# A brief review on ferrites gas sensors types and application

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## Abstract

Ferrite is a crucial technical substance with a variety of features. Some of the significant advancements in the research of ferrite are summarised in this publication. The standards for repotting the physicochemical characteristics of cobalt ferrite, nickel ferrite, and magnesium ferrite, were followed in this systematic review. In this review summary of nanocrystalline ferrites, types of gas sensors, and applications in different fields of technology.

**Key Word-** Cobalt ferrite, nickel ferrite, and magnesium ferrite, Gas sensors

## 1. INTRODUCTION

Since their nano counterparts' uses have expanded to include magnetic drug delivery, contrast agents for magnetic resonance imaging, magnetic refrigeration, and magnetic materials for the hypothermic therapy of cancer cells, ferrite research interest has been steadily increasing [1-4]. In addition to these, there are several applications where ferrites are incompatible with other elements. Among these uses are magnetic tape recording, computer secondary storage devices, switch mode power supplies (SMPS), and ultrasonic electromagnetic cores [5-8]. Nanocrystalline ferrites are being used as gas sensors and biological sensors [9, 10]. The ferrites' intriguing features, chief among which are high permeability and a small dielectric constant at low eddy current losses, have resulted in a diverse range of applicability [11]. Ferrites are magnetic ceramic materials that have a significant amount of $Fe^{3+}$. The spinel ferrites that have received the greatest attention include $NiFe_2O_4$, $CoFe_2O_4$, $MnFe_2O_4$, $MgFe_2O_4$, $CuFe_2O_4$, $LiFe_2O_4$, and $ZnFe_2O_4$. There are several uses for nickel ferrite, or $NiFe_2O_4$, a soft ferrite material with low coercivity and moderate saturation magnetization, such as inductors, minimum power loss higher-frequency materials, electromagnetic wave absorbers, gas sensors, and drug delivery substances [12-14]. Highly permeable manganese ferrite, or $MnFe_2O_4$, is used in the core of high-frequency electromagnets and transformers as well as microwave devices [15, 16]. commercial applications for copper ferrite, or $CuFe_2O_4$, include gas sensors, energy storage, and catalysts

[17]. Lithium ferrite, $LiFe_2O_4$, is suitable for sensing and microwave applications because of its high-Temperature range and electrical resistivity [18]. The barium ferrite, $BaFe_{12}O_{19}$, is used in microwave and shielding devices and is referred to as hexaferrite because of its hexagonal close-packed structure [19, 20]. The body-centered cubic structure of garnets, $Ln_3Fe_5O_{12}$ (where Ln = Y, Dy, Er, Tb, etc.), has applications in optical communications and microwave absorber devices [21].

## 2.1 COBALT FERRITE

With its huge cubic magnetocrystalline anisotropy, strong coercivity, intermediate saturation magnetization, and very high electrical resistivity, cobalt ferrite ($CoFe_2O_4$) are the most significant ferrimagnetic material [22]. Due to its application as a supplementary storage medium for computers, microwave devices, gas and humid sensors, magnetostrictive sensors, and catalysis, this ferrite is significant technologically [23,24]. Magnetic medication delivery, MRI contrast agents, magnetic hypothermia, and biosensors are some of the medicinal uses [25,26]. Due to the finite non-zero magnetic (orbital) moment of $Co^{2+}$ ions, cobalt ferrite has a distinctive cubic anisotropy and is naturally magnetocrystalline. Cobalt ferrite is unutilized in biological applications because of its distinctive high anisotropy and saturation magnetization [27]. It is a good option for biosensor applications due to its superparamagnetic properties and lower toxicity [28]. It is a useful material for electrodes used in electrochemical processes due to the distinctive high coercivity and substantial magnetic loss [27]. The magnetic effect has been seen in the region of the blocking temperature inside the cobalt ferrite nanoparticle of size between 5 and 8 nm [29]. The $CoFe_2O_4$ nanoparticles, which have a diameter of 4.5 nm, demonstrated the MCE at a reasonably high temperature with such a low magnetic field demand [29].

The cobalt ferrite's saturation magnetization (Ms), retentivity (Mr), and coercivity (Hc) have all improved due to the replacement of divalent $Ni^{2+}$ ions [30]. According to the findings, substituted $Cu^{2+}$ ions occupy both the tetrahedral and octahedral positions of cobalt ferrites, which affects the ferrite's structural and magnetic characteristics and makes it a good material for use in microwave devices and biomedicine [30]. The coupled Mg-Zr substitution in the cobalt ferrite was found to improve electrical resistivity, activation energy, and A-B interaction [31]. The Curie temperature has been decreased but the magnetostriction characteristic has been preserved thanks to the substitution of $Mn^{3+}$ by $Fe^{3+}$ ions from $CoFe_2O_4$, allowing the ferrite to be employed in stress sensor applications [32]. The saturation magnetization of the ferrite has been decreased as a result of the replacement of diamagnetic $Al^{3+}$ cations for $Fe^{3+}$ [33-34]. The antibacterial activity of the $Cu^{2+}$ substituted cobalt ferrite increases with the ferrite's increasing $Cu^{2+}$ content. Recently, the catalytic activity for hazardous degradation of dyes in cobalt ferrite replaced with $Bi^{3+}$ was discovered. $Bi^{3+}$ favors the octahedral $B^{-}$site [35].

## 2.2 NICKEL FERRITE

Nickel spinel ferrites are spinel ferrites that include the divalent cation nickel (Ni). Ni-ferrite has a resistivity of more than $10^9$ Ω cm, making it a highly resistant material [36]. An inverse spinel structure is seen in nickel ferrite. Ions occupy 8 tetrahedral voids (A-sites) whereas $Fe^{3+}$ and $Ni^{2+}$ ions occupy 16 octahedral voids (B-sites) in an equal split. The degree of inversion for pure nickel ferrites is 1. Nickel ferrites belong to the category of soft ferrites because of their high electric resistivity, low coercivity, moderate saturation magnetization, as well as low hysteresis losses [37, 38].

These characteristics allow for the practical use of these ferrites in a variety of applications, including the manufacturing of antenna [39,40]. medical diagnostics and biological applications, catalysts [41] circulators [42], computer memory [43], electrical apparatus [44], electronic devices [43], biotechnology, supercapacitor energy storage [45,47], gas detectors [48], superior isolators, filters, and permanent magnets [49], AC/DC converters, electromagnetic noise suppressors, and inductors [50], induction heating [51], internet [52], microwave appliances, communications-related applications [53].

In 2003, liquefied petroleum gas (LPG) in the air was detected using Ni ferrite that had been produced hydrothermal method. This gas sensing application has shown to be successful with Ni ferrite [54].

## 2.3 MAGNESIUM FERRITE

Researchers have been interested in Mg-ferrites for the past few decades [56-59]. The tremendous perspective of this material for applications that depend on higher levels of electrical resistivity, Curie temperature, and saturation magnetization along with minimal dielectric losses and moderate coercive fields is one explanation for this [60].

Magnesium ferrite in its crystallized form is an essential component of the spinel family and a soft magnetic substance. It's an n-type semiconducting material with various uses in adsorption, and sensors, including magnetic applications [61]. The material exhibits good potential for novel applications in humidity, gas sensing, and drug administration due to its nanocrystalline nature and beneficial characteristics [62, 64].

$MgFe_2O_4$ is used in heterogeneous catalysis, especially in addition to magnetic and electrical purposes [65-67]. Magnesium ferrite and also its related compounds are also widely used in microwave devices such as circulators, insulators, phase shifters, and multifunctional devices [68-70] owing to their low magnetic and dielectric losses and high resistivity.

## 3. MAGNETIC PROPERTIES OF MATERIALS

Soft magnetic material is defined as one which is readily magnetized and demagnetized [71]. Whenever extensive magnetization direction changes are necessary, soft magnetic materials are utilized. For making ferrites and garnets for various purposes, microstructural analysis of such material is required. Hard magnetic materials show significant hysteresis loss. In contrast to the soft material, the remnant magnetization and coercivity in the hard magnetic material are quite high [72].

## 4. FERRITES AS A SENSOR

In a variety of sectors, including petrochemical, automotive, mining, and aviation, among others, the industries are crucial to a nation's development. To supply the basic energy needs of people, fossil fuels including coal, natural gas, gasoline, and diesel are a more dependable source. Because they are non-renewable and unsustainable, fossil fuels are more likely to release dangerous contaminants into the environment. Sulfur dioxide ($SO_2$), volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide ($CO_2$), and nitrogen oxides are some of the damaging pollutants (NOx) [73]. Water is the most popular form of hydrogen. Since water contains a mixture of hydrogen and oxygen, a water-splitting splitting process is required to extract the hydrogen energy from the water, however owing to its low efficiency, this cannot be used in industrial applications [74].

In order to create a clean environment, it is essential to be able to identify dangerous chemicals. Among clinical applications, such as health and safety measures and monitoring the environment for dangerous contaminants, sensor technology has attracted substantial interest. Gas sensors could produce an electrical output that can be used to detect and monitor poisonous gases, harmful pollutants, and particles. Consequently, gas sensors are a kind of active sensing material that is formed of metal oxides, polymers, Nanocomposites, etc., and have a transducer that measures low-concentration target gases when they contact the surface to create electrical signals [75].

## 5. NEED FOR GAS SENSORS

According to late 20th century to the early 21st century, the fourth industrial revolution introduced sophisticated, varied technology systems. Because of the release of multiple harmful gases that have caused countless health issues and impacted Mother Nature, the successive industrial revolutions have played a significant role in regulating the environment with defined rules. It is a serious obligation to use a reliable gas sensor to monitor the gas released in different sectors [76]. The automotive, medical, diagnostic, and mining industries have all seen a considerable increase in the requirement for efficient gas sensors. The industrial revolution has caused a variety of dangerous gases and pollutants to be released into the environment, necessitating the monitoring of the gases released by factories, autos, chemical processes, research labs, and other enterprises. There are three different procedures that may be used to monitor the emission of hazardous gases [77].

## 5.1 TYPES OF GAS SENSORS

There are various types of gas sensors depending on the functioning mechanism and instrument design [78-80]. Such as semiconducting metal oxide gas sensors, electrochemical gas sensors, catalytic gas sensors, tc. A theoretical basis for these sensors is briefly described below.

## 5. 2 CATALYTIC BEAD GAS SENSOR

A coil of wire covered with catalyst-coated glass or ceramic makes up a catalytic bead. Whenever combustible gas makes contact with the coil after it has been allowed to heat to a certain temperature, it begins to burn and generates heat proportional to the concentration of such gas. The coil temperature is raised by this heat. The resistance increases in response to the rising temperature. The bead, a reference bead, and two known high-resistors are mostly linked to such Wheatstone bridge in order to quantify the variation. Although the reference bead is the same as the detector bead, it is devoid of the catalyst. In other words, it doesn't react with flammable gas.

## 5.3 METAL OXIDE SEMICONDUCTOR GAS SENSOR

A conventional metal oxide semiconductor gas sensor device has four basic components: a heater, a substrate, contact electrodes, and just a sensitive semiconducting layer. It is also called a metal oxide (MOX) sensor, solid-state semiconductor, resistive, and chemiresistive. The sensor is given a DC voltage, and indeed the result is observed by measuring the electrical resistance. The fundamental component of a semiconductor metal oxide gas sensor is just the variation in resistance that results from the adsorption, diffusion, catalysis, and reaction of analyte upon the surface of such sensing layer.

### 5.4 ELECTROCHEMICAL GAS SENSOR

Two metallic electrodes anode and cathode along with such an electrolyte are found in electrochemical gas sensors. According to an electrochemical reaction taking place on the sensing electrode surface whenever the test gas comes into contact with this, a significant electrical current would be generated. Through the electrolyte, the electrons are moved to another electrode. In such a gas sensor, electrolytes come in both liquid and solid types. Typically solid polymer electrolytes are preferred when liquid electrolytes have such a tendency to leak. Amperometric and potentiometric are the two main designs for electrochemical gas sensors. Although the potentiometric design functions with zero current as well as applies a constant voltage, its amperometric configuration uses a sensor signal which is the prospective difference between the two electrodes. The concept for an electrochemical hydrogen gas sensor. When hydrogen gas molecules split into protons ($H^+$) and electrons ($e^-$) just on the detecting electrode. Protons flow through electrolytes and electrons travel via the external circuit to reach the reference electrode. When reacting also with an oxygen molecule, its counter electrode balances the overall reaction of such sensing electrode.

## 6. INVENTIVE APPLICATIONS FOR FERRITES

### 6.1 INDUCTORS

In such a wide range of electronic circuits, including low-noise amplifiers, filters, voltage-controlled oscillators, and impedance-matching matching networks, ferrites bearing is widely applied as inductive parts. In addition to many other tendencies, their new applications as inductors reflect the overall trend of downsizing and integration into ferrite multilayers for passive functional electronic devices. Additionally, a procedure compatible with the production of integrated circuits should be used to create the ferrite film in order to offer a high permeability at the operation frequency. Sputtering produces films with such a high density, but even the composition can occasionally be tricky to precisely manage, and the annealing procedures can reach high temperatures. High-quality films can be created using pulsed laser deposition, but also an approach that involves preparing the ferrite film using a mix of sol-gel and spin-coating appears to be simpler and less expensive [81].

According to the magnetostriction of the magnetic material, the magnetic field initially imposes a mechanical strain upon this. Such mechanical strain subsequently induces a voltage in the piezoelectric layer. High sensitivity, small size, and also very minimal power usage are all features that these sensors may offer [82].

### 6.2. MAXIMUM FREQUENCY

Although microwave innovation requires greater frequencies and bandwidths up to 100 GHz, there has been increasing in the demand for magnetic materials for high-frequency applications including telecommunication as well as radar systems. Being nonconducting oxides, ferrites permit complete electromagnetic field penetration, unlike metals, in which the skin effect drastically restricts the penetration of high-frequency fields [83] .

### 6.3. POWER

Ferrites' electrical applications are mainly dominated by power supplies for a wide range of gadgets, including computers, various peripherals, TV and video systems, as well as all kinds of small to medium-sized equipment. Modern switched-mode power distribution circuits are where the technology is most commonly used (SMPSs) [84]. A recent approach for improving the efficiency of ferrite cores primarily centered on reducing eddy currents by raising resistivity. Apart from the application of nonconducting additives [85].

### 6.4. ELECTROMAGNETIC INTERFERENCE (EMI) SUPPRESSION

The risk of electromagnetic interference has significantly increased due to the huge increase in the number of electronic devices, including high-speed digital interfaces in laptops and computers, digital cameras, scanners, and other devices, in compact spaces (EMI). Particularly, the rapid advancement of wireless communications has brought about interference brought on by magnetic and electric fields. The performance of an electronic system is negatively impacted by an electromagnetic disturbance known as electromagnetic interference [86].

### 6.5. BIOSCIENCES

Numerous live species include magnetic elements in the form of nanoparticles, primarily magnetite ($Fe_3O_4$), which can be utilized in a variety of applications [86]. Numerous living organisms include magnetic elements in the form of nanoparticles, primarily magnetite ($Fe_3O_4$), which are useful in a variety of applications [87]. The development of biogenic and synthetic magnetic micro- and nanoparticles has led to the creation of numerous biotechnological applications [88]. To target radionuclides to particular tissues, magnetic nanoparticles have been utilized. In rat liver tissue that has been preserved in vivo, a method has been established to directly label a radioisotope with ferrite particles [89].

Its liver is one of the organs that magnetite superparamagnetic particles are selectively associated with in magnetic resonance imaging (MRI). Because these particles alter the rate during which protons decay from excited towards the ground state, which also forms the basis of MRI, such healthy tissue regions exhibit a different, darker contrast [90-91].

It is conceivable to apply the thermal energy from the hysteresis loss of ferrites to heat particular tissues or organs in order to treat cancer. Tumour tissues warm up and become more susceptible to radiotherapy or chemotherapy [92]. By utilizing an external magnetic field, such trapped compounds could be directed to a specific place or can be eliminated from the system. The compounds can direct their effects to a particular area or type of tissue as well as act as affinity ligands to ensnare specific molecules or cell types [93].

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