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SELF-POWERED PEDOT:PSS-PDMS-PRINTED TEXTILE WOVEN TEXTILE FOR MOISTURE SENSING

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***Abstract**. Self-sufficient power sensors that can covert the mechanical stimulus to electrical signals are emerging. In this work, a poly(3,4-ethylene dioxythiophene) polystyrene sulfonate-polydimethylsiloxane-b-polyethylene oxide (PEDOT: PSS-PDMS)-printed conductive fabric was used to construct and characterize a self-powered moisture sensor. The screen printing method transfers a very thin 0.011 g/cm2 add-on on the fabric. Using a two probe resistance measurement method, the electrical resistance of the fabric was found to be 11.36 kΩ/cm. The sensor functions by detecting the change of energy harvested from electrostatic charges developed on the semi-conductive fabric at different moisture contents. A mechanical agitation at the 2-hertz frequency with 250 ms contact time, 200 ms dwell time, and 50 ms uptime, with a tapping device, was performed to study the effect of moisture on the peak output voltage. Increasing the moisture amount from 0 to 50% within the PEDOT: PSS-PDMS-printed semi-conductive cotton fabric caused a considerable increase in the electrostatic output peak voltage from 34V to 93V. This is because water molecules attached to the printed fabric change the electrostatic behavior of PEDOT: PSS-PDMS printed substrate and the electrical resistivity of PEDOT: PSS. The results revealed that using a self-powered PEDOT:PSS: PDMS-printed textile fabric moisture sensor for wearable smart electronics is promising.*

***Keywords:** electrostatic charge; tapping device; printed fabric; smart textile; moisture.*

1. Introduction

Energy harvesting from electrostatic charges offers an option to develop self-powered sensors [1]. In recent years, nano-generators have been presented as self-sufficient power sources capable of converting different kinds of energies to electrical signals [2, 3].

There are different nano-generator categories, including triboelectric, piezoelectric, and pyroelectric. The triboelectric nano-generator's (TENG) working principle is grounded on an accumulation of charges on the surface of two different kinds of materials during their physical contact [4]. Since the first triboelectric nano-generator in 2012, TENGs have made rapid growth in the field of self-powered sensors, biomedical monitoring, energy harvesting, and electronic skin [5, 6].

Ejehi et al described a graphene oxide-based self-powered humidity sensor characterized by a tapping device [1]. Poly(3,4-ethylene dioxythiophene): polystyrene sulfonate (PEDOT: PSS) conductive polymer has been used for humidity sensing with different material combinations, such as molybdenum disulfide MoS_2 [7], polyaniline,and zinc stannate [8], PEDOT:PSS, graphene oxide and methyl red materials [9]. Polydimethylsiloxane-b-polyethylene oxide (PDMS) is a highly negative triboelectric material. It is used in a self-powered tactile sensor [10], and energy harvesting is done from electrostatic charges that develop on its surface [11].

Figure 1(a) shows the negatively triboelectric behavior of PDMS with some other modified 2D materials [12]. The triboelectric series ranks materials according to their tendency to lose or gain an electron. Figure 1(b) demonstrates the charge density of triboelectric knitted and deformable textiles consisting of polymer

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textile fibers. The position of cotton is in the middle of the triboelectric series slightly on the positive side [13]. We use PEDOT: PSS as a moisture sensor and PDMS as a self-powered triboelectric component in this work. In addition, PDMS also aids in giving the coated fabric flexibility and softness. The result is a self-powered, soft, flexible moisture sensor with good economic advantage, as it was developed with woven cotton fabric and a simplified screen printing technique.

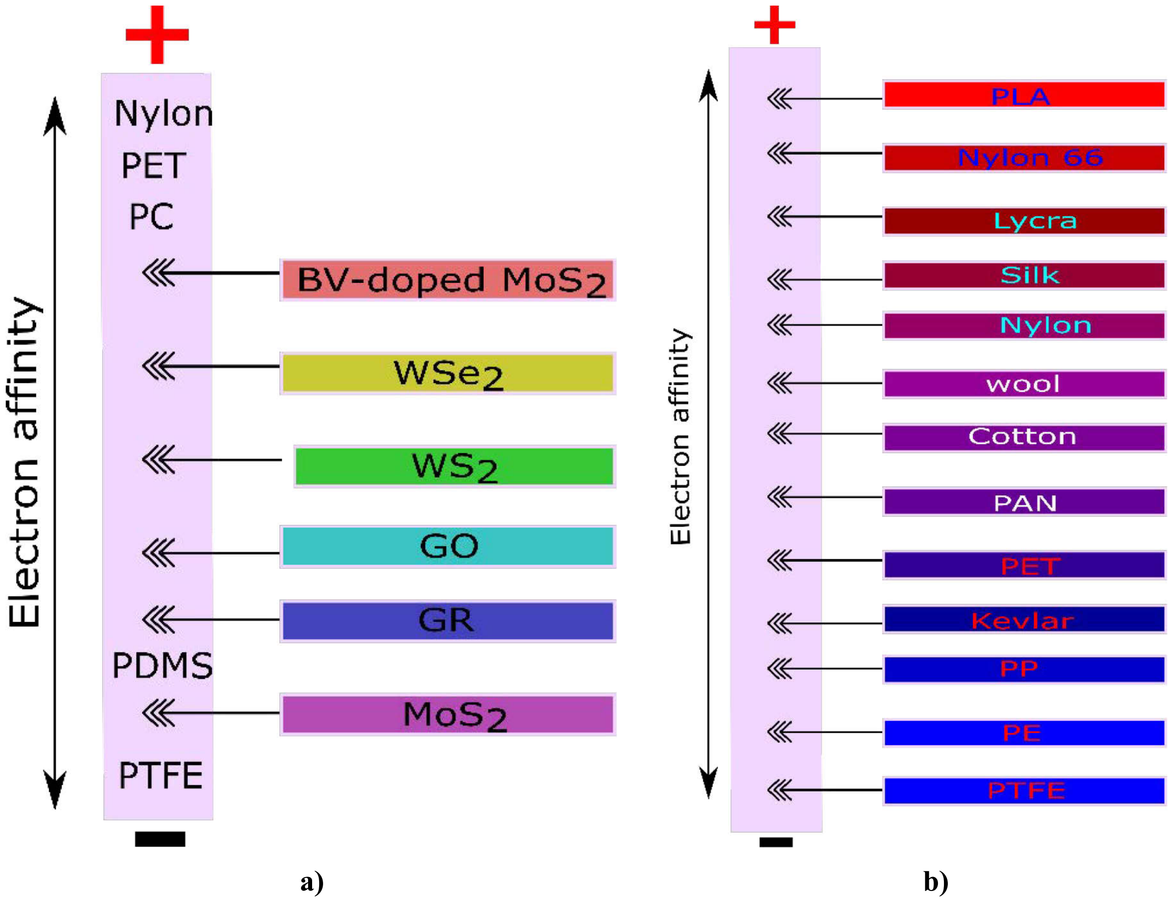


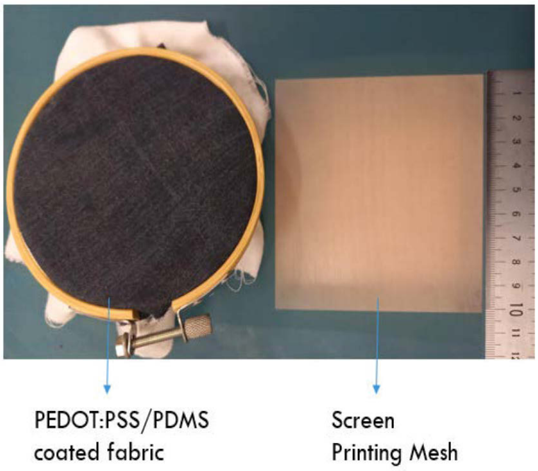
Figure 1 - a) Modified triboelectric series including 2D materials; b) Charge density of triboelectric knitted, porous and deformable fabric made from different polymers.

2. Methodology

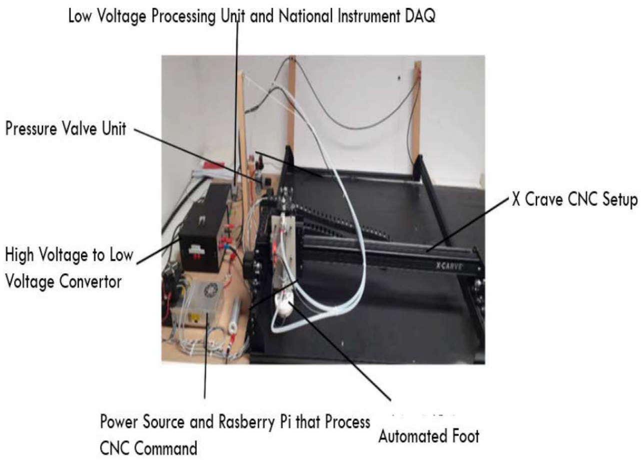
As a fabric substrate, 160 GSM woven white cotton was used. PEDOT: PSS and PDMS were manually mixed at the ratio of 4:1 to prepare a conductive paste. 30 % of the conductive paste 1,2,3,4-butane tetracarboxylic acid (BTCA) was also added to the conductive paste as a crosslinking agent.

The cotton fabric was then printed with the conductive paste using the screen printing method with a polyester mesh of monofilament 90 T, sieve thickness of 110 micrometers, and sieve opening of 45%. Next, the printed fabric was subjected to 70°C for 10 minutes to dry and 150°C for 5 minutes to cure in an oven drier.

The purposes of drying and curing were to remove excess moisture from the printed fabric and fix the conductive polymer paste to the woven fabric, respectively. There was a very thin add-on onto the fabric of 0.011 g/cm2. The electrical resistance was 11.36 kΩ/cm based on a two probe measurement. The electrostatic behavior of fabric was tested on a tapping device with a controlled movement at different moisture regains of the fabric.



a)



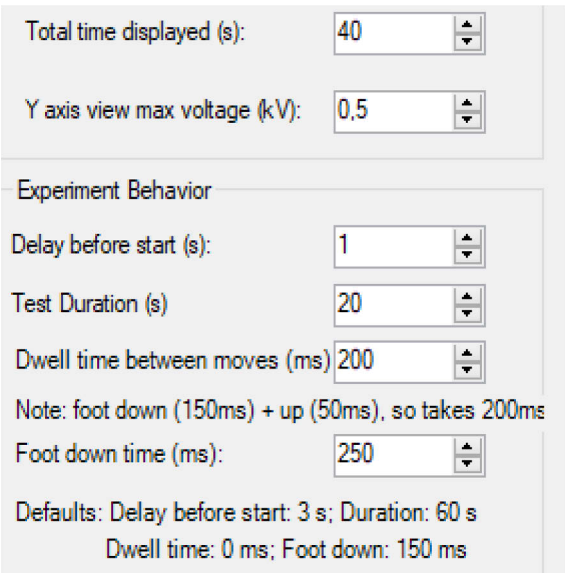
b)

Figure 2 - a) PEDOT:PSS/PDMS printed white woven cotton fabric by using 10x10cm screen printing mesh; b) Tapping device used to characterize the electrostatic behavior of textile fabric.

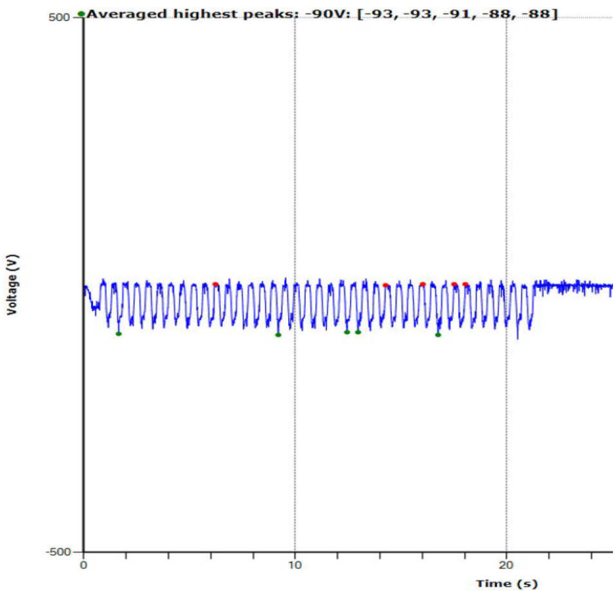
Figure 2(b) shows the mechanical tapping system whose motion could be precisely controlled to characterize the electrostatic behavior of mounted fabric. An XY system driven by stepper motors performs a movement in the horizontal direction. A pneumatic cylinder performs a vertical movement in order to achieve high speed. G-Code controls the whole system. This is a protocol for CNC machines, offering the possibility to control the system through a serial connection from a PC.

3. Results and Discussion

The settings and the moisture response of the PEDOT: PSS-PDMS-printed cotton fabric at mechanically controlled movement with the tapping device are shown in Figures 3(a) and 3(b). The mechanical agitation was done with a tapping device at 2-hertz frequencies with 250 ms contact time, 200 ms dwell time and 50 ms uptime. Figure 3(b) shows the electrostatic voltage produced by the fabric during the tapping movement as a function of time. There is a generation of negative voltage due to the PDMS part of the printed fabric. The electrostatic voltage generated shows a linear response throughout the time of testing.

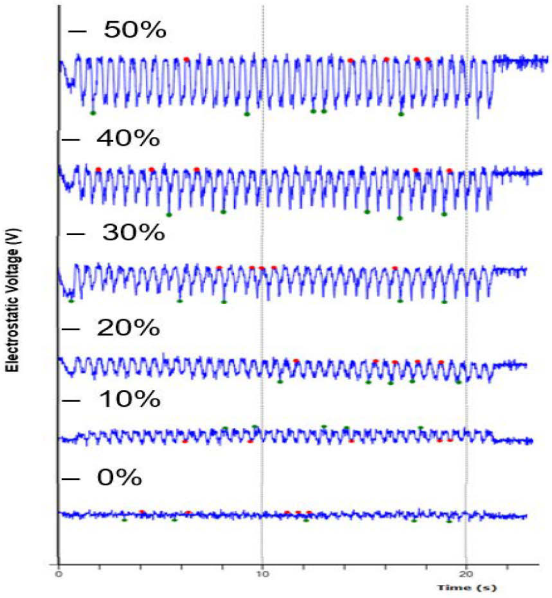


a)

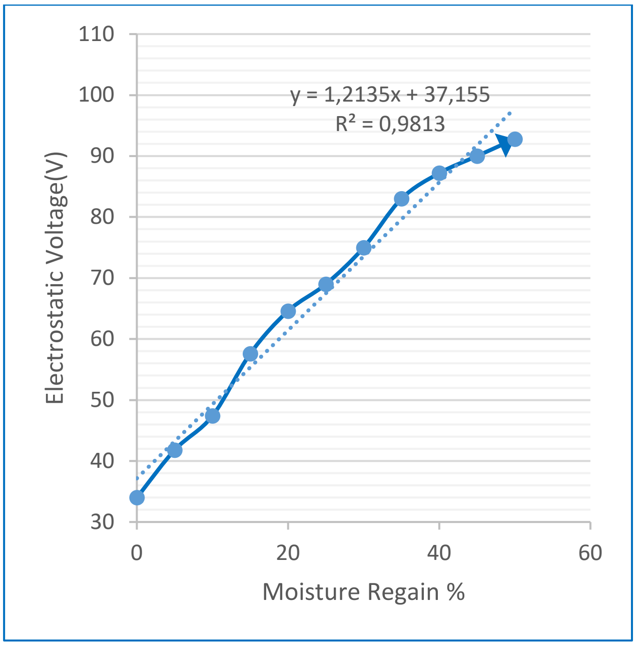


b)

Figure 3 - a) Controlled movement setting dwell time between move 200 ms and downtime 150 ms; b) Electrostatic voltage (Negative) graph for 20-sec tapping movement at 50 % moisture regain.



a)



b)

Figure 4 - a) Electrostatic peak voltage generated as a function of time at different moisture regain b) Calibration curve could be used to determine the humidity regain if the electrostatic voltage is known.

The electrostatic response of the printed fabric with PEDOT: PSS-PDMS at different moisture regain (0 to 50 %) is shown in Figures 4 a) and 4 b). Figure 4 a) shows the electrostatic peak voltage graph as a function of time at different moisture regain of the fabric. It shows that when there is an increase in the moisture regain of the fabric, there is an increase in output peak voltage. Figure 4 b) demonstrate the electrostatic voltage (V) as a function of moisture regain of printed fabric that could be used to determine the moisture regain if the electrostatic voltage is known. As the moisture regain increases from 0 to 50 % of printed fabric, there is a considerable change in the output peak voltage from 34 V to 93 V.

4. Conclusion

In this work, we have developed a self-powered PEDOT: PSS-PDMS-screen printed cotton woven fabric for moisture sensing. The generation of negative electrostatic voltage is due to the presence of PDMS, and its transmission through the fabric changes with changing moisture regain. The PEDOT: PSS allows the charges to be collected to turn the cotton fabric into a semi-conductive fabric. The self-powered PEDOT: PSS-PDMS moisture sensor provides fairly stable sensing and a considerable increase in electrostatic voltage under increasing moisture regain, which was tested up to 50% moisture regain. The developed fabric could potentially be used to sense moisture/humidity in e-textile applications.

Authors' Contributions: H.R.T. conceived the idea, conducted the experiment, and wrote the paper; G.B.T. helped in writing the paper; G.B.T. and B.M. edited the manuscript; B.M. and L.V.L. supervised the project; L.V.L. administrated the project. All the authors have read and agreed to the final version of the manuscript.

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