1.1 GENERAL INTRODUCTION

Magnetic materials which have combined electrical and magnetic properties are known as ferrites. Iron oxide and metal oxides are the main constituents of the ferrites. The importance of ferrite material has been known to mankind for many centuries. In early 12 centuries the Chinese were known to use lodestones (Fe₃O₄) in compasses for navigation [1]. The practical use of ferrite and its study for structural, electrical and magnetic properties have started in the year 1930. Since then ferrites are extensively studied by many researchers.

Ferrite materials are insulating magnetic oxides and possess high electrical resistivity, low eddy current and dielectric losses, high saturation magnetization, high permeability and moderate permittivity. No material with such wide ranging properties exists and therefore ferrites are unique magnetic materials which find applications in almost all fields. Ferrites are highly sensitive to preparation method, sintering condition, amount of constituent metal oxides, various additives include in dopants and impurities [2-4].

Ferrites are magnetic oxide materials with semiconducting nature which are of great technological importance by virtue of their interesting electrical and magnetic properties. They are used in transformer cores, antenna rods, memory chips, high density magnetic recording media, permanent magnets, transducers, activators,
microwave and computer technology etc [5-7]. The ferrites in nanocrystalline form found applications in new fields like magnetically guided drug delivery, magnetic resonance imaging (MRI), catalyst, humidity and gas sensors, magnetic fluids etc [8-10].

The polycrystalline ferrites remain the best magnetic material which cannot be replaceable by any other magnetic materials because of their important contribution in technological applications. Therefore the processing of these materials is important in modifying the properties as per the desired applications [11].

Ferrites exhibit dielectric properties. Exhibiting dielectric properties means that even though electromagnetic waves can pass through ferrites, they do not readily conduct electricity. This also gives them an advantage over iron, nickel and other transition metals that have magnetic properties in many applications because these metals conduct electricity. Another important factor, which is of considerable importance in ferrites and is completely insignificant in metals, is the porosity. Such a consideration helps us to explain why ferrites have been used and studied for several years. The properties of ferrites are being improved due to the increasing trends in ferrites technology. It is believed that there is a bright future for ferrite technology [12].

Basically ferrites are of three types namely spinel, garnet and magneto-plumbite. All these types of ferrites have their own identity and all are equally important for technological applications. Magneto-plumbite ferrites are usually represented by $\text{MFe}_{12}\text{O}_{19}$ ($\text{M}=\text{Ba, Sr, Ca}$ etc.) and are important in permanent magnetic applications. Garnets have the formula $\text{R}_3\text{Fe}_5\text{O}_{12}$ ($\text{R}=\text{Yttrium or rare earth ions like Dy, Gd, La}$ etc.) and have applications in microwave systems. Spinel ferrites are
represented by the chemical formula $M\text{Fe}_2\text{O}_4$ ($M$ is the divalent cations like Co, Ni, Zn, Cd etc.). The crystal structure of spinel ferrite is based on cubic close packed oxygen and ions. The crystal structure of spinel ferrite has two interstitial sites namely tetrahedral (A) and octahedral (B) site in which cations with different valence and ionic radii can be incorporated [1].

### 1.2 PHYSICS IN FERRITES

The advance made in physics of solids has led too much of the recent progress in science and technology. Physics of condensed matter draw attention to chemical composition, atomic configuration, electrical, crystal structure, magnetic ordering and saturation magnetization and the special preference of metallic ions for interstitial sites in the spinel lattice etc. of the solids. It also helps to co-relate the physical and chemical properties of solids and their use in technological applications. In the recent years, solid state physics mainly concentrates on crystal structure, chemical and physical properties of solids. A proper understanding of the nature and properties of solids form the basis for developing new tailor made materials with the desired properties that can be used in many electrical and electronic devices. Ferrites are in general ferromagnetic ceramic materials consisting of ferric oxide in major portion and metal oxides. On the basis of their crystal structure they can be grouped in to three categories namely, spinel ferrite, cubic garnet and hexagonal ferrites. The molecular formula of ferrites is $M^{2+}\text{O. Fe}^{3+}_2\text{O}_3$, where $M$ stands for the divalent metal such as Fe, Mn, Co, Ni, Cu, Mg, Zn or Cd. There are 8 molecules per unit cell in a spinel structure. There are 32 oxygen ($\text{O}^{2-}$) ions, 16 $\text{Fe}^{3+}$ ions and 8 $M^{2+}$ ions, per unit cell. Out of them, 8 $\text{Fe}^{3+}$
ions and 8 $M^{2+}$ ions occupy the octahedral sites. Each ion is surrounded by 6 oxygen ions. Among the different types of ferrite exhibits large applications and are widely used in telecommunication devices.

## 1.3 TYPES OF FERRITS

Ferrite can be classified into three different types

(I) Spinel ferrite (Cubic ferrite)

(II) Hexagonal ferrite

(III) Garnet

Our research work is on spinel ferrite; therefore we shall discuss in detail the spinel ferrite only.

### I) Spinel Ferrite

They are also called cubic ferrite. Spinel is the most widely used family of ferrite. High values of electrical resistivity and low eddy current losses make them ideal for their use at microwave frequencies. The spinel structure of ferrite as possessed by mineral spinel MgAl$_2$O$_4$ was first determined by Bragg and Nishikawa in 1915 [13, 14].

The chemical composition of a spinel ferrite can be written in general as MFe$_2$O$_4$ where $M$ is a divalent metal ion such as Co$^{2+}$, Zn$^{2+}$, Fe$^{2+}$, Mg$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, Cu$^{2+}$ or a combination of these ions such. The unit cell of spinel ferrite is FCC with eight formula units per unit cell. The formula can be written as $M_8$Fe$_{16}$O$_{32}$. The anions are the greatest and they form an FCC lattice. Within these lattices two types of interstitial positions occur and these are occupied by the metallic cations. There are 96 interstitial sites in the unit cell, 64 tetrahedral (A) and 32 octahedral (B) sites. Ni-Cu-Zn (NCZ) come under the umbrella of the soft ferrite and chemically symbolized as MFe$_2$O$_4$. Ni-Cu-Zn (NCZ)
ferrites are a solid solution of inverse \( \text{NiFe}_2\text{O}_4 \), \( \text{CuFe}_2\text{O}_4 \) and normal \( \text{ZnFe}_2\text{O}_4 \) ferrite. Due to the favorable fit of charge distribution, \( \text{Ni}^{2+} \) and \( \text{Cu}^{2+} \) ions show their strong preference to the octahedral B-site. \( \text{Zn}^{2+} \) ions show a strong preference for tetrahedral A-site due to its electronic configuration. NCZ spinel ferrite with their ease of preparation and versatility for use in wide ranging applications are commercially very attractive. These ferrites are used in the surface mount devices (SMD) and multilayer chip-inductors (MLCI) due to their high electrical resistivity and excellent soft magnetic properties at high frequencies.

The spinel ferrite has been classified into three categories due to the distribution of cations on tetrahedral (A) and octahedral (B) sites. (a) Normal spinel ferrite (b) Inverse spinel ferrite (c) Intermediate spinel ferrite

**(a) Normal Spinel**

If there is only one kind of cations on octahedral [B] site, the spinel is normal. In these ferrites the divalent cations occupy tetrahedral (A) sites while the trivalent cations are on octahedral [B] site. Square brackets are used to indicate the ionic distribution of the octahedral [B] sites. Normal spinel have been represented by the formula \( (\text{M}^{2+})_A[\text{Me}^{3+}]_B\text{O}_4 \). Where M represent divalent ions and Me for trivalent ions. A typical example of normal spinel ferrite is bulk \( \text{ZnFe}_2\text{O}_4 \).

\[
\begin{array}{cccccccccc}
\uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
\delta =1 & & & & & & & & & \\
\end{array}
\]

**Figure 1.1 Normal spinel**
In this structure half of the trivalent ions occupy tetrahedral (A) sites and half octahedral [B] sites, the remaining cations being randomly distributed among the octahedral [B] sites. These ferrites are represented by the formula $(\text{Me}^{3+})_A [\text{M}^{2+}\text{Me}^{3+}]_B \text{O}_4$. A typical example of inverse spinel ferrite is $\text{Fe}_3\text{O}_4$ in which divalent cations of Fe occupy the octahedral [B] sites [15].

\[ \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \quad \delta = 0 \quad \text{A} \]

\[ \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \quad \text{B} \]

\textit{Figure 1.2 Inverse spinel}

Spinel with ionic distribution, intermediate between normal and inverse are known as mixed spinel e.g. $(\text{M}^{2+}_{\delta}\text{Me}^{2+}_{1-\delta})_A[\text{M}^{2+}_{1-\delta}\text{Me}^{3+}_{\delta}]_B \text{O}_4$, where, $\delta$ is inversion parameter. Quantity $\delta$ depends on the method of preparation and nature of the constituents of the ferrites. For complete normal spinel ferrite $\delta = 1$, for complete inverse spinel ferrite $\delta = 0$, for mixed spinel ferrite, $\delta$ ranges between these two extreme values. For completely mixed ferrite $\delta = 1/3$. If there is unequal number of each kind of cations on octahedral sites, the spinel is called mixed. Typical example of mixed spinel ferrites are $\text{MgFe}_2\text{O}_4$ and $\text{MnFe}_2\text{O}_4$.

\[ \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \quad \delta = 0.25 \quad \text{A} \]

\[ \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \quad \text{B} \]

\textit{Figure 1.3: Random spinel}
Néel suggested that magnetic moments in ferrites are sum of magnetic moments of individual sub-lattices. In spinel structure, exchange interaction between electrons of ions in A and B-sites have different values. Usually interaction between magnetic ions of A and B-sites (AB-sites interaction) is the strongest. The interaction between AA-sites is almost ten times weaker than that of A-B site interaction whereas the BB-sites interactions the weakest. The dominant AB-sites interaction results into complete or partial (non-compensated) antiferromagnetism known as ferrimagnetism [16]. The dominant AB-sites interaction having greatest exchange energy produces antiparallel arrangement of cations between the magnetic moments in the two types of sub-lattices and also parallel arrangement of the cations within each sub-lattice, despite of AA-sites or BB-sites anti-ferrimagnetic interaction [17].

II) Hexagonal ferrites

This was first identified by Went, Rathenau, Gorter and Van Oostershout 1952 [18] and Jonker, Wijn and Braun 1956. Hexa ferrites are hexagonal or rhombohedral ferromagnetic oxides with formula $\text{MFe}_{12}\text{O}_{19}$, where M is an element like Barium, Lead or Strontium. In these ferrites, oxygen ions have closed packed hexagonal crystal structure. They are widely used as permanent magnets and have high coercivity. They are used at very high frequency. Their hexagonal ferrite lattice is similar to the spinel structure with closely packed oxygen ions, but there are also metal ions at some layers with the same ionic radii as that of oxygen ions. Hexagonal ferrites have larger ions than that of garnet ferrite and are formed by the replacement of oxygen ions. Most of these larger ions are barium, strontium or lead.
III) Garnets

Yoder and Keith reported [18] in 1951 that substitutions can be made in ideal mineral garnet Mn$_3$Al$_2$Si$_3$O$_{12}$. They produced the first silicon free garnet Y$_3$Al$_5$O$_{12}$ by substituting Y$^{III}$+Al$^{III}$ for Mn$^{II}$+Si$^{IV}$. Bertaut and Forret prepared [18] Y$_3$Fe$_5$O$_{12}$ in 1956 and measured their magnetic properties. In 1957 Geller and Gilleo prepared and investigated Gd$_3$Fe$_5$O$_{12}$ which is also a ferromagnetic compound [1].

The general formulas for the unit cell of a pure iron garnet have eight formula units of M$_3$Fe$_5$O$_{12}$, where M is the trivalent rare earth ions (Y, Gd, Dy). Their cell shape is cubic and the edge length is about 12.5 Å. They have complex crystal structure. They are important due to their applications in memory structure.

1.4 Rare Earth Ions in Spinel Ferrites

The rare earth ions can be divided into two categories; one with the radius closes to Fe ions; while the other with ionic radius larger than Fe ions [19].

The rare earth ions have unpaired 4$f$ electrons and the strong spin-orbit coupling of the angular momentum. Moreover, 4$f$ shell of rare earth ions is shielded by 5S$^2$5P$^6$ and almost not affected by the potential field of surrounding ions. Doping rare earth ions into spinel-types ferrites, the occurrence of 4f-3d couplings which determine the magneto-crystalline anisotropy in spinel ferrite can also improve the electric and magnetic properties of spinel ferrites [20-23]. The rare earth ions commonly reside at the octahedral sites by replacing Fe$^{3+}$ ions and have limited solubility in the spinel ferrite lattice due to their large ionic radii [21, 23].
Table 1.1: Structural and magnetic properties of some elements

<table>
<thead>
<tr>
<th>Ions</th>
<th>Electronic configuration</th>
<th>Ion radius Å</th>
<th>Bond energy (KJ/mol)</th>
<th>Magnetic moment µB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni$^{2+}$</td>
<td>[Ar]3d$^8$4s$^2$</td>
<td>0.69</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Cu$^{2+}$</td>
<td>[Ar]3d$^{10}$4s$^1$</td>
<td>0.73</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Zn$^{2+}$</td>
<td>[Ar]3d$^{10}$4s$^2$</td>
<td>0.74</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Fe$^{3+}$</td>
<td>[Ar]3d$^6$4s$^2$</td>
<td>0.64</td>
<td>409</td>
<td>5.92</td>
</tr>
<tr>
<td>Gd$^{3+}$</td>
<td>[Xe]4f$^7$5d$^1$6s$^2$</td>
<td>0.938</td>
<td>715</td>
<td>7.94</td>
</tr>
<tr>
<td>Y$^{3+}$</td>
<td>[Kr]4d$^1$5s$^1$</td>
<td>0.893</td>
<td>725</td>
<td>0</td>
</tr>
<tr>
<td>Sm$^{3+}$</td>
<td>[Xe]4f$^6$6s$^2$</td>
<td>0.964</td>
<td>-</td>
<td>0.85</td>
</tr>
<tr>
<td>Nd$^{3+}$</td>
<td>[Xe]4f$^4$6s$^2$</td>
<td>0.995</td>
<td>709</td>
<td>3.62</td>
</tr>
</tbody>
</table>

The valuable properties on the selected dopant elements viz. Iron, Gadolinium, Yttrium, Samarium, Neodymium oxide bears. The literature values of involved elements properties are summarized in tabular form in Table 1.1.

1.5 APPLICATIONS OF FERRITE

Spinel ferrites ceramic are widely used in microwave devices to control transmission path, frequency, amplitude and phase of microwave signals. Accurate dielectric and magnetic property measurement at the operational frequency and temperature ranges are needed for optimized development of these devices, as well as to assist in the manufacture of the ferrite [24].

The structured magnetic materials have an interesting area of study because of its possible applications in a variety of widely areas ranging from information technology to biotechnology [25].

Ferrites are excellent soft magnetic materials in high-frequency devices due to their low cost, high resistivity and low eddy current
losses, which have been studied extensively for multilayer chip inductor (MLCI) application. Ni-Cu-Zn ferrites have been evolved it meet a claim for the miniaturization of electronic components. Ni-Cu-Zn ferrites can be utilized in multilayer chip inductor application in high frequency region [26-27].

Fig. 1.4 MLCIs are manufactured using thin sheets made of Ni-Cu-Zn ferrite

In the recent years, there has been an increased interest in the application of Ni-Cu-Zn spinel ferrite substituted rare earth ion for the production used in the fabrication of multilayer chip inductors MLFCI components as surface mount devices for miniaturized electronic products such as cellular phones, digital diaries, video camera recorders, floppy drives, etc. silver is often used as the internal
electrode material in various devices due to its low resistivity and lower cost as compared to other noble metals alloys such as Ag-Pd alloy [28]. Multilayer chip inductors are manufactured using thin sheets made of ferrite or special ceramics on which coil patterns are printed with metallic paste (normally silver). By arranging these sheets in multiple layers, a spiral-shaped internal electrode pattern is created. The multilayer technique creates the coil in a three-dimensional space without the need to wind wire on a core, which facilitates miniaturization and mass production. When a current flows through the coil, a magnetic flux is created. The intensity of the flux (i.e. the number of magnetic field lines) is called the inductance (L). The inductance increases proportionally to the number of coil windings squared and proportionally to the cross section area. Using a material with high magnetic permeability such as ferrite as a core results in higher inductance. This is because the higher magnetic permeability of a core has the effect of concentrating the magnetic field lines. Multilayer chip inductors for high-frequency circuit applications use sheets made of dielectric ceramics instead of ferrite. This is because ferrite has higher losses in the frequency range of several hundred MHz and higher, making it difficult to achieve high Q values.

Ni-Cu-Zn ferrites are a potential magnetic material for the MLCIs due to its lower sintering temperature as compared to other ferrite. The applications of the chip inductors include, a) combined with capacitors to form inductor-capacitor (LC) filters, b) as Electromagnetic Interference (EMI) filters c) as an AC choke for active devices (e.g. transistors), d) used in matching circuits, etc. A part from this, ferrites are used in audio and visual equipments such as liquid crystal TV set
head phone stereos, computer and telecommunication devices such as personal wireless communication systems and automobile telephones etc. [29,30]

Ferrites are used widely due to their following properties.

1- Ferrites are important components for the latest products, such as cellular phones, video cameras, note book computers, hard temperatures and floppy drives.

2- Ferrites for the applications in producing multilayer-type chips mainly because these oxides can be sintered at relatively low with a wide range of compositions. In particular, the addition of Cu in the ferrites.

3- Ni-Cu-Zn ferrite has better properties at high frequencies than Mn-Zn ferrite and the lower densification temperatures than Ni-Zn ferrites

4- Ni-Cu-Zn system ferrites have been used extensively for the production of the multilayer chip inductors (MLCI).

5- Ferrites are part of low power and high flux transformers which are used in television.

6- Small antennas are made by winding a coil on ferrite rod used in transistor radio receiver.

7- In computer, non volatile memories are made of ferrite materials. They store in formation even if power supply fails. Non-volatile memories are made up of ferrite materials as they are highly stable against severe shock and vibrations.

8- Ferrites are used in microwave devices like circulators, isolators, switch Phase Shifters and in radar circuits.
9- Ferrites are used in high frequency transformer core and computer memories i.e. computer hard disk, floppy disks, credit cards, audio cassettes, video cassettes and recorder heads.

10- Ferrites are used to produce low frequency ultrasonic waves by magnetostriction.

11- Nickel alloys are used in high frequency equipments like high speed relays, wideband transformers and inductors. They are used to manufacture transformers, inductors, small motors, synchros and relays. They are used for precision voltage and current transformers and inductive potentiometers.

12- They are used as electromagnetic wave absorbers at low dielectric values.

1.6 SURVEY OF LITERATURE

Standard ceramic method is considered favorite as it is classic and operative with a little of chemical knowledge. The series Ni$_{0.25}$Cu$_{0.20}$Zn$_{0.55}$Fe$_{2-x}$R$_x$O$_4$ (R= Gd$^{3+}$,Nd$^{3+}$,Sm$^{3+}$,Y$^{3+}$, x=0.10) and Ni$_{0.25}$Cu$_{0.20}$Zn$_{0.55}$Fe$_{2-x}$Gd$_x$O$_4$ (x=0.00 to 0.10 In the steps of 0.02) ferrites have been prepared using this method.

Ni-Cu-Zn ferrite has been synthesized through standard ceramic method by many investigators [31-33]. In this method, different metal oxides are mixed and calcined to get ferrite powder. However, mechanical mixing of different oxides is hardly intimate and homogeneous and hence it results in composition fluctuation at every stage of processing that also persists after sintering. Solid state process requires calcinations temperature more than 750$^\circ$C for phase formation and sintering temperature more than 1000$^\circ$C to achieve better densification [34].
Muthafar F. Al-Hilli. et.al [35] The effect of rare earth Gd$^{3+}$ ions substitution and sintering temperature on structural and electrical properties of Li-Ni ferrites were studied in detail. Small amount substituted Gd$^{3+}$ in the Fe$^{3+}$ change in structural and increases in electric properties. The result exhibit the formation of simple cubic spinel phase with variation in lattice parameters that are associated with the substitution of large size Gd$^{3+}$ ions. The resistivity was increases with the increases in Gd$^{3+}$ substitution, while it decreases significantly with increasing sintering temperature. The dielectric loss factor was found to increase with sintering temperature.

Ni-Cu-Zn spinel ferrites change in their magnetic and electrical as well as structural properties depending upon the type and the amount of rare earth elements used. Rare earth ions can be divided into two categories: one with the radius closes to Fe ions; while the other with ionic radius larger than Fe ions. The difference in their ionic radii will lead to micro strains, which may cause domain wall motion resulting in deformation of the spinel structure [36]. It has been stated that the rare earth ions commonly reside at the octahedral sites by replacing Fe$^{3+}$ ions and have limited solubility in the spinel lattice due to their large ionic radii [37].

Many investigations have been carried out on the influence of different rare earth atoms (La, Sm, Gd, Nd, Dy, Tb, Ce, Th, Y, Eu) on the properties of ferrites. The results of these researches showed that different rare earth atoms behave differently in spinel ferrite. The effect of different rare earth cations in Ni-Cu-Zn ferrite along with some different ferrites is reviewed below.
Roy and Bera et al.[28] reported the impact of La$^{3+}$ and Sm$^{3+}$ substitution showed an improved resistivity in Ni-Cu-Zn ferrites. He also discussed relative density and grain size of the ferrites increased with increasing Sm$^{3+}$ substitution. Increased densification may be due to the appearance of excess Ni, Cu and Zn compared with Fe in the composition. A significant increase in initial permeability of the ferrites was found at small fraction ($x=0.05$) of Sm$^{3+}$ substitution. Similarly, these substitutions may improve the electromagnetic properties in ferrites.

Rare earth ions can improve densification and increase the permeability and resistivity in (Ni$_{1-x-y}$Zn$_x$Cu$_y$)R$_z$Fe$_{2-z}$O$_4$ ferrites where, R enters into the ‘B’ sites by displacing a proportionate number of Fe$^{3+}$ from ‘B’ to ‘A’ sites. Previous studies suggest that the in homogeneous magnetic spin structure can be effectively suppressed by La doping.

Ishaque et al. [38], nonmagnetic Y$^{3+}$ ions were introduced into Ni ferrites. Their result revealed that the structural and transport properties of Ni ferrites could be improved by doping of Y$^{3+}$ ions. Investigators have reported the influence of trivalent substitution in different magnetic oxides to enhance their structural, electrical and dielectric properties. The influence of the substitution of Gd$^{3+}$ on the structural and electrical conductivity of nickel ferrites has been reported by Said [39]. He has found that the lattice constant increases with Gd$^{3+}$ contents. He also reported that the resistivity of Ni-Gd ferrites increases for low concentration of gadolinium and then decreases for high concentration of Gd$^{3+}$ content.

Ashok B. Gadkari et al. [40] studied the effect of addition of Sm$^{3+}$ ions on the magnetization of Mg-Cd ferrites. He discussed the addition
of Sm$^{3+}$ ions causes increase in saturation magnetization and magnetic moment. The magnetic properties of Sm$^{3+}$ added Mg-Cd ferrites changes in comparison with pure Mg-Cd ferrites. Bhosale et al. [41] studied Mg-Cd ferrites with Gd$^{3+}$ substitution for Fe$^{3+}$ ions. The X-ray analysis indicated the presence of GdFeO$_3$ orthophase in the resulting compound due to reactivity of Gd$^{3+}$ and Fe$^{3+}$.

Rezlescu et al. [42] investigated the effect of Fe$^{3+}$ replacement by RE (Yb, Er, Sm, Tb, Gd, Dy and Ce) ions on the properties of (Ni$_{0.7}$Zn$_{0.3}$)Fe$_{2-x}$RE$_x$O$_4$ ferrite. The results showed that the electrical resistivity of a ferrite increased by substituting a small quantity of Fe$_2$O$_3$ with RE$_2$O$_3$. Sun et al. [43], investigated the effects of rare earth ions on the properties of (Ni$_{0.5}$Zn$_{0.5}$)Fe$_{1.98}$RE$_{0.02}$O$_4$ (RE = Y, Eu or Gd) nominal composition. The partial substitution of Fe$^{3+}$ with a small amount of RE ions increased the electrical resistivity and relative loss factor, whereas, it slightly decreased the Curie temperature.

Jacobo et al. [4] worked on (Zn$_{0.5}$Ni$_{0.5}$RE$_{0.02}$Fe$_{1.98}$O$_4$) ferrites, with RE = Y, Gd and Eu. The results showed a small increase in the hyperfine field parameters and a strong decrease of the total resonant area with respect to the pure Ni-Zn ferrite. Curie temperatures decreased and coercive fields increased with substitution. By adding much large ionic radii rare earth ions resulted in local distortion and disorder, enough to induce a softening of the network (electron density).

Rezlescu et al. [44] investigated the influence of rare earth ions like Yb, Er, Dy, Tb, Gd, Sm substitution on structure, magnetic and electrical properties of (Li$_{0.3}$Zn$_{0.4}$)Fe$_{1.96}$RE$_{0.04}$O$_4$ ferrites. They found that RE$_2$O$_3$ facilitated the formation of secondary phases at grain boundary which suppressed the grain growth. The results also showed
that the Curie point shifted to lower temperature and increased the
electrical resistivity.

**Sattar et al.** [45] investigated Cu-Zn ferrite doped with rare earth
ions like La, Sm, Nd, Gd, and Dy. They found that all samples were of
high relative density and low porosity. The magnetization of the
samples with Sm and La were higher than that of undoped. On the
other hand, samples with Gd and Dy had lower values than that of the
undoped ones. The magnetization values of the sample with Nd may be
higher or lower than that of the undoped ones depending on the
applied magnetizing field. The undoped sample while sample with La,
Sm and Nd had higher values of $\mu_r$ than that of the undoped ones. The
most those with Gd and Dy had lower values of $\mu_r$ important result was
that the relative permeability has increased by about 60%, 35.5% and
25%, in case of Sm, La and Nd, respectively.

**M. A. Gabal et al.** [46] He studied the structural, magnetic
properties of La-substituted Ni$_{0.50}$Cu$_{0.25}$Zn$_{0.25}$Fe$_{2-x}$La$_x$O$_4$ nanocrystalline
ferrites. He also discussed the hysteresis loop measurements indicate a
decrease in the measured saturation magnetization with increasing La
content. Coercivity shows a size dependent behavior. The measured
susceptibility exhibited a decrease in the Curie temperature by the
addition of lanthanum.

After going through the literature survey, it comes to know that no
systematic information is available in the literature on the structural,
magnetic, electric and dielectric properties of different rare earth ions
doped with the Ni$_{0.25}$Cu$_{0.20}$Zn$_{0.55}$Fe$_{2-x}$RE$_x$O$_4$ ferrite. In the present work,
the attempt is made to systematically investigate the structural,
magnetic, electric and dielectric properties of rare earth (RE= Gd$^{3+}$,
Nd$^{3+}$, Sm$^{3+}$, Y$^{3+}$, x=0.10) substituted Ni$_{0.25}$Cu$_{0.20}$Zn$_{0.55}$Fe$_{2-x}$RE$_{x}$O$_4$ spinel ferrite and small amount of Gd$^{3+}$ substituted Ni$_{0.25}$Cu$_{0.20}$Zn$_{0.55}$Fe$_{2-x}$Gd$_x$O$_4$ (x = 0.00 to 0.10 with the steps of 0.02) spinel ferrites is prepared by standard ceramic method. This composition can be used for multilayer chip inductor (MLCI) application.

1.7 AIM AND OBJECTIVE OF THE PRESENT WORK

The aim of the present work is to see the effect of magnetic and non-magnetic rare earth ions (RE = Gd$^{3+}$, Sm$^{3+}$, Nd$^{3+}$, Y$^{3+}$ and x=0.10) in the Ni$_{0.25}$Cu$_{0.20}$Zn$_{0.55}$Fe$_{2-x}$RE$_{x}$O$_4$ spinel ferrite and modifications due to presence of rare earth dopant. In the present work the structural, electrical, magnetic and dielectric properties of selected system will be studied using X-ray diffraction, infrared spectroscopy, magnetic measurements by pulse field hysteresis loop tracer, Curie temperature by AC susceptibility, D. C. electrical resistivity and dielectric variation with frequency.

1) Synthesis of Ni$_{0.25}$Cu$_{0.20}$Zn$_{0.55}$Fe$_{2-x}$RE$_{x}$O$_4$ (RE= Gd$^{3+}$, Sm$^{3+}$, Nd$^{3+}$, Y$^{3+}$ and x= 0.10) and Ni$_{0.25}$Cu$_{0.20}$Zn$_{0.55}$Fe$_{2-x}$Gd$_x$O$_4$ ( x= 0.00 to 0.10 with the steps of 0.02) ferrite using standard ceramic technique.

2) The effect of small amount of Gd$^{3+}$ substitution in the Ni-Cu-Zn spinel ferrites to modification of structural and physical properties.

3) The effect of constant doping different rare earth ions (Gd$^{3+}$, Sm$^{3+}$, Nd$^{3+}$, Y$^{3+}$ ) in the Ni-Cu-Zn spinel ferrites to study the magnetic and physical properties.

4) The effect of Gd$^{3+}$ ions doped in Ni-Cu-Zn spinel ferrites and to study the electric properties.

5) The effect of Gd$^{3+}$ doping on the magnetic and dielectric properties of the Ni–Cu-Zn ferrites at high frequency was investigated.
6) To identify the structural characterization (IR and X-ray) of Ni-Cu-Zn ferrite doped with different rare-earths (Sm$^{3+}$, Nd$^{3+}$, Gd$^{3+}$, Y$^{3+}$) elements.

7) To study the electrical and dielectric properties of Ni-Cu-Zn ferrites doped with different types of rare earths (Sm$^{3+}$, Nd$^{3+}$, Gd$^{3+}$, Y$^{3+}$) ions.

8) To study the variation of saturation magnetization, remanance and coercivity with the different doped rare earths ions in Ni-Cu-Zn spinel ferrites.
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