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Preparation and characterization of conductive fabrics coated uniformly with polypyrrole nanoparticles

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ABSTRACT

We have successfully fabricated a conductive fabric coated densely and uniformly with polypyrrole nanoparticles that were less than 50 nm in size by exposing a fabric immersed in a solution containing an oxidizing agent and a dopant to pyrrole vapor after partially pressing excess solution from the fabric with a nip-roll apparatus. The resistivity and color of the resultant conductive fabric depended on the concentrations of the oxidizing agent and dopant. The resistivity arbitrarily varied from an antistatic level ($10^{10}\ \Omega$ cm) to a high conductivity level ($10\ \Omega$ cm), which was attributed to differences in the size, compactness and adhesiveness of the polypyrrole nanoparticles forming the conducting network. High fastness to rubbing of the conductive fabric was maintained even though the electrical conductivity varied, suggesting that the fabric could be used in ultra-clean and ultra-low dust conditions.

1. Introduction

Conductive fabrics are prepared by coating conductive materials such as carbon and metals on a pristine fabric surface, and have high electrical conductivity with unique advantages, such as being light, thin and flexible. Conductive fabrics are used in practical applications such as electromagnetic interference shielding, microwave absorption and heat generation, and various conductive fabrics have been developed [1–10].

Conductive polymers are easily synthesized by chemical and electrochemical methods, and their electrical conductivity can be arbitrarily changed by adjusting the amount of deposited polymer [6,11]. Therefore, a variety of conductive polymers can be prepared to have electrical conductivity that suits a particular application. Polypyrrole (PPY) [12–17], which is our present target, and polyaniline [18–20] have been used in conductive fabrics to date. Various methods for coating fabrics with PPY have been investigated. One is the immersion of a fabric in a dispersion of PPY particles, and the other is direct polymerization on a fabric [1–10]. In the former method, PPY particles can be densely and uniformly coated on the fabric, but the coating layer becomes thicker with the increasing size of PPY particles. Therefore, thinner coating layers can be formed by using smaller particles or nanoparticles. For this purpose, many PPY nanoparticles dispersed in solutions have been prepared by polymerization of pyrrole in water in the presence of steric stabilizers such as poly(vinyl alcohol), polyvinylpyrrolidone, sodium poly(styrene sulfonate), which impede agglomeration of the PPY nanoparticles [21–23]. The size and stability of PPY nanoparticles are influenced by the structure, molecular weight and concentration of the steric stabilizers as well as the concentration of pyrrole, oxidizing agents and dopants [21–23]. However, since PPY nanoparticles weakly adhere to fabrics, they easily detach from the fabrics during washing. Therefore, the conductive fabrics prepared in this way have a low grade of fastness to rubbing.

Meanwhile, direct polymerization of pyrrole on fabrics is a fascinating method for preparing conductive fabrics, and it is roughly classified into two types. In one method, fabrics are immersed in a solution containing an oxidizing agent, a dopant and pyrrole [1–7]. In the other method, the fabrics or fibers are immersed in a solution containing an oxidizing agent and a dopant, followed by drying and exposing the fabrics or fibers to pyrrole vapor [7–10]. The resultant conductive fabrics have a high grade of fastness to rubbing under dry conditions. Under dry conditions, fabrics produced using the former method have a fastness to rubbing grade of 3–4 and those produced using the latter method have a fastness to rubbing grade of 4–5 according to the international standard (ISO 105-X12)

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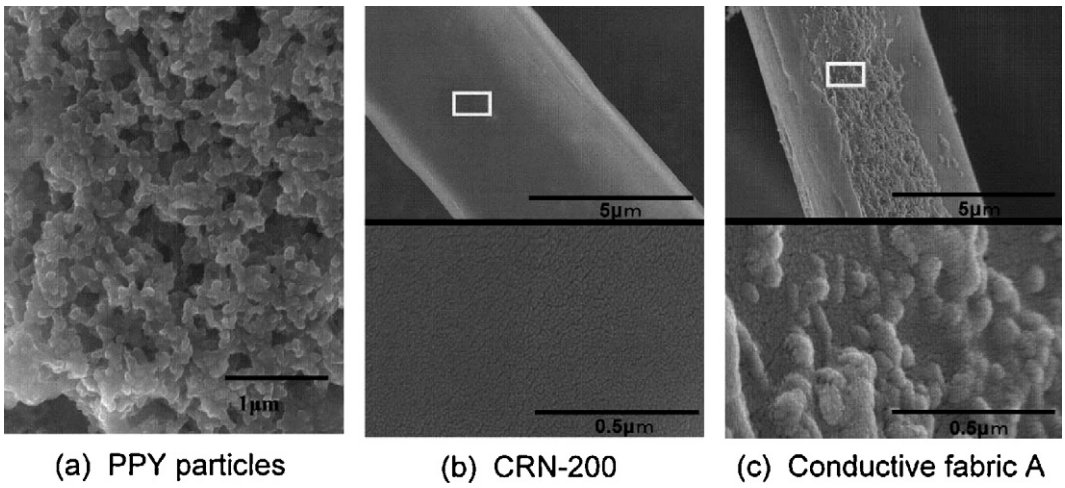

Fig. 1. SEM images of (a) PPY particles, (b, upper) fiber of pristine fabric and (c, upper) fiber of conductive fabric A. Lower images of (b) and (c) show enlarged images of the rectangular areas in the corresponding upper images.

[7]. However, both types of fabrics have a low fastness to rubbing grade (ca. 1) under wet conditions [7]. Perhaps this is caused by the uneven distribution of PPY on the fabrics because the excess solution on fabrics leads to uneven adsorption of the oxidizing agent and dopant on the fabrics during drying, which in turn leads to uneven deposition of PPY. Therefore, to obtain high fastness to rubbing under all conditions, PPY particles should be thinly and evenly coated on fabrics.

In our preliminary investigation, after immersing a fabric in a solution containing an oxidizing agent and a dopant, we partially pressed excess solution from the fabric with a nip-roll apparatus before drying and then exposed the fabric to pyrrole vapor. As a result, we found that PPY nanoparticles less than 50 nm in size thinly and evenly coated the fabric. Therefore, the conductive fabrics prepared by our method can have a high grade of fastness to rubbing as well as low resistivity, which is essential for practical use as a conductive wiping cloth.

In this study, we prepared conductive fabrics using solutions with various concentrations of oxidizing agent and dopant by the proposed method, and examined their characteristics such as resistivity, color, fastness to rubbing and morphology.

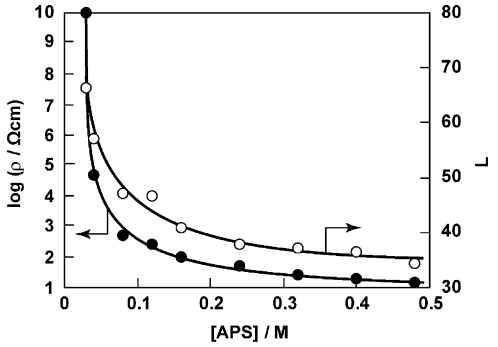

Fig. 3. Change in ρ and L values with APS concentration in solution C. [BANS] = 0.12 M; [Ethanol] = 6 M.

2. Experimental

2.1. Preparation of a dopant solution

1-Butylammonium-2-naphthalenesulfonate (BANS) was used as a dopant in the present study because we have found

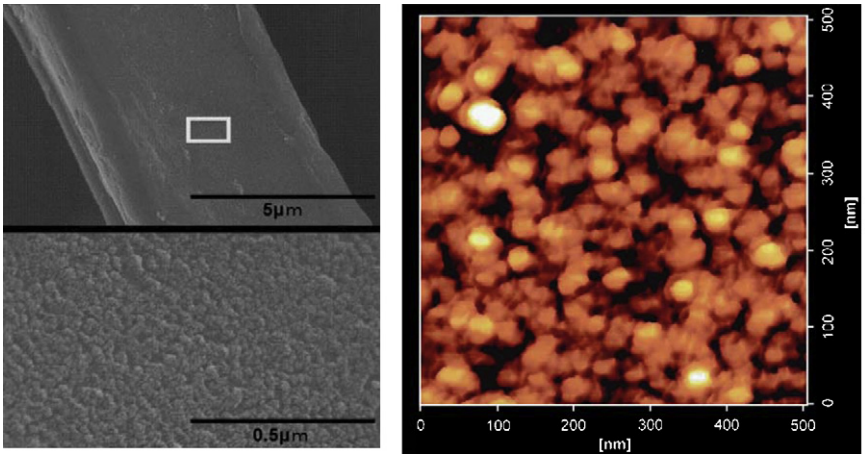

Fig. 2. (a) SEM image (upper) and enlarged image of rectangular area in upper image (lower) and (b) AFM image (500 nm × 500 nm) of fiber of conductive fabric B. [APS] = 0.12 M; [BANS] = 0.12 M; [Ethanol] = 6 M.