Complex Permeability Spectra in Ni-Zn Ferrites

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Abstract:

$NixZn_{1}$-$_{X}Fe_2O_4$ ferrites with x = 0.28, 0.30, 0.32, 0.34, 0.36, 0.38, and 0.40 have been synthesized by oxalate precursor method. This paper describes the variation of real [μ′] and imaginary [μ′′] part of permeability for the present ferrite system in the frequency range (20 Hz to 1 MHz) and from room temperature to Curie temperature T_c. The frequency variation of μ′ and μ′′ clearly indicate the low frequency dispersion which may be attributed to domain wall movements. μ′ and μ′′ do not exhibit much variation with temperature except near T_c where they fall sharply. The maximum of μ′′ near T_c has been attributed to the damping effect of domain wall motion. Variation of Relaxation time suggests that the respond of the material to the field slowed down.

Key words: Complex permeability, Oxalate precursor, Relaxation time, Ni-Zn ferrites.

Introduction:

Spinel ferrite plays an important role in ferromagnetic materials. They have paramount advantage of bearing better electrical properties such as electrical resistivity resulting in low eddy current losses over the wide frequency range. Other magnetic properties are high initial permeability, saturation magnetization and temperature stability. In every electronic equipment contains some ferromagnetic spinel ferrite materials such as loud speaker, motors, deflection yokes, antenna rods, memory devices, recording media, filters, inductors are frequently based on ferrites. Ni-Zn ferrites are considered as one of the most versatile spinel ferrites because of its high resistivity and low eddy current losses [1]. These ferrites have been used in RF circuits, high quality filters and transformer cores [2, 3]. Magnetic properties of these ferrites are dependent upon several factors such as compositions, preparatory techniques, sintering conditions, microstructure and doping constituents [4,5].

Various processing techniques included conventional and non conventional have been developed for the synthesis of ferrites. Non conventional methods such as co-precipitation [6, 7], thermal decomposition [8, 9], and sol gel [10] and hydrothermal [11-12] and other wet chemical techniques [13, 14] were widely used. Conventional ceramic method that involve preferring of raw material mixture in temperature range of about 1000^0C then milling and sintering at high elevated temperature are used for preparation of ferrite material. However uncontrollable in homogeneities and sizes of particles associated with this method is one of its disadvantages. For chemical synthesis, precursor compound with

stoichiometry is first prepared then decomposed at lower temperature to get the required metal oxides [15]. The oxalate precursors are usually preferred due to their low solubility, low decomposition temperature and very fine particle nature [16]. In view of this, it was decided to synthesize various compositions of Ni-Zn ferrites using oxalate precursors method and to study their thermal and frequency variation of complex permeability spectra.

Material and Methods:

The oxalates were synthesized by a method suggest by Wickham [17] and modified later by M.Bremer etal [15] for Mn-Zn ferrites. For each composition, iron acetate Fe^{2+} was prepared by adding AR grade glacial acetic acid to the required amount of iron metal powder and distilled water to make a solution. The entire reaction was carried out in CO_2 atmosphere instead of N_2 atmosphere. The required quantity of warm nickel acetate, zinc acetate and thus prepared iron acetate were slowly added to hot ammonium oxalate solution to precipitate the required oxalate complex which is then filtered and dried. In this manner various oxalate complexes having the chemical formula $Ni_xZn_{1-X}Fe_2(C_2O_4)_3.nH_2O$ were synthesized and decomposed at 350^OC for 3 hours. The decomposed powder was then used to prepare a toroids of OD= 2.5 cm and ID= 1cm. Final sintering was carried out at 1050^0C for ten hours in air atmosphere to get $NixZn_1\text{-}_XFe_2O_4$ ferrite system. The synthesized ferrites were characterized by X-ray powder diffraction analysis using Philips diffractometer PW 1710 with CuKα radiation. The initial permeability determinations were carried out using a LCR-Q meter in the temperature range from room temperature to Curie temperature at 1 KHz from low field inductance measurements of coils with toroidal core and in the frequency range 20 Hz to 1 MHz.

Results and Discussions:

A] Thermal variation of μ′ and μ′′:

The complex permeability is given by $\mu = \mu' - i\,\mu''$ where μ′ and μ′′ are real and imaginary part of initial permeability respectively. The real permeability describes the stored energy expressing the component of magnetic induction B in the phase with the alternating magnetic field H. The imaginary permeability describes the dissipation of energy expressing the components of B 90^0 out of phase with alternating magnetic field. The thermal variation of initial permeability components μ′ and μ′′ are represented for the various compositions of $NixZn_1\text{-}_XFe_2O_4$ are shown in temperature range from room temperature to T_c. From Fig. 1, it is observed that μ′ remains invariant with temperature up to T_c. Near T_c, there is a sharp drop of μ′ to zero. Sharp decrease in μ′ suggests a single phase formation of ferrites. This observation supports the conclusion drawn from XRD analysis that all the compositions are single phase. From Fig. 2, it is seen that, with increase in temperature, μ′′ increases, reaches a maximum neat T_c and then falls sharply near T_c. The loss becomes large near T_c, which may be due to the damping effects of the domain walls which may be small.

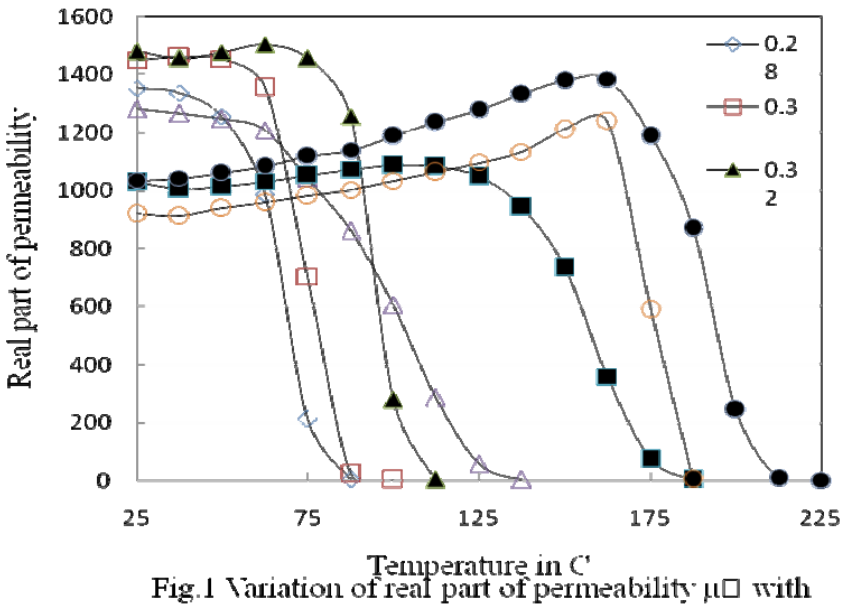

Fig.1 Variation of real part of permeability μ□ with temperature for NixZn1-xFe2O4 ferrites

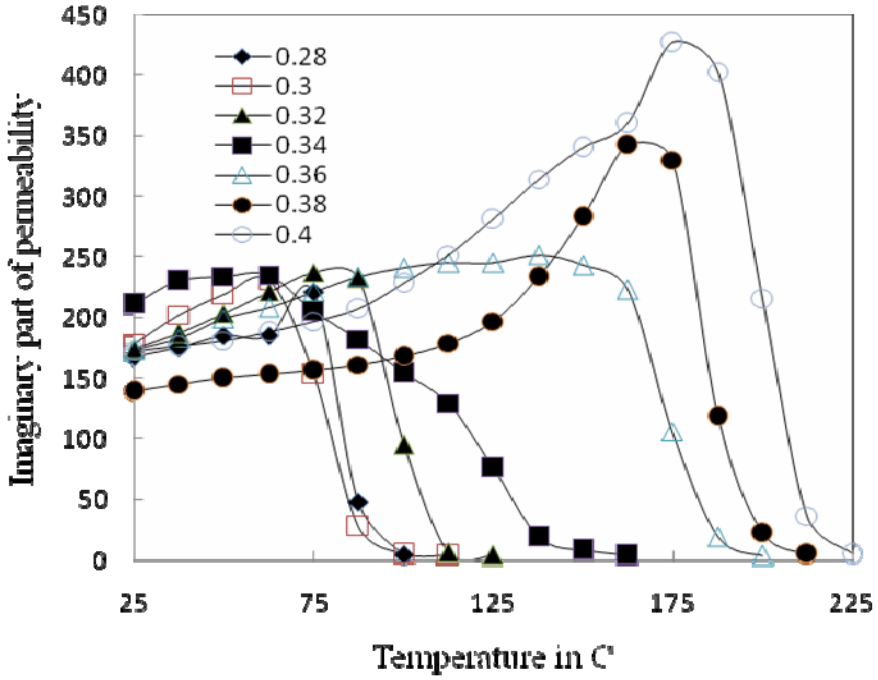

Fig.2 Variation of imaginary part of permeability μ˝ with temperature for NixZn1-xFe2O4 ferrites

B] Frequency dependence of μ´ and μ´´:

From Fig. 3 and 4, it is seen that real part of permeability μ´ increases initially then it remains almost constant between the frequency range 500 Hz to 200 KHz again increases at 1 MHz whereas imaginary permeability gradually decreases and remained constant between the frequency 10 KHz to 200

KHz it again increases at 1 MHz The figure clearly indicates the low frequency dispersion which may be attributed to the domain wall motion. Similar variation of real and imaginary permeability with frequency was reported by Ghodake et al [18] for Ni-Co-Zn ferrites. At low frequency a ferrite inductor is a low loss constant self inductor where μ′ is highest and the core is mostly inductive, rejecting the electromagnetic interference EMI signal to the source. At high frequency where μ′′ parameters becomes more significant, the inductor show high impedance and becomes resistive and dissipative interfering signals rather than reflecting these to the source [19].

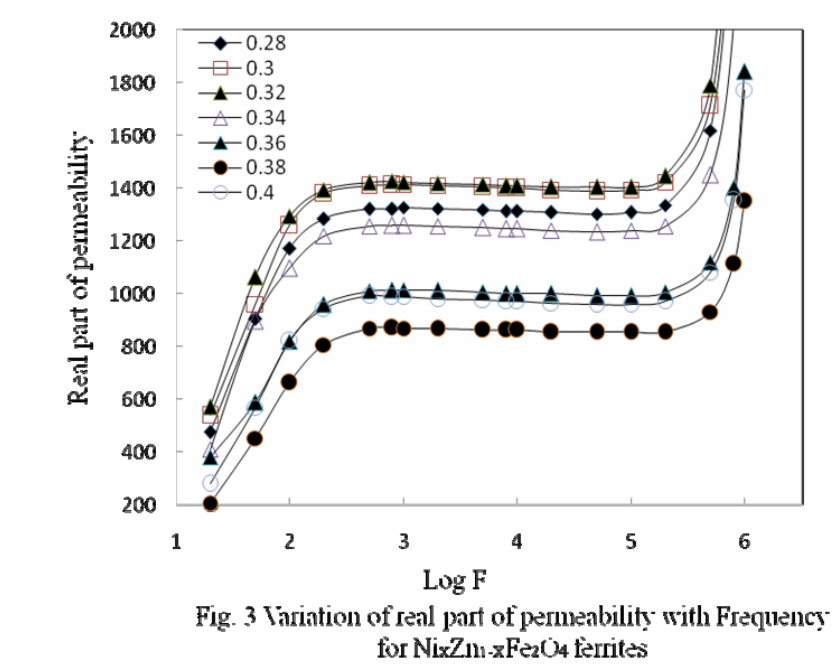

Fig. 3 Variation of real part of permeability with Frequency for $Ni_xZn_{1-x}Fe_2O_4$ ferrites

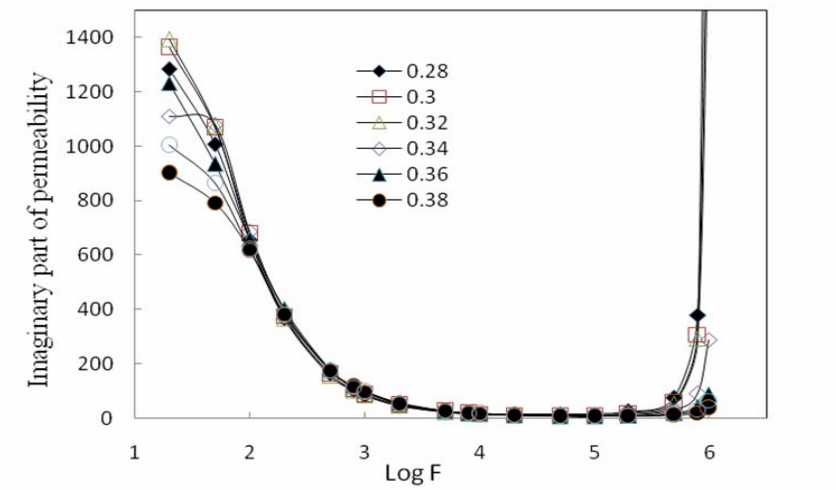

Fig. 4 Variation of imaginary part of permeability with frequency for $Ni_xZn_{1-x}Fe_2O_4$ ferrites

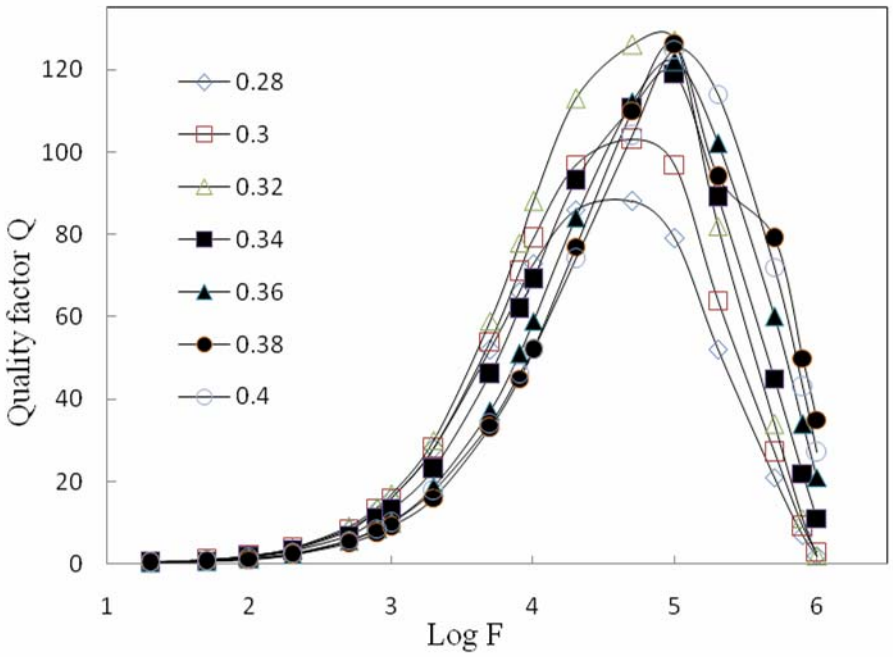

Fig. 5 Variation of quality factor with frequency for $Ni_xZn_{1-x}Fe_2O_4$ ferrites

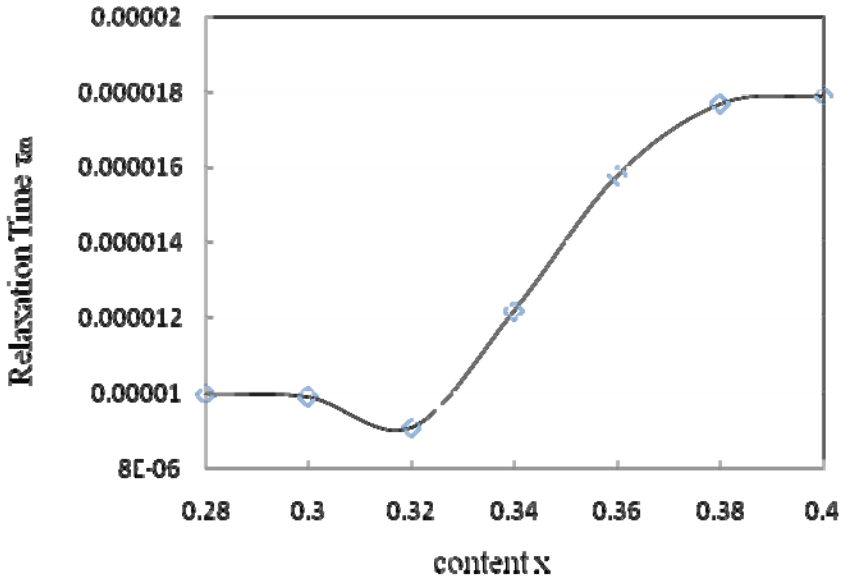

Fig.6 Variation of relaxation time τ_m with content x for $Ni_xZn_{1-x}Fe_2O_4$ ferrites

C] Frequency dependence of Quality Factor Q:

Fig. 5 shows the frequency dependence of quality factor of the sample under investigation. The variation of Q factor with frequency showed a similar trend for all the samples. Q factor increases with an increase in frequency showing a peak and then decreases with frequency. A Similar nature of curves have been observed by M.Marjurul Haque et al [20] for Mg-Cu-Zn ferrites. It is also observed that the peak corresponding to maxima in Q factor shift towards the higher frequency range for the Ni up to x = 0.32 afterword's maxima in Q factor appears at the same frequency for further compositions. The Q factor becomes minimum at higher frequency at 1MHz i.e. the loss tangent is minimum and after it rises. The loss is due to the lag of domain wall motion with applied alternating magnetic field and is attributed to various domain defects [21], which include non-uniform and non repetitive domain wall motion, domain wall bowing and localized variation of flux density, and nucleation and annihilation of domain walls.

D] Relaxation Time (τ_m):

When the magnetic field is applied to a specimen the magnetization does not immediately take-up its equilibrium value but approaches it in such a way that the rate of change of magnetization is proportional to the difference between instantaneous value M and the initial value of magnetization Mo Then,

$$dM/dt = Mo-M/\tau_m \qquad \text{---------- (1)}$$

Where τ_m is constant of proportionality and is known as relaxation time [22]. If the sinusoidal magnetic field is applied H = H' exp (iωt), the resulting magnetization is given by

$$M = Mo / 1+i\omega\tau_m \qquad \text{---------- (2)}$$

Then writing Mo = λoH and $\mu = 1 + \lambda$, it is found

$$\mu'-1 = \lambda o/1+\omega^2\tau^2_m \qquad \text{and } \mu'' = \lambda o\omega\tau_m / 1+\omega^2\tau^2_m$$

$$\tau_m = \mu'' / (\mu'-1)\omega$$

The maximum value of μ'' occurs when $\omega\tau_m = 1$, $\mu''$and $(\mu'-1)$ then have same value [22].

Fig.6 shows the compositional variation of relaxation time τ_m. It is seen that relaxation time is very low for the composition up to x=0.32. For further increase in nickel, it goes on increasing suggesting that the material respond slowly to the applied field.

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