

# Investigations on Complex Permeability Spectra of $\text{Li}^{1+}$ substituted Ni-Zn ferrites

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**ABSTRACT:** Different compositions of  $\text{Ni}_{0.32}\text{Zn}_{0.68-2x}\text{Li}_x\text{Fe}_{2+x}\text{O}_4$  ferrites have been synthesized by using the oxalate precursor's method and investigated for the frequency and thermal variation of real [ $\mu'$ ] and imaginary [ $\mu''$ ] part of permeability and quality factor Q in the frequency range from 20 Hz to 1 MHz and from room temperature to Curie temperature  $T_c$ . Real part of permeability  $\mu'$  do not exhibit much variation with temperature except near  $T_c$ . For lower concentration of  $\text{Li}^{1+}$ , imaginary part of permeability  $\mu''$  increases with temperature up to the Curie temperature  $T_c$  where both  $\mu'$  and  $\mu''$  falls sharply to zero. The frequency variation of  $\mu'$  and  $\mu''$  clearly indicate that the real part of permeability  $\mu'$  increases initially and remains constant between the frequency range 1 KHz to 100 KHz, whereas imaginary part of permeability  $\mu''$  gradually decreases and remained constant between the frequency 10 KHz to 200 KHz, followed by increase at 1 MHz. Quality factor Q decreases with temperature for lithium content up to  $x=0.1$  then after for higher concentration of  $\text{Li}^{1+}$  it remains nearly constant up to  $T_c$ . Q factor increases with an increase in frequency showing a peak and then decreases with further increase in frequency.

**KEYWORDS:** Complex permeability, Oxalate precursor, Quality factor.

## I. INTRODUCTION

The study of spinel ferrites is a great importance from the fundamental as well as applied research point of view. Of all spinel ferrites, the usage of Ni-Zn ferrites has been increasing in the various technological fields such as telecommunication, power applications etc. Ni-Zn ferrites are used in electronic devices suited for both low and high frequency devices because of their high resistivity, high saturation magnetization, hardness and chemical stability [1]. High frequency applications of Ni-Zn ferrites includes large number of microwave components such as circulators, isolators, gyrators, phase shifter, YIG tuned filters, switches and substrates for microwave integrated circuits [2]. Microstructure, magnetic and dielectric properties of Ni-Zn ferrites depend on the method of preparation, sintering condition and doping concentrations [3]. Ni-Zn ferrites synthesized by different methods such as combustion, hydrothermal, citrate, sol gel, oxalate and commonly ceramic method exhibits dissimilar magnetic properties. The preparation of ferrites will influence the parameters such as crystallinity, morphology, particle size and uniformity and affect the magnetic properties. Traditional ceramic method often suffers from stoichiometry, uniformity and high sintering temperature. The chemical synthesis overcome these limitations and makes it possible to synthesize homogeneous and dense ferrites [4-5] at relatively low temperature. Until now, many investigators [6-14] synthesized Ni-Zn ferrites with various substitutions using these various chemical methods and studied their magnetic properties. Complex permeability of ferrites is important factor and many investigations have been carried in experimentally and theoretically [15-17]. In frequency range from radio frequency to the microwave, the permeability spectra of ferrite materials can be characterized by different magnetizing mechanisms i.e domain wall motion, magnetization rotation and gyromagnetic spin rotations [18]. It is well known that the permeability spectra of polycrystalline ferrites can be decomposed into a spin rotational component  $\chi_{\text{spin}}$  and  $\chi_{\text{dw}}$  domain wall component as  $\mu = 1 + \chi_{\text{spin}} + \chi_{\text{dw}}$ . The spin rotational component is of relaxation type (due to large damping factor of spin rotation in the ferrite) and its dispersion is inversely proportional to the frequency. The domain wall component is of resonance type and depends on the square of the frequency.

In present study, it was decided that to synthesis the various compositions of  $\text{Li}^{1+}$  substituted Ni-Zn ferrites using oxalate precursor method and study the temperature and frequency dependence of complex permeability spectra.

## II. EXPERIMENTAL

The oxalates were synthesized by the method suggested by Wickham [19] and later on modified by M. Bremer et al [20] for Mn-Zn ferrites. Lithium oxalate was synthesized by adding hot solution of oxalic acid with Lithium carbonate, was filtered and cooled, when Lithium oxalate was precipitated and then dried [21]. Ni-Zn-Fe oxalate complex was

synthesized by co-precipitation technique using oxalate precursor [19]. Lithium oxalate was mixed to the solid solution of Ni-Zn-Fe for 2-3 hrs. Thus the solid solution of co-precipitated oxalate complexes having general composition,  $\text{Ni}_{0.32}\text{Zn}_{0.68-2x}\text{Li}_x\text{Fe}_{2+x}(\text{C}_2\text{O}_4)_3 \cdot n\text{H}_2\text{O}$  was obtained. The oxalate complexes were decomposed at  $350^\circ\text{C}$  for 3 hours and sintered at  $1050^\circ\text{C}$  for 20 hours to obtain the ferrite system  $\text{Ni}_{0.32}\text{Zn}_{0.68-2x}\text{Li}_x\text{Fe}_{2+x}\text{O}_4$ . The synthesized ferrites were characterized by X-ray powder diffraction analysis using Philips diffractometer PW 1710 with  $\text{CuK}\alpha$  radiation. Toroids were prepared using a die of outer diameter 2 cm and inner diameter 1 cm. The pressure applied was  $10 \text{ ton/m}^2$  for five minutes. Complex permeability spectra determined from initial permeability measurements in the range from room temperature to Curie temperature  $T_c$  at 1 KHz and in the frequency range from 20 Hz to 1 MHz.

### III. RESULTS AND DISCUSSION

#### A] Temperature dependence of $\mu'$ and $\mu''$ :

The complex permeability is given by  $\mu = \mu' - i \mu''$  where  $\mu'$  and  $\mu''$  are real and imaginary part of initial permeability respectively. The real part of permeability describes the stored energy expressing the component of magnetic induction B in the phase with the alternating magnetic field H. The imaginary part of permeability describes the dissipation of energy expressing the components of B  $90^\circ$  out of phase with alternating magnetic field. The thermal variation of initial permeability components  $\mu'$  and  $\mu''$  are represented for the various compositions  $\text{Ni}_{0.32}\text{Zn}_{0.68-2x}\text{Li}_x\text{Fe}_{2+x}\text{O}_4$  are shown in Fig. 1 in the temperature range from room temperature to  $T_c$ . From Fig. 1a, it is observed that  $\mu'$  remains invariant with temperature up to  $T_c$ . Near  $T_c$ , there is a sharp drop of  $\mu'$  to zero. Sharp decrease in  $\mu'$  suggests the single phase formation of spinel ferrites. This observation supports the conclusion drawn from XRD analysis that all the compositions are single phase. From Fig. 1b, it is seen that for lower concentration of  $\text{Li}^{1+}$ , with increase in temperature  $\mu''$  increases, reaches a maximum near  $T_c$  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. For higher concentration of  $\text{Li}^{1+}$  the curves becomes flattened.

#### B] Frequency dependence of $\mu'$ and $\mu''$ :

From Fig. 2a and 2b, it is seen that real part of permeability  $\mu'$  increases initially then it remains almost constant between the frequency range 1 KHz to 100 KHz again increases at 1 MHz whereas imaginary part of permeability  $\mu''$  gradually decreases and remained constant between the frequency 10 KHz to 200 KHz it again increases at 1 MHz. The Figure 3 and 4, clearly indicates the low frequency dispersion which may be attributed to the domain wall motion. We have already shown that the major contribution to initial permeability is due to domain wall movements. The dispersion at frequency 1 MHz is attributed to the spin resonance in the internal anisotropy field. Similar variation of real and imaginary permeability with frequency was reported by Ghodake et al [22] for Ni-Co-Zn ferrites. At low frequency a ferrite inductor is a low loss constant self inductor where  $\mu'$  is highest and the core is mostly inductive, rejecting the electromagnetic interference EMI signal to the source. At high frequency where  $\mu''$  parameters becomes more significant, the inductor show high impedance and becomes resistive and dissipative interfering signals rather than reflecting these to the source [23]. Fig. 3 shows the intersection in the variation of real and imaginary part of permeability with frequency separately. It has been observed that both these curve intersects each other in the lower frequency region between 50 to 500 Hz. The intersection point of frequency of these two characteristics goes on increasing with increase in  $\text{Li}^{1+}$  content in Ni-Zn ferrites.

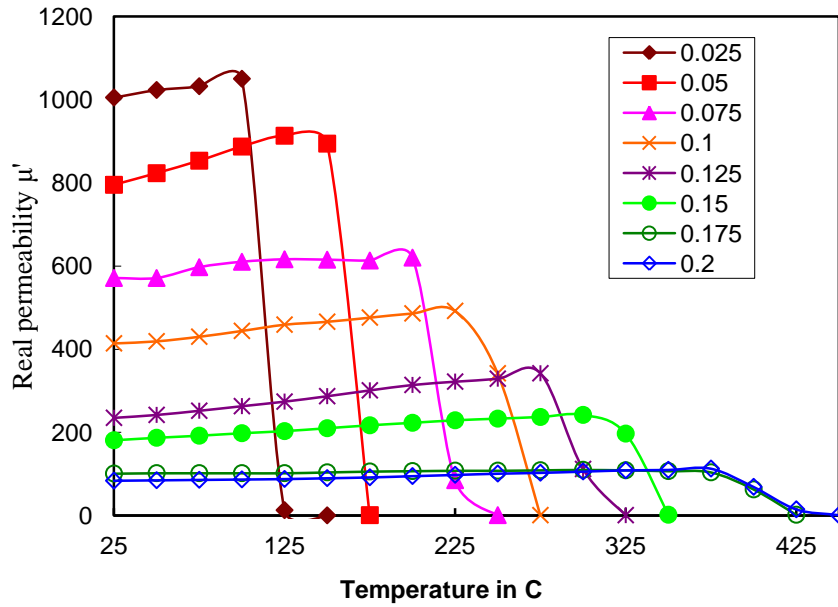


Fig. 1 a

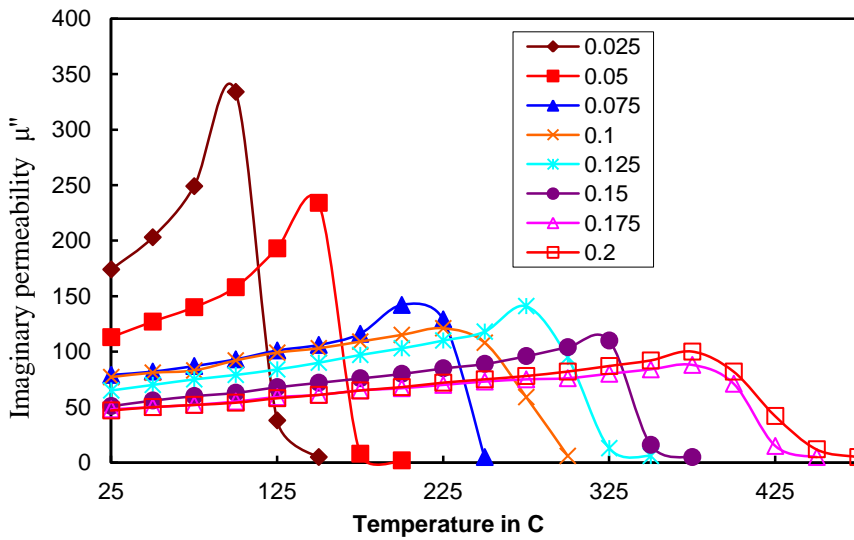


Fig. 1 b

Fig. 1. (a) Thermal variation of real part of permeability and (b) imaginary part of permeability for present ferrite system

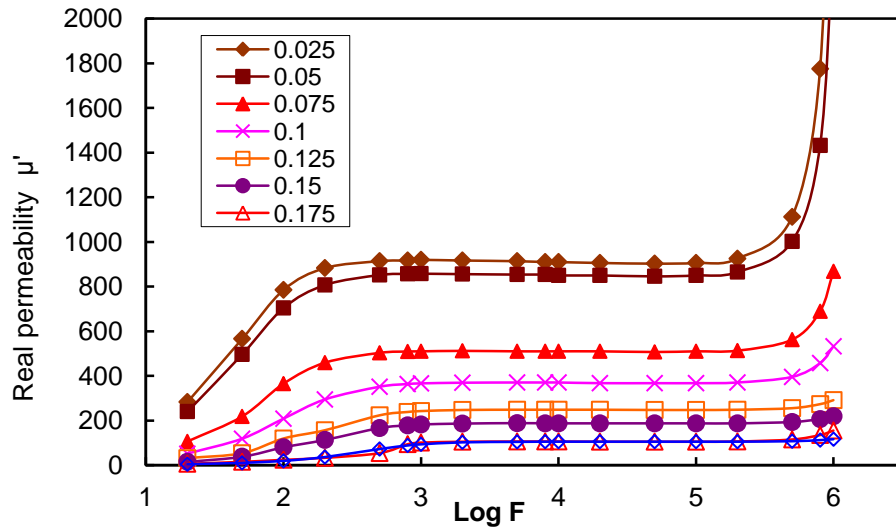


Fig. 2 a

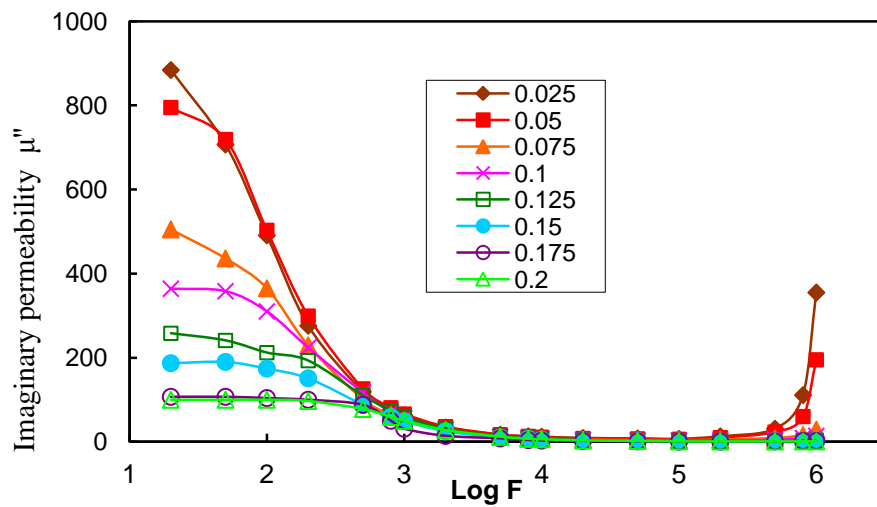


Fig. 2 b

Fig. 2. (a) Frequency variation of real part of permeability and  
(b) imaginary part of permeability for present ferrite system

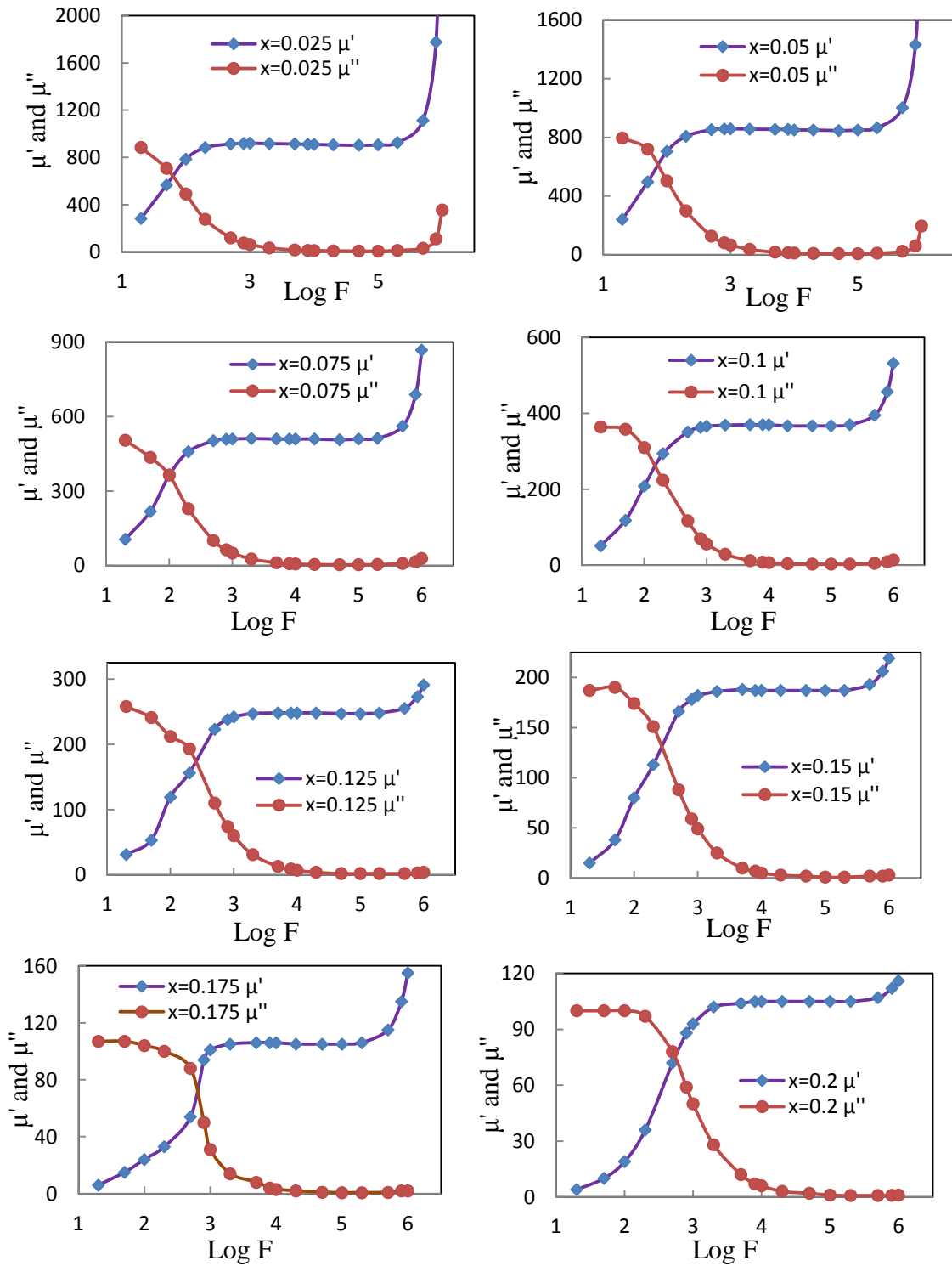


Fig. 3 Frequency variation of real and imaginary part of permeability for present ferrite system

**C] Temperature dependence of Quality Factor Q:**

Since Q is a ratio of permeability to resistivity, this value gives an idea of good quality of ferrite sample. The ferrites having high Q factor are very useful [24]. Fig.4 shows the thermal variation of quality factor for the present ferrite system. It is observed that Quality factor Q rapidly decreases with temperature for the lower concentration of lithium up to  $x=0.1$  then after for higher concentration of  $\text{Li}^{1+}$  it remains nearly constant up to curie point of the composition. At Curie point it drops to lowest value.

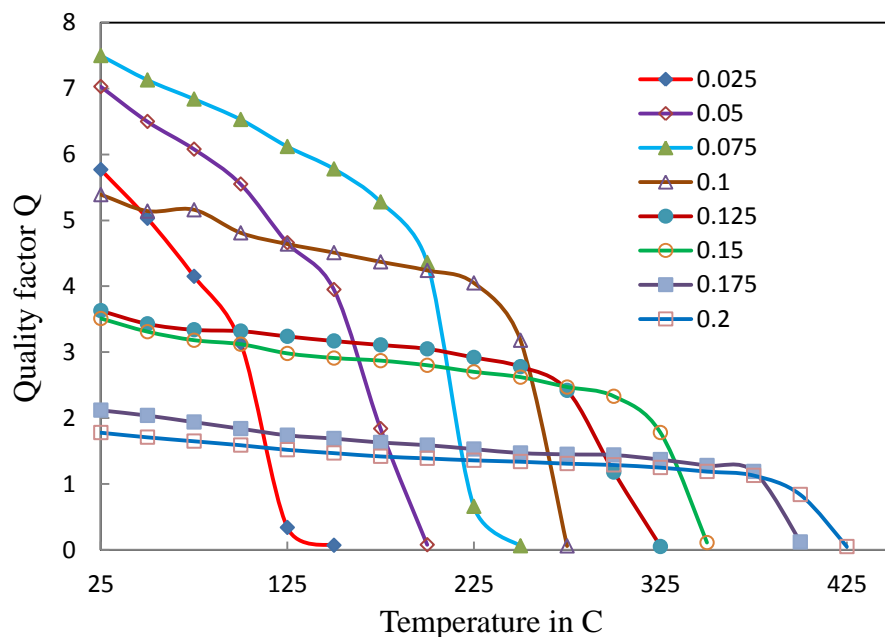


Fig. 4. Thermal variation of quality factor for present ferrite system.

**D] Frequency dependence of Quality Factor Q:**

From the frequency characteristics of Q factor, a perfect frequency band can be identified at which the sample work as good soft magnetic material with low loss. From practical application point of view Q factor of material determine the merit of the material [25]. Kaiser [26] mentioned that at low frequency region, the material with low Q values works as better filters. These types of filter can be used to minimize undesirable oscillations and high frequency content of rapidly passing signals. These materials are successfully used to reduce ringing at high applications.

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. It has been observed that at low frequency side the value of Q factor is minimum and almost constant with frequency. Q factor increases with an increase in frequency showing a peak and then decreases with frequency. The quality factor may deteriorate beyond 1 MHz i.e loss tangent is minimum up to 1 MHz and then rises rapidly. The loss is due to the lag of domain wall motion with applied alternating field and is attributed to the various domain defects [27] which include non-uniform and non-repetitive domain wall motion, domain wall bowing, and localized variation of flux density, nucleation and annihilation of domain walls. This happens at the frequency where the permeability begins to drops. This phenomenon is associated with the ferromagnetic resonance within the domains [28] and at the resonance maximum energy is transferred from the applied magnetic field to the lattice resulting in the rapid decrease of quality factor. It is also observed that the peak corresponding to maxima in Q factor shift towards the higher frequency range as the  $\text{Li}^{1+}$  content becomes higher. Quality factor has the

maximum value of 147 at frequency 100 KHz for  $x=0.05$  and  $0.075$ . Similar nature of quality factor with frequency has been observed by many workers for various substituted ferrites [29-32].

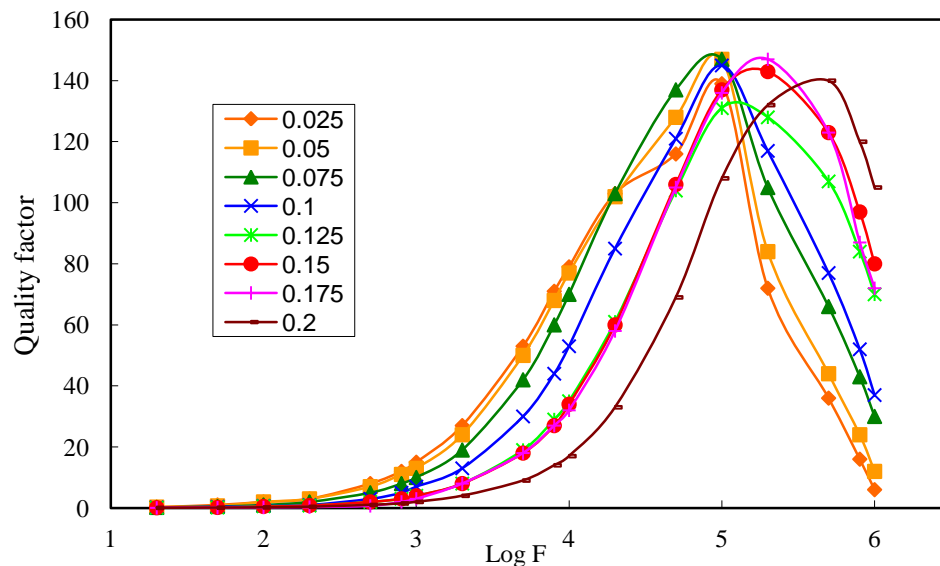


Fig. 5 Variation of quality factor with frequency for present ferrite system

#### IV CONCLUSION

Lithium substituted Ni-Zn ferrites with general formula  $\text{Ni}_{0.32}\text{Zn}_{0.68-2x}\text{Li}_x\text{Fe}_{2+x}\text{O}_4$  have been synthesized using oxalate precursor. The effect of lithium substitution on complex permeability spectra of Ni-Zn ferrites has been investigated in this study. In thermal variation, near  $T_c$ , there is a sharp decrease of  $\mu'$  and  $\mu''$  to zero suggests the single phase formation of spinel ferrites. Frequency dependence of  $\mu'$  and  $\mu''$  clearly indicates the low frequency dispersion which may be attributed to the domain wall motion. Q factor increases with an increase in frequency showing a peak and then decreases with frequency. In frequency variation the peak corresponding to Q maxima shift towards the higher frequency range as the  $\text{Li}^{1+}$  content increases.

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