Analysis of EM Shielding Effectiveness of CNT Films Based on TEM Cell Electric and Magnetic Coupling Fields

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Abstract— In this paper, we evaluated the electromagnetic (EM) shielding effectiveness (SE) of various carbon nanotubes (CNTs)-based films which were prepared with deposited carbon densities and thicknesses of the CNTs. The test environment based on a transverse electromagnetic (TEM) cell was adapted for (1) a comparison of the standard American society for testing and materials (ASTM) test and the near-field test using electric and magnetic field probes and (2) the differences of CNT SE on the electric field and magnetic field according to near end or far-end tests by the rotations of a microstrip patch antenna as a DUT. In addition, (3) the effect of CNTs composites and their thickness on the SE is investigated with TEM cell electric and magnetic field coupling to the DUT.

1. INTRODUCTION

The electromagnetic interference (EMI) of high speed circuits is becoming a cause of malfunction in electronic devices due to the rapid increase in operating frequencies. Therefore, the shielding material used to prevent EMI has become an issue, and its shielding ability has been usually presented with standardized procedures ASTM D 4935-99 for analyzing the characteristics of shielding materials [1]. The near-field SE of ASTM methods based on far-field tests may be calculated for magnetic sources for electrically thin specimens. However, their validity and applicability have not been established for shielding effectiveness (SE) in the near-field between chips because near-field is directly influenced by the E-field and H-field. A lot of research has been carried out about the evaluation method of SE for near-field but a standardized method has not been presented. In this paper, we present the evaluation method of near-field SE using a TEM cell according to the standardized procedures IEC 61967-2 [2] and IEC 62132-2 [3] for the analysis of EM emission of integrated circuits. The newly devised near-field test located CNTs with deposited carbon densities and thicknesses of CNT between the TEM Cell and the patch antenna, and measured by the current direction of the patch antenna as an EM radiated source. This method can also predict the SE of an E-field and H-field by using the H-field's cancelation, according to current direction [4]. Also, the SE on the CNT films for measuring the point of near-field probe (Langer EMV-Technik RF1) is different because the shielding material in the near-field region isn't uniformly measured on all sides by locating the GND contact [5]. Finally, a comparison of the proposed near-field test and far-field test will evaluate the range of use of CNT films by frequency.

2. MEASUREMENT RESULTS

The SE analysis of standardized ASTM 4935-99 procedures were measured and presented with various deposited carbon densities and thicknesses of carbon nanotube (CNT) films as shown in Figure 1 and Figure 2. For SE tests, the manufactured CNTs, having the densities of 2%, 5%, 10% and the thicknesses of 0.3 mm, 1 mm and 2 mm, were measured from 50 MHz to 1.5 GHz. The measure of SE is given as the Equation (1),

$$\mathrm{SE}\,[\mathrm{dB}] = \mathrm{P1}\,[\mathrm{dBm}] - \mathrm{P2}\,[\mathrm{dBm}], \tag{1}$$

where P1 is the input power and P2 is the output power. The SE measurements have different values according to fabricated conditions because their electric conductivity had different levels of densities and thicknesses.

Figure 3(a) shows the test environment of the near-field and its measured coupling between the TEM cell septum and the patch antenna. The TEM cell used in this work was a product of FCC-TEM-JM3. The patch antenna was composed of a 2-layer PCB and the test was repeated four times at angles 0, 90, 180, and 270 degrees between the antenna pattern and the TEM cell septum. The frequency domain measurements were performed by a two-port vector network analyzer (VNA) up to the frequency of 1 GHz.

Figure 3(b) shows the angle-dependent coupling factors when the patch antenna is positioned with respect to the TEM Cell septum because the inductive coupling was affected according to the different angle directions.

Figure 4 shows SE measurements according to densities, thicknesses and directions of the DUT. The SE results were calculated with the equations as follows, SE [dB] = Coupling factor without CNT film [dBm] − Coupling factor with CNT film [dBm].

The SE levels as a function of density changes decreased by increasing frequency and depended on CNT contained percentages (2, 5, or 10%) because of the low CNT percentage having a relatively low electrical conductivity. Also these results show that SE of over 100 MHz didn't shield the EM source by densities. In contrast, SE by thicknesses increased by increasing frequency, except for the thickness of 0.3 mm because inductive coupling at a higher frequency was shielded. But Figures 4(a) and (b) can be properly taken into account in regards to the densities and thicknesses of the CNT films. Figure 4(c) shows SE according to DUT direction. The measured SE of CNT films at 0 and 180 degrees were lower levels than those of 90 and 270 degrees. The four-rotated test results could be explained as CNT films not effectively preventing magnetic fields in low frequencies, but CNT films could reduce electric fields.

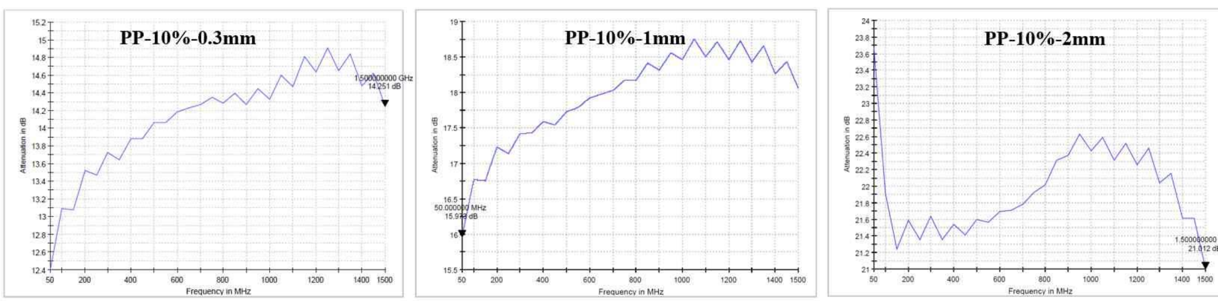


Figure 1: Measured SEs of ASTM on various CNT films by thicknesses.

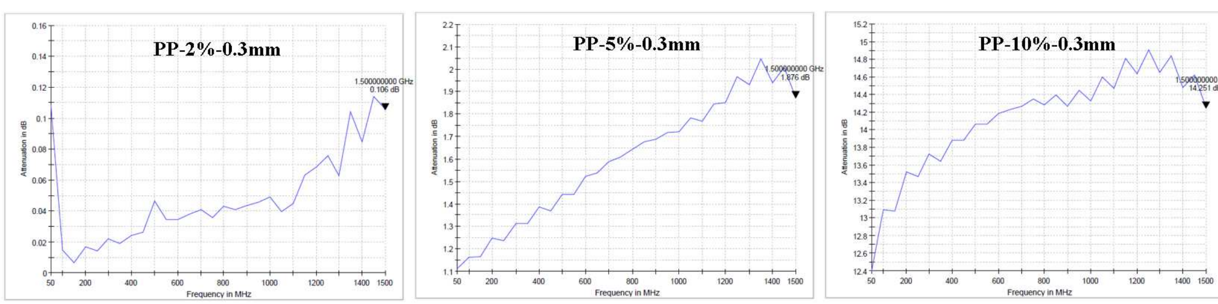
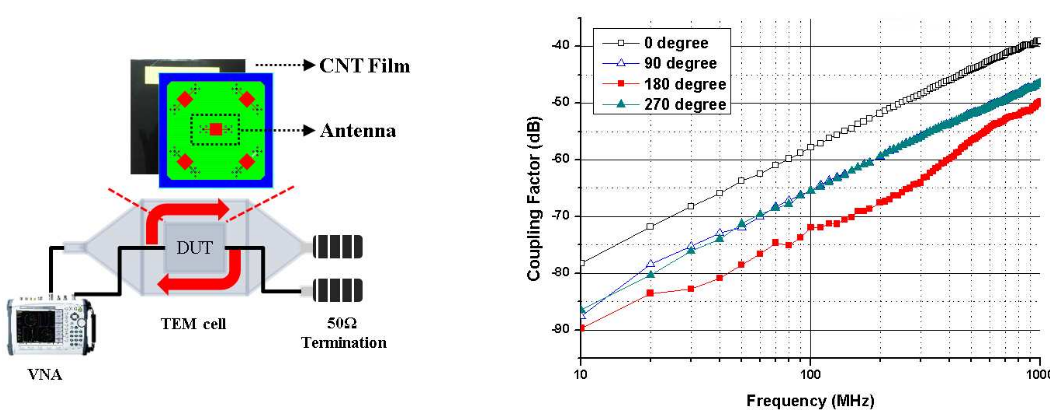
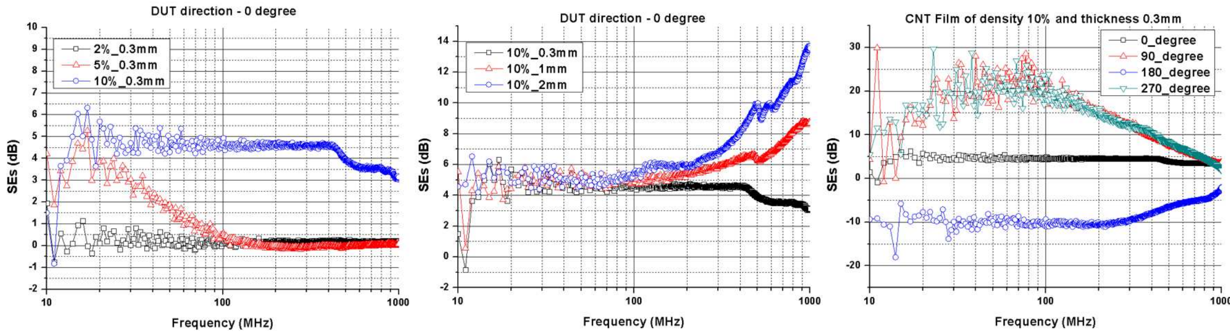


Figure 2: Measured SEs of ASTM on various CNT films by densities.



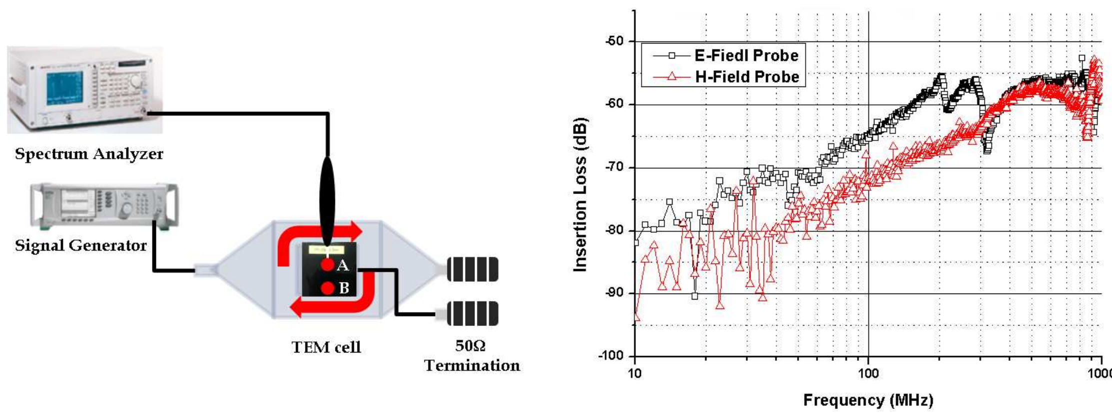
(a) (b)

Figure 3: (a) Near field test environment and (b) coupling factor by DUT direction without CNT film.



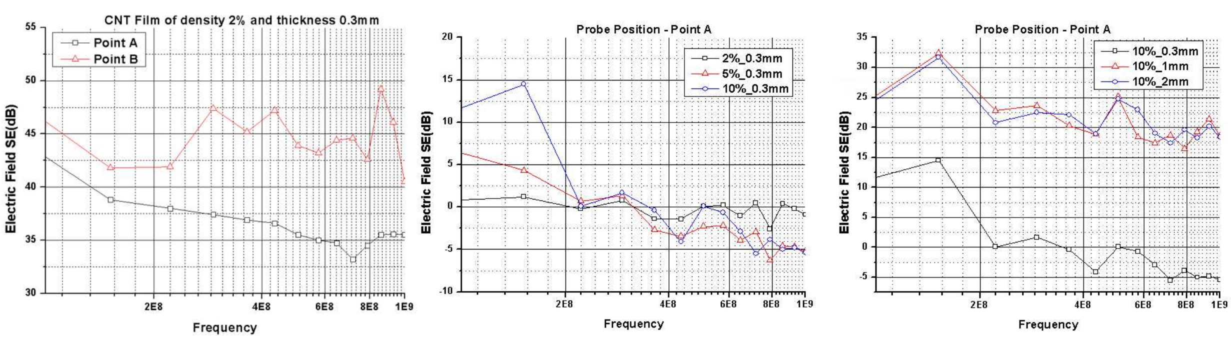
(a) (b) (c)

Figure 4: Shielding effectiveness according to (a) densities, (b) thicknesses, and (c) DUT direction.



(a) (b)

Figure 5: (a) Near field measurement environment based on TEM cell and (b) insertion loss of near field probe without CNT films.



(a) (b) (c)

Figure 6: Electric Field SEs using near field measurement by: (a) probe position, (b) densities, and (c) thicknesses of CNT films.

Figure 5 shows the near-field test environment using a near-field probe and the insertion loss of commercial antennas. Insertion loss was measured for evaluation by a sensitivity of the height of the E-field and H-field. The test method of insertion loss was performed by using a VNA on the septum of a TEM cell and had a height of 2.5 mm from the near-field probe to the top wall of the TEM cell. The test results showed a difference of about 5 dB between the E-field probe and H-field probe below 400 MHz. The E-field SE results decreased by increasing frequency, as shown in Figure 6, because the CNT films didn't effectively shield the capacitive coupling in the high frequency. Also, E-field SE as a function of probe positions showed different results in Figure 6(a). Prior analysis of SE by probe position measured E-field intensity without CNT films at two points. The test results were almost the same value, but SE with CNT film presents different curves in

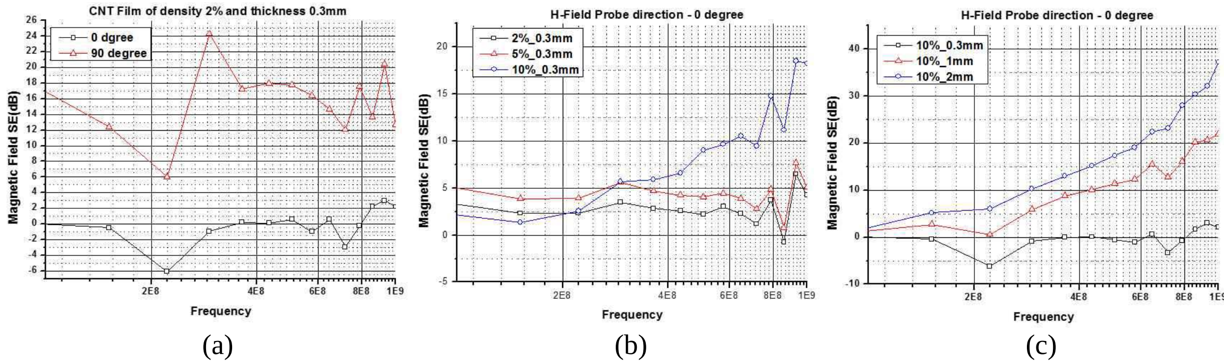


Figure 7: Magnetic Field SEs using near field measurement by: (a) probe direction, (b) densities, and (c) thicknesses of CNT films.

probe position because the resistance and capacitance on CNT film was changed by probe positions.

Figure 7 shows measured SE with the H-field probe. The measured H-field SE was not shielded at the lower frequency because magnetic field cancelation didn't happen between the TEM cell septum and the CNT, which imperceptibly flowed the eddy current on CNT films due to low conductivity.

The test environment based on a TEM cell was adapted for a comparison of the standard ASTM test and the near-field test, which used the electric and magnetic coupling fields of CNT films' SE on an electric field and magnetic field. The SE results of a far-field test as shown in Figure 1 can be explained as those of the electric field shielding effects, however the SE of magnetic field shielding had a relatively lower shielding effect, or negative shield effect, depending on angle characteristics.

3. CONCLUSION

Generally, the analysis of the SE of shielding material has been standardized in test environments based on far-field testing. But far-field tests are not suitable between chips in near-field situations. In this paper, we proposed a near-field test to predict the SE of CNTs. The near-field test used a coupling between the TEM Cell septum and the patch antenna. In order to analyze the SE of CNT films for the near-field test, the measurements for the CNT with deposited carbon densities and thicknesses of the CNTs, the direction of the patch antenna and the probe position on the CNT were measured. The measured results found the appropriate densities and thicknesses of CNTs. Regardless of the densities of the CNTs, the SE results were almost the same; but the SE by thicknesses changed without 0.3 mm of thickness. Also, the tests with 0 or 180 degree angles showed different results between ASTM tests and the near-field test. The measured SE of CNT at 0 and 180 degrees were at much lower levels than those of 90 and 270 degrees because the eddy currents on CNT films gave an additional magnetic coupling effect. The 4 rotated test results could be explained as CNTs not effectively preventing magnetic fields, but CNTs could reduce electric fields. Also, SE in the near-field test by the position of an E-field probe increased the closer to the ground of the TEM Cell. These results show that the placement of a semiconductor package using a CNT film is important.

ACKNOWLEDGMENT

This research was supported by a grant "High efficient heat rejection and supply technologies for zero emission vehicle (10035530)" from the Korea Evaluation Institute of Industrial Technology.

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