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Microwave absorbing characteristics in multilayer absorbers based on barium ferrite and teflon

E Handoko1,*, A B Susila1, I Sugihartono1, M A Marpaung1, Z Jalil2 and M Alaydrus3

1 Dept. of Physics, Universitas Negeri Jakarta, Jalan Rawamangun Muka 13220, Jakarta, Indonesia
2 Dept. of Physics, Syiah Kuala University, Banda Aceh, Indonesia
3 Dept. of Electrical Engineering, Universitas Mercu Buana, Jalan Meruya Selatan No. 1, Jakarta, Indonesia

*erfan@unj.ac.id

Abstract. In order to investigate a new microwave absorbing characteristics of multilayer absorbers. Barium ferrite BaFe12O19 was synthesized by a standard ceramic method. Teflon was obtained from the china product and is available in the market. Multilayer absorbers based on 2 mm of barium ferrite layer thickness and 0.5 mm of teflon layer thickness with 2, 4, 6 and 10 layers were characterized by using vector network analyzer (VNA) Rohde-Schwarz ZVA 67 for 7.5 – 11.5 GHz frequencies. Reflection loss (RL) of multilayer absorbers were calculated and simulated using the transmit line theory. The microwave absorption abilities were enhanced for multilayer structure due to the combination of barium ferrite and teflon layers. The optimal absorption ability was achieved with −20 dB (i.e. 99.9% absorption) of reflection loss.

1. Introduction

Nowadays, the rapid development of electronic devices and microwave technology attracted much attention and become a serious problem [1,2]. To overcome these problems such as interference pollution and electromagnetic (EM) noise, the need of design and development of EM wave absorbers are a very important materials [3–7]. For high capabilities EM wave absorbers, the EM impedance matching and the attenuated EM waves inside the absorber are the important requirements [8–10]. The design such as single-layer, double-layer and multilayer structures could enhance the capabilities of EM wave absorbing materials [11–13]. The certain magnetic materials based oxides such as barium ferrite BaFe12O19 could be considered as promising material candidates for high performance EM wave absorbing materials. Because of its magnetic properties, strong magnetization, magnetic loss and strong dielectric, barium ferrite has ability to reduce the incident EM waves as much as possible [12,14,15]. Some results of magnetic materials have been reported such as BaFe12−2xCo2xZnxO19 (x=0.0; 0.2; 0.4; 0.6) nanocrystalline [16], Ba4Co2−xMnxFe36O60 [17], SrCoZnFe16O27 [18], Ba(CoZn)2Fe16O27 [19], etc.

In this paper, we have used magnetic materials of barium ferrite BaFe12O19 that was prepared by a standard ceramic method and teflon for absorbing material. Microwave absorption characteristics of the single-layer of both barium ferrite and teflon have been investigated at the different thickness. Design of multilayer microwave absorbers based on barium ferrite and teflon have been resulted and discussed in depth.
2. Experimental methods

Magnetic material of barium ferrite BaFe\textsubscript{12}O\textsubscript{19} was synthesized from mixtures powder of Fe\textsubscript{2}O\textsubscript{3} and BaCO\textsubscript{3}, by a standard ceramic method with the ratio of Ba:Fe equal to 1:12. Pellets form of the mixtures powder were sintered at 1100 °C for 3 hours for forming barium ferrite phase. Magnetic powder was resulted by using SPEX M8000 high energy ball mill for 1 hour for measurements. Teflon material was obtained from the market. The powders of barium ferrite BaFe\textsubscript{12}O\textsubscript{19} were characterized using Phillips X-ray diffractometer (XRD) using Cu-K\textsubscript{α} radiation (wavelength \( \lambda = 1.56 \) Å) in the range of 2\( \theta \) = 25 – 45° for evaluating the phase. Magnetic properties have resulted from magnetic hysteresis loop that was recorded by Permagraph with magnetic field of 1 Tesla. Both barium ferrite powders and epoxy resin as binder and teflon material were prepared and placed on to a sample holder by using vector network analyzer (VNA) Rohde-Schwarz ZVA 67 to measure the reflected signal (\( S_{11} \)) and transmitted signal (\( S_{21} \)) for 7.5 – 11.5 GHz frequencies. Circuit and schematic of multilayer absorber composed of barium ferrite (Ba-Ferrite) (\( \mu , \varepsilon , d \)) and teflon (\( \mu , \varepsilon , d \)) were shown in Figure 1. Reflection loss (RL) were calculated and simulated using the transmit line theory by the following equations [16,20–22] :

\[
\text{Reflection Loss, RL (dB)} = 20 \log \left( \frac{Z_{n} - 1}{Z_{n} + 1} \right)
\]

\[
Z_{n-1} = \sqrt{\mu_{n-1} \varepsilon_{n-1}} \tanh \left( j \frac{2\pi fd}{c} \sqrt{\mu_{n-1} \varepsilon_{n-1}} \right)
\]

\[
Z_{n} = \sqrt{\frac{\mu_{n} \varepsilon_{n}}{\mu_{n} \varepsilon_{n}}} \left( Z_{n-1} + \sqrt{\frac{\mu_{n} \varepsilon_{n}}{\mu_{n} \varepsilon_{n}}} \tanh \left( j \frac{2\pi fd}{c} \sqrt{\mu_{n} \varepsilon_{n}} \right) \right)
\]

where:

\( \mu_{n} \) is complex permeability (\( \mu = \mu' - j\mu'' \)) and \( \varepsilon_{n} \) is complex permittivity (\( \varepsilon = \varepsilon' - j\varepsilon'' \)), \( n \) is sum of the layer. \( f \) is frequency and \( d_{1} \) and \( d_{2} \) are the thickness of the n-layer of Ba-Ferrite and teflon, respectively. \( c \) is the velocity of light.

![Figure 1](image-url)  
**Figure 1.** (a) Electrical equivalent circuit and (b) multilayer schematic of barium ferrite (Ba-Ferrite) (\( \mu_{1} , \varepsilon_{1} , d_{1} \)) and teflon (\( \mu_{2} , \varepsilon_{2} , d_{2} \)).
3. Results and discussion

Figure 2. (a) XRD pattern and (b) room temperature hysteresis loops of barium ferrite (Ba-Ferrite).

The result of XRD patterns of barium ferrite (Ba-Ferrite) shows that the main diffraction peaks which are indexed to the hexagonal structure of barium ferrite (international crystal diffraction data (ICDD) number #98-015-7056), and correspond to (110), (0 0 8), (1 1 4), (0 2 3), (0 2 5) and (026) crystal planes (see Figure 2a). Figure 2b shows the hysteresis loop for barium ferrite (Ba-Ferrite) that was sintered at 1100°C for 3 hours. It is seen that the values of the remanence magnetization ($M_r$), the coercive force ($H_c$), and the saturation magnetization ($M_s$) are 0.15 T, 236.87 kA/m, 0.23 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 ferrite.

Figure 3 shows the complex permeability ($\mu = \mu' - j\mu''$) and complex permittivity ($\varepsilon = \varepsilon' - j\varepsilon''$) values for barium ferrite (Ba-Ferrite) and teflon having both real and imaginary parts in the range from 7.5 GHz to 11.5 GHz that have been calculated from scattering parameters of microwave reflection ($S_{11}$) and transmission ($S_{21}$) signal by using the Nicholson–Ross–Weir method [22]. The real part of permeability ($\mu'$) and the permittivity ($\varepsilon'$) are associated with magnetic field and electric field in the hexagonal ferrites respectively. The imaginary parts of them ($\mu''$ and $\varepsilon''$) are related with the dissipation of energy [10,23]. For analysis of these data can result that the real and imaginary part of permittivity of barium ferrite (Ba-Ferrite) increased and decreased as the frequency increases up to 11.5 GHz. While for the real and imaginary part of permeability for teflon remains almost constant in the range of measurements between 7.5 GHz and 11.5 GHz. It is expected that the absorption due to the dielectric characteristic of barium ferrite (Ba-Ferrite) is more dominant due to the magnetic loss.

Figure 3. The relative complex permeability and permittivity of (a) barium ferrite (Ba-Ferrite) and (b) teflon.
In order to analyze the microwave absorbing characteristics of barium ferrite (Ba-Ferrite) and teflon, the complex permeability \((\mu = \mu' - j\mu'')\) and complex permittivity \((\varepsilon = \varepsilon' - j\varepsilon'')\) are used to calculate the reflection loss (RL) by Eq. (1) (see Figure 4). For single layer barium ferrite (Ba-Ferrite) and teflon, the RL curves result different microwave absorbing characteristics with different thicknesses.

According to circuit and schematic (Figure 1) of multilayer absorber composed of barium ferrite (Ba-Ferrite) \((\mu_1, \varepsilon_1, d_1)\) and teflon \((\mu_2, \varepsilon_2, d_2)\), the reflection loss (RL) of multilayer magnetic materials were calculated and simulated by using Eq. (1), Eq. (2), and Eq. (3).

Figure 5 shows microwave absorbing characteristics of multilayer structures of barium ferrite (Ba-Ferrite) and teflon with different thicknesses of layer were investigated in the frequency range of 7.5–11.5 GHz. The results show that multilayer absorbing material showed better microwave absorption ability than single layer of barium ferrite (Ba-Ferrite) and teflon. Multilayer absorbing material which consisted of 2, 4, 6 and 10 layers with different thicknesses of layer demonstrated higher RL values of less than \(-20\) dB (i.e. 99.9% absorption).

**Figure 4.** Reflection loss values of single layer of (a) barium ferrite (Ba-Ferrite) and (b) teflon with different thicknesses.

**Figure 5.** Reflection loss values of multilayer microwave absorbers based on barium ferrite (Ba-Ferrite) and teflon with different thicknesses of layer.
4. Conclusions
In summary, barium ferrite (Ba-Ferrite) materials were used as magnetic layers for preparing microwave absorber. The multilayer structures of barium ferrite (Ba-Ferrite) and teflon with different thicknesses of layer have been prepared which consisted of 10 layers. The results showed that, the microwave absorption abilities were enhanced for multilayer structure due to the combination of barium ferrite (Ba-Ferrite) and teflon layers. In addition to improved RL values, the absorption bandwidth was also extended when multilayer structure was employed. The optimal absorption ability was achieved with less than −20 dB (i.e. 99.9 % absorption).

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