THE COMPLEX PERMEABILITY AND MATCHING FREQUENCY OF FERRITE MICROWAVE ABSORBER

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Abstract-The complex permeability dispersions and the microwave absorbing phenomena are investigated in ferrite microwave absorber. The complex permeability of NiZn ferrite, NiZnCo ferrite, and Y-type hexagonal ferrite were measured in 200MHz-14GHz range. Two types of resonances, the domain wall and the spin rotational resonance, were observed. With a ferrite particle with a diameter of about 1μm, only spin rotational resonance were observed. The theoretical matching frequency is determined by plotting the measured complex permeability locus on the impedance matching solution map. One or two impedance matching phenomena are observed in the ferrite absorbers according to their complex permeability loci on the impedance matching solution map. The first matching frequency, found in the ferrite-rubber composites, which was higher than that of spin rotational resonance, increased with spin rotational resonance frequency.

I. INTRODUCTION

In developing the ferrite microwave absorber, the microwave absorbing characteristics, such as the matching frequency, matching thickness, and band width, have been evaluated during the last two decades. In the metal-backed single-layered absorber, the normalized input impedance at the surface of absorber should be 1 for the zero-specular-reflection[1]. Therefore, its absorbing characteristics depend on the complex permeability and permittivity of an absorbing body. Since the complex permittivity of a ferrite absorber is constant in the GHz frequency range[2], the microwave absorbing characteristics strongly depend on the resonance phenomena of the ferrite body.

The research about the resonance phenomena of ferrites has been extensively studied and described by domain wall motion, spin resonance, etc[3]. But little work has done on the relationship between the complex permeability and matching frequency of ferrite microwave absorber.

In this study, the effect of the complex permeability on the microwave absorbing characteristics and the relationship between the resonance frequency and matching frequency of ferrite microwave absorber were discussed.

II. EXPERIMENTAL

NiZn ferrite, NiZnCo ferrite, and Y-type hexagonal ferrite($Ba_2Ni_{2-x}Zn_xFe_{12}O_{22}$) were prepared by the conventional ceramic process. The starting materials for the expected composition were wet-mixed in a plastic ball mill. After the mixtures were dried, heat treatment was carried out at 1150℃ and 1300℃ for 3hours. Ferrite powders were obtained by milling the aggregated powders. The phase and particle size of the prepared ferrite powders were characterized by x-ray diffraction and scanning electron micrograph, respectively. The toroidally shaped ferrite-rubber composite specimens were made by mixing the ferrite powder and silicone rubber. The outer and inner diameter of toroid are 7mm and 3mm, respectively. The mixing ratio of ferrite powder to rubber(F/R in weight) was fixed at 4 because this mixing ratio produces thin matching thickness and high flexibility. This weight ratio is equivalent to 43 in the ferrite volume percent. The sintered ferrite body was prepared by sintering the green compact at 1300℃ for 3hours in air.

The scattering parameters(S_{11}, S_{21}) of the toroidally shaped specimens were measured using a Hewlett-Packard 8720B network analyzer. The scattering parameters were measured in the frequency range of 200MHz-14GHz, and the complex permeability and permittivity were determined from the measured scattering parameters[4].

III. RESULTS AND DISCUSSIONS

A. Complex Permeability Spectra

In this study, the ferrite compositions were chosen as NiZn ferrite, NiZnCo ferrite, and Y-type hexagonal ferrite($Ni_{2-x}Zn_xY$) because these ferrites showed good microwave absorbing performance in C-X band (4GHz -12.4GHz). The relation between material parameters and microwave absorbing characteristics in investigated for the ferrite-rubber composites prepared by the ferrite powders which have different Ni and Zn contents.

The size of ferrite particles are about 4-5μm in SEM photograph. The x-ray powder diffraction patterns confirmed that the phase of ferrite powder is single phase.

The measurement of complex permeability was carried out in the frequency range from 200MHz–14GHz. The results are showed in Fig.1–Fig.3.

Fig.1, Fig.2, and Fig.3 show the complex permeability spectra of NiZn ferrite–rubber, NiZnCo ferrite–rubber, and $Ni_{2-x}Zn_xY$–rubber composites, respectively. It is found that the complex permeability of ferrite–rubber composites have higher value with increase in Zn content. And, the maximum value of μ'' was moving to low frequency according to increase Zn contents. This phenomenon could be results from decrease the resonance frequency with reducing the magnetocrystalline anisotropy constant.

Two types of resonance were observed in the complex permeability spectra of $Ni_{2-x}Zn_xY$–rubber composites(Fig.3). These resonance phenomena were due to the domain wall resonance(f_{r1}) at lower frequency and the spin rotational resonance(f_{r2}) at higher frequency. No effect of Zn content on variation of the domain wall resonance was found in the complex permeability spectra. It was observed, however, that the spin rotational resonance frequency was shifted toward lower frequency with increasing Zn content.

For spin rotation, general model is the Snoek one[5] which predicts the resonance frequency given by

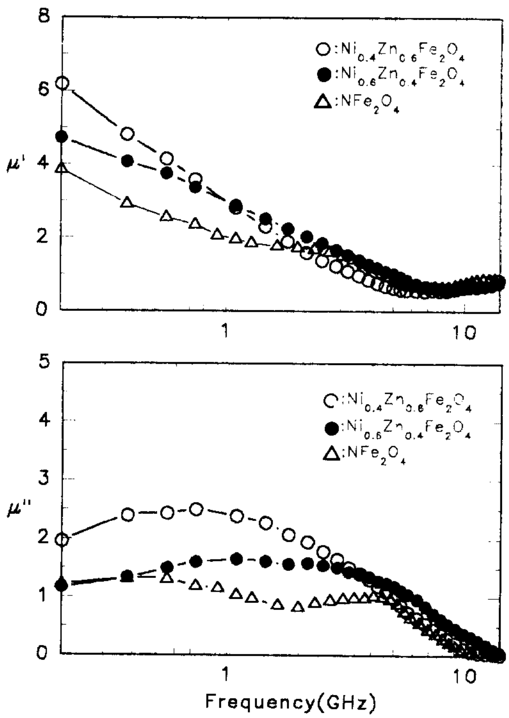

Fig.1. The complex permeability spectra of NiZn ferrite–rubber composites (synthesizing temp.=1300℃).

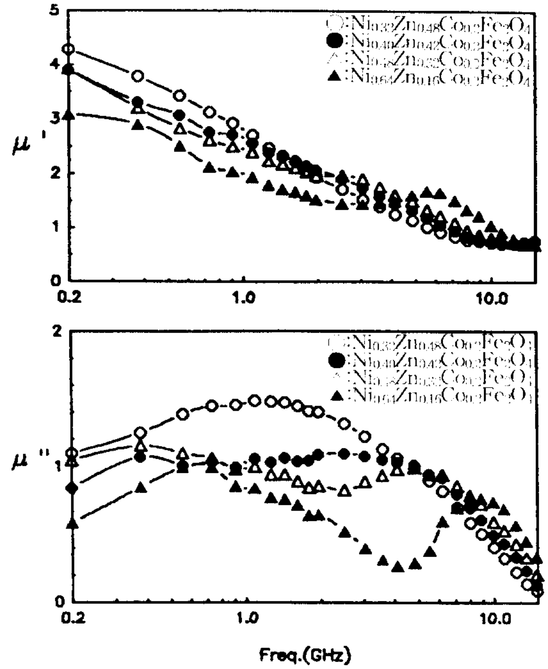

Fig.2. The complex permeability spectra of NiZnCo ferrite–rubber composites (synthesizing temp.=1300℃).

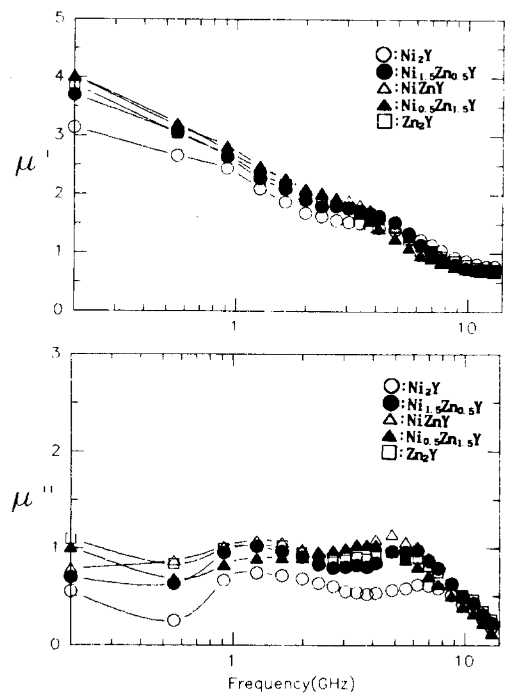

Fig.3. The complex permeability spectra of $Ni_{2-x}Zn_xY$–rubber composites (synthesizing temp.=1300℃).

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$$f_r = (\gamma / 2\pi) H_a, \qquad (1)$$

where γ is a gyromagnetic ratio, H_a is the anisotropy field and f_r is the spin rotational resonance of material. Equation (1) indicates that the spin rotational resonance depends on the anisotropy field. Smit and Wijn[6] reported that the anisotropy field of Ni_2Y and Zn_2Y at room temperature was 14000Oe and 9000Oe, respectively. Thus, decreasing the spin rotational resonance frequency with increasing Zn content indicates that the anisotropy becomes smaller as the Zn content increases.

In order to investigate the effect of particle size on the complex permeability of the $Ni_{2-x}Zn_xY$-rubber composites, $Ni_{2-x}Zn_xY$ powders were synthesized at different temperatures. Fig.4 shows the scanning electron micrographs of ferrite powders synthesized at different temperatures. The particle size of ferrite powder synthesized at 1300℃ was about 4-5μm. On the other hand, a majority of the particles synthesized at 1150℃ were smaller than 1μm.

Fig.5 represents the complex permeability spectra of the sintered $Ni_{1.5}Zn_{0.5}Y$ and $Ni_{1.5}Zn_{0.5}Y$-rubber composites. The complex permeability of sintered ferrite is higher than that of ferrite composite, because ferrite particles in ferrite-rubber composites were covered with a thin nonmagnetic layer of rubber. From the complex permeability spectra of the sintered ferrite and ferrite-rubber composite containing ferrite powder synthesized at 1300℃, one sees both domain wall resonance and spin rotational resonance. However, the composite containing ferrite powder synthesized at 1150℃ shows spin rotational resonance only. This behavior is probably due to the particles being sufficiently small to approach single domain characteristics so that only spin rotations can occur.

(a) 1150℃ (b) 1300℃

Fig.4. SEM photographs of $Ni_{1.5}Zn_{0.5}Y$ powders with different synthesizing temperatures.

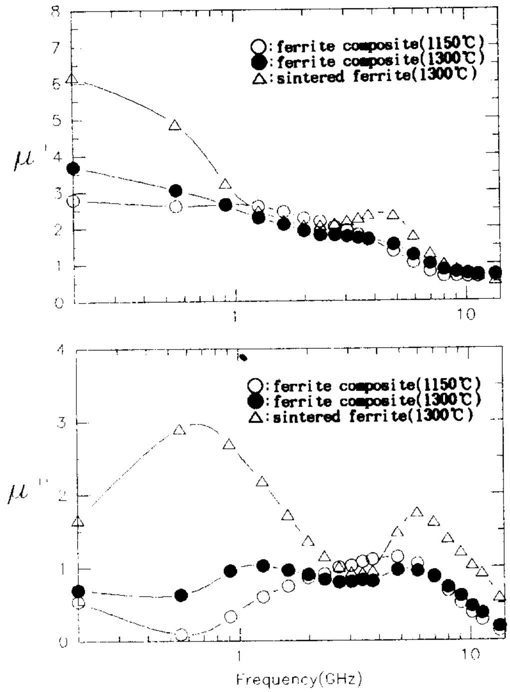

Fig.5. The complex permeability spectra of sintered $Ni_{1.5}Zn_{0.5}Y$ and $Ni_{1.5}Zn_{0.5}Y$-rubber composites.

B. The Impedance Matching Phenomena of Ferrite Absorber

For a microwave absorbing layer backed by a metal plate, the normalized input impedance(Z_{in}) at the absorber surface is given by

$$Z_{in} = 1 = \sqrt{\mu / \varepsilon}\ tanh[j(2\pi / C)\sqrt{\mu\varepsilon}\ f \cdot d], \qquad (2)$$

where μ is the complex permeability($\mu' - j\mu''$), ε is the complex permittivity($\varepsilon' - j\varepsilon''$), C is the velocity of light, f is the frequency, and d is the thickness of absorber. From the result of equation (2), the material parameters such as μ and ε can determine its absorbing characteristics.

To illustrate the impedance matching condition of the single-layered absorber, one should calculate the relationships between these parameters producing zero reflection and construct the graphical map of this relationship. Naito and Musal[1,7] have represented the graphical map of such a relationship for the zero reflection condition. This graphical map is the impedance matching solution map.

Fig.6 illustrates the use of the impedance matching solution map. To determine the impedance matching condition of $Ni_{1.5}Zn_{0.5}Y$-rubber composite, the complex permeability spectra were plotted on the map. The

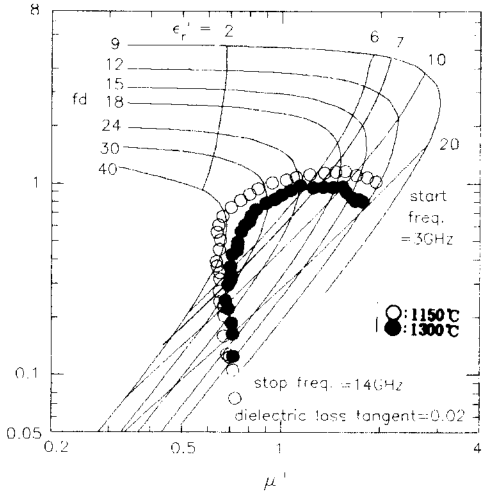

Fig.6. The complex permeability loci of $Ni_{1.5}Zn_{0.5}Y$-rubber composites on the impedance matching solution map.

map for $\tan\delta_\epsilon$=0.02 is applicable since the real and imaginary part of the permittivity of composite are constant at 7 and 0.14, respectively.

In order to satisfy the impedance matching condition, the specific material parameters are needed at a given frequency and thickness. Since the real part of permittivity of the $Ni_{1.5}Zn_{0.5}Y$-rubber composite is about 7, the matching points should be on ϵ' =7 line on the map. The crossing points of the $\mu'-\mu''$ locus and ϵ' =7 line correspond to the impedance matching points. For $Ni_{1.5}Zn_{0.5}Y$-rubber composite containing ferrite powder synthesized at 1150℃, two matching point are found. One occurs at 4.7GHz($f\cdot d$=19.3GHz · mm) and the other at 11.1GHz($f\cdot d$=33.3GHz · mm). Therefore, the first and second matching thickness are predicted to be 4.1mm(d_{m1}) and 3.0mm(d_{m2}), respectively. It is determined that f_{m1} is 5.6GHz and f_{m2} is 12.2GHz for $Ni_{1.5}Zn_{0.5}Y$-rubber composite containing ferrite powder synthesized at 1300℃. Thus, the matching thicknesses are also predicted to be 3.7mm and 2.6mm.

C. The Matching Frequency of Ferrite Absorber

The reflection loss(dB) is a function of Z_{in}, and the reflection loss of the microwave absorber can be calculated at given f and d using equation (3):

$$dB = 20 \log |(Z_{in}-1)/(Z_{in}+1)|. \quad (3)$$

The results of the microwave absorbing characteristics of NiZn ferrite-rubber, NiZnCo ferrite-rubber, and $Ni_{2-x}Zn_xY$-rubber composites calculated from equation (2) and (3) are summarized at Fig.7 and Table I. From Table I, it is observed that if two matching points exist in at low and high frequency, respectively, each microwave absorber has the following a tendency with variation of Ni and Zn contents. This tendency is that first matching frequency move to high frequency region in a proportion to increase of Ni content. This phenomena can be understood that resonance frequency moved to high frequency region by increasing Ni content and the first matching frequency of ferrite absorber is proportional to its spin rotational resonance frequency.

Fig.7 shows the relation between the matching frequency and matching thickness of ferrite-rubber composites. As shown in Fig.7, the matching thickness of NiZnCo ferrite-rubber and $Ni_{2-x}Zn_xY$-rubber composites is reduced than that of NiZn ferrite-rubber composites in the frequency range from 5GHz to 15GHz. This result is due to reduce the $f\cdot d$ term, and considered as an intrinsic property

Table I. The Microwave Absorbing Characteristics of Ferrite-Rubber Composites

Ferrite composition	Matching frequency(GHz) f_{m1}	Matching frequency(GHz) f_{m2}	$f_m\cdot d_m$(GHz · mm) $f_{m1}\cdot d_{m1}$	$f_m\cdot d_m$(GHz · mm) $f_{m2}\cdot d_{m2}$
$Ni_{0.4}Zn_{0.6}Fe_2O_4$	2.1	8.6	15.7	36.1
$Ni_{0.5}Zn_{0.5}Fe_2O_4$	2.6	10.7	15.0	36.3
$Ni_{0.6}Zn_{0.4}Fe_2O_4$	3.7	10.8	19.6	36.7
$Ni_{0.8}Zn_{0.2}Fe_2O_4$	3.8	10.4	19.7	38.4
$NiFe_2O_4$	4.1	7.9	22.9	36.4
$Ni_{0.32}Zn_{0.48}Co_{0.2}Fe_2O_4$	4.2	10.8	22.2	33.4
$Ni_{0.40}Zn_{0.42}Co_{0.2}Fe_2O_4$	5.7	12.0	23.3	33.6
$Ni_{0.48}Zn_{0.32}Co_{0.2}Fe_2O_4$	6.7	13.6	20.7	34.0
$Ni_{0.64}Zn_{0.16}Co_{0.2}Fe_2O_4$	9.9	15.0	24.7	33.0
Ni_2Y	8.9	···	27.5	···
$Ni_{1.5}Zn_{0.5}Y$	5.6	12.2	20.7	31.7
NiZnY	4.9	12.7	19.6	33.0
$Ni_{0.5}Zn_{1.5}Y$	4.9	13.5	20.5	32.4
Zn_2Y	3.0	11.8	17.7	31.8

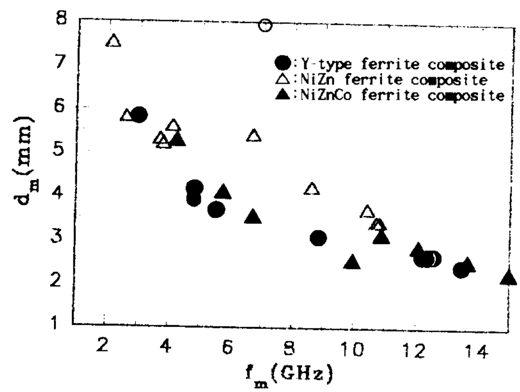

Fig.7. The relation between matching frequency and matching thickness of ferrite-rubber composites.

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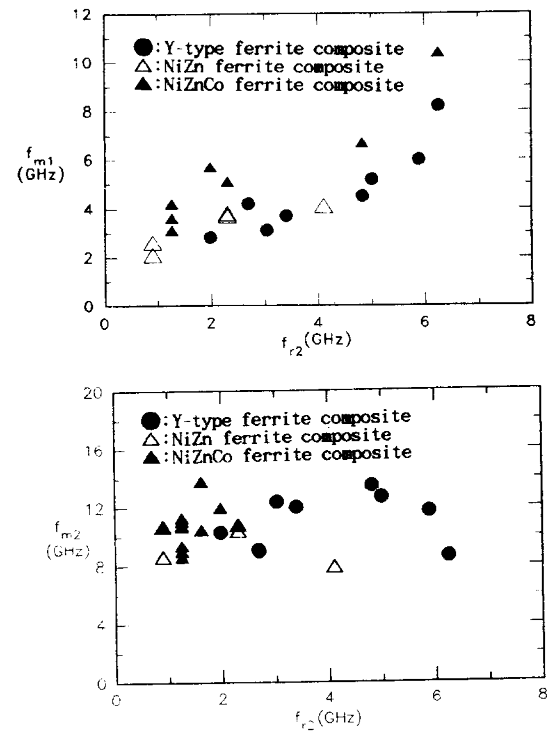

Fig.8. The relation between the spin rotational resonance frequency(f_{r2}) and matching frequency(f_{m1}, f_{m2}) of ferrite-rubber composites.

of NiZnCo ferrite and $Ni_{2-x}Zn_xY$ ferrite.

Fig.8 represents the relation between the spin rotational resonance frequency(f_{r2}) and the first and second matching frequency(f_{m1}, f_{m2}) of ferrite-rubber composites. This figure shows that the first matching frequency(f_{m1}) is higher than that of the spin rotational resonance. The first matching frequency of the ferrite microwave absorber is proportional to its spin rotational resonance frequency, whereas the second matching frequency is independent. Therefore, it could be concluded that the first impedance matching frequency only increased with spin rotational resonance.

Ⅳ. CONCLUSION

The first matching frequency of ferrite-rubber composite increase in an approximately proportion to increase in Ni content. The matching frequency can be controlled in the range of 4~15 GHz by variation of Ni and Zn contents. It can be suggested that NiZnCo ferrite-rubber and $Ni_{2-x}Zn_xY$-rubber composites could be used as microwave absorber in C-X band(4~12.4 GHz).

It was observed that one or two matching frequencies exist in ferrite absorbers. This phenomena strongly depends on the complex permeability locus on the impedance matching solution map. It was found that the first matching frequency, which was always higher than that of the spin rotational resonance, increased with the spin rotational resonance frequency.

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