Reflection Loss Characteristic as Coating Thickness Function on the Microwave Absorbing Paint at a Frequency of 8-12 GHz

Y. E. Gunanto1,*, M. P. Izaak1, H. Sitompul1, W. A. Adi2

1 Department of Physics Education, University of Pelita Harapan Karawaci, Tangerang 15811, Indonesia
2 Center for Science and Technology of Advanced Materials, BATAN, Tangerang Selatan 15314, Indonesia

*Corresponding author’s email: yohanes.gunanto@uph.edu

Abstract. The effect of paint thickness based on Ba0.6Sr0.4Fe10MnTiO19 nanoparticles as a microwave absorber has been investigated. Nanoparticle powder Ba0.6Sr0.4Fe10MnTiO19 was made using a solid-state reaction method milled with seven hundred rpm for fifty hours then characterized first. Qualitative and quantitative analysis of structure and phase was measured by using X-ray diffraction (XRD). The sample has a hexagonal structure with a space group P63/mmc, and no other phase is detected. Meanwhile, scanning electron microscopy (SEM) was used for surface morphology analysis. Homogeneous sample granules with an almost round shape with a nanometer scale between seventy to one hundred nanometers. Loop hysteresis obtained from the measurement of vibrating sample magnetometer has a maximum magnetic value of $M_s = 50$ emu/g, magnetic remanent ($M_r$) of 32.0 emu/g and coercivity ($H_c$) of 0.34 T. Next step the nanoparticles were mixed with paint with a weight ratio composition of 30: 70. The mixture was then sprayed with several variations of paint thickness on the iron metal plate. After that, the reflection loss characteristic was measured by using vector network analyzer on a painted plate and resulted that the best performance of microwaves absorption resulted in the sample with two sprays. It was concluded that the paint thickness could affect the ability of reflection loss, but the thicker the paint does not mean that the loss of reflection is getting better.

Keywords: Reflection loss, coating thickness, microwave absorbing, Ba0.6Sr0.4Fe10MnTiO19

1. Introduction
M-type hexaferrite magnetic material, in the last decade, is still very interesting to the attention of many researchers, for example, barium hexaferrite BaFe12O19 [1-3] or strontium hexaferrite SrFe12O19 [4]. This is because these materials are very applicable, e.g. as a microwave absorber and magnetic recording media [3-9]. To improve its ability in microwave absorption doping is done on atom Ba / Sr, at atom Fe or at the same at both atoms [1-10]. In Ba1.4Ce0.6Fe12O19 material we will get a reflection loss (RL) value of -16.74 dB at 10.3 GHz for $x = 0.15$ [5], while for BaFe12+xA12O19 for $x = 2$ has RL about -43 dB at frequency 15.7 GHz [7], for BaFe12-GaO19 material for $x = 0.9$ has an RL of about -16 dB at 47 GHz frequency [8] and for Ba0.8Sr0.2Fe10MnTiO19 has RL of about - 49 dB at frequency 10.8 [11].

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The ability of materials to absorb microwaves is influenced by the size of particles that can be produced by several methods, e.g., solid-state sintering with variations of growth techniques [10], coprecipitation [2, 4, 6], sol-gel [3, 5, 12] or ball milling [1, 11]. The methods have been used to produce particle size in the order of nanometers. When a particle is small, it is able to absorb microwaves better. An average particle size of 500 nm having an RL of about -16.74 dB [5], the average particle size of 50 - 100 nm has RL ~ - 45 dB [4], and for 20 - 30 nm particle size has an RL ~ 49 nm [11]. The thickness of the composite material also affects the ability of the hexaferrite material in absorbing microwaves. Composite BaFe12O19 ferrite-epoxy with a thickness of approximately 2.8 mm has an RL of about -20.21 dB [3] and for composite Ba0.6Sr0.4Fe10MnTiO19-silicon rubber with a thickness of about 1 mm has an RL ~ -23 dB [9].

In this research, we have used a Ba0.6Sr0.4Fe10MnTiO19 material resulted from the best previous our research [11]. Paint has been mixed Ba0.6Sr0.4Fe10MnTiO19 nanoparticles with a ratio of 30:70 sprayed on 1 mm thick iron plate. Variation of paint thickness is done by varying the frequency of spray on the iron plate. The purpose of this research was to know the influence of paint thickness on its ability to absorb microwaves with the parameter used is reflection loss characteristic.

2. Methods
The Ba0.6Sr0.4Fe10MnTiO19 nanoparticles were produced from stoichiometric mixtures of BaCO3, SrCO3, Fe2O3, MnCO3 and TiO2, each with purity 99%. The mixture was milled with high energy milling (HEM) for 50 hours at 750 rpm and then calcined at 1000 °C for 10 hours [9]. In the state of powder, X-ray diffraction (XRD) type Philip PW1710 was used to analyze the structure and phase. The surface morphology analysis can be conducted through Scanning electron microscopy (SEM) type Jeol JED-2300, while static magnetic analysis can be processed by Vibration of sample magnetometer (VSM). Characterization of microwave absorption capability of paint that was sprayed onto the iron plate was done by using Anritsu MS46322A vector network analyzer (VNA).

3. Results and Discussion
The result of qualitative and quantitative analysis measured by using X-ray diffraction (XRD) on the Ba0.6Sr0.4Fe10MnTiO19 sample with 50 hours milling time can be seen in Figure 1(a) and (b). XRD characterization results indicated that the sample has a single phase, no other phase. The refinement results of the x-ray diffraction pattern of sample Ba0.6Sr0.4Fe10MnTiO19 with milling time 50 hours can be seen in Figure 1(b). This result similar to previous our research [11]. This refinement resulted in a high fitting quality with R-factor value as small as chi-squared ($\chi^2$) value of 1.3 [13]. The structural parameters, Criteria (factor R) and chi-squared ($\chi^2$) of refinement results can be seen in Table 1.

The surface morphology of the sample Ba0.6Sr0.4Fe10MnTiO19 has a relatively homogeneous structure as can be seen in Figure 2. Observation of surface morphology shows that the sample has a relatively round shape and particle size on a nanometer scale, around 75-100 nm. The SEM results indicate the presence of agglomeration. This is due to the magnetic interaction between the particles [14].

VSM showed the characterization of the magnetic properties of Ba0.6Sr0.4Fe10MnTiO19 in the hysteresis curve shown in Figure 3. The hysteresis loop in Figure 3 shows the data summarized in Table 2. These results show that the sample has a high chance to be a microwave absorber (Radar), because it has a poor coercivity value, less number of remanence and a great number of magnetic saturation [11]. The distribution of iron ions in crystallographic lattice sites affects the magnetic behavior of hexaferrite material [14]. The hexagonal structure of the M-type hexaferrite has five sites for iron ions. The direction of the upward spin is represented by 12k, 2a, and 2b, while the direction of the spin downward is represented by 4f1 and 4f2.
Figure 1. (a) X-ray diffraction patterns and (b) Refinement of x-ray diffraction patterns of sample Ba$_{0.6}$Sr$_{0.4}$Fe$_{10}$MnTiO$_{19}$

Figure 2. SEM micrograph of the sample Ba$_{0.6}$Sr$_{0.4}$Fe$_{10}$MnTiO$_{19}$

Table 1. Structural parameters, R-factor and chi-squared ($\chi^2$)

| Phase            | Structural parameters | $a$ = 5.8986(2) Å | $c$ = 23.168(1) Å | $\alpha = \beta$ = 90° | $\gamma$ = 120° | $V$ = 698.13(9) Å$^3$ | $\rho$ = 5.590 g.cm$^{-3}$ | $wRp$ = 3.10 | $Rp$ = 2.27 | $\chi^2$ (chi-squared) = 1.034 |
|------------------|----------------------|-------------------|-------------------|-------------------------|-----------------|-----------------------|---------------------|----------------|-------------|-----------------------------|

Table 2. Summary of magnetic properties data Ba$_{0.6}$Sr$_{0.4}$Fe$_{10}$MnTiO$_{19}$

| $t$ (hours) | $M_s$ (emu/g) | $M_r$ (emu/g) | $H_c$ (T) |
|------------|--------------|--------------|-----------|
| 50         | 50.0         | 32.0         | 0.34      |

The result of the microwave absorption of the Ba$_{0.6}$Sr$_{0.4}$Fe$_{10}$MnTiO$_{19}$ nanoparticles based paints is shown in Figure 4. The weight ratio of the Ba$_{0.6}$Sr$_{0.4}$Fe$_{10}$MnTiO$_{19}$ nanoparticle material as filled with paint is 30:70, with four variations of paint thickness, i.e., once spray, twice spray, three times spray and four times spray. Based on this experiment was found that the best absorption value was twice sprayed. It is assumed that twice the sprays treatment produces the optimum thickness so that the best reflection loss value is obtained [15]. So it can be concluded that the paint thickness can affect the ability of reflection loss, but the thicker the paint does not mean that the loss of reflection is getting better.
Figure 3. Hysteresis curve $\text{Ba}_{0.6}\text{Sr}_{0.4}\text{Fe}_{10}\text{MnTiO}_{19}$ by using VSM

Figure 4. The reflection loss curve (RL) to frequency (f) at the composition of 30:70.

4. Conclusion
We have investigated the material of $\text{Ba}_{0.6}\text{Sr}_{0.4}\text{Fe}_{10}\text{MnTiO}_{19}$ nanoparticles mixed in the paint for microwave absorber. The paint was sprayed on a 1 mm thick iron plate with spray variations up to four times. The best result is obtained twice spraying with the ability of this paint material to absorb microwaves of 65% at a frequency of 9 GHz. The paint thickness can affect the ability of reflection loss, but the thicker the paint does not mean that the loss of reflection is getting better.

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