Effect of different permeability on electromagnetic properties of absorbing materials

Riser Fahdiran*, *Yuliyanti Dwi* Utami, and *Erfan* Handoko*

Universitas Negeri Jakarta, Dept of Physics, Jalan Rawamangun Muka 13220, Jakarta, Indonesia

Abstract. In this study, we have simulated and investigated electromagnetic properties of six types materials using a single layer metal backed absorber model that were determined at microwave frequencies 8.2 up to12.4 GHz. The reflection loss was simulated for different thicknesses in the range of 0.85 to 1.05 mm based on the relative complex permeability and permittivity referring to transmission line theory. The optimal microwave absorbing properties was be resulted by A3 sample. The minimum RL of −23.84 dB can be obtained at 10.72 GHz with thin thickness of 0.95 mm. This method paves a new avenue to design magnetic and dielectric absorbing materials.

1 Introduction

Recently, electromagnetic (EM) interference pollution [1–4] and EM noise have attracted much attention which can be harmful to the human beings [5,6] and affect the operation problems of electronic devices, local internet, radar systems, and mobile communication devices [7,8]. The requirements to alleviate them have been highly urgent to develop EM wave absorbers a very important subject. According to the transmission line theory [9–12], the complex permeability ($\mu = \mu' - j\mu''$) and permittivity ($\varepsilon = \varepsilon' - j\varepsilon''$) are two important values to determine the microwave absorption performance of the EM wave absorbers. Generally, μ' and ε' represent magnetic and electric energy dissipation. While μ'' and ε'' at a certain frequency refers to a high magnetic and electric loss of absorber. Several approaches of EM wave absorbers design have been investigated such as material selection and design. Yuping Sun et.al reported that μ' decreases from 2.97 to 1.79 with the increase in frequency from 0.03 to 18 GHz and resulted an optimal reflection loss (RL) of -43.3 dB at 9.91 GHz for 2.0 mm thickness layer[1]. Xianguo Liu et. al have been found that the values of ε' and ε'' are in the range of 7.58–5.96 and 3.24–1.80 respectively and obtained the optimal RL reaches -17.02 dB at 11.12 GHz for 3.0 mm thickness layer [4]. Erfan Handoko et.al reported that the real (μ') and imaginary (μ'') parts of complex relative permeability of barium hexaferrites resulted the minimum reflection loss value of -29.98 dB at 10.8 GHz for 1.0 mm thickness layer [13]. However, the complex permeability and permittivity are two important factors to find the microwave absorption capabilities of absorber material. In this paper. we prepared six simulated samples (A1, A2, A3, A4, A5, and A6) with the different complex permeability and the same complex permittivity. Then, the reflection loss (RL) of A1, A2, A3, A4, A5, and A6 samples are calculated with the different thicknesses and also investigated their performance as EM wave absorber with high absorption ability.

2 Experimental Methods

Six simulated samples (A1, A2, A3, A4, A5, and A6) with the different complex permeability and the same complex permittivity were prepared by using Bytescout Graph Digitizer Software in the frequency range between 8.2 and 12.4 GHz. The simulated samples consisting of the increasing real (μ') parts of complex permeability of A1, A2, and A3 samples and the decreasing real (μ') parts of A4, A5, and A6 samples have been plotted with different gradient (μ'/f) with increase of frequency. All of imaginary (μ'') parts of complex permeability of simulated samples had the same values. The same complex permittivity of A1, A2, A3, A4, A5, and A6 samples were determined with increase of frequency. To investigate EM wave absorption properties in the frequency range between 8.2 and 12.4 GHz, according to transmission line theory, the reflection loss (RL) was simulated for different thicknesses of the simulated samples using a single layer metal backed absorber model were calculated through following equations [14,15] :

$$\mathrm{RL\ (dB)} = 20\log\left[\frac{(Z-1)}{(Z+1)}\right] \tag{1}$$

$$Z = \sqrt{\frac{\mu}{\varepsilon}}\tanh\left[\frac{-j2\pi f d}{c}\sqrt{\mu.\varepsilon}\right] \tag{2}$$

where Z is impedance, ε is complex permittivity and μ is complex permeability, f is frequency of the EM wave, c is the light velocity and d is the thickness of A1, A2, A3, A4, A5, and A6 samples.

* Corresponding author: erfan@unj.ac.id, riser-fahdiran@unj.ac.id

3 Results and discussion

Fig. 1 shows the complex permittivity and the complex permeability of A1, A2, A3, A4, A5, and A6 samples. It can be found that real (μ′) part values of A1, A2, A3, A4, A5, and A6 are in the range of 1.15–1.09, 1.15–2.63, 1.15–4.17, 4.17–4.10, 4.17–2.69 and 4.17–1.15, respectively, at the 8.2–12.4 GHz frequency range. While the imaginary (μ″) part values of complex permeability of simulated samples had the same values (Figure 2). These results indicate that all samples have the strong magnetic loss and high magnetic energy dissipation.

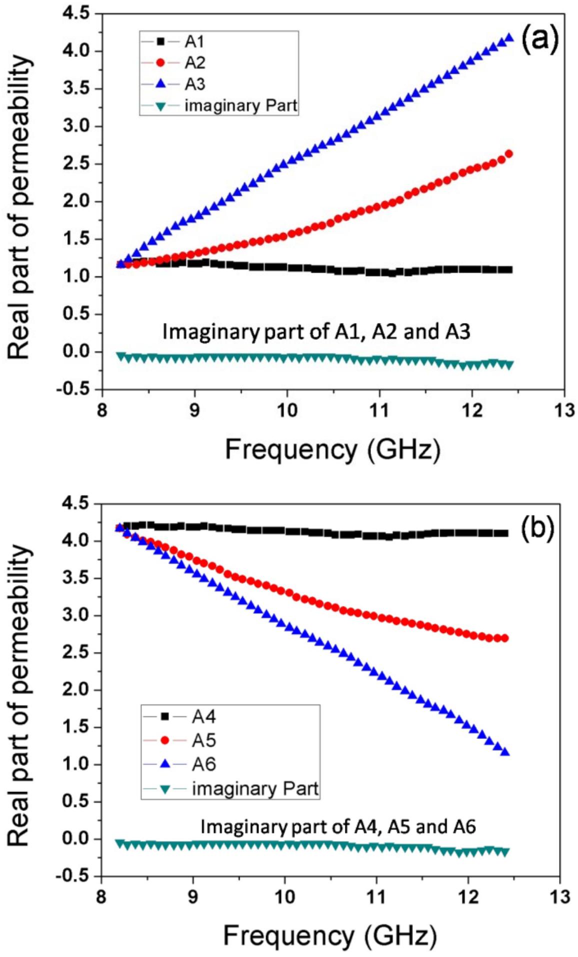

Fig. 1. (a) The real (μ') and imaginary (μ'') parts of relative complex permeability of (a) A1, A2, A3 and (b) A4, A5, A6 samples.

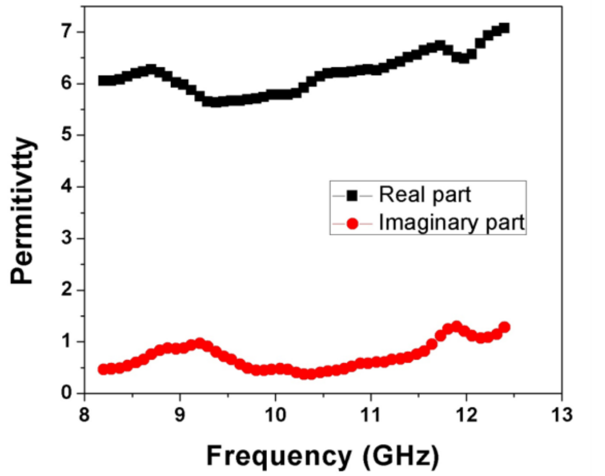

Fig. 2. The real (ε') and imaginary (ε'') parts of permittivity of A1, A2, A3, A4, A5, A6 samples.

The other parameter of EM wave absorption properties of absorber material is the attenuation constant (α) that is correlate with the EM wave absorptin efficiency and can determine the dissipation properties of the absorbing materials [16].

$$\alpha = \frac{\sqrt{2}\pi f}{c}\, x \sqrt{(\mu''\varepsilon'' - \mu'\varepsilon') + \sqrt{(\mu''\varepsilon'' - \mu'\varepsilon')^2 + (\mu''\varepsilon'' + \mu'\varepsilon')^2}} \quad (3)$$

where f is the frequency and c is the velocity of light.

The attenuation constant (α) of A1, A2, A3, A4, A5, and A6 samples in the range frequency of 8.2−12.4 GHz can be shown in the Fig. 3. It can be obtained that the α for A3 has the largest attenuation constant among of the six simulated samples.

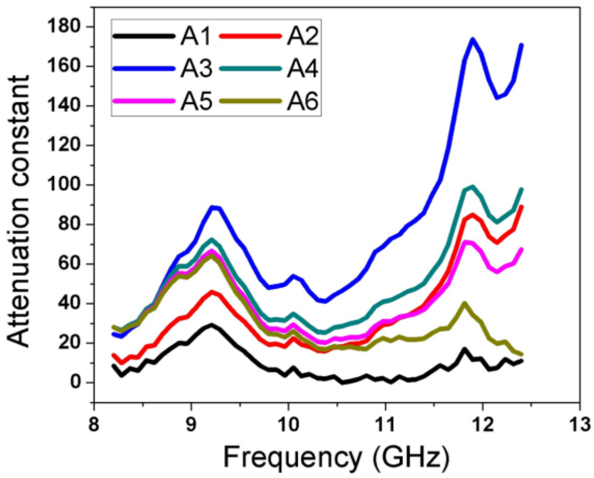

Fig. 3. Attenuation constant (α) versus frequency of A1, A2, A3, A4, A5, and A6 samples.

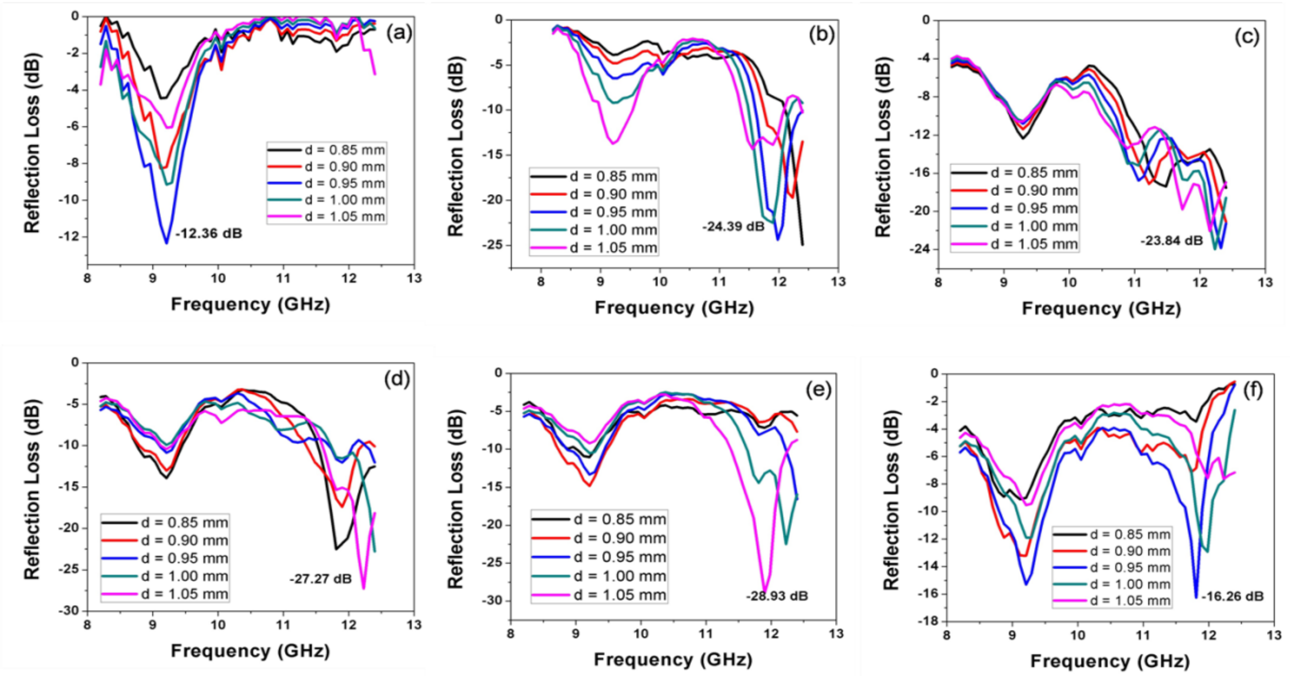

Fig. 4. Reflection loss values of (a) A1, (b) A2, (c) A3, (d) A4, (e) A5, (f) A6 samples different thicknesses.

The Fig. 4 shows RL values of A1, A2, A3, A4, A5, and A6 samples at different thickness 0.85 mm, 0.90 mm, 0.95 mm, 1.00 mm and 1.05 mm. The minimum RL values are caused by thickness of simulated samples. According to the attenuation constant (α) and calculation using the transmit line theory by the following equations 1 and 2 based on the relative complex permeability and permittivity that the optimal microwave absorbing properties was be resulted by A3 sample as shown in Figure 4c. The minimum RL of −23.84 dB can be obtained at 10.72 GHz with thin thickness of 0.95 mm, bandwidth with RL less than −10 dB (90 % microwave absorption) can reach 1.68 GHz (10.72−12.4 GHz). Sample thickness is an important parameter for the determination of minimum RL value and position. For the identification of the effect of thickness on microwave absorption properties, the three-dimensional image map of A3 sample with thicknesses of 0.85–1.05 mm are shown in Fig. 5.

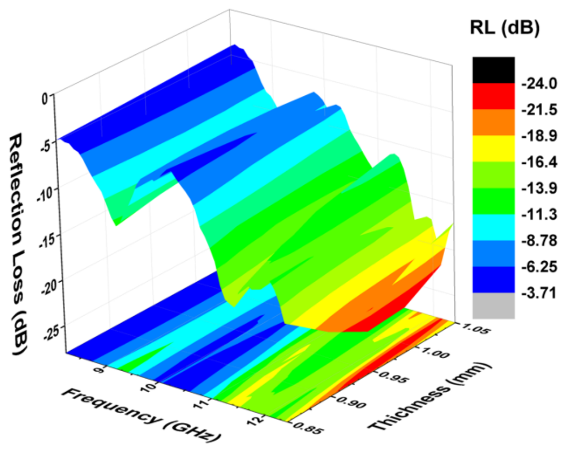

Fig. 5. Three-dimensional representation of RL values of A3 sample.

4 Conclusions

Six simulated samples of A1, A2, A3, A4, A5, and A6 with the different complex permeability and the same complex permittivity have been successfully prepared by using Bytescout Graph Digitizer Software in the frequency range between 8.2 and 12.4 GHz. The optimal microwave absorbing properties was be resulted by A3 sample with the largest attenuation constant (α) and the minimum RL of −23.84 dB can be obtained at 10.72 GHz with thin thickness of 0.95 mm, bandwidth with RL less than −10 dB (90 % microwave absorption) can reach 1.68 GHz (10.72−12.4 GHz).

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