DIELECTRIC PROPERTIES OF $Co_xMg_{1-x}Fe_2O_4$ FERRITE SYSTEM

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ABSTRACT:

The ferrite samples $Co_xMg_{1-x}Fe_2O_4$ with x= 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 were synthesized by ceramic technique. The dielectric properties such as dielectric constant (ε'), ac resistivity (ρ_{ac}), dielectric loss (tan δ) and complex dielectric constant (ε'') of ferrite samples were studied as a function of frequency as well as cobalt content. The significant changes in dielectric parameters in these samples are explained with the help of Maxwell-Wagner interfacial polarization and Koops phenomenological theory.

Keywords: Ceramic technique, dielectric constant and dielectric loss.

Introduction:

Materials in which an electric field can be sustained with a minimum dissipation of power are called as dielectrics. Ferrites are dielectrics and the electric response of dielectrics can be described by its break down strength, ac resistivity, dielectric loss, dielectric constant and time variation of electric field.

The Mg-ferrite is one of the most widely used component of microwave ferrite family [Van Hook, 1972]. The Mg-ferrite is also an important material in the radio engineering and refractory industries. The Co-ferrite on the other hand is promising material for magneto-elastic stress sensors [Paulsen J et. al, 2005]. The Co-ferrite is also used in medical applications as it has high positive magneto-crystalline anisotropy [Amiri S.et.al, 2013]. While the Mg-ferrite has negative magneto-crystalline anisotropy. Thus in the $Co_xMg_{1-x}Fe_2O_4$ ferrite system, the competition between Mg^{2+} and Co^{2+} ions for a particular site in the spinel lattice is expected to give interesting dielectric properties. The dielectric properties of Co-Mg ferrites synthesized by Sol-gel method are already reported [Sharma J. et.al, 2015 and Vithal Vinayak et.al, 2015]. Here the dielectric properties of $Co_xMg_{1-x}Fe_2O_4$ ferrites synthesized by ceramic technique are reported.

EXPERIMENTAL:

The ferrite system $Co_xMg_{1-x}Fe_2O_4$ (with x = 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0) were synthesized by the ceramic technique. High purity ferric oxide (Fe_2O_3), cobalt oxide (CoO) and magnesium oxide (MgO) were taken in calculated molar proportions and mixed thoroughly in the acetone medium in agate mortar. The pre-sintering was carried out at 800^0C for 10 hours and samples were cooled at the rate of 80^0C per hour.

To prepare pellets, approximately 1 gm of pre-sintered powder was taken and subjected to a pressure of about 5 tonnes per square inch for two minutes by keeping it in a die of 1 cm diameter. The pellets were again sintered at 1250^0C for 40 hours and cooled at the rate of 80^0C per hour.

The dielectric properties of $Co_xMg_{1-x}Fe_2O_4$ ferrite system were made with the help of a LCR bridge (model H.P. 4275 and 4284) in the frequency range 10 Hz to 10 MHz with excitation voltage of 5 mV,at Meltron, Pune.

RESULTS AND DISCUSSION:

The dielectric parameters such as dielectric constant (ε'), dielectric loss tangent ($\tan\delta$) and ac resistivity was calculated from capacitance C using the equations.

$$\varepsilon' = \frac{Ct}{A} \times 11.4$$
$$\varepsilon'' = \varepsilon' \tan\delta$$

Where;   t is thickness of pellet
           A is cross-sectional area of the flat surface of the pellet.
           ε'' is complex dielectric constant
           δ is phase angle (time lag quantity)

The variation of dielectric constant (ε'), ac resistivity (ρ_{ac}) and dielectric loss ($\tan\delta$) with frequency for $Co_xMg_{1-x}Fe_2O_4$ ferrites are shown in Fig. 1, 2 and 3 respectively.
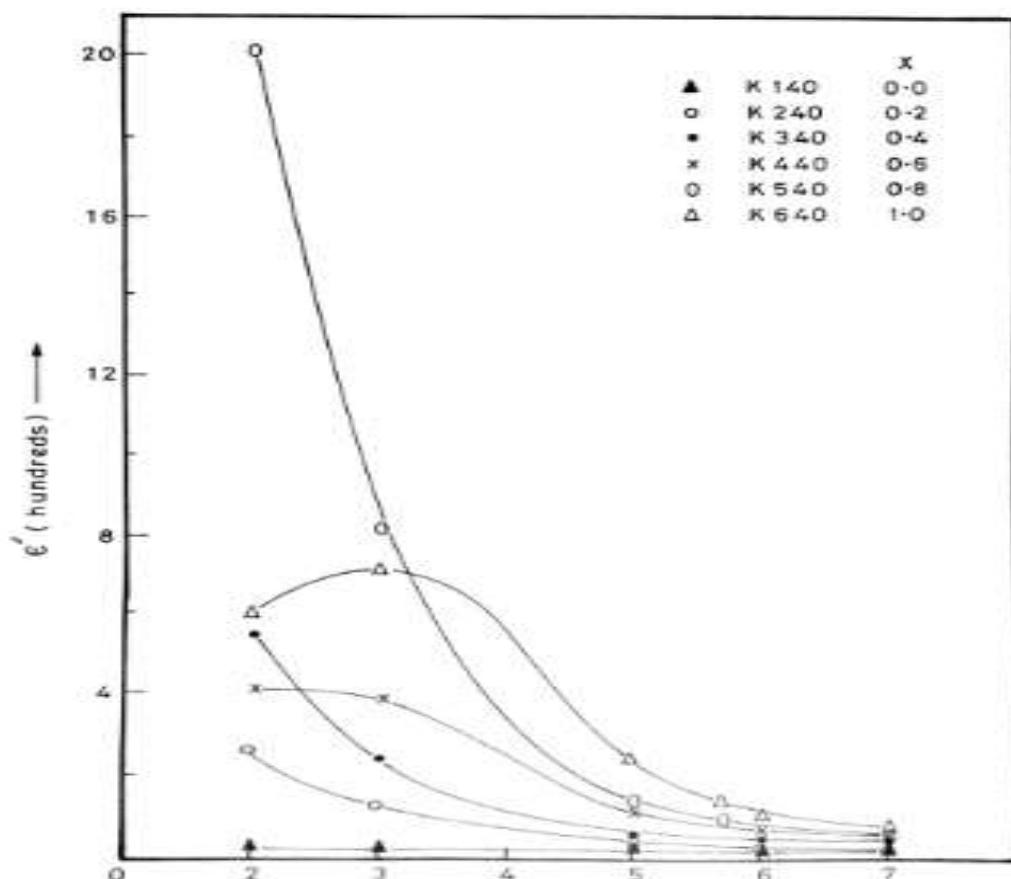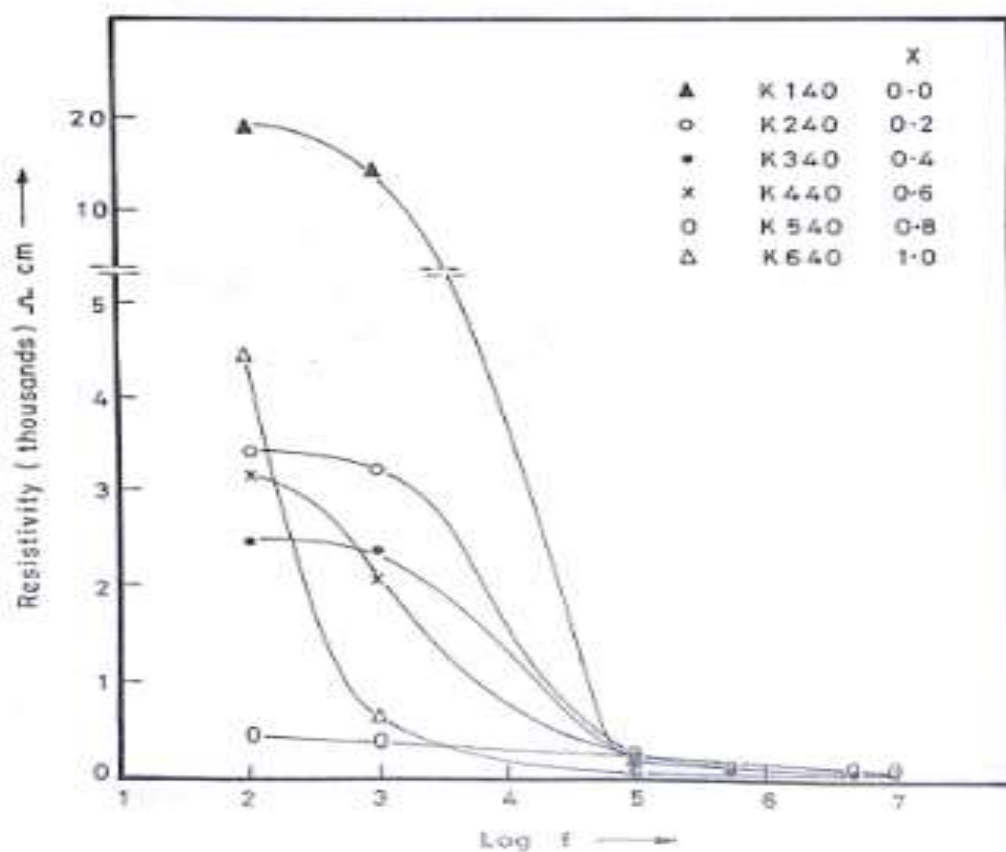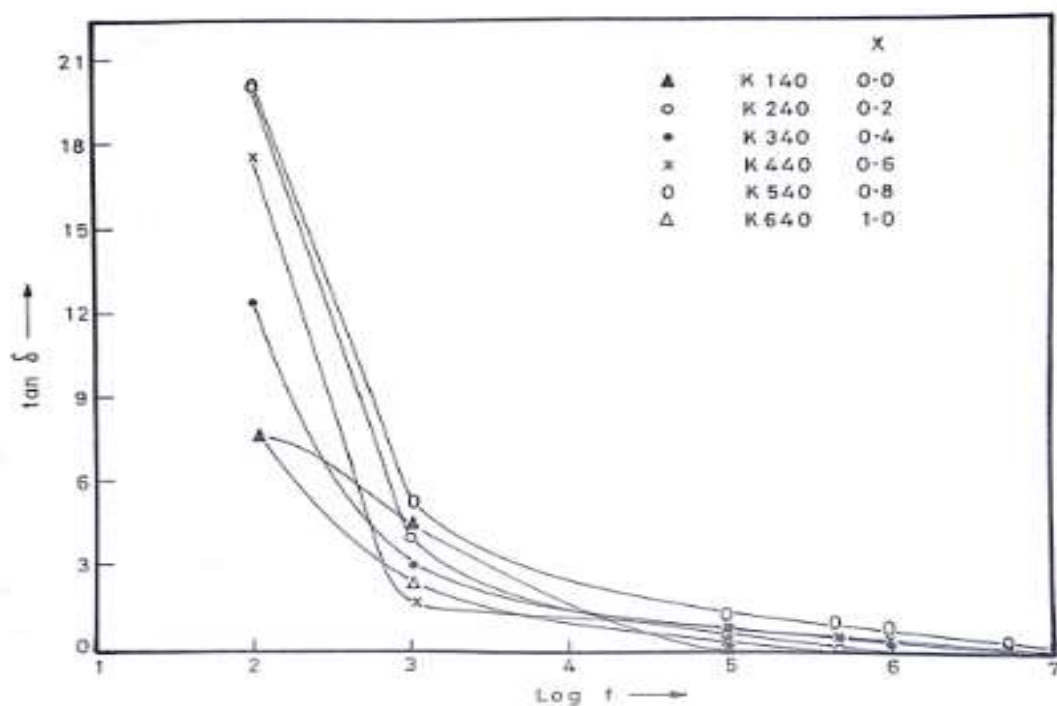

Fig:1. variation of ε' with log f of $Co_xMg_{1-x}Fe_2O_4$ ferrite system

Fig:2. variation of resistivity with log f of $Co_xMg_{1-x}Fe_2O_4$ ferrite system.

Fig:3. variation of tanδ with log f of $Co_xMg_{1-x}Fe_2O_4$ ferrite system.

The significant changes in the dielectric parameters are observed and are large on the low frequency side and tend to level off for the frequencies greater than 100 KHz. Such a behavior is exhibited due to the Maxwell [1973] – Waguer [1913] interfacial polarization in agreement with Koops phenomenological theory [1972] . In ferrites, there are various possible mechanism for polarization -like electronic, ionic, dipolar and space charge. The decrease in polarization with increasing frequency is due to fact that beyond a certain frequency, the electron exchange $Fe^{2+} \leftrightarrow Fe^{3+}$ cannot follow the alternating field.

The behavior of dielectric constant (ε') and resistivity (ρ_{ac}) as a function of cobalt content are represented in Fig. 4 and 5 respectively at different frequencies.
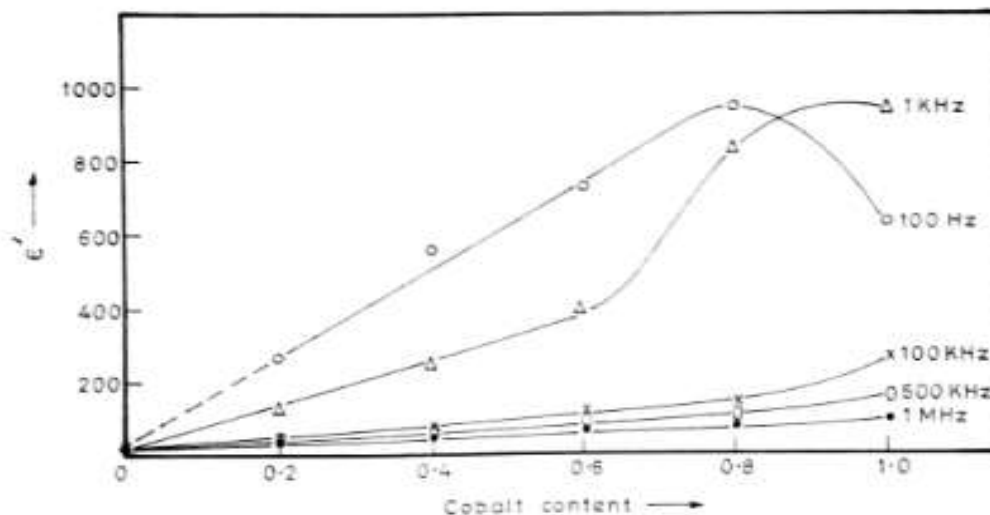

Fig:4. variation of ε' with cobalt content of $Co_xMg_{1-x}Fe_2O_4$ ferrite system at different frequencies.

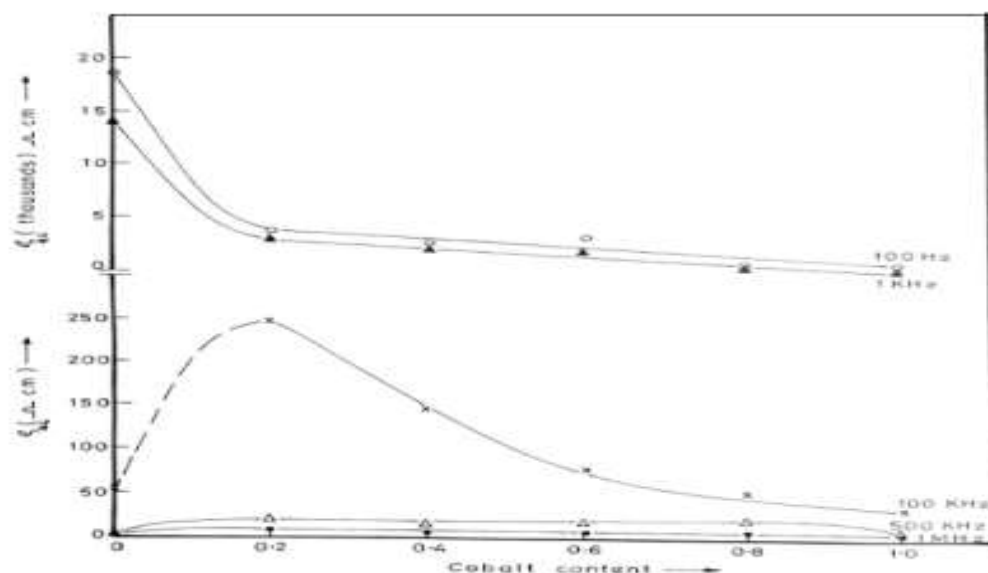Fig:5. variation of resistivity with cobalt content of $Co_xMg_{1-x}Fe_2O_4$ of ferrite system at different frequencies.

From Fig. 4, it is seen that dielectric constant (ε') increases with increasing cobalt content at frequencies 100 Hz, 4KHz and 500 KHz. On the other hand, from Fig. 5, it is observed that

resistivity decreases with increasing cobalt content at frequencies 100 Hz, 1KHz, 100 KHz and 500 KHz. At higher frequencies, resistivity as well as dielectric constant is almost independent of cobalt content.

The compositional variation of dielectric constant can be explained by assuming that the mechanism of dielectric polarization is similar to that of conduction processes. Accordingly, the presence of cobalt on the octahedral site of spinel ferrite favors the conduction mechanism.

$$Co^{2+} + Fe^{3+} \leftrightarrow Co^{3+} + Fe^{2+}$$

As the concentration of cobalt content is increased, more number of Co^{2+} ions will be present at the octahedral site. As the number of Co^{2+} ions are increased, the mechanism $Co^{2+} \rightarrow Co^{3+}$ becomes more and more dominant and increase in dielectric loss is expected if the loss is arising due to the hopping between these ions. In the present study, increase in dielectric loss with increase in cobalt content is observed. This is due to the hopping mechanism between Co^{2+} & Co^{3+} and Fe^{2+} & Fe^{3+} ions.

In Table 1, the data on complex dielectric constant (ε'') and dielectric loss (tan δ) at 100 KHz and 500 KHz is presented.

Table 1 : data on complex dielectric constant and dielectric loss for $Co_xMg_{1-x}Fe_2O_4$ ferrite system at frequencies 100 KHz and 500 KHz

x	100 KHz		500 KHz	
	ε''	tan δ	ε''	tan δ
0.0	2	0.08	0.7	0.02
0.2	15	0.50	4.0	0.16
0.4	29	0.55	9.2	0.21
0.6	67	0.65	26.5	0.41
0.8	122	1.14	63.2	0.84
1.0	158	--	76.0	--

From Table 1, it is seen that with increasing cobalt content, complex dielectric constant (ε'') and dielectric loss (tanδ) increase at both frequencies. The complex dielectric constant and dielectric loss are less at 500 KHz than at 100 KHz. In spinel ferrites, one can expect that with increasing frequency, dielectric constant (ε') and hence the complex dielectric constant (ε'') should go on decreasing . The same trend is observed in $Co_x Mg_{1-x} Fe_2O_4$ ferrite system.

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