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Behavior of dielectric constant and dielectric loss tangent in Cd^{2+} and Cr^{3+} substituted magnesium ferrites

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ABSTRACT

Spinel ferrites with general formula $Cd_xMg_{1-x}Fe_{2-y}Cr_yO_4$ *(x=0,0.2,0.4, 0.6, 0.8, and 1.00; y=0, 0.05 and 0.10) were prepared by standard ceramic method. Dielectric constant (έ) and dielectric loss tangent (tan δ) were determined in the frequency range 20Hz to 1MHz at room temperature. To study the behavior, έ and tan δ were plotted against frequency. These plots show dispersion at lower frequencies. Such behavior is attributed to the Maxwell-Wagner interfacial polarization. It is also found that Dielectric constant increases with cadmium content while it decreases with chromium content. This is explained on the basis of conduction mechanism, wherein addition of cadmium content increases conduction and decreases with chromium content*

Keywords: dielectrics, ferrites, magnesium and cadmium ferrites.

INTRODUCTION

Ferrites find many applications at radio frequencies due to their characteristic dielectric properties. The dielectric constant of ferrites depends upon methods of preparation [1], chemical compositions [2] and substitutions [3]. The study of composition and frequency dependence of dielectric behavior gives valuable information regarding localized charge carriers and dielectric polarization. Rezlescu and Rezlescu [4] were studied dielectric parameter as a function of composition, temperature and frequency for Cu-Zn, Cu-Ni and Cu-Mn ferrites. The dielectric properties of Ni-Zn ferrites were studied by Murthy et al [5]. They found that there is decrease in the dielectric constant with increase in frequency and they explained the behavior on the basis of electron happing from Fe^{2+} to Fe^{3+}. Microstructure, frequency and temperature dependent dielectric properties of Co-Li ferrites were studied by Watave et al [6] and explained the behavior on the basis of Koops theory. Bhasker et al [7] studied dielectric properties of Mn added Mg-Cu-Zn ferrites prepared by microwave sintering method. Dielectric behavior of Ti^{4+} substituted Mg ferrites was studied by Ahmed et al [8] and found that dielectric constant decreases with increasing Ti^{4+} concentration. EI Hiti [9] studied the dielectric behavior and ac conductivity of zinc substituted Ni-Mg ferrites.. Effect of Gd^{3+} substitution on dielectric behavior of Cd-Cu ferrite was also studied by Kolekar et al [10] and showed decrease in dielectric constant with Gd^{3+} substitution. Dielectric properties of In^{3+} and Cr^{3+} substituted Mg-Mn ferrites were studied by Lakshman et al [11]. They found that dielectric constant decreases with trivalent substitution and explained the results on basis of space charge polarization.

In this communication we report the behavior of frequency dependent dielectric constant and dielectric loss tangent of Cd^{2+} and Cr^{3+} substituted magnesium ferrites.

MATERIALS AND METHODS

Polycrystalline spinel ferrites with general formula $Cd_xMg_{1-x}Fe_{2-y}Cr_yO_4$(x=0,0.2,0.4, 0.6, 0.8, and 1.00; y=0, 0.05 and 0.10) were prepared by standard ceramic method by using AR grade oxides of Fe_2O_3, MgO, CdO and Cr_2O_3(LOBA- Chemi, India). These oxides were mixed in their atomic weight proportion and wet milled using acetone. The powdered compositions were presintered at 700 ^{0}C for 12 h and sintered at 1050 ^{0}C for 12 h. The powdered compositions were again wet milled and pressed using hydraulic press to form pellets of 1 cm diameter and 2-3 mm in thickness. These pellets were again sintered at 1050 ^{0}C for 12 h for better compaction.

The sintered powder compositions were characterized by X-ray diffraction using Philips powder diffractometer (PW 3710) using CuKα radiation of wavelength 1.54A^0 and by IR absorption spectroscopy, at room temperature, in the range of 350 cm $^{-1}$ to 800 cm $^{-1}$ using FTIR spectrophotometer.

The parallel capacitance (Cp) and loss tangent (tanδ) were measured by using Hewlett-Packard precession LCR-Q meter (model HP 428A) with accuracy 0.05 % for Cp and 0.005 for dielectric loss tangent (tanδ) at room temperature in the frequency range from 20 Hz to 1 MHz. The dielectric constant was then calculated using parallel capacitance.

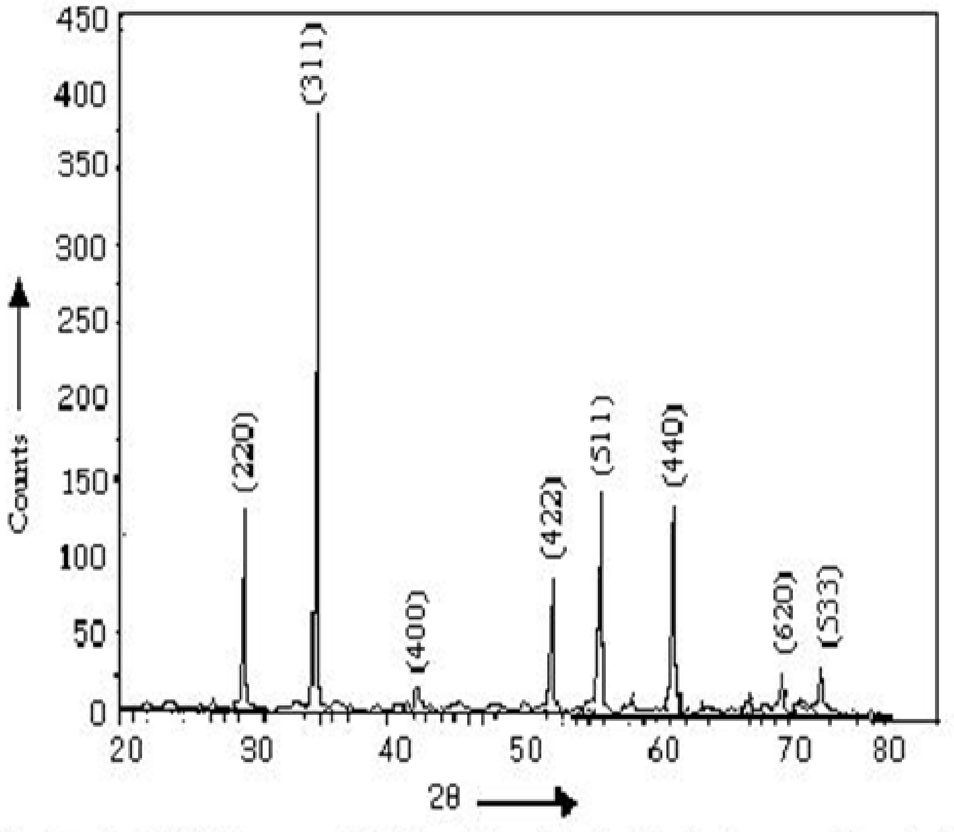

Fig. 1 Typical XRD Pattern of Cd_xMg_{1-x} Fe_{2-y} Cr_y O_4 Ferrite System with x=0.6, y=0

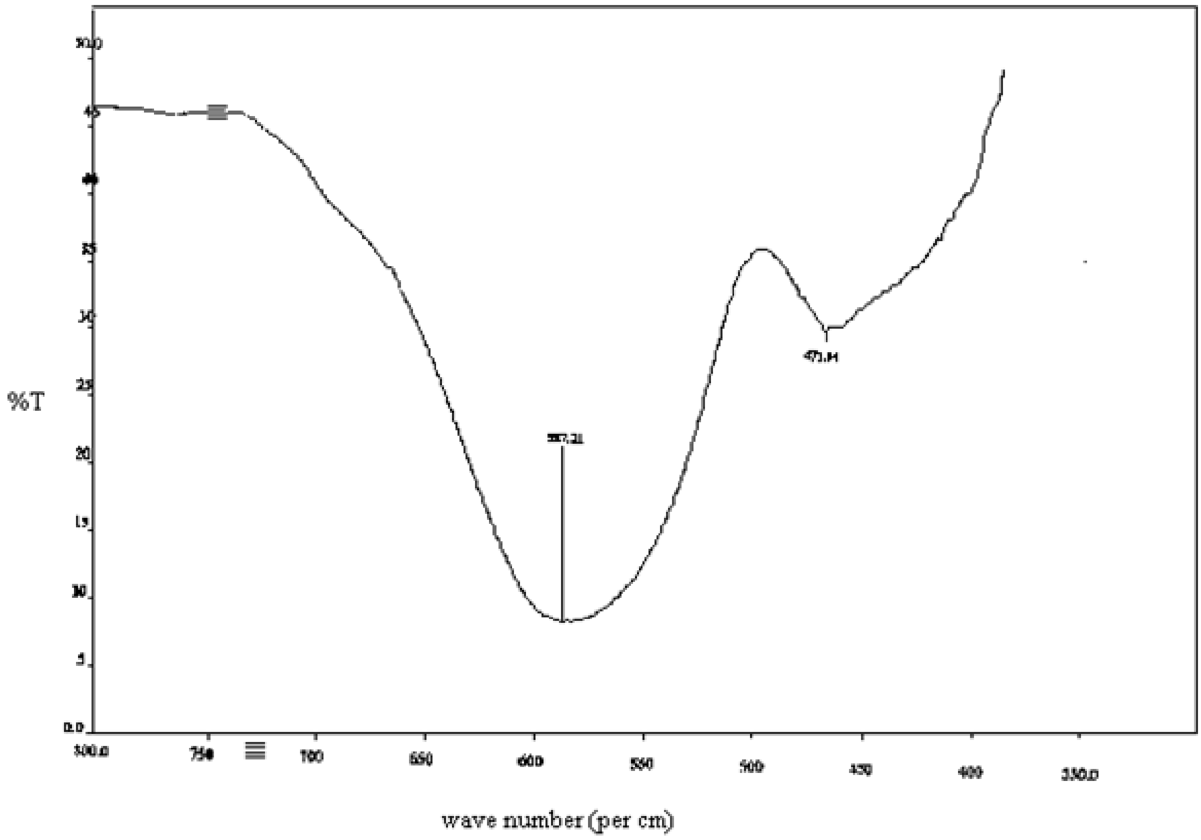

Fig. 2 Typical IR absorption spectrum of $Cd_xMg_{1-x}Fe_{2-y}Cr_yO_4$ ferrite system with x= 0.4, y=0

RESULTS AND DISCUSSION

Characterization

X-ray diffraction study reveals that all the compositions under investigation are face centered cubic spinel. Typical X-ray diffractogram is presented in fig.1. The lattice constant was calculated from X-ray diffractograms and it was found to increase with Cd^{2+} concentration. Such increase in the lattice constant due to addition of cadmium content is reported in the literature [10]. This increase in lattice constant was attributed to the difference in ionic radii of Cd^{2+} ion ($1.03A^0$) and Fe^{3+}ion ($0.67A^0$). On substitution of Cr^{3+} ion, the lattice constant is found to decrease [12]. This also attributed to the difference in ionic radii of Cr^{3+} ion ($0.63A^0$) and Fe^{3+}($0.67A^0$).

Typical IR absorption spectrum is presented in Fig.2. IR absorption spectra of all the compositions show two dominant absorption bands one around 600 cm^{-1} (ν_1) and other at 400 cm^{-1} (ν_2) which are characteristic of ferrite family. The absorption band observed around 600 cm^{-1} (ν_1) is due to the tetrahedral or A-sites and that of around 400 cm^{-1} (ν_2) is due to octahedral or B-sites respectively [13]. This confirms the formation of ferrites under investigation.

Dielectric properties

Graph of dielectric constant (ε) verses Log F were ploted and typical is presented in Fig 3. From these plots it can be noted that there is dispersion of dielectric constant at lower frequencies while at higher frequencies it levels off. The dispersion in dielectric constant at lower frequency suggests that process of polarization is of Maxwell –Wagner interfacial polarization [9,10]. The Maxwell-Wagner polarization in these ferrites is directly related to Verway type conduction [11] with jumping of electrons from $Fe^{2+}$to Fe^{3+}. This clearly shows that electronic and ionic conduction significantly contributes in the polarization process. At lower frequency the grain boundaries of lower conductivity are effective while at higher frequency the ferrite grains of moderate conductivity are prominent. From these plots it is also observed that the dielectric constant of cadmium ferrites in the low frequency range is much higher than that of magnesium ferrites. It is reported in the literature that the dielectric constant is directly proportional to the grain size[12]. In our composition grain size increases with increase in cadmium content, which leads the increase in dielectric constant while grain size decreases with chromium content resulting corresponding decrease in dielectric constant. Such variation of grain size was also reported in the literature[12,13].

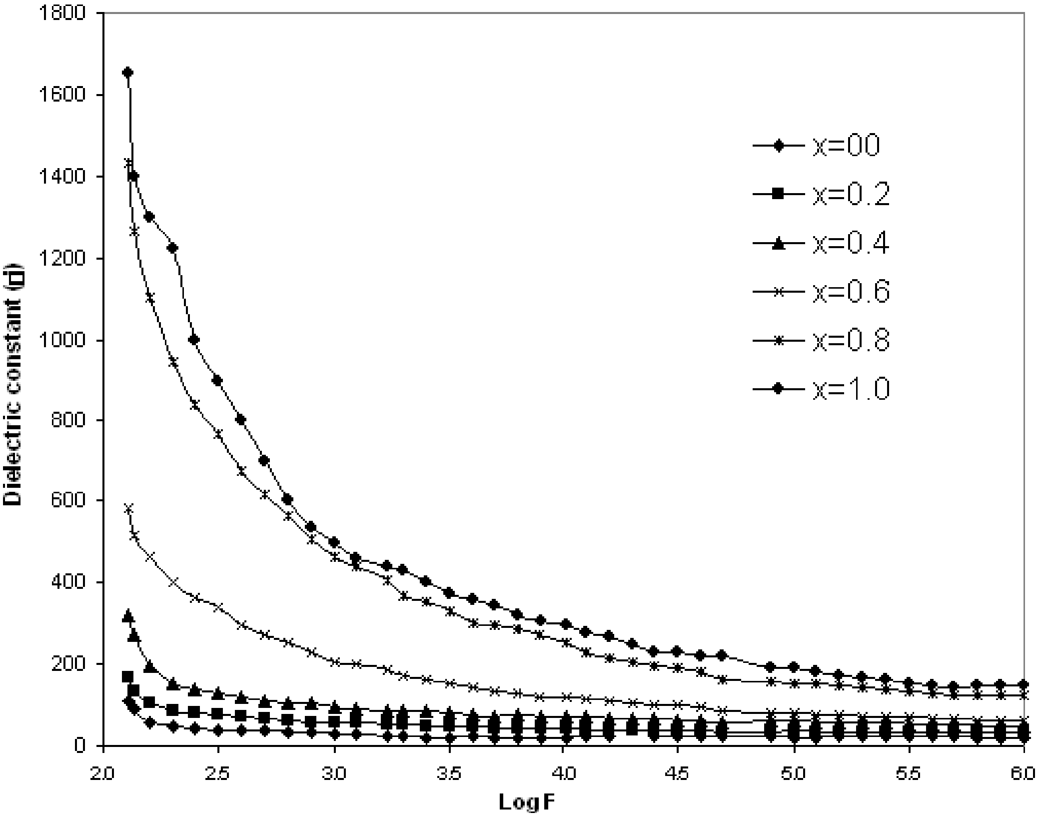

Fig.3. Plot of dielectric constant (ε') Versus Log of frequency for y=00

Graph of dielectric loss tangent (tanδ) versus Log F were ploted and typical is presented in Fig 4. From these plots it can be seen that the dielectric loss tangent decreases with increase in frequency for all the compositions. From these plots it is seen that cadmium ferrites has higher dielectric loss in the low frequency range, which may be due to smaller resistivity of the ferrites. The smaller value of dielectric constant at lower frequency range for $MgFe_2O_4$ is due to larger value of resistivity.

The dielectric constant is higher in chromium substituted cadmium ferrites than that of chromium substituted mixed Mg-Cd ferrites. The decrement in dielectric constant in Mg-Cd ferrites with Cr^{3+}content can be attributed to the increase in resistivity with Cr^{3+} in these ferrites. In Cr^{3+} substituted (y=0.05 and 0.10) Mg-Cd ferrites, Cr^{3+} occupies B-sites [13], which replaces Fe^{3+} ions causing increase in resistivity. Substituted Cr^{3+} participates in the process of polarization. Due to stable valency of Cr^{3+}, it does not contribute to the conduction but provides the hindrance and hence reduction in dielectric constant. Mechanism of dielectric polarization in ferrite is similar to that of conduction mechanism [14]. The increase in the local displacement in direction of applied field determines polarization [15]. It supports increase in dielectric constant with Cd^{2+} content and decrease in dielectric constant with Cr^{3+} content.

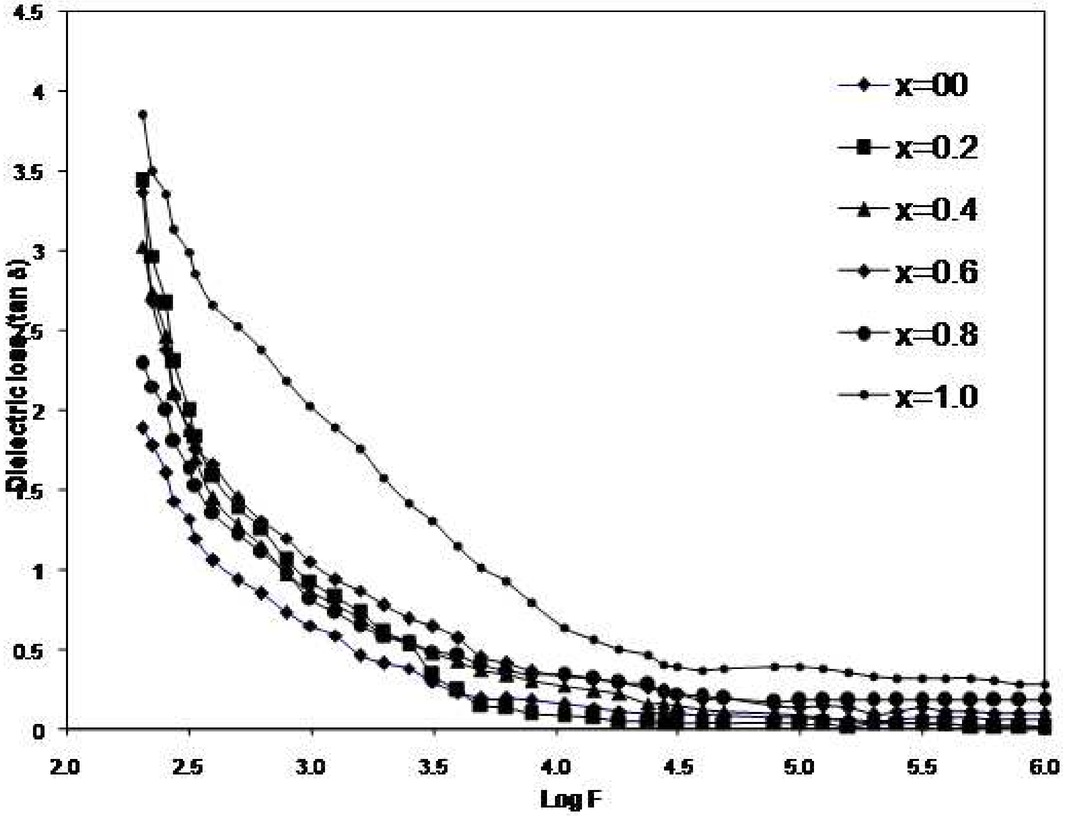

Fig. 4 Plot of dielectric loss tangent versus Log of frequency of ferrites with y=0.05

CONCLUSION

The study of dielectric behavior reveals that dielectric constant and dielectric loss tangent shows dispersion with frequency for Mg-Cd ferrites and Cr^{3+} substituted Mg-Cd ferrites, which is attributed to interfacial polarization. The dielectric polarization depends on composition and found increasing with Cd^{2+}content whereas decrease with Cr^{3+} substitution. Substituted Cr^{3+} ion reduces the conduction resulting in the decrement of dielectric constant and dielectric loss tangent.

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