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Fabrication of Polymer Nanofiber-Conducting Polymer Fabric and Noncontact Motion Sensing Platform

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Abstract. Conductive polymer-electrospun polymer nanofiber network was combined to host iron oxide nanoparticles providing micrometer thick sensing interface. The sensor has fabricated as free-standing fabric exhibiting 10 to 100 KOhm base resistivity upon bias applied. The moving object has been sensed through the electrostatic interactions between fibers and object. The sensing range has been found to be 1-5 cm above the surface of fabric. By the controlled combination of conductive polymers electrospun polymer nanofibers effective device miniaturization has been provided without loss of performance. The noncontact motion sensor platform has unique flexibility and light weight holding a potential for wearable sensor technology.

Introduction

Conductive polymers (CPs) draw attention in the last decades due to their dramatic regulatable conductivity, ease of synthesis, low cost and wide range of optical properties. CPs have remarkable electrical and optical properties comparable with metals and inorganic semiconductors due to their unique electronic structures [1]. As CPs are organic polymers, their electrical and optical properties can be tuned via varying synthesis conditions [2]. CPs are subjected to many applications such as; light-emitting diodes, chemical sensors, biosensors, etc. [3-5]. Among CPs, Poly(3,4-ethylenedioxy thiophene) (PEDOT) steps forward based on its high conductivity, stability and optical transparency in the conducting state [6]. Even though PEDOT is unlikely to cast into films due to low solubility, doping with poly(styrenesulfonate) (PSS) lead to constitute well dispersed aqueous solution. PEDOT:PSS complex (shown in figure 1.) consist of cationic, oxygen doped polythiophene derivation, PEDOT, and semi-insulator PSS [5].

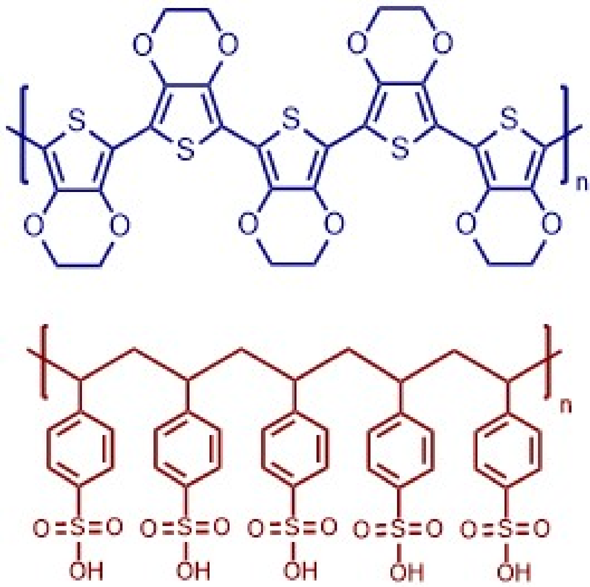

Fig. 1 Chemical structure of PEDOT (blue) and PSS (red).

The carbon nanotube (CNT) that was discovered on 1991 [7] is also an excellent choice among carbon matrixes for sensor application due to its morphology and electrical and optical properties [8-11]. CNTs hold numerous π-conjunctive that allow them support organic and inorganic electrocatalysts for nano devices like sensors. Furthermore, π-conjunctives and unique hydrophobic structure of CNT that can act both as a metal or a semiconductor enables good electrical conductivity for nanostructures [12]. Nevertheless, chemical touch to the CNT arise active functional groups like hydroxyl and carboxyl [13, 14]. Recently, in our experiments, CNT is a great reference to compare with PEDOT:PSS. Electrospun nanofibers, that shows structural hierarchy, surfaces are much denser and mechanically stronger than their flat film derivatives which makes them excellent candidates for working with Volatile Organic Compounds (VOCs), tissue engineering, optical sensors so as mass carrier [15-18].

Low-cost and low-power indoor localization or tracking infrared sensors have attraction in market and scientific community for location-based products like automatic lighting or heating switches [19]. Furthermore, occasionally, high accuracy is beside the point [20]. For example, following an elder human alone in the living space which can detect unusual activities e.g. oversleeping or staying in a space more than usual that may due to a disease or heart attack [19, 21]. On the other hand, the other method that measures the electrical field change affected by conductive objects is capacitive sensors. A well-known example is the Theremin instrument that can be controlled touchless with two bare hands [22]. Measuring dielectric forces of human tissues were always carrying a great importance in sensor development and physiological sciences [23-25]. In the past, dielectric properties of human tissues were measured in variety of frequency range [26-28]. However, we suggest a novel noninvasive measurement technique that can detect proximity without any radiation sources. Here we explained that combination of conductive polymer-electrospun polymer nanofiber network to host iron oxide nanoparticles providing micrometer thick sensing interface. The sensor has fabricated as free-standing fabric exhibiting 10 to 100 kOhm base resistivity upon bias applied. The moving object has been sensed through the electrostatic interactions between fibers and object. The sensing range has been found to be 1-5 cm above the surface of fabric. By the controlled combination of conductive polymers electrospun polymer nanofibers effective device miniaturization has been provided without loss of performance. The noncontact motion sensor platform has unique flexibility and light weight holding a potential for wearable sensor technology.

Materials and Methods

Chemicals. Poly vinyldifloridine (PVDF) (M_w = 275 000 g/mol), PEDOT:PSS (1.3wt%), DMF (≥99.8%) and acetone (EMSURE®) was supplied from Sigma Aldrich, USA. Silver paste, cupper tape and Poly Methylmetacrylate (PMMA) (3mm thickness) was purchased from local market.

Electrospinning PVDF Nanofibers. PVDF solution was prepared by dissolving 4.59 g PVDF in 12 mL DMF and 3 mL Acetone and kept under stirring for 15 hours at 50 ^oC to obtain homogeneous solution. Prepared solution was loaded into 20 mL plastic syringe. Loaded syringe was connected to electrospinning instrument (İnovenso) with rotating collector. The voltage for electrospinning was 24 kV. The distance between the nozzle tip and the collector was 14 cm. The rotating speed of collector was 500 rpm to collect aligned PVDF nanofibers.

Fabricating PMMA Surface. PMMA plate was cut into 10.8 x 7.2 mm outer frame. Engraved area of the PMMA surface was 6.8 x 3.2 mm. The depth of engraved area was 1mm.

Preparation of Network Circuit Sensor. PMMA surface, functionalized with cupper tapes on each edge, was placed on the collector of the electrospinning. Then, the same procedure on 2.2. was applied to obtain PVDF nanofibers hanging between edges of the surface. Each edge of the collected surface was painted with silver paste to make ohmic contact. After that, PEDOT:PSS or CNT that includes certain amount of Iron nanoparticles (FeNPs) was drop casted on the PVDF nanofibers. Finally, 4 hours of incubation at 60 ^oC was performed to get conductive network between poles.

Resistivity Measurements. All the resistivity measurements have been performed instantaneously with Keysight Technologies 34401A Digital Multimeter. External DC supply was used for utilizing I-V curve.

Scanning Electron Microscopy Characterizations. Scanning Electron Microscopy (SEM) images were obtained from Quanta 250 FEG (FEI Corporation, OR, USA) that located in **Center for Materials Research in Iztech.**

Results and Discussion

Structure and Electrical Properties. The polymer nanofiber network has been obtained by electrospinning on conductive metal substrate coated PMMA surface offering dramatic change in the morphology of PVDF nanofibers apart from the ones collected on the foil and the cupper tape. As shown in figure 2, the cavity in the middle of the PMMA surface causes discontinuity in the electric flux while electrospinning the PVDF nanofibers and the cupper tapes on each side attract the electrical flux so as PVDF nanofibers. The disturbance causes alignment of PVDF nanofibers in the middle of the PMMA surface. On the other hand, it is unlikely to observe alignment collected on aluminum foil or cupper tape as there is no disturbance in electrical flux on the flat surface. The electrospun nanofiber network formation has provided free-standing fabric like texture. The PVDF fabric has exhibited reasonably high loading of conductive material on surface that connect two poles of sensor platform. CNT and PEDOT:PSS has not been electrospunned as pristine; therefore, drop casting them on the PVDF nanofibers formed a conductive layer. The thickness of both PEDOT:PSS and CNT circuits were 100 nm that increase sensitivity and response time which was about 500 ns (figure 3 a, b). Drop casted CPs agglomerated and composed a polymeric circuit that have a ohmic behavior between 0.1 V to 10 V (figure 3 c, d).

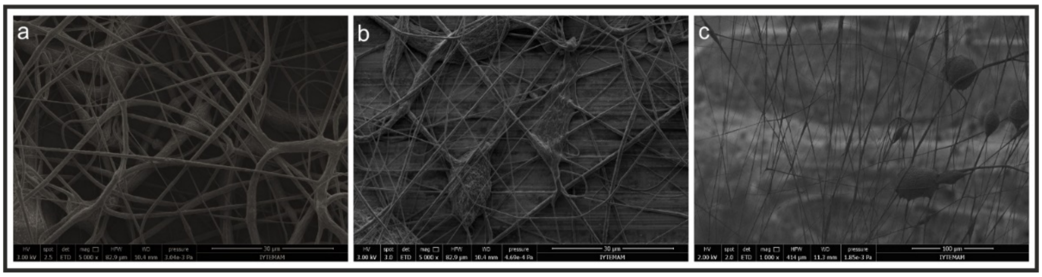

Fig. 2 SEM images of PVDF nanofiber collected on (a) aluminum foil, (b) cupper tape and (c) above cavity of the PMMA surface.

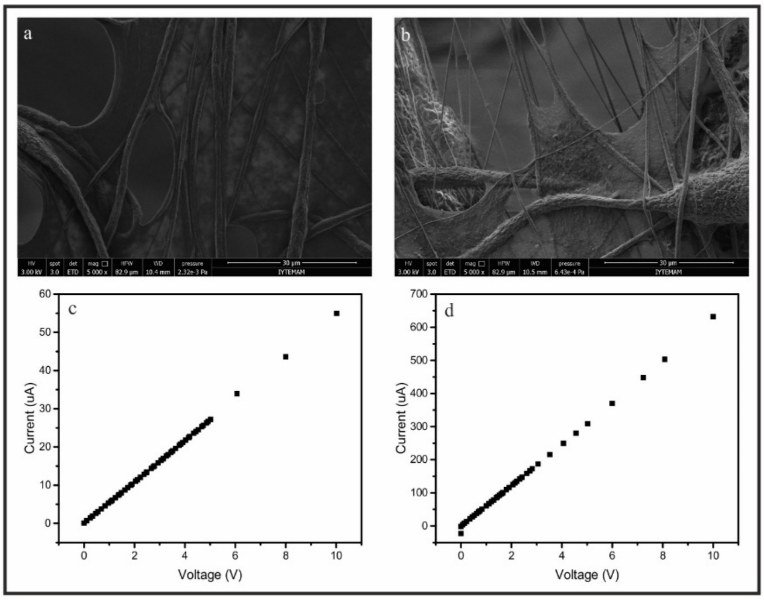

Fig. 3 (a-b) SEM images and (c-d) I-V curves of PEDOT:PSS-PVDF and CNT-PVDF nanofiber network.

Sensor Behavior to Dielectric Forces. SEM images on figure 4a and 4b were shown that FeNPs dispersed well on CPs network which amplifies the charge-charge interaction with circuit linearly. Well-dispersed (Figure 4 c, d) FeNPs reinforced ultra-thin circuits were amplified the sensitivity to dielectric forces, human finger. Figure 4c and 4d shows that both PEDOT:PSS and CNT drop cast sensors work well when exposure to dielectric force. In figure 4c, PEDOT:PSS-PVDF network, doping FeNP beyond 0.1% causes saturation, on the other hand; in figure 4d, CNT-PVDF network, linear increment without saturation was observed. The sensing range was found to be 1-5cm from sensor interface referring to electrostatic interaction range of human finger and surface is traceable distance for wearable fabric technology. The signal reproducibility was 95 % for hundred trials assuring the reusability of sensor. The sensor response exhibit variation substantially among ten volunteers. This result confirms that finger electrostatic extent is person specific and our sensor platform response to the variation.

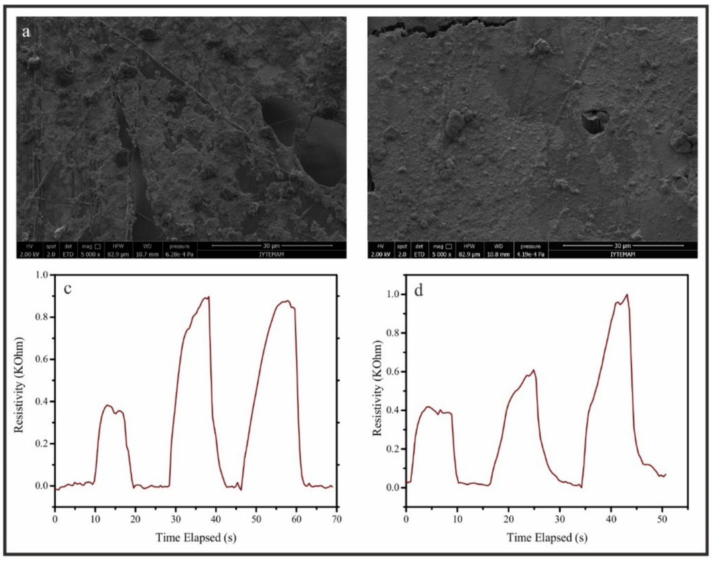

Fig. 4 (a-b) SEM images and of 0.2% FeNP doped PEDOT:PSS-PVDF and CNT-PVDF nanofiber network (c-d) responsivity of FeNP-PEDOT:PSS-PVDF and FeNP-CNT-PVDF nanofiber network to human finger at 0.05%, 0.1% and 0.2% FeNP in order.

Conclusion

This study describes noncontact sensing of human finger motion by conducting polymer-electrospun nanofiber network free standing fabric type sensor platform. The moving object has been sensed through the electrostatic interactions between fibers and object and sensing range has been found to be 1-5 cm above the surface of fabric. The noncontact motion sensor platform has unique flexibility and light weight holding a potential for wearable sensor technology.

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