Dielectric Behaviour of $Cu_{0.4}Zn_{0.6}Fe_2O_4$ Nano-Ferrite

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Abstract: **$Cu_{0.4}Zn_{0.6}Fe_2O_4$ Nano ferrite is prepared using Citrate-nitrate sol-gel auto combustion method. Dielectric properties such as dielectric constant and dielectric loss factor are reported for $Cu_{0.4}Zn_{0.6}Fe_2O_4$ ferrite. The variation of dielectric constant and dielectric loss with frequency are measured in the frequency range 100 Hz to 120 MHz at room temperature. Dielectric constant as a function of temperature is studied at different temperatures ranging from 303 K to 500 K using a Wayn Kerr 6500B Precision impedance analyzer. The crystal structure and grain size of the particles are studied using XRD.**

Keywords: **Nanoparticles, spinel ferrite, dielectric constant.**

1. INTRODUCTION

The field of spinel ferrites is well cultivated because of their various potential application and the interesting physics properties involved in it. [1] These materials are finding wide technological applications in making cores of audio frequency and high frequency transformers, coils, chokes, permanent magnets and microwave absorbers. Ferrites are materials of interest for these purposes due to their unique electric, dielectric and magnetic properties. With a view to the understanding of dielectric phenomena in Cu-Zn ferrite, a systematic study of dielectric properties as a function of frequency and temperature is undertaken; the result of the study of dielectric behavior of nano particles of $Cu_{0.4}Zn_{0.6}Fe_2O_4$ in frequency range of 100 Hz to 120 MHz at room temperature as well as on different temperatures ranging from 300 K to 500 K are presented in this paper.

2. EXPERIMENTAL DETAILS

The mixed Cu -Zn ferrite powders having chemical formula $Cu_{0.4}Zn_{0.6}Fe_2O_4$ is synthesized by citrate-nitrate sol- gel auto combustion technique [2]. The as-burnt powder is then ground in an agate mortar to make fine powder and is uniaxially pressed through hydraulic press with pressure of 10 ton/cm^2 to form pallet specimen. By applying silver coating on both sides of pallet appropriate contacts were applied. In this way, pallet was acting as a capacitor. The structural characterization of the sample is carried out by X-ray diffraction (XRD) technique using CuKα radiation (1.5418 Å). Dielectric constant and dielectric loss tangent of prepared sample is measured in the frequency range 100 Hz to 120 MHz at room temperature using Wayn Kerr 6500B precision impedance analyzer available at our center. Capacitance of the pellet is determined from the LCR meter and the dielectric constant of prepared sample is calculated using the formula.

$$\varepsilon' = C\,d / \varepsilon_0 A \qquad (1)$$

Here 'C' is the capacitance of the pellet in farad, 'd' is the thickness of the pellet in meters, 'A' is the cross-sectional area of the flat surface of the pellet and εo is the constant of permittivity for free space ($\varepsilon 0 = 8.86 \times 10^{-12}$ F/m). The imaginary part of dielectric constant ε'' is obtained from the relation:

$$\tan\delta = \varepsilon'' / \varepsilon' \qquad (2)$$

The A.C. conductivity is calculated using the relation

$$\sigma_{ac} = \varepsilon' \varepsilon_0 \omega \tan\delta \qquad (3)$$

The frequency dependence of the dielectric constant of the sample is measured at room temperature as well as in the temperature range 303K to 500 K.

3. RESULT AND DISCUSSION

Structural characterization

XRD pattern of the prepared ferrite sample, obtained through Panalatical X'pert PRO MPD is shown in Figure 1. The crystallite size estimated using the (311) peak and by using Scherrer Formula is 23 nm. The value of lattice constant obtained through calculations is 8.4036 Å.

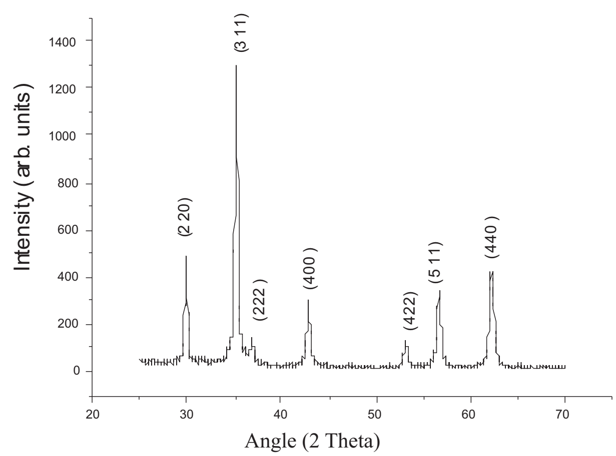

Fig. 1: XRD pattern of ferrite

The SEM image for the ferrite sample is shown in fig. 2. This image shows flake-like grains with nearly uniform dispersion. These results are obtained through SEM model ZEISS EVO18 available at our centre.

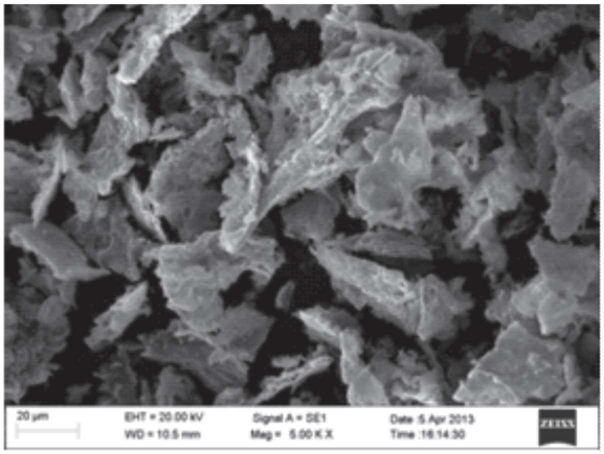

Fig. 2: SEM image of $Cu_{0.4}Zn_{0.6}Fe_2O_4$

Dielectric properties

Dielectric Constant: The behavior of dielectric constant as a function of frequency is obtained at room temperature and is shown in Fig 3. The general trend of variation in ε' is similar to that observed earlier [3] i.e. Dielectric constant decrease with increasing frequency. In ferrites, it is well-known that the samples consist of well conducting grains separated by poorly conducting grain boundaries. The electrons reach the grain boundaries through hopping and if the resistance of the grain boundary is high enough, electrons pile up at the grain boundaries and produce polarization. However, as the frequency of the applied field is increased, the electron does not follow the alternating field. This decreases the probability of electron reaching the grain boundaries and as a result, the polarization decreases as reported by Maxwell [4]. This decreasing behavior of dielectric constant on increasing frequency of the applied field is similar to that reported earlier by Koops [5].

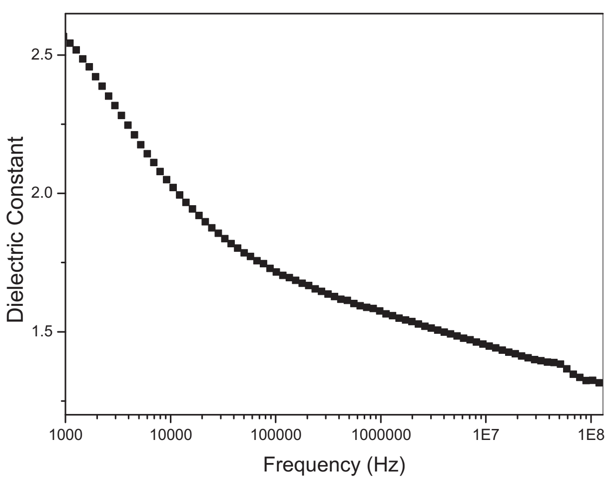

Fig. 3: Variation of dielectric constant (ε') with Frequency at room temperature

Dielectric Loss: Figure 4 shows the variation of dielectric loss tangent tan δ as a function of frequency at room temperature. Initially, there is a decrement in dielectric loss followed by resonance peak with increase in frequency. This behaviour is similar to that reported by Jacob et al. [6]. The appearance of a resonance peak can be explained in a way that if an ion has more than one equilibrium position, say two positions A and B of equal potential energies separated by the potential barrier, the probabilities of jumping of ions from A to B and from B to A are the same. Depending upon this probability, the ion exchanges position between the two states with some frequency, called the natural frequency of jump between the two positions. When an external alternating electric field of same frequency is applied, maximum electrical energy is transferred to the oscillating ions and power loss shoots up, thereby resulting in resonance according to Debye relaxation theory [7].

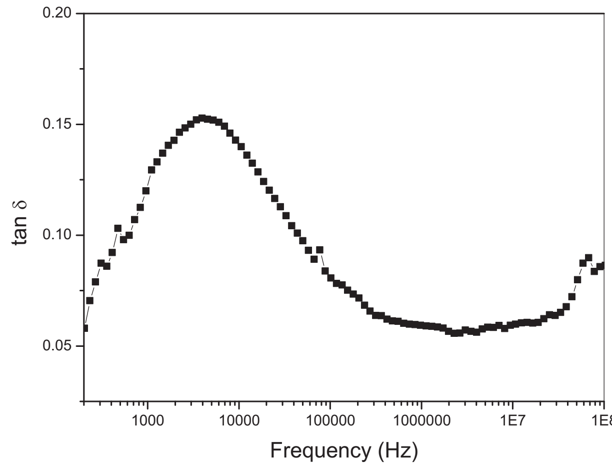

Fig. 4: Variation of loss tangent (tan δ) with Frequency at room temperature

Effect of Temperature Variation: Figure 5 shows the variation of dielectric constant with temperature at different frequencies (1 MHz, 5 MHz, 10 MHz, 100 MHz). At higher frequencies (10 MHz and 100 MHz), the dielectric constant increases gradually with increase in temperature while at lower frequency (1 MHz and 5 MHz) the rate of increase in dielectric constant with temperature is much higher than tested at two other frequencies. This increasing behaviour of dielectric constant with temperature is similar to that realized by Gangatharan et al. [8]. At a fixed temperature designated as dielectric transition temperature (Td) the maximum value of dielectric constant is realized. For our sample, this temperature is 563 K. Beyond this dielectric transition temperature, the values of the dielectric constant is again found to decrease continuously.

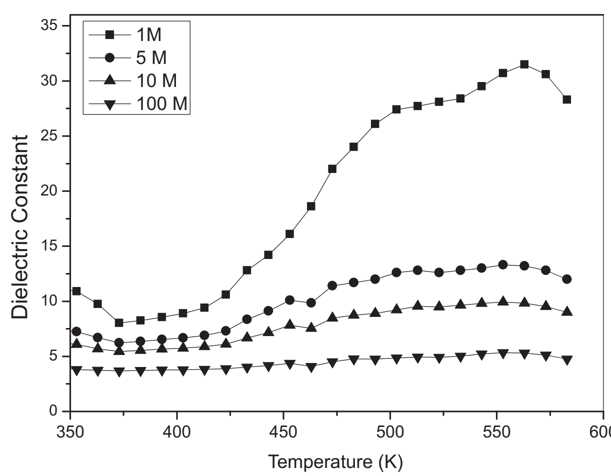

Fig. 5: Effect of temperature on Dielectric constant (∈') for different frequencies

A. C. conductivity

Figure 6 shows the variation of A. C. conductivity ($ohm^{-1}m^{-1}$) with frequency at room temperature.

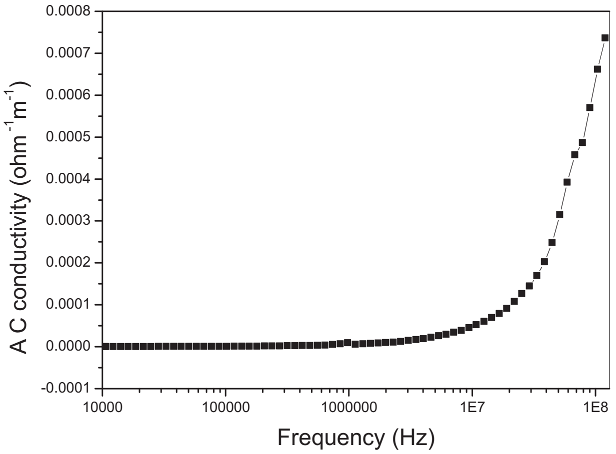

Fig. 6: Plot of AC conductivity (σ_{ac}) with Frequency at room temperature

The composition shows increase in conductivity with increase in frequency, which is the normal behaviour of ferrites. This conduction mechanism in ferrites can be explained on the basis of exchange of charge carriers between Fe^{2+} - Fe^{3+} ions on octahedral sites [8].

4. CONCLUSION

The $Cu_{0.4}Zn_{0.6}Fe_2O_4$ powder is prepared using sol-gel auto-combustion technique. The XRD study of tested sample confirms the formation of spinel phase in the sample. The particle size is found to be 23 nm while obtained lattice constant is close to 8.4036A°. Dielectric constant ε' of prepared sample decreases sharply with increasing frequency while dielectric loss tangent tan δ decreases on increasing the frequency which can be explained qualitatively. The dielectric constant increases with increase in temperature as a result of thermally activated electron hopping between Fe^{2+} and Fe^{3+}. The ac conductivity of prepared ferrite samples is high at higher frequency which can be attributed to localized charge carriers.

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