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# Preparation and Electromagnetic Properties of an Electromagnetic Wave Absorber

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**In this study, we report the as-prepared MgO-doped $BaFe_{12}O_{19}$, which was prepared by calcination technique and high-energy ball milling process, as an electromagnetic wave absorber. The phase analysis of $BaFe_{12}O_{19}$ and the as-prepared MgO-doped $BaFe_{12}O_{19}$ was detected utilizing X-ray Diffractometer (XRD). The microstructure was characterized using Scanning Electron Microscope (SEM). By means of the transmission/reflection coaxial line method, the electromagnetic properties and microwave absorbing properties of the as-prepared electromagnetic wave absorber were studied. It is found that the electromagnetic wave absorber has a minimum reflection loss value of –41 dB at 4.27 GHz with a matching thickness of 2.6 mm. The experiment results revealed that the as-prepared electromagnetic wave absorber could find potential applications in many military as well as commercial industries.**

**Keywords :** MgO-doped $BaFe_{12}O_{19}$, microwave absorbing properties, microwave absorber

## 1. Introduction

With the development of communication devices which use the electromagnetic waves of GHz range, the problems of electromagnetic interference (EMI) have become increasingly serious [1, 2]. Adopting microwave absorbing materials to convert the electromagnetic waves energy into heat is one of the most effective methods for eliminating the above-mentioned problems. Moreover, radar absorbing materials (RAM) play a significant role in military stealth technologies [3, 4]. To satisfy the needs of military and commercial applications, therefore, the microwave absorbing materials have been extensively investigated [5-8]. Barium ferrite ($BaFe_{12}O_{19}$), which possesses excellent physical properties has long been used as an important microwave absorber [9-11]. In order to be accustomed to specific applications, a lot of work has been done to optimize electromagnetic parameters of barium ferrites, such as substitutions for $Fe^{3+}$ with other cations, shape, modified composition, and so on [12-16]. In particular, some oxides, which include $Ho_2O_3$ [17], $TiO_2$ [18], $SnO_2$ [19], $Ga_2O_3$ [20], $Sm_2O_3$ [21], $Co_3O_4$ [22], etc., were doped into $BaFe_{12}O_{19}$ to regulate and improve its physical properties. Serving as a conventional additive, magnesium oxide (MgO) has been successfully added to some ceramics such as BSTO [23], $Bi_{0.5}Na_{0.5}TiO_3$ [24], $ZrO_2$ [25], AlN [26], $Ba_3(Co_{0.4}Zn_{0.6})_2Fe_{23.6}O_{41}$ [27], $LiNbO_3$ [28], etc. MgO as sintering aids is believed to be able to improve densification and avoid the tendency of discontinuous grain growth during the sintering process. However, very few reports concerned regarding MgO-doped $BaFe_{12}O_{19}$ to the best of the authors knowledge. The purpose of this paper is, therefore, to prepare MgO-doped $BaFe_{12}O_{19}$ by calcination technique and high-energy ball milling process. The microwave absorption properties, phase composition, topography of the as-prepared MgO-doped $BaFe_{12}O_{19}$ have been investigated.

## 2. Materials and Methods

All regents used were of analytical purity and used without further purification in the present work. The $BaFe_{12}O_{19}$ powder was synthesized by sol-gel method with brief details as the following. The as-prepared $BaFe_{12}O_{19}$ powder was mixed with 1 wt% MgO and was well dispersed through high energy ball-milling in a QM-


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BP planetary ball mill for 5 h at a rotation speed of about 400 rpm. The ball-to-composite mass ratio was 6:1. The mixture of $BaFe_{12}O_{19}$ and MgO particle was subsequently cold pressed into pellets under 300 MPa pressure, and was subsequently calcined at 1030°C in an electric resistance furnace for 12 h to form a dense sintered body of MgO-doped $BaFe_{12}O_{19}$. Then, the fine MgO-doped $BaFe_{12}O_{19}$ powders with an average grain size of 200 nm were prepared after the as-prepared pellets were ball-milled in a QM-BP planetary ball mill. Finally, powdery electromagnetic wave absorber was obtained.

Phase composition of the as-prepared electromagnetic wave absorber was identified by means of an X-ray diffractometer (RIGAKUD/Max-A) using Cu Kα radiation ($\lambda = 1.5405$) at a 2θ range of 10-70°. The morphology of the as-prepared electromagnetic wave absorber was characterized via scanning electron microscope (SEM, JSM-6700F). In order to study the electromagnetic parameters and microwave absorbing properties, the as-prepared electromagnetic wave absorber was molded into toroidally-shaped samples (with an inner diameter of 3.04 mm, outer diameter of 7 mm, and thickness of about 3 mm), mixed with 30 mass% paraffin wax. The toroidally-shaped samples were inserted in a standard coaxial sample holder, and reflection coefficient ($S_{11}$ parameter) and transmission coefficient ($S_{21}$ parameter) were measured by an AV3618 network analyzer in the range from 0.5 to 6 GHz. The complex permittivity ($\varepsilon = \varepsilon' - j\varepsilon''$), complex permeability ($\mu = \mu' - j\mu''$) and reflection loss ($RL$) of the as-prepared electromagnetic wave absorber was calculated from $S_{11}$ and $S_{21}$ parameters by the transmission/reflection coaxial line method [29].

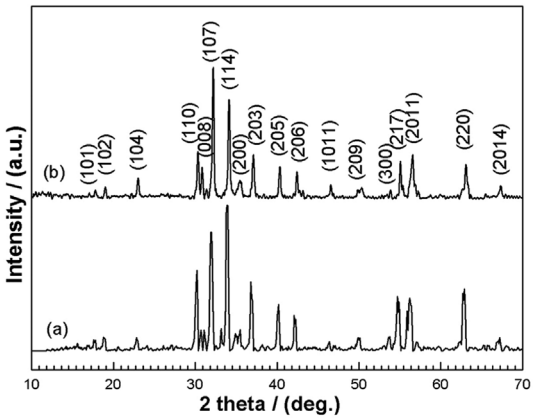


**Fig. 1.** X-ray diffraction patterns of $BaFe_{12}O_{19}$ (a) and as-prepared electromagnetic wave absorber (b).

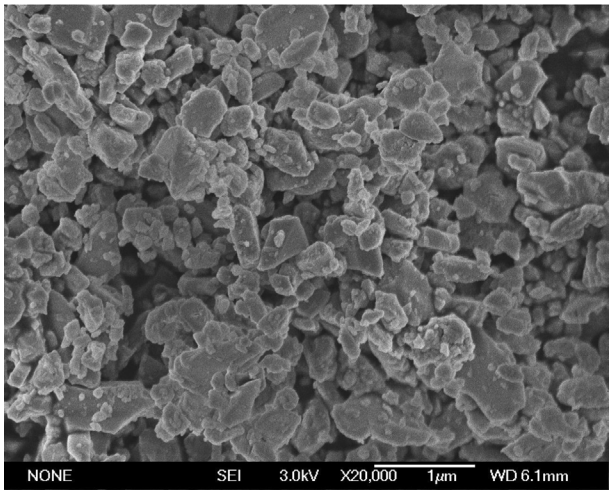


**Fig. 2.** The SEM micrograph of the as-prepared electromagnetic wave absorber.

## 3. Results and Discussion

The typical XRD patterns of (a) $BaFe_{12}O_{19}$ prepared with sol-gel process and (b) the as-prepared electromagnetic wave absorber are shown in Fig. 1. From Figure 1(a), it was found that $BaFe_{12}O_{19}$ prepared by sol-gel method comprised of pure phase. Figure 1(b) indicates that all peaks could be indexed to the standard patterns as reported by the Joint Committee on Composite Diffraction Standards (JCPDS) for hexagonal $BaFe_{12}O_{19}$ (PDF#43-0002). The characteristic peaks of MgO are not detected in the patterns. The results reveal that MgO dissolved in $BaFe_{12}O_{19}$ lattice. In addition, compared with pattern (a) in Figure 1, the peaks of the as-prepared electromagnetic wave absorber moved to higher diffraction angles. It is believed that the right shift rose from dissolving MgO into the lattice of $BaFe_{12}O_{19}$ phase [30]. Fig. 2 shows the SEM image of the as-prepared electromagnetic wave absorber. It displays flaky microstructure which is believed to be the best structure for microwave absorber. The particle size of the as-prepared electromagnetic wave absorber was about 200 nm.

Figure 3 shows the frequency dependence of the complex permeability ($\varepsilon'$ and $\varepsilon''$) the the range varied from 0.5 to 6 GHz for the as-prepared electromagnetic wave absorber. It shows that the real part of permittivity declined from 12.3 to 1.4 with the increases of the frequency. Except for a minimum value at 1.9 GHz, the $\varepsilon''$ values were almost constant within 0.5 to 6 GHz. Fig. 4 shows the frequency dependence of complex permeability ($\mu'$ and $\mu''$) of the as-prepared electromagnetic wave absorber. From the pattern (shown in Fig. 4), we can see that the imagine part of permeability rose with the increasing frequency and presents a peak at 5.0 GHz, then decreases. However, the real part of complex permeability has an

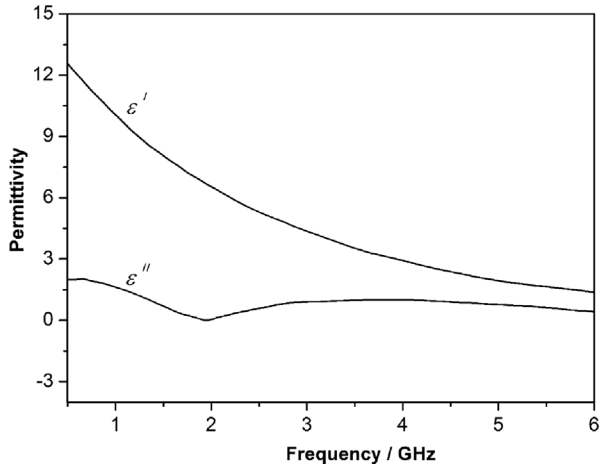


**Fig. 3.** The permittivity spectra of the as-prepared electromagnetic wave absorber.

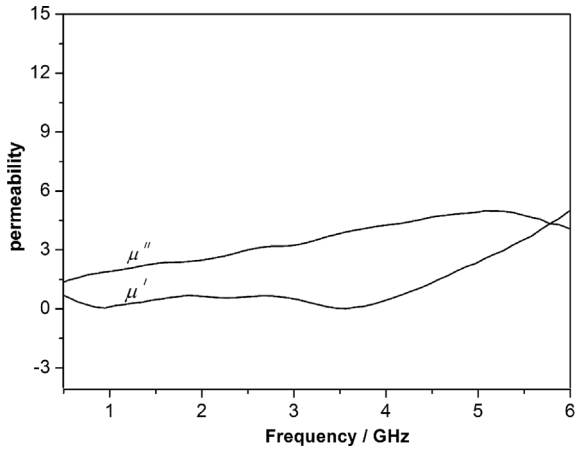


**Fig. 4.** The permeability spectra of the as-prepared electromagnetic wave absorber.

increasing trend at the range from 3.6 GHz to 6.0 GHz.

According to the transmission line theory, the normalized input impedance ($Z_{in}$) at the microwave absorber surface is given by formulas (1) for a microwave absorbing layer that is backed metal plate [31].

$$Z_{in} = Z_0\sqrt{\mu/\varepsilon}\tanh\left\{j(2\pi fd/c)\sqrt{\mu\varepsilon}\right\} \quad (1)$$

Where $\mu$ and $\varepsilon$ are the complex permeability ($\mu = \mu' - j\mu''$) and the complex permittivity ($\varepsilon = \varepsilon' - j\varepsilon''$), $f$ is the frequency, $Z_0$ is the impedance of air, $c$ is the velocity of electromagnetic waves in free space, and $d$ is the thickness of the absorber. The reflection loss ($RL$) can be expressed as formula (2)[16].

$$RL = 20\log\left|(Z_{in} - Z_o)/(Z_{in} + Z_o)\right| \quad (2)$$

From formula (1) and (2), the reflection loss for the as-prepared electromagnetic wave absorber can be calcu-

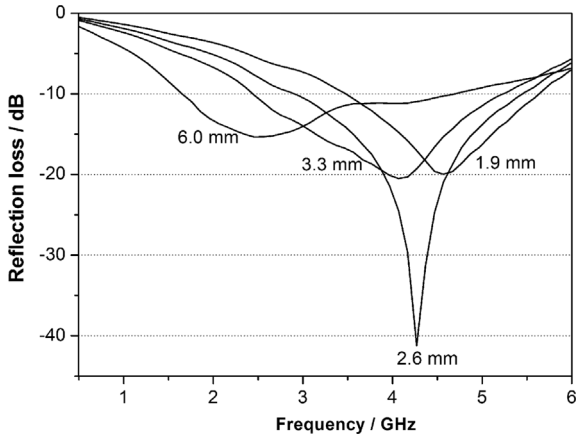


**Fig. 5.** The calculated reflection loss of the as-prepared electromagnetic wave absorber at different matching thickness.

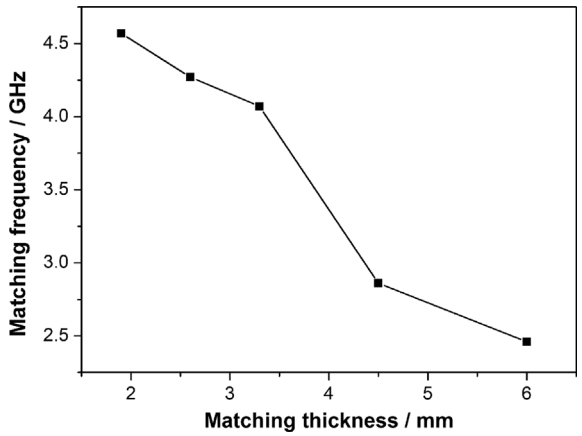


**Fig. 6.** Relation between matching frequency and matching thickness for the as-prepared electromagnetic wave absorber.

lated. Obviously, the reflection loss is negative value. Furthermore, the lower the reflection loss is, the stronger the electromagnetic wave absorbing ability is. Figure 5 shows the frequency dependence of the calculated reflection loss of the as-prepared electromagnetic wave absorber at the thickness of 1.9, 2.6, 3.3, and 6 mm, respectively. It is found that the minimum value of reflection loss has very close relationship with the material's thickness. The bandwidth with the reflection loss less than –10 dB reaches more than 3 GHz with a matching thickness of 6.0 mm. typically, the reflection loss was less than –20 dB at the range from 4.07 to 4.57 GHz, and the minimum reflection loss value reached –41 dB at 4.27 GHz with a matching thickness of 2.6 mm. It can be seen that MgO-doped $BaFe_{12}O_{19}$ shows more attractive microwave absorbing properties than the undoped $BaFe_{12}O_{19}$ in the range of 0.5 to 6 GHz [32]. Evidently MgO-doped $BaFe_{12}O_{19}$ have much more effective microwave absorbing effects. Figure 6 shows the relationship of the matching thickness

and matching frequencies for minimum reflection loss. It is very obvious that the matching frequency linearly reduces with the increase of the matching thickness.

## 4. Conclusions

The as-prepared electromagnetic wave absorber was successfully synthesized from $BaFe_{12}O_{19}$ and MgO powder by calcination process combined with high-energy ball-mill. The complex permittivity and permeability spectra and microwave absorbing properties of the as-prepared electromagnetic wave absorber were investigated in the frequency range 0.5-6 GHz. It is found that this composite has a minimum reflection loss value of –41 dB at 4.27 GHz with a matching thickness of 2.6 mm. The bandwidth with the reflection loss less than –10 dB reaches more than 3 GHz with a matching thickness of 6.0 mm. The results suggest that the as-prepared electromagnetic wave absorber can be used as a good microwave absorption candidate in the range of 0.5-6 GHz.

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