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Characterization of a Y-type hexagonal ferrite-based frequency tunable microwave absorber

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Abstract: A Y-type hexaferrite rod with the composition of $Ba_2Co_{1.8}Cu_{0.2}Fe_{12}O_{22}$ was presented as an absorbing material with high absorbance. Its high absorbance and wide absorption band result from ferromagnetic resonance (FMR) that is self-biased by strong shape and magnetocrystalline anisotropy fields. Around the FMR frequency the specimen of the ferrite rods exhibits very high absorbance and the FMR frequency can be tuned by the rod dimension. In addition to the high absorbance and the wide tunable absorption band, the microwave absorber has another advantage of light weight due to the use of the ferrite rods instead of ferrite slabs.

Keywords: hexagonal ferrite; microwave materials; microwave absorbers; cobalt compounds; ferromagnetic resonance

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1. Introduction

An electromagnetic absorber is essential for various electronic devices in the applications of electromagnetic shielding, wireless communication, local area networks, satellite television, heating systems, *etc.* [1-2]. One necessary condition for a microwave absorber is that the incident electromagnetic wave must enter the absorber and be attenuated rapidly through the material layer, thus reducing the emerging wave to an acceptable low magnitude [3]. Therefore, microwave-absorbing materials must have large electric and magnetic loss in a certain frequency range. A ferrite that contains magnetic ions can produce spontaneous magnetization and maintain good dielectric properties, so it has been widely used as a microwave-absorbing material [4]. Usually, the resistivity of a ferrite is high, so the magnetic loss results from various resonances, such as ferromagnetic resonance (FMR), domain wall resonance, and natural resonance [5-6].

The domain wall resonance of a ferrite always happens in the kHz or MHz range, so it is not suitable for microwave absorption. The natural resonance is a special FMR, and it is induced by the internal magnetocrystalline anisotropy and the demagnetizing field instead of the external field. For a ferrite with spinel or garnet structure, the frequency of natural resonance is always below 100 MHz. For a hexagonal ferrite with strong planar magnetocrystalline anisotropy, the frequency of natural resonance is much higher [7]. For example, the frequency of natural resonance for Co_2Y can reach 4 GHz, which is the highest among various ferrites. Therefore, microwave-absorbing materials with magnetic loss are usually used in the low microwave frequency range. However, due to the absence of excitation of the external field, the resonance is weak and exhibits a relaxation character, so it should be improved for the application of ab-

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sorbers. If an external field is used, the resonance absorption can be enhanced and the working frequency can also be increased. In practice, it is very difficult to introduce an external field; therefore, a self-bias field is a better choice to excite FMR. However, because the special molding process is needed, the fabrication of self-biased magnetic materials is very complicated. In this paper, an efficient and convenient method was proposed to realize the self-bias field using ferrite rods. The use of a series of discrete ferrite rods instead of a bulk ferrite sample also meets the trend of light weight of microwave-absorbing materials.

2. Experimental

A hexagonal ferrite with the composition of $Ba_2Co_{1.8}Cu_{0.2}Fe_{12}O_{22}$ was prepared using analytical reagent grade $BaCO_3$, Fe_2O_3, Co_3O_4, and CuO as starting materials. All the raw materials were weighted according to their molecular weight ratios and mixed in a ball mill for 4 h using ZrO_2 balls and alcohol as the media. The dried mixture was calcined at 1050°C in air for 6 h and then ground for 4 h again. The resulting powders obtained were mixed with 5 wt% polyvinyl alcohol as a binding lubricant and pressed under a pressure of 7 MPa in a stainless-steel die. The pressed bulk samples were sintered at 1150°C and sliced and ground precisely to ferrite slabs with a dimension of 22 mm×4 mm×10 mm and ferrite rods with a dimension of *a* (2.75, 3.3, 3.8, 4.1, 5.5) mm×4 mm×10 mm. The ferrite-wax composite was prepared by dispersing the ferrite powder in wax and ground to a dimension of 22 mm×4 mm×10 mm.

The phase composition of the powder was confirmed by means of powder X-ray diffraction (XRD) using Cu K_α radiation, and the diffraction patterns were recorded from 20° to 70°. The microwave scattering parameters of the samples were measured by a HP 8720ES network analyzer in a rectangular waveguide.

3. Results and discussion

To identify the crystalline structure of the sample, XRD analysis is performed on the ferrite powder. Fig. 1 shows the typical XRD patterns of the $Ba_2Co_{1.8}Cu_{0.2}Fe_{12}O_{22}$ powder calcined at 1050°C for 4 h. The result shows that only one phase is formed and the phase is confirmed to be pure Y-type hexaferrite when compared to the standard XRD pattern (JCPDS 44-0206).

Fig. 2 shows the amplitude of the transmission curve (S_{21}) for a ferrite slab, a ferrite rod (3.3 mm×4 mm×10 mm), and a ferrite-wax composite bulk within the frequency range of 9 to 12 GHz. The S_{21} curve of the ferrite slab is an oblique line, which means that the absorption does not change remarkably during the whole measured frequency range. It indicates that the ferrite slab is not proper to serve as a microwave absorber. For the ferrite rod, there is a deep transmission gap in the S_{21} curve that is induced by FMR. Due to the absence of an external magnetic field, the FMR of the ferrite rod is excited only by the internal fields of the shape anisotropy field and the magnetocrystalline anisotropy field. The strong magnetocrystalline anisotropy of Co_2Y ferrite strictly limits the spin rotation in the easy magnetization plane, and the large aspect ratio of the ferrite rod provides a strong shape anisotropy field along the rod to excite FMR [8]. Within the deep transmission dip, a ferrite rod has much lower transmission than a ferrite slab, although the effective volume is much smaller. Therefore, the ferrite rod is an appropriate absorbing material in the vicinity of the resonance frequency.

We experimentally measured the complex frequency

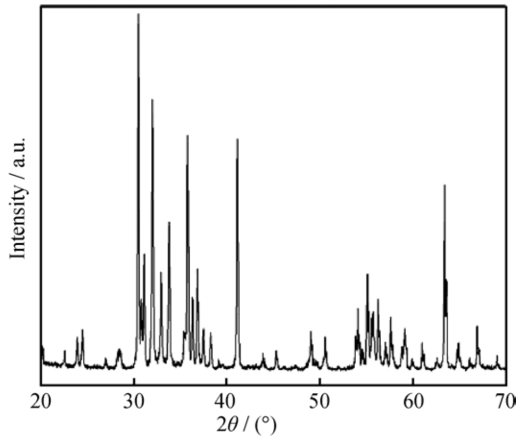

Fig. 1. XRD pattern for the samples of $Ba_2Co_{1.8}Cu_{0.2}Fe_{12}O_{22}$.

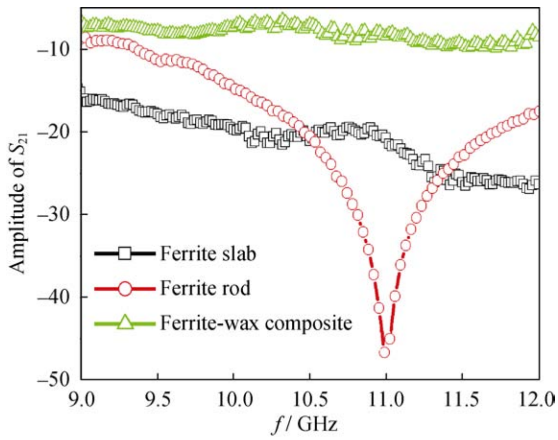

Fig. 2. Amplitude of S_{21} for a ferrite slab, a ferrite rod, and a ferrite-wax composite samples.

(ω)-dependent S parameters, S_{11} and S_{21}, where $T(\omega)=|S_{21}|^2$, $R(\omega)=|S_{11}|^2$, and $A(\omega)$ are the transmission, reflectance, and absorbance respectively. In theory, $A(\omega)=[1-T(\omega)-R(\omega)]$, which is expected to approach 100% for an ideal absorber. For ferrite materials, absorbance relies on the magnetic loss, which reaches the maximum value due to various resonances. The resonance frequency of domain resonance is limited, and natural resonance is relative weak due to the absence of an external field, so FMR excited by the external magnetic field or the internal self-bias field is a better choice for a microwave absorber. Fig. 3 shows the reflectance, transmission, and absorbance of the ferrite rod (3.3 mm×4 mm×10 mm). In the absorbance curve, it is found that $A(\omega)$>98% in the frequency range of 10 to 12.2 GHz, which means that it is a good microwave absorber within a wide frequency range.

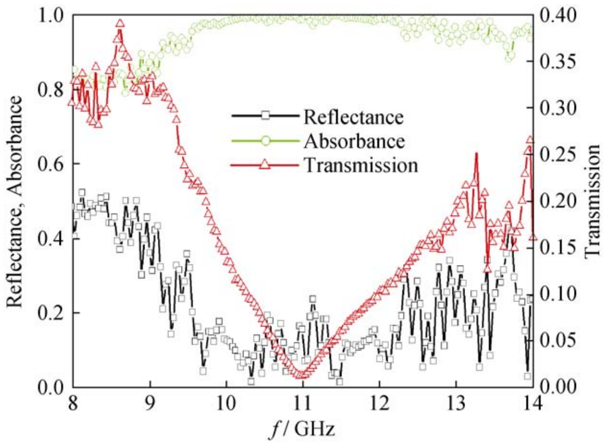

Fig. 3. Relations of the reflectance ($R(\omega)$), absorbance ($A(\omega)$) and transmission ($T(\omega)$) of the ferrite rod to frequency.

As we know, FMR happens in a ferrite rod due to the internal self-bias field of the shape anisotropy field. Therefore, the FMR frequency can be controlled by the rod's dimension parameters. Fig. 4 shows the dependence of resonance frequency on the rod's wideness. It can be seen that the resonance frequency decreases monotonically with the increase of the rod's wideness. Subsequently, the microwave absorber made by the ferrite rods with different widenesses will change and widen the working frequency range.

Based on the discussion above, we can conclude that ferrite rod is an appropriate candidate for being used as the microwave-absorbing material. The working frequency of the ferrite rod can be tuned by changing its wideness. Moreover, the ferrite rod is much lighter than the ferrite slab, which is also beneficial for a microwave absorber. To achieve a light-weight microwave absorber, the ferrite-polymer is another choice [9-11]. In a ferrite-polymer, the effective volume of the ferrite is only dozens of percent, which is similar to that of the ferrite rod sample. However, because the effective volume of the ferrite is low in a ferrite-polymer and no resonance is excited to increase the magnetic loss, the absorbance of a ferrite-polymer is very weak, and most electromagnetic waves can transmit through the sample with little loss (Fig. 2). It indicates that the ferrite-polymer is not appropriate as an absorbing material. Conclusively, compared to the ferrite-polymer composite, the ferrite rod is a light-weight microwave-absorbing material with high absorbance and wide absorbing frequency range.

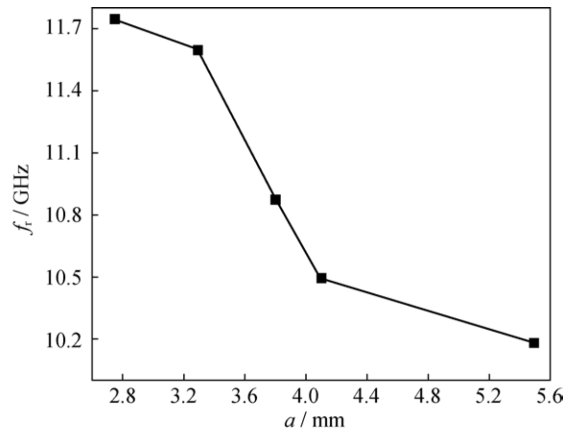

Fig. 4. Resonant frequency (f_r) *versus* ferrite rod's wideness (a) for the sample.

4. Conclusion

The single phase of a hexagonal ferrite with the composition of $Ba_2Co_{1.8}Cu_{0.2}Fe_{12}O_{22}$ was synthesized by the conventional solid-state method. Microwave scattering parameters, S_{11} and S_{21}, of the ferrite slab, the ferrite rod, and the ferrite-wax composite were measured experimentally. For the ferrite rod, FMR happens due to the excitation of the self-bias field of shape and magnetocrystalline anisotropy fields. The absorbance ($A(\omega)$) of the ferrite rod is higher than 98% in a wide frequency range of 10 to 12.2 GHz. Moreover, The FMR frequency can be tuned by the dimension parameters of the ferrite rod. Conclusively, the ferrite rod is an ideal microwave-absorbing material because of its high absorbance and light weight.

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