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Fabrication and Characterization of Electro-Active Polymer for Flexible Tactile Sensing Array

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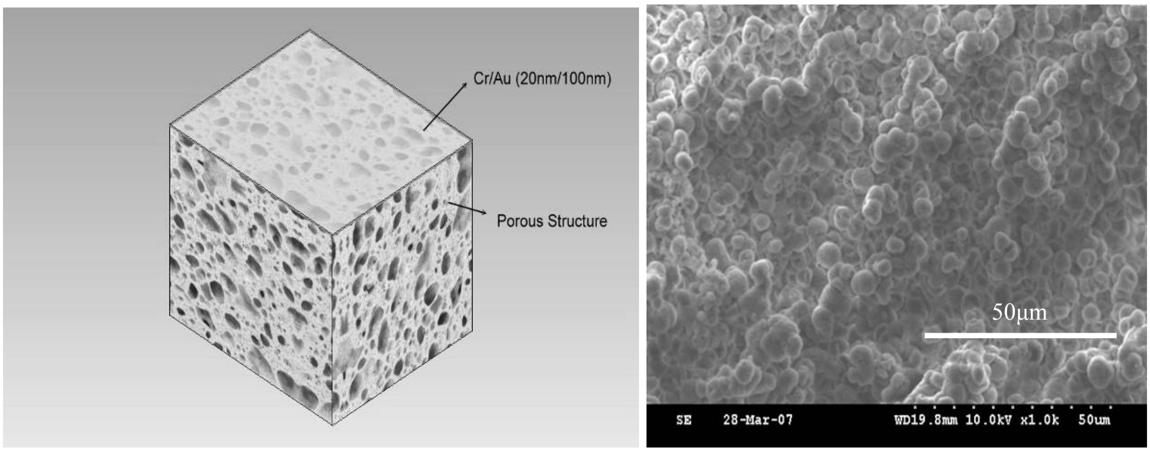
Abstract. This paper presents fabrication and characterization of a pressure-sensitive polymeric composite on a flexible readout circuit as an artificial skin. Porous nylon was used as the matrix, which provided skin-like mechanical properties. Inside the matrix, polypyrrole was electrochemically deposited and acted as conductive dopant. The fabrication was detailed. The conductivity of the fabricated composite increased when a compressive load was applied. The electro-mechanical characteristics of the composite were measured.

Introduction

The development of flexible tactile sensor array is an emerging field in flexible electronics and intelligent robotics. Large arrays of miniaturized tactile sensors can be fabricated on flexible substrates using micromachining techniques [1] or organic transistors [2,3]. Piezoresistive materials are commonly used in micromachined sensor arrays to detect contact pressure. Typical piezoresistive materials in flexible sensor arrays include thin metal films and conductive polymeric composites. Conductive polymeric composites are favored for its low material cost and high mechanical flexibility. Typical conductive polymeric composites are comprised of rubber and conductive dopants such as carbon particles [4]. The resistance of the composites dramatically decreases when an external pressure is applied [5].

This paper presents a flexible tactile sensor which is completely made of polymeric materials. Specifically, porous nylon is used as the matrix of the polymeric composite as illustrated in Fig. 1 and provides good mechanical flexibility. Electro-active polymer acts as the dopant in the flexible matrix [6,7]. The fabrication process is simple and suitable for batch production. Fabrication and characterization of the flexible tactile sensor will be detailed.



(a) (b)

Fig.1 (a) Schematics of the flexible tactile sensor; (b) SEM image of porous nylon.

Method

Materials. Nylon is known to have good mechanical strength, high solvent resistance, and high melting point. It is hydrophilic, and the contact angle of water droplet on nylon is 75-80 degrees. Porous nylon is used as the matrix of the pressure-sensitive composite in this work. Its hydrophilicity allows monomer solution of pyrrole to penetrate into the pores in nylon. As a result, polypyrrole (PPy) can be deposited in the nylon matrix to serve as conductive dopants. The conductivity of PPy ranges from 500S/cm to 7500S/cm, depending on adopted deposition methods. The major methods of fabricating PPy include chemical polymerization, electrochemical polymerization, and chemical vapor deposition. Electrochemical polymerization is used in this work because it allows PPy to be selectively deposited on patterned electrodes [8].

Fabrication. Porous nylon is fabricated using phase inversion method [8]. Nylon polymer with porous structure inside is formed by dissolving nylon polymer with a solvent first. Then the solvent is replaced by a non-solvent. Pores of root shape are formed after the non-solvent evaporates. An alternative process of phase inversion method is to directly evaporate the solvent inside the nylon polymer. Pores of strip shape are formed in this case. For nylon layers thicker than 100μm, it is found that higher thickness uniformity and lower surface roughness are obtained by directly evaporating solvent inside nylon. However, direct evaporation of nylon solvent requires much longer process time compared to the process of replacing the solvent first. To improve the thickness uniformity and surface roughness for the process of replacing the solvent, the polymerization process has been optimized. The dominating parameters in the process include volume ratio of formic acid in nylon and the mixing and dissolving temperature, which is found to be 45°C. Using this process, porous nylon of 300um in thickness has been fabricated on glass substrate. Firstly, nylon segments were dissolved in pure formic acid. Then the solution was rinsed by formic acid of 10% volume concentration in deionized water. Deionized water formed liquid cavities in nylon solution. The deionized water in theses cavities was then sequentially replaced by isopropanol alcohol and hexane. The hexane evaporated instantaneously, leaving air pores in solidified nylon. The fabricated porous nylon is shown in Fig. 2.

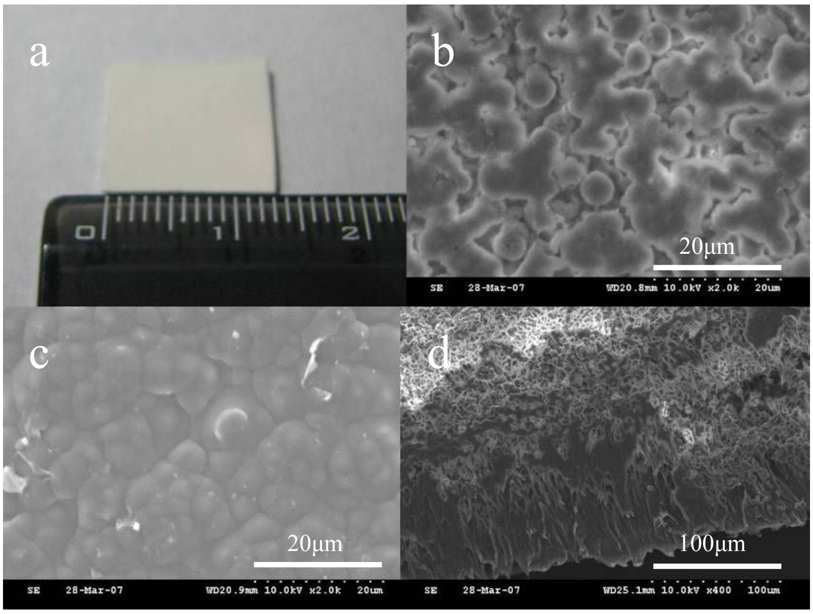


Fig.2 (a) Photograph of fabricated porous nylon; (b)(c) SEM images of bottom and top surfaces of porous nylon, respectively; (c) Cross-sectional SEM image of porous nylon.

To form piezoresistive material, cavities inside the fabricated nylon were filled with PPy by electrochemical polymerization. A seed layer of Cr/Au (20nm/100nm in thickness) was first sputtered on one side of the porous nylon. PPy monomer was used as the electroplating solution. To conduct the electrochemical polymerization, a positive bias was applied to the seed layer. Meanwhile, a platinum electrode, which was connected to ground, was also placed in the electroplating solution. Constant current of 4mA/cm^2 was applied during the polymerization, and the fabrication was conducted at room temperature. The porous nylon was completely filled with PPy when its surface turns black, as shown in Fig. 3.

Figure 4 shows the applied bias voltage as a function of the polymerization time. It has been observed that the bias voltage decreased continuously due to decrease of the nylon resisivity as PPy grew. It should be noted that the electroplating solution should be stored at 4°C to avoid oxidation. The concentration of the PPy electroplating solution was reduced by both oxidation and electroplating operation. Nevertheless, it was still sufficient to carry mobile ions so that low bias voltage was maintained.

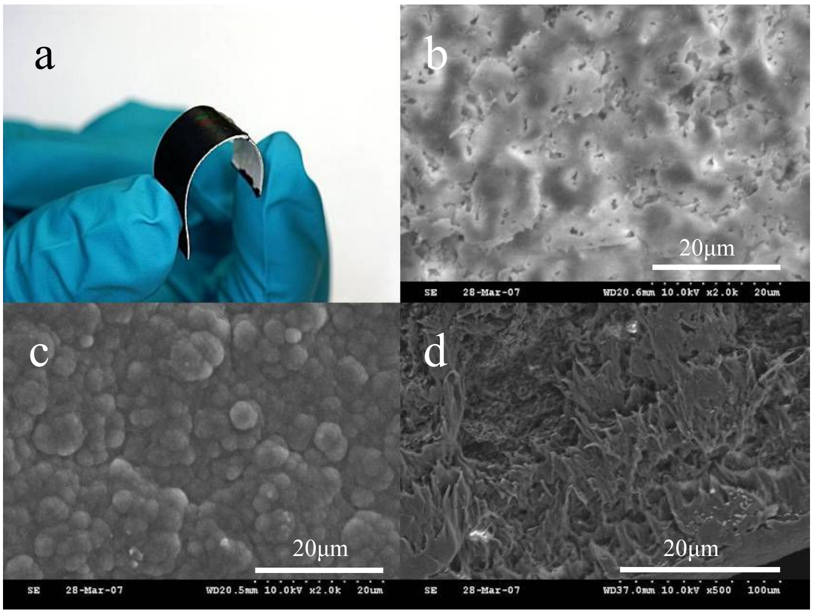


Fig.3 (a) Photograph of flexible nylon filled with PPy; (b)(c) SEM images of the bottom and top surfaces of the porous nylon filled with PPy, respectively; (d) Cross-sectional SEM image of flexible nylon filled with PPy.

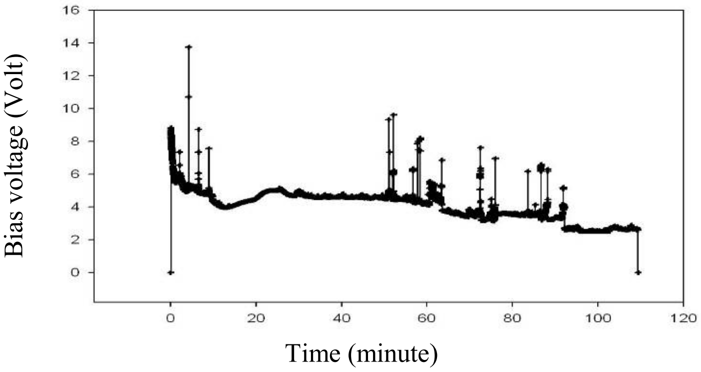


Fig.4 Bias voltage as a function of deposition time for PPy polymerization.

Measurement. To characterize fabricated polymeric composite, a vertically movable stage was employed to apply compressive force on the composite. The magnitude of the applied force was determined through a load cell, and the deformation of the composite was measured by a digital encoder. Under different applied forces, the electrical resistance of the composite was measured by using a multimeter.

Results

The electrical resistance of the fabricated polymeric composite changed when the composite was subjected to different external pressure. The measured deformation of the composite as a function of the applied pressure is given in Fig. 5. It was found that the material hysteresis significantly reduced after the composite has been loaded/unloaded three times and repeatable results have been obtained. Figure 6 shows the resistance change as a function of the applied pressure. Stable sensitivity of 0.023%/kPa for pressure greater than 20kPa has been obtained after the same loading/unloading tests.

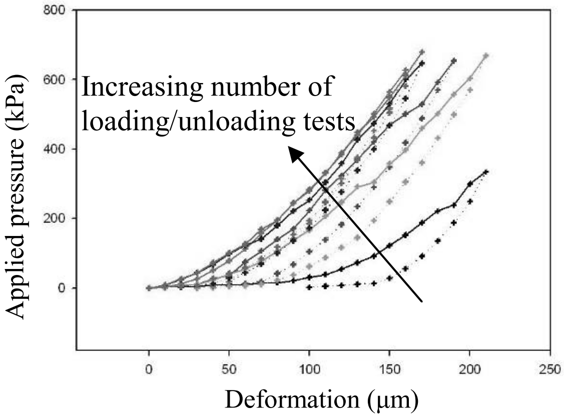


Fig.5 Measured deformation as a function of applied pressure.

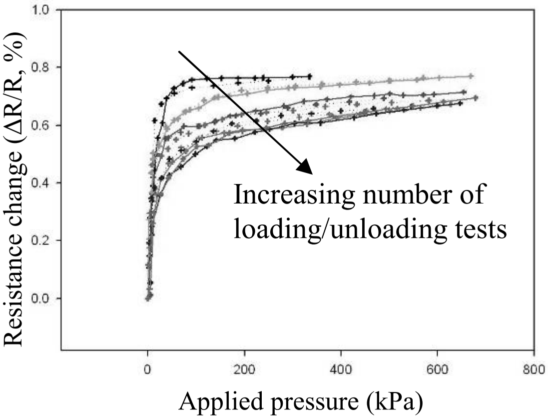


Fig.6 Measured resistance change as a function of applied pressure.

Conclusions

We have fabricated a pressure sensitive polymeric composite. The process has been detailed in this paper. The fabricated composite has been characterized through repetitive electromechanical tests. It showed repeatable mechanical performance, small hysteresis, and stable sensitivity. The mechanical flexibility and simple fabrication steps of the proposed composite allows it to be applied to flexible tactile sensor arrays in the future.

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