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Energy harvesting from piezoelectric textile fibers

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Abstract

In the present paper, energy harvesting properties of a recently developed piezoelectric textile bi-component fiber were investigated. This study covers fiber manufacturing, weaving of the textile, high voltage polarization, addition of outer electrode, modeling and measurement of the piezoelectric textile ability to convert mechanical strain to electrical energy. The results show that it is possible to scavenge around 0.7 mW of power from the fibers in the textile.

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Keywords: Piezoelectric fibers; Energy harvesting; Smart textiles; Melt spinning; Conductive fibers

1. Introduction

Electronic systems are rapidly progressing towards miniaturization, smartness, flexibility and reduced energy consumption. This trend is particularly strong within wearable consumer electronics which consist of a number of wearable devices using wireless short-distance communication to send the data to a central unit [1, 2]. Power consumption of these wearable devices (sensors and data transmitters) is usually in the range of micro- to milliwatts. As example, blue tooth transmitters, which is only required to be active during short periods, has a driving power ~5 mW; data transmission rate ~ 500 kbits/s; power consumption 10 nW/bit [3]. Substantial larger amount of abundant energy is generated in our daily living environment, as in example 67 W of mechanical energy is generated when walking [4].

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If batteries could be exchanged to a never ending power source converting ambient energy into electrical energy, electronic devices could then be autonomous, thus reducing the need of maintenance, wiring and with less environmental impact. Several researchers have presented piezoelectric polymer PVDF in different energy harvesting applications for the conversion of mechanical stain into electrical charges [5, 6].

The purpose of this paper is to investigate how much energy can be generated by the piezoelectric fibers when integrated into a textile structure and deformed in uniaxial tension. The mean output power was measured for different load impedances. To the best of our knowledge, measurements of energy harvesting of bi-component PVDF fibers have not previously been described in the literature.

2. Manufacturing piezoelectric fibers

Bi-component fiber spinning was performed using melt spinning equipment from Extrusion Systems Limited (ESL, Leeds, England) equipped with two single screw extruders, one for the core material, and one for the sheath material. Details about the setting can be found in [7]. Fig. 1 shows the fibers sheath core structure. Fibers were cold drawn with a solid state draw ratio (SSDR) of 4 assuring the conversion of unpolar α crystal phase to the polar β phase in the PVDF sheath [8].

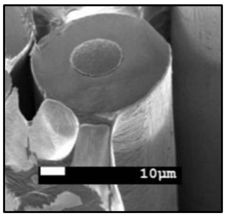

Fig 1. FEG-SEM micrograph of bi-component fiber structure showing fibers structure PVDF sheath and conductive composite core.

Fibers core was interconnected by fusion welding of fiber ends between two thin sheets of electrical conductive soft thermoplastic elastomer. Before the outer electrode was applied, the band was corona polarized using an in-house design equipment in an oven. A negative voltage of –6 kV at the tip of the needles was applied for 40 minutes at 80 °C followed by cooling down to ambient temperature before the voltage was removed., The fabric was coated with a conductive silicone as outer electrode.

3. Characterization of piezoelectric fibers

The piezoelectric harvester was characterized employing an impedance analyzer Autolab PGSTAT302N. Thus, an AC voltage was applied to the piezoelectric fiber while its current response was measured. A frequency sweep was done in order to model the piezoelectric fiber at a certain frequency range. With the current response obtained and setting an electrical equivalent circuit, the software of the impedance analyzer was able to perform a fitting process and calculate the values of the components for the equivalent circuit.

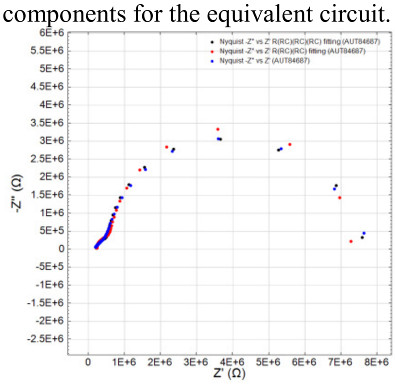

Fig 3. Impedance measurements in blue and fitting results of two different equivalent circuits in black and red.

Fig.3 shows in blue the Nyquist plot for the measured impedance of the textile harvester in a frequency range from 20 mHz to 500 Hz and in red and in black the Nyquist plots obtained from a fitting process employing a R-RC-RC and R-RC-RC-RC networks as equivalent circuits, respectively. Depending on the PVDF fiber and the frequency range under test, one or the other equivalent circuit gave a lower estimated error for the values of the components combined with a good fitting result. Table 1 shows the value of the electrical elements and its associated estimated error for the R-RC-RC equivalent circuit.

Table 1. Value of the electrical elements of the equivalent circuit of the PVDF fibers.

Element	Value (Ω)	Estimated Error (%)
R1	2.26×10^{5}	4.65
R2	3.83×10^{5}	6.10
C1	1.29×10^{-8}	9.96
R3	6.67×10^{6}	0.76
C2	3.99×10^{-8}	1.55

4. AC-DC circuits for energy harvesting

Fig. 4 shows the output power as a function of the output load for several AC-DC converters while the sample was mechanically excited employing an electrodynamic shaker with one end fixed and the other end displaced 1 mm at 4.5 Hz. The AC-DC circuits tested were a diode bridge (DB1 and DB2 curves), a negative voltage converter with a Schottky diode (MosB1 and MosB2 curves) and a negative voltage converter with an active diode (ActMOSB1 and ActMOSB2 curves) [9].

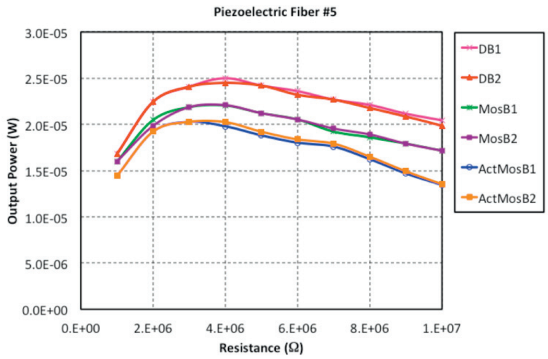

Fig 4. The fibers output power with different AC-DC circuits.

For each rectifier, there are two different curves since different electronic components were tested. The best performance was obtained with the diode bridge topology. Diodes employed in the rectifier are Schottky diodes with low forward voltage, low capacitance and low reverse current.

5. Conclusions

The results show that the process is stable for a poling voltage of -6 kV. The electrical conductivity of the fiber core is 0.03 S/cm and the conductivity of the two sheet used for the interconnection is 0.1 S/cm. The measured outer silicone electrode conductivity on samples extruded with a syringe is 0.09 S/cm.

Fig. 5 shows the output power at different load impedances when exposing the band to a uniaxial load of 50 N. Maximum output power was achieved for a load impedance of 1.4 MΩ. The voltage waveform obtained for the maximum output power is shown in Fig. 6 and a resulting mean power P_{mean} of 652 μW is obtained. The mean energy can be estimated by:

$$E_{mean} = P_{mean} \times T$$

where T= 0.46 s is the time during which the force impulse is applied which corresponds to E= 300 μJ of energy. The power density of our fibers is 30.7 μW/gfiber. Results from our previous study, where single piezoelectric yarn was characterized the available mean power was theoretically estimated to 44 μW/gfiber [8]. Thus, there is difference between the amounts of strain applied in the two different cases. In a single yarn, the strain in is well defined while in the present case, a weave with interlacing piezoelectric and cotton yarn introduces waviness of tows and consequently the true strain in the piezoelectric yarn is unknown.

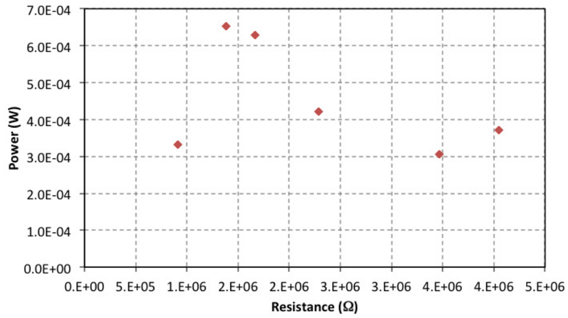

Fig 5. Output power as function of the load resistance, a maximum in output power is observed at 1.4 MΩ.

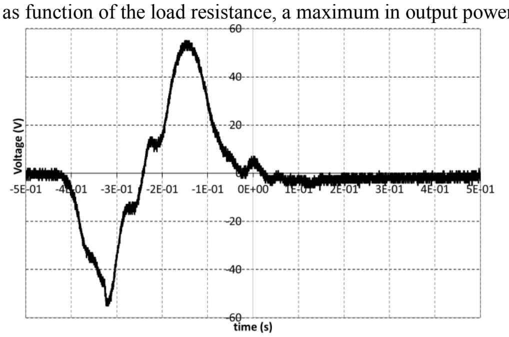

Fig 6. Output voltage of the piezoelectric strap at maximum output power at load impedance of 1.4 MΩ.

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