STRUCTURAL, DIELECTRIC AND MAGNETIC PROPERTIES OF ZINC–ALUMINUM CO-SUBSTITUTED IN COBALT FERRITE NANOPARTICLES SYNTHESIZED VIA CO-PRECIPITATION METHOD

SAMAD ZARE

Universiti Teknologi Malaysia

STRUCTURAL, DIELECTRIC AND MAGNETIC PROPERTIES OF ZINC–ALUMINUM CO-SUBSTITUTED IN COBALT FERRITE NANOPARTICLES SYNTHESIZED VIA CO-PRECIPITATION METHOD

SAMAD ZARE

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Physics)

Faculty of Science
Universiti Teknologi Malaysia

AUGUST 2016

Dedicated to my beloved family especially my parents, wife and daughter and my brother soul. Thank you very much for being supportive, helpful and understanding.

ACKNOWLEDGEMENT

In the name of Allah the most beneficent the most merciful, first and foremost, I thank God for everything that has made this dissertation possible. This research project would not have been possible without the support of many people. I would like to express my deep gratefulness to my supervisor, Prof. Dr. Zulkafli Othaman who was abundantly helpful and offered invaluable assistance, support and guidance.

And finally, my parents, my wife and Dr. Ali A Ati that provided me with patience and understanding also my group mate, Shadab Dabagh and Rizuan Mohd Rosnan for their constant encouragement and emotional support kept my vigor and life line alive in research.

My appreciation also goes to all the lecturers and laboratory officers at both the Department of Physics and Ibnu Sina Institute of Fundamental Science Study UTM.

.

ABSTRACT

Spinel ferrite nanoparticles (NPs) have raised interest due to their technological applications. Fabrication of doped cobalt (Co) ferrite NPs with high crystallinity, good dielectric and modified magnetic properties are demanded for many applications. This thesis determined the influence of zinc-aluminum substitution on the structural, dielectric and magnetic properties of Co ferrite NPs. A series of $Co_{(1-x)}Zn_{(x)}Fe_{(2-x)}Al_xO_4$ NPs with $0.0 \leq x \leq 1.0$ (x in wt.%) were prepared by chemical co-precipitation method and calcined at 700 °C, 800 °C and 900 °C. The synthesized samples were characterized using X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), Field-emission scanning electron microscopy (FESEM), Vibrating sample magnetometer (VSM) and the Impedance Analyser. The achieved high crystallinity and formation of spinel structure with mean particle size 17–30 nm is confirmed by XRD analyses. The FESEM micrographs displayed the formation of well-defined and homogenous crystalline grains having Gaussian size distribution with narrow open pores. FTIR spectra revealed two absorption bands which confirmed the presence of A and B sublattices for the spinel structure. The values of saturation magnetization and magnetic coercivity were increased from 13.80–88.61 emu/g and 23.99–109.63 Oe, respectively as the temperature was increased from 700 °C to 900 °C. The room temperature dielectric properties were measured in the frequency range of 100 Hz to 10 MHz. The dielectric constant and dielectric loss were found to decrease with increasing frequency before reached a stable value. Increased saturation magnetization of NPs with high crystallinity and good homogeneity make these doped ferrites suitable for many applications.

ABSTRAK

Zarah nano (NP) ferit spinel mendapat perhatian yang luas disebabkan oleh aplikasi teknologinya. Fabrikasi NP ferit kobalt (Co) terdop dengan kehabluran tinggi, sifat dielektrik dan pengubahsuaian magnetik yang baik diperlukan untuk pelbagai aplikasi. Tesis ini menentu-ukur pengaruh penggantian zink-aluminum terhadap sifat struktur, dielektrik dan magnetik NP ferit Co. Satu siri NP $Co_{(1-x)}Zn_{(x)}Fe_{(2-x)}Al_xO_4$ dengan $0.0 \leq x \leq 1.0$ (x dalam % berat) telah disediakan menggunakan kaedah pemendakan kimia dan pembakaran pada suhu 700 °C, 800 °C dan 900 °C. Sampel yang telah disintesis, kemudian dicirikan menggunakan pembelauan sinar-X (XRD), spektroskopi inframerah transformasi fourier (FTIR), mikroskop pengimbas elektron pengeluaran medan (FESEM), magnetometer sampel bergetar (VSM), dan penganalisa impedans. Kehabluran tinggi dan formasi struktur spinel yang diperolehi dengan saiz purata zarah 17-30 nm telah disahkan oleh analisa XRD. Mikrograf FESEM menunjukkan formasi zarah kristal yang jelas dan homogen yang mempunyai taburan saiz Gaussian dengan liang terbuka yang sempit. Spektrum FTIR menunjukkan dua jalur serapan yang mengesahkan kehadiran sub-kekisi A dan B bagi struktur spinel. Nilai pemagnetan tepu dan koersiviti telah meningkat masing-masing dari 13.80–88.61 emu/g dan 23.99–109.63 Oe, apabila suhu meningkat daripada 700 °C kepada 900 °C. Sifat dielektrik pada suhu bilik telah diukur pada julat frekuensi 100 Hz sehingga 10 MHz. Pemalar dan kehilangan dielektrik menunjukkan penurunan dengan peningkatan frekuensi sebelum mencapai nilai stabil. Peningkatan pemagnetan tepu NP, dengan kehabluran tinggi dan kehomogenan yang baik menjadikan ferit terdop ini sesuai untuk pelbagai aplikasi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SEM	-	Scanning Electron Microscope
EDX	-	Energy Dispersive X-Ray
FESEM	-	Field Emission Scanning Electron Microscopy
FTIR	-	Fourier Transform Infrared
FWHM	-	Full With at Half Maximum
LCR	-	Inductance Capacitance Resistance
VSM	-	Vibrating Sample Magnetometer
XRD	-	X-ray Diffraction
JCPDS	-	Joint Committee on Powder Diffraction Standards
FCC	-	Face-Centered Cubic
TEM	-	Transmission Electron Microscopy
H_c	-	Coercive Field
M_s	-	Saturation Magnetization
M_r	-	Retentivity
NaOH	-	Sodium Hydroxide
BSE	-	Back-Scattered Electrons
EXAFS	-	Extended X-Ray Absorption Fine

Structure

PEG	-	Polyethylene Glycol
$Zn\ (NO_3)_2 \cdot 6H_2O$	-	Zinc Nitrate Hexahydrate
$Fe\ (NO_3)_3 \cdot 9H_2O$	-	Iron (III) Nitrate
$Al\ (NO_3)_3 \cdot 6H_2O$	-	Aluminium Nitrate Hexahydrate
$Co\ (CH_3COO)_2 \cdot 4H_2O$	-	Cobalt (II) Acetate Tetrahydrate

LIST OF SYMBOLS

ΔE	-	Activation energy
μ_0	-	Permeability
A	-	Area
μ	-	Moment
Å	-	Angstrom
a, c	-	Lattice parameter
$\Delta\mu_v$	-	Volume free energy
$\Delta\mu_s$	-	Surface free energy
ΔG	-	Total free energy
C	-	Capacity
σ	-	Surface tension
r	-	Radius
hkl	-	Miller indices
Co	-	Cobalt
G_v	-	Free energy per unit volume
ρ	-	Density
q	-	electron charge
Cu K_α	-	Copper K-alpha line
P_i	-	Ionic polarization
P_o	-	Orientation polarization
P_e	-	Electronic polarization
P_s	-	Space Charge polarization
d	-	Interplaner distance
χ_e	-	electrical susceptibility
d	-	Thicknesses of grain boundary

Z	-	Atomic number

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Nanomaterials have advantages and unique electrical, magnetic, optical and mechanical properties and have therefore drawn significant research attention. Magnetism and magnetic materials are one of the most highly demanded disciplines in the field of condensed matter physics. Due to great chemical and thermal stability and robust nature, metal oxide nanostructures are of specific interest. By controlling the composition, morphology, crystallinity and size of nanostructures, their diversified extraordinary properties can be fine-tuned in meeting specific objectives.

Ferrites are the mixed metal oxides containing iron oxide as their main component. Although literature has been in existence for hundreds of years, the research in ferrites was initiated at the end of Second World War. The paper by Neel in 1948, in which theory of a new class of magnetic materials, ferrimagnets, was put forward, initiated a great stream of experimental and theoretical investigations of ferrites and other ferrimagnets [1]. Ferrites are the best in high density recording media and high frequency circuits among several magnetic materials. Also, they are comparatively economical and cannot be substituted by other magnetic materials.

Ferrites are an example of an important magnetic material with wide application in various technological fields, such as electronics, automobile, IT and other new emerging fields. It is well known that changing its composition or the method or condition of preparation could modify the properties of ferrites. With appropriate selection of the preparation methodology and composition, the ferrite properties can be enhanced along with the making of new ones with the steady application of material science and technology. Extraordinary electrical, optical and magnetic properties displayed by ferrites depend on factors like substitution of cations stoichiometry, calcining temperature and preparation methodology. Commercially, the chemically homogenous, fine grain size, high density ferrites have proven to be very important in technological applications [2, 3].

Depending on the nature of magnetic behaviour of the ferrite materials, they are classified into two broad categories, soft ferrites and hard ferrites. Soft ferrites have small coercive field so they can be easily magnetized and demagnetized. Hard ferrites can be used as permanent magnets as they retain their magnetism once magnetized due to their large coercive field. The characterization of soft and hard ferrites in general is based upon some important factors like saturation magnetization (M_s), remanence (M_r) and coercivity (H_c).Taking into account the crystal structure and the magnetic ordering, ferrites can be grouped into three different categories namely spinel, garnet and Hexagonal ferrites [4].

The spinel ferrites are named after the naturally occurring mineral spinel, having the general chemical formula written as MFe_2O_4, where M is a divalent transition metal or a suitable combination of these ions. The composition of spinal lattice includes a closely packed oxygen crystal arrangement in which unit cell (the smallest unit repeated in the crystal network) is formed by 32 oxygen ions. The packing of these anions leaves two types of spacing between anions in face centred cubic (FCC) arrangement. Tetrahedral coordinated sites (A), bounded by four adjacent oxygen atoms, and octahedral coordinated sites (B), bounded by six nearby neighbour oxygen atoms are the two types of spacing as shown in Figure 1.1. In the unit cell there are 64 tetrahedral sites and 32 octahedral sites in total, out of which only 8 tetrahedral and 16 octahedral sites are occupied, resulting in an electrically neutral structure [9, 10].

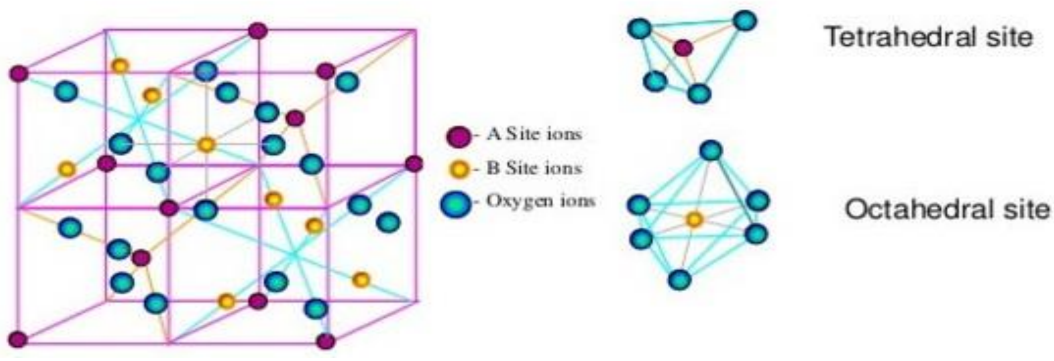

Figure 1.1 Schematic of two sub cells of a unit cell of the spinet structure, showing octahedral and tetrahedral sites [5].

The factors which can influence the distribution of the metal ions over tetrahedral and octahedral sites include the electronic configuration of the metal ions, the ionic radii and the electrostatic energy of the spinel lattice and more recently the preparation condition. The degree of use for spinel ferrite properties depends on the competition between the various types of super-exchange interaction amongst A and B site cations i.e. J_{AB} (A–O–B), J_{BB} (B–O–B), and J_{AA} (A–O–A). Specific amounts of cation site exchange will be sufficient to change J_{AB} and J_{BB} interactions, which has significantly changed the magnetic behaviour of spinel nanoparticles compared to the bulk variety. The composition and microstructure of ferrites affects their structural and magnetic properties, which are dependent on processing conditions and synthesis routes [6].

Various techniques are being employed in many fields including physics, chemistry, biology and engineering for production of nanomaterial. The striking point for careful study and potential exploitation and possibilities associated with nanomaterials is creating definite monodisperse structures of predictable size, shape, crystallinity, and morphology using simple synthesis technique. As is well known, the preparation of nanocrystalline oxide samples mainly follows two approaches: (i) Top to bottom approach: physical methods (ii) Bottom to top approach: chemical methods are followed.

Physical methods are commercially attractive because it is generally easier to produce larger volumes of product, but they tend to impact physical stresses in the materials which can require further processing and result in wider size distributions. The most popular physical methods are ball milling, laser pyrolysis and plasma torch.

Chemical techniques are generally better for the synthesis of mixed cation nanoparticles because they can provide control over the particle stoichiometry, shape, size distribution, crystallinity and phase purity. Numerous chemical methods have been developed that have proven viable for the synthesis of nanoparticles. The most popular chemical methods of synthesis of nanomaterials are sol-gel processing mechanism and co-precipitation methods. These methods have their own set of advantages and disadvantages in terms of ease of preparation, duration of synthesis, extent of instrumentation required and the availability of the precursors and their economic viability. Among many types of preparation and processing techniques, chemical co-precipitation is one of the popular methods for obtaining homogenous ferrite powder of crystalline size. It is the inherent ability of this reaction system to control the size and size distribution that makes it attractive for the synthesis of nanoparticles. In addition, the co-precipitation method is also free from contamination, simple, low cost, offers more homogeneous mixing of the components and demonstrates good control over the particle size of the powder [7].

A good candidate for hard magnetic material having high coercivity (H_c) and mode rate magnetization (M_s) is cobalt ferrite. $CoFe_2O_4$ nanoparticles are very suitable for magnetic recording applications like high-density digital recording disks, audio and video tape etc. due to the properties mentioned above along with great chemical and physical stability [8]. The structure of cobalt ferrite is inverse spinel. The lattice parameter of the unit cell of $CoFe_2O_4$ is 8.36 Å consists of eight formula units. The Fe^{3+} ions are aligned in tetrahedral sites anti-ferromagnetically with respect to the Fe^{3+} ions in the octahedral sites giving oxygen ions mediated super-exchange interactions. Hence, the saturation magnetism is 3μB per formula unit as determined by Co^{+2} ions. According to literature, due to its high value, they have become perfect for using in high density magnetic storage materials, medical diagnosis, magneto-mechanical, and torque sensors. However, there are many limitations by using cobalt ferrite in many applications that need improvement in saturation magnetization and decrease in coercivity [9].

1.2 Problem Statement

Magnetic ferrite is a group of technologically important magnetic materials. Due to their useful electromagnetic characters ferrites have a large number of applications. One of the subjects of primary scientific importance is the synthesis of ferrite nanoparticles with tailorable magnetic properties and controllable size along with structure-property relationship understanding [10, 11].

The difference in properties and performance of ferrites as compared with most other magnetic materials is due to the fact that the ferrites are oxide materials rather than metals. Ferromagnetism is derived from the unpaired electron spins in only a few metal atoms, these being iron, cobalt, zinc, aluminum, and some rare earth elements. It is not surprising that the highest magnetic moments and therefore the highest saturation magnetizations are to be found in the metals themselves or in alloys of these metals.

Cobalt ferrite is categorized as a hard magnet due to its high corecivity and moderate magnetization. Due to its high magnetic corecivity value and good physical and chemical stability it has been used for various applications. Cobalt ferrite ($CoFe_2O_4$) neither has a spinel or inverse spinel structure. Some applications require saturation magnetization as large as possible and coercivity value as low as possible [9, 12]. With respect to this, substitution of Zn/Al ions in the structure of $CoFe_2O_4$ is expected to enhance the structural, dielectrical and magnetic properties.

Various methods used for synthesis of nanosized spinel ferrite powders include mechanical milling [13], sol–gel [14], reverse micelle [15], citrate–gel [16] and microemulsion [17]. However, these methods are not suitable and non-economical for large scale production. They also often involve toxic reagents, complicated synthetic steps, high reaction temperature, and long reaction time. The selection of an appropriate synthetic procedure often depends on the desired properties and the final applications. The co-precipitation method, however, has advantages such as free from contamination, simple, low cost, more homogeneous mixing of the components and good control over the particle size of the powder.

No systematic studies have been reported in literature about the magnetic, structural and electrical properties of $Co_{(1-x)}Zn_{(x)}Fe_{(2-x)}Al_{(x)}O_4$ (x = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0) prepared by wet chemical co-precipitation method. Although separate studies are carried out about magnetic and structural properties of $Co_{1-x}Zn_xFe_2O_4$ [18] and $CoFe_{2-x}Al_xO_4$ [19] ferrite system prepared by co-precipitation method, the doped Zn/Al on cobalt ferrites have not been studied yet.

Synthesizing aluminium and zinc substituted cobalt ferrite $Co_{1-x}Zn_xFe_{2-x}Al_xO_4$ ($0.0 \leq x \leq 1.0$) is extremely important due to immense significance of cobalt ferrites and the fact that their properties change significantly on substitution with trivalent metal cations. The nano-size ferrites are synthesized by using co-precipitation method to investigate their dielectric and magnetic behavior in systematic way, with a view to improve their structural, magnetic, dielectric properties.

1.3 Objectives of Research

In view of above discussions, the main objectives of this research can be listed as the followings:

I. To determine the structure of Zinc-Aluminum substituted Cobalt ferrite by chemical co-precipitation method in different temperature and ratio.

II. To determine the magnetic behavior of Zinc-Aluminum substituted Cobalt ferrite at different calcination temperatures and different ratio.

III. To determine the dielectric properties of Zinc-Aluminum substituted Co ferrite at different dopant ratio.

1.4 Scope of the Study

Present work consists of the synthesis, characterization and investigation of structural, magnetic and dielectric properties of $Co_{(1-x)}Zn_{(x)}Fe_{(2-x)}Al_{(x)}O_4$ nanoparticle. The concentrations of Zinc/Aluminum expressed as wt% were ($0.0 \leq x \leq 1.0$).

This material is selected for this study in view of their technological importance. Zinc aluminum substituted on cobalt ferrite $Co_{(1-x)}Zn_{(x)}Fe_{(2-x)}Al_{(x)}O_4$ are prepared by co-precipitation method by using cobalt acetate, Zinc, aluminum and iron nitrates. The crystallinity of the powder is developed by calcinate at 700 °C, 800 °C and 900 °C.

Crystalline phase is investigated by using X-ray Diffractometer (XRD). The average crystallite size for nanoparticles is determined by Scherrer's formula. Fourier Transform Infrared Spectroscopy (FTIR) is one of the preferred methods for infrared spectroscopy to identify the chemical and structural changes occurring in particular sample. The morphology of the calcined sample is investigated by field emission scanning electron microscopy (FESEM). Energy dispersive X-ray spectrometer (EDX) is used for elemental analysis of the sample. To understand the magnetic properties of $Co_{(1-x)}Zn_{(x)}Fe_{(2-x)}Al_{(x)}O_4$ ferrite samples, the field dependence magnetization of all the samples is measured using vibrating sample magnetometer (VSM). The investigations of dielectric properties of consolidated nanoparticles of the test samples are performed by using two point probe. Chemically synthesized samples are used to prepare nanoparticles and subjected to a different calcinate temperature in order to study the effect of calcination temperature on various properties of nanoparticles.

1.5 Significance of the Study

Nanomaterial has unique electronic, magnetic, optical and mechanical properties, which led to increasing interest in research of further applications. Metal oxide nanostructures are of particular interest due to their robust nature and high chemical and thermal stability, as well a vast array of other remarkable properties.

These diverse properties can be fine-tuned for specific purposes by controlling the size, morphology composition and crystallinity of the nanostructure.

Ferrites are one of the vital categories of technological materials which have substantial applications having range from millimeter wave integrated circuitry to transformer cores and magnetic recording. Due to the requirement of magnetic materials in many new discoveries, the importance of ferrites in technology is increasing constantly. It has become one of the subjects of primary scientific importance, to synthesize the ferrite nanoparticles with tailorable magnetic properties and controllable dimensions along with structure-property relationship understanding.

Present research gives a better understanding into synthesis of nanomaterials in particulate by making use of hydroxide. Co-precipitation method is almost preferred to be able to obtain high quality product. The properties of ferrites can be fine-tuned purposely by reliable controlling of dimensions, composition, morphology and crystallinity of these nanostructures. There is a wide range of recording media applications of Zn/Al doped co-ferrites, where controllable size and least magnetic and electrical loss are desired. There is a requirement of soft magnetic material having a square hysteresis loop, low-coercivity and high-remanence, for applications in sensors and recording media.

REFERENCES

1. Néel, L. Théorie du traînage magnétique des ferromagnétiques en grains fins avec applications aux terres cuites. *Annals of Geophysics*. 1949. 5(2): 99-136.

2. Kondo, K., Chiba, T. and Yamada, S. Effect of microstructure on magnetic properties of Ni–Zn ferrites. *Journal of Magnetism and Magnetic Materials*. 2003. 254: 541-543.

3. Sharifi, I. and Shokrollahi, H. Structural, Magnetic and Mössbauer evaluation of Mn substituted Co–Zn ferrite nanoparticles synthesized by co-precipitation. *Journal of Magnetism and Magnetic Materials*. 2013. 334: 36-40.

4. Zenger, M. Modern ferrite technologies and products. *International Journal of Materials and Product Technology*. 1994. 9(4-6): 265-280.

5. Slick, P. Ferrites for non-microwave applications. *Ferromagnetic Materials*. 1980. 2: 189-241.

6. Prévot, M. and Dunlop, D. Louis Néel: Forty years of magnetism. *Physics of the Earth and Planetary Interiors*. 2001. 126: 3-6.

7. Cushing, B. L., Kolesnichenko, V. L. and O'Connor, C. J. Recent advances in the liquid-phase syntheses of inorganic nanoparticles. *Chemical Reviews*. 2004. 104(9): 3893-3946.

8. Ati, A. A., Othaman, Z. and Samavati, A. Influence of cobalt on structural and magnetic properties of nickel ferrite nanoparticles. *Journal of Molecular Structure*. 2013. 1052(0): 177-182.

9. Iqbal, M. J., Ashiq, M. N., Hernandez-Gomez, P. and Munoz, J. M. Magnetic, physical and electrical properties of Zr–Ni-substituted co-precipitated strontium hexaferrite nanoparticles. *Scripta Materialia*. 2007. 57(12): 1093-1096.

10. Raju, K., Venkataiah, G. and Yoon, D. Effect of Zn substitution on the structural and magnetic properties of Ni–Co ferrites. *Ceramics International*. 2014. 40(7): 9337-9344.

11. Wang, S. F., Chiang, Y.J., Hsu, Y.F. and Chen, C.H. Effects of additives on the loss characteristics of Mn–Zn ferrite. *Journal of Magnetism and Magnetic Materials*. 2014. 365: 119-125.

12. Kambale, R., Shaikh, P., Kamble, S. and Kolekar, Y. Effect of cobalt substitution on structural, magnetic and electric properties of nickel ferrite. *Journal of Alloys and Compounds*. 2009. 478(1): 599-603.

13. Ponce, A., Chagas, E., Prado, R., Fernandes, C., Terezo, A. and Baggio-Saitovitch, E. High coercivity induced by mechanical milling in cobalt ferrite powders. *Journal of Magnetism and Magnetic Materials*. 2013. 344: 182-187.

14. Raut, A. V., Barkule, R. S., Shengule, D. R. and Jadhav, K. M. Synthesis, structural investigation and magnetic properties of Zn^{2+} substituted cobalt ferrite nanoparticles prepared by the sol–gel auto-combustion technique. *Journal of Magnetism and Magnetic Materials*. 2014. 358–359(0): 87-92.

15. Ghasemi, A., Šepelák, V., Shirsath, S. E., Liu, X. and Morisako, A. Mössbauer spectroscopy and magnetic characteristics of $Zn_{1-x}Co_xFe_2O_4$ (x = 0−1) nanoparticles. *Journal of Applied Physics*. 2011. 109(7): 07A512.

16. Arabi, H. and Moghadam, N. K. Nanostructure and magnetic properties of magnesium ferrite thin films deposited on glass substrate by spray pyrolysis. *Journal of Magnetism and Magnetic Materials*. 2013. 335: 144-148.

17. Pemartin, K., Solans, C., Alvarez-Quintana, J. and Sanchez-Dominguez, M. Synthesis of Mn–Zn ferrite nanoparticles by the oil-in-water microemulsion reaction method. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2014. 451: 161-171.

18. Hassadee, A., Jutarosaga, T. and Onreabroy, W. Effect of zinc substitution on structural and magnetic properties of cobalt ferrite. *Procedia Engineering*. 2012. 32: 597-602.

19. Jiao, Y., Wu, Y. and Fang, Q. The influence of Al^{3+} substituted for Fe^{3+} on the structure and magnetic properties of cobalt ferrite [J]. *Journal of Tianjin Normal University (Natural Science Edition)*. 2008. 1: 010.

20. Buschow, K. New developments in hard magnetic materials. *Reports on Progress in Physics*. 1991. 54(9): 1123.

21. Callister, W. D. and Rethwisch, D. G. *Fundamentals of Materials Science and Engineering: an Integrated Approach*: John Wiley & Sons. 2012.

22. Brau, C. A. *Modern Problems in Classical Electrodynamics*: Oxford university press. 2004.

23. Balavijayalakshmi, J., Suriyanarayanan, N., Jayaprakash, R. and Gopalakrishnan, V. Effect of Concentration on Dielectric Properties of Co-Cu Ferrite Nano Particles. *Physics Procedia*. 2013. 49(0): 49-57.

24. Kumar, P., Juneja, J. K., Prakash, C., Singh, S., Shukla, R. K. and Raina, K. K. High DC resistivity in microwave sintered $Li_{0.49}Zn_{0.02}Mn_{0.06}Fe_{2.43}O_4$ ferrites. *Ceramics International*. 2014. 40(1, Part B): 2501-2504.

25. Stergiou, C. A. and Zaspalis, V. Analysis of the complex permeability of NiCuZn ferrites up to 100;GHz with regard to Cu content and sintering temperature. *Ceramics International*. 2014. 40(1, Part A): 357-366.

26. Mathew, D. S. and Juang, R.S. An overview of the structure and magnetism of spinel ferrite nanoparticles and their synthesis in microemulsions. *Chemical Engineering Journal*. 2007. 129(1): 51-65.

27. Liu, S., Ji, D., Xu, J., Li, Z., Tang, G., Bian, R., Qi, W., Shang, Z. and Zhang, X. Estimation of cation distribution in spinel ferrites $Co_{1+x}Fe_{2-x}O_4$ ($0.0 \leqslant x \leqslant 2.0$) using the magnetic moments measured at 10K. *Journal of Alloys and Compounds*. 2013. 581: 616-624.

28. Smit, J. and Wijn, H. P. J. *Ferrites: Physical Properties Of Ferrimagnetic Oxides In Relation To Their Technical Applications*: Wiley. 1959.

29. Goh, S., Chia, C., Zakaria, S., Yusoff, M., Haw, C., Ahmadi, S., Huang, N. M. and Lim, H. N. Hydrothermal preparation of high saturation magnetization and coercivity cobalt ferrite nanocrystals without subsequent calcination. *Materials Chemistry and Physics*. 2010. 120(1): 31-35.

30. Cullity, B. D. and Graham, C. D. *Introduction To Magnetic Materials*: John Wiley & Sons. 2011.

31. Cornell, R. M. and Schwertmann, U. *The Iron Oxides: Structure, Properties, Reactions, Occurrences and Uses*: John Wiley & Sons. 2003.

32. Willard, M. A., Nakamura, Y., Laughlin, D. E. and McHenry, M. E. Magnetic Properties of Ordered and Disordered Spinel-Phase Ferrimagnets. *Journal of the American Ceramic Society*. 1999. 82(12): 3342-3346.

33. Ghate, B. B. and Goldman, A. Ferrimagnetic Ceramics. *Materials Science and Technology*.

34. Attia, S. Study of cation distribution of Mn–Zn ferrites. *Egyptian Journal of Solids*. 2006. 29(2): 329-340.

35. Harris, V. G., Geiler, A., Chen, Y., Yoon, S. D., Wu, M., Yang, A., Chen, Z., He, P., Parimi, P. V. and Zuo, X. Recent advances in processing and applications of microwave ferrites. *Journal of Magnetism and Magnetic Materials*. 2009. 321(14): 2035-2047.

36. Kao, K. C. *Dielectric Phenomena in Solids*: Academic Press. 2004.

37. Raju, G. G. *Dielectrics in Electric Fields*, Vol. 19: CRC Press. 2003.

38. Sirdeshmukh, D. B., Sirdeshmukh, L. and Subhadra, K. *Micro-and Macro-properties of Solids*: Springer.Press. 2006.

39. Sugimoto, M. The past, present, and future of ferrites. *Journal of the American Ceramic Society*. 1999. 82(2): 269-280.

40. Waser, R. *Nanoelectronics and Information Technology*: John Wiley & Sons. 2012.

41. Kingery, W. D. Introduction to ceramics. Wiley, Press1960.

42. Hu, N., Masuda, Z., Yan, C., Yamamoto, G., Fukunaga, H. and Hashida, T. The electrical properties of polymer nanocomposites with carbon nanotube fillers. *Nanotechnology*. 2008. 19(21): 215701.

43. Chinnasamy, C., Jeyadevan, B., Shinoda, K., Tohji, K., Djayaprawira, D., Takahashi, M., Joseyphus, R. J. and Narayanasamy, A. Unusually high coercivity and critical single-domain size of nearly monodispersed $CoFe_2O_4$ nanoparticles. *Applied Physics Letters*. 2003. 83(14): 2862-2864.

44. Chinnasamy, C., Senoue, M., Jeyadevan, B., Perales-Perez, O., Shinoda, K. and Tohji, K. Synthesis of size-controlled cobalt ferrite particles with high coercivity and squareness ratio. *Journal of Colloid and Interface Science*. 2003. 263(1): 80-83.

45. Kumar, V., Rana, A., Yadav, M. and Pant, R. Size-induced effect on nano-crystalline $CoFe_2O_4$. *Journal of Magnetism and Magnetic Materials*. 2008. 320(11): 1729-1734.

46. Yamamoto, H. and Nissato, Y. Magnetic properties of Co-Ni spinel ferrite fine particles with high coercivity prepared by the chemical coprecipitation method. *Magnetics, IEEE Transactions on*. 2002. 38(5): 3488-3492.

47. Toksha, B., Shirsath, S. E., Patange, S. and Jadhav, K. Structural investigations and magnetic properties of cobalt ferrite nanoparticles prepared by sol–gel auto combustion method. *Solid State Communications*. 2008. 147(11): 479-483.

48. Xiao, S. H., Xu, H. J., Hu, J., Li, L. Y. and Li, X. J. Dependence of structural and magnetic properties of $CoFe_2O_4/SiO_2$ nanocomposites on annealing temperature and component ratio. *Physica E: Low-dimensional Systems and Nanostructures*. 2008. 40(10): 3064-3067.

49. Pillai, V. and Shah, D. Synthesis of high-coercivity cobalt ferrite particles using water-in-oil microemulsions. *Journal of Magnetism and Magnetic Materials*. 1996. 163(1): 243-248.

50. Yin, J., Ding, J., Liu, B., Miao, X. and Chen, J. Nanocrystalline Co-ferrite films with high perpendicular coercivity. *Applied Physics Letters*. 2006. 88(16): 162502.

51. Ding, J., Gong, H., Melaka, R., Wang, S., Shi, Y., Chen, Y. and Phuc, N. SiO_2 modified Co-ferrite with high coercivity. *Journal of Magnetism and Magnetic Materials*. 2001. 226: 1382-1384.

52. Mekala, S. and Ding, J. Magnetic properties of cobalt ferrite/SiO_2 nanocomposite. *Journal of Alloys and Compounds*. 2000. 296(1): 152-156.

53. Silva, J. B., De Brito, W. and Mohallem, N. D. Influence of heat treatment on cobalt ferrite ceramic powders. *Materials Science and Engineering: B*. 2004. 112(2): 182-187.

54. Sharifi, I., Shokrollahi, H., Doroodmand, M. M. and Safi, R. Magnetic and structural studies on $CoFe_2O_4$ nanoparticles synthesized by co-precipitation, normal micelles and reverse micelles methods. *Journal of Magnetism and Magnetic Materials*. 2012. 324(10): 1854-1861.

55. Chen, H. K. and Yang, C. Y. A study on the preparation of zinc ferrite. *Scandinavian Journal of Metallurgy*. 2001. 30(4): 238-241.

56. Baranchikov, A., Ivanov, V., Murav'eva, G., Oleinikov, N. and Tret'yakov, Y. D. Kinetics of the formation of zinc ferrite in an ultrasonic field. Proceedings of the *Doklady Chemistry*: Springer. 146-148.

57. Bera, S., Prince, A., Velmurugan, S., Raghavan, P., Gopalan, R., Panneerselvam, G. and Narasimhan, S. Formation of zinc ferrite by solid-state reaction and its characterization by XRD and XPS. *Journal of Materials Science*. 2001. 36(22): 5379-5384.

58. Hochepied, J., Bonville, P. and Pileni, M. Nonstoichiometric zinc ferrite nanocrystals: syntheses and unusual magnetic properties. *The Journal of Physical Chemistry B*. 2000. 104(5): 905-912.

59. Yao, C., Zeng, Q., Goya, G., Torres, T., Liu, J., Wu, H., Ge, M., Zeng, Y., Wang, Y. and Jiang, J. $ZnFe_2O_4$ nanocrystals: synthesis and magnetic properties. *The Journal of Physical Chemistry C*. 2007. 111(33): 12274-12278.

60. Tung, L. D., Kolesnichenko, V., Caruntu, G., Caruntu, D., Remond, Y., Golub, V., O'connor, C. and Spinu, L. Annealing effects on the magnetic properties of nanocrystalline zinc ferrite. *Physica B: Condensed Matter*. 2002. 319(1): 116-121.

61. Xiangfeng, C., Xingqin, L. and Guangyao, M. Preparation and gas sensitivity properties of $ZnFe_2O_4$ semiconductors. *Sensors and Actuators B: Chemical*. 1999. 55(1): 19-22.

62. Sohn, B. and Cohen, R. Processible optically transparent block copolymer films containing superparamagnetic iron oxide nanoclusters. *Chemistry of Materials*. 1997. 9(1): 264-269.

63. Sun, S. and Murray, C. Synthesis of monodisperse cobalt nanocrystals and their assembly into magnetic superlattices. *Journal of Applied Physics*. 1999. 85(8): 4325-4330.

64. Tanaka, K., Makita, M., Shimizugawa, Y., Hirao, K. and Soga, N. Structure and high magnetization of rapidly quenched zinc ferrite. *Journal of Physics and Chemistry of Solids*. 1998. 59(9): 1611-1618.

65. Pavljukhin, Y. T., Medikov, Y. Y. and Boldyrev, V. Magnetic and chemical properties of mechanically activated zinc and nickel ferrites. *Materials Research Bulletin*. 1983. 18(11): 1317-1327.

66. Sato, T., Haneda, K., Seki, M. and Iijima, T. Morphology and magnetic properties of ultrafine $ZnFe_2O_4$ particles. *Applied Physics A*. 1990. 50(1): 13-16.

67. Clark, T. M. and Evans, B. Enhanced magnetization and cation distributions in nanocrystalline $ZnFe_2O_4$: a conversion electron Mossbauer spectroscopic investigation. *Magnetics, IEEE Transactions on*. 1997. 33(5): 3745-3747.

68. Zhihao, Y. and Lide, Z. Synthesis and structural characterization of capped $ZnFe_2O_4$ nanoparticles. *Materials Research Bulletin*. 1998. 33(11): 1587-1592.

69. Toledo-Antonio, J., Nava, N., Martınez, M. and Bokhimi, X. Correlation between the magnetism of non-stoichiometric zinc ferrites and their catalytic activity for oxidative dehydrogenation of 1-butene. *Applied Catalysis A: General*. 2002. 234(1): 137-144.

70. Kundu, A., Upadhyay, C. and Verma, H. Magnetic properties of a partially inverted zinc ferrite synthesized by a new coprecipitation technique using urea. *Physics Letters A*. 2003. 311(4): 410-415.

71. Ahn, Y., Choi, E. J., Kim, S., An, D. H., Kang, K. U., Lee, B.-G., Baek, K. S. and Oak, H. N. Magnetization and Mossbauer Study of Nanosize $ZnFe_2O_4$ Particles Synthesized by Using a Microemulsion Method. *Journal-Korean Physical Society*. 2002. 41: 123-128.

72. Hamdeh, H. H., Ho, J., Oliver, S., Willey, R. and Oliveri, G. Magnetic properties of partially-inverted zinc ferrite aerogel powders. *Journal of Applied Physics*. 1997. 81(4): 1851-1857.

73. Cheng, P., Li, W., Zhou, T., Jin, Y. and Gu, M. Physical and photocatalytic properties of zinc ferrite doped titania under visible light irradiation. *Journal of Photochemistry and Photobiology A: Chemistry*. 2004. 168(1): 97-101.

74. Li, F., Wang, L., Wang, J., Zhou, Q., Zhou, X., Kunkel, H. and Williams, G. Site preference of Fe in nanoparticles of $ZnFe_2O_4$. *Journal of Magnetism and Magnetic Materials*. 2004. 268(3): 332-339.

75. Gong, C., Chen, D. and Jiao, X. Sol-gel synthesis of hollow zinc ferrite fibers. *Journal of Sol-Gel Science and Technology*. 2005. 35(1): 77-82.

76. Atif, M., Hasanain, S. and Nadeem, M. Magnetization of sol–gel prepared zinc ferrite nanoparticles: Effects of inversion and particle size. *Solid State Communications*. 2006. 138(8): 416-421.

77. Komarneni, S., D'Arrigo, M. C., Leonelli, C., Pellacani, G. C. and Katsuki, H. Microwave-hydrothermal synthesis of nanophase ferrites. *Journal of the American Ceramic Society*. 1998. 81(11): 3041-3043.

78. Jiang, W., Cao, Z., Gu, R., Ye, X., Jiang, C. and Gong, X. A simple route to synthesize $ZnFe_2O_4$ hollow spheres and their magnetorheological characteristics. *Smart Materials and Structures*. 2009. 18(12): 125013.

79. Goya, G. and Rechenberg, H. Ionic disorder and Néel temperature in $ZnFe_2O_4$ nanoparticles. *Journal of Magnetism and Magnetic Materials*. 1999. 196: 191-192.

80. Bid, S. and Pradhan, S. Preparation of zinc ferrite by high-energy ball-milling and microstructure characterization by Rietveld's analysis. *Materials Chemistry and Physics*. 2003. 82(1): 27-37.

81. Shenoy, S., Joy, P. and Anantharaman, M. Effect of mechanical milling on the structural, magnetic and dielectric properties of coprecipitated ultrafine zinc ferrite. *Journal of Magnetism and Magnetic Materials*. 2004. 269(2): 217-226.

82. Ammar, S., Jouini, N., Fiévet, F., Beji, Z., Smiri, L., Moliné, P., Danot, M. and Grenèche, J.-M. Magnetic properties of zinc ferrite nanoparticles synthesized by hydrolysis in a polyol medium. *Journal of Physics: Condensed Matter*. 2006. 18(39): 9055.

83. Jiao, Z., Wu, M., Gu, J. and Qin, Z. Preparation and gas-sensing characteristics of nanocrystalline spinel zinc ferrite thin films. *Sensors Journal, IEEE*. 2003. 3(4): 435-438.

84. Kundu, A., Anand, S. and Verma, H. A citrate process to synthesize nanocrystalline zinc ferrite from 7 to 23 nm crystallite size. *Powder Technology*. 2003. 132(2): 131-136.

85. Roy, M., Haldar, B. and Verma, H. Characteristic length scales of nanosize zinc ferrite. *Nanotechnology*. 2006. 17(1): 232.

86. Xue, H., Li, Z., Wang, X. and Fu, X. Facile synthesis of nanocrystalline zinc ferrite via a self-propagating combustion method. *Materials Letters*. 2007. 61(2): 347-350.

87. Yang, J. and Yen, F.-S. Evolution of intermediate phases in the synthesis of zinc ferrite nanopowders prepared by the tartrate precursor method. *Journal of Alloys and Compounds*. 2008. 450(1): 387-394.

88. Mohai, I., Szépvölgyi, J., Bertóti, I., Mohai, M., Gubicza, J. and Ungár, T. Thermal plasma synthesis of zinc ferrite nanopowders. *Solid State Ionics*. 2001. 141: 163-168.

89. Yan, A., Liu, X., Yi, R., Shi, R., Zhang, N. and Qiu, G. Selective synthesis and properties of monodisperse Zn ferrite hollow nanospheres and nanosheets. *The Journal of Physical Chemistry C*. 2008. 112(23): 8558-8563.

90. Sivakumar, M., Takami, T., Ikuta, H., Towata, A., Yasui, K., Tuziuti, T., Kozuka, T., Bhattacharya, D. and Iida, Y. Fabrication of zinc ferrite nanocrystals by sonochemical emulsification and evaporation: observation of magnetization and its relaxation at low temperature. *The Journal of Physical Chemistry B*. 2006. 110(31): 15234-15243.

91. Nakashima, S., Fujita, K., Tanaka, K. and Hirao, K. High magnetization and the high-temperature superparamagnetic transition with intercluster interaction in disordered zinc ferrite thin film. *Journal of Physics: Condensed Matter*. 2005. 17(1): 137.

92. Chinnasamy, C., Narayanasamy, A., Ponpandian, N., Chattopadhyay, K., Guerault, H. and Greneche, J. Magnetic properties of nanostructured ferrimagnetic zinc ferrite. *Journal of Physics: Condensed Matter*. 2000. 12(35): 7795.

93. Cvejić, Ž., Rakić, S., Jankov, S., Skuban, S. and Kapor, A. Dielectric properties and conductivity of zinc ferrite and zinc ferrite doped with yttrium. *Journal of Alloys and Compounds*. 2009. 480(2): 241-245.

94. Thomas, M. and George, K. Infrared and magnetic study of nanophase zinc ferrite. *Indian Journal of Pure and Applied Physics*. 2009. 47: 81-86.

95. Yu, S.-H., Fujino, T. and Yoshimura, M. Hydrothermal synthesis of $ZnFe_2O_4$ ultrafine particles with high magnetization. *Journal of Magnetism and Magnetic Materials*. 2003. 256(1): 420-424.

96. Schiessl, W., Potzel, W., Karzel, H., Steiner, M., Kalvius, G., Martin, A., Krause, M., Halevy, I., Gal, J. and Schäfer, W. Magnetic properties of the Zn Fe_2O_4 spinel. *Physical Review B*. 1996. 53(14): 9143.

97. Lee, P., Suematsu, H., Nakayama, T., Jiang, W. and Niihara, K. Synthesis of $ZnFe_2O_4$ nanosized powders from pulsed metallic zinc and iron wire discharge in oxygen. *Journal of Magnetism and Magnetic Materials*. 2007. 312(1): 27-31.

98. Chinnasamy, C., Narayanasamy, A., Ponpandian, N., Chattopadhyay, K., Guerault, H. and Greneche, J.M. Ferrimagnetic ordering in nanostructured zinc ferrite. *Scripta Materialia*. 2001. 44(8): 1407-1410.

99. Ehrhardt, H., Campbell, S. and Hofmann, M. Structural evolution of ball-milled $ZnFe_2O_4$. *Journal of Alloys and Compounds*. 2002. 339(1): 255-260.

100. Druska, P., Steinike, U. and Šepelák, V. Surface structure of mechanically activated and of mechanosynthesized zinc ferrite. *Journal of Solid State Chemistry*. 1999. 146(1): 13-21.

101. Burghart, F., Potzel, W., Kalvius, G., Schreier, E., Grosse, G., Noakes, D., Schäfer, W., Kockelmann, W., Campbell, S. and Kaczmarek, W. Magnetism of crystalline and nanostructured $ZnFe_2O_4$. *Physica B: Condensed Matter*. 2000. 289: 286-290.

102. Ehrhardt, H., Campbell, S. and Hofmann, M. Magnetism of the nanostructured spinel zinc ferrite. *Scripta Materialia*. 2003. 48(8): 1141-1146.

103. Hofmann, M., Campbell, S., Ehrhardt, H. and Feyerherm, R. The magnetic behaviour of nanostructured zinc ferrite. *Journal of Materials Science*. 2004. 39(16-17): 5057-5065.

104. Jeyadevan, B., Tohji, K. and Nakatsuka, K. Structure analysis of coprecipitated $ZnFe_2O_4$ by extended x-ray-absorption fine structure. *Journal of Applied Physics*. 1994. 76(10): 6325-6327.

105. Oliver, S., Harris, V., Hamdeh, H. and Ho, J. Large zinc cation occupancy of octahedral sites in mechanically activated zinc ferrite powders. *Applied Physics Letters*. 2000. 76(19): 2761-2763.

106. Oliver, S., Hamdeh, H. and Ho, J. Localized spin canting in partially inverted $ZnFe_2O_4$ fine powders. *Physical Review B*. 1999. 60(5): 3400.

107. Tawfik, A., Hamada, I. and Hemeda, O. Effect of laser irradiation on the structure and electromechanical properties of Co–Zn ferrite. *Journal of Magnetism and Magnetic Materials*. 2002. 250: 77-82.

108. Gul, I., Abbasi, A., Amin, F., Anis-ur-Rehman, M. and Maqsood, A. Structural, magnetic and electrical properties of $Co_{1-x}Zn_xFe_2O_4$ synthesized by co-precipitation method. *Journal of Magnetism and Magnetic Materials*. 2007. 311(2): 494-499.

109. Gözüak, F., Köseoğlu, Y., Baykal, A. and Kavas, H. Synthesis and characterization of $Co_xZn_{1-x}Fe_2O_4$ magnetic nanoparticles via a PEG-assisted route. *Journal of Magnetism and Magnetic Materials*. 2009. 321(14): 2170-2177.

110. Dey, S. and Ghose, J. Synthesis, characterisation and magnetic studies on nanocrystalline $Co_{0.2}Zn_{0.8}Fe_2O_4$. *Materials Research Bulletin*. 2003. 38(11): 1653-1660.

111. Arulmurugan, R., Jeyadevan, B., Vaidyanathan, G. and Sendhilnathan, S. Effect of zinc substitution on Co–Zn and Mn–Zn ferrite nanoparticles prepared by co-precipitation. *Journal of Magnetism and Magnetic Materials*. 2005. 288: 470-477.

112. Islam, M. U., Rana, M. U. and Abbas, T. Study of magnetic interactions in Co–Zn–Fe–O system. *Materials Chemistry and Physics*. 1998. 57(2): 190-193.

113. Vaidyanathan, G., Sendhilnathan, S. and Arulmurugan, R. Structural and magnetic properties of $Co_{1-x}Zn_xFe_2O_4$ nanoparticles by co-precipitation method. *Journal of Magnetism and Magnetic Materials*. 2007. 313(2): 293-299.

114. Duong, G., Hanh, N., Linh, D., Groessinger, R., Weinberger, P., Schafler, E. and Zehetbauer, M. Monodispersed nanocrystalline $Co_{1-x}Zn_xFe_2O_4$ particles by forced hydrolysis: Synthesis and characterization. *Journal of Magnetism and Magnetic Materials*. 2007. 311(1): 46-50.

115. Waje, S. B., Hashim, M., Yusoff, W. D. W. and Abbas, Z. Sintering temperature dependence of room temperature magnetic and dielectric properties of $Co_{0.5}Zn_{0.5}Fe_2O_4$ prepared using mechanically alloyed nanoparticles. *Journal of Magnetism and Magnetic Materials*. 2010. 322(6): 686-691.

116. Josyulu, O. and Sobhanadri, J. DC conductivity and dielectric behaviour of cobalt-zinc ferrites. *Physica Status Solidi (a)*. 1980. 59(1): 323-329.

117. Sharma, R. K., Suwalka, O., Lakshmi, N., Venugopalan, K., Banerjee, A. and Joy, P. Synthesis of chromium substituted nano particles of cobalt zinc ferrites by coprecipitation. *Materials Letters*. 2005. 59(27): 3402-3405.

118. Suwalka, O., Sharma, R. K., Sebastian, V., Lakshmi, N. and Venugopalan, K. A study of nanosized Ni substituted Co–Zn ferrite prepared by coprecipitation. *Journal of Magnetism and Magnetic Materials*. 2007. 313(1): 198-203.

119. Satyanarayana, R., Murthy, S. R., Rao, T. S. and Rao, S. Electrical conductivity of Ni-Zn ferrites. *Journal of the Less Common Metals*. 1983. 90(2): 243-250.

120. Reddy, A. R., Mohan, G. R., Boyanov, B. and Ravinder, D. Electrical transport properties of zinc-substituted cobalt ferrites. *Materials Letters*. 1999. 39(3): 153-165.

121. Islam, M. U., Ashraf Chaudhry, M., Abbas, T. and Umar, M. Temperature dependent electrical resistivity of Co–Zn–Fe–O system. *Materials Chemistry and Physics*. 1997. 48(3): 227-229.

122. Anis-ur-Rehman, M. Synthesis and Thermophysical Studies of Nanoferrites. *Journal of Superconductivity and Novel Magnetism*. 2011. 24(1-2): 535-540.

123. Bayoumi, W. Structural and electrical properties of zinc-substituted cobalt ferrite. *Journal of Materials Science*. 2007. 42(19): 8254-8261.

124. Pandya, P., Joshi, H. and Kulkarni, R. Bulk magnetic properties of Co-Zn ferrites prepared by the co-precipitation method. *Journal of Materials Science*. 1991. 26(20): 5509-5512.

125. Jadhav, S. S., Shirsath, S. E., Patange, S. M. and Jadhav, K. Effect of Zn substitution on magnetic properties of nanocrystalline cobalt ferrite. *Journal of Applied Physics*. 2010. 108(9): 093920.

126. Arulmurugan, R., Vaidyanathan, G., Sendhilnathan, S. and Jeyadevan, B. Co–Zn ferrite nanoparticles for ferrofluid preparation:Study on magnetic properties. *Physica B: Condensed Matter*. 2005. 363(1): 225-231.

127. Li, W. and Fa-Shen, L. Structural and magnetic properties of $Co_{1-x}Zn_xFe_2O_4$ nanoparticles. *Chinese Physics B*. 2008. 17(5): 1858.

128. Néel, L. Propriétés magnétiques des ferrites. Ferrimagnétisme et antiferro magnétisme. *Annals of Physics*. 1948. 3: 137-198.

129. Veverka, M., Jirák, Z., Kaman, O., Knížek, K., Maryško, M., Pollert, E., Závěta, K., Lančok, A., Dlouhá, M. and Vratislav, S. Distribution of cations in nanosize and bulk Co–Zn ferrites. *Nanotechnology*. 2011. 22(34): 345701.

130. Pettit, G. and Forester, D. Mossbauer study of cobalt-zinc ferrites. *Physical Review B*. 1971. 4(11): 3912-3924.

131. Urcia-Romero, S., Perales-Pérez, O., Uwakweh, O., Osorio, C. and Radovan, H. Tuning of magnetic properties in Co–Zn ferrite nanocrystals synthesized by a size controlled co-precipitation method. *Journal of Applied Physics*. 2011. 109(7): 07B512.

132. Fayek, M., Bahgat, A., Abbas, Y. and Moberg, L. Neutron diffraction and Mossbauer effect study on a cobalt substituted zinc ferrite. *Journal of Physics C: Solid State Physics*. 1982. 15(11): 2509.

133. Aquilanti, G., Cognigni, A. and Anis-ur-Rehman, M. Cation Distribution in Zn Doped Cobalt Nanoferrites Determined by X-ray Absorption Spectroscopy. *Journal of Superconductivity and Novel Magnetism*. 2011. 24(1-2): 659-663.

134. Padalia, B. and Krishnan, V. X-ray spectroscopic study of cobalt-zinc ferrites. *Journal of Physics and Chemistry of Solids*. 1975. 36(3): 199-203.

135. Yousefi, M., Manouchehri, S., Arab, A., Mozaffari, M., Amiri, G. R. and Amighian, J. Preparation of cobalt–zinc ferrite ($Co_{0.8}Zn_{0.2}Fe_2O_4$) nanopowder

via combustion method and investigation of its magnetic properties. *Materials Research Bulletin*. 2010. 45(12): 1792-1795.

136. Bhukal, S., Bansal, S. and Singhal, S. Magnetic Mn substituted cobalt zinc ferrite systems: structural, electrical and magnetic properties and their role in photo-catalytic degradation of methyl orange azo dye. *Physica B: Condensed Matter*. 2014. 445: 48-55.

137. Gabal, M., Abdel-Daiem, A., Al Angari, Y. and Ismail, I. Influence of Al-substitution on structural, electrical and magnetic properties of Mn–Zn ferrites nanopowders prepared via the sol–gel auto-combustion method. *Polyhedron*. 2013. 57: 105-111.

138. Singhal, S., Barthwal, S. and Chandra, K. XRD, magnetic and Mössbauer spectral studies of nano size aluminum substituted cobalt ferrites ($CoAl_xFe_{2-x}O_4$). *Journal of Magnetism and Magnetic Materials*. 2006. 306(2): 233-240.

139. Kumar, L. and Kar, M. Influence of Al^{3+} ion concentration on the crystal structure and magnetic anisotropy of nanocrystalline spinel cobalt ferrite. *Journal of Magnetism and Magnetic Materials*. 2011. 323(15): 2042-2048.

140. Luo, H., Rai, B., Mishra, S., Nguyen, V. and Liu, J. Physical and magnetic properties of highly aluminum doped strontium ferrite nanoparticles prepared by auto-combustion route. *Journal of Magnetism and Magnetic Materials*. 2012. 324(17): 2602-2608.

141. Chae, K. P., Kwon, W. H. and Lee, J.-G. Influence of aluminum doping in Li–Co–Ti ferrite. *Journal of Magnetism and Magnetic Materials*. 2012. 324(18): 2701-2705.

142. Nlebedim, I. C., Ranvah, N., Melikhov, Y., Williams, P. I., Snyder, J. E., Moses, A. J. and Jiles, D. C. Effect of temperature variation on the

magnetostrictive properties of $CoAl_xFe_{2-x}O_4$. *Journal of Applied Physics*. 2010. 107(9): 09A936.

143. Enkovaara, J., Heczko, O., Ayuela, A. and Nieminen, R. Coexistence of ferromagnetic and antiferromagnetic order in Mn-doped Ni_2MnGa. *Physical Review B*. 2003. 67(21): 212405.

144. Sharma, A., Parmar, K., Kotnala, R. and Negi, N. Magnetic and Dielectric Properties of $Co_xZn_{1-x}Fe_2O_4$ Synthesized by Metallo-Organic Decomposition Technique. *International Journal of Advanced Engineering Technology*. 2012. 5: 544-554.

145. Raghavender, A., Kulkarni, R. and Jadhav, K. Magnetic properties of mixed cobalt-aluminum ferrite nanoparticles. *ChineseJournal of Physics*. 2010. 48(4): 512-522.

146. Tang, Y., Jia, L., Zhang, H. and Liu, B. Internal digital video broadcasting-handheld antenna with a low loss Z-type hexaferrite for folder-type mobile phones. *Microwave and Optical Technology Letters*. 2012. 54(6): 1380-1385.

147. Schmelzer, J. W., Röpke, G. and Priezzhev, V. B. *Nucleation theory and applications*: Wiley Online Library. 2005.

148. Skoog, D. A. *Fundamentals of analytical chemistry*: Grupo Editorial Norma. 2004.

149. Upadhyay, R., Mehta, R., Parekh, K., Srinivas, D. and Pant, R. Gd-substituted ferrite ferrofluid: a possible candidate to enhance pyromagnetic coefficient. *Journal of Magnetism and Magnetic Materials*. 1999. 201(1): 129-132.

150. Khorsand Zak, A., Abd. Majid, W. H., Abrishami, M. E. and Yousefi, R. X-ray analysis of ZnO nanoparticles by Williamson–Hall and size–strain plot methods. *Solid State Sciences*. 2011. 13(1): 251-256.

151. Fawzi, A. S., Sheikh, A. D. and Mathe, V. L. Composition dependent electrical, dielectric, magnetic and magnetoelectric properties of $Co_{0.5}Zn_{0.5}Fe_2O_4$ PLZT composites. *Journal of Alloys and Compounds*. 2010. 493(1–2): 601-608.

152. Kulawik, J., Szwagierczak, D. and Guzdek, P. Magnetic, magnetoelectric and dielectric behavior of $CoFe_2O_4$–$Pb(Fe_{1/2}Nb_{1/2})O_3$ particulate and layered composites. *Journal of Magnetism and Magnetic Materials*. 2012. 324(19): 3052-3057.

153. Patankar, K. K., Mathe, V. L., Mahajan, R. P., Patil, S. A., Reddy, R. M. and SivaKumar, K. V. Dielectric behaviour and magnetoelectric effect in $CuFe_2O_4$–$Ba_{0.8}Pb_{0.2}TiO_3$ composites. *Materials Chemistry and Physics*. 2001. 72(1): 23-29.

154. Zhang, H. and Mak, C.-L. Impedance spectroscopic characterization of fine-grained magnetoelectric $Pb(Zr_{0.53}Ti_{0.47})O_3$–$(Ni_{0.5}Zn_{0.5})Fe_2O_4$ ceramic composites. *Journal of Alloys and Compounds*. 2012. 513(0): 165-171.

155. Lobaton-Sulabo, A. S. *Packaging and storage effects on Listeria monocytogenes reduction and attachment on ready-to-eat meat snacks*. Kansas State University; 2014.

156. Gauglitz, G. and Vo-Dinh, T. *Handbook of Spectroscopy*: John Wiley & Sons. 2006.

157. Ashiq, M. N., Iqbal, M. J. and Gul, I. H. Structural, magnetic and dielectric properties of Zr–Cd substituted strontium hexaferrite ($SrFe_{12}O_{19}$) nanoparticles. *Journal of Alloys and Compounds*. 2009. 487(1–2): 341-345.

158. Hankare, P., Patil, R., Garadkar, K., Sasikala, R. and Chougule, B. Synthesis, dielectric behavior and impedance measurement studies of Cr-substituted Zn–Mn ferrites. *Materials Research Bulletin*. 2011. 46(3): 447-452.

159. Gul, I. and Maqsood, A. Structural, magnetic and electrical properties of cobalt ferrites prepared by the sol–gel route. *Journal of Alloys and Compounds*. 2008. 465(1): 227-231.

160. Sundararajan, M., Kennedy, L. J., Vijaya, J. J. and Aruldoss, U. Microwave combustion synthesis of $Co_{1-x}Zn_xFe_2O_4$ ($0 \leqslant x \leqslant 0.5$): structural, magnetic, optical and vibrational spectroscopic studies. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2014. 140(5): 421–430.

161. Khan, M. A., Khan, K., Mahmood, A., Murtaza, G., Akhtar, M. N., Ali, I., Shahid, M., Shakir, I. and Warsi, M. F. Nanocrystalline $La_{1-x}Sr_xCo_{1-y}Fe_yO_3$ perovskites fabricated by the micro-emulsion route for high frequency response devices fabrications. *Ceramics International*. 2014. 40(8): 13211-13216.

162. Džunuzović, A. S., Ilić, N. I., Vijatović Petrović, M. M., Bobić, J. D., Stojadinović, B., Dohčević-Mitrović, Z. and Stojanović, B. D. Structure and properties of Ni–Zn ferrite obtained by auto-combustion method. *Journal of Magnetism and Magnetic Materials*. 2015. 374(0): 245-251.

163. Dong, C. PowderX: Windows-95-based program for powder X-ray diffraction data processing. *Journal of Applied Crystallography*. 1999. 32(4): 838-838.

164. Wang, Z., Wu, M., Jin, S., Li, G., Ma, Y. and Wang, P. Ni_3Zn ferrite octahedral nanoparticles with high microwave permeability and high magnetic loss tangent. *Journal of Magnetism and Magnetic Materials*. 2013. 344(0): 101-104.

165. Suzuki, K., Namikawa, T. and Yamazaki, Y. Preparation of zinc-and aluminum-substituted cobalt-ferrite thin films and their Faraday rotation. *Japanese Journal of Applied Physics*. 1988. 27(3R): 361.

166. Singhal, S., Namgyal, T., Bansal, S. and Chandra, K. Effect of Zn substitution on the magnetic properties of cobalt ferrite nano particles prepared via sol-gel route. *Journal of Electromagnetic Analysis and Applications*. 2010. 2(6): 376-381

167. Shannon, R, Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides. *Acta Crystallographica Section A: Crystal Physics, Diffraction, Theoretical and General Crystallography*. 1976. 32(5): 751-767.

168. Kulkarni, R., Trivedi, B. S., Joshi, H. and Baldha, G. Magnetic properties of copper ferrite aluminates. *Journal of Magnetism and Magnetic Materials*. 1996. 159(3): 375-380.

169. Sawatzky, G., Van der Woude, F. and Morrish, A. Note on cation distribution of $MnFe_2O_4$. *Physics Letters A*. 1967. 25(2): 147-148.

170. Li, F. S., Wang, L., Wang, J. B., Zhou, Q. G., Zhou, X. Z., Kunkel, H. P. and Williams, G. Site preference of Fe in nanoparticles of $ZnFe_2O_4$. *Journal of Magnetism and Magnetic Materials*. 2004. 268(3): 332-339.

171. Raming, T., Winnubst, A., van Kats, C. M. and Philipse, A. The synthesis and magnetic properties of nanosized hematite (α-Fe_2O_3) particles. *Journal of Colloid and Interface Science*. 2002. 249(2): 346-350.

172. White, W. and DeAngelis, B. Interpretation of the vibrational spectra of spinels. *Spectrochimica Acta Part A: Molecular Spectroscopy*. 1967. 23(4): 985-995.

173. Waldron, R. D. Infrared Spectra of Ferrites. *Physical Review*. 1955. 99(6): 1727-1735.

174. Kumar, V., Rana, A., Kumar, N. and Pant, R. P. Investigations on Controlled-Size-Precipitated Cobalt Ferrite Nanoparticles. *International Journal of Applied Ceramic Technology*. 2011. 8(1): 120-126.

175. Priyadharsini, P., Pradeep, A., Rao, P. S. and Chandrasekaran, G. Structural, spectroscopic and magnetic study of nanocrystalline Ni–Zn ferrites. *Materials Chemistry and Physics*. 2009. 116(1): 207-213.

176. Kawade, V., Bichile, G. and Jadhav, K. X-ray and infrared studies of chromium substituted magnesium ferrite. *Materials Letters*. 2000. 42(1): 33-37.

177. Ishaque, M., Islam, M., Khan, M. A., Rahman, I., Genson, A. and Hampshire, S. Structural, electrical and dielectric properties of yttrium substituted nickel ferrites. *Physica B: Condensed Matter*. 2010. 405(6): 1532-1540.

178. Rath, C., Sahu, K., Anand, S., Date, S., Mishra, N. and Das, R. Preparation and characterization of nanosize Mn–Zn ferrite. *Journal of Magnetism and Magnetic Materials*. 1999. 202(1): 77-84.

179. Ravinder, D. Far-infrared spectral studies of mixed lithium–zinc ferrites. *Materials Letters*. 1999. 40(5): 205-208.

180. Mohammed, K., Al-Rawas, A., Gismelseed, A., Sellai, A., Widatallah, H., Yousif, A., Elzain, M. and Shongwe, M. Infrared and structural studies of $Mg_{1-x}Zn_xFe_2O_4$ ferrites. *Physica B: Condensed Matter*. 2012. 407(4): 795-804.

181. Birajdar, A., Shirsath, S. E., Kadam, R., Mane, M., Mane, D. and Shitre, A. Permeability and magnetic properties of Al^{3+} substituted $Ni_{0.7}Zn_{0.3}Fe_2O_4$ nanoparticles. *Journal of Applied Physics*. 2012. 112(5): 053908.

182. Batoo, K. M., Kumar, S. and Lee, C. G. Study of ac impedance spectroscopy of Al doped $MnFe_{2-2x}Al_{2x}O_4$. *Journal of Alloys and Compounds*. 2009. 480(2): 596-602.

183. Waldron, R. D. Infrared Spectra of Ferrites. *Physical Review*. 1955. 99(6): 1727-1735

184. Kulal, S. R., Khetre, S. S., Jagdale, P. N., Gurame, V. M., Waghmode, D. P., Kolekar, G. B., Sabale, S. R. and Bamane, S. R. Synthesis of Dy doped Co–Zn ferrite by sol–gel auto combustion method and its characterization. *Materials Letters*. 2012. 84(0): 169-172.

185. Ghatage, A. K., Choudhari, S. C., Patil, S. A. and Paranjpe, S. K. X-ray, infrared and magnetic studies of chromium substituted nickel ferrite. *Journal of Materials Science Letters*. 1996. 15(17): 1548-1550.

186. Šepelák, V., Tkáčová, K. and Rykov, A. I. Rietveld Analysis of Mechanically Activated Powdered Zinc Ferrite. *Crystal Research and Technology*. 1993. 28(1): 53-56.

187. Manova, E., Kunev, B., Paneva, D., Mitov, I., Petrov, L., Estournes, C., D'Orléan, C., Rehspringer, J.-L. and Kurmoo, M. Mechano-synthesis, characterization, and magnetic properties of nanoparticles of cobalt ferrite, $CoFe_2O_4$. *Chemistry of materials*. 2004. 16(26): 5689-5696.

188. Kulkarni, R. G., Trivedi, B. S., Joshi, H. H. and Baldha, G. J. Magnetic properties of copper ferrite aluminates. *Journal of Magnetism and Magnetic Materials*. 1996. 159(3): 375-380.

189. Bercoff, P. G. and Bertorello, H. R. Localized canting effect in Zn-substituted Ni ferrites. *Journal of Magnetism and Magnetic Materials*. 2000. 213(1–2): 56-62.

190. Shirsath, S. E., Toksha, B. and Jadhav, K. Structural and magnetic properties of In^{3+} substituted $NiFe_2O_4$. *Materials Chemistry and Physics*. 2009. 117(1): 163-168.

191. Jadhav, S. S., Shirsath, S. E., Toksha, B., Shengule, D. and Jadhav, K. Structural and dielectric properties of Ni-Zn ferrite nanoparticles prepared by co-precipitation method. *Journal of Optoelectronics and Advanced Materials*. 2008. 10(10): 2644-2648.

192. Mallapur, M., Shaikh, P., Kambale, R., Jamadar, H., Mahamuni, P. and Chougule, B. Structural and electrical properties of nanocrystalline cobalt substituted nickel zinc ferrite. *Journal of Alloys and Compounds*. 2009. 479(1): 797-802.

193. Xing, Q., Peng, Z., Wang, C., Fu, Z. and Fu, X. Doping effect of Y^{3+} ions on the microstructural and electromagnetic properties of Mn–Zn ferrites. *Physica B: Condensed Matter*. 2012. 407(3): 388-392.

194. Saafan, S., Assar, S. and Mansour, S. Magnetic and electrical properties of $Co_{1-x}Ca_xFe_2O_4$ nanoparticles synthesized by the auto combustion method. *Journal of Alloys and Compounds*. 2012. 542: 192-198.

195. Khan, A., Bhuiyan, M. A., Al Quaderi, G. D., Maria, K. H., Choudhury, S., Hossain, K. M. A., Akther, S. and Saha, D. Dielectric and transport properties of Zn-substituted cobalt ferrites. *Journal of Bangladesh Academy of Sciences*. 2013. 37(1): 73-82.

196. Gupta, N., Kashyap, S. and Dube, D. Dielectric and magnetic properties of citrate-route-processed Li–Co spinel ferrites. *Physica Status Solidi (a)*. 2007. 204(7): 2441-2452.

197. Roy, P. and Bera, J. Effect of Mg substitution on electromagnetic properties of $(Ni_{0.25}Cu_{0.20}Zn_{0.55})Fe_2O_4$ ferrite prepared by auto combustion method. *Journal of Magnetism and Magnetic Materials*. 2006. 298(1): 38-42.

198. Batoo, K. M. Study of dielectric and impedance properties of Mn ferrites. *Physica B: Condensed Matter*. 2011. 406(3): 382-387.

199. Jadhav, K., Kawade, V., Modi, K., Bichile, G. and Kulkarni, R. Structural, magnetization and susceptibility studies on cobalt–ferri-aluminates synthesized by wet-chemical method. *Physica B: Condensed Matter*. 2000. 291(3): 379-386.

200. Chaudhari, S. and Patil, R. Dielectric behavior and AC Conductivity in Cu-Ti Ferrites. Advances. 2013.

201. Jeppson, P., Sailer, R., Jarabek, E., Sandstrom, J., Anderson, B., Bremer, M., Grier, D., Schulz, D., Caruso, A. and Payne, S. Cobalt ferrite nanoparticles: Achieving the superparamagnetic limit by chemical reduction. *Journal of Applied Physics*. 2006. 100(11): 114324-114324.

202. Zare, S., Ati, A. A., Dabagh, S., Rosnan, R. M. and Othaman, Z. Synthesis, structural and magnetic behavior studies of Zn–Al substituted cobalt ferrite nanoparticles. *Journal of Molecular Structure*. 2015. 1089(0): 25-31.

203. Kharabe, R., Jadhav, S., Shaikh, A., Patil, D. and Chougule, B. Magnetic properties of mixed Li–Ni–Cd ferrites. *Materials Chemistry and Physics*. 2001. 72(1): 77-80.

204. Ati, A. A., Othaman, Z., Samavati, A. and Doust, F. Y. Structural and magnetic properties of Co–Al substituted Ni ferrites synthesized by co-precipitation method. *Journal of Molecular Structure*. 2014. 1058: 136-141.

205. Jae-Gwang Lee, J. Y. P., Chul Sungm Growth of ultra-fine cobalt ferrite particles by a sol–gel method and their magnetic properties. *Journal of Materials Science* 1998. 33: 3965 - 3968

206. Karimi, Z., Mohammadifar, Y., Shokrollahi, H., Asl, S. K., Yousefi, G. and Karimi, L. Magnetic and structural properties of nano sized Dy-doped cobalt ferrite synthesized by co-precipitation. *Journal of Magnetism and Magnetic Materials*. 2014. 361(0): 150-156.

207. Alone, S. and Jadhav, K. Structural and magnetic properties of zinc-and aluminum-substituted cobalt ferrite prepared by co-precipitation method. *Pramana*. 2008. 70(1): 173-181.

208. Singhal, S., Namgyal, T., Bansal, S. and Chandra, K. Effect of Zn substitution on the magnetic properties of cobalt ferrite nano particles prepared via sol-gel route. *Journal of Electromagnetic Analysis and Applications*. 2010. 2: 376-381.

209. Kharabe, R. G., Jadhav, S. A., Shaikh, A. M., Patil, D. R. and Chougule, B. K. Magnetic properties of mixed Li–Ni–Cd ferrites. *Materials Chemistry and Physics*. 2001. 72(1): 77-80.

210. Masti, S. A., Sharma, A. K., Vasambekar, P. N. and Vaingankar, A. S. Influence of Cd^{2+} and Cr^{3+} substitutions on the magnetization and permeability of magnesium ferrites. *Journal of Magnetism and Magnetic Materials*. 2006. 305(2): 436-439.

211. Gabal, M. A., El-Shishtawy, R. M. and Al Angari, Y. M. Structural and magnetic properties of nano-crystalline Ni–Zn ferrites synthesized using egg-white precursor. *Journal of Magnetism and Magnetic Materials*. 2012. 324(14): 2258-2264.

212. Mazen, S. A. and Abu-Elsaad, N. I. Analogous study in low magnetic field between Cu–Ge and Cu–Si ferrites. *Journal of Magnetism and Magnetic Materials*. 2010. 322(2): 265-274.

213. Deraz, N. M. and Hessien, M. M. Structural and magnetic properties of pure and doped nanocrystalline cadmium ferrite. *Journal of Alloys and Compounds*. 2009. 475(1–2): 832-839.

214. Brusentsova, T. N. and Kuznetsov, V. D. Synthesis and investigation of magnetic properties of substituted ferrite nanoparticles of spinel system $Mn_{1-x}Zn_x[Fe_{2-y}L_y]O_4$. *Journal of Magnetism and Magnetic Materials*. 2007. 311(1): 22-25.

215. Hergt, R., Andra, W., d'Ambly, C. G., Hilger, I., Kaiser, W. A., Richter, U. and Schmidt, H.-G. Physical limits of hyperthermia using magnetite fine particles. *Magnetics, IEEE Transactions on*. 1998. 34(5): 3745-3754.

216. Kodama, R. H. Magnetic nanoparticles. *Journal of Magnetism and Magnetic Materials*. 1999. 200(1–3): 359-372.

217. Khedr, M., Omar, A., Nasr, M. and Sedeek, E. Effect of firing temperature on microstructure and magnetic properties of nanocrystalline $Ni_{0.5}Zn_{0.5}Fe_2O_4$ prepared by wet and dry methods. *Journal of Analytical and Applied Pyrolysis*. 2006. 76(1): 203-208.

218. Ju, Y.-W., Park, J.-H., Jung, H.-R., Cho, S.-J. and Lee, W.-J. Fabrication and characterization of cobalt ferrite ($CoFe_2O_4$) nanofibers by electrospinning. *Materials Science and Engineering: B*. 2008. 147(1): 7-12.

219. Rajendran, M., Pullar, R. C., Bhattacharya, A. K., Das, D., Chintalapudi, S. N. and Majumdar, C. K. Magnetic properties of nanocrystalline $CoFe_2O_4$ powders

prepared at room temperature: variation with crystallite size. *Journal of Magnetism and Magnetic Materials*. 2001. 232(1–2): 71-83.

220. Pillai, V. and Shah, D. O. Synthesis of high-coercivity cobalt ferrite particles using water-in-oil microemulsions. *Journal of Magnetism and Magnetic Materials*. 1996. 163(1–2): 243-248.

221. Qu, Y., Yang, H., Yang, N., Fan, Y., Zhu, H. and Zou, G. The effect of reaction temperature on the particle size, structure and magnetic properties of coprecipitated $CoFe_2O_4$ nanoparticles. *Materials Letters*. 2006. 60(29): 3548-3552.

222. Maaz, K., Mumtaz, A., Hasanain, S. and Ceylan, A. Synthesis and magnetic properties of cobalt ferrite ($CoFe_2O_4$) nanoparticles prepared by wet chemical route. *Journal of Magnetism and Magnetic Materials*. 2007. 308(2): 289-295.

223. Ibrahim, A. M., El-Latif, M. A. and Mahmoud, M. M. Synthesis and characterization of nano-sized cobalt ferrite prepared via polyol method using conventional and microwave heating techniques. *Journal of Alloys and Compounds*. 2010. 506(1): 201-204.

224. Gul, I., Maqsood, A., Naeem, M. and Ashiq, M. N. Optical, magnetic and electrical investigation of cobalt ferrite nanoparticles synthesized by co-precipitation route. *Journal of Alloys and Compounds*. 2010. 507(1): 201-206.

225. Zhao, L. and Jiang, Q. Effects of applied magnetic field and pressures on the magnetic properties of nanocrystalline $CoFe_2O_4$ ferrite. *Journal of Magnetism and Magnetic Materials*. 2010. 322(17): 2485-2487.

226. Haruta, M. and Delmon, B. Preparation of homodisperse solids. *Journal de Chimie Physique*. 1986. 83(11-12): 859-868.