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A Noble Method for Improvement of the Sheet Resistance of Transparent CNT Film

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A simple process for the fabrication of transparent, electrically conductive thin films of Single-Walled Carbon Nanotubes on a glass substrate is reported. SWNTs dispersed in a 1, 2 dichlorobenzene surfactant were spin-coated onto a glass substrate. The as-prepared SWNT film had a transmittance of nearly 90% over a wide visible spectra range, and its sheet resistance was measured to be approximately 5800 Ω/□. To improve the sheet resistance of the SWNT film, aluminum was deposited by RF magnetron sputtering on a SWNT film that was spin-coated onto a glass substrate and annealed in a nitrogen atmosphere for 3 hours. A SWNT film with 50Å-thick Al deposited onto it obtained a transmittance of nearly 80% over a wide visible spectra range. The sheet resistance was 2400 Ω/□.

Keywords: single-walled carbon nanotubes (SWNTs), aluminum, transparent film, spin-coating

Carbon nanotubes (CNTs) have attracted great interest as a new nanomaterial. As CNTs are nanosized, they can be used directly as the basic elements of a nano-building material [1]. In addition, due to the unique characteristics of CNTs and their structure, including their diameter, length, and chirality, considerable effort has been expended searching for potential applications of CNTs in a wide range of scientific fields, including aeroscience, electronics, biology, medicine, energy, and material engineering[2]. Recently, flat panel displays (FPDs) have become more important in the electronic display market, and there have been efforts to use carbon nanotubes for FPD application [3]. The research on CNTs for FPD use has mainly focused on the potential applications of the field emission display tip due to the high aspect ratio and the small tip radius of curvature of CNTs [4]. In addition, interest in transparent and conductive thin films has increased for applications such as liquid crystal displays, touch panels, and flexible displays. CNTs are among the most appropriate materials for conductive films for displays due to their excellent high mechanical strength and electrical conductivity. However, as CNTs themselves are not transparent, it is very important to coat them uniformly to an ultra-thin thickness for fabricating a transparent film. Several results have been reported for preparing transparent nanotube films, including drop-drying from a solvent[5], dip coating[6], vacuum filtering[7], and polymerization with ultra-sonication[8]. However, there are a number of restrictions when applications to various substrates and/or complicated processes are necessary to obtain a uniform film. In this article, a simple process for the fabrication of transparent single-walled carbon nanotubes (SWNTs) film and the reduction of its sheet resistance on glass substrates is reported.

SWNTs were grown via a dc arc-discharge process. The purity of the SWNTs was approximately 90%. The synthesized SWNTs were dispersed with ultra-sonication for 40 minute in 1,2 dichlorobenzene, anhydrous 99% solutions prior to the formation of the film. The concentration was 0.1mg/ml. The dispersed SWNT solution was spin-coated at 300 rpm on an Al buffer layer deposited onto a glass substrate and dried on a hotplate at a temperatures ranging from 110 - 130°C. The thicknesses of the Al buffer layers were 30, 50, 100 and 150Å. Al buffer layer was used in order to improve the sheet resistance of the SWNT film. The coated SWNT film on Al/glass was annealed in a furnace for 3 hours under a nitrogen atmosphere. The surface morphology of the transparent conductive film was characterized by field emission scanning electron microscopy (FESEM, JEOL, JSM-6330F). The sheet resistance and optical transmission properties of the transparent conductive film were measured with a four-point probe method and a UV-visible spectrometry (UV S-2100, Scinco), respectively.

Figure 1 shows the sheet resistance and transmittance of the SWNT films according to the aluminum thickness. The sheet resistance and transmittance of SWNT films decrease as the aluminum thickness increases. The SWNT film with a 50-Å-thick Al buffer layer had a transmittance of 80% and a sheet resistance value of 2400 Ω/□. A transmittance of 80%

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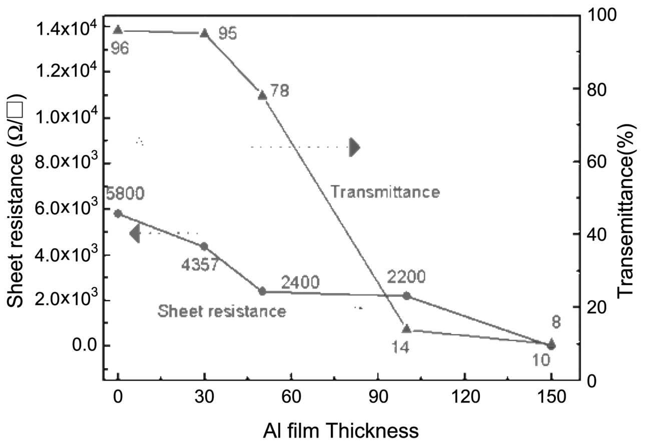


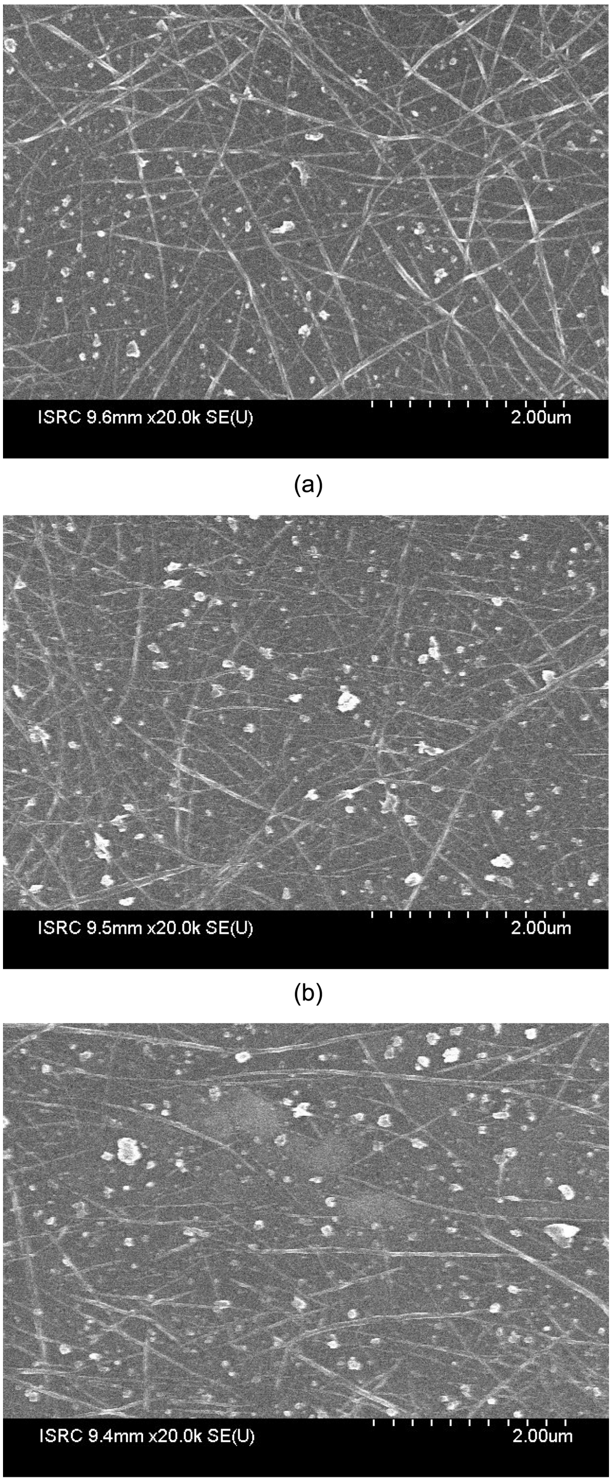
Fig. 1. Sheet resistance and transmittance of SWNTs films as a function of the aluminum thickness.

or higher is appropriate for transparent film in a display. In contrast, the sheet resistance of the film in the figure is higher than that of ITO (Indium Tin Oxide) with 100 Ω/□. It is believed that the higher sheet resistance of the SWNT film in this study was induced by the degree of SWNT purification. This degree of SWNT purification was 90%, while this was typically 95% or higher in earlier studies[12]. Further studies are needed to decrease fully the sheet resistance of the SWNT film itself.

Figure 2 shows the surface morphology of the SWNT film with different Al thicknesses after annealing for 3 hours at temperature of 400°C under a nitrogen atmosphere. As shown in Fig. 2, the SWNT film contains impurities such as Fe catalyst, which increases the sheet resistance of the SWNT film regardless of the thickness of the Al buffer layer. In addition, amount of impurity on SWNT films and the distribution of SWNT do not affect the function of the Al thickness.

There are several possible explanations for the reduction of the sheet resistance in SWNT films with a Al buffer layer. As one possible explanation, the reduction of the sheet resistance may be related to the formation of a contact by the Al buffer layer between each SWNT. The existence of Al particles between SWNTs was investigated via an EDS (Energy Dispersive Spectroscopy) analysis. However, the existence of Al particles between SWNTs was not distinguishable for the 50-Å-thick Ni catalyst layer due to the EDS resolution. Therefore, it is unclear whether the formation of contact by the Al buffer layer between SWNTs is responsible for reducing the sheet resistance of the SWNT film.

As another possible explanation, referring to the effect of Al doping for CNTs, Oh *et al.*[11] suggested that Al acts as n-type dopant on the normally p-type CNT field-effect transistors. Most of the CNT field-effect transistors (CNFET) are likely to show p-type characteristics, which is either due to hole doping by environmental oxygen or a lower Schottky barrier for the hole current at the metal-CNT contact. In experiments in the present study, the role of the dopant Al for



(a)

(b)

(c)

Fig. 2. Surface morphologies of SWNT films with (a) No Al deposition, (b) 50-Å-thick Al and (c) 150-Å-thick Al after annealing for 3 hours under a nitrogen atmosphere.

SWNTs remains unclear. This is a topic for further investigation.

In this study, a transparent conductive film was fabricated using an Al buffer layer to decrease the sheet resistance. The effect of the Al buffer layer on the sheet resistance and the transparency of SWNT film were investigated. When 50Å-thick Al was adopted to a SWNT film, the sheet resistance of the SWNT film decreased from 5800 Ω/□ to 2400 Ω/□, and the transparency of the SWNT film decreased from 90% to 78%. The reason for the reduction of the sheet resistance when using the Al buffer layer is not yet clearly understood. However, the reduction of SWNT film by the Al buffer layer has great potential for practical applications.

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