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Electromagnetic Interference Shielding Efficiency and Noise Suppression in a Transmission Line for Carbon-Coated Magnetic Composite Films

J. W. Lee, C. Y. Lee, Y. K. Hong, S. H. Kim and J. Joo*
Department of Physics and Hybrid Nanostructure Laboratory, Korea University, Seoul 136-713

S. W. Kim, Y. B. Kim and K. Y. Kim
Korea Institute of Science and Technology, Seoul 136-791

Y. C. Yun and K. S. Lee
Chang Sung Corporation R&D Center, Incheon 450-846

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We report on the electromagnetic interference (EMI) shielding in the far-field and the near-field regions and on the noise suppression characteristics for carbon-coated Fe-Si-Al/polymer composite films in the frequency range from 20 MHz to 5 GHz. The carbon-coated Fe-Si-Al/polymer composite films were placed in a single microstrip line (MSL) and the reflection and transmission coefficients were measured to determine the noise suppression characteristics (*i.e.*, power loss). The near-field EMI shielding efficiencies (SEs) were measured using the double MSLs method. The frequency dependence of the near-field EMI SE was similar to that of the dielectric constant and the permeability of the composite films. The far-field EMI SEs were measured for the composite films with various surface resistances. The EMI SE in the far-field region and the noise suppression of the composite films increased with decreasing surface resistance of the composite films. The measured EMI SEs and their frequency dependences in the far-field and the near-field regions qualitatively agree with the theoretical results obtained from the computer simulations.

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Keywords: Magnetic composite film, Electromagnetic interference shielding efficiency, Noise suppression, Power loss, Microstrip line

I. INTRODUCTION

Electromagnetic radiation from alternating current (AC) circuits can be an important factor for the electromagnetic interference (EMI), the EM compatibility and the reliability of electronic systems. In microstrip patch antennas and printed circuit boards (PCB), the EM radiation is induced by a magnetic field at the signal line and a time-varying fringing electric field at the edges of the board [1]. In order to reduce the unnecessary EM radiation, the EMI shielding, the placement of decoupling capacitors [2,3], the placement of resistive terminations on the edges of the board [4] and the employment of lossy components throughout the board [5] were studied earlier. The most common method to reduce the unnecessary EM radiation from AC circuits was the use of noise suppressors, such as highly permeable magnetic materials, which were placed onto the electronic circuit lines [6–10].

Recently, composite films, consisting of soft-magnetic-metallic powder and insulating polymer materials, have been used to reduce the noise of EM radiation in the radio-frequency (RF) and the microwave ranges [11]. Instead of the EMI shielding package on the equipment, a direct reduction of the EM noise from the signal line or the electrical components could be adopted by using magnetic materials with high permeability in the near-field region.

Here, we report on the effects of carbon-coated Fe-Si-Al/polymer composite films on the EM noise suppression and EMI shielding efficiency (SE) in the far-field and the near-field regions. Sandwitch-type double microstrip lines (MSLs) and a coaxial line, in the frequency range from 50 MHz to 2 GHz, were employed to measure the EMI SEs in the near-field and the far-field regions, respectively. We observed an increase in noise suppression and EMI SE in the far-field region of the composites, with decreasing surface resistance of the composite films, because of the coating of conducting carbon. The near-field EMI shielding characteristics were similar to those of the dielectric constant and the permeability in terms

*E-mail: jjoo@korea.ac.kr; Fax: +82-2-927-3292

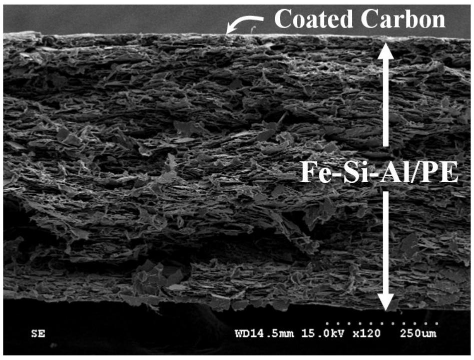

Fig. 1. Cross-sectional SEM image of the carbon-coated Fe-Si-Al/PE composite film.

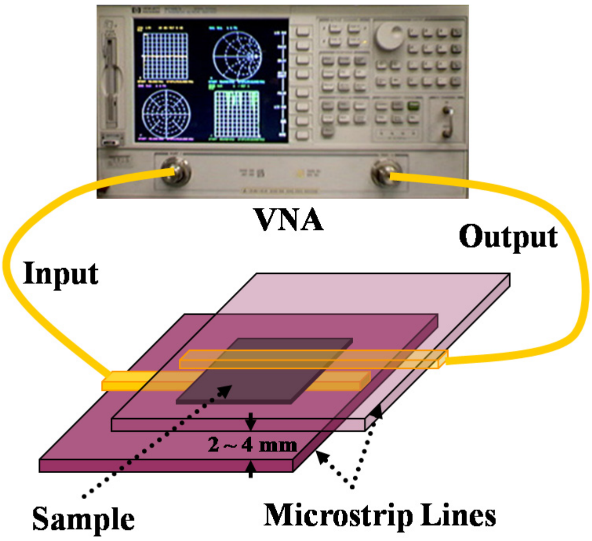

Fig. 2. Schematic diagram of the experimental setup for double MSLs connected to a VNA for the EMI SE measurement in the near-field region.

of the frequency dependence.

II. EXPERIMENTS

The magnetic composite films consisted of the sphere-like sendust (Fe-Si-Al) alloy and insulating polyethylene (PE). The weight percentage (wt.%) of the sendust vs. PE was 83 : 17. The average diameter of the Fe-Si-Al particles was ~80 μm. Attrition of the granule powders was performed by using an micro-forging. The carbon powder was coated on the magnetic composite films by using a spray method. The thickness of the coated-carbon was ~10 μm. The surface resistance (R_s) of the carbon-coated composites varied in the range of 100 ~ 1000 $\Omega/\Box$. The R_s of the carbon-coated composites was measured by using the 4-point contact method. Figure 1 shows a cross-sectional SEM image of the carbon-coated Fe-Si-Al/PE composites. A vector network analyzer (VNA) and a coaxial sample holder were employed to measure the real part of the complex permeability (μ') and the real part of the complex permittivity (ϵ') of the composite films as functions of frequency (20 MHz ~ 6 GHz) [12,13].

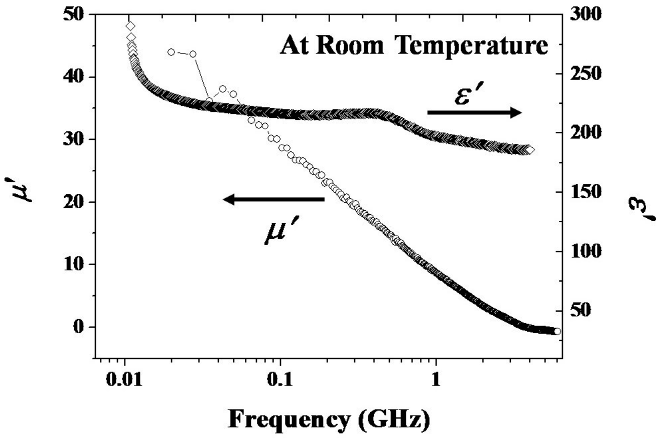

Fig. 3. Frequency dependence of the real parts (ϵ' and μ') of the complex permittivity and the complex permeability of the composite films (thickness = 0.5 mm).

The experimental method of the single MSL method for noise suppression was reported earlier [11]. In order to measure the EMI SE in the near-field region, we connected the top and the bottom MSLs to a HP 8719ES VNA with a synthesized sweep oscillation and a scattering (S)-parameter test set, as shown in Figure 2. The composite sample was inserted between the top and the bottom MSLs, as shown in Figure 2. The $S11$ (reflection) and the $S21$ (transmission) parameters were measured from 50 MHz to 5 GHz. The transmission power loss was deduced from the equation $P(\text{loss})/P(\text{in}) = 1 - (—\Gamma—^2 + —T—^2)$ (dB), where Γ is the reflection coefficient defined as $\Gamma = (Z - Z_0)/(Z + Z_0)$ and T is the transmission coefficient [11,14,15]. The composite films were prepared in the size of the 50 mm^2 with various thicknesses (0.3 mm, 0.5 mm and 1 mm) and were placed at the center of two MSLs while maintaining a constant distance from the signal line. We measured the EMI SE of the composite films in the far-field region by using a coaxial transmission line with a flange [16–18]. The measured EMI SEs in the far-field and the near-field regions were compared with the theoretical results obtained from the computer simulations based on the boundary conditions of Maxwell's equations [17,19].

III. RESULTS AND DISCUSSION

The frequency dependent ϵ' and μ' of the carbon-coated magnetic composite film (thickness = 0.5 mm) are shown in Figure 3. The ϵ' and the μ' of the composite films decreased with increasing frequency, as shown in Figure 3 [20]. In the frequency range of 20 MHz ~ 5

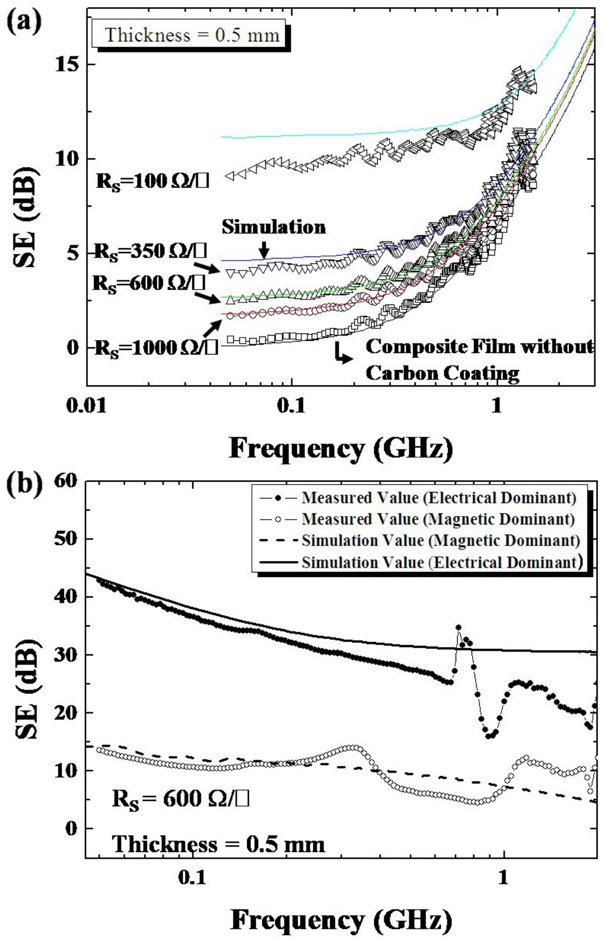

Fig. 4. Measured EMI shielding efficiency (SE) of the carbon-coated magnetic composite films (a) in the far-field region and (b) in the near-field region. The solid and the dotted lines were obtained from computer simulations.

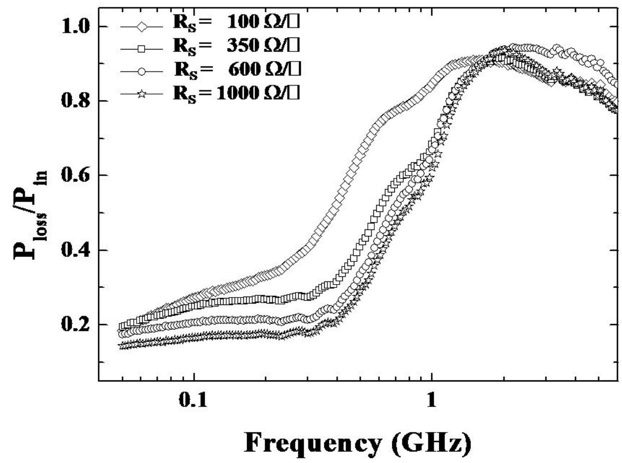

Fig. 5. Frequency dependence of the power loss, P_{loss}/P_{in} (*i.e.*, noise suppression), of carbon-coated magnetic composite films (thickness = 0.5 mm), as measured by using the single MSL method.

GHz, the μ' had a stronger frequency dependency than the ϵ'. The relatively high ϵ' and μ' of the composites originated from the carbon coating and the Fe elements in the sendust, respectively.

Figures 4(a) and (b) show the frequency-dependent EMI SE of the carbon-coated magnetic composite films (thickness 0.5 mm and R_s = 600 $\Omega/\Box$) in the far-field and the near-field regions, respectively. The EMI SE in the far-field region increased with decreasing R_s of the films in the measured frequency region, as shown in Figure 4(a). The results originated from the increase in the electrical conductivity of the coated carbon. The EMI SEs of the composite films increased with increasing frequency, as shown in Figure 4(a), because of the increase in the absorption of the EM radiation for the thick sample [11]. However, the EMI SEs for the electric- or magnetic-field-dominant cases of the composite films in the near-field region decreased with increasing frequency, as shown in Figure 4(b). These might originate from the intrinsic nature of the frequency dependences of the ϵ' and the μ' obtained from the results of Figure 3. The measured EMI SEs (markers in Figure 4) of the composites in the far-field and the near-field regions agree well with the theoretical results (solid or dotted lines in Figure 4) obtained from the computer simulation, as shown in Figures 4(a) and (b) [11,19].

Figure 5 shows the normalized power loss (P_{loss}/P_{in}), *i.e.*, the noise suppression of the composite films, for different surface resistances. With increasing frequency from 50 MHz to 2 GHz, the power loss (P_{loss}/P_{in}) increased; then, it decreased from $\sim$ 2 GHz to 5 GHz, as shown in Figure 5. The P_{loss}/P_{in} of the composite films increased as the R_s decreased in the frequency range of 50 MHz $\sim$ 2 GHz. The results for the P_{loss}/P_{in} as a function of frequency or R_s were qualitatively similar with those of the EMI SEs in the far-field regions, but the decrease in the P_{loss}/P_{in} above 2 GHz should be further studied.

IV. CONCLUSION

The EMI SEs in the far-field and the near-field regions and the noise suppression for the carbon-coated Fe-Si-Al/PE magnetic composite films were studied in the RF and the microwave ranges. With decreasing surface resistance of the composites, the EMI SE in the far-field region and the noise suppression efficiency increased. The EMI SEs in the near-field region decreased with increasing frequency, which were similar with the frequency dependences of the ϵ' and μ'. The results of the EMI SEs in the far- and near-field regions agree with those obtained from computer simulations. The RF and the microwave noise suppression and the EMI SE could be controlled by using the intrinsic properties of the composite films, such as the surface resistance, the permittivity and the permeability.

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