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Effect of thickness on microwave absorptive behavior of La-Na doped Co-Zr barium hexaferrites in 18.0–26.5 GHz band

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ABSTRACT

In this research, the microwave properties of Lanthanum-Sodium doped Cobalt-Zirconium barium hexaferrites, intended as microwave absorbers, are analyzed on Vector Network Analyzer in K-band. The results indicate that the doping has resulted in lowering of real permittivity and enhancement of dielectric losses. Real permeability has shown increase while magnetic losses have shown decrease in value with doping. All these four properties have shown very small variation with frequency in the scanned frequency range which indicates the relaxation type of behavior. Microwave absorption characteristics of these compositions are analyzed with change in sample thickness. The results demonstrate that the matching frequency of the microwave absorber shifts towards lower side of frequency band with increase in thickness. The complete analysis of the prepared microwave absorbers shows a striking achievement with very low reflection loss and wide absorption bandwidth for all the six compositions in 18–26.5 GHz frequency band.

1. Introduction

In recent years, there is an increase in electromagnetic (EM) pollution due to the rapid development of electronic systems and telecommunication coming into the gigahertz frequency range [1,2]. Subsequently, EM pollution and related problems have arisen and become serious. The electromagnetic interference (EMI) causes serious interruptions in electronically controlled systems which cause device malfunctioning, generation of false signals, interference to radars and military devices and systems. EMI also has potential health hazards to humans, animals and birds associated with exposure to electromagnetic radiations [3,4], due to which, there is a strong need of reducing these unwanted radiation. These materials are also useful to camouflage the targets like aircrafts, ships etc. in warfare. For these applications, microwave absorbers, fabricated from hexaferrites, have been developed by many researchers [1–7]. Hexagonal ferrites, with in-plane oriented anisotropy field are considered to be the most promising materials for EMI suppression or as microwave absorbers due to their strong absorbing ability, broad-band absorbency and low-cost preparation [8,9]. These absorbers are placed in the enclosures of the electronic gadgets placed around potential sources of EMI, in order to suppress the spurious signals. Among all the ferrites, barium ferrites with hexagonal M-type structure have been considerably studied as one of the most important microwave absorbing materials because of their high coercive force, large magneto-crystalline anisotropy, high saturation magnetization, as well as high natural resonance frequency [10,11].

In this study, the effect of doping of lanthanum (La) and sodium (Na) in varying amount has been analyzed on the microwave absorption properties of cobalt zirconium M-type barium hexaferrites in K-band. Firstly, the variation of complex permittivity and complex permeability with respect to (w.r.t.) frequency and composition has been investigated and then the variation of absorption w.r.t. thickness and composition of sample has been discussed.

2. Experimental procedure

The synthesis of the hexaferrite powders with chemical formula $Ba_{(1-2x)}La_xNa_xFe_{10}CoZrO_{19}$ (with x=0.0, 0.05, 0.10, 0.15, 0.20, 0.25) was done by using solid state reaction technique. The preparation method and detailed structural analysis of this series have already been published [12]. XRD analysis of this series has confirmed the formation of magnetoplumbite structures (JCPDS data file no. 078-0131) in all the test specimens [12]. SEM analysis has confirmed the uniform distribution of grains in all the samples and the average grain size lied between 250 nm and 380 nm [12]. The X-band characterization of this series has been reported earlier [13] which presented these materials as useful absorbers in X-band. In the present research, the characteriza-

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tion of same samples has been done in frequency range of 18–26.5 GHz and the effect of sample thickness has been introduced. The evaluation of complex scattering (S) parameters has been done using Agilent N5225A Vector Network Analyzer. Nicolson Ross [14] and Weir [15] method has been used to calculate the electromagnetic properties from the S-parameters. For K-band analysis, rectangular pellets of dimension 10.67 mm×4.32 mm×2 mm were prepared after mixing with 5% polyvinyl alcohol. The samples were finally cured for 30 min.

3. Results and discussion

Fig. 1 shows the variation of real part of permittivity (dielectric constant) of the prepared hexaferrite samples in K-band. It can be clearly seen that the values of permittivity (ε′) varies from approximately 8.5 to 6.5 on increasing frequency from 18 GHz to 26.5 GHz. Also, it can be seen that the undoped sample has got relatively higher values of permittivity (ε′) as compared to doped samples in this frequency range. Permittivity is directly proportional to the polarization induced in the material as a result of alternating voltage. The decrease in ε′ values suggests that interfacial and dipole polarization have reduced as result of substitution of barium with lanthanum-sodium. This decrease in value can also be attributed to the decrease in conductivity of the samples with substitution as ε′ is dependent on conductivity [16]. With respect to frequency, ε′ of the undoped sample has shown decrease while that of doped samples have shown almost constant behavior. Decrease in ε′ with frequency is a typical behavior of ferrites, simulated by the separation of conducting grains by poorly conducting grain boundaries [17].

The dielectric loss (ε″) for all the samples is presented in Fig. 2. It can be inferred that the undoped sample has observed dielectric loss close to zero. But with the doping of lanthanum and sodium, the losses have increased to the range 1–2. This increase is very useful from absorption application point of view because high losses mean high energy dissipation. As the value of substitution (x) is increased, the hopping of charges between Fe^{2+} and Fe^{3+} increases. This charge hopping leads to the hopping conduction due to which the dielectric loss has increased. Dielectric losses have shown almost frequency independent behavior in this frequency range.

Fig. 3 is presented to display the variation of real part of permeability (μ′) for different compositions. It is clear that the real part of permeability (μ′) shows a decrease with increase in substitution after 23 GHz, which may be due to increase in porosity and grain boundaries of the samples with substitution. This causes a high reluctance to magnetic domain motion by inducing low demagnetizing fields, thereby decreasing μ′. The frequency variation of permeability is almost constant, in range of 1.1–1.5. Due to weak applied field, the real permeability has low values close to one.

Magnetic loss arises due to lag between magnetization and applied field. The variation of magnetic losses (imaginary permeability) is plotted in Fig. 4 for all the compositions. The undoped sample has losses around 0.5, whereas the doped compositions have registered losses around 0.1–0.2. The imaginary permeability has not shown any significant variation with frequency.

The curves of reflection loss (RL), in upper part of Fig. 5(a)–(f) are simulated from the complex permittivity and complex permeability for various sample thicknesses using the following Eq. (1). Reflection Loss (RL) is related to input impedance Z_i of a metal-backed microwave absorbing layer as

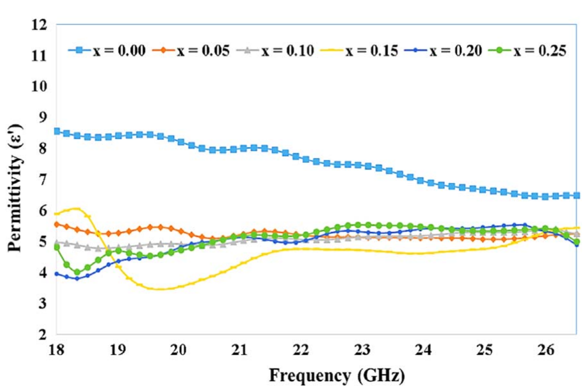

Fig. 1. Variation of dielectric constant (ε′) with frequency for the samples $Ba_{(1-2x)}La_xNa_xFe_{10}CoZrO_{19}$ in K-band.

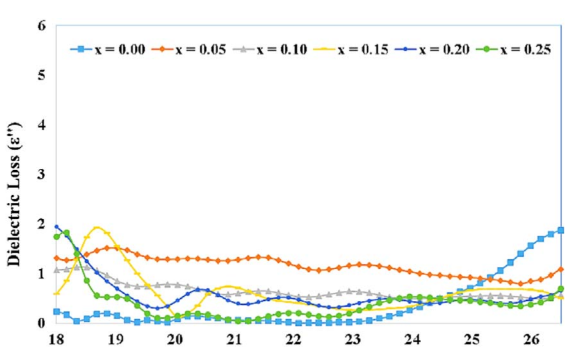

Fig. 2. Variation of dielectric loss (ε″) with frequency for the samples $Ba_{(1-2x)}La_xNa_xFe_{10}CoZrO_{19}$ in K-band.

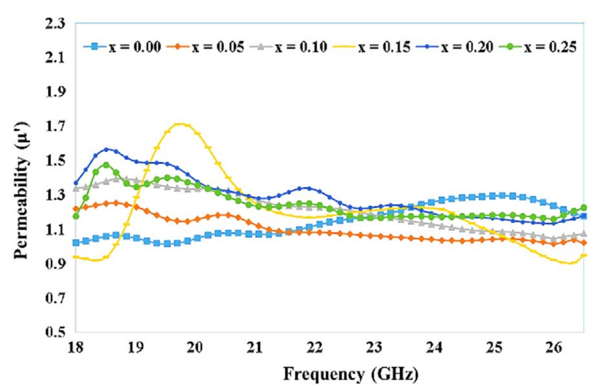

Fig. 3. Variation of permeability (μ′) with frequency for ferrite samples.

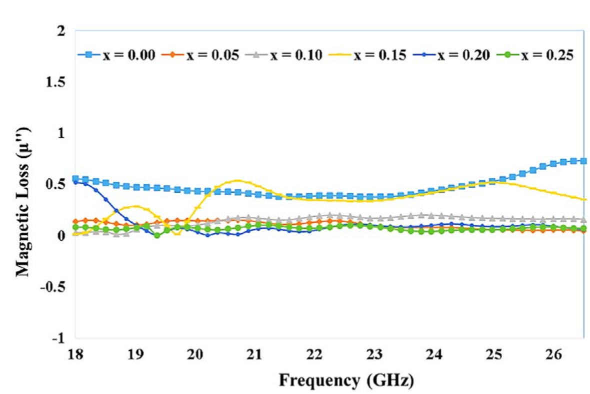

Fig. 4. Variation of magnetic loss (μ″) with frequency for ferrite samples.