Influence of ethylene glycol treatment on conductivity and stability of poly(3, 4-ethylenedioxythiophene) polystyrene sulfonate coated cotton yarn

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Abstract. Recently electronic textiles have received much interest due to their board applications in wearable electronics such as solar energy, physical and chemical sensors. In this work, the conductive cotton is prepared by dip coating poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) on commercial cotton yarn. The electrical conductivity of conductive cotton can be enhanced by secondary treated PEDOT:PSS with ethylene glycol (EG). The EG-treated conductive cotton exhibits lower resistance of 600 Ω/cm by comparison with the pristine PEDOT:PSS coated cotton yarn (110 kΩ/cm). The electrical resistances of the conductive cottons are also investigated as a function of temperature and humidity. The pristine conductive cotton increases in electrical resistance as the temperature increases, while there is no resistance change for EG-treated conductive cotton. SEM images show well distribute of PEDOT:PSS on the cotton yarn surface. FTIR analysis also confirms the residue of PEDOT:PSS coated on cotton yarn. In addition, the treated conductive cotton exhibit high stability under air as they show slightly change in electrical resistance after keeping for 30 days.

1. Introduction

Electric textiles with high performance and stretchability are of great interest owing to their potential applications in wearable electronics and portable devices [1, 2]. Generally, conductive textiles are relying on metal based technology which drawback in flexibility and gives weight burden to textiles. The coating of intrinsically conducting polymers on textile substrate is one of the suitable alternative method to fabricate conductive textiles. Among the different available conducting polymers, poly(3, 4-ethylenedioxythiophene) doped with poly(styrene sulfonate) (PEDOT:PSS) is one of the most used. It has attracted wide attention as electrode material in several applications, due to its excellent characteristics such as high transparency, good flexibility, and thermally stability [3]. However, intrinsic PEDOT:PSS films suffer from a low conductivity because the ambiguous phase segregation and the excessive components of insulating PSS in PEDOT:PSS matrix [4]. The conductivity of PEDOT:PSS has been reported to be increased by the addition of solvents, such as dimethyl sulphate (DMS) [5], dimethyl sulfoxide (DMSO) [6]. However, the use of DMSO may irritate human skin, and fabrics are
vulnerable to acid, preventing the use of post-treatment with a strong acid. A several methods have been employed, for instance, doping the PEDOT:PSS aqueous solutions with secondary solvents of methanol, ethylene glycol (EG) [4, 7], and glycerol [8], or using other dopants (anionic and ionic surfactants) [3, 9]. However, EG-doping is considered as a simple and effective method for substantially boosting the conductivity of the PEDOT:PSS.

In this work, we report a simple method to fabricate conductive cotton by dip coating PEDOT:PSS on cotton yarn and enhance its conductivity by treating PEDOT:PSS with EG. The conductive cotton properties show higher conductivity and stability after treated with EG. They exhibited slightly change in electrical resistance under humidity and temperature increases.

2. Experimental

2.1. Conductive cotton preparation

Aqueous solution of PEDOT:PSS and EG were purchased from Sigma-Aldrich. All chemicals were used as received. The conductive cotton was prepared by dip coating process of undyed 100% cotton yarn (Venus Thread Co., Ltd.) in 1.1 wt% PEDOT:PSS solution. Firstly, cotton yarn was cleaned with acetone under ultrasonication for 10 min to remove organic contaminants and dried in oven at 60°C for 30 min. Then, the cleaned cotton yarn was immersed in PEDOT:PSS for 5 min and dried in oven at 60°C for 30 min. For electrical enhancement of conductive yarn, the conductive cotton was dipped in EG and dried in oven at 60°C for 2 h.

2.2. Conductive cotton characterization

The surface morphologies of bare and conductive cottons were characterized by scanning electron microscope (SEM, Quanta 450 FEI). Fourier-transform infrared spectroscopy (FTIR, Nicolet iS50) with attenuated total reflectance (ATR) mode was used to determine the chemical structure of the bare and PEDOT:PSS coated cotton yarn. The electrical properties were characterized by using two probes digital multimeter (Agilent 34970A). The temperature-dependent electrical conductivity of conductive cotton was studied by a digital source meter (Keithley 2400) within the temperature ranging from 40°C to 80°C. In addition, the effect of humidity and electrical stability of conductive cotton were also investigated.

![Figure 1](image-url)  
Figure 1. (a) Electrical resistance of the conductive cottons with different EG treatment cycles, (b) SEM images of bare and PEDOT:PSS coated cotton yarns, and (c) FTIR spectra of bare and conductive cottons with and without EG treatment.
Figure 2. (a) Electrical characteristics of conductive cottons measured at temperature of 80 °C, and (b) relative current change of pristine (square) and EG-treated conductive cotton (cycle) as a function of temperature.

3. Results and discussion

Figure 1a shows an electrical resistance of PEDOT:PSS coated cotton yarn with and without EG treatment. After coated with PEDOT:PSS, the cotton exhibits a resistance value of 110.6 kΩ/cm. This resistance value was dramatically decreased below 600 Ω/cm after EG-treated conductive cotton. However, there are no variation change under increase EG treatment cycles. The effect of EG on electrical conductivity of conductive cotton can be attributed to a relaxation distance between the polymer chains [7].

The surface morphology of bare and PEDOT:PSS coated cotton yarns are observed by SEM images as shown in Figure 1b. The bare cotton shows a smooth surface and a well distribution of PEDOT:PSS was observed on cotton yarn. To confirms the residue of PEDOT:PSS on cotton yarn, FTIR analysis was examined and results are showed in Figure 1c. The FTIR spectra exhibit almost the same peaks for both bare and conductive cottons. The FTIR spectrum of the pristine conductive cotton showed peaks at 1460, 1364, 1308, and 893 cm⁻¹ correspond to C=C, C–C, and C–S bonds, respectively, which originated from thiophene ring in PEDOT’s monomer structure [3, 10]. The observed peak at 1054 cm⁻¹ is originated from to C-O-C bond stretching in the ethylenedioxy group in the PEDOT:PSS monomer [3, 10]. The peaks assigned at 1641 and 1154 cm⁻¹ correspond to C=C bond from aromatic ring of PSS and symmetrical vibration of SO₂H in PSS [3, 10].

To investigate the environment stability of the PEDOT:PSS coated cotton yarn, the effect of temperature on the electrical conductivity of conductive cotton was observed. A relative current change, \( \Delta I = I - I_0 \), where \( I_0 \) and \( I \) are the response current before and after applied heating temperature, is observed for pristine and EG-treated conductive cotton under a constant temperature of 80 °C as shown in Figure 2a. The temperature profile (red solid line) of 80 °C also revealed here. The pristine conductive cotton demonstrates a change in electrical current followed as increasing and decreasing of environment temperature. The relative current change and temperature is linearly increased as temperature increases (Figure 2b). In contrast, the EG-treated conductive cotton exhibit slightly decrease in electrical conductivity. A highly stable in temperature has been found for treated conductive cotton as indicated no-variation change in relative current in Figure 2b.

The effect of humidity on electrical characteristics of conductive cottons are investigated by applied voltage and measured current pass through the sample before and after soaking in a water drop (Figure 3). The current-voltage curve of the pristine conductive cotton shows a good ohmic behaviour. The decrease in conductivity and hysteresis of I-V characteristics was observed during soaking in a water drop. This is due to the surface effect between PEDOT:PSS and water molecules. In addition, some residues PEDOT:PSS can be dissolved in water. Whereas, the EG-treated conductive cotton does not change in conductivity under water drop.
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