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Characteristics of silver meshes coated with carbon nanotubes via spray-coating and electrophoretic deposition for touch screen panels

Bu-Jong Kim, Jong-Seol Park, Young-Jin Hwang, Jin-Seok Park *

Dept. of Electronic Systems Engineering, Hanyang University at ERICA, Republic of Korea

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ABSTRACT

This study demonstrates hybrid-type transparent electrodes for touch screen panels. The hybrid-type electrodes were fabricated by coating silver (Ag) meshes with carbon nanotubes (CNTs). Thin Ag films were deposited on glass substrates using the sputtering method, and were then patterned via photolithography to obtain mesh structures with a 10 μm line width and 300 μm line-to-line spacing. The Ag meshes were coated with CNTs using two different methods: spray coating and electrophoretic deposition (EPD). For the samples of Ag meshes with no CNT coating as well as of CNT-coated Ag meshes, the visible-range transmittance and reflectance as well as the surface morphology were characterized and compared. The change in sheet resistance due to long-term exposure to air with an 85 °C temperature and 85% humidity was also measured. The experimental results indicated that the reflectance of the Ag mesh electrodes was substantially reduced by the CNT coating. Especially, the Ag mesh electrodes with EPD-coated CNTs showed excellent properties, such as higher than 80% transmittance, lower than 8% reflectance, and better stability.

1 . Introduction

Thin films of indium-tin-oxide (ITO) are being used as transparent conductive electrodes of various electronic devices, such as displays, solar cells, and touch screen panels [1–3]. ITO has several disadvantages, however, in applications to next-generation flexible electric devices, such as its brittle nature (i.e., low fracture strain and lack of flexibility), its requirement of a high processing temperature to achieve its excellent electrical characteristics (which damages the plastic substrates), its low adhesion to polymeric materials, and its limited supply as a rare Earth metal (which makes its price unstable) [4,5]. Therefore, studies for replacing the ITO electrode with novel materials such as metal meshes [6], silver (Ag) nanowires [7,8], conductive polymers [9], graphene [10], and carbon nanotubes (CNTs) [11] are actively being pursued.

Among the aforementioned novel materials being explored, metal mesh may be the leading candidate for commercialization as a transparent electrode due to its lower electric sheet resistance and higher visible transmittance compared to the other alternative electrodes. For these reasons, some studies on the fabrication methods of metal mesh electrodes are being conducted [12–14]. The reflectance generated by metal on a mesh-type electrode, however, causes the moiré phenomenon, which leads to a visibility problem [15]. Also, the sheet resistance of metal may increase greatly when exposed to air for a long time due to the oxidation of metals. Several methods have been investigated to protect metals from oxidation in metal nanowires [16–19]. However, the researches on the long-term stability of metal meshes are still insufficient. Besides, CNTs for the transparent electrode also have advantages in terms of chemical stability, thermal conductivity, mechanical strength, and flexibility, but it is difficult for CNTs to form a smooth film due to their tubular structures. Furthermore, a relatively high degree of contact resistance of tube–tube junctions may occur in CNTs [20]. Although various studies aiming to improve the electric characteristics of CNTs have been reported of late [21,22], the transparent electrodes using CNTs only show relatively high resistance thus far.

In this study, to solve the problems demonstrated by the currently developed metal meshes, such as poor visibility due to reflectance and instability due to oxidation, hybrid-type electrodes were fabricated by coating Ag meshes with CNTs. Here, CNT coating was done using two different methods: electrophoretic deposition (EPD) and spray coating. The transmittance and reflectance characteristics of the CNT-coated Ag mesh electrodes, along with the changes in their sheet resistances due to air exposure, were analyzed and compared with those of the conventional Ag mesh electrodes.

2 . Experimental Details

To fabricate an Ag mesh electrode, photolithography was performed, employing the following process. A 2.1- to 2.3-μm-thick photoresist (PR) was deposited via spin coating on a 3 × 3 cm glass (Corning, Eagle 2000) substrate that had been cleaned. The spin coating was

* Corresponding author at: Room #306, Engineering Building #3, Hanyang University, 1271 Sa-3dong, Sangnok-gu, Ansan, Gyeonggi-do 426-791, Republic of Korea.
E-mail address: jinsp@hanyang.ac.kr (J.-S. Park).

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performed for 1 min at 3000 rpm, and the soft banking was performed for 2 min in a 100 °C oven. Thereafter, UV light was radiated using an aligner, and mesh patterns were formed through the process of development. A 100-nm-thick Ag film was deposited via DC sputtering and was then patterned using a lift-off technique to produce an Ag mesh electrode.

The suspension of the single-walled CNTs (NanoAmor, 1284YJ) used in the spray coating and EPD methods was prepared through the following purification and dispersion processes. First, CNT powder (10 mg) was placed in a mixture of H_2SO_4 and HNO_3 (at a 2:1 volume ratio) to eliminate the impurities (e.g, metal catalysts, amorphous carbons) in the CNT powder. This solution was mixed in an agitator for 35 min, via ultrasonic dispersion. The purified CNTs were filtered out using the vacuum filtering system, and were dispersed for 30 min in the ultrasonic generator after adding $Mg(NO_3)_2 \cdot 6H_2O$ (15 mg) and isopropyl alcohol (IPA, 50 ml) [23]. Finally, the well-dispersed supernatant was extracted using a centrifugal separator operated at a speed of 4000 rpm for 30 min. To check the degree of dispersion of the CNT suspension that was produced in this way, the CNT suspension's zeta-potential was measured, which was around 36.1 mV, indicating that the CNT suspension showed very stable dispersion. The CNTs were deposited on the Ag mesh via spray coating, with the process times varying at 60–180 s, by fixing the injection pressure at 0.6 MPa, the injection rate of 1 ml/min, and the hotplate temperature at 100 °C. In the case of the EPD method, a cathode with a Ag mesh and an anode (Cu) were placed in the suspension, and CNTs were deposited on the Ag mesh with 30–200 s process times, by applying 100 V (DC) to the two electrodes with the spacing fixed at 10 mm.

For all the samples, including the Ag mesh and the CNT-coated Ag meshes, the surface morphologies were inspected using a field emission scanning electron microscope (FESEM, SIGMA, Carl Zeiss). The optical properties, such as the transmittance and reflectance, were measured in the wavelength range of 400–700 nm, using a spectrum colorimeter (Konica Minolta, CM-5). Also, a stability test where the electrode specimens were exposed to air was performed for 5 days at an 85 °C temperature and 85% humidity. The changes in the electrical sheet resistance of the Ag meshes and the CNT-coated Ag meshes were measured using a non-contact sheet resistance measurement device (NAPSON, EC-80P).

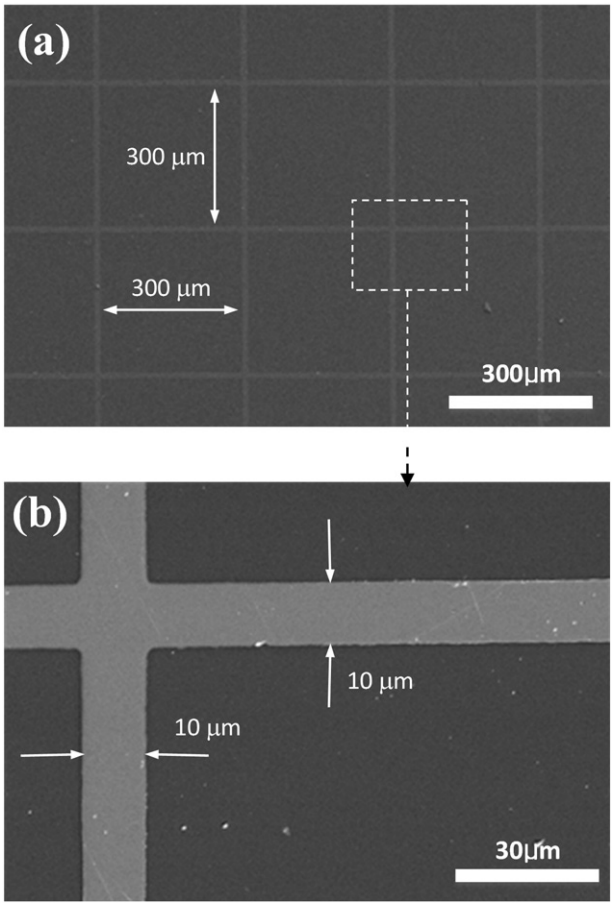

Fig. 1. (a) FESEM image of Ag meshes with a 10 μm line width and 300 μm line spacing. (b) Enlarged (10×) image of (a).

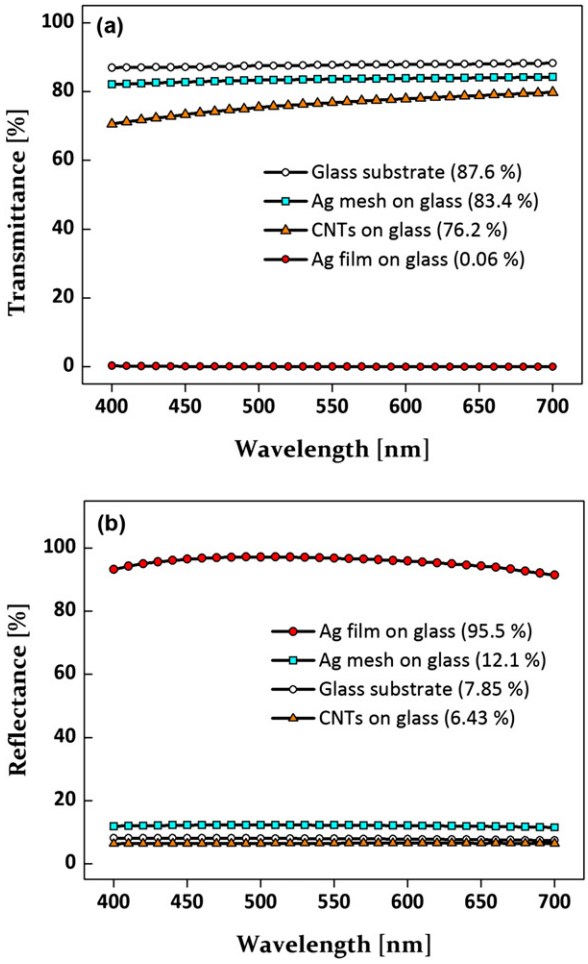

Fig. 2. Visible transmittance and reflectance of (a) glass, Ag film, and Ag mesh according to the wavelength. (b) CNTs used for coating the glass substrate via spray coating.

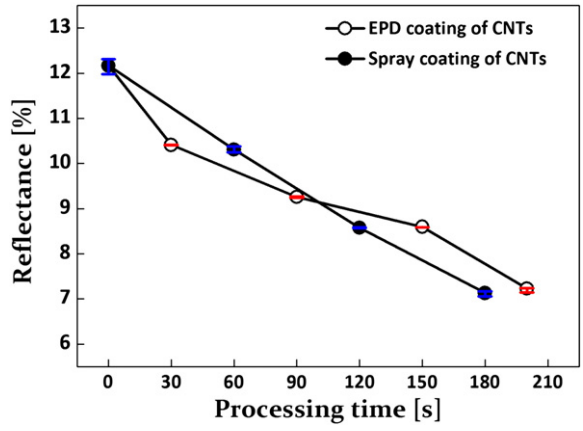

Fig. 3. Changes in the reflectance of the Ag mesh electrodes according to the CNT coating. The processing time indicates the CNT coating time in the EPD and spray coating processes.