Electromagnetic Shielding Performance for a 2.5 Gb/s Plastic Transceiver Module Using Dispersive Multiwall Carbon Nanotubes

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Abstract

Electromagnetic (EM) shielding performance for a plastic composite by employing polyimide-based dispersive multiwall carbon nanotubes (MWCNTs) is presented. A well-dispersed MWCNT composite offers a higher electrical conductivity with a lower weight percentage of MWCNTs. The dispersive MWCNT composites with their high shielding effectiveness (SE) are suitable for packaging low-cost optical transceiver modules used in fiber to the home (FTTH) lightwave transmission systems.

1. Introduction

The electromagnetic susceptibility (EMS) or electromagnetic immunity of the optical transceiver modules to the electromagnetic interference (EMI) is one of the major concerns to maintain good signal quality of over gigabit transmission rate [1]-[3]. It is well known that metallic package provides excellent shielding effectiveness (SE). However, owing to its low cost nature and ease of manufacture, plastic composite package technology has been considered to be one of the major choices for reducing the costs of fabricating optical transceiver modules for use in the fiber to the home (FTTH) applications [3]-[7].

Plastics alone are inherently transparent to electromagnetic (EM) radiation and provide no shielding against radiation emissions. To improve the EM shielding for the plastic packaging, electronic conductive properties have to be added into the plastic hosts for adequate EM shielding. The currently available techniques for preventing EMI shielding include electro-plating or electrolysis-plating, conductive sprays, zinc-arc spraying, conductive painting, conductive fillers, and other metallization processes. Among these methods, the most popular one for EM shielding is to compound plastics with discontinuous electronic conductive fillers such as metal particles, metal flakes, stainless fiber, graphitized carbon particles, graphitized carbon fibers, metal-coated glass, and carbon fibers [8]-[9]. Recently, several types of plastic composite package for the optical transceiver modules have been demonstrated with effective EM shielding ability. These plastic composites are the nylon and liquid crystal polymer (LCP) reinforced with carbon fibers [10]-[11], and the woven continuation fiber (WCCF) [3], [7], and [12].

The electronic and mechanical properties of MWCNTs are remarkable [13-14] that the MWCNTs have been the focus of considerable research and development for use in nanoscale electronic and optoelectronic applications such as integrated circuit (IC) interconnections [15], optical emission devices [16], and optical transceiver modules [17-18]. MWCNTs are used as one of the electronic conductive fillers for EM shielding of plastic module package applications [15-16] because of their smaller diameter, higher aspect ratios, higher conductivity, and better mechanical properties. The aspect ratios of most MWCNTs are higher than 1000, which offers a good condition to form overlapping conductive MWCNTs networking to provide a high EM shielding.

However, the MWCNTs are not easily dispersed within the plastic hosts. This is because the van der Waals force between the MWCNTs made them hardly separated during mixing process. If the MWCNTs are not well dispersed within the plastic hosts, the MWCNTs may locally cluster, and result in poor uniformity of the MWCNTcomposite. In this case, the weight percentage of the MWCNTs may increase in order to maintain the good electrical conductivity of the MWCNT composite for a comparable SE. Therefore, well-dispersed MWCNTs are very important in the fabrication of the MWCNT composites.

In this work, we present EM shielding performance for a plastic composite by employing polyimide (PI)-based dispersive MWCNTs. The MWCNTs are fabricated by an arc-discharge method (ADM) and a chemical vapor deposit (CVD). The physical methods for the dispersion of the MWCNTs are used in this study. The MWCNT-PI composites are formed in thin films, and their conductivities and SE are measured in different MWCNT weight percentages and different film thickness. The results showed that the MWCNT-PI composites with more weight percentages of the MWCNTs exhibit a higher conductivity and higher SE. This indicates that the dispersive MWCNT composites with their high SE are suitable for packaging low-cost and high-performance optical transceiver modules used in FTTH lightwave transmission systems.

2. Fabrication of MWCNT Composite

A. Material Properties of Multi Walled Carbon Nanotubes (MWCNTs)

MWCNT has excellent electrical and mechanic characteristics such as high current density, high electrical conductivity, and high yield strength. The large aspect ratios of MWCNTs are easy to build the conductive network inside a composite. This makes it suitable to be the conductive filler of the polymer-based plastic composites. The electrical properties of MWCNTs depend on their molecular structure and deformations. The MWCNT can have semiconducting or metallic properties depending on its charity, which makes different bandgaps. Basically, MWCNT, which is constructed from carbon atoms, is a hollow tube with semispherical caps at ends. This kind of hollow structure of carbons is called a fullerene. Usually, the fullerenes' atomic bonding structure consists of hexagons and pentagons that form a spherical shape [14].

MWCNTs usually can be produced by ADM [19] or CVD. For ADM, the electrodes are graphite rods and with a distance about 1-2 mm. The applied voltage is about 20 V, the operated dc current is around 100 A, and the applied Argon gas pressure is around 700 mbars. The deposit at cathode includes MWCNTs, carbon nanocapsules, and amorphous carbons. The aspect ratio of these MWCNTs is about 500 under SEM observation. The MWCNTs produced by ADM are needle-like shape, as shown in Fig. 1(a), not like those produced by CVD, as shown in Fig. 1(b). Usually CVD produced carbon nanotubes are 95% pure and 40~60 nm in diameter and 0.5~10 μm in length.

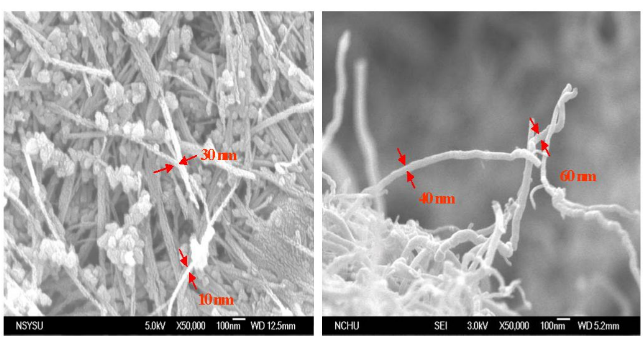

Fig. 1 (a) ADM produced MWCNTs, (b)CVD produced MWCNTs.

B. Dispersion of MWCNT and Fabrication of MWCNT-PI

Carbon nanotubes (CNTs) have remarkable mechanical strengths and it is expected that CNTs can be used as additives for reinforcements of composite materials. However, many studies have shown that addition of CNTs did not result in high-performance composite materials due to the inhomogeneous dispersion and poor interactions with the matrix. Therefore, how to avoid CNTs aggregation and to improve the CNT-matrix adhesions are two key issues determining their reinforcement effects. In addition, incorporating MWCNTs into other materials has been inhibited by the surface chemistry of carbon. Problems such as phase separation, aggregation, poor dispersion within a matrix, and poor adhesion to the host matrix must be overcome. To overcome these problems, a surface treatment technology must be developed to optimize the interaction between CNTs and the host matrix.

MWCNTs tend to aggregate and are difficult to disperse in water and organic solvents because they have strong van der Waals attractions between MWCNT molecules. Usually, there are two methods used for the dispersion of MWCNTs. The first method is a chemical modification and the other is a physical adhesions. The chemical modification requires acids such as HNO_3, H_2SO_4, and these acids may damage the MWCNT structure. For the physical adhesion, it may not damage the MWCNT structure. However, it requires a lot of mediums in the adhesion process.

In this study, two different approaches of the physical method for the dispersion of the MWCNTs are used. First approach is to mix the silicate platelets (Micas or Clays) with MWCNTs. After grinding, the mixture of MWCNTs and Micas are dispersed into a solvent to form the MWCNT-Mica hybrid solution. An UV-vis spectrometer was used to examine the uniformity of the MWCNT-Mica hybrid solution by analyzing the absorption grade of the incident 550 nm light. A laboratory made poly amic acid (PAA) was used to mix with the dispersed MWCNT-Mica hybrid solution under a MWCNT weight percentage of 0.1~30%. Then this mixture was cast to form an MWCNT-PI thin film with the thickness 5~80μm. The fabrication process is shown in Fig. 2.

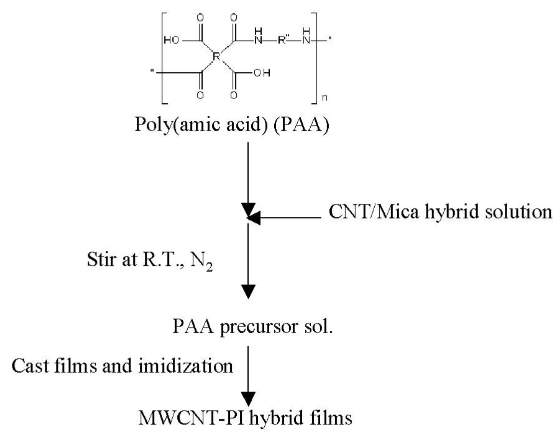

Fig. 2 Fabrication process of MWCNT-PI composites.

The second approach is to mix the ionic liquid dispersant (IL) with MWCNTs. Basically the process is similar to Fig. 2, but the Mica is replaced with the IL. Normally, the van der Waals force and π-π stacking interactions between the MWCNTs made them hardly separated during mixing process of MWCNT composites [20]. It was reported that the mixture of IL of imidazolium ions with CNTs was formed a hybrid solution [20]. The dispersion was efficiently reinforced by taking advantage of a strong affinity of the imidazolium ion toward the π-electronic CNT surface. The dispersion mechanism in this work is that the organic cations of the IL, which potentially interact with π-electronic compounds through so-called "cation-π" interaction.

3. Measurement Results of MWCNT Composite

A. Uniformity of CNT Composite

An UV-vis spectrometer is used to examine the uniformity of the MWCNT-Mica hybrid solution by analyzing the absorption grade of the incident 550 nm light. Four different solvents are used to compare their dispersion abilities: H_2O, DMAC, NMP, and NMP-co-DMAC. The experimental result showed that the H_2O was a better solvent, as indicated in Table 1. Both ADM produced MWCNTs and CVD produced MWCNTs are used to form MWCNT-Mica hybrid solutions in H_2O, and their uniformities are examined by the UV-vis spectrometer.

Table 1. Dispersion of MWCNT, Mica and MWCNT-Mica hybrid in various solvents.

Solvents	Mica[1]	MWCNT	MWCNT1-Mica hybrid	MWCNT2-Mica hybrid
H_2O	○	×*	○	○
DMAC	○	×*	○ *	○
NMP	○	×*	△ *	○ *
MNP-co-DMAC	○	×*	○ *	○

○ : Dispersed well by shaking only .

*: Dispersed by shaking and ultrasonication.

△ *: Dispersed sluggishly, even by both shaking and ultrasonic procedures.

×: Poor dispersion or sedimentation.

[1] 2 mg pristine Mica dispersion in 20 g solvents.

[2] MWCNT1 and MWCNT2

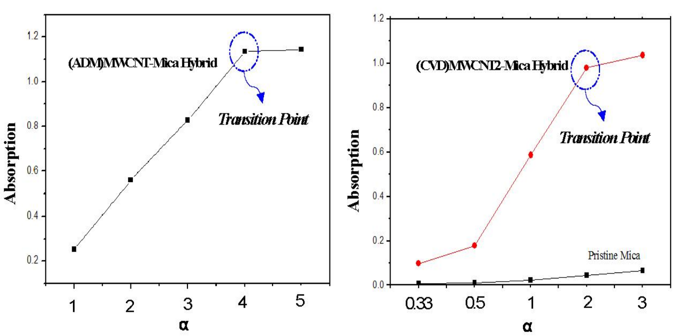

Fig. 3 UV-vis spectra absorption of various weight ratios of MWCNT-Mica hybrid and pristine Mica dispersed in water at wavelength of 550 nm.

Fig. 3 shows the UV-vis spectra absorption of various weight ratios of MWCNT-Mica hybrid and pristine Mica dispersed in water at wavelength of 550 nm (1 mg MWCNT/20g water; α is the weight ratio of Mica over MWCNT in the ground hybrids). We found that the CVD produced MWCNTs were easier dispersed than ADM produced MWCNT. This is because of the impurities of CVD produced MWCNTs are much less than ADM produced MWCNTs. The CVD produced MWCNTs are 95% pure; whereas the ADM produced MWCNTs in this experiment are not well purified before dispersion. There are a lot of impurities such as carbon nano capsules (CNC), carbonaceous impurities or ash, and amorphous carbon existed in the ADM [18]. Therefore, we need more Mica to separate the ADM produced MWCNTs to achieve the equal uniformity. A laboratory made poly amic acid (PAA) was used to mix with the dispersed MWCNT-Mica hybrid solution under a MWCNT weight percentage of 0.1~30%.

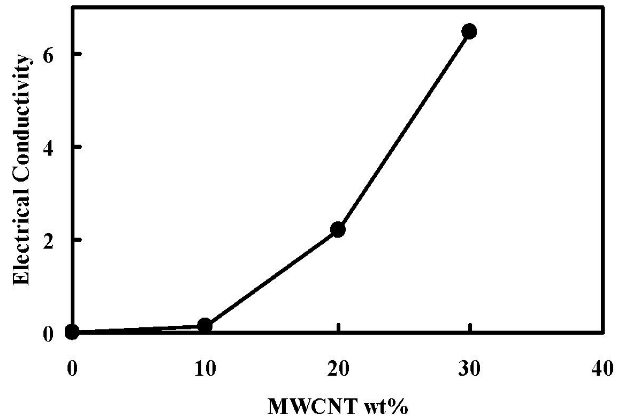

Fig. 4 Relation between MWCNT weight percentage of IL dispersed MWCNT-PI thin film and electrical conductivity (S/cm).

B. Conductivity of MWCNT-PI Thin Film

According to the basic EM shielding theory, the higher conductivity has the higher SE [7]. The more MWCNTs that are added, the more overlapping conductive MWCNT networking are formed, and hence the higher conductivity and the higher SE are obtained. The conductivity of the MWCNT-PI thin films were measured by a four-terminal technique. Fig. 4 shows the relations between weight percentage of MWCNTs and electrical conductivity. The MWCNTs inside this thin film were dispersed by IL dispersant. However, due to the insulation nature of the Mica, the Mica dispersant did not provide good conductivity. Fig. 4 revealed that the higher weight percentage of MWCNTs exhibited to a higher electrical conductivity. The measurement results of conductivity in thin-film composites show a remarkable improvement in comparing with our previous results [17]-[18], and also comparable to Kim's results [21]-[22]. That's mainly due to the contribution from a well dispersion of MWCNTs.

C. Shielding Effectiveness of MWCNT-PI Thin Film

Fig. 5 shows a setup for the SE measurement and a cross-section of the coaxial type transmission lines holder. A flanged coaxial transmission-line holder was designed by following the ASTM D4935 method [23], which is used to measure the SE of an MWCNT-PI thin film in far-field source. The testing frequency range is from 1 GHz to 3 GHz, since we focus on 2.5Gbps lightwave transmission applications. The diameter of the inner conductor was 33mm and the outer conductor had inner and outer diameters of 76mm and 133mm, respectively. The SE of the MWCNT-PI thin film was measured by an insertion of the thin film between the two identical flanges. The purpose of the SE test procedure is to quantitatively measure the insertion loss that results from introducing the test specimens.

The influence of the weight percentage on SE in MWCNT-PI thin film (20μm) is shown in Fig. 6. The results show that the SE of the MWCNT composites increases as the weight percentages of the MWCNTs increases. The more weight percentage of the MWCNTs in the MWCNT composites exhibits a higher SE. Fig. 7 shows that the SE of the 30%

weight percentage MWCNT-PI composites increases as the film thickness increases (20μm, 30μm, 50μm, 70μm). The SE results are comparable to Kim's results [21]-[22].

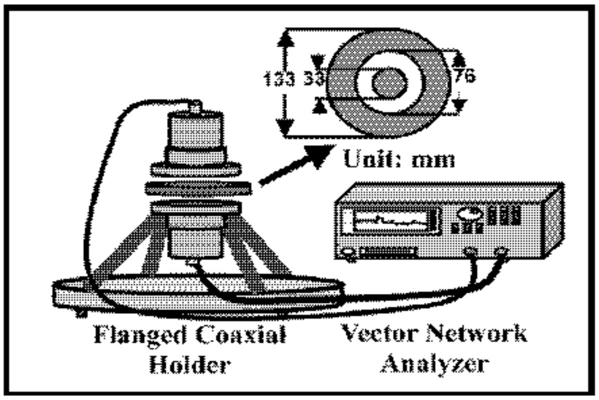

Fig. 5 Setup for the SE measurement and a cross-section of the coaxial type transmission lines holder.

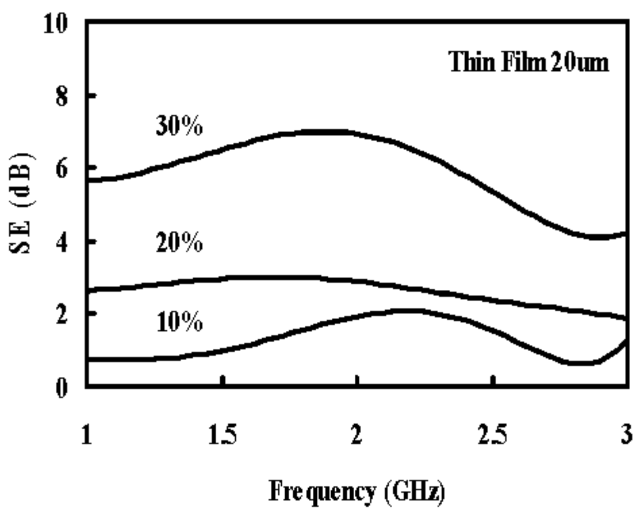

Fig. 6 SE as a function of frequency for different weight percentage of MWCNTs.

The shielding effectiveness of reflection (SEr) and shielding effectiveness of absorption (SEa) are derived from a total SE to realize the domination properties of them in different frequencies and different film thicknesses. Fig. 8 shows that the SEr and SEa decreases and increases as the frequency increases, respectively. This indicates that the SEr or SEa dominates at the lower and higher frequency range, respectively. Fig. 9 shows SEa-SEr increases as the frequency increases. As the difference between SEa and SEr larger than zero, the SEa dominates. Fig. 9 also indicates that the SEa dominates at the thicker film as the frequency swept from 1GHz to 3GHz. Therefore, the SEa is proportional to film thickness.

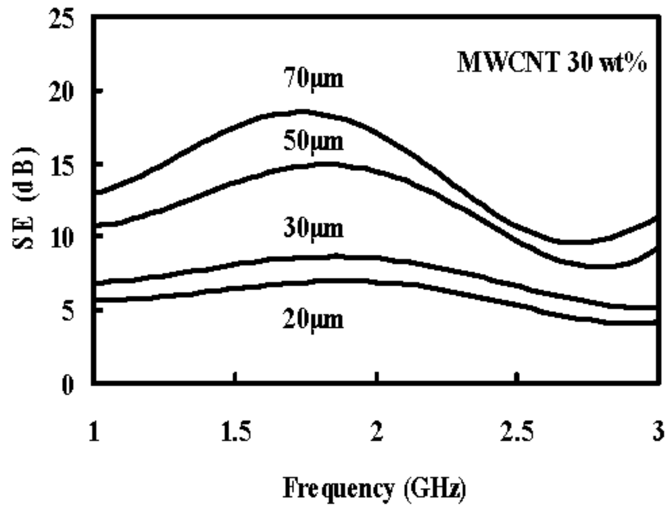

Fig. 7 SE as a function of frequency for different film thickness of MWCNT-PI.

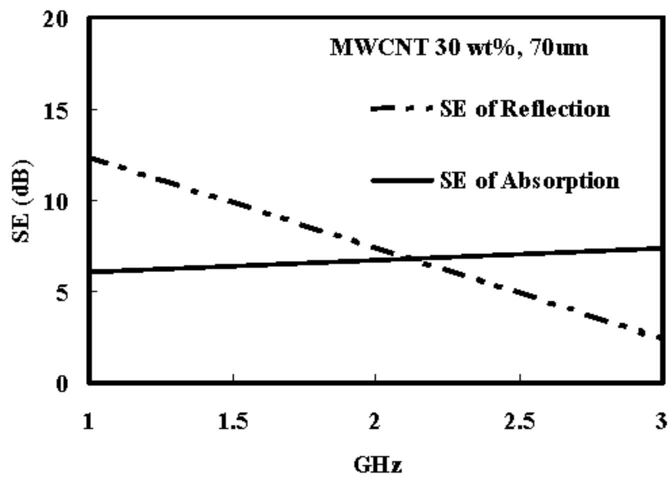

Fig. 8 SEr of reflection vs. SEa of absorption.

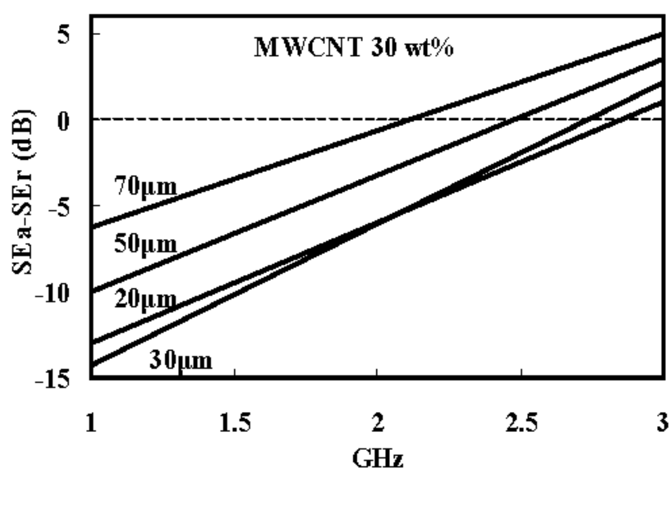

Fig. 9 SEa-SEr as a function of frequency.

Conclusions

To perform a low percentage percolation, a well-dispersed MWNTs is necessary. The well-dispersed MWCNT-PI composite can enhance the electrical conductivity and high SE under a lower weight percentage of MWCNTs. A plastic package based on MWCNT-PI composite for a 2.5Gb/s optical transceiver module is currently under investigation and will be presented. The MWCNT composites with their high SE are suitable for packaging low-cost and high-performance optical transceiver modules used in the FTTH lightwave transmission systems.

References

1. J. T. DiBene, and J. L. Knighten, "Effects of device variations on the EMI potential of high speed digital integrated circuits," *IEEE Electromagn. Compat.*, pp. 208-212, Aug. 1997.
2. D. M. Hockanson, X. Ye, J. L. Drewniak, T. H. Hubing, T. P. V. Doren, and R. E. DuBroff, "FDTD and Experimental Investigation of EMI from Stacked-Card PCB Configurations," *IEEE Trans. Electromagn. Compat.*, vol. 43, No. 1, pp. 1-9, Feb. 2001.
3. T. L.Wu, M.C. Lin, C.W. Lin, T.T. Shih, and W. H. Cheng, "High electromagnetic susceptibility performance plastic package for 10 Gibt/s optical transceiver modules," *Electron. Lett.*, vol. 41, no. 8, pp. 494–495, Apr. 2005.
4. K. Tatsuno, K. Yoshida, T. Kato, T. Hirataka, T. Miura, K. Fukuda, T. Ishikawa, M. Shimaoka, and T. Ishii, "High-performance and low cost plastic optical modules for access network system applications," *J. Lightwave Technol.*, vol. 17, no. 7, pp. 1211–1216, Jul. 1999.
5. M. Fukuda, F. Ichikawa, Y. Shuto, H. Sato, Y. Yamada, K. Kato, S.Tohno, H. Toba, T. Sugie, J. Yoshida, K. Suzuki, O. Suzuji, and S.Kondo, "Plastic module of laser diode and photodiode mounted on planar lightwave circuit for access network," *J. Lightwave Technol.*, vol.17, no. 7, pp. 1585–1590, Jul. 1999.
6. T. L. Wu, W. S. Jou, S. G. Dai, and W. H. Cheng, "Effective electromagnetic shielding of plastic packaging in low-cost optical transceiver modules," *J. Lightwave Technol.*, vol. 21, no. 6, pp. 1536–1543, Jun. 2003.
7. W.H. Cheng, W.C. Hung, C.H. Lee, G.L. Hwang, W.S. Jou, and T.L. Wu, "Low cost and low electromagnetic interference packaging of optical transceiver modules", *J. Lightwave Technol.,* vol. 22, no. 9, pp. 2177–2183, Sept. 2004.
8. P. B. Jana, A. K. Mallick, and K. De, "Effects of sample thickness and fiber aspect ratio on EMI shielding effectiveness of carbon fiber filled polychloroprene composites in the X-band frequency range," *IEEE Trans. Electromagn. Compat.*, vol. 34, no.11, pp. 478–492, Nov. 1992.
9. P. F. Wilson, M. T. Ma, and J.W. Adams, "Technique, for measuring the electromagnetic shielding effectiveness of materials. I. Far-field source simulation," *IEEE Trans. Electromagn. Compat.*, vol. 3, no. 8, pp. 239–247, Aug. 1988.
10. W. S. Jou, T. L. Wu, S. K. Chiu, and W. H. Cheng, "Electromagnetic shielding of nylon-66 composites applied to laser modules," *IEEE/TMS J. Electro. Material*, vol. 30, no. 10, pp. 1287–1293, Oct. 2001.
11. W. S. Jou, T. L. Wu, S. K. Chiu, and W. H. Cheng, "The influence of fiber orientation on electromagnetic shielding in liquid crystal polymers," *IEEE/TMS J. Electro. Material*, vol. 31, no. 3, pp. 178–184, Mar. 2002.
12. T. L.Wu, W. S. Jou, W. C. Hung, C. H. Lee, C.W. Lin, and.W. H. Cheng, "High electromagnetic shielding of plastic package for 2.5 Gbps optical transceiver modules," *IEEE Trans. Adv. Packag.*, vol. 28, no. 1, pp. 89-95, Feb. 2005.
13. E. D. Minot, Y. Yaish, V. Sazonova, J. Y. Park, M. Brink, and P. L. McEuen, "Turning carbon nanotube band gaps with strain," *Phys. Rev. Lett.*, vol. 90, no. 15, pp. 154601–154604, Apr. 2003.
14. K.B.K. Teo, etc, "Carbon nanotube technology for solid state and vacuum electronics", IEE Proc.-Circuits Devices Syst., vol. 151, no. 5,pp. 443-451, Oct. 2004.
15. J. Li, Q.Ye, A. Cassell, H. T. Ng, R. Stevens, J. Han, and M. Meyyappan, "Bottom-up approach for carbon nanotube interconnects," *Appl. Phys. Lett.*, vol. 82, no. 15, pp. 2491–2493, Apr. 2003.
16. J. A. Misewich, R. Martel, P. Avouris, J. C. Tsang, S. Heinze, and J. Tersoff, "Electrically induced optical emission from a carbon nanotube FET," *Science*, vol. 300, pp. 783–786, May 2003.
17. C.M. Chang, M.C. Lin, J.C. Chiu, W.S. Jou, and W.H. Cheng, "High-Performance Electromagnetic Susceptibility of Plastic Transceiver Modules Using Carbon Nanotubes, " *J. Sel. Topics Quantum Electron.,* vol. 12, no. 6, pp. 1091-1096, Nov/Dec. 2006.
18. C.M. Chang, J.C. Chiu, W.S. Jou, T.L. Wu, and W.H. Cheng, "New Package Scheme of a 2.5Gb/s Plastic Transceiver Module Employing Multiwall Nanotubes for Low Electromagnetic Interference, " J. Sel. Topics Quantum Electron., vol. 12, no. 5, pp. 1025-1031, Sept/Oct. 2006.
19. W.S.Jou, H.Z.Cheng, and C.F. Hsu, "A carbon nanotube polymer-based composite with high electromagnetic shielding," *IEEE/TMS J. Electro. Material*, vol. 35, no. 3, pp. 462–470, Mar. 2006.
20. Takanori Fukushima, Atsuko Kosaka, Yoji Ishimura,Takashi Yamamoto, Toshikazu Takigawa, Noriyuki Ishii,Takuzo Aida1, "Molecular Ordering of Organic Molten Salts Triggered by Single-Walled Carbon Nanotubes", SCIENCE, vol 300,pp.2072-2074, 27 JUNE 2003
21. H.M. Kim, K. Kim, S.J. Lee, J. Joo, H.S. Yoon, S.J. Cho, S.C. Lyu, C.J. Lee," Charge transport properties of composites of multiwalled carbon nanotube with metal catalyst and polymer: application to electromagnetic interference shielding", *Current Appl. Phys.*, vol. 4. pp. 577–580, 2004.
22. H. M. Kim, K. Kim, C. Y. Lee, J. Jooa, S. J. Cho, H. S. Yoon, D. A. Pejakovic´, J. W. Yoo, and A. J. Epstein "Electrical conductivity and electromagnetic interference shielding of multiwalled carbon nanotube composites containing Fe catalyst", *Appl. Phys. Lett.,* vol. 84, no. 4, pp. 26, Jan. 2004
23. Standard Testing Method for Measuring the Electromagnet Electromagnetic Shielding Effectiveness of Planner Materials, ASTM D4935-92. (ASTM, Philadelphia, PA, USA).