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The Effect of Nonstoichiometry on Microwave Absorbing Properties of Ni-Zn Ferrites

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Abstract. Microwave absorbing properties of the nonstoichiometric compounds of Ni-Zn ferrites with excess Fe_2O_3 are investigated. Toroidal compacts of $(\text{Ni}_{0.5}\text{Zn}_{0.5}\text{O})_{1-y}(\text{Fe}_2\text{O}_3)_{1+y}$ spinels are prepared by the conventional ceramic processing technique. The magnetic permeability and dielectric constant are greatly dependent upon the amount of excess Fe_2O_3 ($y > 0$). Both the real and imaginary components of permeability decrease as the excess Fe_2O_3 increases. On the other hand, the dielectric constant increases with the increase of excess Fe_2O_3 . The combined effect of high dielectric constant and low permeability results in a lower-frequency impedance matching. The plate thickness at the zero-reflection frequency is predicted using the approximated impedance-matching relationship between wavelength and material parameters.

1. INTRODUCTION

The sintered plate of Ni-Zn ferrite is widely used as an electromagnetic wave absorber in the VHF/UHF region [1,2]. The main task in designing of the ferrite tile absorber used in those frequency band is to obtain the superior absorbing properties especially in the low frequencies. One of the approach to solve this problem is to endow the ferrite tiles with high dielectric constant and low permeability. Based on this background, the nonstoichiometric compounds of Ni-Zn ferrite with excess Fe_2O_3 are chosen and their microwave absorbing properties are investigated. It is expected that the increased ferrous ion content from the excess Fe_2O_3 is effective in increasing the dielectric constant and, thereby, results in an impedance-matching at the lower frequency.

2. EXPERIMENTALS

The specimens of $(\text{Ni}_{0.5}\text{Zn}_{0.5}\text{O})_{1-y}(\text{Fe}_2\text{O}_3)_{1+y}$ spinels were prepared by conventional ceramic processing technique, where y denotes the excess of iron. The toroidal compacts were sintered at 1250 °C for 2 hrs in air. The complex permeability and permittivity and microwave absorbing properties were measured by the reflection/transmission technique described in the earlier paper [3].

3. RESULTS AND DISCUSSION

Fig.1 shows the complex permeability ($\mu_r' - j\mu_r''$) and permittivity ($\epsilon_r' - j\epsilon_r''$) spectra determined in $(\text{Ni}_{0.5}\text{Zn}_{0.5}\text{O})_{1-y}(\text{Fe}_2\text{O}_3)_{1+y}$ samples. As shown in Fig.1(a) and Fig.1(b), both μ_r' and μ_r'' , which are decreasing functions of the frequency, decrease with the increase of the iron-excess content (y). In the case of stoichiometric compound ($y=0$), μ_r' is 45 and μ_r'' is 60 at 130 MHz. On the while, in the iron-excess sample with $y=0.16$, μ_r' and μ_r'' decreases to 14 and 25, respectively.

On the contrary to the magnetic permeability, dielectric constant increases with the increase of excess iron content as shown in Fig.1(c). As compared to the dielectric constant of stoichiometric compound ($\epsilon_r'=12$), a much higher value of ϵ_r' (about 32) is observed in the sample with $y=0.08$. The high dielectric constant is attributed to the more enhanced electrical conduction with the increase in ferrous ion (Fe^{2+}) content in the spinel lattice. The dielectric loss (ϵ_r'') was small, but has a tendency to increase with the increase of excess iron. For the sample of $y=0.08$, the value of ϵ_r'' is about 5.

Fig.2 shows the microwave reflectance calculated from the measured μ_r and ϵ_r . The calculation procedure was described in the previous paper [4]. A specified frequency with the minimum reflection loss moves to lower frequency as the excess iron increases (600 MHz at $y=0$, 240 MHz at $y=0.08$) and the corresponding absorber thickness increases (3.9 mm at $y=0$, 5.7 mm at $y=0.08$).

For a microwave absorbing layer terminated by a metal, a zero-reflection condition is determined by a proper combination of material parameters and absorber thickness, which is given by

$$\sqrt{\mu_r' \epsilon_r'} \tanh [j(2\pi d/\lambda) \sqrt{\mu_r' \epsilon_r'}] = 1 \quad (1)$$

where d is thickness and λ is wavelength. For the absorbers with high magnetic loss ($\mu_r' < \mu_r''$) and low dielectric loss as in the case of ferrite tiles, the parameters requirements for zero-reflection can be approximated by the simple relationships [1,2]:

$$d/\lambda = 1/2\pi \mu_r'' \quad (2a)$$

$$\mu_r' = \epsilon_r'/3 \quad (2b)$$

In the present study, Eq.(2) can also be used in determining the microwave absorbing properties. Fig.3 shows the illustrations of determining the absorber thickness and zero-reflection frequency. For the stoichiometric compound ($y=0$), Eq.(2) is satisfied at a frequency of 600 MHz and where the absorber thickness is 3.9 mm (Fig.3(a)). The lower zero-reflection frequency and larger absorber thickness in the iron-excess sample ($y=0.08$) can be explained in Fig.3(b). Zero-reflection frequency and absorber thickness are found to be 245 MHz and 5.7 mm, respectively. The predictions are in good agreement with the result of reflection loss shown in Fig.2.

The impedance-matching at a lower frequency in the iron-excess ferrite is attributed to the lower value of μ_r' and higher value of ϵ_r' , which is arising from the increase in Fe^{2+} content in the spinel lattice. It can thus be suggested that the compositional control of nonstoichiometry is one of the convenient ways to control the microwave absorbing properties of Ni-Zn ferrites.

Fig.1. Material constants of $(\text{Ni}_{0.5}\text{Zn}_{0.5}\text{O})_{1-y}(\text{FeO})_{1-y}$ samples : (a) μ_r' , (b) μ_r'' , and (c) ϵ_r' .

Fig.2. Microwave reflectance determined in $(\text{Ni}_{0.5}\text{Zn}_{0.5}\text{O})_{1-y}(\text{FeO})_{1-y}$ samples.

Fig.3. Prediction of zero-reflection frequency and absorber thickness in $(\text{Ni}_{0.5}\text{Zn}_{0.5}\text{O})_{1-y}(\text{FeO})_{1-y}$ samples : (a) $y=0$, (b) $y=0.08$.

4. CONCLUSION

It was demonstrated that the microwave absorbing properties (especially, absorbing frequency band) of Ni-Zn ferrite tiles can be controlled by the nonstoichiometry (excess of iron) of the spinel compound. The increase of excess iron resulted in the lower magnetic permeability and higher dielectric constant which, in turn, produced an impedance-matching at the lower frequency. The plate thickness was then determined using the approximated impedance-matching relationship between wavelength and material parameters.

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