1. INTRODUCTION

The emergence of nanoscience and Nanotechnology has played most vital role in the world of science to accelerate the growth of materials in 21st century. Nanoscience is a multidisciplinary subject contributed by Physicists, chemists, material scientists, engineers, pharmacologists and biologist for the proper development. Nanotechnology is the branch of technology that deals with the design, fabrication and applications of nanoparticles or nanomaterials (Edward L. Wolf., 2006). The nanotechnology has wide range of applications in nanoscale electronics, optics, nanomedicine and nanobiological systems.

Nanoscience and nanotechnology considers dimension or length scale of the order less than 100 nm. This produces transition from micro particles to nanoparticles with number of changes in physical properties. The nanometer dimensions has large surface to volume ratio. This increase in surface to volume ratio improves the behavior of surface atoms with respect to interior part of matter. This changes the properties of particle and its interaction with other particles. This is starting point of quantum size effect playing its role. The nano-sized materials exhibits superior physiochemical properties compared with micro sized materials.

The magnetic materials play an important role in our life. Ferrites are technologically very important materials. Recently Nano-ferrites have growing interest due to their unusual properties compared with those of bulk materials. The nanomaterials are applicable at high frequency applications such as inductors, isolators, circulators and waveguide applications due to their unique structural, dielectric and magnetic properties. The most important feature of Soft ferrite nanomaterials is that they have very low hysteresis energy loss at high frequencies. This property is useful for the applications of nano-ferrites in the cores of switched mode power supply (SMPS), RF transformers and inductors. The wide range of applications of magnetic materials significantly advances in informational and biological technologies including information storage, magnetic sensors bio separation and drug delivery. The researchers are working for further miniaturization of magnetic devices by developing superior magnetic properties of nanosized materials. Magnetic effect of electric current emphasizes that when electric current i.e. electrons flow through the conductor, a magnetic field is produced in its surrounding region. This magnetic field can be detected by using a compass needle. A magnetic field exerts a force on the compass needle is another example of magnetic dipole. Since all
substances are composed of atoms, they all are affected more or less degree by the presence of external magnetic field.

**Type of Magnetism**

Depending on how the materials react with an external magnetic field and the magnetic properties of the materials they are classified into five types (B. D. Cullity, 1972)

I) Diamagnetism
II) Paramagnetism
III) Ferromagnetism
IV) Anti-ferromagnetism
V) Ferrimagnetism or Ferrites

**I) Diamagnetism**

Diamagnetism is a fundamental property of all substances. These substances consist of atoms or molecules with no net magnetic moments. i.e. all orbital shells are completely filled and there are no unpaired electrons. When placed in an external magnetic field it induces very small magnetic moments opposite to the applied field. The magnetic susceptibility is negative and of the order of $-10^{-5}$ and is temperature dependent.

**II) Paramagnetism**

In paramagnetic materials, each atom possesses a permanent magnetic moment due to unpaired electron in partially filled orbitals. In the absence of an external magnetic field, orientations of atomic dipole moments are random hence the material doesn’t possess any magnetic property. The external magnetic field change the direction of the moment and induces magnetization parallel to the applied field and material has positive and temperature dependent susceptibility ranging from $10^{-5}$ to $10^{-2}$.

Both diamagnetic and paramagnetic materials are considered to be non-magnetic as they posses magnetization only when placed in an external magnetic field.

**III) Ferromagnetism**

Ferromagnetic materials are metallic materials possessing permanent magnetic moment in the absence of an external magnetic field. For these materials atomic dipole moment can interact to align parallel to each other due to exchange coupling. This results in the domain structure. Ferromagnetism appears only below certain temperature called as Curie temperature ($T_c$). Above Curie temperature, the magnetic moments are randomly oriented giving zero magnetization.
Ferromagnetic materials are transition metals iron, Co, Ni and alloy of transition or rare-earth elements. These materials are used to prepare permanent magnets. These materials have positive and high value of magnetic susceptibility.

**IV) Anti-ferromagnetism**

Anti-ferromagnetism is phenomenon of magnetic moment coupling between adjacent atoms or ions occurring in the materials. This coupling results in an anti-parallel alignment. The net magnetic moment for anti-ferromagnetic materials are zero at all temperatures this is because of the exact cancellation of the magnetic moment of the adjacent atoms or ions and behave as paramagnetic material.

**V) Ferrimagnetism or Ferrites**

Ferrimagnetic materials or Ferrites are ceramic materials exhibiting a permanent magnetization. The magnetic characteristics of ferromagnets and ferrimagnets are similar; the difference is in the net magnetic moments. These materials have magnetization below critical temperature called as Curie temperature (T_c) and above this temperature materials behave like paramagnetic. The magnetic susceptibilities for ferromagnetic and ferrimagnetic materials are similar but difference in their alignment of magnetic dipole moments.

**Classification of ferrites**

Ferrites are electrically non-conducting ferrimagnetic ceramic materials formed by reacting metal oxides. Depending upon the magnetization properties (i.e. size and shape of hysteresis curve) of ceramic materials or ferrites are classified as hard ferrites and soft ferrites

**Hard ferrites**

The permanent magnets are hard ferrites which have large magnetic energy loss per unit volume of material per magnetization–demagnetization cycle (Hysterisis loss). The high coercivity shows that the materials have high resistance to demagnetize and is characteristic of permanent magnets. For example, Barium ferrite (BaFe_{12} O_{3}), Strontium ferrite (SrFe_{12}O_{19}).

**Soft ferrites**

Soft ferrites are ferrimagnetic materials having low hysteresis energy losses due to increase in the electrical resistivity and used as electrical insulators at high frequency applications. These materials reache to its saturation magnetization with a low applied magnetic field. The electrical and magnetic properties of these materials are structure sensitive and can be
altered by doping or substitution. Soft ferrites have high value of initial permeability and low value of coercivity ($H_c$).

**Types of ferrites**

Ferrites are most significant magnetic materials useful in modern electronic technologies. Nanoparticles of spinel ferrites are of practical use for a wide range of applications like high density magnetic information storage, magnetic resonance imaging, targeted drug delivery etc. due to their various properties at high frequency applications (R.D. McMichael et al. 1992, D.G. Mitchell, 1997). Ferrites are mixed metal oxides with Fe$^{3+}$ oxides as main component. Ferrites are classified into three different types, i.e. Spinel ferrites (cubic ferrites), Garnets, Hexagonal ferrites (Charles Kittel, 1996; R. Valenzuela 1994).

Since our work is based on spinel ferrites hence only spinel ferrites are discussed in detail.

**Spinel Ferrites**

The spinel ferrite structure was first determined from the mineral MgAl$_2$O$_4$ by Bragg in 1915 (K. J. Standley, 1972). The spinel ferrites are cubic ferrites having high electrical resistivity and low eddy current losses which make them useful at microwave frequencies. The spinel structure formed by oxygen ion lattice with oxygen anions are packed in face centered cubic arrangement. There are two kinds of interstitial space between anions–tetrahedrally co-ordinated A sites and octahedrally co-ordinated B sites. The spinel structure has eight formula units of MFe$_2$O$_4$ (where M=Fe, Mg, Mn, Ni, Zn, Cd, Co, Cu, Al or mixture of these) in the unit cell. Thus unit cell consists of 32 oxygen anions, 64 tetrahedral sites and 32 octahedral sites. Out of 64 tetrahedral sites and 32 octahedral, only 8 and 16 sites are occupied respectively.

Factors like ionic radii of the cations, preference of ionic to specific sites, modlung energy responsible for distribution of cations in the spinel ferrite. The general cation distribution represented as $(M^{2+}_{2/6}Fe^{3+}_{1/6})[M^{2+}_{2/6}Fe^{3+}_{1/6}]O_4$ where parenthesis for tetrahedral sites and Squarebracket for octahedral sites. For $\delta$=1, normal spinel ferrite form, for example CdFe$_2$O$_4$, all metal cation distributed in tetrahedral sites. When $\delta$=0, it is inverse spinel ferrite, for example NiFe$_2$O$_4$, CoFe$_2$O$_4$,the metallic cation occupies octahedral sites only with ferric ions equally distributed in both sites (R. Valenzuela, 1994; V. R. K. Murthy et al., 1962). For random or mixed ferrite $\delta$ is in between 0 and 1.
Different ferrites react in different ways with external magnetic field. The substitution of zinc and cadmium in the inverse ferrites like Nickel ferrite, copper ferrite or cobalt ferrite is useful by increasing their saturation magnetization, resistivity with decrease of Curie temperature. Among these, copper ferrite shows the abnormal behavior because of the John-Teller nature of Cu$^{2+}$ ions. The substitutions of cadmium and Zinc in copper ferrites have been studied by many researchers as well as substitution of Zn$^{4+}$, Sn$^{4+}$, Ti$^{4+}$ have been studied. In the copper ferrite system Cu$^{2+}$ and Fe$^{3+}$ both are John-Teller ions, which can respond to change of valance, thus affecting the electric and magnetic behaviour of the system. Lanthanum is most trivalent nonmagnetic and resistive element having stable configuration. Present work aims to study the change in structural, magnetic, electrical and morphological properties of Lanthanum substituted cobalt-nickel ferrite.