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Microwave absorption properties of single and double-layer absorbers based on BaFe₁₂O₁₉ and SiO₂

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Abstract. In order to study a new microwave absorption properties of single and double layer barium hexaferrite and silica have been investigated in X-band (8.2–12.4 GHz) frequencies. Barium hexaferrite BaFe₁₂O₁₉ was synthesized by ceramic method and Silica SiO₂ was prepared from beach sand. Barium hexaferrite and silica SiO₂ with a total thickness of 3 mm, 4 mm, 5 mm, 6 mm and 7 mm, were characterized at room temperature using vector network analyser (VNA) Keysight PNA-L N5232A. Reflection loss (RL) of single and double-layer absorbers of barium hexaferrite and silica were calculated and simulated using the transmit line theory. The minimum RL value (less than – 10 dB) of single layer barium hexaferrite is –21 dB at 9 GHz. The minimum RL values (less than – 10 dB) of single layer silica SiO₂ is –40 dB at 9.2 GHz with 4 mm of thickness. The results show that double layer absorbing material showed different RL values than single layer of barium hexaferrite BaFe₁₂O₁₉ and silica SiO₂.

1. Introduction

Nowadays, the operation of electronic devices, local internet, radar systems, and mobile communication devices affect electromagnetic (EM) noise problems [1–4] and EM interference pollution. The developing of EM wave absorbers are a very important subject to attenuate them. Barium hexaferrite BaFe₁₂O₁₉ (BHF) with superior magnetic properties has attracted considerable attention as EM wave absorbers [5–9]. the other candidate absorber, silica (SiO₂) is a good insulator [10,11]. A mixture of SiO₂ powder with a magnetic material can decrease the dielectric constant, high-permeability and results effective impedance match [12–14]. In this paper, we have investigated a new microwave absorbing properties of single and double layer barium hexaferrite BaFe₁₂O₁₉ and silica SiO₂. The complex permeability ($\mu = \mu' - j\mu''$) and permittivity ($\epsilon = \epsilon' - j\epsilon''$) that are two important values to determine the reflection loss (RL) values [15–17], can be resulted by vector network analyser (VNA) Keysight PNA-L N5232A. For the single layer of barium hexaferrite BaFe₁₂O₁₉ and silica SiO₂, RL values have been calculated with different thicknesses and for double layer absorbers composed of the layer 1 (Silica) as the absorption layer and layer 2 (BHF) as the matching layer were studied in detail.



2. Experimental methods

Barium hexaferrite, $\text{BaFe}_{12}\text{O}_{19}$ (BHF) was prepared from stoichiometric mixtures of BaCO_3 and Fe_2O_3 with high purity starting materials ($\geq 99\%$ Aldrich) by solid state reaction method and sintering at 1100°C for 3 hours. The powder of BHF was produced by high planetary ball mill for 1 hour. Silica SiO_2 was prepared from beach sand. Vector network analyser (VNA) *Keysight* PNA-L N5232A was used to analyse microwave absorbing properties in range of 8.2–12.4 GHz (X-band). For a double-layer absorber composed of the layer 1 (Silica) as the absorption layer and layer 2 (BHF) as the matching layer shown in Fig. 1. Reflection loss (RL) of double-layer can be calculated and simulated using the transmit line theory by the following Eq. 1, 2 and 3 [18–20].

$$\text{RL (dB)} = 20 \text{ Log} \left[\frac{(Z_2 - 1)}{(Z_2 + 1)} \right] \quad (1)$$

$$Z_1 = \sqrt{\frac{\mu_1}{\varepsilon_1}} \tanh \left[j \left(\frac{2\pi f d_1}{c} \right) \sqrt{\mu_1 \varepsilon_1} \right] \quad (2)$$

$$Z_2 = \frac{\sqrt{\frac{\mu_2}{\varepsilon_2}} \left(Z_1 + \sqrt{\frac{\mu_2}{\varepsilon_2}} \tanh \left[j \left(\frac{2\pi f d_2}{c} \right) \sqrt{\mu_2 \varepsilon_2} \right] \right)}{\sqrt{\frac{\mu_2}{\varepsilon_2}} + Z_1 \tanh \left[j \left(\frac{2\pi f d_2}{c} \right) \sqrt{\mu_2 \varepsilon_2} \right]} \quad (3)$$

layer 1 is the absorption layer (Silica) and layer 2 is the matching layer (BHF). μ_1 and μ_2 are complex permeability ($\mu = \mu' - j\mu''$) and ε_1 and ε_2 are complex permittivity ($\varepsilon = \varepsilon' - j\varepsilon''$), f is frequency. d_1 and d_2 are the thickness of silica and BHF, respectively. c is the velocity of light.

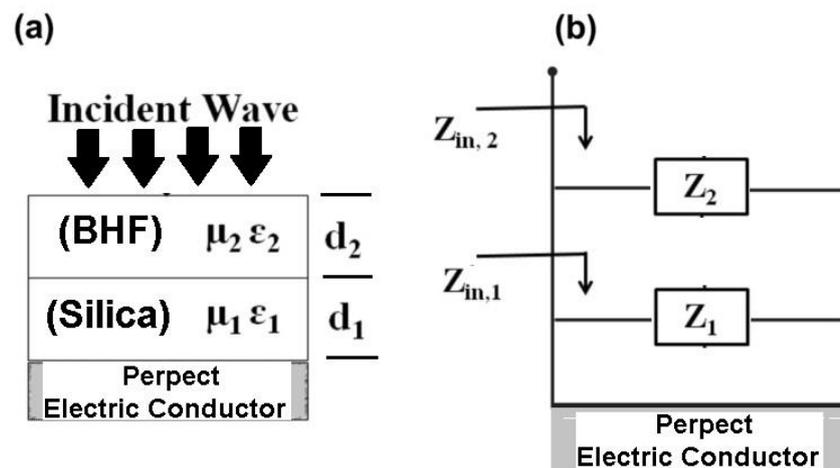


Figure 1. (a) Schematic and (b) electrical equivalent circuit of double-layer structure of the absorption layer (Silica) and the matching layer (BHF).

3. Results and discussion

Generally, absorbing materials are determined by the complex permeability ($\mu = \mu' - j\mu''$) and permittivity ($\varepsilon = \varepsilon' - j\varepsilon''$). Fig. 2a and 2b show the values of the complex permeability and permittivity of barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$ and silica SiO_2 which are measured in the frequency range of 8.2 – 12.4 GHz. The real (ε') and imaginary (ε'') parts of the complex permittivity of silica SiO_2 are larger than

barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$. The ϵ' values of barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$ and silica SiO_2 tend to be constant and there is polarization that occurs when given EM wave in the frequency range of 8.2 – 12.4 GHz. It's indicate that BHF and silica have ability to store the microwave energy. The imaginary (ϵ'') part of the complex permittivity of silica SiO_2 are larger than barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$ in frequency of 8.2 – 12.4 GHz that indicate the strong electric loss. The real (μ') and imaginary (μ'') parts of complex permeability of barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$ and silica SiO_2 are shown in the figure 2a and 2b. As can be seen from the figure, the μ' and μ'' values relatively constant in the range frequency of 8.2–12.4 GHz. These results indicate the strong magnetic and electric loss are same between barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$ and silica SiO_2 .

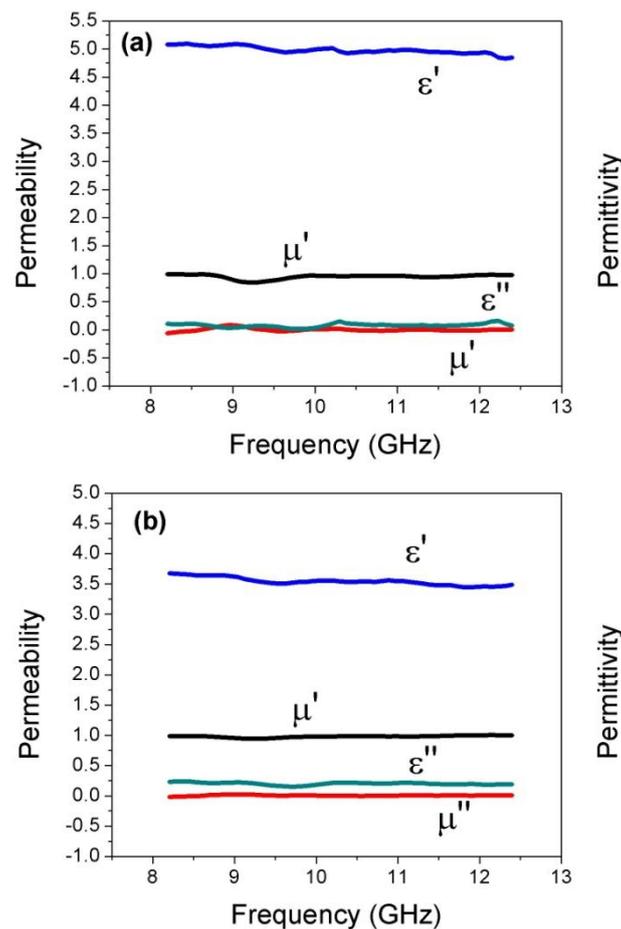


Figure 2. (a) The relative complex permeability and permittivity of (a) barium hexaferrite (BHF) and (b) silica.

In order to investigate the microwave absorption ability of single layer barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$ and silica SiO_2 , the complex permeability and permittivity are used to calculate and simulate the reflection loss (RL) with different thicknesses by using $Z_{in} = \sqrt{\frac{\mu}{\epsilon}} \tanh \left[j \left(\frac{2\pi f d}{c} \right) \sqrt{\mu \cdot \epsilon} \right]$ and $\text{RL (dB)} = 20 \text{ Log} \left[\frac{(Z_{in}-1)}{(Z_{in}+1)} \right]$ and results are shown in Fig. 3. Fig. 3a shows the RL curves of single layer hexagonal ferrite $\text{BaFe}_{12}\text{O}_{19}$ with a thickness of 1.90 mm, 1.95 mm, 2.00 mm, and 2.05 mm. The minimum RL value (less than -10 dB) of BHF is -21 dB at 9 GHz. The RL curves of single layer silica SiO_2 with a

thickness of 1 mm, 2 mm, 3 mm, 4 mm and 5 mm. The minimum RL values (less than -10 dB) of silica SiO_2 is -40 dB at 9.2 GHz with 4 mm of thickness (see Fig. 3b).

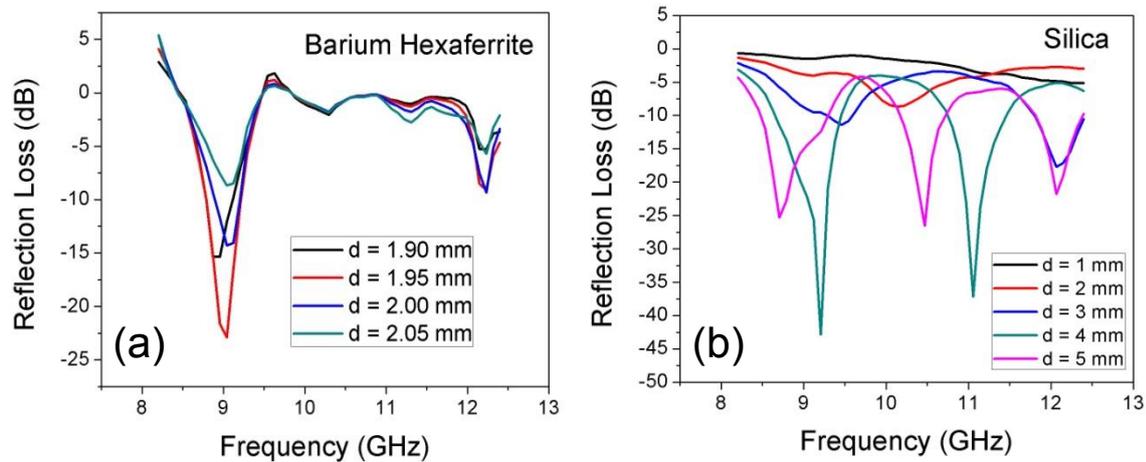


Figure 3. Reflection loss values of single layer (a) barium hexaferrite (BHF) and (b) silica with different thicknesses.

According to circuit and schematic (Fig.1) of double layer absorber composed of the absorption layer (Silica) and the matching layer (BHF), the reflection loss (RL) of double layer absorbers were calculated and simulated by using Eq. (1), Eq. (2), and Eq. (3). Fig. 6 shows the RL values of double layer structures with different thicknesses in the frequency range of 8.2–12.4 GHz. The results show that double layer absorbing material showed different RL values than single layer of barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$ and silica SiO_2 .

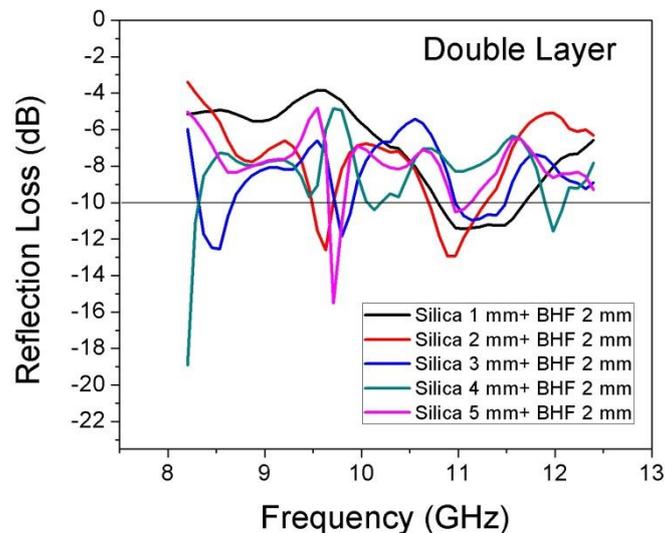


Figure 4. Reflection loss values of double layer based on barium hexaferrite (BHF) and silica with different thicknesses.

4. Conclusions

In summary, Barium hexaferrite, $\text{BaFe}_{12}\text{O}_{19}$ (BHF) have been successfully prepared by solid state reaction method. Silica SiO_2 have been prepared from beach sand. The double layer structures of

composed of the absorption layer (Silica) and the matching layer (BHF) with different thicknesses have been prepared to calculate the reflection loss (RL) values. The results showed that, double layer absorbing material showed different RL values than single layer of barium hexaferrite $\text{BaFe}_{12}\text{O}_{19}$ and silica SiO_2 .

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