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Dielectric behavior of Al^{3+} substituted Cd ferrites

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ABSTRACT

The spinel ferrite series of $Cd_1Al_xFe_{2-x}O_4$ where x varies from x=0.0 to 0.5 in the steps of 0.1 were prepared by the conventional double sintered ceramic method. The formation of single phase spinel structure was confirmed from XRD. The dielectric measurements were carried out as a function of temperature using two probe method with L-C-R-Q meter. The dielectric constant, dielectric loss and dielectric loss tangent are calculated using the data. The dielectric parameters show normal dielectric behavior. The dielectric properties i.e., dielectric constant (ε'), dielectric loss (tan δ) decrease with Al^{3+} ion doping.

Keywords: Spinal, Ferrite, Composite Material, Dielectric.

INTRODUCTION

The studies in spinel ferrites are of enormous importance because of their attractive combined electric and magnetic properties. The magnetic properties of ferrites make them useful in transformers, ultrasonic generators, modulators, phase shifters, isolators, memory devises, recording devices, sensors etc. In spinels the intra sub-lattice interactions are weaker than the inter sub-lattice interactions. Due to this there are unsatisfied bonds in the ferrimagnetic region which brings various exchange interactions. These exchange interactions in spinels allows variety of magnetic orders. The magnetic order can be controlled by proper cation substitution. By substituting proper magnetic and non-magnetic cations we can get desired properties resulting from cation distribution in crystal lattice.

The substitution for Fe^{3+} by another trivalent cation is one of the most effective means to control saturation magnetization. The dielectric study of Al^{3+} substituted Fe_3O_4 ferrite nanoparticles N. Kumari, Vinod Kumar, and S. K. Singh, *Int. J. Mod. Phys. B* **28**, 1450193 (2014) has been studied by K. M. Jadhav et. al. [1]. Electrical Properties of Cadmium Substitution in Nickel Ferrites has been studied by Ande Ashok et. al. [2]. Effects of cadmium on physical and magnetic properties of Co-Cd ferrites has been studied by Saroaut Noor et. al. [3].

In the survey of reported work so far, there is no information available to our knowledge about the systemic study of the dielectric behavior of mixed magnetic oxides $CdFe_{2-x}Al_xO_4$. Therefore, the present work is an attempt to study the effect of substitution of non-magnetic cation Al^{3+} on the dielectric properties Cd ferrites.

METHODOLOGY

Synthesis of $Cd_1Al_xFe_{2-x}O_4$

The spinel ferrite series of $Cd_1Al_xFe_{2-x}O_4$ where x varies from x=0.0 to 0.5 in the steps of 0.1 were prepared by the conventional ceramic method. The chemicals for ferrite systems were of analytical grade high purity oxides CdO, Al_2O_3 & Fe_2O_3 were mixed in proper proportion so as to yield the desired stoichiometry composition. Each of these compositions was ground for half an hour in an agate mortar. This mixture was then presintered at 850°C for 24 hours then slowly cooled to room temperature. The presintered samples were gain milled to fine powder. The powder was then pressed at around 5 tones/square inch of pressure to form pellets of about 1 cm in diameter. Pellets of good quality were obtained by using poly vinyl alcohol as binder & maintaining the pressure for about ten minutes each time. The pellets were finally sintered at 900°C for 24 hours and naturally cooled to room temperature.

The X-Ray diffraction patterns for all the powdered samples were recorded on X-ray diffractometer by using CuKα radiation with wavelength 1.542 Å.

The dielectric measurements were carried out as a function of temperature using two probe method with L-C-R-Q meter.

RESULTS AND DISCUSSION

X-ray diffraction

The X-ray diffraction patterns of all the six samples of the $Cd_1Al_xFe_{2-x}O_4$ system are shown in **figure (1)**. The formation of single phase spinel structure was confirmed from XRD.

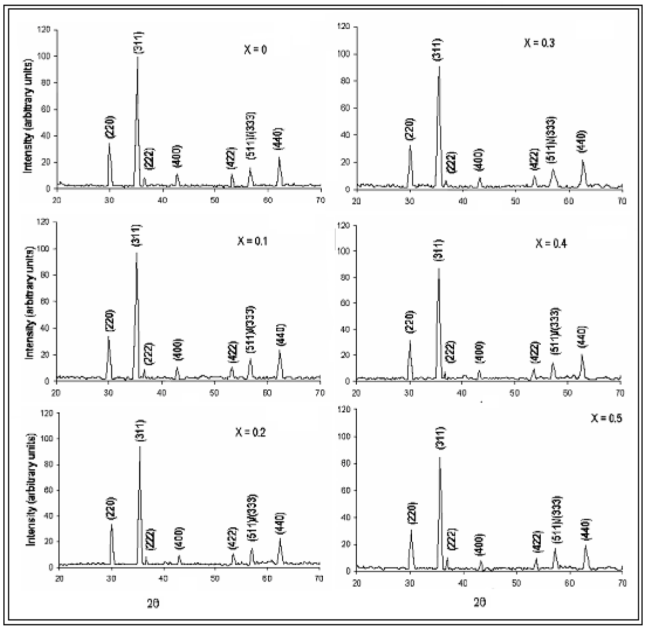

Figure1. Typical X-ray diffractograms of the $Cd_1Al_xFe_{2-x}O_4$ system.

Dielectric Properties

The dielectric measurements were carried out as a function of temperature using two probe method with L-C-R-Q meter at the Dept. of Physics, Dr. B.A.M.U. Aurangabad. The dielectric constant, dielectric loss and dielectric loss tangent are calculated using the data.

The values of dielectric constant (ε′) have been calculated and the variation of dielectric constant as a function of temperature at 1 K.Hz. frequency for all the samples is shown in **figures (2 to 3)**. The dielectric constant is found to increase gradually with increase in temperature up to 600 K and thereafter increases rapidly with temperature.

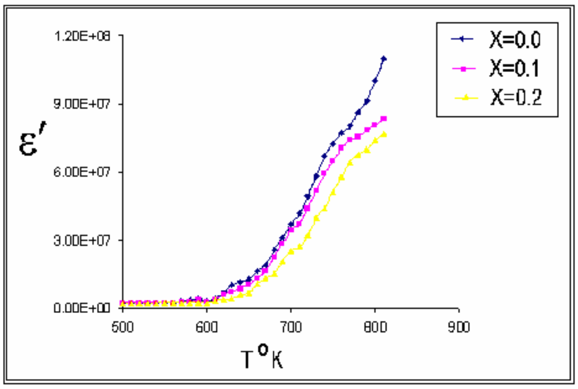

Figure 2. Variation of dielectric constant **(ε′)** as a function of temperature for $Cd_1Al_xFe_{2-x}O_4$

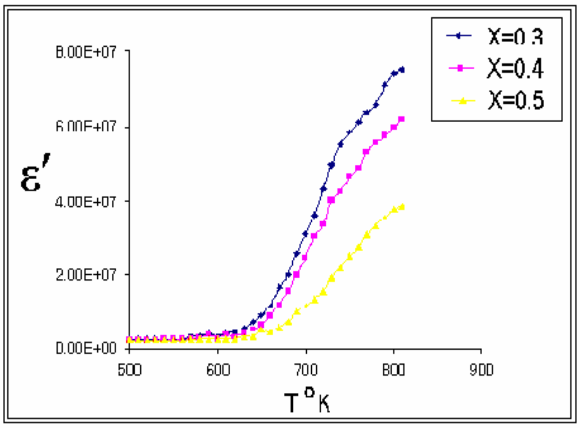

Figure 3. Variation of dielectric constant **(ε′)** as a function of temperature for $Cd_1Al_xFe_{2-x}O_4$

The variation in dielectric constant is due to interfacial polarization. The interfacial polarization arises due to distribution of electrical resistivity in ferrites because of non-uniform distribution of oxygen ions induced during the sintering process. Polarization results in an electronic exchange between Fe^{2+} and Fe^{3+} ions which produces local displacement in the direction of applied external field. Similarly the Al^{3+} and Al^{2+} ions give hole concentration which produces the local displacement opposite to the direction of applied field. These displacements determine the polarization and dielectric properties in the ferrites. The observed decrease in dielectric constant is normal dielectric behavior which may be due to interfacial polarization explained on the basis of Koop's theory [4] in accordance with Maxwell–Wagner two layer modal according to which ferrite materials consist of fairly conducting grains separated by less conducting grain boundaries.

Resistivity and dielectric constant are inversely related to each other. Since resistivity of ferrites decreases with the increase in temperature, the increase in dielectric constant with the increase in temperature is the expected result. Such behaviour has been reported in number of ferrite systems [5-7]. As the temperature rises, the number of charge carriers increases resulting in increase of space charge polarization [8-9] and hence there is increase in dielectric constant. With the increase in Al^{3+} concentration the number of charge carriers decrease resulting in decrease of dielectric constant.

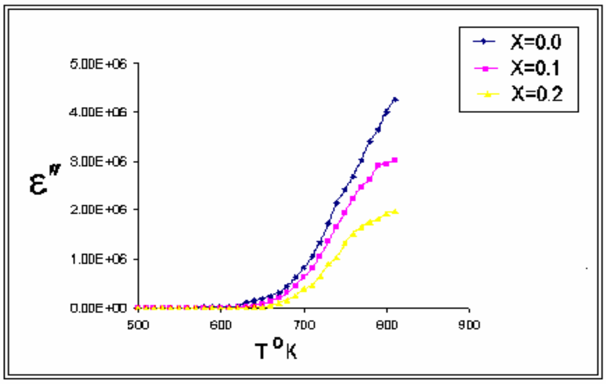

Figure 4. Variation of dielectric loss **(ε′′)** as a function of temperature for $Cd_1Al_xFe_{2-x}O_4$

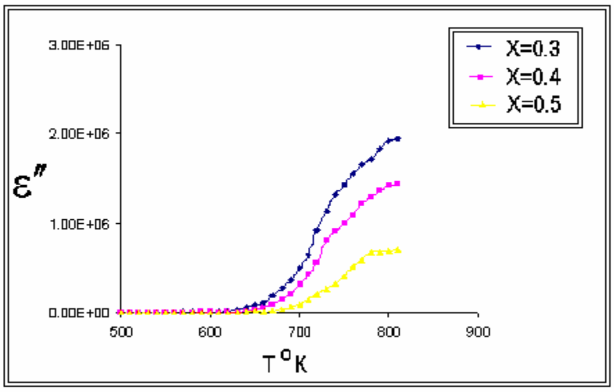

Figure 5. Variation of dielectric loss **(ε′′)** as a function of temperature for $Cd_1Al_xFe_{2-x}O_4$

The variation of dielectric loss (ε′′) with temperature for all the samples is shown in **figures (4 to 5)**. It is observed that the dielectric loss varies very slowly up to temperature 650 K (approximately) and then increases rapidly with the increase in temperature. This behavior of dielectric loss is in full agreement with that obtained by V. A. Loffe et. al. [10] for spinel ferrites. The dielectric loss decreases with increase in Al^{3+} concentration of the system [11].

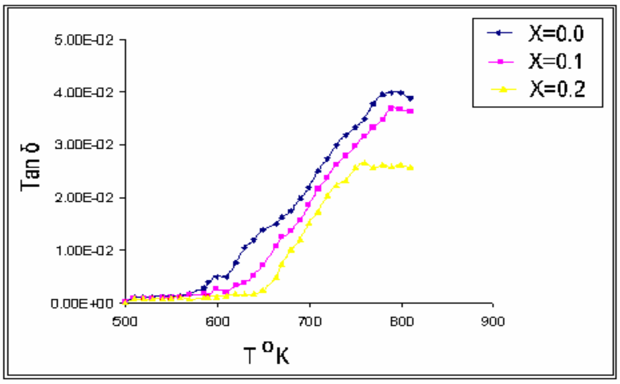

Figure 6. Variation of dielectric loss tangent **(tanδ)** as a function of temperature for $Cd_1Al_xFe_{2-x}O_4$

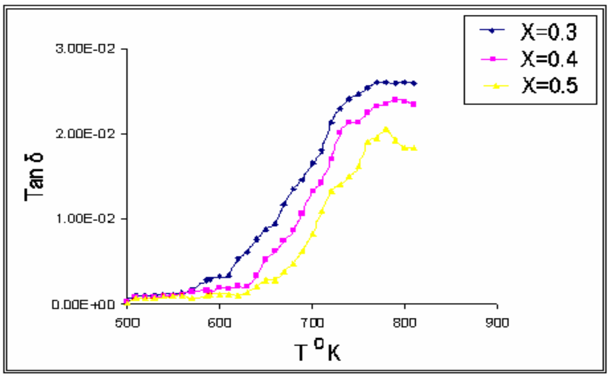

Figure 7. Variation of dielectric loss tangent **(tan δ)** as a function of temperature for $Cd_1Al_xFe_{2-x}O_4$

The thermal variation of dielectric loss tangent (tanδ) is as shown in **figures (6 to 7).** Similar to dielectric loss, dielectric loss tangent (tanδ) also increases slowly in the beginning and then rapidly increases with the increase in temperature. It is in agreement with a general rule that (tanδ) appreciably increases with the rise in temperature [12]. The dielectric loss tangent decreases with increase in Al^{3+} concentration of the system.

CONCLUSION

The system $Cd_1Al_xFe_{2-x}O_4$ with x = 0 to 0.5 (with step of 0.1) has a single phase spinel structure. The dielectric constant decreases with increase in Al^{3+} content. The dielectric loss decreases with the increase in Al^{3+} content. The dielectric loss tangent decreases with increase in Al^{3+} concentration of the system. The dielectric parameters show normal dielectric behavior in accordance with Maxwell–Wagner two layer models. Low value of dielectric loss (tan δ) obtained in these ferrites is suitable for devices where low core losses are required

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Conflicts of interest: The authors stated that no conflicts of interest.

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