 mC/m² during external voltage of 330 V (see Fig. 7).

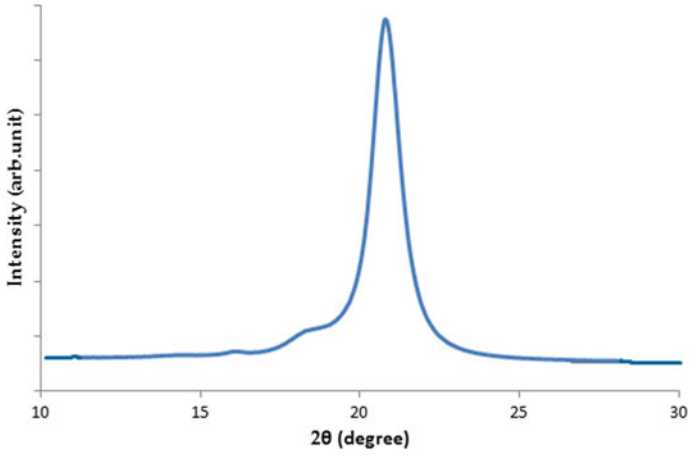


Fig. 6 XRD peaks of β - PVDF phase in P(VDF-TrFE) thick film harvester

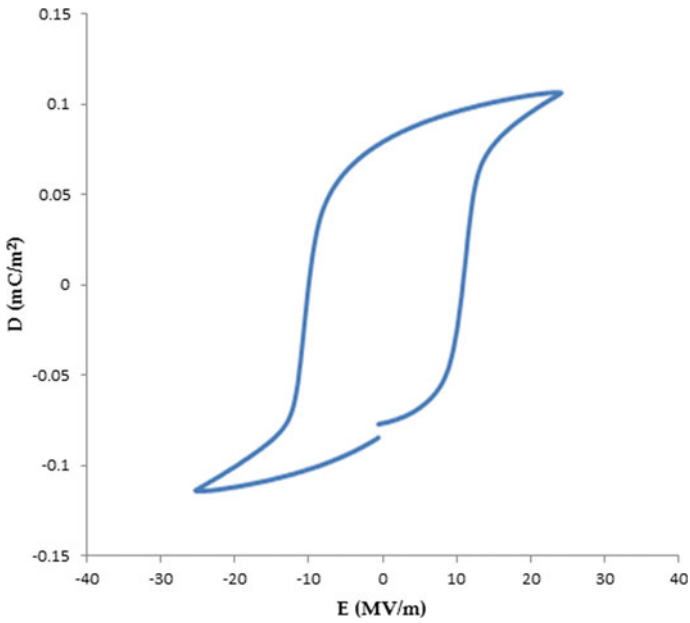


Fig. 7 P-V Hysteresis loop of P(VDF-TrFE) harvester

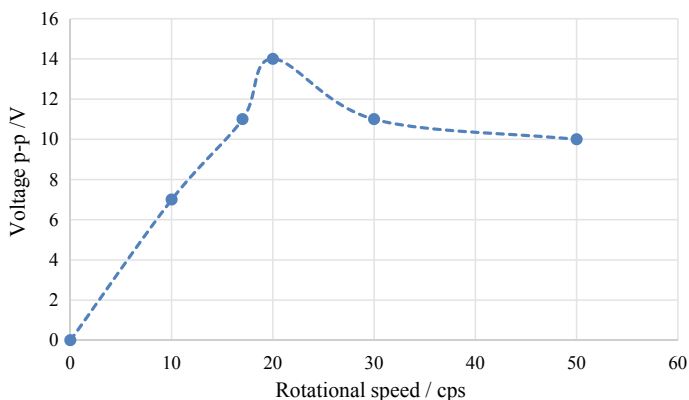


Fig. 8 Voltage output of P(VDF-TrFE) harvester

Maximum output voltage peak-to-peak achieved 7 V when mechanical energy by finger tapping and releasing finger of the hand at frequency of 40 Hz. The output voltage of P(VDF-TrFE) device as function of speed of the rotating blades measured by portable digital vibrometer, (PDV-100, Polytec) and digital oscilloscope. The maximum output voltage peak-to-peak was generated about 14 V at rotational speed of 20 cps. The decrease of output voltage reduced slowly after 30 cps (see Fig. 8). The experiment result shows the P(VDF-TrFE) piezoelectric material is compatible with PET substrate, thus the generator is biocompatible for self-powered wearable applications. The P(VDF-TrFE) flexible power generator has mechanical flexibility, capable at low frequency, and has good sensitivity piezoelectric response [14–16].

4 Conclusion

P(VDF-TrFE) thick film was casted on PET substrate to produce piezoelectric micro-power generator device based on mechanical energy. For the first time of the experiment setup, the piezoelectric voltage output was recorded about 7 V (voltage peak-to-peak). A consistent mechanical tapping generated output voltage up to 14 V was obtained under external speed of 20 cps. The research work is clearly show that the P(VDF-TrFE) device micro-power generator have huge potential as self-powered micro-power generator to harvest electric energy from mechanical energy.

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