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Structural and Electrical Characterization of Ni-Zn Ferrites

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Abstract: The effect of Zn substitution on the DC electrical resistivity, AC electrical conductivity and microstructure of V_2O_5 doped $Zn_{(1-x)}Ni_xFe_2O_4$ with $x=0.0, 0.1, 0.2, 0.3, 0.4$ (5 samples) were prepared by conventional ceramic technique has been investigated. The structural characterization of nickel-zinc ferrites were done by X-ray diffraction technique. Micro-structural and morphological studies were carried out by scanning electron microscope technique. The lattice constant determined from XRD data is in the reported range (8.4086 Å). DC electrical resistivity exhibits excellent semiconducting behavior. The result shows that AC conductivity increase with the increases in frequency. The micrographs of the samples shows that the average grain size increases with the decreases of Zn content while the grain size decrease with decreasing of Ni content. The variation of DC electrical resistivity with temperature is explained in this work.

Keywords: DC resistivity; Electrical; Grain size; Microstructure; Transition temperature; Structural;

I. Introduction

In 1928 Forestier [1] prepared ferrites by heat treatment. Neel [2] in 1948 developed the model of ferrimagnetisms as a distinct class of magnetism. In 1985 A. B Naik and J. I Power [5] studied the dependence of resistivity and activation energy of Ni-Zn ferrites on sintering temperature and porosity. Ferrites are considered as soft magnetic materials [4]. The most important types of ferrites are manganese–zinc (Mn–Zn) and nickel–zinc (Ni–Zn) ferrites [6-7]. The resistivity of ferrites varies from 10^2 to 10^{10} ohm-cm which is up to 15 orders of magnitudes higher than that of iron [18]. The utility, variety and versatility make these materials highly demandable for high frequency application such as microwave devices, permanent magnets, electrical and component [8]. Ferrites are highly important electric materials widely used in electronic industries. Ferrites have most promising characteristics of excellent magnetic and electrical performance, high quality, low price and large number of controllable parameters etc [9]. Also transformer cores, rod antennas, radio frequency coils, multilayer chip inductors [10], wave absorbers, and converters. Recently, they were used as radar-absorbing materials. [7] At low frequencies, this interaction is small, and the eddy current losses are negligible. However, at high frequencies, the interaction causes unique phenomena, leading to application in microwave ferrite devices [11], such as telecommunication in cellular telephones and reception/transmission antennas [12], frequency-tunable oscillators and filters, isolators, circulators, and phase shifters [13]. Other specialized application of Ni–Zn ferrites are in the magnetic cores of read/write heads for high-speed digital tape or disk recording [14]. Ni–Zn ferrites have been intensely studied because of their remarkable high-frequency operation (1–100 GHz) as well as because they exhibit high chemical stability and high permeability in the radio frequency region [15]. In the present work our sample was V_2O_5 doped Ni-Zn ferrites by conventional ceramic technique. Our present investigation gives us an idea of the electrical properties of locally prepared materials. It has been shown that small amounts of Vanadium pentaoxide (V_2O_5) tend to remain in the grain boundary region, acting as liquid phase sintering aids [16].

II. Experimental Procedure

All the reagents used for the synthesis of nickel-zinc ferrites were analytical grade and used as received without further purification. Zinc Oxide (ZnO), Ferosoferic Oxide (Fe_2O_3), Nickel Oxide (NiO) were used for the preparation of $Zn_{(1-x)}Ni_xFe_2O_4$ samples (where $x=0.0, 0.1, 0.2, 0.3$, and 0.4) and the raw oxide were collected from local market. The samples were prepared by conventional ceramic technique where ZnO and Fe_2O_3 were used as the parent materials and NiO were used as an additive. Samples were mixed with a mortar and pestle for fine particle size of the powders. Then the mixed was transferred into a porcelain dished were inserted into a central constant temperature controlled up to 700°C . The dishes were kept at this temperature for 3 hours and then switched “Off” the furnace. After 18 hours the dishes were taken out of the furnace. The materials become lightly red color. The pre-sintering materials again mixed with mortar and pestle formed into uniform powders. Small quantity of pre-sintered powder was mixed well with some drops of poly-vinyl alcohol of 0.1% as a binder. V_2O_5 was used as additive in 0.1%, mole percentage. For the sintering requirements [17] we sintered the samples at 1200°C for 3 hours in a crucible and then the furnace was switched “off” for slow cooling after 18

hours the crucible was taken out of the furnace. The rough sides of the tablet were then polished on a fine grade emery paper. The samples were then cleaned to avoid any unwanted dust or impure particles. After that the samples were pasted with air drying type silver paste for electrical contacts. Sides of the sample were taken free for protecting short circuit. The tablet was then kept in an oven for twenty four hours for complete drying. The structural characterizations were carried out by the X-ray diffraction. XRD data were taken at a room temperature using Cu-K α ($\lambda=1.5406$ Å). A scanning electron microscope (SEM) was employed for the observation of the surface morphology and an estimate of grain sizes with increasing NiO content. These pellets were used for the measurement of the temperature dependent resistivity. A two-probe method was used for the measurement of the resistance and capacitance of the samples. The heat treatment was performed in a programmable furnace.

III. Results and discussion

A. Structural properties

The Crystalline phases were identified using a Bruker X-ray powder diffractometer using λ (Cu-K α) = 1.5406 Å. The x-ray diffraction (XRD) patterns of Ni-Zn ferrites were collected at room temperature with a step size of 0.02 2 θ° and a counting time of 10s. The determination of the lattice constant and other structural parameters of the spin phases was made from the X-ray diffraction patterns. The structural parameters and atomic positions for the spinel phase were taken from the literature. Figure 1 shows the powder X-ray diffraction pattern (XRD) of nickel-zinc ferrites. All the peak belongs to the cubic spinel structure and analysis of XRD patterns prove the formation of single phase samples. The lattice constant “a” was calculated using the formula

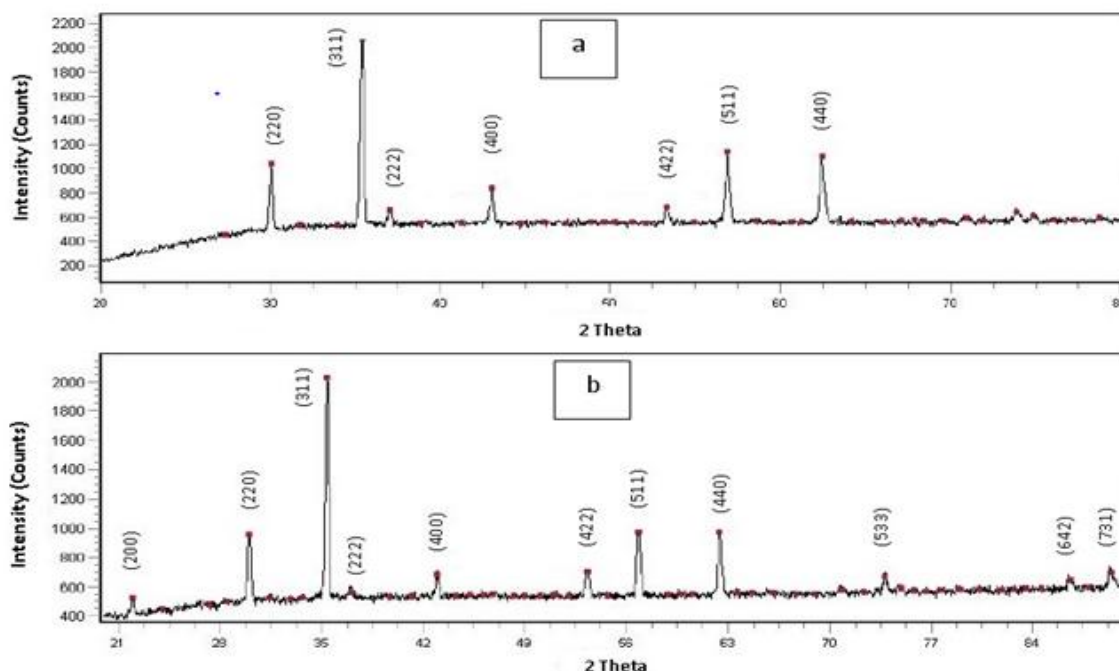
$$a = d_{hkl} \sqrt{h^2 + k^2 + l^2} \text{ Where } h, k, l \text{ are the Miller indices and } d_{hkl} \text{ is the inter planer spacing.}$$

The lattice constant obtained from XRD data is in reported range (8.4086 Å). The effects of Zn substitution V₂O₅ addition to Ni-Zn ferrites compared in the SEM micrographs shown in figure 2. The micro structure of Ni-Zn ferrites exhibits homogeneous grain distributions. The grain size and transition temperature (T_c) increase with the decreases of the Zn content while the grain size and Transition temperature (T_c) decrease with decreasing Ni content in Ni-Zn ferrites as shown in figure 3.

Table I. Different parameters of Ni-Zn ferrites

Sample Composition	Average grain size, D(μ m)	Resistivity, ρ in Ω -m at room temperature.	Transition temperature T _c ($^\circ$ C)	Resistivity ρ in Ω -m at T _c	Activation energy E _p in eV at T _c
ZnFe ₂ O ₄	4.3610	1.960×10^2	215	1.978×10^2	3.8400×10^{-4}
Zn _{0.9} Ni _{0.1} Fe ₂ O ₄	3.0007	1.690×10^4	150	2.369×10^4	1.231×10^{-2}
Zn _{0.8} Ni _{0.2} Fe ₂ O ₄	3.6580	2.090×10^4	165	3.598×10^4	2.0509×10^{-2}
Zn _{0.7} Ni _{0.3} Fe ₂ O ₄	5.1650	1.210×10^3	295	1.650×10^4	1.5550×10^{-2}
Zn _{0.6} Ni _{0.4} Fe ₂ O ₄	5.5660	6.895×10^3	310	2.363×10^5	1.7760×10^{-2}

Figure 1. X-ray diffraction pattern for Ni-Zn ferrites. (a) x=0.0, (b) x=0.1, (c) x=0.2, (d) x=0.3, (e) x=0.4



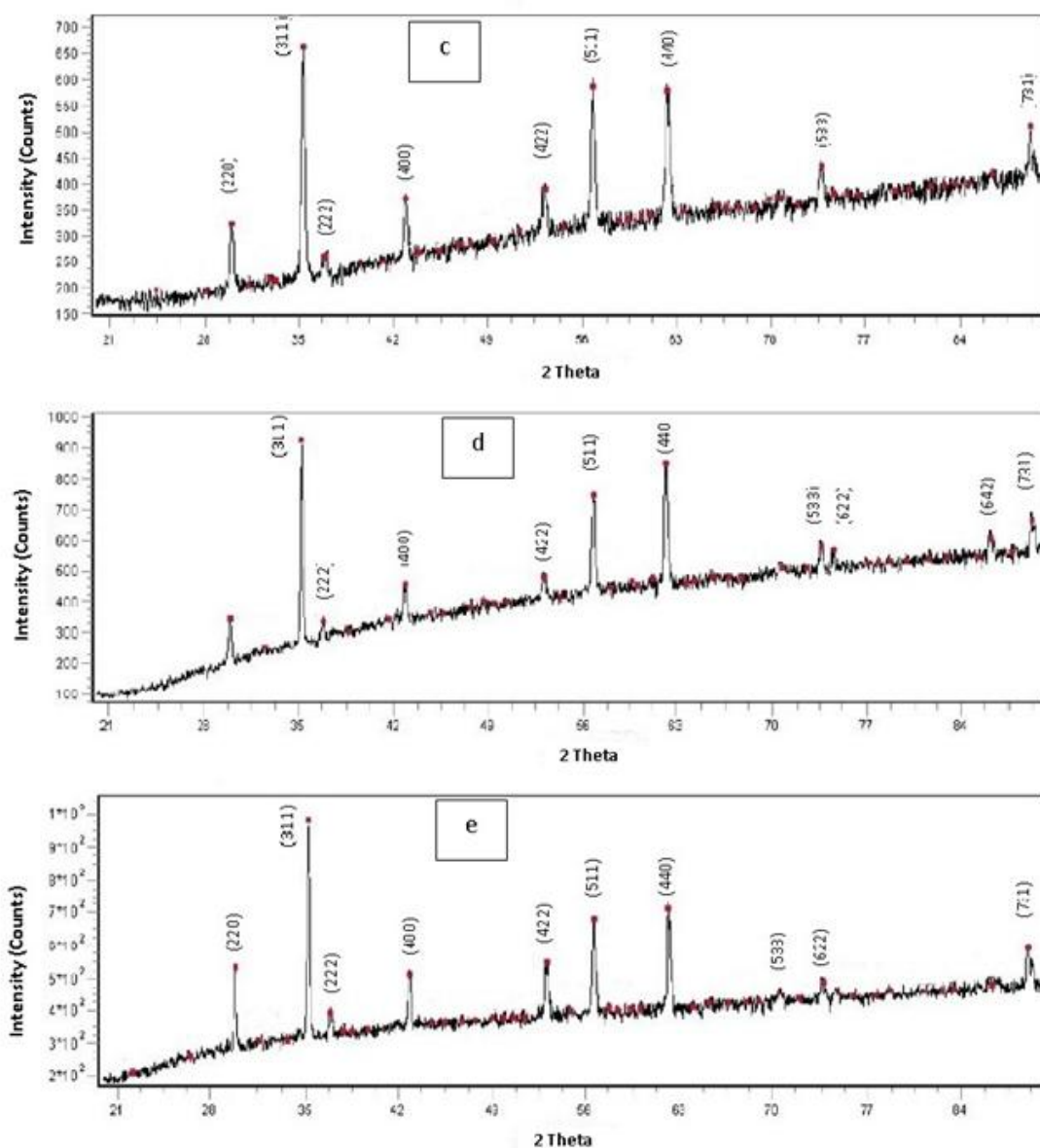
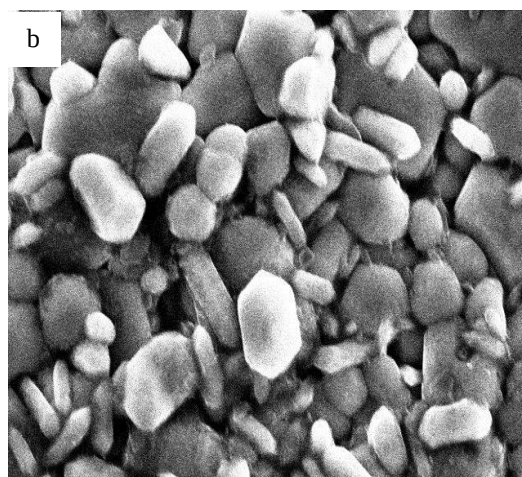
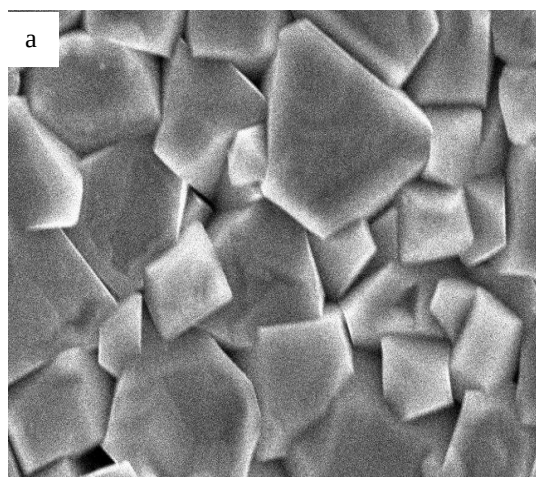


Figure 2. Scanning electron micrographs taken on surface at 10 μ m scale of $Zn_{(1-x)}NiFe_2O_4$ samples sintered at 1200 $^{\circ}$ C during 18 h with (a) x=0.0, (b) x=0.1, (c) x=0.2, (d) x=0.3, (e) x=0.4



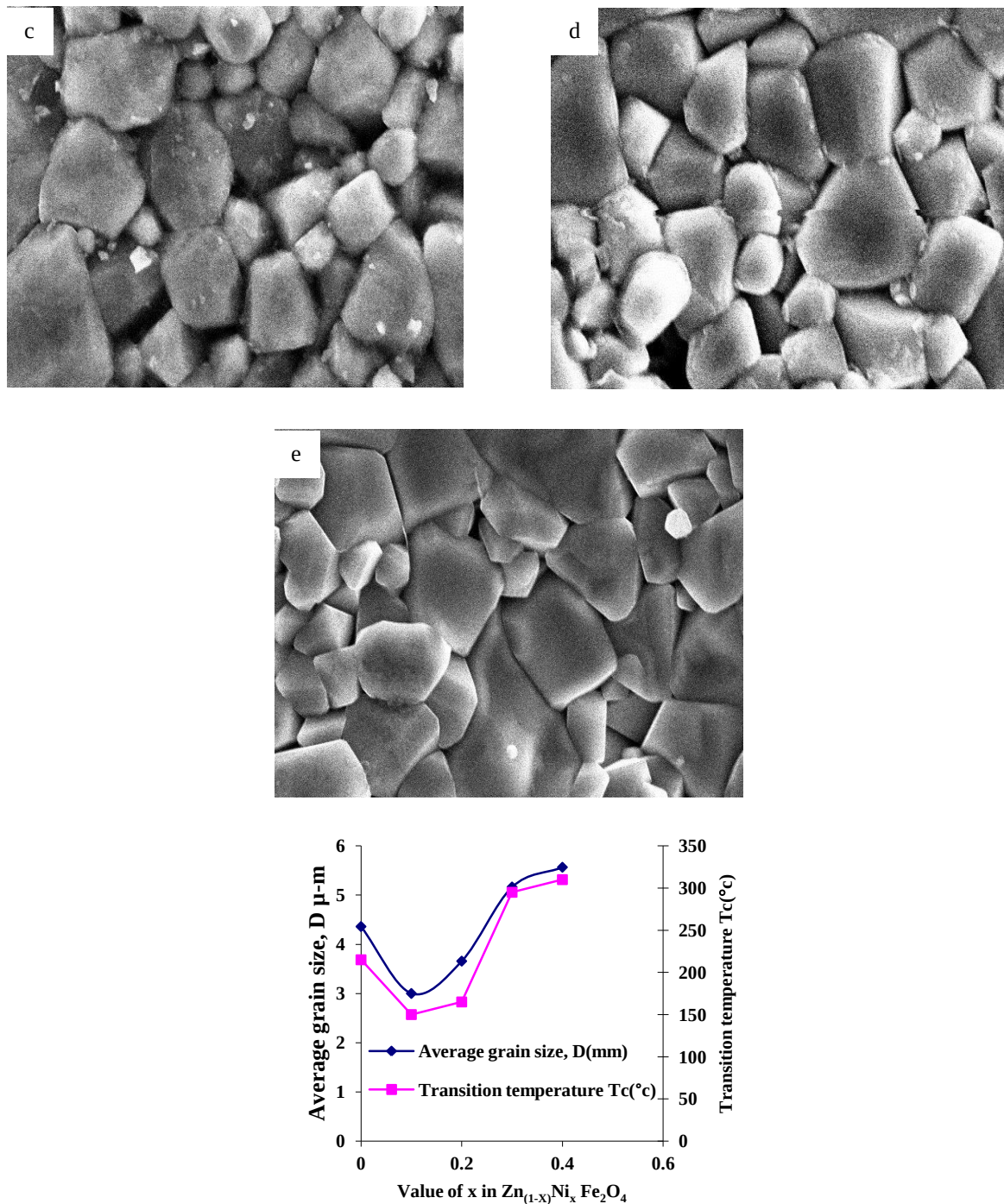


Figure 3. Change of transition temperature (T_c) and grain size (D) due to Ni doping in $Zn_{(1-x)}Ni_xFe_2O_4$

B. Electrical properties

B1. Effect of DC electrical resistivity

The effect of appropriate V_2O_5 on the electrical behavior of doped Ni-Zn ferrites can be analyzed through resistivity Vs temperature curves as shown in figure 4. The DC resistivity was measured as a function of temperature and showed that the DC resistivity is almost same up to definite temperature in the case of each sample and then it falls into ups and downs. It continues up to knocking at the Curie temperature T_c . After T_c the DC resistivity decreases gradually with the increase of temperature. The resistivity of the samples $ZnFe_2O_4$ at this transition temperature was found to be $1.978 \times 10^2 \Omega \cdot m$. The resistivity of samples V_2O_5 doped $Zn_{(1-x)}Ni_xFe_2O_4$ show the same characteristics, but the value of resistivity decrease with an increase of the doping concentration which is represented in table-I. The activation energy (E_p) increases with the decrease of Zn content. It also notes that Ni concentration shifts the Curie point of Ni-Zn ferrites to higher temperature. The

sharp decrease in resistivity above the Curie temperature T_c can be explained on the basis of clusters of Zn^{2+} ions [17].

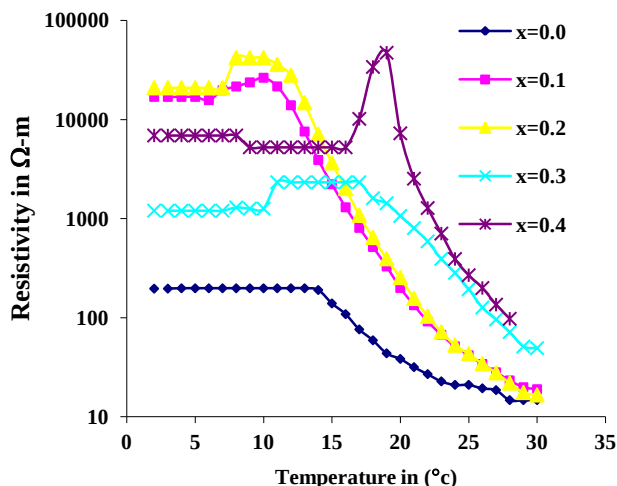


Figure 4. Resistivity in Ω -m Vs temperature in $^{\circ}C$ for samples

B2. Effect of AC electrical resistivity

The effect of different composition for Ni-Zn ferrites, AC conductivity as a function of frequency is shown in figure 5. The values of AC conductivity are depending on frequency. The polarization behavior of ferrites is the electronic exchange [19] between $Fe^{2+} \leftrightarrow Fe^{3+}$ [3] is proposed under this investigation of the frequency dependence of the AC conductivity.

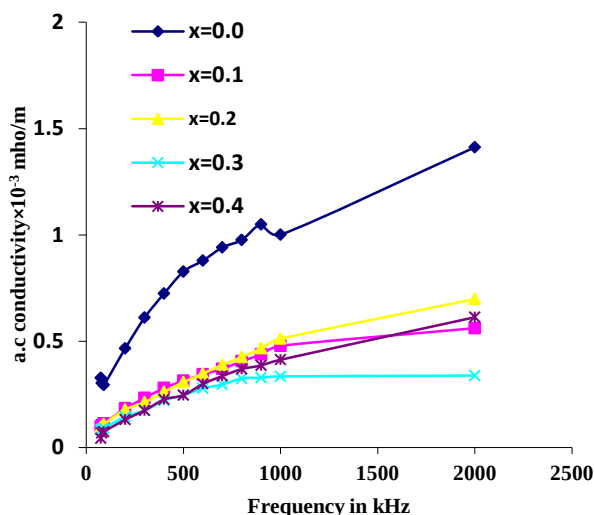


Figure 5. AC conductivity Vs Frequency of the samples

Table II. AC electrical properties measurements for five Ni-Zn ferrites samples

Sample No	Conductivity (σ_{ac}) in mho/m at frequency	
	75(KHz)	2(MHz)
X=0.0	0.327×10^{-3}	1.412×10^{-3}
X=0.1	0.097×10^{-3}	0.561×10^{-3}
X=0.2	0.095×10^{-3}	0.699×10^{-3}
X=0.3	0.082×10^{-3}	0.338×10^{-3}
X=0.4	0.043×10^{-3}	0.613×10^{-3}

IV. Conclusion

The DC electrical resistivity and micro structural properties of Ni-Zn ferrites were influenced significantly by small additions of V_2O_5 . It was found that with an increase of Ni in $Zn_{(1-x)}Ni_xFe_2O_4$ (where $x=0.0, 0.1, 0.2, 0.3, 0.4$) the grain size of the samples increases. Samples 5 ($x=0.4$) exhibited the highest resistivity among the all samples. The resistivity increases with temperature up to a maximum at a temperature which is termed as the Curie temperature or the transition temperature (T_c) and then the resistivity decreases. The T_c rises with an increase of the value of x in $Zn_{(1-x)}Ni_xFe_2O_4$ as well as the grain size.

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