Dielectric studies of nano ferrites useful for moderate frequency dependent high performance devices

Daruka Prasad B[1,*], Nagabhushana H[2], K Thyagarajan[3]

[1] *Department of Physics, BMS Institute of Technology and Management, VTU Belagavi Affiliated, Bangalore - 560 064, India*
[2] *Prof. CNR Rao Centre for Advanced Materials Research, Tumkur University, Tumkur - 572 103, India*
[3] *Department of Physics, JNTUA College of Engineering, Pulivendula - 516 390, India*

***

Abstract - In this work, Mg1-xZnxFe2O4 (x = 0.00, 0.25, 0.50, 0.75 and 1.00) nano ferrite particles were prepared by using the solution combustion method. The effects of composition on the dielectric properties of the samples were studied using an impedance analyzer over a frequency range from 100 Hz to 10 MHz at room temperature. The dielectric properties of the samples showed that the dielectric permittivity and the dielectric loss tangents were decreased with increase in Zn2+ composition. Complex impedance plots constructed for the samples showed distorted semicircles with increasing diameter as a function of the Zn2+ composition, indicating improved resistance.

Key Words: Nanoparticles, Dielectrics, Grain boundaries.

1. INTRODUCTION

Magnesium ferrites are very good dielectric materials and have found wide spread applications in microwave devices because of their low eddy current and low dielectric losses [1]. The dielectric properties of these ferrites depend on many factors such as the method of preparation, grain size and the substituted ions type and concentration. The addition of nonmagnetic Zn^{2+} ions results in modifications to the dielectric properties of magnesium ferrites. In this work, It is reported on the complex impedance and dielectric behaviour of nanocrystalline Mg-Zn ferrites at room temperature (RT) over a frequency range from 100 Hz to 10 MHz. The reported results may be useful in designing improved transducers and electro optic and electromagnetic values.

2. EXPERIMENTAL

Mixed Mg-Zn ferrites were prepared by the solution combustion technique. In our previous work [2], it was reported on the preparation methods and performed a detailed characterization of the samples. To study the dielectric and impedance properties of the same samples, the powder samples were pressed into pellets using hydraulic pelletizer by applying 5 T pressure for 5 min. The surfaces of the pellets were polished and coated with AR grade silver paste to ensure the conductivity through the samples. The dielectric and impedance measurements were carried out using an Alpha-A high performance frequency analyzer (Novacontrol, Germany).

3. RESULT AND DISCUSSION

Figure 1 presents the dielectric permittivity (ε′) plots for the as-synthesized $Mg_xZn_{1-x}Fe_2O_4$ (x = 0.00, 0.25, 0.50, 0.75 and 1.00) ferrite nanoparticles studied over a frequency range from 100 Hz to 10 MHz at (RT) . The dielectric permittivity was found to decrease sharply at lower frequencies and is almost frequency independent over the higher frequency region. The variation in the dielectric permittivity as a function of the frequency can be explained by Maxwell-Wagner type interfacial polarization and also Koops phenomenological theory [3 -5]. According to these models, the ferrite has the conducting grains and the poorly conducting grain boundaries. At lower frequencies, the grain boundaries contribute more to dielectric permittivity, whereas at higher frequencies, only the grains contribute to the same. According to Iwauchi [6], in ferrites the polarization and the variation in the dielectric permittivity are due to the exchange of electrons between Fe^{2+} and Fe^{3+} at the octahedral sites. At higher frequencies the electron exchange cannot follow the changes in the applied alternating field, which results to decrease in polarization. Figure.1 shows the decreasing trend of the dielectric permittivity with the increase in the non magnetic Zn^{2+} composition in the present samples. This is due to the increase in the resistivity of the Mg-Zn ferrite with the Zn^{2+} concentration, as the dielectric permittivity is inversly proportional to the square root of the resistivity. The loss tangent represents energy dissipation in the ferrite system. The dielectric loss arises when the polarization lags behind the applied field. The variations in the loss tangent (tan δ) as a function of the frequency at RT are shown in Fig.2.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 11 | Nov - 2021 ISSN: 2582-3930

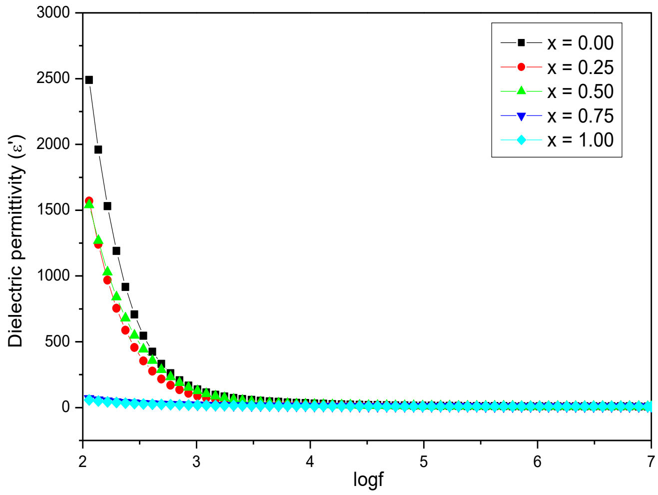

Fig.1 Variation of real part of dielectric permittivity (ε') with frequency for $Mg_xZn_{1-x}Fe_2O_4$ ferrite nanoparticles

Abnormal dielectric loss behavior is observed in all of the samples and is due to the resonance effect. All of the samples exhibit peak behaviour and these loss peaks occurs when the hopping frequency of the electrons are equal to the frequency of the applied field and when the condition $\omega\tau = 1$ is satisfied [7]. It is observed that ω_{max} shifts towards the lower frequency side as the Zn content increases. The decrease in ω_{max} indicates that the hopping probability per unit time decreases as the Zn^{2+} ion content increases. This reduction in jumping probability may be due to the decrease in the concentration of the iron ions at the octahedral sites, which are responsible for the polarization of these ferrites.

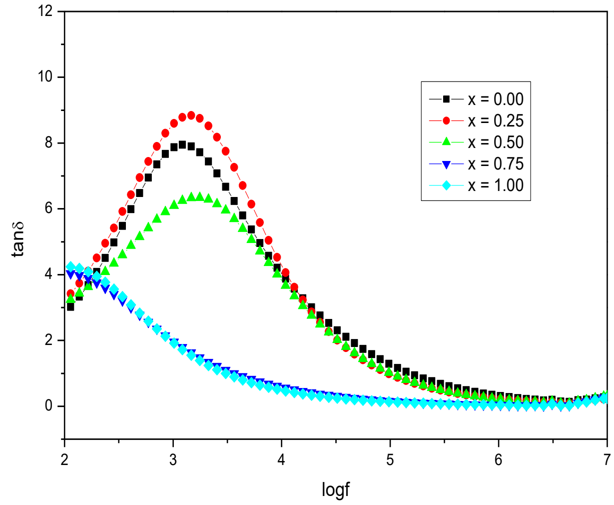

Fig.2 Variation of tanδ with frequency of $Mg_xZn_{1-x}Fe_2O_4$ ferrite nanoparticles.

The variation of the AC conductivity ($\log\sigma_{ac}$) as a function of frequency over the frequency range of 100 Hz - 10 MHz at RT is shown in Fig.3.

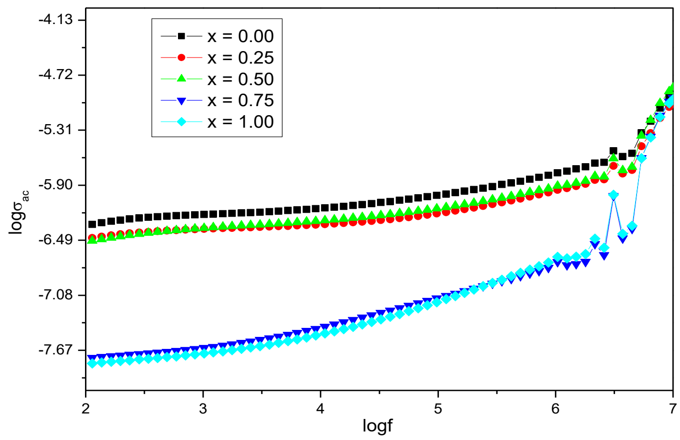

Fig.3 Variation of AC conductivity with frequency of $Mg_xZn_{1-x}Fe_2O_4$ ferrite nanoparticles.

It is observed that the AC conductivity increases linearly with the frequency for the applied field for all the compositions. As the frequency of the applied field increases, the degree of carrier hopping also increases, thereby increasing conductivity. The decrease in resistivity is explained using the Maxwell–Wagner two layer model [3, 8]. This explanation is in consistent with the explanation provided in the first paragraph of the results and discussion section. Fig.3 shows the decreasing trend in the AC conductivity as a function of increasing the Zn^{2+} composition in the studied samples. This is due to the jump length (L) of the charge carrier. The jump length (L) of the tetrahedral (A) and octahedral (B) sites is calculated using relationship [9]:

$$L_A = a\left(\frac{\sqrt{3}}{4}\right) \text{ and } L_B = a\left(\frac{\sqrt{2}}{4}\right) \quad \text{..... (1)}$$

where a is the lattice parameter. It has been observed that the jump length (L) increases with the increase in Zn composition. The observed increase in the jump length implies that the charge carrier requires more energy to jump from one cationic site to another, which causes the increase in resistivity. Hence, the resistivity increases with the increase in the Zn composition.

The contributions from the grain and grain boundaries to the total resistivity in the materials can be understood using complex impedance plots or the Cole-Cole plots. Fig. 4 shows that all of the samples exhibit one complete semicircle, which is due to the conduction of the grains and one incomplete arc which is due to grain boundary conduction. The incomplete arc in the low frequency region indicates that the grain boundary resistance is outside of the measured frequency range. According to the Debye relaxation model,

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 11 | Nov - 2021 ISSN: 2582-3930

the center of the semicircle must lie on the real Z-axis. The observations showed (Fig.4) the existence of a distorted semicircle with its center lying below the real axis, indicating existence of non Debye type relaxation in the studied samples [10].

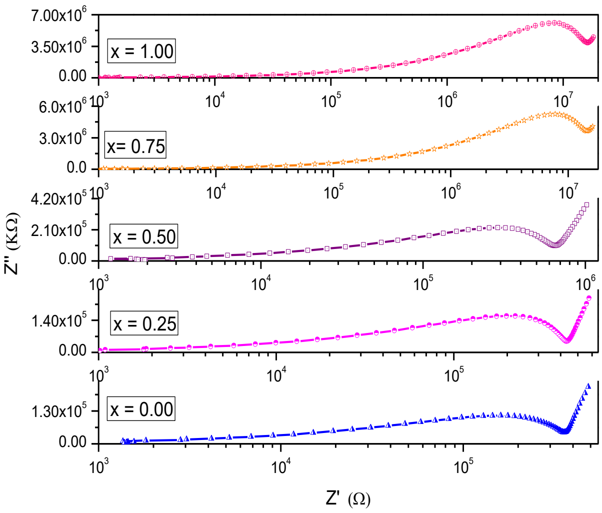

Fig.4 Cole-Cole plots of $Mg_xZn_{1-x}Fe_2O_4$ ferrite nanoparticles.

The observed increase in the diameter of the semicircle containing the Zn^{2+} indicates an increase in the total resistance (which is the sum of the grain and grain boundary resistance). The improved resistance in the samples facilitates the eddy current losses which generally occur at high frequencies. The composition variation in the dielectric permittivity discussed earlier exhibited a decreasing trend. Thus, the tendencies observed for both the dielectric permittivity and impedance measurements are in good agreement with each other.

4. CONCLUSION

Ferrites with a general formula of $Mg_{1-x}Zn_xFe_2O_4$ (x = 0.00, 0.25, 0.50, 0.75 and 1.00) were prepared using the solution combustion method. The dielectric permittivity and loss factor of the samples decrease as the number of Fe^{2+} ions at B-sites decreases. The impedance analysis showed that the improved resistance was related to the material composition. The present samples exhibited reasonably good dielectric properties, which are suitable for the improved designing of transducers and electro optic and electromagnetic values.

Acknowledgements

Author Dr. Daruka Prasad B would like to acknowledge the VGST, Government of Karnataka for funding towards the project [KPSTePS/VGST-RFTT/2016-19/GRD-620/2017-18/156/45611, dated 9.5.2018] which helped in purchasing the chemicals and glass wares. The authors thank CIF, Pondicherry University, for providing experimental facilities.

References

[1] E. Melagiriyappa, H.S. Jayanna, B.K. Chougule, Mater. Chem. Phys 112 (2008) 68.
[2] C. Choodamani, G.P. Nagabhushana, S. Ashoka, B. Daruka Prasad, B. Rudraswamy,
G.T. Chandrappa, J. Alloys. Compd. 538 (2013) 103.
[3] J.C. Maxwell, Electricity and magnetism..1(1954) 328.
[4] K.W. Wagner, Ann. Phys. (Leipzig) 40 (1913) 817.
[5] C.G. Koops, Phys,Rev.83 (1951) 121.

[6] K. Iwauchi, Jpn. J. Appl. Phys. 10 (1972) 1520.
[7] S.A. Saafan, S.T. Assar, S.F. Mansour, J. Alloys. Compd. 542 (2012) 192.
[8] K.W. Wagner, Arch. Elektrotechn. 2 (1914) 371.
[9] D. Varshney, K. Verma, Mater. Chem. Phys. 140 (2013) 412.
[10] Ch. Sujatha, K.Venugopal Reddy, K.Sowri Babu, A.Rama Chandra Reddy. M, Buchi Suresh, K.H.Rao,J. Phys. Chem. Solids 74 (2013) 917.