1.1 Introduction

Material science plays a principal role in the development of chemical sciences and has in turn made enormous contributions to this field. The improvement of human society has been indexed by many devices based on the progress of this interdisciplinary branch of science. Material science is an interdisciplinary subject involving different branches such as physics, chemistry, engineering, biology, etc. The variety of subjects such as thermodynamics, crystallography, solid state chemistry, polymer science, biochemistry, etc can be brought under one umbrella of material science. The solid state chemistry concentrates attention on the chemical composition of real solids and helps to correlate their chemical and physical properties.

Materials science is one of the oldest form of engineering and applied science. In material science, new branches are still evolving with the advent of knowledge. Nanotechnology is one such example. In the past decade nanostructures including nanotubes, nanowires, nanofibers and nanobelts have received much attention due to their distinctive properties compared with their bulk or particle counterparts and potential technological applications.

Now, the objectives of material science can be divided into two aspects:

1. To understand structure-properties relationship.
2. To manipulate atomic and micro structural processes to create novel materials with desired structure and properties.

Among the various polycrystalline solid state materials, spinel ferrites are preferred as potential materials because of their chemical stability, mechanical hardness, reasonable cost, ease of synthesis, controlled compositions, etc [1–2]. The spinel ferrites have received appreciable interest owing to their promising optical, electrical, magnetic properties, etc and hence these are extensively used in microwave devices, ferrofluids, ferroseals, memory cores of computers, high-voltage generating equipments, circulators, filters, gas sensing, photocatalysis, etc [3–10]. Ferrites are generally belonging to one of the structural classes of spinel, garnet, magnetoplumbite and perovskite.
Mixed metal oxides possessing spinel structure have been investigated by a number of workers [11–12] as they exhibit interesting structural, electrical and magnetic properties. These properties are dependent on the nature of ions, their charges and their site distribution among tetrahedral and octahedral sites. Ternary oxides crystallizing with spinel structures are found to exhibit interesting solid state and catalytic properties.

1.2 Introduction to Ferrites

Ferrites are the class of oxides with remarkable magnetic properties, which have been investigated and applied during the last 50 years [13]. Their applications encompass an impressive range extending from millimeter wave integrated circuitry to power handling, simple permanent magnets, and magnetic recording. These applications are based upon the very basic properties of ferrites: a significant saturation magnetization, a high electrical resistivity, low electrical losses, and a very good chemical stability.

Basically, the mixed metal oxides with iron oxide preferably are known as “ferrites”. There are two categories of ferrites based on coercivity, namely hard ferrites and soft ferrites. The chemical formula for the ferrite may be written as AB$_2$O$_4$, where A is divalent metal ion, B is Fe$^{3+}$ and O is divalent oxygen ion. In spinel structure, the oxygen atoms are closely packed in face centered cubic (fcc) lattices, into the interstices of which the metal ions are distributed. Lodestone (FeO.Fe$_2$O$_3$) is the first naturally occurring ferrite which fulfils the ferrite structure. Ferrites are said to have spinel structure as that of the structure exhibited by natural mineral MgAl$_2$O$_4$ (magnetite) which is the familiar example of ferrite. This structure is particularly stable, since there is an extremely large variety of oxides which adopt it, fulfilling the conditions of overall cation–to–anion ratio of 3/4, a total cation valency of 8, and relatively small cation radii. Cation valency combinations known are 2, 3(as in Ni$^{2+}$Fe$^{3+}$O$_4$); 2, 4 ( as in Co$_2$GeO$_4$); 1, 3, 4 (as in LiFeTiO$_4$); 1, 3 (as in Li$_{0.5}$Fe$_{2.5}$O$_4$); 1, 2, 5 (as in LiNiVO$_4$); 1, 6 (as in Na$_2$WO$_4$).
Neel studied the ferrimagnetic materials in his pioneer research work [14–15]. He interpreted the theoretical magnetic properties of this newly formed oxide material called ferrites. In order to understand the magnetic properties of these materials, scientist Neel proposed a new model called Neel model of two interpenetrating sub-lattices with oppositely directed magnetic moments. According to this model, the resultant macroscopic magnetic moment is due to two oppositely directed unequal spin moments. The stage was now set for the development of microwave ferrite devices.

Hogan, from Bell Laboratory, made the first non-reciprocal microwave device at 9 GHz that was based on the Faraday rotation effect [14,16]. Research was completed to improve the properties of the spinel ferrite materials by various cation substitutions. This modified the magnetic properties for different frequency ranges, power requirements and phase shift applications.

After that, Neel, Bertaut, Forrat, and Pauthenet [14,17] discovered the garnet ferrite class of materials. This type of ferrite material has three sub-lattices and is also referred to as rare-earth iron garnets. These materials although having a magnetization lower than spinel ferrite, possess extremely low ferromagnetic line width. Another class of ferrite material that was developed during this time is the hexagonal ferrite. These materials have three basic sub-lattices combined in different numbers in a hexagonal structure. The high anisotropy fields have been utilized in microwave ferrite devices in the millimeter range.

Smit and Wijn [14,18] wrote a comprehensive book on ferrite materials entitled ‘Ferrite’. Developments have been made on the magnetic characteristics of ferrite materials. In the United States, many researchers were engaged in the study of ferrites from 1950 to till date and they attained remarkably fruitful results both in the technical as well as in fundamental research.

Ferrites are of great technical importance because they exhibit a spontaneous magnetic moment below Curie temperature. The requirements of
electronic and magnetic properties in the advanced electronics and microwave devices have focused the attention of researchers in ferrites. Ferrites are the salts of transition metals particularly, crystallize in the spinel structure and contain in some extent one of the known ferromagnetic elements.

During last three decades, a remarkable research work on mixed metal oxides i.e ferrites has been done. Researchers have shown that mixed ferrites usually have better performance than the simple ferrites and show properties and stability depending on the stiochiometry, nature of the metallic ions in the final mixture, method of preparation and size of the particles. Single and multi-component transition metal oxides exist in many different crystallographic forms [19].

1.3. Spinels
1.3.1 Structural Properties

The ferrite spinel structure corresponds to the chemical formula AFe$_2$O$_4$. Its structure is derived from the mineral spinel MgAl$_2$O$_4$. The unit cell of ferrite spinel consists of eight formula units (8 x AFe$_2$O$_4$), where, A is the divalent metal ion. The unit cell consists 32 oxygen atoms which form face centered cubic lattice having 64 tetrahedral sites (A−sites) surrounded by four oxygens and 32 octahedral sites (B−sites), surrounded by six oxygens. In unit cell of 32 oxygen ions, there are 64 tetrahedral sites and 32 octahedral sites. If all these sites are filled by these metal ions, of either 2+ or 3+ valency, the positive charge is much greater than the negative charge and so structure would not be electrically neutral. It terms that out of the 64 tetrahedral sites only 8 are occupied. If as in the mineral spinel, the tetrahedral sites are occupied by divalent ions and the octahedral sites are occupied by the trivalent ions, the total positive charges will be 8 x (+2) = +16 plus the 16 x (+3) = 48, or total of 64 which is needed to balance the 32 x (− 2) = −64. The tetrahedral sites available in an ideal close packed structure of rigid oxygen ions are occupied only by metal ions with a radius ≤ 0.30Å, while the available octahedral sites are occupied only by metal ions with a radius ≤ 0.55Å. To accommodate metal
ions of Co, Cu, Mg, Mn, Ni, and Zn, the lattice has to be expanded. The difference between the expansion of octahedral and tetrahedral sites is characterized by a parameter called oxygen parameter (u). In an ideal spinel, both sites are enlarged in same ratio and accordingly the distance between the tetrahedral site (0, 0, 0) and oxygen site is 3/8 and hence $u_{\text{ideal}} = 3/8$. However, the incorporation of divalent metal ions in tetrahedral sites induces a greater expansion of the tetrahedral sites, leading to the higher value for u than the ideal value.

The crystal structure can be described by dividing a unit cell into eight octants, with metal ions in every octant, which is shown in Fig. 1. The oxygen ions are arranged in identical manner in all octants. Each octant contains four oxygen ions on the body diagonals and at the alternate corner of a tetrahedron. Each oxygen ion is located at a 1/4 distance of the body diagonal from alternate corners of the octant. The array of oxygen ions in a whole crystal forms fcc lattice with edge $a/2$. Thus, there are such four interpenetrating fcc oxygen lattices.

According to the site occupancy of the metal ions, the spinel ferrites have been classified in three groups [20]:

- Normal spinel ferrite
- Inverse spinel ferrite
- Random spinel ferrite

![Fig. 1. Spinel structure of ferrite](image-url)
(a) Normal Spinel Ferrites

In normal spinel ferrites, all the divalent metal ions occupy A sites and all the trivalent ions occupy B sites. The structural formula for normal ferrite is given as:

$$[M^{2+}]_{A-site} [Fe^{3+}]_{2B-site} O_4$$

Metal oxides having such structures are nonmagnetic. Ferrites such as CdFe$_2$O$_4$ and ZnFe$_2$O$_4$ exhibit this type of structure.

(b) Inverse Spinel Ferrites

In inverse spinel ferrite, 8 divalent metal ions (M$^{2+}$) occupy B–sites and 16 trivalent ion (Fe$^{3+}$) are equally divided between A and B sites. The general cation distribution is written as:

$$[Fe^{3+}]_{A-site}[M^{2+}Fe^{3+}]_{B-site} O_4^{2-}$$

This type of ferrites are magnetic in nature. Their examples are Fe$_3$O$_4$, NiFe$_2$O$_4$ and CoFe$_2$O$_4$ etc.

(c) Random Spinel Ferrites

Random spinel structure is intermediate between normal and inverse spinel. Fractions of divalent and trivalent ions get randomly distributed along A and B sites depending on synthesis conditions. The cation distribution of this spinel is represented as:

$$[M_x^{2+}Fe_{1-x}^{3+}]_{A-site}[M^{2+}_{1-x}Fe_x^{3+}]_{B-site} O_4^{2-}$$

Where x is the coefficient of normalcy and 1–x is the coefficient of inversion. For the normal spinel ferrite, the coefficient x = 1 and for inverse spinel ferrite x = 0. The examples of random spinel ferrite are MnFe$_2$O$_4$, MgFe$_2$O$_4$ and CuFe$_2$O$_4$ etc.

1.3.2 Electrical Properties of Spinel Ferrites

Electrical conductivity is one of the important properties of spinel ferrite material which gives valuable information about conduction mechanism. These are magnetic semiconductors and their conduction mechanism is quite different from that of usual semiconductors. The conventional band theory fails to predict the semiconducting properties of these materials. In such cases, the conduction has to be explained on the basis of the hopping mechanism.
Electrical conductivity of material depends on the method of preparation, sintering temperature and sintering span, chemical composition and nature of substitution metal [21].

The ferrites such as copper ferrite, nickel ferrite, magnesium ferrite behave as semiconductors with low mobility of charge carriers. Their electrical conductivity ($\sigma$) is low in comparison with that in magnetic metals. Spinel ferrites, in general, are semiconductors with their conductivity values varying between $10^2$ and $10^{11}$ Ohm$^{-1}$ cm$^{-1}$.

In transition metal oxides, electrical resistivity is low if the compound contains the cations of the same element situated at the similar site but with their valency differing by unity [22,23]. The high resistivity in ferrite is associated with the occupation of B−sites by divalent metal ions and trivalent iron ions. Such an arrangement requires higher activation energy for hopping of electrons. The hopping mechanism of conduction was the first time described by Verwey [24].

The temperature dependence of conductivity of magnesium ferrite has been investigated by Gillaud and Bertrand et al. [25]. Further an activated transfer process in which charge carriers hopping from one site to other site was explained by Morin [26], Johnson et al. [27], Jonker [28] Holestein [29], Yamashita et al. [30], etc have helped to elucidate the mechanism of conduction. The most probable mechanism is electron hopping between Fe$^{2+}$ and Fe$^{3+}$ ions as shown below:

$$\begin{align*}
\text{Fe}^{2+} + \text{Fe}^{3+} &\rightarrow \text{Fe}^{3+} + \text{Fe}^{2+} + \Delta E \\
\text{M}^{2+} + \text{Fe}^{3+} &\rightarrow \text{M}^{3+} + \text{Fe}^{2+} + \Delta E
\end{align*}$$

Where $\Delta E$ is activation energy i.e. energy required to transfer the electrons from M$^{2+}$ to M$^{3+}$ and vice versa. Daniels et al. [31] have carried out Mössbauer study of Ni−Zn ferrite systems and proposed a cation distribution formula $[\text{Zn}^{2+}\text{Fe}^{3+}_{1-x}]_{A\text{-site}} [\text{Ni}^{2+}_{1-x} \text{Fe}^{3+}_{1+x}]_{B\text{-site}} \text{O}_4^{2−}$. The presence of nickel on octahedral sites favors the conduction mechanism [32] as per following conversion:

$$\text{Ni}^{2+} + \text{Fe}^{3+} \leftrightarrow \text{Ni}^{3+} + \text{Fe}^{2+}$$
This explains the predominant conduction mechanism in the Ni–Zn ferrite system.

1.3.3 Magnetic Properties of Spinel Ferrites

The development of magnetic nanoparticles has been intensively pursued due to their broad applications in biomedical system, magnetic data storage, catalysis and so on [33–35]. The ferromagnetic and ferrimagnetic spinel ferrites are considered to be most important magnetic materials because of their combined electrical and magnetic properties. The versatile in magnetic properties and applications, these materials have made tremendous interest by physicists, chemists, metallurgists and also the researchers working in the field of materials science. Ferrites are considered as uncompensated ferromagnetic materials.

In crystal lattice of ferrites, the metallic ions occupy two different sites i.e. divalent metal ion possesses tetrahedral while trivalent ion occupy octahedral site. There are three kinds of magnetic interactions between metallic ions through the intermediate O\(^{2−}\) ion, by super exchange mechanism (Viz: A–A, B–B and A–B interactions).

The ferrites exhibit all properties similar to ferromagnetic materials. The properties of ferrites can be classified into two categories such as intrinsic and structure sensitive. Saturation magnetization, anisotropy, magnetostriction, and Curie temperature are the intrinsic properties; while permeability and hysteresis are very much structure sensitive. The above said properties are very sensitive to the structural aspects such as grain size, porosity, impurities and inclusion of non-magnetic ions. The excess work is done in magnetizing a specimen to saturation. During magnetization cycle hysteresis phenomenon is observed. Thus, hysteresis loop of ferrites gives us valuable information regarding saturation magnetization (Ms), coercive force (Hc) and remanence (Mr); which is shown in Fig. 2.
Fig. 2. Hysteresis (B–H) loop in ferrites.

The magnetism of metal oxides with spinel structure has been explained by Neel et al. [15]. Magnetic materials exhibit different kinds of magnetic ordering depending upon spin orientation. Ferrimagnetic materials with the moment of ions oriented in the same direction give rise to high values of magnetic moment while antiferromagnetic substances, with spins aligned in antiparallel fashion, show a resultant magnetic moment of zero value.

The value of magnetic moment of B lattice ($M_B$) is greater than that of A lattice ($M_A$) so that, resultant saturation magnetization ($M_S$) is written as;

$$M_S = |M_B - M_A|$$

With the help of this theory, Neel could explain the experimentally observed magnetic data for ferrites.

Ferrites are mainly classified into two different categories based on their coercivity value. In general the coercive force for all ferrites can range from 0.1 Oe to 3 KOe. The ferrites in the coercivity range from 0.1 Oe to 1.5 KOe are termed as ‘soft ferrites’ and the ferrites in the coercivity range from 1.5 KOe to
3 KOe are termed as ‘hard ferrites’. Hysteresis properties are mainly dependent on the parameters such as crystal structure, cation distribution, chemical composition, sintering atmosphere and conditions and final fabrication.

1.4 Applications of Spinel Ferrites

1.4.1 Gas Sensors

In last decade, remarkable efforts have been taken for the development of ferrite gas sensors in detection of toxic gas pollutants from vehicle exhaust, biological hazards, environment and pollution monitoring. Gas sensors have a great influence in many areas such as environmental monitoring, domestic safety, public security, automotive applications, spacecrafts, houses and sensor networks [36]. The parameters such as phase formation, crystallite size, particle size, grain size, dopants, surface area, sensitivity, selectivity, operating temperature, gas concentration, response time, and recovery time play an important role in development of ferrite gas sensors. There are various methods used to prepare ferrite gas sensors. The prime requisite for developing a good quality ferrite gas sensor is optimization of preparation conditions, sintering temperature, operating temperatures, concentration of dopants, etc. Nowadays, ferrite materials are used as gas sensors because they show more selectivity and stability for a particular gas than other sensors. Detection is necessary in different fields such as industrial emission control, household security, vehicle emission control and environmental monitoring [37–40]. Semiconductor gas sensors like SnO₂, ZnO or Fe₂O₃ have been well studied to detect most of the reducing gases and they are considered interesting for their low cost and simple sensing methods [41–47]. Due to that applications of gas sensors have been growing at a consistent pace in the recent years. The mixed–metal oxide gas sensors offer advantages over other gas sensors devices because of their simple implementation, low cost and good reliability for real time control systems [48]. In order to optimize the performance of these sensors, many other studies were focused on the use of noble metals, metal doped oxides or mixed–oxide/composites [49] and Zirconia based electrochemical sensors [50]. Transition
spinel ferrites synthesized by the conventional ceramic method have a limitation as a gas sensor.

The responses of ferrites as sensors towards various gases have been reported by various investigators. Reddy et al. [51] reported nickel ferrite exhibiting good response towards chlorine. Mulla et al. [52] synthesized zinc ferrite which gives sensitivity towards H$_2$S gas, while Liu et al. [53] reported doped noble metal nickel ferrite to be sensitive toward H$_2$S. Recently, Xiangfeng et al. [54] synthesized nanotubes and nanorods of nickel ferrite using a hydrothermal method which were found to be sensitive toward triethylamine. Some of the earlier reports on ferrites as gas sensing materials include the work of Arai et al. [55] on nickel ferrite which was used as a highly reproducible humidity sensor. There is also a report on semiconducting cadmium ferrite that has been used as a high performance ethanol sensor by Liu et al. [56]. Most of the researchers have focused on detection of LPG, SO$_x$, H$_2$S, H$_2$, NO$_x$ and NH$_3$ because of their toxicity, their relation with atmospheric composition or to their high levels in some environments. Organic vapors such as methanol, acetone and ethanol have also been detected [57,58]. Zinc ferrite prepared by Chu et al. [59] was tested for CO, CH$_4$, C$_2$H$_5$OH, and CH$_3$COCH$_3$. The gas sensitivity was reported for different pH and temperature. They found that the sensitivity increases with an increase in reaction temperature.

1.4.2 Photocatalytic Activity

Photocatalytic technique has now become one of the popular research subject in the field of photochemistry and environment protection due to it’s lower cost, non toxicity, stronger antioxidation and so on [60–62].

Over the last 10 years the scientific and engineering interest in the application of semiconductor photocatalysis has grown exponentially. Semiconductor photocatalysts have attracted much attention in the past decade because of their potential applications in the removal of all kinds of pollutants in air or water [63–66]. Most of the investigations have focused on
mixed–metal oxides which show relatively high reactivity and chemical stability under ultraviolet (UV) light. The photocatalytic degradation of organic molecules is of great importance in water treatment. In most cases, dyes are studied as model compounds for large organic molecules. However, ferrites are also effective in the degradation of many other potential organic contaminants.

In the areas of water, air, and waste water treatment alone, more than 200 papers are published per year which attempt to give an overview of some of the underlying principles governing semiconductor photocatalysis and to review the current literature in terms of its potential applications as an environmental control technology [67]. Given the tremendous level of interest in semiconductor photochemistry and photophysics over the last 15 years, a number of review articles have appeared. Recent reviews are provided by Ollis and Al–Akabi [68], Blake [69], Mills [70], Bahnemann et al. [71], Pichat [72], Semiconductor photocatalysis with a primary focus on TiO$_2$ as a durable photocatalyst has been applied to a variety of problems of environmental interest in addition to water and air purification.

It has been shown to be useful for the destruction of microorganisms such as bacteria [73] and viruses [74]. Semiconductors (e.g., TiO$_2$, ZnO, Fe$_2$O$_3$, CdS, and ZnS) can act as sensitizers for light–reduced redox processes due to their electronic structure, which is characterized by a filled valence band and an empty conduction band [75]. The approaches also include the incorporation of transition metals by chemical doping in ferrites [76–78]. Spinel zinc ferrite (ZnFe$_2$O$_4$), is a narrow band gap semiconductor that has a potential application in the conversion of sunlight, because of its sensitivity to ultra–violet light and has no photochemical corrosion [79]. In contrast, on bulk semiconductor electrodes only one species, either the hole or electron, is available for reaction due to band bending [80]. However, in very small semiconductor particle suspensions both species are present on the surface. Therefore, careful consideration of both the oxidative and the reductive paths are required.
1.5 Aim of the Present Work

The spinel containing mixed-metal oxides are of great commercial importance in modern technology. So that, mixed metal oxides containing transition metal ions are found to be of great significance in modern ceramic and solid state device technology. In this class of compounds, the metal ions are capable of possessing one or more oxidation states and they can occupy tetrahedral and octahedral sites. The physico-chemical properties such as crystal structure, electronic conduction, magnetism are greatly influenced by the cations present in two different interstices. The nanostructures of the material and their high surface area are the basic criteria to perform their catalytic and gas sensing activities. Therefore, to find out metal ion distribution in spinel lattice various techniques are used such as X-ray diffraction analysis, electrical resistivity, magnetic hysteresis and infrared spectroscopy.

The physical properties and distribution of metal ions in the spinel also depend upon the preparative technique. In the conventional ceramic techniques the mixture of oxides, nitrates, carbonates etc. are subjected to heat treatment at relatively high temperature using long span of time. The newer co-precipitation method reduces the heating period and sintering temperature appreciably and hence in the present work the systems were prepared by this method.

To keep up this view, following aspects of the present research work are aimed at –

(i) To prepare different series of mixed metal oxides in the regime of nanoscale.
(ii) To characterize these materials by various physic-chemical properties.
(iii) To test these material for the gas sensing response towards various oxidizing and reducing gases.
(iv) To investigate the use of these ferrites as catalyst in UV-light induced photochemical transformations.

With these objectives, we have prepared the economically cheap and efficient materials for gas sensing applications and characterized these materials by various physic-chemical and surface properties.
The crystal structures, electronic properties, grain size, magnetic behavior of the above systems were investigated. It is observed from these studies that nature of cations, thermodynamic aspects, covalence effect and crystal field stabilization energy (CFSE), distributions of cations and site preference energy etc. play an important role in stabilizing the spinel lattice.

The X−ray diffraction studies confirm the completion of solid state reaction, determination of crystal structure and calculations of lattice parameter. FT−IR study is used to detect internal vibrations due to tetrahedral and octahedral metal ions. Scanning electron microscopy is used to reveal ferrite microstructure which involves aspects of grain growth and porosity. Measurements of conductivity have been done for calculation of activation energy and to propose conduction mechanism, while hysteresis measurements were carried out to evaluate magnetization characters.

The demand of gas sensor has been increased to control on the emission of harmful and hazardous gases from the industries and domestic uses. Gas sensing activity is surface phenomenon just like catalysis. Gas sensing performance carried out for different gases/vapours such as LPG, ethanol, CO₂, H₂, Cl₂, ammonia, hydrogen and hydrogen sulphide. Also, gas sensing performance towards various oxidizing and reducing gases at various operating temperatures was also investigated.

UV−light induced photodegradation performance of above systems has been carried out for Congored dye at different irradiation time. The change in the concentration in each degraded solution was monitored on a UV−Vis−NIR spectrophotometer Shimadzu (3600) by measuring the absorbance in 200−800 nm. Distilled water was used as the reference sample. The observed photocatalytic activity is correlated with the physicochemical properties of the catalysts.
1.6. Literature Survey

Substituted ferrites have gained importance because they possess the excellent magnetic, electrical as well as optical properties [81–85] which make them technologically significant. These spinel ferrites have potential applications in various devices such as high density storage devices, microwave devices, humidity sensor, DNA separation, magnetic resonance imaging (MRI), hyperthermia, high–frequency telecommunication devices operating in the range of MHz–GHz as well as in isolator elements for high–voltage generating equipments, circulators, filters and also in microwave, gas sensing and ferrofluid applications, etc [86–93]. Recently, various research groups have developed various chemical methods to synthesize these substituted spinel ferrites by new chemical routes, such as co–precipitation [94, 95], ceramic method [96], reverse micelle method [97], sol–gel [98], molten salt synthesis [99], and hydro–solvothermal synthesis [100]. In the proposed research investigation, we are going to make attempts for the synthesis of mixed spinel ferrites using the simple co–precipitation method.

Tang et al. reported the synthesis of Cu_{0.5−x}Ni_{0.5}Zn_xFe_2O_4 using reaction bath containing stiochiometric amount of nickel chloride, copper chloride, iron chloride and zinc chloride [101]. All samples exhibited a single phase cubic spinel structure, and the saturation magnetization of the samples was found to increase with increasing Zn content. The series of Co_{1−x}Ni_xFe_2O_4 samples, in the form of nanofibers, with average diameter of 110 nm and length up to several millimeters have been prepared by Guo et al. [102]. The effect of nickel composition on the structure and magnetic properties of the resultant nanofibers have been investigated in detail. Nanocrystalline nickel ferrite (NiFe_2O_4) powder was prepared by a co–precipitation method using precursors of nickel and iron [103]. In the present scheme, Niasari et al. interpreted the sample exhibited typical ferromagnetic behavior at room temperature, while a finite coercivity of 245.5 Oe was present at 300 K. Sugunan et al. [104] reported the selective alkylation of aniline to N–methyl aniline using chromium manganese ferrospinel. The catalytic activities of the samples have been related to their
acidity–basicity as well as on the cation distribution throughout the ferrites host lattice. The catalytic synthesis of 2-ethyl phenol using Cu$_{1-x}$Co$_x$Fe$_2$O$_4$ was carried out by Gopinath et al. [105]. Fetisova reported new generation of magnetic field sensors [106]. These sensors can provide a high sensitivity, miniature size, and virtually zeropower consumption. Sensors for ac and dc magnetic fields, ac and dc electric currents were fabricated. Sensors based on nickel ferrite (Ni$_{1-x}$Zn$_x$Fe$_2$O$_4$ with x=1–0.5)/lead zirconate–titanate (PbZr$_{0.52}$ Ti$_{0.48}$O$_3$) have shown an excellent performance. Tianshu reported a cadmium ferrite in gas sensing applications [107]. The semiconducting cadmium ferrite has been used as a high–performance ethanol sensor by Liu et al. [56]. The zinc, copper, cobalt, and nickel ferrites are studied by Reddy et al. [108] for detection of toxic gases and chlorine as well. Chen et al. [109] studied spinel type oxides with formula MFe$_2$O$_4$ (M = Cu, Zn, Cd, and Mg) as important mixed oxides in gas sensors. They investigated these oxides for detection of both oxidizing and reducing gases. The oxygen sensing properties of magnesium, zinc, and nickel ferrites in comparison with those of chromites like magnesium, zinc, and nickel were studied by Shimiza et al. [110]. They observed more sensitivity of p–type chromites than n–type ferrites to oxygen. For reducing gases, Liu et al. [111] reported that the n–type semiconductor CdFe$_2$O$_4$ exhibits high sensitivity and selectivity to alcohol vapor. In the last decade, materials with small particle size and large surface areas were studied in the field of gas sensors [112–113]. Recently Muraishi reported the excellent gas sensing characteristics of porous nickel ferrite added with rare earth metal [114].

Rezlescu demonstrated that the nickel ferrites are to be good materials for gas sensing applications [115]. Darshane also reported gas sensing properties of zinc ferrite nanoparticles [116]. Cu$_{1-x}$Mn$_x$Fe$_2$O$_4$ system were synthesized by Abdel Halim et al. [117] and they reported that the effect of temperature shows catalytic oxidation of CO using Cu–Mn ferrite increases with an increase in calcination temperatures.
Ferrites possess important photocatalytic properties for many industrial processes. The oxidative dehydrogenation of hydrocarbons by using photocatalytic activity of magnesium ferrite was reported by Gibson et al. [118]. Manova, et al. have studied the decomposition of alcohols and hydrogen peroxide [119]. The oxidation of compounds such as CO was studied by Pal Dey et al. [120]. Silva et al. studied the oxidation of H₂, CH₄ and chlorobenzene [121]. The photocatalytic activity of Co and Ni Based Ferrospinels was carried towards the alkylation of phenol and methanol by Sreekumar [122]. Magnetic ordering of Ni–Cd ferrite was studied by Nath et al. [123], reported that the magnetic moment and saturation magnetization initially increases with cadmium content up to a certain limit and then tends to decrease.
References


