

Unique Magnetic and Electric Properties

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ABSTRACT

The general formula of spinel ferrite is represented by AB_2O_4 in which the metal cations A and B occupy tetrahedral (A) and octahedral (B) interstitial sites formed by the face centred cubic arrangement of oxygen anions. Nickel ferrite ($NiFe_2O_4$) and cobalt ferrite ($CoFe_2O_4$) are among the most studied ferrites in bulk and nano form. $NiFe_2O_4$ is a soft magnetic material utilized for applications in electronic devices, gas sensors, magnetic guided drug delivery and magnetic resonance imaging. On the other hand, cobalt ferrite ($CoFe_2O_4$) is a well-known hard magnetic material which has been explored for its high coercivity, moderate to high saturation magnetization with remarkable chemical stability and mechanical hardness. These properties make it suitable for various technological applications such as audio/video tapes, high density digital recording disks, magnetic drug delivery, radio-frequency hyperthermia, magnetic separation and magnetic resonance imaging. Both $NiFe_2O_4$ and $CoFe_2O_4$ have centrosymmetric cubic lattice of mixed spinel structure of $Fd\bar{3}m$ space group. The mixed spinel structure of $CoFe_2O_4$ and $NiFe_2O_4$ is represented as $(Co\delta^{2+}/Ni\delta^{2+}Fe^{1-\delta}3^+)A[Co^{1-\delta}2^+/Ni^{1-\delta}2^+/Fe^{1+\delta}3^+B]$ where δ is the degree of inversion which depends on the synthesis conditions. There are various superexchange interactions which exist in such type of structure like $Fe^{3+}(B)-O-Co^{2+}(B)/Ni^{2+}(B)$, $Fe^{3+}(B)-O-Fe^{3+}(B)$, $Fe^{3+}(B)-O-Fe^{3+}(A)$, $Fe^{3+}(A)-O-Co^{2+}(B)/Ni^{2+}(B)$, $Co^{2+}(A)/Ni^{2+}(A)-O-Fe^{3+}(A)$ and $Fe^{3+}(B)-O-Co^{2+}(A)/Ni^{2+}(A)$. These superexchange interactions are responsible for the magnetic behaviour of these ferrites. The other important parameter which determines the performance of the ferrites is its electrical conductivity.

Introduction

Ferrites are one of the most exploited materials employed in technological applications owing to their unique magnetic and electric properties. Nanotechnology has created a recent surge in the research interest in spinel ferrite nanomaterials which showed altered properties in comparison to their bulk counterpart. Nanoparticles have a high surface to volume ratio, which results in distinct material properties and hence, ferrite nanomaterials are being explored for their potential applications in colour imaging, catalytic activity, high density data storage, magnetically guided drug delivery, ferro-fluids, magnetic refrigeration systems and biomedical applications. The Synopsis-2 charge carriers hopping mechanism between cations at octahedral sites are responsible for the conduction in these ferrites. This conductivity is strongly influenced by stoichiometry, cationic interexchange and the creation of oxygen or cation vacancies. The dielectric behaviour of ferrites is greatly influenced by the magnitude of their conductivity. Recently, rare earth ions (like Y^{3+} , Gd^{3+} , Ho^{3+} , Sm^{3+} and Nd^{3+} etc.)

Objectives

To know the properties of magnetic characters of ferrites

To understand the nature Of Magnetic And Electric Properties

Method

The Experimental method is used for the study

Experiments

Substitution in ferrites system has been explored which leads to structural disorder, lattice strain and eventually alters the properties of ferrites 1-15. Rare-earth ions substitution into $CoFe_2O_4$ tends to decrease the room-temperature magnetization and reduce its Curie temperature (TC) 4. This lowering of TC made it a more promising candidate for magneto-optical recording applications 4. The ionic radii of rare earth ions are higher than that of Fe, Ni and Co ions, therefore, very small amount of rare earth ions substitution at Co/ Ni and/or Fe site is expected to induce a large strain in the parent lattice. This large strain may further restrict the rare earth ions to adjust in the spinel lattice of ferrites. The substitution of rare earth ions (4f electrons) in place of Fe^{3+} (3d electrons) gives rise of $RE^{3+}-Fe^{3+}$ interactions of their 4f-3d electrons which might alter the magnetic properties of ferrites 2. Over the last decade in the field of sensors, ferrite based gas sensors are extensively explored to detect and monitor pollution and toxic gases 6. The measurement of pollution and toxic gases is important for an ecologically suitable and stable development. The well known Metal Oxide (MO) semiconductors used for gas sensing application such as SnO_2 , ZnO or WO_3 , show high sensitivity, cost effectiveness and ease of fabrication 7,18. However, their use is limited in devices due to low selectivity and high operating temperatures. Therefore, gas sensors based on ternary transition metal oxides, particularly ferrites, are being explored for their expected good sensitivity and selectivity towards a particular gas 9-24. Nano-materials based sensors show high sensitivities

compared to their bulk counterpart because of their special surface and morphology. Ferrite nanoparticles are suitable candidate of many technological applications and their properties depend on their composition, microstructure and hence are sensitive to the synthesis method adopted. There are several physical and chemical methods used for the synthesis of these materials such as ceramic method, co-precipitation method, hydrothermal method, organic precursor method and sol-gel method, 25-28. However, the co-precipitation method is widely used because of its simplicity, low cost, low synthesis temperature, high yield and small particle size. The advantages of this method over others are that the crystallite size can be easily controlled by controlling the sintering temperature and pH values and also no extra heat treatments are required. There are numerous reports available on different properties with composition but little work is being done on the cation distribution in sublattices of ferrites which is an important attribute in selecting properties of ferrite nanoparticles. Also there is contradiction in available reports on rare earth substitution which leads the researchers to show a great curiosity towards spinel ferrite nanoparticles. Objectives of the present work: The main objectives of the present work are: Synthesis of pure phase NiFe₂O₄, CoFe₂O₄ and mixed Ni_{1-x}Co_xFe₂O₄ nanoparticles systems by wet chemical co-precipitation method and their systematic study on structural, magnetic, dielectric and optical properties and to establish a correlation between cations distribution and observed magnetic properties. A detailed investigation on the effect of rare earth ion (Gd³⁺) doping on the structural, microstructural, magnetic, optical and dielectric properties of NiFe₂O₄ and CoFe₂O₄ nanoparticle systems and to relate microscopic structure to observed magnetic properties. Gas sensing properties of NiFe₂O₄, CoFe₂O₄ and mixed Ni_{1-x}Co_xFe₂O₄ nanoparticles towards atmospheric pollutants and hazardous gases like CO and ethanol. System Studied: To achieve above said objectives, the following systems were studied: 6 Phase pure NiFe₂O₄ nanoparticles were synthesized by co-precipitation method and synthesis conditions were

optimized. 7 Ni_{1-x}Co_xFe₂O₄ nanoparticles with x = 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 were synthesized by co-precipitation method and studied their structural, magnetic, dielectric and optical properties. 8 CoGdxFe_{2-x}O₄ nanoparticles with x = 0.0, 0.03, 0.05, 0.07, 0.10 and 0.15 were synthesized by co-precipitation method and studied their detailed structural, magnetic, dielectric and optical properties. Synopsis-4 9 NiGdxFe_{2-x}O₄ nanoparticles with x = 0.0, 0.03, 0.05, 0.07 and 0.10 synthesized by coprecipitation method and studied their structural, magnetic and dielectric properties. 10 Gas sensing properties of pure NiFe₂O₄, CoFe₂O₄ and mixed Ni_{1-x}Co_xFe₂O₄ nanoparticles as a function of composition and temperature were studied.

Results

Electron holography allowed the researchers to study the magnetism of the ultrathin (a few nanometers in size) grain boundary region in Nd-Fe-B permanent magnets with pinpoint accuracy, and could lead to stronger permanent magnets for use in better-performing traction motors in hybrid electric vehicles.

Conclusion

By allowing scientists to observe the magnitude and direction of the magnetic fields of materials at unprecedented resolutions, electron holography is deepening understanding of the magnetic properties and behaviour of materials, leading to new directions in materials science and engineering. Although scientists have been able to separate the electric and magnetic fields to observe them at resolutions less than one nanometer, they have not been able to achieve this at the atomic level.

“Recent advances in electron microscopes are reaching a technological limit,” explains Tanigaki. “For the next breakthrough, we are looking to combine electron holography with information science by using artificial intelligence to improve the signal-to-noise ratio, and could allow us to achieve magnetic field observations with atomic-level resolution.

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