Microwave Absorbing Studies of Magnetic Materials for X-Band Frequencies

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Abstract—Magnetic materials, Barium hexaferrite BaFe12-2x(Co8xTi8Mn8-x)O19 (x = 0 and x = 1) have been synthesized by ceramic method and sintered at temperature 1100 °C for 5 hours in the atmosphere. In order to realize a microwave absorber composite, the ferrites powder are mixed with the resin. The structure of the crystal and magnetic properties were performed by using XRD and Permagraph, respectively, whereas the reflection characteristics were investigated by an vector network analyzer. The results confirm that the barium hexaferrite has single phase with hexagonal structure and Co-Ti-Mn change magnetic properties and improve the values of reflection characteristics.

Keywords—Barium hexaferrite; permeability; permittivity; reflection characteristics.

I. INTRODUCTION

A material, which shows certain absorbing performances at microwave frequencies, is a valuable topic for military purposes for radar-absorbing material (RAM), i.e., in stealth technology [1,2] has drawn considerable attention of many countries. Microwave absorbing materials based on barium hexaferrites has been studied for absorbing materials [3]. A few studies of barium hexaferrite have been reported for determination of its microwave absorbing properties in X-band frequencies [4-8]. Barium hexaferrite is potential absorbing materials due to their high resistivity, dielectric and magnetic losses in microwave frequency [3]. Some reports, substitution of Mn-Ti [5], Zn-Co [9], Ti-Co [10], and Mn-Ti [11] change the intrinsic magnetic coercivity (Hc), remanence (Mr), magnetic saturation (Ms) of barium hexaferrite [12].

In this paper, we report the study of magnetic and microwave absorption properties of Co-Ti-Mn doped barium hexaferrite and find their microwave absorbing properties. The crystal structure, magnetic and microwave absorption properties of BaFe12−2x(Co8xTi8Mn8-x)O19 (x = 0 and x = 1) for X-band frequencies (8.2-12.4 GHz) will be discussed.

II. EXPERIMENTAL

The BaFe12−2x(Co8xTi8Mn8-x)O19 (x = 0 and x = 1) have been synthesized by stoichiometric mixtures of BaCO3, Fe2O3, CoO4, TiO2 and MnCO3. The mixtures were crushed for 1 hour and sintered in the atmosphere at 1100 °C for 5 hours. The powder was obtained by high energy ball mill for 1 hour. The samples were characterized using X-ray diffraction (XRD) for analysis of its crystal structure, hysteresis loop recorded by Permagraph for knowing its magnetic properties, and vector network analyzer (VNA) (Rohde-Schwarz ZVZ13) were used to analyze microwave absorption properties for X-band frequencies (8.2-12.4 GHz).

III. RESULTS AND DISCUSSION

A. Phase identification

Fig. 1 shows the XRD pattern of BaFe12−2x(Co8xTi8Mn8-x)O19 (x = 0 and x = 1) sintered at 1100 °C for 5 hours. The sintered temperature is lower 100 °C compare to the other report [13]. According to the XRD results, it's indicate that the samples of BaFe12−2x(Co8xTi8Mn8-x)O19 (x = 0 and x = 1) have single phase with hexagonal structure and the main crystal planes (110), (001), (114), (023) and (025). Meanwhile, the intensity of XRD pattern different for various composition. It can be concluded that there are some crystalline planes change due to different composition of Co-Ti-Mn.

The intensity of the sample with x = 1 has most intense peaks. It’s predicted that Co-Mn ions occupy Fe ions site tend to modify structure of hexagonal closed packed lattice of BaFe12−2x(Co8xTi8Mn8-x)O19 (x = 0 and x = 1). As results, the planes orientation of crystal structure improved.
C. Absorption characteristics

The values of the real and imaginary part of permeability and permittivity as a function of frequency of barium hexaferrites BaFe_{12-2x}(Co_{0.8}Ti_{0.8}Mn_{0.4})_xO_{19} (x=0 and x=1) in the frequencies of 8.2 - 12.4 GHz are given in Fig. 3. For permeability values decreased significantly for x=0 and x=1. The value of $\mu'(x=0)$ decreasing from 23 at 8.2 GHz to 2 at 11.75 GHz and then rising to 6 at 12.4 GHz. The same is for $\mu''$. While Value $\varepsilon'$ and $\varepsilon'' (x=1)$ also decreases. So for all the samples there is a decrease of the relative complex permeability. Nevertheless, the permit value with frequency in this range of studied frequencies is tended to be constant for (x=0 and x=1).

The reflection characteristics (RL) of barium hexaferrites BaFe_{12-2x}(Co_{0.8}Ti_{0.8}Mn_{0.4})_xO_{19} (x=0 and x=1) are showed in Fig. 4. The RL calculated using the formula RL (dB) = 20 log $\left[ |(Z-1)/(Z+1)| \right]$ where $Z = \sqrt{\mu/\varepsilon} \tanh \left[ (-2\pi f d/c)\sqrt{\mu/\varepsilon} \right]$. $\mu = \mu' - i\mu''$ and $\varepsilon = \varepsilon' - i\varepsilon''$ are complex-valued relative permeability and permittivity (depicted in Fig. 3.), f is the frequency ranging from 8.2 GHz to 12.4 GHz and d = 2 mm is the thickness of the samples.

It is observed that the RL of the samples decreases for all compositions. The RL value is below -10 dB at the frequency of 8.2 GHz and -20 dB on 12.4 GHz. This means that less than 30% of the electromagnetic waves are reflected by the magnetic material at a frequency interval of 8.2 - 12.4 GHz. But for the case x = 0, there has been an increase in frequency 10.75 GHz - 11.25 GHz. This can be due to the impurity of the sample. Nevertheless the microwave is absorbed more effectively by with the frequency above 11.5 GHz.

B. Magnetic properties

Hysteresis loops in quadrants 1 and 2, are used to determine magnetic properties. Fig. 2 shows that the saturation magnetization ($M_s$) and coercivity ($H_c$) of barium hexaferrites are changed. $M_s$ value increases from 0.3 T (x=0) be 0.35 T (x=1) on the external field 400 kA/m. While the value of $H_c$ decreased significantly from 250 kA/m (x=0) to be less than 50 kA/m (x=1). The values of coercivity in doped samples (x=1) decrease, which can be caused by substituting the Fe^{3+} ion through Co^{2+}, Ti^{4+}, and Mn^{2+}. The small coercive value has shown that magnetic stability decreases with the easier direction of the magnetic dipole of the magnetic material (x=1) moving.

Fig. 1. XRD pattern of barium hexaferrites: BaFe_{12-2x}(Co_{0.8}Ti_{0.8}Mn_{0.4})_xO_{19} (x=0 and x=1)

Fig. 2. Room temperature hysteresis loops of BaFe_{12-2x}(Co_{0.8}Ti_{0.8}Mn_{0.4})_xO_{19} (x=0 and x=1)
The reflection characteristics (RL) for BaFe_{12-2x}(Co_{x}Ti_{3}Mn_{x})O_{19} (x=0 and x=1) of the samples having differences in their composition, as measured with using perfect conductor backing as a substrate, lie between 8.2 – 12.4 GHz (see Fig. 5). The RL value is calculated from the absolute value of the S11 reflected signal from the direct measurement result. The figure shows a minimum reflection loss of −10 dB for the both samples at an thickness of 2 mm with peak value at 9.25 GHz for x=0 and at 9.75 GHz, 12 GHz for x=1.

IV. CONCLUSION

Barium hexaferrites, BaFe_{12-2x}(Co_{x}Ti_{3}Mn_{x})O_{19} (x=0 and x=1) as magnetic materials were synthesized by the usual ceramic method and had a single-phase crystal with many fields. The samples that have higher permeability, larger coercivity in x=0 and small coercivity in x=1, have resulted larger microwave-absorbing ability. The samples of magnetic material could be obtained by the substituted value of Co, Ti and Mn elements in barium hexaferrites and have satisfactory reflection losses in a range of 8.2–12.4 GHz (X-band).

ACKNOWLEDGMENT

Thanks are due to Ministry of Research, Technology and Higher Education of Republik Indonesia for INSINAS 2017 Research Grant with no. RD-2016-0146.

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