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Wideband electromagnetic wave absorber using doped barium hexaferrite in Ku-band

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ABSTRACT

Substituted barium hexaferrite $BaMg_{0.25}Mn_{0.25}Co_{0.5}Ti_{1.0}Fe_{10}O_{19}$ was prepared in powder configuration by solid state reaction. The ferrite powders were mixed with polyvinylcloride (PVC) plasticizer to fabricate a microwave absorbing composite. X-ray diffraction (XRD), scanning electron microscope (SEM), vibrating sample magnetometer (VSM), and vector network analyzer were employed to characterize phase identification coupled with size and morphology of powder and microwave absorption properties of synthesized composites. It was found that the maximum reflection loss of −40 dB was appeared at frequency range of 12–18 GHz. In the present work, new cation substitutions in iron sites in the crystal lattice of barium ferrite, which can easily tune the bandwidth of the reflection loss, were used. To the best of our knowledge, this is the first study which displays the wideband absorber by employing single layer hexaferrite backed on the surface of copper.

1. Introduction

With the development of radar, microwave communication technology and especially the requirement for anti-electromagnetic interference coatings, self-concealing technology and microwave darkrooms, and the study of electromagnetic wave (EM) absorbing materials are attracting attentions recent years [1–3].

Recent developments in microwave absorber technology have resulted in materials that can effectively reduce the reflection of electromagnetic signals on the one hand, and have good performance and lower production cost on the other. For a suitable and high performance absorbing material, two important conditions must meet the requirements. The first is the matched characteristics impedance, in which intrinsic impedance of the material must be equal to the intrinsic impedance of free space. Second, the incident electromagnetic wave must enter and be attenuated rapidly through the material layer, thus reducing the emerging wave to an acceptably low magnitude [4–7].

M-type barium ferrite (BaM) is of great interest for use as microwave absorbers due to their magnetic losses in microwave frequency band [7]. The magnetic loss of these materials results mainly from resonance absorption of moving magnetic domains in a low frequency and incoherent rotation of magnetization in a relatively higher frequency [8].

Recently, we have focused our studies on the microwave attenuation properties of doped barium hexaferrite [9,10]. Even though many literatures have been reported on the fabrication of single layer wave absorbers [7–11], this is the first research which shows the possibility of fabrication of absorbers with the wideband EM absorption by substituting suitable cations. The current interest is to introduce substitution in barium ferrite which can easily tune the bandwidth of the reflection loss values. The results exhibit a wideband single-layer microwave absorber with a satisfactory reflection loss (more than −20 dB) throughout Ku-band.

2. Experimental

2.1. The preparation of powder ferrite

The raw materials utilized in the present paper were barium carbonate, iron oxide, magnesium oxide, manganese carbonate, and titanium oxide. M-type barium ferrite with the composition of $BaMg_{0.25}Mn_{0.25}Co_{0.5}Ti_{1.0}Fe_{10}O_{19}$ was prepared in a powder configuration by traditional ceramic processing. The starting materials were mixed in a ball mill for 3 h and sintered in air at 1250 °C for 3 h. Finally, the sintered ferrite was crushed again for 8 h to obtain powder with a wide distribution of particle sizes.

The composite specimens for measurement of microwave absorber properties were prepared by mixing doped barium ferrite and PVC with a concentration of 70:30 by weight. The pressed composites were in a cylindrical form with thicknesses of (t = 1.9 mm, t = 2.1 mm, t = 2.3 mm, t = 2.5 mm, t = 2.7 mm) and a constant diameter of 40 mm.

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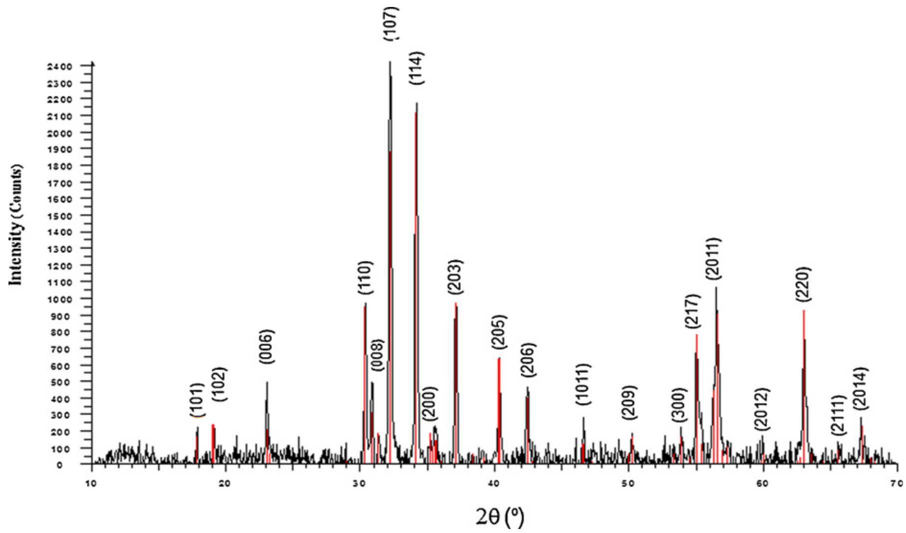

Fig. 1. XRD pattern of doped ferrite.

2.2. Measurement of properties

The identification of the crystalline phases was carried out by X-ray powder diffractometer using CuKα and the diffraction points were recorded from 20° to 70° with scan rate of 2°/min). Scanning electron microscopy (SEM) evaluation was performed for observation morphology and size distribution of prepared powder. Vibrating sample magnetometer (VSM) with the maximum field of 24 kOe was used to plot the hysteresis loop of ferrite sample at room temperature. Variation of the reflection loss in (dB) versus frequency in the range of 12–18 GHz has been investigated using a vector network analyzer.

3. Results and discussion

3.1. Microstructure and magnetic characteristics

The results obtained from XRD pattern in Fig. 1 indicate that the sample is identified to be single phase with only M-type hexagonal barium ferrite, and based on the accuracy of this technique no other phases were detected. The peaks for the doped barium ferrite appear at the same positions as for the undoped ferrite, but with different intensities. The change in relative intensities may be related to the occupation of crystallographic sites by substituted ions [7,9]. It also indicates that Fe^{3+} ions substitution causes considerable change in easily magnetized *c*-axis which leads to the deviation of lattice parameters *a* and *c* of doped barium ferrite compared do the undoped one [9].

Fig. 2 shows the distribution of particles for the prepared sample. It is revealed from the micrograph that the sample contains rather hexagonal particles with a wide range of distribution. Fig. 3 reflects the hysteresis loop of doped BaM ferrite. The H_c of pure barium hexaferrite is very high (about 4.5 kOe) which is due to strong uniaxial anisotropy along *c*-axis of M-type barium hexaferrite [12,13]. Fig. 3 demonstrates that with substitutions of Mg, Mn, Co and Ti, coercive force decreases to 3.1 kOe.

3.2. Microwave characteristic

The reflection loss of electromagnetic radiation under normal incident wave at the surface of single-layer material backed by a perfect conductor can be defined by the transmission line theory [14]. The following reflection relation can give the ferromagnetic resonance frequency of barium ferrite,

$$2\pi f_r = \gamma H_a \quad (1)$$

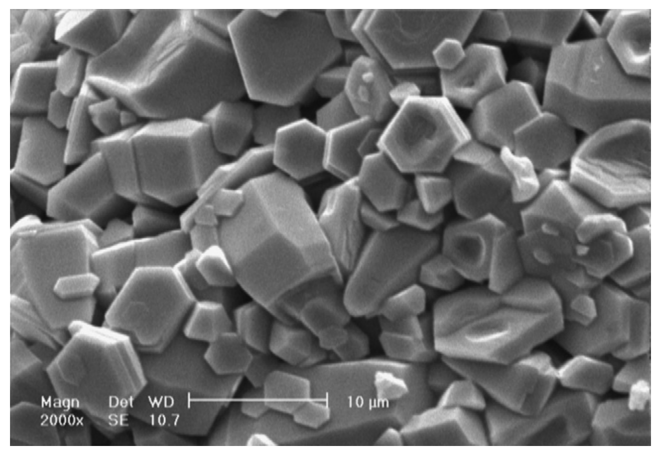

Fig. 2. SEM micrograph reveals morphology of doped ferrite.

The above equation shows that the ferromagnetic resonance frequency is closely related to the magnetocrystalline anisotropy field H_a of barium ferrite. It is known that M-type hexagonal ferrites have a ferromagnetic resonance frequency of 50–60 GHz due to large crystalline magnetic anisotropy. It is also known that resonance frequency (f_r) can be shifted to lower frequency by substituting

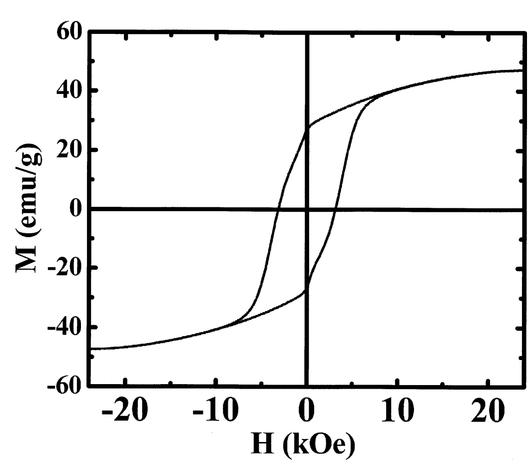

Fig. 3. Room temperature hystersis loop of doped ferrite.

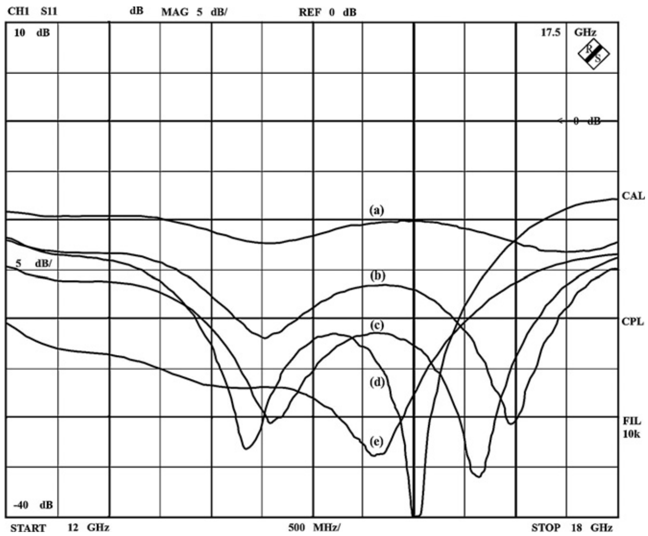

Fig. 4. Variation of reflection loss versus frequency of ferrite-resin composites with 70 wt.% of ferrite in (a) 1.9 mm, (b) 2.1 mm, (c) 2.3 mm, (d) 2.5 mm, (e) 2.7 mm thicknesses.

Fe^{3+} with other metal ions [12]. As a matter of fact, H_a is closely related to Mn^{2+},Mg^{2+},Co^{2+} and Ti^{4+} substitutions.

Fig. 4 shows the variation of reflection loss versus frequency of composites with different thicknesses. Here the bandwidth is defined as the frequency width in which the reflection loss is more than −20 dB. It is clearly apparent from Fig. 4 that there are two clear absorption peaks with significantly different values and positions resulting in the domain wall motion at lower frequency and incoherent rotation of magnetization at higher frequency, respectively [8]. From the reflectivity curves, it can be seen that the matching frequency increases with a decrease in matching thickness which is well consistent with the previous reports [15,16]. This frequency shift can be seen clearly in Fig. 4. For the sample "(a)", is a minimum reflection loss value (−10 dB) observed over 12–18 GHz. The matching frequencies of sample "(b)" are equal to 14.5 and 16.9 GHz in Ku-band, and a minimum reflection loss value of −31 dB was observed at 16.9 GHz. The corresponding value of matching thickness is 2.1 mm. Sample "(c)" with matching thickness of 2.3 mm exhibits a minimum reflection loss of −36 dB at 16.7 GHz. The bandwidth that can be covered by this sample is 3.6 GHz. Fig. 4 clearly displays that the reflection loss higher than −40 dB at matching frequency of 16 GHz can be obtained by the sample "(d)". There is also another matching frequency at 14.3 GHz with the reflection loss of −33 dB. Sample "(e)" with matching thickness of 2.7 mm shows the widest bandwidth of those obtained from other samples. The bandwidth that can be achieved by utilization of this sample is 4.5 GHz. Minimum reflection loss of −34 dB can be obtained by sample "(e)". In comparison to previous papers [7–9,15–22], the obtained results indicate that by substituting iron with Mg, Mn, Co, and Ti, almost all Ku-bands can be covered.

4. Conclusions

The work reported here is the first research which shows the possibility of fabrication of single-layer electromagnetic wave absorbers with wideband absorption by substituting suitable cations. The bandwidth of 4.5 GHz can be covered by this composition at a thickness of 2.7 mm. Such a wide absorption width indicates the attractive potential in microwave applications as a radar absorbing media.

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