Dielectric behaviour of erbium substituted Mn–Zn ferrites

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Abstract. Dielectric properties such as dielectric constant (\(\varepsilon'\)) and dielectric loss tangent (tan \(\delta\)) of mixed Mn–Zn–Er ferrites having the compositional formula \(\text{Mn}_{6.58}\text{Zn}_{3.42}\text{Fe}_{2.05}\text{Er}_x\text{O}_4\) (where \(x = 0.2, 0.4, 0.6, 0.8\) and \(1.0\)) were measured at room temperature in the frequency range 1–13 MHz using a HP 4192A impedance analyser. Plots of dielectric constant (\(\varepsilon'\)) vs frequency show a normal dielectric behaviour of spinel ferrites. The frequency dependence of dielectric loss tangent (tan \(\delta\)) was found to be abnormal, giving a peak at certain frequency for all mixed Mn–Zn–Er ferrites. A qualitative explanation is given for the composition and frequency dependence of the dielectric constant and dielectric loss tangent. Plots of dielectric constant vs temperature have shown a transition near the Curie temperature for all the samples of Mn–Zn–Er ferrites. However, \(\text{Mn}_{6.58}\text{Zn}_{3.42}\text{Er}_x\text{Fe}_{2.05}\text{O}_4\) does not show a transition. On the basis of these results an explanation for the dielectric mechanism in Mn–Zn–Er ferrites is suggested.

Keywords. Dielectric constant; dielectric loss tangent; Mn–Zn–Er ferrites; electrical resistivity.

1. Introduction

The dependence of dielectric properties of Li–Mg–Zn ferrites as a function of frequency, composition and temperature has been studied (Shaikh et al 1999). The dielectric behaviour of the Ni–Zn (where \(0 \leq x \leq 1\)) as a function of frequency, composition and temperature was reported (Abdun 1999). The dielectric behaviour of the Ba–Ni–Zn ferrites also as a function of temperature and frequency was reported (Ela et al 1999). The dielectric properties of Ni–Zn ferrites as a function of sintering temperature, sintering time and frequency have been investigated (Rao and Rao 1997). A strong correlation between conduction mechanism and the dielectric behaviour of ferrites has been reported (Iwauchi 1971). The dielectric properties of Mg–Zn ferrites were investigated (Ravinder and Lata 1999). With a view to the understanding of dielectric phenomena in mixed Mn–Zn–Er ferrites, a systematic study of dielectric properties as a function of frequency, composition and temperature was undertaken and the results of the study are presented in this paper.

2. Experimental

Polycrystalline mixed Mn–Zn–Er ferrites having the chemical formula \(\text{Mn}_{6.58}\text{Zn}_{3.42}\text{Fe}_{2.05}\text{Er}_x\text{O}_4\) (where \(x = 0.2, 0.4, 0.6, 0.8\) and \(1.0\)) were prepared by a conventional double sintering ceramic method. X-ray diffractometer studies of the samples using CuK\(_a\) radiation of Rigaku DMAX II X-ray Diffractometer confirmed the spinel formation. The dielectric measurements were made in the frequency range 1–13 MHz using impedance analyser (Model HP4192 A of Hewlett-Packard). The value of the dielectric constant (\(\varepsilon'\)) of the ferrite sample is calculated using the formula

\[
\varepsilon' = \frac{C \times t}{\varepsilon_0 A},
\]

where \(\varepsilon_0\) is an electrical constant equal to 8.854 \(\times\) \(10^{-2}\) \(\text{pF/cm}\), \(C\) the capacitance of the specimen in \(\text{cm}\), \(t\) the thickness of the specimen in \(\text{cm}\) and \(A\) the area of the specimen in \(\text{sq cm}\). The complex dielectric constant (\(\varepsilon''\)) of the ferrite sample is given by

\[
\varepsilon'' = \varepsilon' \tan \delta.
\]

The Curie temperature, \(T_c\) of the samples was determined by the gravity method.

3. Results and discussion

3.1 Composition dependence of dielectric behaviour

The room temperature values of the dielectric constant (\(\varepsilon'\)), dielectric loss tangent (tan \(\delta\)) and complex dielectric constant (\(\varepsilon''\)) of mixed Mn–Zn–Er ferrites as derived from the experiments are given in table 1. The values of electrical conductivity (\(\sigma\)) and \(\text{Fe}^{2+}\) concentration are also included in the table to facilitate discussion. It can be seen from the table that the \(\varepsilon'\), tan \(\delta\) and \(\varepsilon''\) of the mixed...
Mn–Zn–Er ferrites decreases with decreasing concentration of Fe$^{2+}$ ions till the concentration ($x$) of erbium is equal to 0.4. Beyond $x = 0.4$, these parameters show an increase with increase of erbium content. Among all the ferrites, the specimen with the composition Mn$_{0.58}$Zn$_{0.37}$Er$_{0.05}$O$_4$, which has the lowest Fe$^{2+}$ concentration, exhibits the lowest dielectric constant, the lowest dielectric loss tangent and the lowest complex dielectric constant. The dielectric studies of Gd$^{3+}$ substituted copper–cadmium ferrites as a function of composition and frequency was investigated by Kolekar et al (1995). Ramana Reddy et al (1999) have investigated the dielectric behaviour of Ni–Zn ferrites as a function of temperature and frequency. Iwauchi (1971) reported a strong correlation between the conduction mechanism and the dielectric behaviour of the ferrites starting with the conjecture that the mechanism of the polarization process in ferrites is similar to that of the conduction process (Rabinkin and Novikova 1960). They observed that the electronic exchange between Fe$^{2+}$ ⇔ Fe$^{3+}$ results in local displacements which determine the polarization behaviour of the ferrites.

A similar explanation is proposed for the composition dependence of the dielectric constants of the ferrites under this investigation. It can be observed from table 1 that the composition, Mn$_{0.58}$Zn$_{0.37}$Er$_{1.0}$Fe$_{1.65}$O$_4$, has the maximum divalent iron ion concentration among all the mixed Mn–Zn–Er ferrites. Correspondingly the dielectric constant for this specimen has a maximum value of 446 at 1 MHz. This high value can be explained on the basis of the fact that it has maximum number of ferrous ions which involve in the phenomenon of exchange Fe$^{2+}$ ⇔ Fe$^{3+}$ giving rise to maximum dielectric polarization. Table 1 reveals that the variation of the dielectric constant of Mn–Zn–Er ferrites runs parallel to the variation of available ferrous ions on octahedral sites. It is significant to note that Mn$_{0.58}$Zn$_{0.37}$Er$_{0.4}$Fe$_{1.65}$O$_4$ which has the lowest ferrous ion concentration also possesses the lowest dielectric constant. It is also pertinent to mention that the variation of electrical conductivity with composition (table 1) parallels the variation of ferrous ion concentration (Ravinder 1988). Thus, it is the number of ferrous ions on the octahedral sites that play a dominant role in the processes of conduction as well as dielectric polarization. This result is in agreement with the assumption made earlier (Rabinkin and Novikova 1960).

3.2 Frequency dependence of dielectric constant ($\varepsilon'$)

The variations of dielectric constant as a function of frequency for mixed Mn–Zn–Er ferrites with different compositions is shown in figure 1. It can be seen from the figure that the value of dielectric constant decreases continuously with increasing frequency. The dispersion of dielectric constant is maximum for Mn$_{0.58}$Zn$_{0.37}$Er$_{1.0}$Fe$_{1.65}$O$_4$.

The decrease of dielectric constant with increase of frequency as observed in the case of mixed Mn–Zn–Er ferrites is a normal dielectric behaviour. This normal dielectric behaviour was also observed by several other investigators (Chandra Prakash and Bajal 1985; Ravinder 1993; Ramana Reddy et al 1999). The normal dielectric behaviour of spinel ferrites was also explained by Rezlescu and Rezlescu (1974). Following their work, the

### Table 1. Composition dependence of room temperature dielectric data for erbium substituted Mn–Zn–Er ferrites at 1 MHz.

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Ferrite composition</th>
<th>$\varepsilon'$</th>
<th>tan $\delta$</th>
<th>$\varepsilon''$</th>
<th>$\sigma$ (Ω$^{-1}$ cm$^{-1}$)</th>
<th>Fe$^{2+}$ composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mn$<em>{0.58}$Zn$</em>{0.37}$Er$<em>{0.05}$Fe$</em>{1.65}$O$_4$</td>
<td>276</td>
<td>0.32</td>
<td>88.32</td>
<td>1.58 x 10$^{-7}$</td>
<td>1.24</td>
</tr>
<tr>
<td>2.</td>
<td>Mn$<em>{0.58}$Zn$</em>{0.37}$Er$<em>{0.04}$Fe$</em>{1.65}$O$_4$</td>
<td>124</td>
<td>0.16</td>
<td>19.84</td>
<td>5.86 x 10$^{-9}$</td>
<td>0.92</td>
</tr>
<tr>
<td>3.</td>
<td>Mn$<em>{0.58}$Zn$</em>{0.37}$Er$<em>{0.04}$Fe$</em>{1.65}$O$_4$</td>
<td>224</td>
<td>0.24</td>
<td>53.76</td>
<td>5.05 x 10$^{-8}$</td>
<td>1.18</td>
</tr>
<tr>
<td>4.</td>
<td>Mn$<em>{0.58}$Zn$</em>{0.37}$Er$<em>{0.03}$Fe$</em>{1.65}$O$_4$</td>
<td>338</td>
<td>0.42</td>
<td>141.96</td>
<td>8.56 x 10$^{-7}$</td>
<td>1.32</td>
</tr>
<tr>
<td>5.</td>
<td>Mn$<em>{0.58}$Zn$</em>{0.37}$Er$<em>{0.03}$Fe$</em>{1.65}$O$_4$</td>
<td>446</td>
<td>0.52</td>
<td>231.92</td>
<td>2.00 x 10$^{-3}$</td>
<td>1.68</td>
</tr>
</tbody>
</table>