Electromagnetic Wave Shielding Effectiveness of SWNT-coated, Transparent, Conducting Panels

I.W. Nam*, H.K. Lee**, J.B. Sim*** and S.M. Choi****

*KAIST, Daejeon, South Korea, namiru@kaist.ac.kr
**KAIST, Daejeon, South Korea, haengki@kaist.ac.kr
***KAIST, Daejeon, South Korea, junbo@kaist.ac.kr
****KAIST, Daejeon, South Korea, sungmin0@kaist.ac.kr

ABSTRACT

Needs for electromagnetic wave shielding/absorbing have been increased in order to prevent electromagnetic interference (EMI), eavesdropping, and harmful effects to human bodies. Single-walled carbon nanotubes (SWNTs) have been well-known for their extraordinary electric conductivity that could contribute to high electromagnetic wave shielding efficiency. The objective of the present work is to examine the electromagnetic wave shielding effectiveness of SWNT-coated, transparent, and conducting panels. SWNTs were spray-coated on the transparent panels in accordance with the procedure proposed by Geng *et al.* (2007) [1]. Electromagnetic wave shielding effectiveness (EM wave SE) of the panels was measured using a network analyzer with a coaxial waveguide. The EM SE was not improved at most of frequency range of interest although a concentration of SWNT solution used for spray coating increased up to 0.10 %. It was attributable to low concentration of SWNTs used for coating the panels and thinness of SWNT coatings.

Keywords: electromagnetic interference shielding, transparent conducting panels, single-walled carbon nanotubes, electromagnetic wave shielding effectiveness, spray coating method

1 INTRODUCTION

Electromagnetic wave (EM wave) shielding refers to reflection and/or absorption of EM waves by means of conductive materials such as copper, steel, carbon fiber, carbon black, etc [2,3]. Materials with high electrical conductivity is expected to have high EM wave shielding effectiveness [2,3].

EM wave shielding is necessary due to the following three reasons: First, electromagnetic interference (EMI) may cause malfunction of electronic facilities, e.g. trains, elevators, medical equipment, etc [3]. Train or elevator accidents resulted from EMI have been reported [3]. Second, the electromagnetic waves need to be blocked in order to safeguard confidential information which transmits in the form of EM waves [3]. Military and business secrets can be protected from eavesdropping [3]. Third, human bodies can be safe from noxious influence of the EM waves although influence of the EM wave to human bodies is still controvertible [3]. Cases of harmfulness to human bodies caused by EM waves were reported [4]. Importance of EM wave shielding increases with use of electronic devices in the modern society [2,3].

Transparent EM wave shielding materials are important part in a field of EM wave shielding materials since plenty of EM waves leak through windows of building rooms or cars etc.

Carbon nanotubes, which have extraordinary electrical properties (1000 times greater than copper), have been considered as a promising material used for a fabrication of transparent, conductive materials [5]

A variety of studies has been conducted in an effort to fabricate transparent conducting materials with carbon nanotubes (CNTs). Kaempgen *et al.* fabricated single-walled carbon nanotube (SWNT) networks on glass and examined transparency and conductivity of the network with 90 %, 1 kΩ /sq, respectively, at room temperature [6]. Geng *et al.* investigated effects of acid treatment on CNT-based transparent conducting films and achieved improvement of the film conductivity by a factor ~4 with little degradation in optical property [1]. Dan *et al.* reported a fast and simple process for large scale fabrication of transparent, conductive thin films with SWNTs and showed sheet resistance of 100 Ω /sq and transparency of 70 % [7].

Numerous works have been done for fabrication of CNT networks on transparent materials and enhancement of their electrical properties was attained. However, investigations of the transparent conducting materials with CNTs for applicability of EMI shielding are scarce.

The present work was made to examine EMI shielding effectiveness (SE) of SWNT-coated transparent, conductive panels. A fabrication procedure was systematically implemented; SWNTs were dispersed in water with variation of their concentrations, and then it was sprayed on the transparent panels. EMI SE was determined using a network analyzer with a coaxial waveguide. The present work was conducted for a preliminary test to develop the transparent EMI shielding panels exploiting the spray coating method of SWNTs.

2 EXPERIMENTAL PROGRAM

2.1 Fabrication of the SWNT-incorporated solutions

Purified HiPCO SWNTs (purity > 90%) and Sodium dodecyl sulfate (SDS), which is a dispersion agent, were used. Water was purified with a Millipore direct-q system immediately before use.

SWNTs with SDS were dissolved in the purified water. They were sonicated in bath type and tip type sonicators. After the sonication, the SWNT solution was centrifuged. The upper part of solution was withdrawn and used for fabrication of the SWNT-coated transparent panel.

After centrifugation, the concentration of SWNTs in solution was measured using UV-vis-NIR spectrometer. The concentration of obtained SWNT-dispersed solution was calculated with 0.1%. By diluting this solution, solutions with SWNT concentrations of 0.02 %, 0.04 %, 0.06 %, and 0.08 % were prepared.

Details of fabrication procedures of the SWNT-incorporated solutions can be found in Nam *et al.* [8].

2.2 Fabrication of the SWNT-coated transparent panels.

The fabrication of SWNT-coated transparent panel followed the procedure proposed by Geng *et al.*[1]. The prepared SWNT solutions were sprayed with air brush pistol on the transparent panels (glass substrates). All transparent panels were heated and kept 100 ℃ for quick evaporation of droplets on the surfaces. After spray process, the substrates were rinsed with the purified water and dried in oven. After all coating process, the panels were immersed in HNO_3 solution to remove surfactant on the panels and rinsed with the purified water.

Details of fabrication procedures of the SWNT-coated transparent panels can be found in Nam *et al.* [8].

3 MEASUREMENT METHOD

3.1 EM wave shielding effectiveness measurement

The EM wave SE of SWNT-coated transparent conductive panels was evaluated using the network analyzer (Agilent technology PNA series E8364A) in collaboration with the coaxial waveguide as shown in Fig. 1. The process of determining EM wave SE values was as follows : electromagnetic energy generated from a port 1 (left port shown in Fig. 1.) encountered the SWNT-coated transparent, conductive panel in the coaxial waveguide after transmitting through a left cable. A part of the electromagnetic energy was reflected by the SWNT coating on the transparent panel and another part of the electromagnetic energy was absorbed within it. A leftover of the electromagnetic energy after reflecting and absorbing the electromagnetic energy was transmitted into a port 2 (right port shown in Fig. 1.). The network analyzer yielded S parameters, evaluating the electromagnetic energy data acquired at the port 1 and port 2. The frequency range of interest was from 45 MHz to 18 GHz.

Fig. 1 : The network analyzer that calculated the EMI SE

4 RESULTS AND DISCUSSION

The EM wave SE values of three replications for each kind (according to SWNT concentrations : 0 %, 0.02 %, 0.04 %, 0.06 %, 0.08 %, 0.10 %) were averaged. The EM wave SE of transparent, conductive panels coated with varying SWNT concentrations is shown in Fig. 2. Although the concentrations of SWNT in water sprayed on the transparent panels were varied, the EM wave SE values of each specimen were analogous one another in a frequency range of 45 MHz to 10 GHz. Therefore, it can be said that SWNT coating with its concentration up to 0.10 % doesn't improve the electrical conductivity of the transparent, conductive panels. It is likely due to low concentration of SWNT coated on the transparent panels and thinness of SWNT coatings.

The EM wave SE of all specimens continuously increased up to at a frequency of 5 GHz and appeared to stay at a certain level of the EM wave SE at a frequency range of 5 to 9 GHz. Most of specimens exhibited dramatic increments at frequency of 12 GHz or nearby it. The EM wave SE of all specimens at a frequency range of 13 to 17 GHz was less than the EM wave SE at the frequency range of 45 MHz to 10 GHz. However, all specimens' EM wave SE appeared to increase again with the frequency as exceeding 15 GHz.

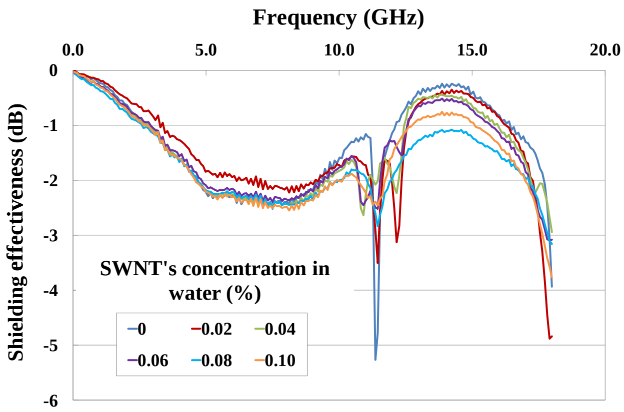

Fig. 2 : The EM wave SE of SWNT-coated transparent, conductive panels

5 CONCLUSIONS

To examine the EM wave SE of SWNT-coated transparent, conductive panels, SWNTs were dispersed in water with variation of their concentrations, and then it was sprayed on the transparent panels.

- The EM wave SE of all specimens at most of frequency range of interest did not differ from each other except the frequency range of 13 to 17 GHz.
- SWNT-coating did not improve electrical conductivity of the transparent, conductive panels due to low concentration of SWNT used for coating the panels and thinness of SWNT coatings.

The SWNT layers on transparent, conductive panels will be thickened and their EM wave shielding characteristics will be examined in a forthcoming study.

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