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CONDUCTIVE GRID EFFECTS IN MAGNETIC COMPOSITES ON POWER ABSORPTION

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To evaluate the electromagnetic power absorption in near field, the magnetic composites with the conductive grids were fabricated. The magnetic composites were composed of the 50 wt.% NiFe nanoparticles and silicon rubber. The transmission power absorptions of the magnetic composites on a microstrip line were measured by vector network analyzer up to 6 GHz. The measuring results were compared with those of the 3D FEM simulation results. By the insertion of the conductive grid in magnetic composite, the power absorption ratio was greatly increased from about 20% to 80% and the bandwidth of the absorption frequency broadened from about 2 GHz to 5 GHz, respectively, in comparison with those of the magnetic composite without conductive grid.

1. INTRODUCTION

As increasing the switching frequency of the electronic devices and functionalizing the electronic components, the electromagnetic interference (EMI) between the devices and circuits should be increased. To reduce these complicated electromagnetic (EM) noise in electronic circuits and devices, a few kinds of considerations are essential such as the volume, high resistivity, and high magnetic loss of the magnetic materials in noise suppression materials. The magnetic films and composites as a noise suppressor have been widely employed [1-3]. However, the magnetic composites have some limitations that the contents of the magnetic materials in composite are not enough to reduce the EM noise. In general, the conventional magnetic composites have been studied for the applications of near-field electromagnetic noise suppression [4]. On the other hand, the conductive grids have been used in a far-field region as filters in far infrared (FIR) and sub-millimeter region [5]. In order to enhance the electromagnetic absorption performance of the magnetic composites at near-field region, the conductive grid was employed in magnetic composite. Therefore, the conductive grid effects in magnetic composite were studied on EM noise suppression in the broadband radio-frequency range from 50 MHz to 6 GHz in near field.

2. FABRICATION AND MEASUREMENT

The magnetic composites (NiFe nanoparticles in nonmagnetic matrix) were fabricated by using film casting method. And the 500 μm-thick magnetic composite with the conductive grids were fabricated with the same method after the conductive grid was placed on center between bottom and top compos-

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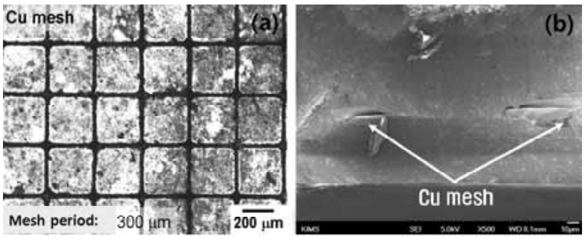

Fig. 1. Images of Cu grid (a) top view and (b) SEM image of cross section in the composite.

ite films. At the first stage, NiFe nanoparticles were manufactured by pulsed wire evaporation (PWE) method and then the magnetic nanoparticles were mixed with the silicone rubber resin by the mechanical stirrer and three-roll mill successively. In the three-roll mill process, gaps between the rolls were 5 μm / 5 μm and the rolls made 200 rpm in gap-mode. In order to make the bottom-side composite film, the dispersed mixture of the nanoparticles and resin were injected into the comma-roll type film casting equipment. And then the Cu grid was placed on the bottom-side composite film; subsequently they were inserted into the film casting equipment with simultaneous injection of the nanoparticle/resin mixture on them. Finally, 15 minutes hardening process at 120 °C followed.

The images of Cu grid and the composite with the grid are shown in Fig. 1. The thickness and width of Cu grid line were 30 μm × 30 μm and the space between grid lines was 300 μm. The cross section of the composite with the grid was observed by Scanning Electron Microscope which the grid line perfectly buried in the magnetic composite as shown in Fig. 1b.

The transmission microstrip line (MSL) technique was used for evaluation of power absorption ability of the composite film in near field. MSL was designed with the characteristic impedance of 50 Ω and fabricated by IEC standard (IEC62333) as shown in Fig. 3a. MSL was composed of 3 μm-thick and 50 mm-long Cu signal line on a PTFE substrate with Cu ground. When the power absorption of composite was measured, the 48 mm × 48 mm ($w \times l$) sized composite specimen was closely contacted on the MSL. To measure and calculate the power absorption, the reflection (S_{11}) and transmission (S_{21}) coefficients were measured by vector network analyzer (HP 8510C) in the frequency range of 50 MHz to 6 GHz. From these coefficients, the absorbed power loss can be calculated by the relation, $P_{LOSS}/P_{IN} = 1 - |S_{11}|^2 - |S_{21}|^2$.

For the comparison with the measured and the simulated results, the MSL model with 500 μm-thick composite was designed as shown in Fig. 2b and simulated by 3D FEM (HFSS ver. 12, by ANSYS). In simulations, the composite size was restricted to 40 mm × 40 mm because the number of mesh is limited by the lack of solving capability of simulator and sever computer. The power losses were calculated with the change of various conditions as follows MSL itself, 50 wt.% NiFe composite, and the 50 wt.% NiFe composite with the Cu grid, respectively.

3. RESULTS AND DISCUSSIONS

The complex permeability and permittivity profile of the magnetic composite were measured by the coaxial cable method. The real part of relative permeability was decrease from 1.7 to 1.3 with the incre-

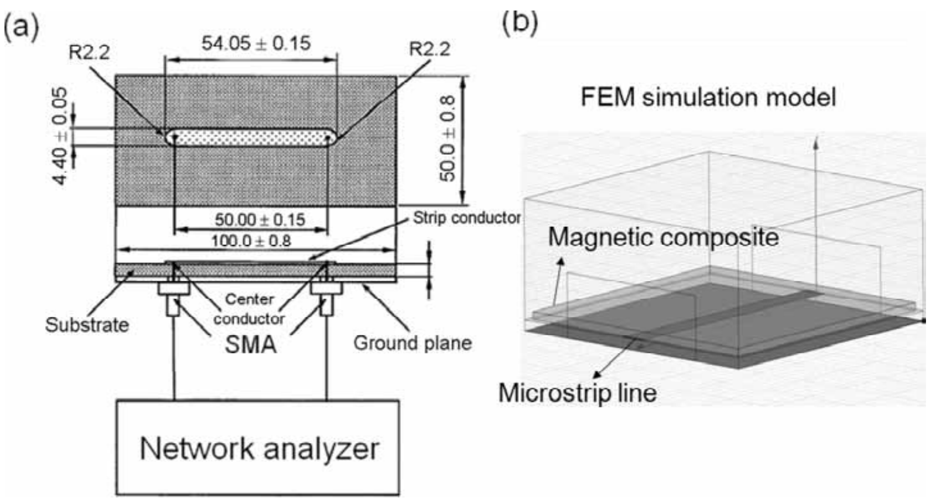

Fig. 2. Schematic of evaluation models (a) IEC standard model and (b) 3D FEM simulation model.

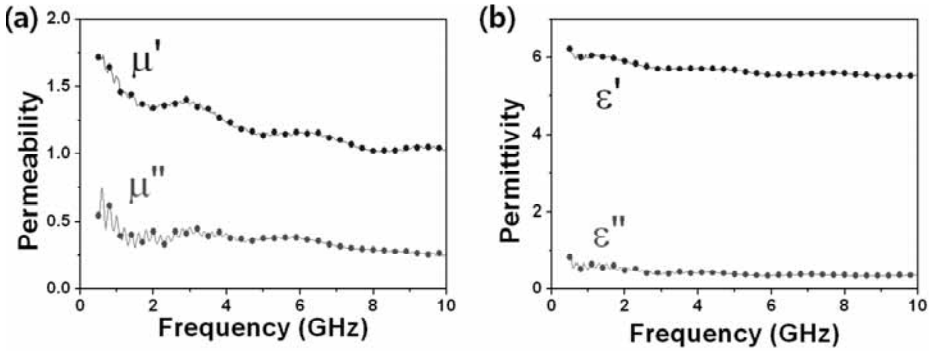

Fig. 3. The measured complex (a) permeability and (b) permittivity profiles of the NiFe magnetic composite.

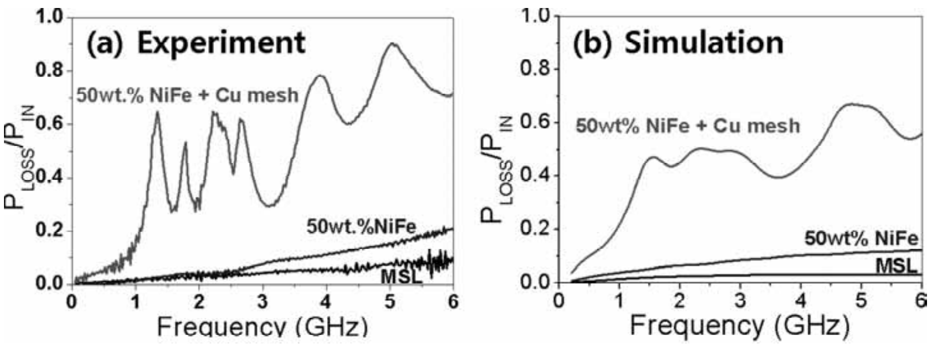

Fig. 4. The power losses of the NiFe composite and NiFe composite with Cu grid (a) measured by vector network analyzer and (b) simulated by 3D FEM HFSS.

ment of frequency up to 6 GHz while the imaginary part of permeability was almost same value around 0.3 as shown in Fig. 3a. For such a low loss term by means of the imaginary part of permeability, it could be predicted that the power loss of the composite is very low. The real and imaginary part of relative permittivity for the magnetic composite was changed a little bit with the increment of frequency, which values were around 8.5 and 0.3, respectively as shown in Fig. 3b. It implies that the dielectric contributions for the power loss also could be not so high.

The measured and simulated power losses of the composite, Cu grid and their mixture were shown in Figs. 4a and 4b. Although there were discrepancies between measured and simulated power loss value and resonance frequency, they showed same tendency as follows. The power loss of the NiFe 50 wt.% composite was very small, less than 20% in experiment and 10% in simulation. As the conductive grid was combined into the magnetic composite film, the power absorption was greatly enhanced in both the power loss values and power loss frequency band. The power loss reached up to 90% in experiment and 70% in simulation, which the broadband frequency performance showed above 1 GHz up to 6 GHz. For the discrepancies of the power absorption values between the experimental and simulated results, the reason can be deduced from the interaction effects of the magnetic nanoparticles in composite and the electrical parameters such as a dielectric constant, conductivity of Cu grid and composite, etc. In simulations, it was supposed that the magnetic nanoparticles are not interacting with each particle in composite. However, the magnetic nanoparticles could be magnetically interacting with each particle partially in composite by means of the nonuniform dispersion of magnetic particles. It could be confirmed the tendencies and the effects of the conductive grid insertion in magnetic composite in this study although the values have the some discrepancies between experiment and simulated results. Therefore, it needs the further study about the interaction effects of the magnetic nanoparticles in composite to analyze and reduce the differences between the experimental and simulated results.

For the explanation of the above results, much complicated theoretical works are required since the plane wave approximation is not suitable for the near field transmission line model. The magnetic fields distributions were generated by the simulation as shown in Fig. 5. It could give a clue to the explanation of the power absorption enhancement by the

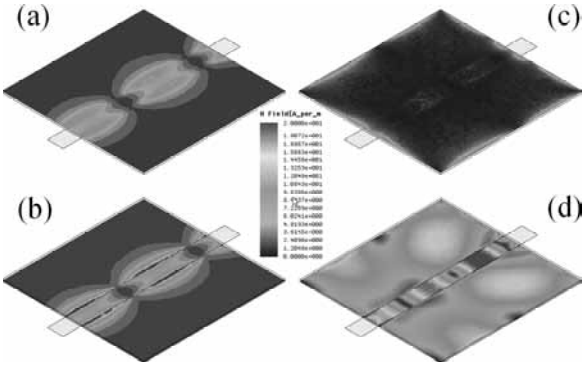

Fig. 5. Magnetic field distributions of top (a, c) surface and bottom (b, d) surface of magnetic composite film with the grid (c, d) and without the grid (a, b).

conductive grid in magnetic composite. For the simplicity, Fig. 5 shows the signal line and surface magnetic field distribution on the top (a, c) and bottom (b, d) surface of the magnetic composite with Cu grid (c, d) and without Cu grid (a, b), respectively. From the magnetic fields distributions of bottom surface, the magnetic fields delivered from the transmission signal line was distributed over the whole area of the magnetic composite by the conductive grid, while the magnetic fields were localized around the signal line for the case without the conductive grid. As a result, whole volume of the magnetic composite contributed to the power absorption as shown in the magnetic fields distributions on top surfaces.

4. CONCLUSIONS

The magnetic nanoparticles composites with Cu grid and without Cu grid were fabricated and evaluated their power absorptions by the microstrip line method. The magnetic composite with Cu grid showed high power absorption and broadband frequency performance in comparison with those of the magnetic composite without Cu grid. As simulation results, the conductive grid in magnetic composites has an important role in a magnetic fields distribution in the whole volume of the magnetic composites for the enhancement of power absorption in near field. In order to solve the discrepancies of the power absorption values between the experimental and simulated results, we'll further study about the interaction behaviors of the magnetic nanoparticle as the condition of particle dispersion in composite in the next.

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