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The Development of Pad-Dry-Cure Compatible Method for Preparing Electrically Conductive Copper Coated Cotton Woven Fabrics

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Abstract

Electrically conductive cotton fabrics were successfully prepared by a first free radical polymerization, assisted by a conventional pad-dry-cure textile technology and subsequent electroless deposition (ELD) of copper thin layers on cotton fiber surfaces. Pad-dry-cure takes a major role in the even uptake and penetration of the monomer [2-(methacryloyloxy)ethyl]trimethyl-ammonium chloride (METAC) solution throughout the cotton fabrics, making subsequent ELD plating of copper metal uniform. The surface electrical resistivity of as-prepared electro-conductive cotton fabrics varies from 10^3 to $10^{-1}\Omega$/sq, depending on the ELD conditions. The whole process is low cost, low chemical wastage and compatible with current wet processing in the textile industry, which provides a great potential in commercialization in a bulk scale.

Keywords: Electronic Textiles; Pad-dry-cure; Polymer Brushes; Electroless Deposition; Cotton

1 Introduction

The new era of electronics is no longer constrained by rigid board circuits, but promoted to an advanced level which is flexible and wearable. Such a take-over contributes significantly to human mankind, especially in leisure, healthcare, military and sports fields [1]. The rapid introduction and advancement of flexible and wearable electronic devices result in the high demand of performance conductors as interconnects, contacts and electrodes. Textiles, of high flexibility and wearability, are one of the suitable candidates for fulfilling such purpose. Numerous literatures about synthesizing flexible electro-conductive textiles were massively reported in the past decades [2-10]. Yarns made of metals and metal oxides were the pioneers [11]. Later, increasing interest in nanotechnology triggered the development of carbon nanotubes (CNTs) for making highly electro-conductive textiles [12]. However, due to high production cost, precise control on parameters and low throughput, coating of intrinsic conducting polymer (ICP)

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such as polyaniline (PAni) and polypyrrole (Ppy) on textile fiber were later developed as alternatives [13-16]. Recent years, innovation of making such electro-conductive textiles is adjusted in a more optimized and tuneable fashion. But still, the low electrical conductivity attained limits wider application in flexible and wearable electronics, of which the durability, washability and commercialization of such electro-conductive fibers remain a major concern.

The employment of grafting techniques of polymer brushes, however, brings a breakthrough [17-23]. Recently, we reported our success in grafting a thin polyelectrolyte layer on cotton surfaces by using atom transfer radical polymerization (ATRP) [20]. With polymer brushes chemically tethered to the surface of cotton fibers, followed by subsequent electroless deposition (ELD) of thin copper metal layer, durable conductive cotton fabric was yielded. Such approach successfully provides electro-conductive yarns with conductivity as high as ∼1 S/cm. Even after many stretching, bending, rubbing and washing cycles, robust mechanical and electrical durability of the as-made yarn were still maintained.

To date, the textile industry is developing rapidly. The demand of scale production, especially in making electro-conductive textiles, has been exponentially increasing. Nevertheless, there is no practical, low cost and user friendly technology transfer, to allow textile manufacturing sector to utilize current textile technology to produce easy-to-make electrically conductive textiles in bulk. Although some available surface coating techniques such as chemical vapor deposition (CVD) and plasma-enhanced CVD (PECVD) give sophisticated metal coating that can be used in the industry [24-29], they often involve great investment in advanced instrumentation, specialized workforce and precise control on parameters. A recent advance on using jig-dye machine for making electro-conductive cotton fabric [30] has a great potential in being applied in the textile industry; however, the conductivity is far from satisfactory. Hence, a reliable yet inexpensive process to voluminously produce electro-conductive textile still remains a significant challenge faced by textile manufacturing sector.

To address this challenge, we report here the development of pad-dry-cure compatible technology for preparing electrically conductive cotton fabric by using conventional free-radical polymerization, followed by ELD of copper metal, with an aid of conventional pad-dry-cure incorporated into the monomer uptake and polymerization process. Pad-dry-cure has long been an established technique in textile wet processing, which not only aims at the even distribution of finishing agent on the fabric surfaces, but also imparts deep penetration into the fiber structure. Such technology involved are inexpensive, simple and the instrument used is already been widely utilized in the industry, to bring additional functionalities such as increasing hydrophobicity, flame retardance, wrinkle resistance, thermoregulation, anti-microbial properties, self-cleaning characteristics and ultraviolet protection [31-38].

This paper reports a compatible knowledge for making high-throughput electrically conductive cotton fabrics, with conventional pad-dry-cure technique combined with our previous invention. As-made fabrics were characterized with respect to their morphology by scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX) and electrical surface resistivity by four-probe method. The feasibility of producing cotton fabrics in a wider range of electrical conductivities by varying electroless plating time was also investigated and reported in this paper.