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Low Loss Niobium Doped Nickel Zinc Ferrite for Power Applications

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ABSTRACT

$Ni_{0.65}$ $Zn_{0.35}$ Fe_2 O_4 +xNb_2 O_5 (x = 0,0.3,0.6,0.9,1.2,1.5 wt%) samples are prepared by powder ceramic method. Electrical and magnetic properties, surface micro structures are investigated in relation to dielectric and core losses of these samples. Better density and grain sizes are obtained for higher concentration of niobium. Higher resistivity values are noticed for 0.9wt%. At this concentration, it exhibited low magnetic loss. Low dielectric constant, dielectric loss and core loss are observed in the range of 0.6-0.9 wt%. Modification of these parameters are supported by density, grain size and niobium dissolution into grains.

KEY WORDS: Dielectric constant, Dielectric loss, Resistivity, Permeability,Core loss

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INTRODUCTION

Ferrites are the most popular materials in core applications, Swiched Mode Power Supplies (SMPS). Low magnetic and dielectric losses, large saturation magnetization, permeabilty, resistivity and low values of dielectric constant are essential parameters in the field of power applications. The main task of magnetic core is to establish flux linkage between the magnetic elements, inductor. It is an important element to link a magnetic source to a magnetic element. High permeability Permalloy's are not able to store the energy. Further, the resistance of permalloy are very low where as nickel zinc ferrites are high, which is a required characteristic for minimizing eddy current losses[1]. Nickel zinc ferrites are the well known core materials used in power applications, SMPS[2]. Core loss is an important core limitation in these applications. Eddy current losses is a predominant factor in the working of power ferrites. Hence, research is focused to develop low loss material for power applications[3].

Core loss is mainly hysteresis loss at low frequencies. Eddy current losses play a greater role in todays high frequency power applications. Losses and initial permeability rely mainly on concentrations of impurity and sintering parameters. Many research reports mentioned the correlation between grain size and permeability[4]. Density and pores of the finished products plays an important role of the ferrite permeability. The review of literature suggested that the micro structural features of the ferrites are influenced by minor additions of impurities or changing sintering conditions. it is made clear that the that the necessary modifications can be brought by adding minor additions of impurities or changing sintering conditions[5] .

High frequency ferrite material with desirable characteristics is an ever difficult task. Minimum core losses and large saturation magnetization are the preferred characteristics for the above materials. Losses due to eddy current and hysteresis are responsible for core losses. Ni Zn ferrite are useful for working at greater than 1MHz frequency as they could reduce losses because of its high resistivity nature. High initial permeability and uniform micro structure would control other core losses. The right selection of composition, sintering schedule are important to obtain the material suitable for power applications.

Literature Review

It is well known that higher permeability materials generally displayed higher loss[6]. Core loss is reported to be improved by in Nickel Zinc Copper ferrite system[7]. The addition of cobalt, Mn O_2 further improves the core loss is also observed[8] Small amount of V_2O_5 (0.6–1.2 wt%) brings positive effect on core loss in the nickel zinc ferrite system[9]. Combined effects of vanadium and Mn CO_3 additions brings improvement in power loss nickel zinc ferrite at microwave frequencies[10].

Past research studies showed that Low-μ materials are low response to mechanical stress and NiZn ferrite with multigap design would not suffer much core losses[11].

Objective of the Work

As the addition of different dopant ions, copper, Mn, cobalt, niobium, vanadium, etc. brings improvement in core loss properties, it is proposed to study the addition of vaandium in nickel zinc ferrite system in relation to core loss parameter. $Ni_{0.65}$ $Zn_{0.35}$ Fe_2 O_4 is selected for present investigation which has large saturation magnetization at room temperature. Many researchers reported higher valence ion additions brought improvement in core-loss losses of Mn Zn ferrites[12]. Pentavalent addition is one of the choice in this direction. It is proposed to investigate the magnetic micro structure properties of niobium additions in the above system.

MATERIALS AND METHODS

Ferrites, mostly, are prepared as ceramic materials by the conventional methods with very little modifications. The ferrite system chosen for the present study can be written as $Ni_{0.65}Zn_{0.35}Fe_2O_4$ + x Nb_2O_5 analytical reagent grade oxides were used for preparation of the samples. After weighing the starting materials in correct proportions, samples of the basic composition with equal mass were kept in six separate containers. Then in order to study the influence of niobium concentration of various properties, niobium pentoxide powders with six different concentrations (x= 0.0,0.3,.6,0.9,1.2,1.5 wt%) were separately added to the basic composition. These ingredients are thoroughly mixed and ground for 5 hours by agate mortar and pestle using methanol. The calcination and sintered temperatures are selected as 900^0C for four hours and 1210^0C for four hours in air atmosphere.

RESULTS AND DISCUSSION

Significant variations are observed in electromagnetic properties of all the niobium doped nickel zinc ferrite samples. Resistivity, Dielectric constant, dielectric loss, magnetic loss tanδ, Magnetic tanδ/u, grain size and sintered density values are given in table1.

Electrical Properties

Variations of d.c. resistivity, dielectric constant and loss are analyzed in this section. The non uniform and electron tunneling to interface contributes to the dielectric constant variations. Dielectric constant depends on electronic, ionic, dipolar and space charge polarization. The resistivity and dielectric constant variations are in opposite trend for all the samples. This is quite expected and reported by many researchers[13] . D.C. resesitivity is found to decrease up to 0.6wt%

and increased for 0.9wt%. The variations are explained by suggesting the vanadium occupies into lattice in between vanadium wt% 0.3-0.9, encourages hopping in the octahedral sub lattice. The proposed hopping mechanism would be $Fe^{3+} \rightarrow Fe^{2+} + e^{-1}$, $Ni^{2+} + Fe^{3+} \rightarrow Fe^{2+} + Ni^{3+}$. The electronic polarization explains the variations of dielectric constant. Dielectric loss is due to the lagging of polarization behind field, caused by structural inhomogenieties[14].

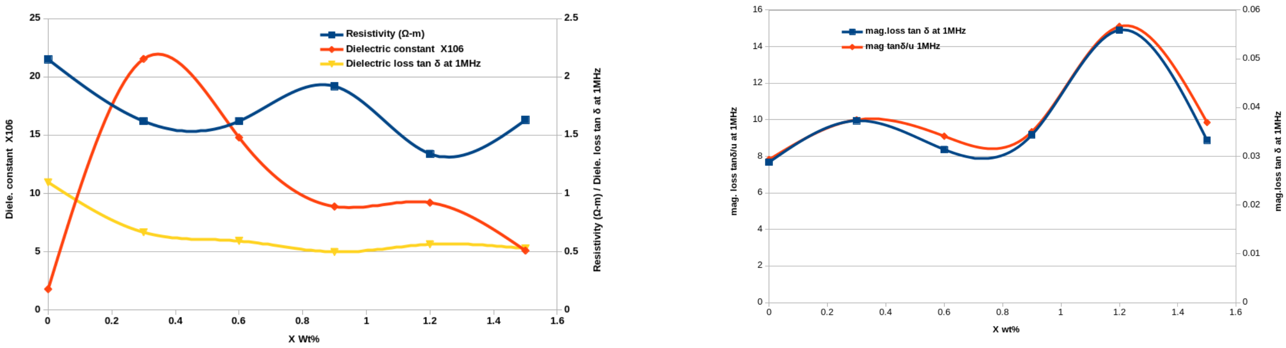

Figure1. Variations of dielectric constant, resistivity, dielectric loss, and magnetic loss

Tabl:1 Variations of electromagnetic properties with x wt% in $Ni_{0.65}Zn_{0.35}Fe_2O_4+xNb_2O_5$

x	Resistivity (ohm-m)	Dielectric constant x10^6	Dielectric loss tanδ at 1MHz	permeability	Grain size (microns)	Core loss (KW/m^3) at IMHz,10m T	Magnetic loss tan δ at 1MHz	Magnetic tanδ/u at 1MHz
0.0	2.15	1.794	1.096	386	6	89.482	0.0288	7.8261
0.3	1.62	21.54	0.667	393	4	97.369	0.0373	10.000
0.6	1.62	14.8	0.593	366	5.7	114.45	0.0314	9.1014
0.9	1.92	8.88	0.4986	390	7.3	101.58	0.0344	9.3478
1.2	1.34	9.21	0.5644	389	9.7	108.62	0.0559	15.1081
1.5	1.63	5.1	0.527	357	13.2	110.12	0.0333	9.8521

The losses are represented by loss tangent. Low loss material have a fairly good value of Q. Low dielectric loss, dielectric constant values are observed at nearly 0.6 wt%.magnetic loss, permeability, power loss and for niobium doped Ni Zn ferrite ,figure1.

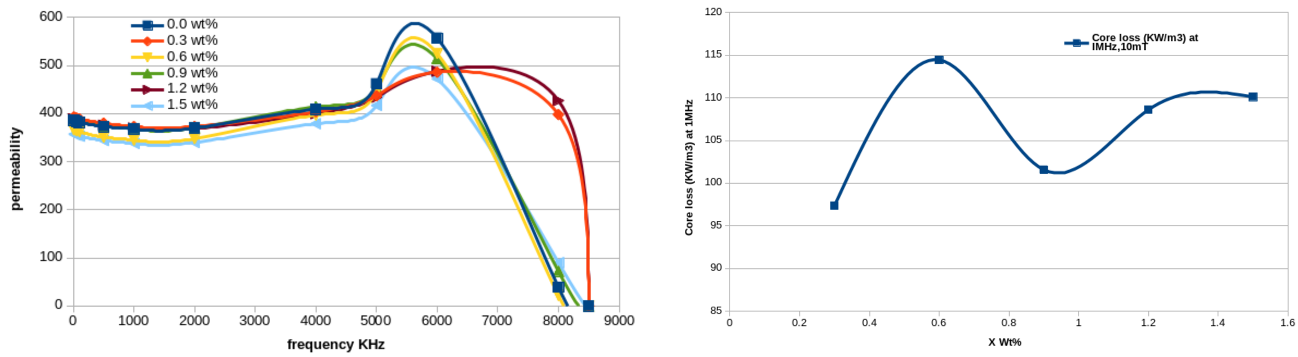

Figure:2 Variation of permeability - frequency and Core loss at 1MHz for different applied fields with x wt%

Magnetic Properties

Permeability, core loss variations with the addition of niobium ions in the nickel zinc ferrite is presented in this part. Permeability with different additive concentrations and frequency are presented in figure2. The permeability values are sufficient to maintain the current at a reasonably agreed level in power applications. Frequency dispersion of permeability, with niobium ion content showed that the relaxation or critical frequency is pushed towards higher levels and slightly lower permeability up to 9MHz for concentrations 0.3 to 0.9 wt%. This has been attributed to the promotion of grain growth in niobium samples. A simultaneous higher values of permeability are observed for higher critical frequency, an unusual behavior is also observed for 0.9 wt%. This would be explained by conducting further studies on the samples. A usual broad peaks are observed for the resonance phenomenon of imaginary permeability. It may well be termed the Snoek limit, a product of critical frequency and peremeablity or susceptibility. From the Snoek relation, it is expected that higher permeabilty samples should have lower critical frequency. The variations of permeability values are in accordance with the saturation magnetization, grain size as per Globus relation. The variations in critical frequency, with niobium concentration, are explained with Snoek relation. The unusual behavior, where permeability as well as critical frequency are large, is attributed to dimensional resonance, as reported in case of Mn Zn ferrites[15]. Low magnetic loss is observed at 0.6 wt%.

Core loss becomes plays a vital role and limits the frequency of operation in power ferrites, the most important limitation in transformer applications. Core loss has two components, i) loss factor tan delta, ratio of resistance to reactance, a sum of hysteresis, eddy-current and residual losses; ii) relative loss factor $\tan\delta/\mu$, loss factor per unit effective permeability,also called as material characteristic. Core loss is mainly hysteresis loss at low frequencies whereas eddy current loss dominates at high frequency. Inductance can be reduced with high permeabilty and low core losses. Core losses are also observed to be low at 0.9wt% where low dielectric constant, dielectric loss, and reasonable resistivity, grain size values are recorded.

At the initial concentrations the dopant ions lies in the grain boundary and enters into grains, dissolved into lattice for higher percentage of dopant ions. The proposal is in tune with the variations of density and electromagnetic properties. Density has been observed to decrease beyond 0.9 wt%. The grain size variations corroborated the proposal. The variations of grain size and sintered density are similar except higher dopant levels where sintered density is decreased because of the segregation at grain boundary. Variations of sintered density and porosity further confirms our argument.

CONCLUSIONS

Densification is observed for the additive concentration 0.6-0.9 wt%. Variations of density, grain size supports the changes in dielectric and magnetic losses. Both dielectric constant and loss decreased with niobium concentration. Resonance relaxation frequency is shifted 8 to 9 MHz at higher dopant concentration. The intersection point of dielectric constant and dielectric loss is observed in between 0.6-0.9 wt% of niobium. Reasonable resistivity values and low magnetic loss and loss factor are also observed for the same range of dopant concentration. These materials are useful for power storage applications.

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