Effect of La-Ni substitution on structural, magnetic and microwave absorption properties of barium ferrite

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ABSTRACT

In this paper, La-Ni substituted barium ferrite nanoparticles were prepared by a co-precipitation method. The morphology, structure, magnetic and microwave absorption properties of samples were accomplished by X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), transmission electron microscope (TEM), vibrating sample magnetometer (VSM) and vector network analysis. From the results evaluation, it can be seen that the magnetoplumbite structure for all of the samples have been formed and the average crystallite sizes of \( \text{Ba}_{1-x}\text{La}_x\text{Fe}_{12-x}\text{Ni}_x\text{O}_{19} \) nanoparticles within in the range of 50.9−65.5 nm. \( \text{Ba}_{0.9}\text{La}_{0.1}\text{Fe}_{11.9}\text{Ni}_{0.1}\text{O}_{19} \) exhibits a remarkable reflection loss of −13.5 dB at 13.05 GHz with a matching thickness of 1.5 mm. The reflection loss results indicate that \( \text{Ba}_{0.9}\text{La}_{0.1}\text{Fe}_{11.9}\text{Ni}_{0.1}\text{O}_{19} \) nanoparticles may be used as a potential for thin microwave absorbers.

1. Introduction

In recent years, the rapidly development of electronics industry coming into microwave frequency range, which has resulted in electromagnetic wave interference (EMI) among devices and electromagnetic compatibility problems in both civil and military application [1−6]. In order to address the problem posed by EMI, thinner microwave absorbing materials can be a good solution [7]. The researchers are interested to consider the ferrites due to their obvious advantages [8]. Among all ferrites, barium ferrite with hexagonal magnetoplumbite structure, has been studied as great electromagnetic wave absorbers due to their high stability, low cost, high electrical permittivity and permeability is benefi
dical to obtain excellent micro

As is well known, it is an effective way to change the microwave absorption properties of barium ferrite by using other metal ions to replace the barium ions (Ba\textsuperscript{2+}) and ferric ions (Fe\textsuperscript{3+}) [12−15]. Aminreza Baniasadi and his co-workers [3] have studied the substituted M-type Sr-ferrite and minimum reflection loss of −36.13 dB at 13.43 GHz. Reza Shams Alam and his partners have studied the nickel ions (Ni\textsuperscript{2+}) and manganese ions (Mn\textsuperscript{2+}) were employed to partially replace the cobalt ions (Co\textsuperscript{2+}) in \( \text{BaCoTiFe}_{12}\text{O}_{19} \), it was found that the composite \( \text{Ba(MnNi)}_{0.2}\text{Co}_{0.6}\text{TiFe}_{10}\text{O}_{19} \) possessed a minimum reflection loss of −52.8 dB at 13.4 GHz with a matching thickness of 1.8 mm. Moreover, the maximum attenuation could reach −69 dB when its thickness was 1.8 mm, and also the bandwidth less than −20 dB was ranging from 13.2GHz to 18 GHz [16].

In this study, the elements of La\textsuperscript{3+} and Ni\textsuperscript{2+} are chosen to replace Ba\textsuperscript{2+} ions and Fe\textsuperscript{3+} ions, respectively. The structure, ferromagnetism, electromagnetic and microwave absorption properties of La-Ni substituted barium ferrite nanoparticles are discussed. Subsequently, the complex permittivity, permeability and microwave absorbing performance are discussed in detail.

2. Experimental

\( \text{Ba}_{1-x}\text{La}_x\text{Fe}_{12-x}\text{Ni}_x\text{O}_{19} \) hexaferrite (x=0, 0.05, 0.1, 0.15, 0.2) were synthesized by the chemical co-precipitation method. The stoichiometric amount of chloride compounds of Ba, Fe, La and Ni with chemical compositions of \( \text{Ba(NO}_3)_2, \text{Fe(NO}_3)_3, \text{La(NO}_3)_3 \text{and Ni(NO}_3)_2 \) were dissolved in deionized water at 60 °C to form a homogeneous solution. The mixed solution was added dropwise to the aqueous solution of NaOH and Na\textsubscript{2}CO\textsubscript{3} using vigorous stirring to obtain the precipitate. Then the pH of the solution was adjusted slowly to 10 by adding drop wise NaOH solution (1 mol/L) to form a brownish yellow suspension of the hybrid complex. After precipitation, the precipitate was obtained by filtrating and washed with distilled water and ethanol.

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Then the precipitate was dried at 60 °C in vacuum for 24 h to obtain the precursor. The precursor was calcined at 900 °C for 2 h to obtain the Ba$_{1-x}$La$_x$Fe$_{12-x}$Ni$_x$O$_{19}$.  

3. Characterization

The resulting powder was characterized by X-ray powder diffraction (XRD) using a diffractometer (RIGAKU, model D/max) with CuK$_\alpha$ radiation of wavelength $\lambda=1.5418$ Å. Its morphology was studied with a field emission scanning electron microscope (JEOL, model JSM-7001F) and a transmission electron microscope (JEOL, model JEM 2001). Fourier transform infrared spectroscopy (FTIR) for the prepared samples were carried out using the infrared spectrophotometer (NICOLET, model NEXUS 670) in the range from 4000 to 400 cm$^{-1}$. Magnetization measurements were taken at room temperature (293 K) using a vibrating sample magnetometer (LDJ, model 9600-1). The measured samples were dispersed in paraffin homogeneously with a sample-to-paraffin weight ratio of 1:2, then the mixtures were pressed into cylindrical-shaped specimens (measured samples were dispersed in paraflin) and thickness of about 2 mm. The complex permittivity and permeability of the samples were measured by a microwave vector network analyzer (AGILENT, model N5244A) in the frequency range 2–18 GHz by using coaxial reflection/transmission technique.

4. Results and discussion

The XRD patterns of all the samples prepared at room temperature are presented in Fig. 1. The obtained peaks in XRD patterns were matched with the standard pattern of the Barium hexaferrite (PDF Card #33-1340). XRD patterns (up to x=0.15) confirm the formation of single phase hexagonal ferrites. On the contrary, when x reaches 0.2, the peaks of α-Fe$_2$O$_3$ phase state appeared when x=0.2, it will restrain the growth of crystallite size. The lattice constant ratio c/a may be used to quantify the structure type and M-type hexaferrite structure might be assumed if the lattice constant ratio is observed to be lower than 3.98. From Table 1, the lattice constant ratio c/a is in range from 3.944 to 3.936 and confirmed the formation M-type hexaferrite structure. It is consistent with the standard pattern for hexagonal barium ferrite.

![Fig. 1. XRD patterns of Ba$_{1-x}$La$_x$Fe$_{12-x}$Ni$_x$O$_{19}$ at various amounts of substitution.](image)

**Table 1** Lattice constants (a, c), ratio (c/a), cell volume and crystallite size of Ba$_{1-x}$La$_x$Fe$_{12-x}$Ni$_x$O$_{19}$ (x=0, 0.05, 0.1, 0.15, 0.2).

<table>
<thead>
<tr>
<th>x</th>
<th>a (Å)</th>
<th>c (Å)</th>
<th>Ratio (c/a)</th>
<th>Unit cell volume V (Å$^3$)</th>
<th>Crystallite size (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.9025</td>
<td>23.2818</td>
<td>3.944</td>
<td>702.9</td>
<td>65.5</td>
</tr>
<tr>
<td>0.05</td>
<td>5.8922</td>
<td>23.2282</td>
<td>3.942</td>
<td>698.9</td>
<td>62.0</td>
</tr>
<tr>
<td>0.1</td>
<td>5.8906</td>
<td>23.2081</td>
<td>3.940</td>
<td>697.9</td>
<td>60.5</td>
</tr>
<tr>
<td>0.15</td>
<td>5.8891</td>
<td>23.1955</td>
<td>3.939</td>
<td>697.1</td>
<td>57.3</td>
</tr>
<tr>
<td>0.2</td>
<td>5.8874</td>
<td>23.1719</td>
<td>3.936</td>
<td>696.0</td>
<td>50.9</td>
</tr>
</tbody>
</table>

![Fig. 2. FTIR spectra of barium hexaferrite with various quantities of the dopant.](image)