Double Layer Microwave Absorption Characteristics of Barium Hexaferrite/Silica Composite for X-Band Frequencies

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Abstract. Microwave absorption characteristics of double layer of barium hexaferrite attached on the silica to from a composite on the basis of wave propagation theory have been investigated. Barium hexaferrite, BaFe₁₂O₁₉, was synthesized through ceramic method from stoichiometric mixtures of BaCO₃ and Fe₂O₃ as precursors. The mixture was pelletized under the pressure of 10 MPa and sintered at 1100 °C for 5 hours. Silica in the forms of powder was purified by using HCl. The crystal structure of the samples was characterized using X-ray diffraction (XRD), microstructure was examined using scanning electron microscope (SEM), hysteresis curves recorded by PERMAGRAPH techniques, whereas the microwave absorbing properties for X-band was recorded using a vector network analyzer (VNA). Relative complex permeability and permittivity, and reflection loss values were calculated at given thickness according to transmittance line theory within the range 8.2–12.4 GHz. Based on this study, the layer dimension and frequency that results in low reflection loss can be estimated from the material properties of the barium hexaferrite/silica composite material.

Introduction

The microwave absorbing materials are rising interest in the business field [1], especially in electromagnetic waves for wireless telecommunication systems [2]. These materials are also valuable topics in military for radar-absorbing material (RAM) purposes, i.e., in stealth technology [3]. Because of that, materials with these microwave absorbing properties have drawn considerable attention of many researchers in many countries [4-5].

Progress of research in the microwave absorbing materials of barium hexaferrites have been studied for many years for the purpose of absorbing materials [5]. Barium hexaferrite with general formula BaFe₁₂O₁₉ as permanent magnet material is a special kind of absorbing materials due to its high resistivity and tunable dielectric and magnetic properties in microwave frequency. Various stable phases of hexaferrites are M-, Y-, X-, Z- and U-type, the M-type phase including the procedure for preparation of barium hexaferrite, thermal stability, crystal structure and observation of ferromagnetic properties have been studied by many investigators [6-8]. Few studies of barium hexaferrite have been reported on determination of its microwave absorbing properties in X-band frequencies [9-13]. However, all of these previous studies of barium hexaferrite were used as a single phase.
In this study, the magnetic and microwave absorbing properties of barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$ attached on the silica to form a composite were studied on the basis of wave propagation theory. With this composite structure, the microwave absorbing properties would be improved. Detailed on the microstructure, magnetic and microwave absorbing studies of $\text{BaFe}_{12}\text{O}_{19}/\text{SiO}_2$ composites for X-band (8.2–12.4 GHz) frequencies are presented and discussed.

**Experimental Setup**

**Materials and Synthesis.** All chemicals used in this work were obtained from Sigma Aldrich. Barium hexaferrite, $\text{BaFe}_{12}\text{O}_{19}$ was synthesized through a ceramic method from stoichiometric mixtures of $\text{BaCO}_3$ and $\text{Fe}_2\text{O}_3$ as precursors. Silica powder ($\text{SiO}_2$, quartz) was obtained in the form of silica sand and was purified using HCl. The mixtures were crushed by high energy ball milling for 1 hour and pelletized under a pressure of 10 MP to increase the hard phase of barium hexaferrite and sintered in a furnace at 1100 °C for 5 hours and ready for characterization.

**Characterization.** Crystal structure of the samples was characterized at room temperature using PANalytical X-ray diffractometer (XRD) using Cu Kα radiation ($\lambda = 1.5418$ Å) in the range of 2θ = 20 – 65° whereas the microstructure was analyzed using scanning electron microscopy (SEM). Hysteresis curves for magnetic properties were recorded using PERMAGRAPH techniques measured at room temperature with an applied field of up to 1 T. A vector network analyzer (VNA) Rohde-Schwarz ZVL13 was used to analyze microwave absorbing properties for X-band (8.2–12.4 GHz) frequencies. The powders of barium hexaferrite/silica composite were mixed with epoxy resin to be converted into a microwave absorbing composite. The mixing ratio of ferrite to epoxy resin was 3 : 2 in weight and placed in a sample holder with a dimension of width 22.86 mm, height 10.16 mm and thickness 2 mm. Reflection loss (RL) were calculated with the electromagnetic parameters data through the NRW formula and transmission line theory [14] using the equation:

$$L(dB) = -20 \log \left( \frac{(z - 1)}{(z + 1)} \right).$$

where $z = \sqrt{\mu/\varepsilon} \tanh \left( (-j2\pi f d/c)\sqrt{\mu/\varepsilon} \right)$, $\mu = \mu' - j\mu''$ and $\varepsilon = \varepsilon' - j\varepsilon''$, $f$ is frequency and $d$ is the thickness of the samples.

**Results and Discussion**

**Phase identification.** Figure 1 shows the XRD pattern of barium hexaferrite sintered at 1100 °C for 5 hours and silica. XRD pattern of silica indicates that all of intensities are the diffraction peaks of silica phase as SiO$_2$ structure. XRD pattern of barium hexaferrite shows that the precursor is composed of only stoichiometric mixtures of $\text{BaCO}_3$ and $\text{Fe}_2\text{O}_3$. After sintering at 1100 °C for 5 hours, hexagonal barium ferrite phase has successfully formed polycrystalline structure.
Figure 1. X-ray diffraction patterns of barium hexaferrites $\text{BaFe}_{12}\text{O}_{19}$ and silica

**SEM Microstructures.** The SEM microstructure of barium hexaferrite and silica are shown in Fig. 2. After milling, the powders of samples are relatively same in size. The average size of both samples is less than 5 $\mu$m. This powder size of barium hexaferrite and silica is enough to be mixed with epoxy resin for preparation a microwave absorbing material.

Figure 2. Secondary electron images of barium hexaferrites $\text{BaFe}_{12}\text{O}_{19}$ and silica

**Magnetic Properties.** Hysteresis loops of barium hexaferrite sintered at 1100 oC for 5 h are shown in Fig. 3. It is seen that the values of the residual magnetization ($M_r$), the coercive field ($H_c$), and the saturation magnetization ($M_s$) are 0.181 T, 278.7 kA/m, 0.312 T, respectively. It indicates that there is a good correlation between the magnetic property and structural (XRD pattern) one. It also proves the sample as permanent magnet barium hexaferrite.
Electromagnetic Properties. The real and imaginary parts of relative complex permeability and permittivity of our samples are calculated at given thickness according to NRW formula and transmit line theory. The results are shown in Figs. 4 and 5. The permeability and permittivity values vary within the range of 8.2–12.4 GHz.

In barium hexaferrite sample, resonance peaks of permeability decrease at frequencies of 8.2 – 10.5 GHz for real part, while for imaginary part at frequencies of 8.2 – 10 GHz. Further both real and imaginary parts start increasing at 11.5 – 12.4 GHz (Fig. 4). The permittivity values show the similar behavior. Difference behavior in permeability and permittivity are shown by silica as nonmagnetic material, where both permeability and permittivity values decrease continuously within frequencies range 8.2 – 12.4 GHz (Fig. 5).
Figure 5. Relative complex permeability and permittivity of silica

**Mono Layer Microwave Absorber.** The RL values of mono layer microwave absorber of the barium hexaferrites and silica in the range of 8.2 and 12.4 GHz are shown in Fig. 6. The RL values of both samples are less than -13 dB. The lowest RL value of barium hexaferrite is -16 dB at 10 GHz and 11.5 GHz. Surprisingly perfect absorption (RL value less than -20 dB) is shown by silica at frequencies range of 10.5 GHz and 12.4 GHz. Furthermore, these results suggest that at radar frequencies (10 GHz) RL values of both samples are very good (less than -15 dB).

Figure 6. Absorption characteristics of the barium hexaferrites BaFe_{12}O_{19} and silica

**Double Layer Microwave Absorber.** The RL values of double layer microwave absorber of barium hexaferrite for different thicknesses and silica are shown in Fig. 7. At the thickness of 2 mm, double layer barium hexaferrite has RL value of -15 dB in the range 9 GHz to 12.4 GHz. This value is similar with mono layer barium hexaferrite (Fig.6). At 8.2 – 12.4 GHz, as the thickness of barium hexaferrite was increased, the RL values did not changed significantly. This means there in no effect of sample thickness on absorption of frequency. Furthermore, it suggests that silica as a substrate did not influence the resulted RL values of double layer microwave absorber.
Conclusion

Barium hexaferrite BaFe$_{12}$O$_{19}$ were prepared using BaCO$_3$ and Fe$_2$O$_3$ as precursors by ceramic method. Silica powder is resulted from silica sand with purification using HCl. Relative complex permeability and permittivity of samples vary within the range of 8.2–12.4 GHz. The RL values of mono layer microwave absorber of the barium hexaferrites and silica are less than -13 dB in the range of 8.2 and 12.4 GHz. For double layer microwave absorber of barium hexaferrite for different thicknesses and silica, the RL values did not changed significantly. These values are similar with mono layer of barium hexaferrite. No effect of sample thickness on absorption of frequency. And silica as a substrate did not influence the resulted RL values.

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