Electrical and Dielectric Properties Analysis of Vanadium Penta-Oxide (V_2O_5) Doped Ni-Zn Ferrite Samples.

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ABSTRACT

Vanadium penta-oxide (V_2O_5) Doped Zn_{1-x} Ni_x Fe_2O_4 Ferrite samples (x=0, 0.1, 0.2, 0.3 and 0.4) have been prepared by conventional ceramic technique. The effect of Zn and Ni substitution on the electrical properties and microstructure has been investigated. Temperature dependent graphs show that the resistivity increases with increasing temperature up to the Curie temperature and then decreases gradually. The frequency dependent curves indicate that with increasing frequency, the dielectric constant (ε) and dielectric loss tangent (tanδ) decrease while the A.C. conductivity ($\sigma_{a.c}$) and Q-factor increase. The $Zn_{0.7}Ni_{0.3}$ Fe_2O_4 has the highest Q-factor (Q=9.60 at 2 MHZ).Finally, the best electrical and dielectric properties have been found for the sample $Zn_{0.7}Ni_{0.3}$ Fe_2O_4 with maximum quality factor, Q=9.60 at 2 MHZ. Moreover, microstructure of the samples (five) has been analyzed based on the average grain size. Hence, this locally produced low cost Ni-Zn ferries can be used in electronics and discrete microwave devices.

(Keywords: Ni-Zn ferrite, resistivity, Curie temperature, Q-factor, microstructure.)

INTRODUCTION

Ferrite constitutes a special branch of ferromagnetic material which is considered as highly important electric materials used widely in electronic industries, information, and communication technology. In the modern society of today, a constant challenge is being posted by ever increasing demands for ferrite materials in home communication appliance, computer etc area. A handsome number of papers related to this field have been published. But we describe the synthesis of V_2O_5 doped Ni-Zn Ferrite and hence study the electrical and dielectric properties of Ni-Zn ferrites.

Crystallographic and Magnetic Properties of V_2O_5 -doped Titanium Cobalt Ferrites were investigated by Woo Hyun Kwon, Seung Wha Lee, Jae-Gwang Lee, and Kwang Pyo Chae *et al.*[1] and found that the average grain size of the samples increases with V_2O_5 concentration [1]. Microstructure and magnetic properties of Ni-Zn ferrites doped with MnO_2 have been studied by Su Hua, Zhang Huai-wu, Tang Xiao-li, Jing Yu-lan, *et al.*[2]. The average grain size, sintering density and real permeability gradually decrease with the increase of the MnO_2 content [2]. Substituted Ni-Zn ferrites for passive sensors application were synthesized by Jozef Slámas, Anna Grusková, Mariana Ušáková, Elemír Ušák, Ján Šubrt, Jozef Lukáč *et al.*[3]. The influence of small Cu substitution on various magnetic properties of Ni-Zn ferrites has been analyzed by means of various experimental methods and interpreted from the point of view of preparation technology optimization and possible applications of such materials in sensor technology. A strong correlation between the substituent content and resulting properties has been observed [3].

The effect of additive on the microstructure and complex permeability of Ni-Zn ferrites were investigated by B. Parvatheeswara Rao, K.H. Rao, P.V. Ramana, O.F. Caltuna, *et al.*[4] with the formula $Ni_{0.65}$ $Zn_{0.35}$ Fe_2 O_4 + *x*. Nb_2 O_5 / V_2 O_5

where *x* values ranging from 0.0 wt% to 1.5 wt% has been prepared by conventional ceramic technique and observed vanadium additions results in fine grain structures with grain sizes of 4.9 µm whereas niobium additions promoted grain growth with an increase in grain size from 5.7 µm to 13.2 µm [4].

The present study has been undertaken to synthesize V_2O_5 doped Ni-Zn Ferrite by conventional ceramic technique and study on their intrinsic properties (such as D.C. electrical resistivity, Curie temperature, semiconducting behavior, activation energy as a function of temperature and A.C. electrical conductivity, dielectric constant, dielectric loss tangent, Q-factor as a function of frequency & the morphology analysis) of the five sintered specimens with the series of $Zn_{1-x}\,Ni_x\,Fe_2O_4$ (x=0, 0.1, 0.2, 0.3 and 0.4).The best electrical and dielectric properties have been found for the sample $Zn_{0.7}\,Ni_{0.3}\,Fe_2O_4$ with maximum Q-factor; Q=9.60 at 2MHz.Not much information is yet available in literature on Ni-Zn ferrites, the present investigation has been undertaken to give an idea on the electrical properties of locally prepared materials that can be tailored for the requirement of further investigation in future.

EXPERIMENTAL SETUP

We take a Varaic (0 to 300V) for the control of the temperature of the tube furnace. Three digital multi-meters are used to measure the D.C. (one is used to measure the voltage against the fixed resistance, the second to measure the voltage against the sample and the third for measuring the temperature that temperature given from the external agency, as shown in Figure 1.

Figure 1: Experimental Setup for D.C. Resistivity Measurement.

Three different types of experiments are used to measure the electrical property (D.C. and A.C.) and microstructure of the samples.

(A) D.C. Electrical Property Measurement

To measure the D.C. electrical property of the synthesized ferrite samples, we have measured (1) temperature dependent D.C. resistivity (2) Curie temperature (3) Semiconducting behavior and (4) Activation energy.

For D.C. resistivity measurement, we used a constant D.C. current source, fixed resistance, etc. After obtaining the D.C. resistivity, we plotted the graphs lnρ versus 1000/T for each sample where ρ defines the D.C. resistivity in Ω-m and T defines the given temperature in ^{0}C. These graphs show the Curie points, after passing the Curie points the magnetic domains are broken and the alignment of the dipoles are also in different directions in which ferromagnetic substances converted into paramagnetic substances for a certain temperature .This temperature is termed as the Curie temperature (T_c), as shown in figure . Thus we get the Curie temperature for five samples.

After the Curie temperature, the resistivity decreases gradually with increasing temperature, therefore, shows the excellent semiconducting behavior and obeys the following formula:

$$\rho=\rho_0\exp(E_p/K_B T_c) \qquad \textbf{(1)}$$

where, ρ_0 =Resistivity at room temperature
E_p =Activation energy
K_B=Boltzmann constant = 8.62×10^{-5} eV/ ^{0}K
T_c=Curie temperature

At Curie temperature the energy of the thermal motion of the atoms is sufficient to overcome the interactions forces between the atomic moments. Because at this temperature the magnetic alignment within the domains is fully destroyed by thermal agitation and as a result the saturation flux density falls and the material becomes paramagnetic. Near T_c, some of the intensive parameters such as magnetization, susceptibility, thermal and electrical conductivities are known to behave differently than predicted by classical molecular field theory.

Knowing the values of ρ_0, ρ, $T_{c,}$ we can determine the Activation energy (E_p) from the equation of $\rho=\rho_0 \exp(E_p/K_B T_c)$.

(B) A.C. Electrical Property Measurement

To determine the A.C. electrical property of the synthesized ferrites we have determined the Q-factor, A.C electrical conductivity ($\sigma_{\text{a.c}}$), dielectric constant (ε) and dielectric loss tangent ($\tan\delta$) with the help of a LCR-Q meter which gives automatically the resistance (R_p in KΩ) of the samples by changing frequencies ranging from 75 KHz to 2MHz.

(C) Microstructure Measurement Of The Samples

The surface morphology of the samples was measured by high resolution Scanning Electron Microscope (SEM-Hitachi, S- 3400N).

RESULT ANALYSIS

(A) D.C. Electrical Property Analysis

The lnρ versus 1000/T curves have been plotted for each sample, as shown in Figure 2 .The Curie temperature for the samples of 1, 2, 3, 4, and 5 are 215^0C,150^0C, 165^0C, 295^0C, and 310^0C respectively, as shown in the figures. At these temperatures the magnetic alignment within the domains is fully destroyed by thermal agitation and as a result the saturation flux density falls and the material becomes paramagnetic from ferromagnetic.

Table 1 gives the Curie temperature, D.C. resistivity (at room and Curie temperature) and activation energy (Ep) at Tc for the samples. From the above result we find the maximum Curie temperature 310^0C for sample-5 and minimum 150^0 C for sample-2. Resistivity **(ρ),** 2.363×10^5 Ω-m at Tc for sample-5 which is the maximum of all the samples.

(B) A.C. Electrical Property Analysis

The result of the frequency dependent A.C electrical Property (Q-factor, A.C electrical conductivity ($\sigma_{\text{a.c}}$), dielectric constant (ε) and dielectric loss tangent ($\tan\delta$)) of the five Ni-Zn ferrite samples given in Table 2.

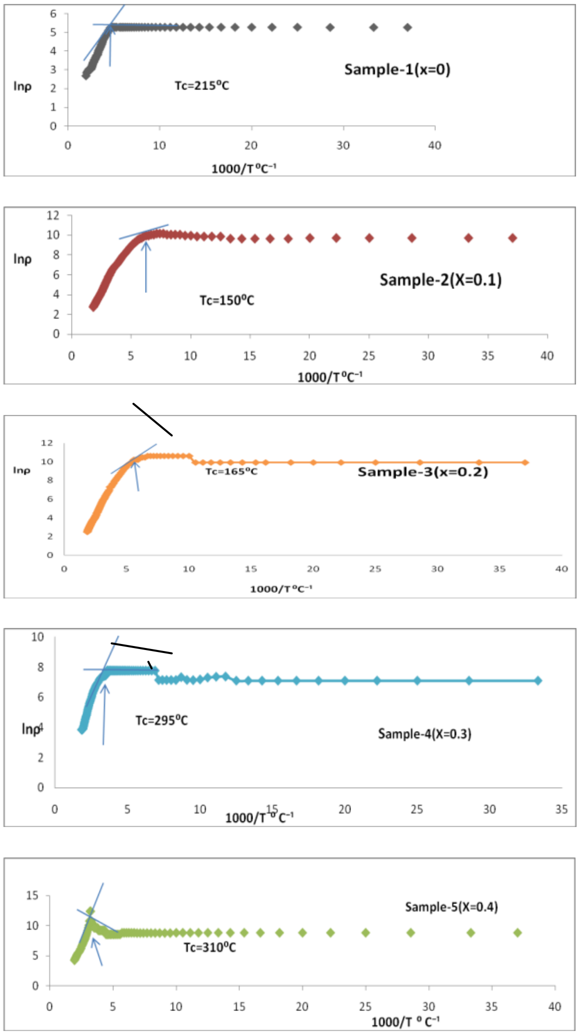

Figure 2: The lnρ versus 1000/T Curves for Samples.

Table 1: Electrical Properties of Samples.

Sample No.& Chemical formula	Curie Temperature in °C.	Resistivity, ρ in Ω-m at room temperature	Resistivity, ρ in Ω-m at Tc	Activation energy, Ep in eV at Tc
Sample -1(x=0) ($ZnFe_2O_4$)	215	$1.960\text{x}10^2$	$1.978\text{x}10^2$	$3.840\text{x}10^{-4}$
Sample -2(x=0.1) ($Zn_{0.9}Ni_{0.1}Fe_2O_4$)	150	$1.690\text{x}10^4$	$2.369\text{x}10^4$	$1.231\text{x}10^{-2}$
Sample -3(x=0.2) ($Zn_{0.8}Ni_{0.2}Fe_2O_4$)	165	$2.090\text{x}10^4$	$3.598\text{x}10^4$	$2.0509\text{x}10^{-2}$
Sample -4(x=0.3) ($Zn_{0.7}Ni_{0.3}Fe_2O_4$)	295	$1.201\text{x}10^3$	$1.650\text{x}10^3$	$1.555\text{x}10^{-2}$
Sample -5(x=0.4) ($Zn_{0.6}Ni_{0.4}Fe_2O_4$)	310	$6.895\text{x}10^3$	$2.363\text{x}10^5$	$1.776\text{x}10^{-2}$

Table 2: A.C. Electrical Property.

Sample No. ↓ / Freq. →	**Conductivity, ($\sigma_{a.c}$) in mho/m**		**Dielectric Constant (ε)**		**Dielectric Loss Tangent (tanδ)**		**Q-Factor**	
	75(KHz)	2(MHz)	75(KHz)	2(MHz)	75(KHz)	2(MHz)	75(KHz)	2(MHz)
Sample - 1(x=0)	$0.327\text{x}10^{-3}$	$1.412\text{x}10^{-3}$	104.52	53.33	0.8018	0.239	1.25	4.18
Sample - 2(x=0.1)	$0.097\text{x}10^{-3}$	$0.561\ \text{x}10^{-3}$	60.71	32.38	0.403	0.156	2.48	6.37
Sample - 3(x=0.2)	$0.095\text{x}10^{-3}$	$0.699\text{x}10^{-3}$	58.78	29.77	0.420	0.204	2.33	4.74
Sample - 4(x=0.3)	$0.082\text{x}10^{-3}$	$0.338\text{x}10^{-3}$	44.66	29.29	0.393	0.102	2.34	9.60
Sample - 5(x=0.4)	$0.043\text{x}10^{-3}$	$0.613\text{x}10^{-3}$	53.22	30.55	0.350	0.170	3.10	6.50

Q-factor, A.C. electrical conductivity ($\sigma_{a.c}$), Dielectric constant (ε), and Dielectric loss tangent (tanδ) Vs frequency graphs have been plotted for all samples as shown in Figures 3-6.

Frequency dependent graphs (Figure 3-6) show that with increasing frequency Dielectric constant (ε) and Dielectric loss tangent (tanδ) decrease but Q-factor and A.C electrical conductivity ($\sigma_{a.c}$) increase with increasing frequency. The above result indicates, the $Zn_{0.7}Ni_{0.3}Fe_2O_4$ (Sample-4; x=0.3) has the maximum Q-factor (Q=9.60 at 2 MHz).

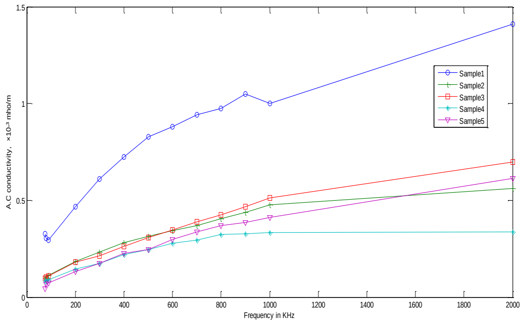

Figure 3: A.C. Conductivity vs. Frequency Graph.

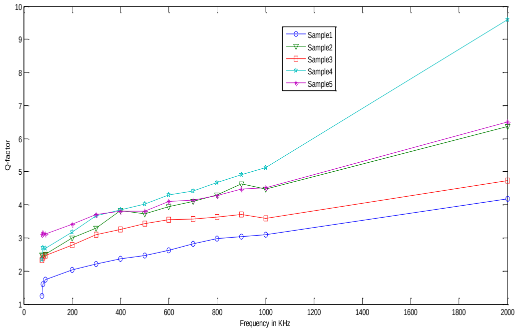

Figure 4: Q-factor vs. Frequency Graph.

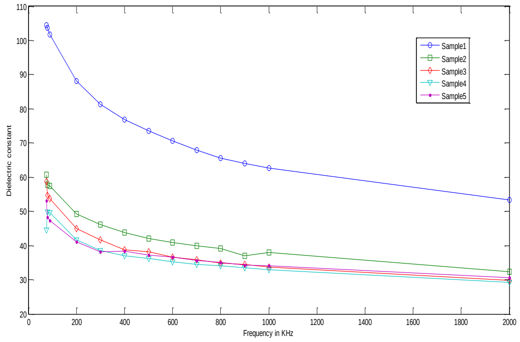

Figure 5: Dielectric Constant vs. Frequency Graph.

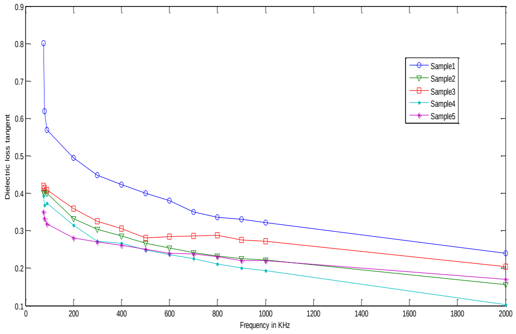

Figure 6: Dielectric Loss Tangent vs. Frequency Graph.

(c) Microstructure Analysis

The microstructure of the samples has been measured by using the Scanning Electron Microscope. The scanning electron micrographs of Ni-Zn ferrite samples sintered at 1200°C given as follows:

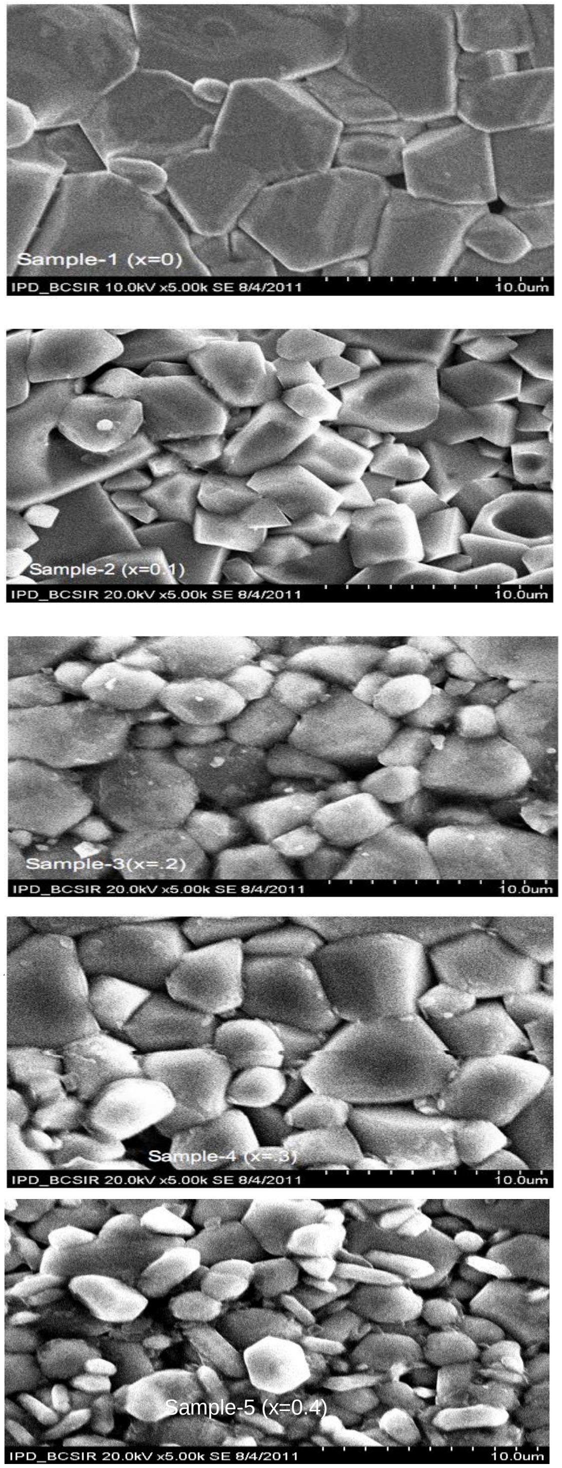

Figure 7: Scanning Electron Micro Graphs of Five Samples.

CONCLUSIONS

Present research work demonstrates the intrinsic properties of Ni-Zn ferrite samples are strongly dependent on chemical composition, sintering temperature and site locations of various cations. It has been investigated in the case of five samples that the D.C. resistivity increases with increasing temperature up to the Curie temperature, T_c, and then decreases gradually. It has been observed that A.C. electrical conductivity and Q-factor were found to be higher for higher frequency.

Comparing the electrical properties of five compositions can be said that the mixed $Zn_{0.7}Ni_{0.3}Fe_2O_4$ ferrite**,** sample-4 (x=0.3)**,** shows the highest Q-factor of all and therefore more elaborate investigation should be needed with this composition. The micrographs of the samples show that the average grain size increases with decreasing Zn content but decreases with decreasing Ni content. The results indicate that the sample-5 (x=0.4) is characterized by large grain, smallest porosity on the boundary and on the surface of the grains which features the highest magnetic performances. So the locally prepared low cost Ni-Zn ferrite materials have the advantages of high resistivity, high Curie temperature, low relative loss, good high permeability feature which can be used in telecommunication technology, electronics industries and discrete microwave devices.

FUTURE WORK

The next goal of our research would focus on exploring applications on different types of ferrites (e.g., Magnesium-Manganese ferrites, Yttrium-iron garnet, and Aluminum–iron garnet) which might have applications in microwave gyrators, phase shifters, isolators, and memory cores. Moreover, we want to work on Li-Zn and Ni-Zn ferrites.

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