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ELECTRIC PROPERTIES OF IODINE DOPED COTTON FIBERS PRETREATED WITH AQUEOUS ALKALINE SOLUTION

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Abstract

The electric properties of 5% and 10% iodine doped cotton fibers, pretreated with 2% and 20% alkaline solution, are studied in the dark and ultraviolet light, respectively. The concentrations of iodine solution as well as the pretreated aqueous alkaline solution influence the electric properties of doped fibers. The results show that the concentration of pretreated alkaline solution has important effects on the cotton fiber structure and as a result, it affects the electric properties significantly. In addition, the result of temperature dependence of current density indicates that the dominant conductive mechanism is variable range hopping in the measured temperature region.

Keywords*:* cotton fiber, electrical conductivity, current-voltage features, diffusion.

Introduction

Conducting polymers have attracted considerable attentions because of their great potential applications in optoelectronics and microelectronics devices [1, 2]. Typically, these polymers are made conducting by chemicals doping, resulting in polycations or polyanions with a relative mobile charge [3]. Recent efforts have focused on searching for inexpensive renewable conducting polymers combined with the corresponding effective stable dopants [4]. As one of the most common natural polymers, the cotton cellulose fibers have the tremendous potential commercial uses as an alternative to the conducting polymers by chemical doping. Cellulose is an organic compound with the formula of $(C_6H_{10}O_5)_n$, a polysaccharide consisting of a linear and un-branched chain of several hundred to over ten thousand glucose units bond with each other by β-1, 4-glucosidic link, carrying secondary hydroxyl and methyl group. The detailed structure modification, physicochemical and mechanical properties of the cotton cellulose has been quite well studied [5-7].

Understanding of the electrical properties of the conducting polymers is considerable important for the electric and optical applications. Recent efforts have been directed to the cotton cellulose dielectric constant and AC electric conductivity with various chemical modification treatments [8, 9]. However, there is very little attention being paid to the possibility of altering cotton fibers to behavior semiconductor properties. In addition, since the discovery that iodine can be used as dopant to enhance the conductivity of poly-acetylene by several orders of magnitude, a large effort has been devoted to making other polymers conductive and improving the materials properties [10]. In this paper, we study the DC electrical properties of the iodine doped cotton fibers as a function of the cellulose structural changes with relation to different concentration of aqueous alkaline solution pretreatment and doped iodine solution. In addition, the temperature dependences of current density for iodine doped cotton fibers are also measured and the conductivity mechanism is discussed.

Experiment The raw Usbekistan cotton fibers were used in this experiment. In order to remove impurities that attached on the cotton fiber surface, the raw cotton fibers were pretreated in the 20% aqueous NaOH solution with a duration of 2 min at room temperature (sample A and sample B) and 2% aqueous NaOH solution for 90 min at 95°C (sample C and sample D), respectively. After alkaline solution pretreatment, the cotton fibers were immersed in distilled water for twice to remove excess alkaline and air-dried for 24 h in sequence. The completely dried cotton fibers were then doped in the solution of 10% (sample A and sample C) and 5% (sample B and sample D) weight fraction of iodine in ethanol for 5 h to make the fibers be fully doped (Table 1), respectively. The doped cotton fibers were keep flat with a thickness of 0.05 cm on the top of ITO glass and then covered with another ITO glass in order to make contact for electrical measurement. The prepared ITO/Cotton fibers/ITO structure has the contact area of 1×1 cm2. In order to remove any water that might be present on cotton fibers, the samples were then annealed for 5 h at 60°C. All the reagents were analytically pure and used without purification during the procedure. The morphology of the cotton fiber was measured by field emission scanning electron microscopy (FE-SEM) at 25 kV working voltage. The DC electric conductivity was carried out in the dark and UV light with a wavelength of 254 nm under air at room temperature by Keithley 617 electrometer. Temperature dependence of conductivity was measured in a heat chamber by two probe technique. The SEM image shows that the doped cotton fibers have an average diameter of 15μm and the surfaces present clockwise helical direction (not shown here).

Results and Discussion

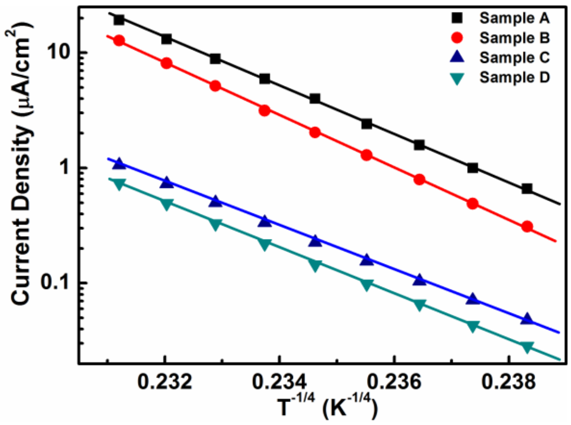

Figure 1 Temperature dependence of current density at 10 V applied voltage of doped cotton fibers. Points are experimental data and lines are fits to Mott's VRH expression.

The current density at 10 V applied voltage with the reciprocal of absolute temperature for iodine doped cotton fibers is represented in Fig. 1. The positive temperature coefficient of current density indicates that the doped cotton samples have semiconductor characteristic in the investigated temperature region. It shows that the results follow Mott's 3D variable range hopping (VRH) expression $J (T) = A \exp (-BT^{-1/4})$, where J is current density, T is the absolute temperature, and A is a constant [11]. In this model, B is denoted as $2.06(\alpha^3 K_B N)^{-1/4}$, where K_B is the Boltzmann constant, α is the decay length of the localized states, and N is the density of the localized states available for carrier conduction. The VRH conduction mechanism of the iodine doped cotton fibers implies a high degree of disorder in the fibers and the conduction is mediated by phonon-assisted tunneling between electronic localized states [12].

Figure 2 shows the I-V characteristics as a function of pretreated aqueous alkaline solution and doped iodine solution concentrations at room temperature in the dark. From the semi-logarithmic curve (Fig. 2 inset), we can clear see that the current densities are symmetric at forward and inversed applied voltage for all iodine doped cotton samples, as well as the neutral cotton fibers without any treatments. The current density of neutral cotton fibers is dramatically suppressed compared with the iodine doped fibers, indicating that neutral fibers essentially remain insulator.

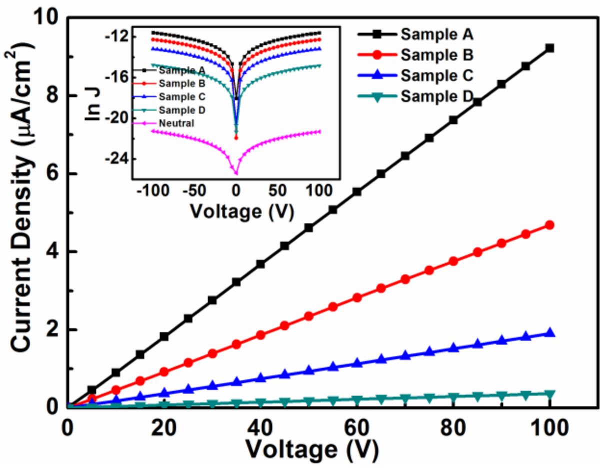

Figure 2 I-V characteristics of iodine doped cotton fibers as a function of pretreated aqueous alkaline solution and doped iodine solution concentrations in the dark.

It can be seen that at the same voltage, the current density of sample A (sample B) with 20% aqueous alkaline solution pretreatment is almost one order higher than sample C (sample D) with 2% alkaline pretreatment. This phenomenon can be attributed to the formation of more available localized states induced by more amorphous region of cotton fibers with 20% alkaline solution pretreatment. As discussed previously [5], the cotton fiber is only purified without changing the cellulose structure with 2% aqueous alkaline solution pretreatment. While with 20% alkaline solution pretreatment, the cellulose structure changed from cellulose I to cellulose II, causing an increment of amorphous region, resulting more active groups formed on the surface to enhance the reactivity to iodine dopant. Eventually, more available localized states are induced to enhance the conductivity of iodine doped fibers. In addition, at the same concentration of pretreated alkaline solution concentration and applied voltage, the current density of sample A with 10% iodine doped solution (sample C) is about one time higher than sample B (sample D) with 5% iodine solution, indicating that the higher density of available localized states are increased with increasing the iodine solution concentration. The results show that the structure of cotton fibers with relation to alkaline solution pretreatment is the most important factor for the current density.

In order to investigate the photo response of the iodine doped cotton fibers, further electrical properties are measured in UV light after a 30 s light exposure. I-V characteristics of iodine doped cotton samples are shown in Fig.3, as a comparison which is measured in the dark (Fig. 2). The current densities are also highly symmetric at forward and inversed applied voltage (Fig. 3 inset), indicating that the UV response time for all doped cotton samples is less than 30 s and then keep quite constant after exposure. For all iodine doped cotton fibers after 30 s UV light exposure, the current densities increase several times than in the dark (Table 1). The photo response is evaluated by $\Delta J/J_{Dark}$, where $\Delta J = (J_{UV} - J_{Dark})$, J_{UV} and J_{Dark} is the current density measured at 100 V applied voltage in the UV light and dark, respectively. Sample A (sample B) with 20% aqueous alkaline solution pretreatment exhibits 5.20 (5.09) times enhancement, while sample C (sample D) with 2% alkaline treatment only exhibits 3.32 (3.20) times. It indicates that the increment of the amorphous region with 20% aqueous alkaline solution pretreatment can also enhance the photo response ability.

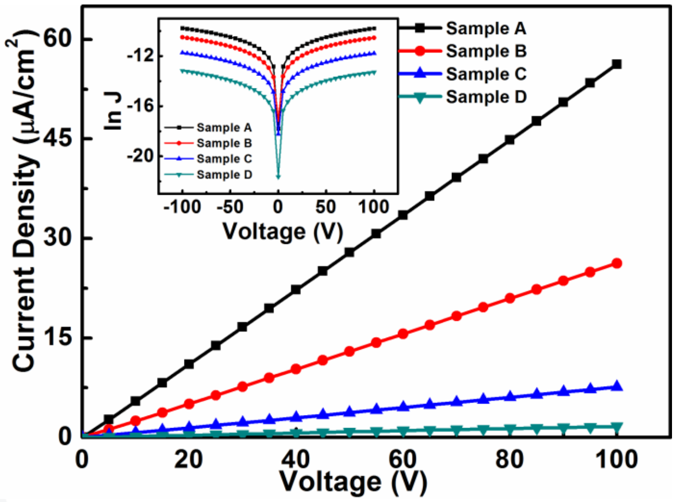

Figure 3 I-V characteristics of iodine doped cotton fibers as a function of pretreated aqueous alkaline solution and doped iodine solution concentrations in the UV light.

Table 1. The caption of a table. Aqueous NaOH solution concentration, iodine solution concentration, current density at 100 V applied voltage in the dark and UV light, and UV response of iodine doped cotton fibers.

Sample	Pretreatment	Doped solution	J_{Dark} [A/cm²]	J_{UV} [A/cm²]	$\Delta J/J_{Dark}$
A	20% NaOH	10% I_2	9.22E-6	5.72E-5	5.20
B	20% NaOH	5% I_2	4.63E-6	2.82E-5	5.09
C	2% NaOH	10% I_2	1.86E-6	8.02E-6	3.32
D	2% NaOH	5% I_2	3.86E-7	1.62E-6	3.20

The UV light response of iodine doped cotton fibers can be attributed to the improvement of carrier density rather than carrier transport mobility as the dominant factor [13]. The charges generation efficiency is enhanced for iodine doped fiber in the UV light and then the charges transfer between iodine and the cotton surface to increase the current density [14]. The more amorphous region of cotton fibers with 20% alkaline pretreatment would be more easily accessible to be doped by iodine than with 2% pretreatment and as a result, the higher photo response occurs due to the higher doped level. In sum, the cotton fibers with 20% aqueous alkaline solution pretreatment would have higher electric conductivity and photo response.

Conclusions

In summary, the I-V characteristics were measured at room temperature in the dark and UV light for iodine doped cotton fibers with different concentrations of aqueous alkaline solution pretreatment. The results showed that cotton fibers with 20% aqueous alkaline pretreatment presented higher current density and were more sensitive to UV light than with 2% pretreatment at the same iodine doped solution. With higher doped iodine solution concentration, the current density was also enhanced. It indicated that the structure of cotton fibers with relation to alkaline solution pretreatment was the most important factor for the current density. In addition, the temperature dependence of current density showed that variable range hopping mechanism was responsible for the conductive in the measured temperature region.

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