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A Study of Electrical and Magnetic Properties of Nano Ferrites

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Abstract: Nano sized ferrites show a significant change in physical, electrical, and magnetic properties in contrast to their bulk counterparts due to their high surface to volume ratio of the grains. Ferrite nanomaterials have been prepared by coprecipitation method. X-ray diffraction analysis confirms the single-phase cubic close-packed lattice formation of synthesized materials. Vibrating Sample magnetometer is used to get the information regarding magnetic properties. The synthesized nanomaterials possess high saturation magnetization and moderate coercive field and may have a potential for different magnetic applications. Impedance spectroscopy is used for getting information about metallic and semiconducting behaviour. Electrical conduction in ferrite nanomaterials is due to electronic hopping between ion pairs of the same type of element on equivalent sub lattice sites but having different valence state. Variation in resistivity with dopant concentration is explained based on occupancy of cations in the sub-lattices of the spinel structure. Dielectric behavior of the spinel ferrites is explained by considering interfacial polarization due to surface effect. This work is an attempt to meet the challenges for the advancements in the new ferrite technology.

Keywords:- Nano Ferrires, X-ray diffraction, Coprecipitation, Impedance Spectroscopy Vibrating Sample magnetometer.

1. INTRODUCTION

The emergence of nanoscience and nanotechnology as a leading Technology of 21st century has accelerated the growth of material Science. It involves several disciplines of science which includes solid state physics, solid state chemistry, material Engegineering, medical science and biotechnology. Among diverse nanomaterials, ferrite nanoparticles have become incalculably popular for a spacious variety of applications.

Ferrites (Fe_3O_4) are usually ferromagnetic compounds which (Fe_3O_4) are the oldest material invented as loadstone having lot of applications in the bulk form. In our study we have considered Ferrites in Nanoscale because the transition from bulk to Nanoscale leads to a number of changes in structural, physical, magnetic and electrical properties of the sample. Preparation of single domain Fe_3O_4 superparamagnetic particles, opened a new avenue in the field of magnetism.

The dispensation routes to synthesize ferrites are many such as microemulsion method, co-precipitation, sol-gel, ball milling, ceramic method, hydrothermal method and solvothermal synthesis etc [1-3]. Among these, co-precipitation is an uncomplicated and economically viable technique to prepare ferrite nanoparticles at low temperatures.

In this work, we have synthesized ferrite nanoparticles via the co-precipitation technique to investigate their structural, optical, magnetic property and their degradation efficiency. Nanoparticle are of great scientific interest because they represent a bridge between bulk materials and molecules and structures at atomic level.

2. STRUCTURE OF NANO FERRITES

A ferrite is a type of ceramic compound of iron oxide combined chemically with one or more additional metallic elements such as strontium, barium, manganese, nickel and Zinc. In ferrite unit cell, there are 8 molecules [7]. Therefore in a ferrite unit cell, there are 8 divalent metal ions, 16 ferric ions and 32 oxygen ions.

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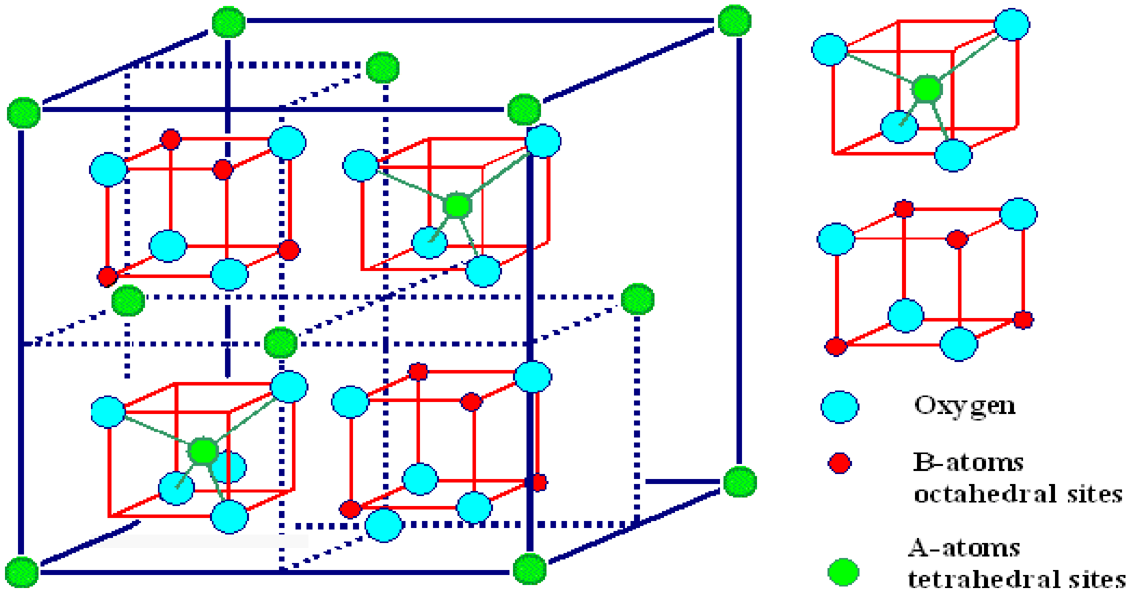


3. TYPES OF SPINEL:

The ferrite spinel structure is based on a closed-packed oxygen lattice, in which tetrahedral (called A sites) and octahedral (called B sites) interstices are occupied by the cations.[11] Normally there are three types of structures in ferrites

1. Regular Spine
2. Inverse Spine
3. Mixed Spine

1. **Regular Spine**:- Spinels with only divalent ions in tetrahedral sites are called normal or regular spines.
(A)[B2]O4 => A-Tetrahedral (2+ - divalent) ; B-Octahedral (3+ - trivalent)
All divalent are in A site. Example $ZnFe_2O_4$
2. **Inverse Spine**:- Spinels with only trivalent ions in tetrahedral sites are called Inverse spines.
(B)[AB2]O4 = > B site shared by both divalent and trivalent where A site completely filled with trivalent ions. Example $CoFe_2O_4$
3. **Mixed Spine**:- Spinels with divalent and trivalent ions both in tetrahedral and octahedral sites are called Mixed spines. **(**A1-XBx)[AxB2-X]O4 => Divalent and trivalent occupies both A and B site.
Example $MnFe_2O_4$

4. PREPARATION OF FERRITE

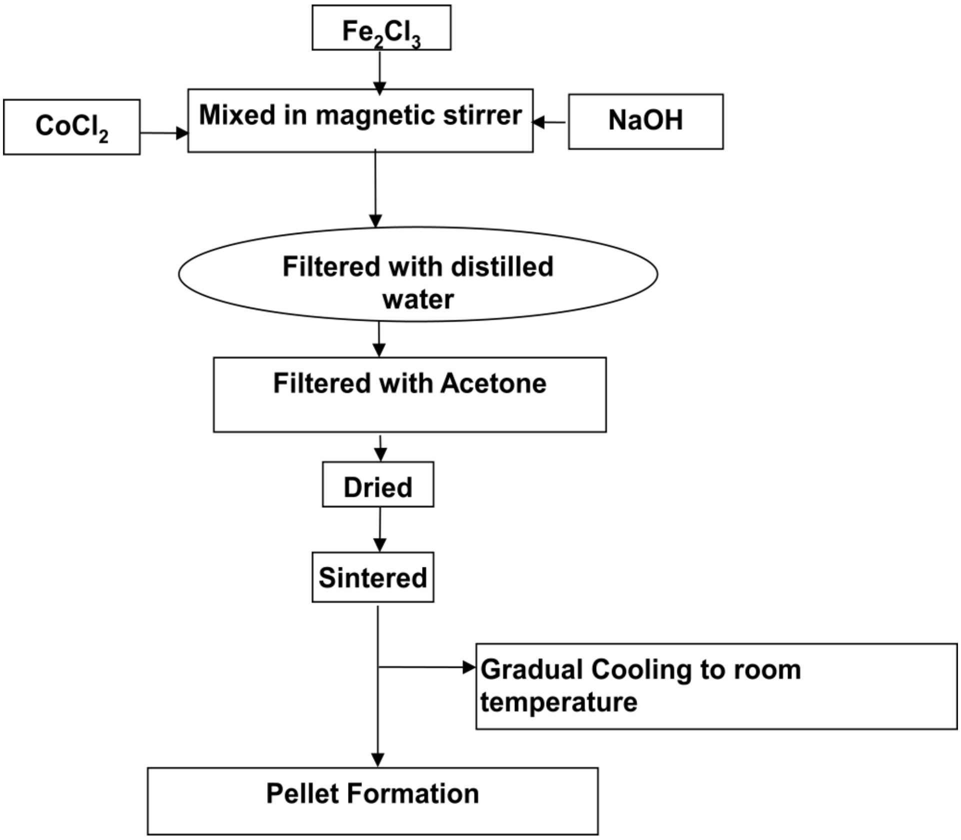
The vast application of nano ferrites in; permanent magnets, ferrofluids, storage devices, targeted drug delivery and other uses, has attracted much attention in their way of synthesizing these nano materials .Synthesis techniques play an important role in controlling the size and surface area of materials.

Large-scale applications of ferrites with small particles and tailoring of specific properties have prompted the development of widely used chemical methods, including combustion, coprecipitation, sol-gel, mechanical alloying and precipitation for the fabrication of stoichiometric and chemically pure spinel ferrite nanoparticles.

Here in this case we use coprecipitation method for our study. Co-precipitation is the least expensive and the simplest approach for making nanoparticles. This method produces nanoparticles in large quantities (order of grams) in a relatively short interval of time and utilizes inexpensive and readily available chemicals as precursors[15-17]. Inexpensive iron salts may be mixed with a precipitating agent such as NaOH to form nanoparticles of iron oxides [4].

In Co-precipitation, the nucleation and growth steps overlap, but the particles are usually harvested in the time period before Ostwald ripening fully takes into effect.

Flow chart for preparing ferrite by coprecipitation



5. CHARACTERIZATION:-

The characterization of the prepared ferrite nanoparticles was conducted by using following three techniques to verify the particle size and distribution and to explore other parameters of interest.
(1)Structural analysis
(2)Electrical Properties
(3)Magnetization Studies

5.1 Structural analysis

The structure of the Ferrites nanoparticles is characterized by the XRD technique. XRD is one of the most extensively used techniques for the characterisation of nanoparticles. XRD measures the size, shape, internal stress of small crystalline regions and average spacing's between the layers or rows of atoms[24]. It determines the orientation of a single Crystal or grain and helps to find the crystal structure of an unknown material.

5.2Electrical properties

Electrical properties of ferrites generally depend upon the composition and preparative parameters of the synthesized materials.The electrical properties of the nano ferrites are characterized by the following methods

(1) Impedance analysis
(2) AC conductivity
(3) Dielectric analysis

5.2.1 Impedance analysis

❖ Existence of single semicircle is due to grain boundary volume, suggesting that the main contribution for conductivity comes from grain boundaries because the grain boundary volume is very large due to smaller particle size[22].

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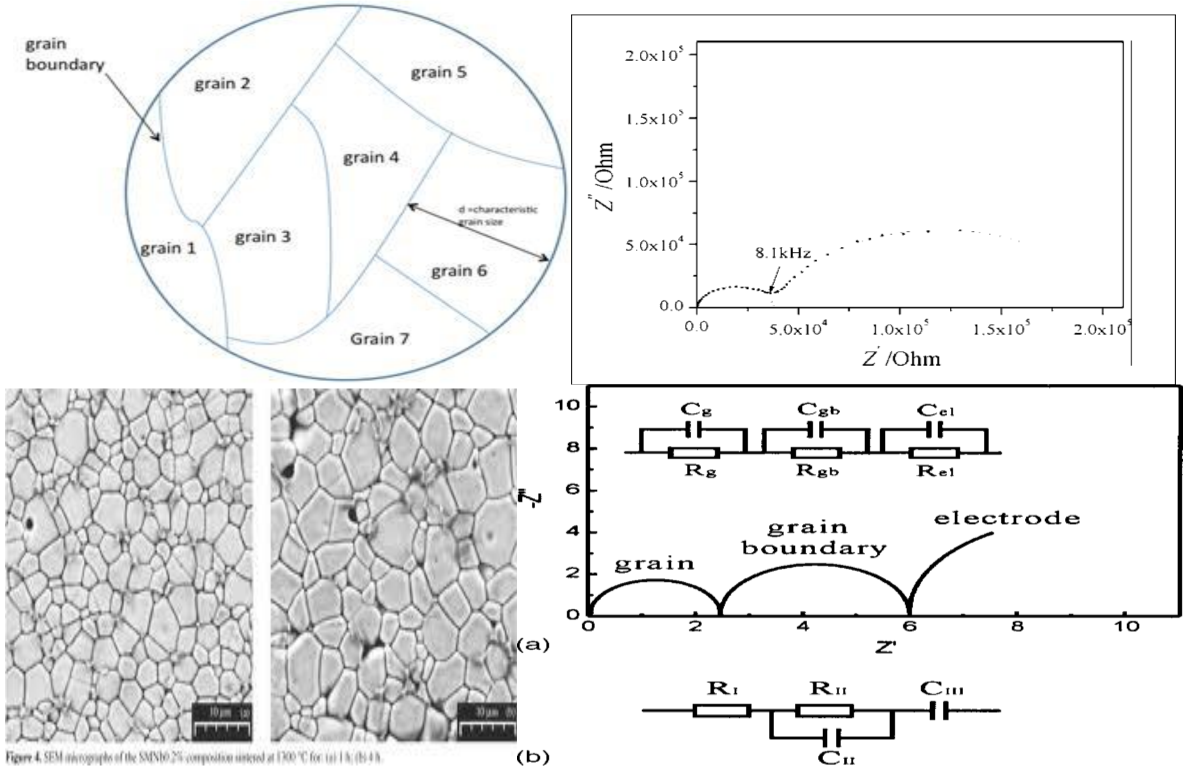
❖ Existences of two semicircle is explained by means of an equivalent circuit(i.e) two parallel R(resistance) and C (Capacitance) circuits connected in series. The low frequency arc corresponds to the grain boundary relaxation mechanism, while the high frequency arc to the grain relaxation in polycrystalline ceramics.



5.2.2 AC conductivity

Electrical conduction in ferrite nanomaterials is due to electronic hopping between ion pairs of the same type of element on equivalent sublattice sites but having different valence state. The number of such ion pairs depends upon the sintering conditions and extent of reduction of Fe^{3+} to Fe^{2+} at elevated temperature. $Fe2^{+}/Fe3^{+}$ ratio on the B-sites controls the overall resistivity in ferrites materials. AC conductivity helps to understand the conduction mechanism and type of polarons responsible for the conduction. The switch over from the frequency independent conductivity region to frequency dependent region is the signature of the conductivity relaxation, which shifts towards higher frequencies as the temperature increases.

5.2.3 Dielectric analysis

Dielectric behavior of the spinel ferrites can be explained by considering interfacial polarization due to surface effect. At low frequency, the dipolar and interfacial polarization both contribute to the value of dielectric constant but at higher frequency, only the electronic polarization becomes significant. At low frequency, the electron exchange between Fe^{2+} and Fe^{3+} ions is capable to follow the alternating field but the frequency of electron exchange between two ions cannot follow the high alternating field. This results in a decrease in polarization and the conduction lag beyond a certain frequency of externally applied field. Therefore, the value of dielectric constant is lower at high frequencies than at low frequencies. Furthermore, the dielectric properties of heterogeneous systems like ferrites are dependent on several factors including the method of preparation, sintering temperature, sintering atmosphere, etc. Since, ferrite powdered samples are sintered under slightly reducing conditions, the divalent iron Fe^{2+} is expected to be formed in the body of the ferrite material leading to high conductivity grains [19-22]. When such a material is cooled in an atmosphere of oxygen, it is possible to form layers of very low conductivity over its constituent grains. Almost all the ferrites in the polycrystalline form have such high conductivity grains separated by low conductivity layers so that they behave as heterogeneous dielectric materials. Due to the heterogeneous dielectric behavior, dielectric constant as high as 10^3–10^5 is observed in the case of ferrites at low frequencies.

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5.3 Magnetization Studies

Magnetic measurement is a powerful method to characterize properties of materials. Among numbers of magnetic measurement equipment, Vibrating sample magneto-meter (VSM) is known as a very effective way to determine magnetization. By analyzing the results, much useful information of materials can be extracted. Magnetization studies independently confirm the migration of cations between A and b sites due to the size effect apart from electrical properties [32].

CONCLUSION:-

Ferrites naoparticles are synthesized using coprecipitation technique, resulting into favorable magnetic, optical properties and small particle size. Synthesized samples were structurally and magnetically characterized using x-ray diffraction (XRD) and room-temperature hysteresis cycle X-ray diffraction revealed the formation of cubic spinel structure nanoparticles. In FTIR spectrum, the foremost band at 549 cm-1 corresponds to metal-oxygen, stretching vibrations located at octahedral and tetrahedral positions. The TEM image of Ferrite nanoparticle gives an idea about the distribution of spinel shape nanoparticles. VSM measurements revealed the weak ferromagnetic behavior from which the magnetic parameters were observed. The magnetic studies showed that the saturation, magnetization, and remanent magnetization of the cobalt ferrite nanoparticles increased as temperature increased while the coercivity field and remanence ratio increased, until they achieved a maximum value and then decreased. Finally, We would like to describe our views on the future prospects of ferrites. As described at the beginning, no one doubts that the production of quantity ferrite will continue to increase each year, even in the future, as will the advancement of electronic technologies. If researchers and engineers who are concerned with ferrites take a deeper look at the future aspects of ferrites and devote themselves to the subjects of great value, the future of ferrites will experience a steady and more advanced prosperity in science and technology, and their industries will be continue to grow in the future.

REFERENCES

1. A.K Nikumbh,, R.A Pawar, D.V Nighot, G.S Gugale, M.D Sangale, M.B Khanvilkar, A.V Nagawade, Structural, electrical, magnetic and dielectric properties of rare-earth substituted cobalt ferrites nanoparticles synthesized by the co-precipitation method, J.Magu.Magn.Mater, 2014 DOI: 10.1016/j.jmmm.2016.08.02
2. A.B Salunkhe, V.M Khot, M.R Phadatare, S.H Pawar, Combustion synthesis of cobalt ferrite nanoparticles – Influence of fuel to oxidizer ratio, J.Alloys comp 2012 DOI: 10.1016/j.jallcom.2011.10.094.
3. Yuksel Koseoglu, Furkan Alan, Muhammed Tan, Resul Yilgin, Mustafa Ozturk, Low temperature hydrothermal synthesis and characterization of Mn doped cobalt ferrite nanoparticles, Ceram.Int, 2012 DOI:10.1016/j.ceramint.2012.01.001.
4. Shokrollahi H, 2008. Magnetic properties and densification of Manganese – Zinc Soft ferrites (Mn1-xZnxFe2O4) doped with low melting point oxides. Journal of Magnetism and Magnetic Materials, 320 (3-4): 463-474.
5. M. Sugimoto, "The past, present, and future of ferrites," Journal of the American Ceramic Society, vol. 82, no. 2, pp. 269–280, 1999.View at: Google Scholar
6. H.-M. Fan, J.-B. Yi, Y. Yang et al., "Single-crystalline MFe2O4 nanotubes/nanorings synthesized by thermal transformation process for biological applications," ACS Nano, vol. 3, no. 9, pp. 2798–2808, 2009.View at: Publisher Site | Google Scholar
7. M. H. Khedr, A. A. Omar, and S. A. Abdel-Moaty, "Magnetic nanocomposites: preparation and characterization of Co-ferrite nanoparticles," Colloids and Surfaces A, vol. 281, no. 1–3, pp. 8–14, 2006.View at: Publisher Site | Google Scholar
8. J. B. Silva, W. De Brito, and N. D. S. Mohallem, "Influence of heat treatment on cobalt ferrite ceramic powders," Materials Science and Engineering B, vol. 112, no. 2-3, pp. 182–187, 2004.View at: Publisher Site | Google Scholar
9. Z. Zi, Y. Sun, X. Zhu, Z. Yang, J. Dai, and W. Song, "Synthesis and magnetic properties of CoFe2O4 ferrite nanoparticles," Journal of Magnetism and Magnetic Materials, vol. 321, no. 9, pp. 1251–1255, 2009.View at: Publisher Site | Google Scholar
10. V. L. Calero-DdelC and C. Rinaldi, "Synthesis and magnetic characterization of cobalt-substituted ferrite (CoxFe3−xO4) nanoparticles," Journal of Magnetism and Magnetic Materials, vol. 314, no. 1, pp. 60–67, 2007.View at: Publisher Site | Google Scholar
11. D. Zhao, X. Wu, H. Guan, and E. Han, "Study on supercritical hydrothermal synthesis of CoFe2O4 nanoparticles," Journal of Supercritical Fluids, vol. 42, no. 2, pp. 226–233, 2007.View at: Publisher Site | Google Scholar

12. L. Chen, Y. Shen, and J. Bai, “Large-scale synthesis of uniform spinel ferrite nanoparticles from hydrothermal decomposition of trinuclear heterometallic oxo-centered acetate clusters,” Materials Letters, vol. 63, no. 12, pp. 1099–1101, 2009.View at: Publisher Site | Google Scholar
13. M. Gharagozlou, “Synthesis, characterization and influence of calcination temperature on magnetic properties of nanocrystalline spinel Co-ferrite prepared by polymeric precursor method,” Journal of Alloys and Compounds, vol. 486, no. 1-2, pp. 660–665, 2009.View at: Publisher Site | Google Scholar
14. I. H. Gul and A. Maqsood, “Structural, magnetic and electrical properties of cobalt ferrites prepared by the sol-gel route,” Journal of Alloys and Compounds, vol. 465, no. 1-2, pp. 227–231, 2008.View at: Publisher Site | Google Scholar
15. V. Pillai and D. O. Shah, “Synthesis of high-coercivity cobalt ferrite particles using water-in-oil microemulsions,” Journal of Magnetism and Magnetic Materials, vol. 163, no. 1-2, pp. 243–248, 1996.View at: Google Scholar
16. J. Zhang and C. Q. Lan, “Laser-generated Ni and Co nanoparticles in organic media,” Materials Letters, vol. 62, no. 10-11, pp. 1521–1524, 2008.View at: Google Scholar
17. G. Baldi, D. Bonacchi, C. Innocenti, G. Lorenzi, and C. Sangregorio, “Cobalt ferrite nanoparticles: the control of the particle size and surface state and their effects on magnetic properties,” Journal of Magnetism and Magnetic Materials, vol. 311, no. 1, pp. 10–16, 2007.View at: Publisher Site | Google Scholar
18. K. V. P. M. Shafi, A. Gedanken, R. Prozorov, and J. Balogh, “Sonochemical preparation and size-dependent properties of nanostructured CoFe2O4 particles,” Chemistry of Materials, vol. 10, no. 11, pp. 3445–3450, 1998.View at: Google Scholar
19. S. Singhal, J. Singh, S. K. Barthwal, and K. Chandra, “Preparation and characterization of nanosize nickel-substituted cobalt ferrites (Co1−xNixFe2O4),” Journal of Solid State Chemistry, vol. 178, no. 10, pp. 3183–3189, 2005.View at: Publisher Site | Google Scholar
20. J. Jiang and L. H. Ai, “Synthesis and characterization of Fe-Co binary ferrospinel nanospheres via one-step nonaqueous solution pathway,” Materials Letters, vol. 64, no. 8, pp. 945–947, 2010.View at: Publisher Site | Google Scholar
21. Y. Sui, X. Huang, Z. Ma et al., “The effect of thermal annealing on crystallization in a-Si:H/SiO2 multilayers by using layer by layer plasma oxidation,” Journal of Physics Condensed Matter, vol. 15, no. 34, pp. 5793–5800, 2003.View at: Publisher Site | Google Scholar
22. P. Laokul, V. Amornkitbamrung, S. Seraphin, and S. Maensiri, “Characterization and magnetic properties of nanocrystalline CuFe2O4,NiFe2O4,ZnFe2O4 powders prepared by the Aloe vera extract solution,” Current Applied Physics, vol. 11, no. 1, pp. 101–108, 2011.View at: Publisher Site | Google Scholar
23. M. I. Mendelson, “Average grain size in polycrystalline ceramics,” Journal of American Ceramic Society, vol. 52, no. 8, pp. 443–446, 1969.View at: Google Scholar
24. B. D. Cullity, Elements of X-Ray Diffraction, Addison-Wesley, London, UK, 2nd edition, 1978.
25. M. I. Loría-Bastarrachea, W. Herrera-Kao, J. V. Cauich-Rodríguez, J. M. Cervantes-Uc, H. Vázquez-Torres, and A. Ávila-Ortega, “A TG/FTIR study on the thermal degradation of poly(vinyl pyrrolidone),” Journal of Thermal Analysis and Calorimetry. In press.View at: Publisher Site | Google Scholar
26. M. Sangmanee and S. Maensiri, “Nanostructures and magnetic properties of cobalt ferrite (CoFe2O4) fabricated by electrospinning,” Applied Physics A, vol. 97, no. 1, pp. 167–177, 2009.View at: Publisher Site | Google Scholar
27. V. A. M. Brabers, “Infrared spectra of cubic and tetragonal manganese ferrites,” Physica Status Solidi, vol. 33, no. 2, pp. 563–572, 1969.View at: Google Scholar
28. Y. J. Kwon, K. H. Kim, C. S. Lim, and K. B. Shim, “Characterization of ZnO nanopowders synthesized by the polymerized complex method via an organochemical route,” Journal of Ceramic Processing Research, vol. 3, no. 3, pp. 146–149, 2002.View at: Google Scholar
29. Y. Qu, H. Yang, N. Yang, Y. Fan, H. Zhu, and G. Zou, “The effect of reaction temperature on the particle size, structure and magnetic properties of coprecipitated CoFe2O4 nanoparticles,” Materials Letters, vol. 60, no. 29-30, pp. 3548–3552, 2006.View at: Publisher Site | Google Scholar
30. M. K. Roy, B. Haldar, and H. C. Verma, “Characteristic length scales of nanosize zinc ferrite,” Nanotechnology, vol. 17, no. 1, pp. 232–237, 2006.View at: Publisher Site | Google Scholar
31. T. Giannakopoulou, L. Kompotiatis, A. Kontogeorgakos, and G. Kordas, “Microwave behavior of ferrites prepared via sol-gel method,” Journal of Magnetism and Magnetic Materials, vol. 246, no. 3, pp. 360–365, 2002.View at: Publisher Site | Google Scholar
32. M. P. Gonzalez-Sandoval, A. M. Beesley, M. Miki-Yoshida, L. Fuentes-Cobas, and J. A. Matutes-Aquino, “Comparative study of the microstructural and magnetic properties of spinel ferrites obtained by co-precipitation,” Journal of Alloys and Compounds, vol. 369, no. 1-2, pp. 190–194, 2004.View at: Publisher Site | Google Scholar