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Wide Bandwidth Microwave Absorbers of Ferrite-Rubber Composites with Square-Rod Structure

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Abstract. As one way of shape control for the wide bandwidth in microwave absorbers, a square-rod structure of ferrite composite is proposed. Microwave absorbance of the square-rod absorber is analyzed by the transmission line approximation which provides the reflection loss as a function of material parameters and dimension of the structure. In particular, the absorption bandwidth is greatly dependent upon the size of the square rod, which has been identified in both composites of Ni-Zn ferrite and Co_2Z hexagonal ferrites. With a controlled geometry of square rod in those composites, a wide bandwidth (about 6 GHz with respect to –20 dB reflection loss) has been predicted.

Keywords: ferrite composites, microwave absorbers, square-rod structure, wide bandwidth

1 Introduction

In response to the need to suppress the unwanted electromagnetic wave, the application of microwave absorbers has become more diverse in electronic and communication equipment [1]. As the noise spectrum is expanded from radio frequency to GHz range, microwave absorbers with wide bandwidth in GHz range are more desired. One of the wide bandwidth technologies is the shape control of the absorbers. Grid-type [2], wedge-type [3] and more complex-shaped ferrites [4] have been proposed for obtaining the wide bandwidth microwave absorbance in radio frequencies. The similar technique can be applied to ferrite-rubber composite sheets to broaden the bandwidth in GHz range.

In this study, wide band absorbing characteristics are investigated in the ferrite-rubber composites with a square-rod structure shown in Fig. 1. This type of absorbers can be treated as the two-layered absorbers with upper square-rod structure and bottom bulk layer. By control of the air space volume in the upper layer and thickness of the two layers, wide bandwidth microwave absorbers in GHz frequencies can be designed.

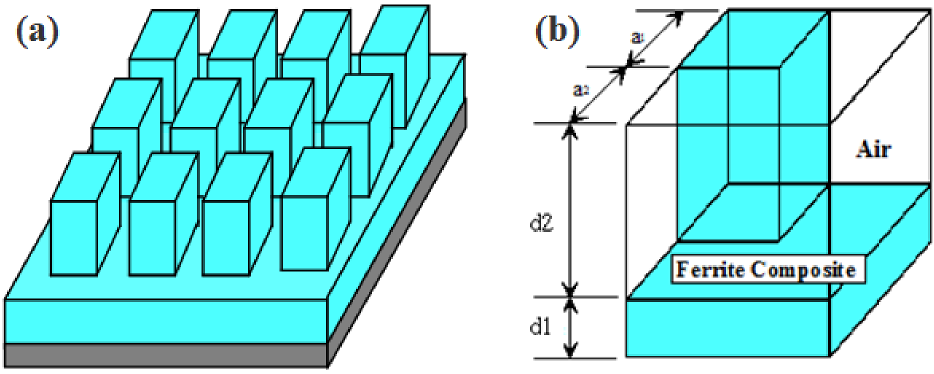

Fig. 1 Schematic description of (a) square-rod type absorber and (b) its periodic unit cell.

2 Experimental Procedure

The powders of Ni-Zn ferrite ($Ni_{0.2}Zn_{0.8}Fe_2O_4$) and Co_2Z hexagonal ferrite ($Ba_3Co_2Fe_{24}O_{41}$) were used as the absorbent fillers, which were prepared by conventional ceramic processing. Silicon rubber was used as a matrix material and mixed with ferrite powders of which content was 80% by weight. The mixture was molded in a coaxial die with 3 mm in inner-diameter and 7 mm in outer-diameter. The complex permeability and permittivity were determined from the measured reflected and transmitted scattering parameters in the frequency range from 50 MHz to 18 GHz by using a network analyzer.

3 Results and Discussion

In the proposed square-rod type absorbers (Fig. 1(a)), the periodic unit cell can be represented as shown in Fig. 1(b), where a_1 and a_2 are width of area occupied by ferrite composite and air, respectively. If the period (a_1+a_2) is small compared to a wavelength, the periodic structure can be treated as an effective medium. For instance, at the frequency of 12 GHz, the period (a_1+a_2) should be controlled below 25 mm. Then the equivalent permeability (μ_{eq}) and permittivity (ε_{eq}) are given by as a function of ferrite volume rate (defined by $K=a_1/(a_1+a_2)$) from the synthesized inductance and capacitance model [4-6],

$$\mu_{eq} = (1-K) + \frac{K\mu_r}{(1-K)\mu_r + K} \tag{1}$$

$$\varepsilon_{eq} = (1-K) + \frac{K\varepsilon_r}{(1-K)\varepsilon_r + K} \tag{2}$$

where μ_r and ε_r are intrinsic relative permeability and permittivity of the ferrite composites, respectively.

Transmission line approximation of the two-layered structure gives the input impedance at the surface of bottom and upper layers (Z_1 and Z_2, respectively), which is expressed as,

$$Z_1 = Z_{c1}\tanh \gamma_1 d_1 \tag{3}$$

$$Z_2 = Z_{c2} \frac{Z_1 + Z_{c2} \tanh \gamma_2 d_2}{Z_{c2} + Z_1 \tanh \gamma_1 d_1} \qquad (4)$$

where Z_c, v and d is characteristic impedance, propagation constant and thickness of the bottom layer (denoted by subscript 1) and the upper layer (subscript 2), respectively. Z_c and v are expressed as a function of equivalent permeability and permittivity,

$$Z_c = \sqrt{\frac{\mu_{eq}}{\varepsilon_{eq}}} \qquad (5)$$

$$\gamma = j2\pi f \sqrt{\mu_{eq} \varepsilon_{eq}} \qquad (6)$$

where f is frequency. The reflection loss (RL) of the incident electromagnetic wave normal to the two-layered structure is given by,

$$RL = 20 \log \left| \frac{Z_2 - Z_0}{Z_2 + Z_0} \right| \qquad (7)$$

where Z_0 is the intrinsic impedance of the plane wave in free space (377 Ω).

Fig. 2 shows the complex permeability ($\mu_r = \mu_r' - j\mu_r''$) and permittivity ($\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$) spectrum of the composite specimens of Ni-Zn ferrite and Co_2Z hexagonal ferrite powders. A typical ferromagnetic resonance spectrum is observed in both composites. Constant values of dielectric constant ($\varepsilon_r' \approx 7$ and $\varepsilon_r'' \approx 0$) is observed.

In a single layer composite, a narrow band absorbing characteristics is found, as shown in Fig. 3. Bandwidth is only about 1 GHz with respect to -20 dB reflection loss in both Ni-Zn ferrite and Co2Z hexagonal ferrite powders.

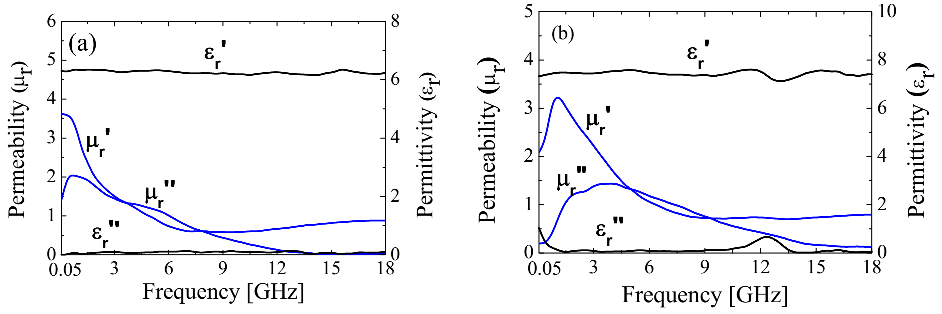

Fig. 2. Complex permeability and permittivity of (a) Ni-Zn ferrite and (b) Co_2Z ferrite.

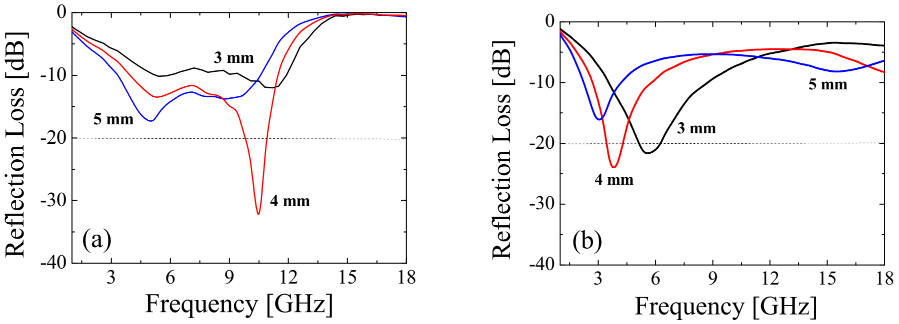

Fig. 3. Reflection loss determined in the single layer composite of (a) Ni-Zn ferrite and (b) Co2Z hexagonal ferrite powders.

A great increase in absorption bandwidth is predicted in the ferrite composites with square-rod structure with a controlled dimension. Fig. 4 shows the reflection loss determined in the composites of Ni-Zn ferrite. The most critical parameter affecting the absorbing bandwidth is size (represented by *K*) and height (d_2) of the square rod in the upper layer. At a value of *K*=1/2, the widest bandwidth (4-10 GHz with respect to -20 dB reflection loss) was predicted with the thickness of bottom layer (d_1=4 mm) and the height of square rod (d_2=6 mm). At the value of K=1/3, a slightly reduced bandwidth (5-9 GHz) was estimated with d_1=3 mm and d_2=4 mm. At the value of *K*=2/3, the bandwidth is greatly reduced as shown in Fig. 4(c).

The similar results were obtained in the specimens of Co_2Z ferrite, as shown Fig. 5. The widest bandwidth (5-11 GHz with respect to -20 dB reflection loss) was predicted in the specimen of *K*=1/2 with layer thickness d_1 = 3 mm and d_2 = 7 mm, as shown in Fig. 5(b). On the while, a very narrow bandwidth was predicted in the specimen of *K*=2/3, as shown in Fig. 5(c).

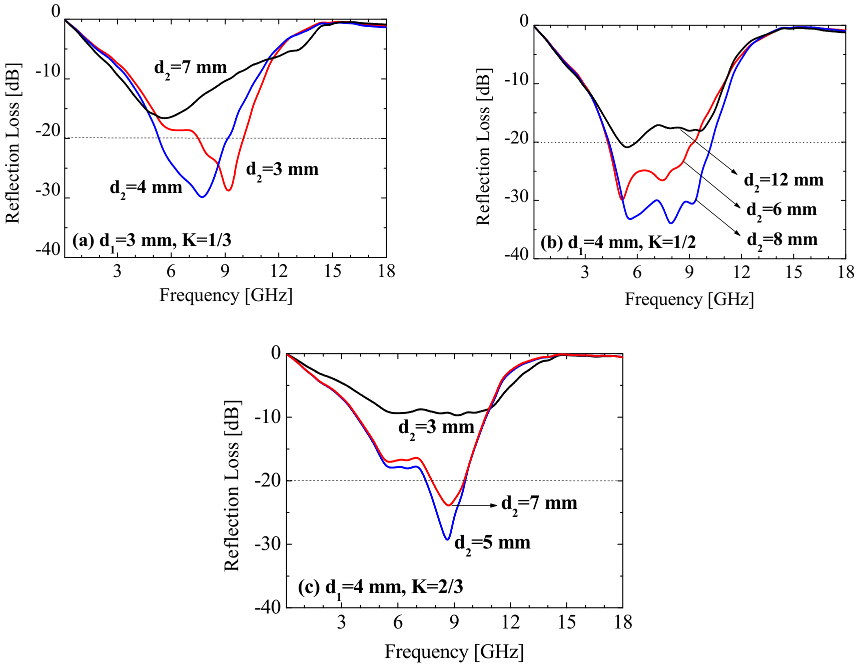

Fig. 4. Reflection loss determined in the composites of Ni-Zn ferrite: (a) K=1/3, (b) K=1/2, and (c) K=2/3.

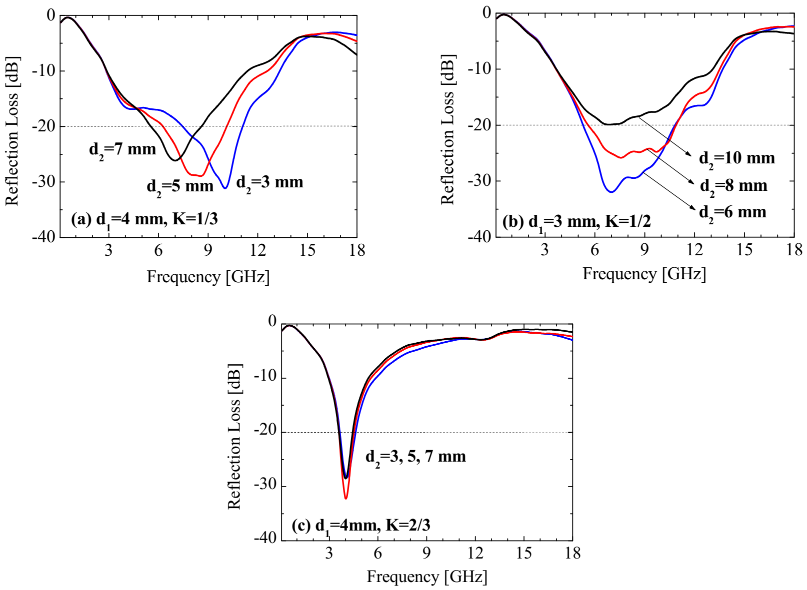

Fig. 5. Reflection loss determined in the composites of Co2Z ferrite: (a) K=1/3, (b) K=1/2, and (c) K=2/3.

4 Conclusion

Wide bandwidth in microwave absorbance was predicted in the ferrite-rubber composites with the square-rod structure. Transmission line approximation of the square-rod absorbers predicts the optimum dimension of the structure and this result was identified in two kinds of ferrite composites (Ni-Zn ferrite and Co_2Z hexagonal ferrite). With a total height of square-rod absorber (approximately 10 mm), wide bandwidth (about 6 GHz with respect to –20 dB reflection loss) was demonstrated.

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