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Electromagnetic Wave Absorption Properties in Fe-based Nanocrystalline P/M Sheets with Carbon Black and $BaTiO_3$ Additives

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Abstract In order to increase the magnetic loss for electromagnetic (EM) wave absorption, the soft magnetic $Fe_{73}Si_{16}B_7Nb_3Cu_1$ (at%) alloy strip was used as the basic material in this study. The melt-spun strip was pulverized using an attrition mill, and the pulverized flake-shaped powder was crystallized at 540°C for 1h to obtain the optimum grain size. The Fe-based powder was mixed with 2 wt% $BaTiO_3$, 0.3~0.6 wt% carbon black, and polymer-based binders for the improvement of electromagnetic wave absorption properties. The mixture powders were tape-cast and dried to form the absorption sheets. After drying at 100°C for 1h, the sheets of 0.5 mm in thickness were made by rolling at 60°C, and cut into toroidal shape to measure the absorption properties of samples. The characteristics including permittivity, permeability and power loss were measured using a Network Analyzer (N5230A). Consequently, the properties of electromagnetic wave absorber were improved with the addition of both $BaTiO_3$ and carbon black powder, which was caused by the increased dielectric loss of the additive powders.

Keywords: Nanocrystalline, Permittivity, Permeability, Carbon black, $BaTiO_3$, Electromagnetic wave absorber

1. Introduction

The spread of mobile phones and high-frequency electronic devices has led to a rise in the amount of electromagnetic waves they emit, which results in malfunctions, noises within modern electronic devices, and disturbance of Specific Absorption Ratio (SAR) in human body. Electromagnetic wave absorbing materials have been developed to reduce electromagnetic interference (EMI) for electronic devices. The development of electromagnetically compatible devices is thus extremely important. To overcome the electromagnetic interference problems, electromagnetic wave absorbing materials with the capability of absorbing unwanted electromagnetic signals are suggested [1]. Among the materials for EM wave absorbers, the rapidly solidified and heat-treated nanocrystalline Fe-Cu-Nb-Si-B alloy powder is one of promising materials for magnetic loss of EM wave [2]. The Fe-Cu-Nb-Si-B soft magnetic powders have been widely known to show excellent permeability when annealed [3]. Thus, the Fe-based powder mixture with binder is expected to decrease the reflection ratio of EM waves, and increase the skin depth by reducing the eddy current [4-5]. However, the soft magnetic Fe-based P/M sheets couldn't play a key role at a high frequency of ~GHz. For this reason, the additions of dielectric and conductive powder are highly recommended to increase the power loss in the EM wave absorption sheets. Accordingly, the absorber sheets were made by using the mixture of the nanocrystalline powders, $BaTiO_3$ and carbon black additives in this study, and the effects of the addition of the additive powders on the EM wave absorption were investigated in detail.

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2. Experimental procedure

The amorphous $Fe_{73}Si_{16}B_7Nb_3Cu_1$(at%, Finemet Alloy) strip, with excellent magnetic loss for EM wave absorption, was pulverized using a high energy attrition mill after annealing at 425°C for 90 minutes [6-7]. After the ball milling process to make the powder uniform-sized, the powder of -270°C mesh (under 53 μm) was crystallized at 540°C for 1h under a nitrogen atmosphere in order to crystallize amorphous matrix. With the aim to improve the EM wave absorption properties, carbon black (Aldrich, USA) and $BaTiO_3$ (Aldrich, USA) were added to the Fe-based powder, and then mixed with binders and a dispersant using a ball mill for the improvement of electromagnetic (EM) wave absorption. The amount of additive powders were 2 wt% $BaTiO_3$ and either 0.3 or 0.6 wt% carbon black. The powder mixtures were tape-cast with polyurethane binders to effectively reduce the eddy current loss and solvent using an impeller, and then dried to form the absorption sheets. The tape-cast sheets were warm-rolled to EM wave absorption sheets with 0.5 mm in thickness at 70°C. The absorbing properties including permittivity, permeability and power loss were measured using a network analyzer (N5230A) and the power loss was calculated with scattering parameter (S_{11} and S_{21}) in a frequency range of 10 MHz to 10 GHz.

3. Results and Discussion

The complex permeability ($\mu_r^*=\mu_r'-j\mu_r''$) and permittivity ($\varepsilon_r^*=\varepsilon_r'-j\varepsilon_r''$) of the material in EM wave absorbers determines their reflection and transmission characteristics. Fig. 1(a) and (b) showed the real and imaginary part of permittivity for the Fe-based EM wave absorption sheets mixed with 2 wt% of $BaTiO_3$ and either 0.3 wt% or 0.6 wt% carbon black. The sheets without any additive powder were also prepared as a reference. Among the specimens, the maximum value of the real permittivity (~46) was obtained from the sheets mixed with 2 wt% $BaTiO_3$

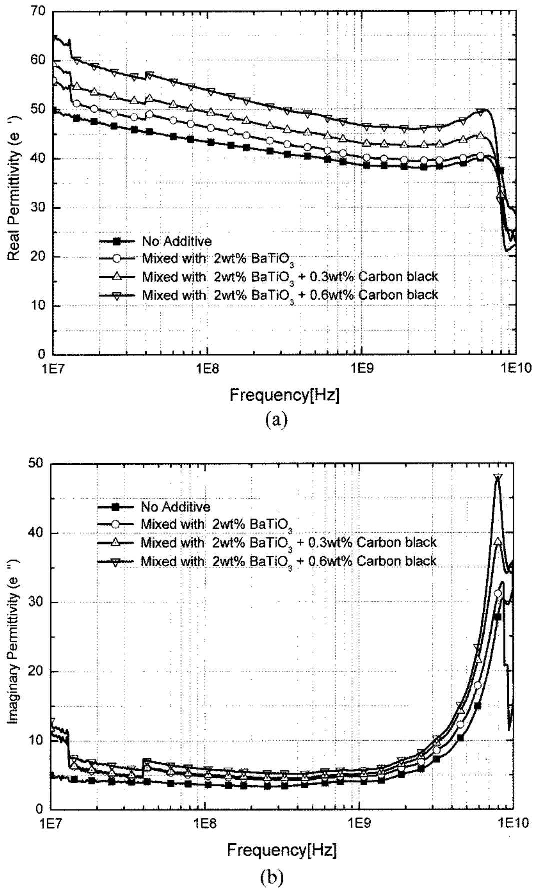

Fig. 1. Variations of (a) real permittivity and (b) imaginary permittivity for Fe-based soft magnetic powder EM absorption sheets mixed with $BaTiO_3$ powder and carbon black.

and 0.6 wt% carbon black powders in the frequency range of 10 MHz~10 GHz. With the increased amount of carbon black, the real permittivity was increased in the EM wave absorption sheets (Fig. 1(a)). The imaginary permittivity also gradually increased by increasing the amount of carbon black (Fig. 1(b)). The maximum value of the imaginary permittivity was obtained from the specimen mixed with 2 wt% $BaTiO_3$ and 0.6 wt% carbon black in the entire range of frequency.

Fig. 2(a), (b) shows that the values of both the real permeability and imaginary permeability of the Fe-based EM wave absorption sheets mixed with 2 wt% $BaTiO_3$ and either 0.3 or 0.6 wt% carbon black pow-

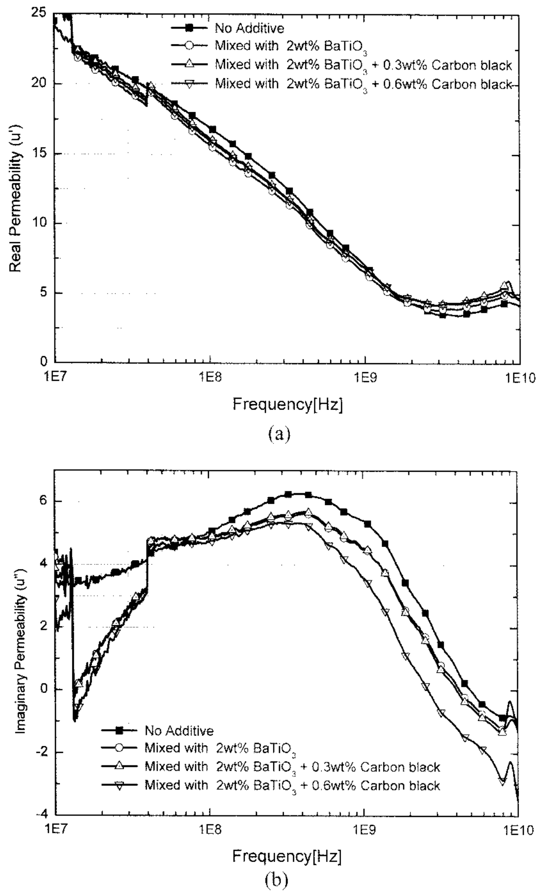

Fig. 2. Variations of (a) real permeability and (b) imaginary permeability for Fe-based soft magnetic powder EM absorption sheets mixed with $BaTiO_3$ powder and carbon black.

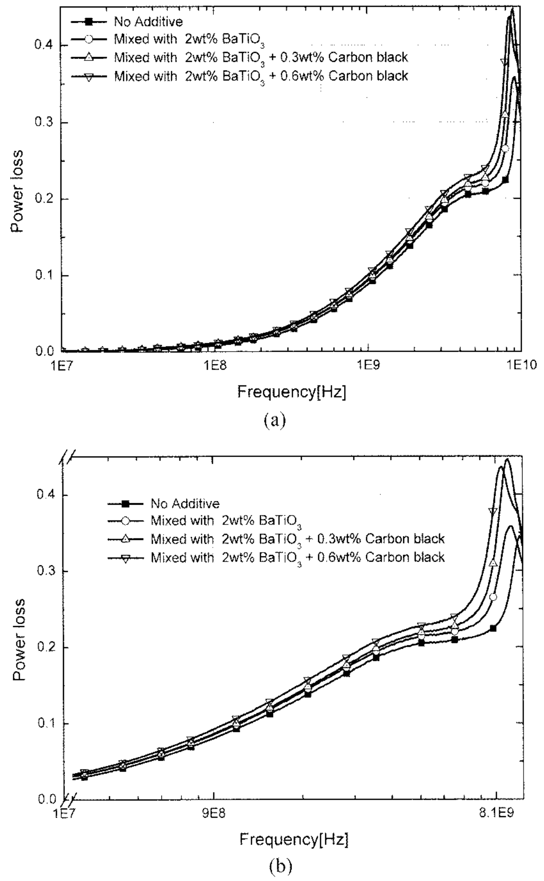

Fig. 3. Power loss curve for the Fe-based nanocrystalline soft magnetic powder sheets mixed with $BaTiO_3$ powder and carbon black.

der. The decrease in both the real permeability and imaginary permeability could be attributed to the lowered density of the Fe-based P/M sheets with the addition of the additive powders. This implies that the magnetic loss can't be increased at the high frequency.

Fig. 3(a), (b) shows the power loss curve for the Fe-based nanocrystalline soft magnetic powder sheets mixed with $BaTiO_3$ powder and carbon black. Power loss was calculated by subtracting the energy of the reflected wave and transmission wave from the energy of the incident wave, and it means the fraction of energy that is changed to heat. With increasing the content of carbon black powder, the power losses were remarkably increased especially at the high frequency of about 7 GHz. The P/M sheets showed the improved power loss at high frequencies in sequence of the specimens, with the content of 2 wt% $BaTiO_3$ and 0.6 wt% carbon black, 2 wt% $BaTiO_3$ and 0.3 wt% carbon black, 2 wt% $BaTiO_3$, and no additive. Based on the results, it can be concluded that the additions of $BaTiO_3$ and carbon black powder play an important role in the power loss for the Fe- based nanocrystalline soft magnetic sheets.

4. Conclusions

The effects of the additions of 2 wt% $BaTiO_3$ and 0.3~0.6 wt% carbon black powder on the power loss of Fe-based EM wave absorbers have been evaluated as follows :

$BaTiO_3$ and carbon black additions played an important role in the power loss for the $Fe_{73}Si_{16}B_7Nb_3Cu_1$ (at%) base nanocrystalline soft magnetic P/M sheets. The properties of electromagnetic wave absorber were improved with the addition of both $BaTiO_3$ and carbon black powder, which was caused by the increased dielectric loss of the additive powders.

As a result, the P/M sheets with the content of 2 wt% $BaTiO_3$ and 0.6 wt% carbon black showed the most improved power loss in the frequency range of 10 MHz~10 GHz among the specimens for EM wave absorption.

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