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Electrical properties of multi-walled carbon nanotubes/PEDOT:PSS nanocomposites thin films under temperature and humidity effects

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ABSTRACT

The effect of temperature and humidity on the electrical properties of thin films based on multi-walled carbon nanotubes (MWCNTs) dispersed in sodium dodecylbenzene sulfonate (SDBS) and mixed with poly (3,4-ethylene dioxythiophene)–poly (4-styrenesulfonate) (PEDOT:PSS) were investigated systematically. The change in DC-resistivity was measured by 4-wire technique as a function of the temperature and the relative humidity (RH). The investigation of temperature influence shows semiconducting behavior in the temperature range from 20 °C to 80 °C. This behavior is due to the tunneling barrier, which is expected to dominate the overall film resistance in this temperature range. Moreover, the investigation of humidity effects at temperatures up to 60 °C shows that the resistivity increases exponentially until 70% RH and then it starts to decrease sharply because of development of water layer on PEDOT:PSS film. This effect plays a minor role at high working temperature e.g. 70 °C. Below the saturation point, the films act as a humidity sensor with high sensitivity around ~0.07%RH.

1. Introduction

Since their discovery by Shirakawa et al. [1], intrinsic conductive polymers (ICPs) known also as electro-active polymers have attracted a huge interest. The ICPs combine the electrical, electronic and magnetic properties of a metal and the mechanical properties of a conventional polymer, directing into multifunctional materials which enables them to be used in flexible electronics and many applications such as field effect transistors [2], transparent electrodes [3], solar cells [4] and strain sensors [5–8]. Among others, the polythiophene derivative, poly (3,4-ethylenedioxythiophene) (PEDOT) has been intensively studied because of the their remarkable electronic, chemical and mechanical properties [9,10]. Among others, it has a very high conductivity compared with other polymers. However, the poor solubility of this polymer in water and organic solvents limits its application in the field of flexible electronics [2,4,8]. This problem can be solved by using water-soluble polyelectrolyte, such as poly-(styrene sulfonic acid) (PSS) and PEDOT as dopant to form a PEDOT:PSS aqueous composite [11,12]. This doping process makes the PEDOT:PSS to be a hole conductive colloidal suspension. For this reason, it is widely used in solar cells as hole injection layer instead of the brittle indium tin oxide (ITO) [13–15].

Furthermore, nanofillers such as carbon nanotubes (CNTs) can be used not only to reinforce the existing properties of the ICPs [16], but also to enlarge the field of application e.g. in smart membranes [6,17] and supercapacitors [18]. During the lifetime of the sensor or storage element, environmental effects such as humidity and temperature affect the conduction properties and the functionality of the sensor. Therefore, a detailed investigation of sensor behavior under environmental conditions is a crucial step for the sensor operation. There are numerous studies on the investigation of environmental effect of thin films based PEDOT:PSS and CNTs individually [16,19–23].

S. Taccola et al. [19] used PEDOT:PSS/iron oxide nanoparticles spin-coated on a poly(dimethylsiloxane) (PDMS) elastomer layer on silicon for sensing relative humidity in the range of 30–70% RH at

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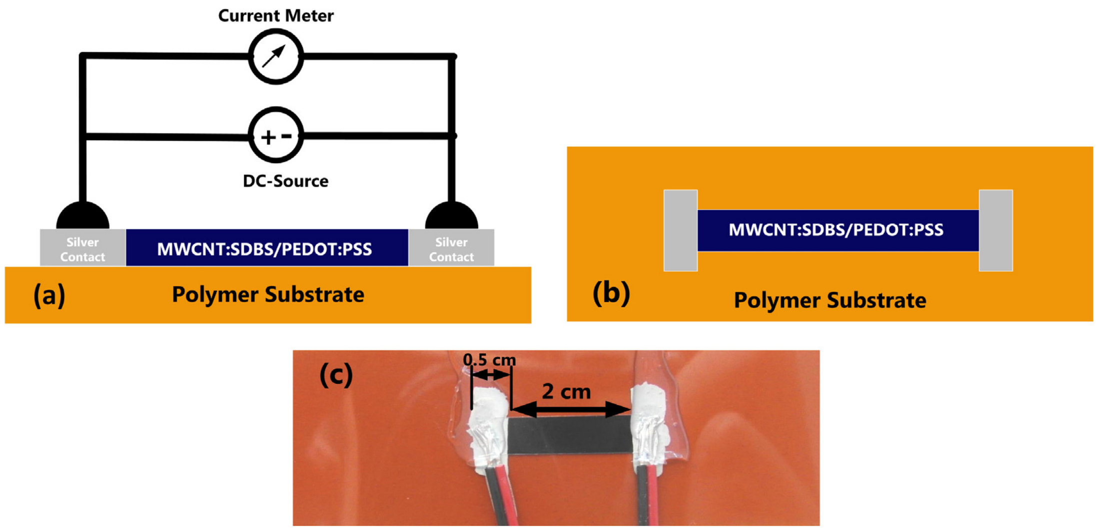

Fig. 1. Schematic drawing of the thin film with electrical contacts, (a) side view, (b) top view, (c) optical micrograph of the MWCNT/PEDOT:PSS thin film.

a constant temperature of 30 °C. It has been observed that the films provide a linear increase in resistance in relation to the increase in RH% and also as the concentration of nanoparticles increased, the humidity sensing capabilities of the film are highly enhanced. Recently Liu et al. [20] and Kus et al. [21] reported about the use of PEDOT:PSS for humidity sensing applications. It has been seen that the resistivity increases linearly up to 80% RH and above this value a sharp decrease in resistivity was observed due to the formation of a water meniscus layer on the top of the PEDOT:PSS thin film. Moreover, Okuzaki et al. reported the use of freestanding PEDOT:PSS films as humidity sensor for leverage actuator and Braille cell [22]. They showed that the desorption of water molecules occurs due to joule heating. However, up to now no systematic studies on the environmental effects on composite thin films based on CNT and PEDOT:PSS nanocomposites have been published to our best knowledge. Even if the combination of both CNT and PEDOT:PSS is very interesting for sensing applications [2,5–7], no specific study about the effect of humidity and temperature influence was performed until now.

In this paper, we investigate the effects of temperature, and of relative humidity on the DC-resistivity, sensitivity and the conduction mechanism of PEDOT:PSS films and MWCNT/PEDOT:PSS composite thin films. These parameters are found to be important for the sensor behavior.

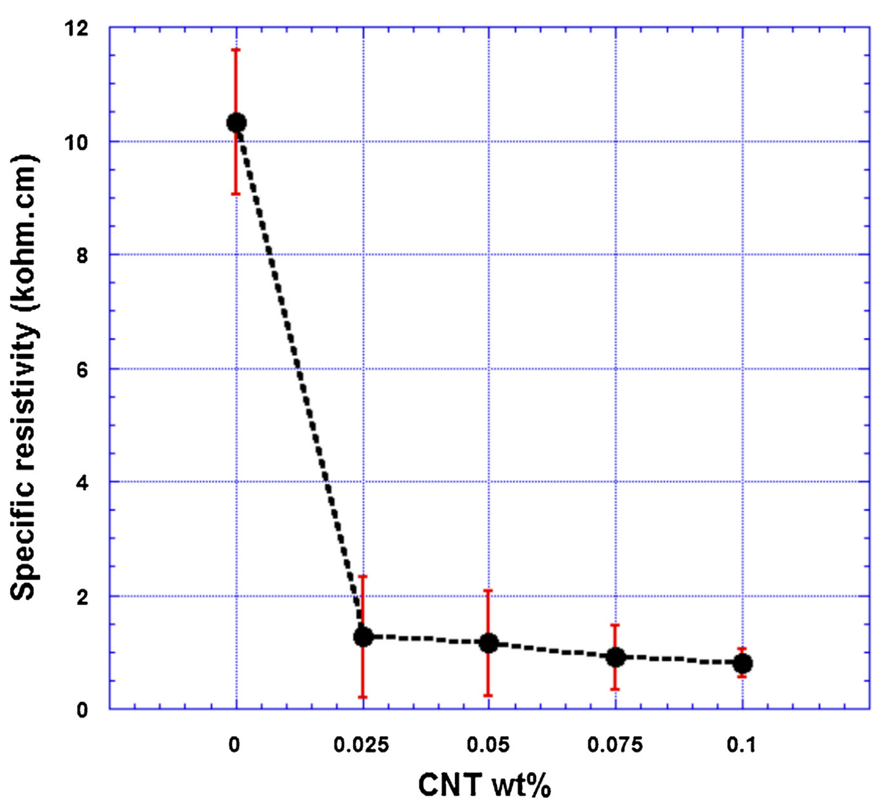

Fig. 2. The specific resistivity of MWCNT/PEDOT:PSS composite film as a function of the MWCNT content.