Materials and Design 95 (2016) 486–489

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

A broadband far-field microwave absorber with a sandwich structure

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ARTICLE INFO

Article history:
Received 14 September 2015
Received in revised form 29 December 2015
Accepted 21 January 2016
Available online 22 January 2016

Keywords:
Microwave absorber
Multilayer absorber
Broadband

ABSTRACT

It is a tough task to get the broad working frequency for the far-field absorber with flat and continuous layer structure. In this work, a simple method is proposed to drastically broaden the absorption bandwidth based on a common magnetic absorber made by carbonyl iron (CI) composite. The broadband absorber has a sandwich structure of CI composite/thin amorphous alloy slice/CI composite. The measurements results show that two strong absorption peaks simultaneously appear at different frequencies and the summation of the two strong absorption peaks dramatically broadens the absorption bandwidth. The analysis of the results reveals that the thin amorphous alloy slice plays an important role to generate two absorption peaks. This study explores a facile route to extend the bandwidth of the absorber filled by magnetic particles.

1. Introduction

The requirement of absorber working in GHz band becomes more and more intense in prevention of electromagnetic radiation and military radar stealth with the wide applications of microwave techniques [1]. As microwave devices can work in a wide frequency range, broad absorption band is critical for an absorber with a fixed thickness, and this is especially important for far-field stealth coating [2]. To evaluating the absorption properties of the far-field absorber with normally incident electromagnetic wave, the dependence of complex permeability and complex permittivity on frequency for the absorber is first measured by vector network analyzer. Then the absorption performance for the single layer absorber terminated by a perfect conductor is evaluated by calculating the reflection loss (RL) properties according to the transmission line theory. The RL curves at a given absorber thickness is calculated from the complex permeability and permittivity by means of the following expressions [3,4]:

$$Z = \frac{Z_{in}}{Z_0} = \sqrt{\frac{\mu_r}{\varepsilon_r}} \tanh\left(j\frac{2\pi t}{\lambda}\sqrt{\mu_r \varepsilon_r}\right), \tag{1}$$

$$RL(dB) = 20\log\left|\frac{Z-1}{Z+1}\right|, \tag{2}$$

where Z (Z_{in}/Z_0) is the normalized input impedance related to the impedance in free space; ε_r and μ_r are the complex permittivity and permeability, respectively; λ is the wavelength in free space; and t the thickness of the absorber. Additionally, the absorption property of an absorber can also be directly obtained in coaxial line by detecting the reflection coefficients ($S_{11\text{-short}}$) of the absorber terminated by a metal plate [5,6].

As a far-field absorber, it has been certificated that the smaller thickness can be achieved for the composite filled by metallic soft magnetic particles due to their large permeability and permittivity [7]. It is well known that the entire entry into a composite layer for the electromagnetic wave from free space is $\varepsilon_r = \mu_r$. For the composite filled by metallic soft magnetic particles, ε_r is generally much larger than μ_r. Hence, the electromagnetic loss inside the absorber is finite because only a part of electromagnetic wave can enter the absorber from the air-absorber interface. However, the strong absorption peak with high absorption ratio can be achieved by quarter-wavelength cancelation [8–10]. The characterization of quarter-wavelength cancelation is that the absorption peak frequency does not appear at the maximum value of dielectric and magnetic loss factors but strongly depends on absorber thickness and the absorption peak moves to lower frequency with the increase of absorber thickness. Although quarter-wavelength cancelation is important to achieve strong absorption peak at a small absorber thickness, the narrow frequency band with high absorption performance is not easy to overcome for a single layer absorber due to the thickness sensitivity of this absorption mechanism. To overcome this difficulty, typical efforts including improving permeability, adding a matching layer on surface of the absorber layer or combining with dielectric material have been attempted to enhance the absorption band [11–16]. Despite the absorption band is somewhat improved, the absorber thickness is simultaneously increased and the single strong absorption peak in RL curve is not changed essentially. Recently, the metamaterial, the magnetic composite layer incorporating a frequency selective surface (FSS) and a patterned magnetic layer have been reported as effective methods

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http://dx.doi.org/10.1016/j.matdes.2016.01.096
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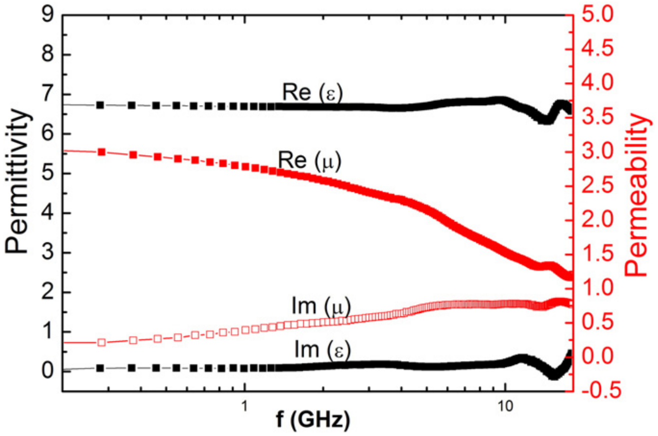

Fig. 1. Complex permittivity and complex permeability of the CI composite with frequency.

to enhance the absorption band [17–20]. However, the complex fabrication process and the relatively large total thickness might limit their application. Carbonyl iron (CI) particles, as a metallic magnetic material, are one of the most common absorbents and widely concerned due to their advantages of good temperature stability, broad absorption bandwidth, strong designability, etc. In this work, we propose a simple method to greatly broaden the absorption band of CI composite. The absorber has a sandwich structure composed of CI composite/thin amorphous alloy slice/CI composite. The inset of the thin amorphous alloy slice between two CI composite layers leads to a double of strong absorption peaks which dramatically broaden the absorption bandwidth. The origin mechanism of the two strong peaks is discussed in this paper.

2. Experiment and characterization

The carbonyl iron (CI) particles were purchased from TianYi superfine metallic powder Co. Ltd. (JiangSu, China). Their size is from 2 to 3 μm with spherical morphology. The CI particles were uniformly dispersed in paraffin with a weight percentage of 78%. The area density is 2.84 kg/m^2 if the composite thickness is 1.0 mm. To measure the electromagnetic parameters, the CI composite layers with various thicknesses were prepared by pressing the composite into a toroidal shape with outer and inner diameters of 7.00 mm and 3.04 mm. The FeCuNbSiB (FINEMET) amorphous strip with a thickness of 20 μm and resistivity of $130 \times 10^{-6}\ \Omega \cdot \mathrm{m}$ was used as middle layer in the sandwich structure. A toroidal FINEMET slice with outer and inner diameters of 7.00 mm and 3.04 mm was cut from the strip. This toroidal slice can be put into the middle of two CI composite layers during $S_{11\text{-short}}$ measurement. An Agilent E8363B vector network analyzer in the range from 0.1 to 18 GHz was used to measure the complex permeability and permittivity of the CI composite. The reflection coefficient of the sandwich absorber terminated by a metal plate ($S_{11\text{-short}}$) was directly detected to evaluate its absorption properties.

3. Results and discussion

Fig. 1 gives the frequency dependence of complex permittivity ε_r and complex permittivity μ_r, including their real part (Re) and imaginary part (Im), for the CI composite. The magnetic spectra exhibit a relaxation type and the permittivity keep almost unchanged in the entire measurement range. As a comparison between complex permittivity and complex permeability, the ε_r is much larger than the μ_r in the entire frequency range.

With the purpose of characterizing the electromagnetic wave absorption properties for the single layer CI composite, the RL curves at different absorber thickness are simulated using Eqs. (1) and (2) by using its complex permeability and permittivity. The results are shown in Fig. 2(a). From the RL curves we can get that the absorption peak frequency strongly depends on the absorber thickness and the absorption peak moves to lower frequency with the increase of thickness. This phenomenon is consistent with that of nearly all other reported far-field absorbers, and the quarter-wavelength cancelation has been successfully used to explain this phenomenon [6,8]. As the absorber thickness increases, the bandwidth with RL ≤ −10 dB is not found to increase. Even the thickness is 2.8 mm, the RL curve still exist one absorption peak with a small bandwidth. Fig. 3(a) shows the scheme of the sandwich-structure absorber. The fact picture of the CI composite and FINEMET slice with toroidal shape are shown in Fig. 3(b). When the absorption property is measured, the electromagnetic wave is normally incident to the absorber from layer 2 and layer 1 is terminated by a metal plate. The red curve in Fig. 2(b) is the measured absorption performance for the sandwich absorber with $t_1 = 0.5$ mm and $t_2 = 1.6$ mm. The total CI composite thickness is 2.1 mm in this sandwich structure. As the thickness of the FINEMET slice is only 20 μm, its thickness can be neglected compared with the CI composite layer. For this sandwich absorber, two strong absorption peaks locating at 7.8 GHz and 14.5 GHz appear in the RL curve. The effective absorption with RL ≤ −10 dB is achieved from 6.3 to 18.0 GHz and the bandwidth reaches 11.7 GHz.

As a comparison, the absorption performance for the single layer CI composite with t = 2.1 mm is shown in this figure as a black curve. There is only one strong absorption peak in the RL curve and the bandwidth with RL ≤ −10 dB is only 5.3 GHz. The results clearly demonstrate that the sandwich absorber by putting a thin amorphous alloy slice in

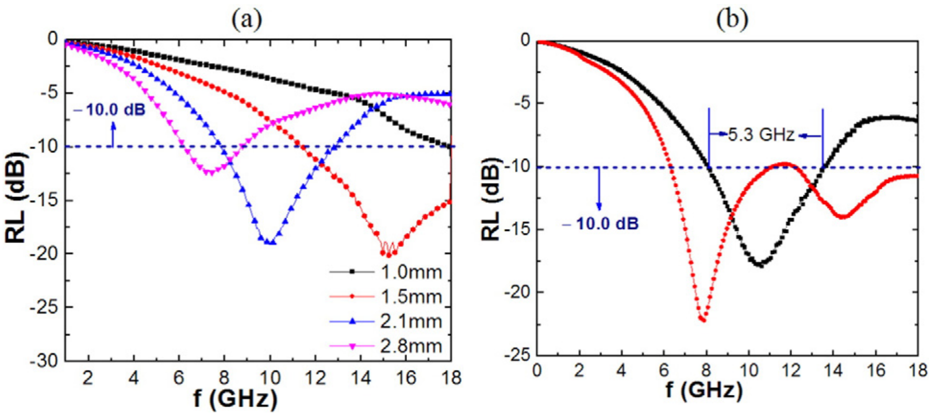

Fig. 2. (a) Dependence of RL on frequency at various absorber thicknesses for single layer CI composite. The black line in the inset shows dependence of λ/4 in CI composite on frequency. The red dots correspond to the absorber thickness at their peak frequencies. (b) The absorption performance comparison between the single layer CI composite and sandwich structure with the same thickness of 2.1 mm. In this sandwich absorber, the thicknesses of layer 1 and layer 2 are 0.5 mm and 1.6 mm, respectively.