UNIVERSITI PUTRA MALAYSIA

SYNTHESIS AND CHARACTERIZATION OF NICKEL ZINC FERRITE THIN FILMS DEPOSITED USING SPIN COATING TECHNIQUE

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By

YUSNITA BINTI YUSUF

Thesis Submitted to the School of Graduate Studies, Univetsiti Putra Malaysia, in Fullfillment of the Requirement for the Degree of Master of Science

December 2016

DEDICATION

To my lovely:

Parents

&

Siblings

Thank you for supports and encourages until I completed this project.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

SYNTHESIS AND CHARACTERIZATION OF NICKEL ZINC FERRITE THIN FILM DEPOSITED USING SPIN COATING TECHNIQUE

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December 2016

Chairman: Dr Rabaah Syahidah Azis, PhD
Faculty : Institute of Advanced Technology

The trend for downsizing electronic devices and the potential applications of soft ferrite materials have leads to the fabrication of ferrite thin films. However, the main problem concerning the existing research is the fabrication of ferrite films, to make a simple technology at low temperature. Thus, in this work, we report some research findings on relationship of low annealing temperature towards morphological, magnetic and optical properties. Nickel zinc ferrite thin film was prepared via sol-gel and spin-coating technique. The films were coated with indium tin oxide (ITO) glass substrates and spin-coated. The samples were annealed from 400 °C to 700 °C using 100 °C increments with any one sample being subjected to only one annealing temperature. The structural and microstructural of $Ni_{0.3}Zn_{0.7}Fe_2O_4$ thin films were carried out by using X-ray diffraction (XRD) and field emission scanning electron microscope (FESEM). The *M-H* hysteresis loop of thin film was observed by using vibrating sample magnetometer (VSM). The formation of films and the vibration of molecules were also confirmed by using Fourier Transform Infrared (FTIR) spectroscopy. The XRD patterns showed an improvement of crystallinity with increasing annealing temperature. Plane (311) most intense plane formed nickel zinc ferrite phases. The spinel structure was also confirmed by FTIR. FESEM image showed films have dense and homogenous grains with average grain size are 18.61 nm (400 °C), 26.25 nm (500 °C), 28.12 nm (600 °C) and 41.32 nm (700 °C). The measured resistivity was found to increase with increasing temperature, however decreased after annealed at 700 °C due to the combined effect of increased grain size and Fe^{2+} ions due to increasing zinc loss. The synthesized of $Ni_{0.3}Zn_{0.7}Fe_2O_4$ ferrite thin films showed narrow with a low saturation magnetization (M_s). The value of M_s are 1.28, 2.39, 2.65 and 3.42 emu/g respectively. These attributed to the presence of small nanoparticles containing a spin-glass-like surface layer and ferrimagnetically

lined-up core spins. The coercivity is decreases as increase the average grain size, 16.18, 16.54, 12.28, and 8.30 Oe respectively. The highest of energy bandgap obtained for direct and indirect bandgap 3.57 and 3.30 eV.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

SINTESIS DAN PENCIRIAN TERHADAP SAPUT NIPIS NIKEL ZINK FERIT MENGGUNAKAN TEKNIK SALUTAN PUTAR

Oleh

YUSNITA BINTI YUSUF

Disember 2016

Pengerusi : Dr. Rabaah Syahidah Azis, PhD
Fakulti : Institut Teknologi Maju

Permintaan untuk teknologi termaju dalam elektronik bersaiz kecil telah menarik minat terhadap ciri struktur, magnetik dan elektrik ferit. Walau bagaimanapun, masalah utama berkaitan dengan kajian yang sedia ada adalah fabrikasi filem ferit menggunakan teknologi yang mudah dengan suhu yang rendah. Suhu pemendapan yang tinggi menghadkan pilihan untuk bahan subtrak serta menyekat aplikasi bahan yang berbeza dari saput nipis ferit. Jadi dalam kajian ini, kami melaporkan beberapa penemuan penyelidikan mengenai hubungan suhu rendah terhadap sifat-sifat mikrostruktur, magnetik, dan optik. Ferit nikel zink telah disediakan dengan kaedah sol-gel dan teknik spin-salutan. Filem disalut atas substrak kaca indium tin oksida (ITO). Sampel telah penyepuhlindapan dari 400 °C hingga 700 °C dengan kenaikan 100 °C dengan menggunakan sampel berlainan bagi setiap suhu. Sifat struktur dan mikrostruktur sapus nipis diperiksa dengan menggunakan pembelauan sinar-X (XRD) dan mikroskop elektron imbasan pengeluaran medan (FESEM). Kajian magnet dijalankan dengan magnetometer sampel bergetar (VSM). Pembentukan saput nipis juga dipastikan dengan menggunakan spektroskopi transfom Fourier gelombang merah (FTIR). Corak pembelauan sinar–X menunjukan peningkatan penghabluran dengan meningkatnya penyepuhlindapan. Struktur spinel juga dipastikan dengan FTIR. Mikrograf FESEM menunjukan saiz butiran meningkat dengan suhu penyepuhlindapan dengan purata butir 18.61 nm (400 °C), 26.25 nm (500 °C), 28.12 nm (600 °C) dan 41.32 nm (700 °C). Kerintangan didapati meningkat disebabkan oleh kesan gabungan pertambahan dan bilangan ion Fe^{3+} daripada peningkatan kehilangan zink. Pemagnetan tepu saput nipis $Ni_{0.3}Zn_{0.7}Fe_2O_4$ yang diperoleh dalam suhu bilik dari gelung histerisis adalah meningkat dengan suhu penyepuhlindapan. Nilai pemagnetan tepu 1.28, 2.39, 2.65 dan 3.42 emu/g. Ini dikaitkan dengan kehadiran nanopartikel kecil yang mengandungi lapisan

permukaan sampingan kaca dan ferrimagnetik yang berbaris. daya paksa adalah penurunan sebagai meningkatkan saiz butiran purata. Nilai daya paksa menurun dengan peningkatan saiz butir, 16.18, 16.54, 12.28, dan 8.30 Oe. Nilai jurang tenaga yang tertinggi diperoleh secara langsung dan tidak langsung memberikan nilai jurang 3.57 dan 3.30 eV.

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I certify that a Thesis Examination Committee has met on 23 December 2016 to conduct the final examination of Yusnita binti Yusuf on her thesis entitled **"**Synthesis and Characterization of Nickel Zinc Ferrite Thin Film Deposited Using Spin Coating Technique**"** in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF SYMBOLS AND ABBREVIATIONS

XRD	X- ray diffraction
FESEM	Field Emission Scanning Electron Microscopy
VSM	Vibrating Sample Measurement
FTIR	Fourier Transform Infrared Spectroscopy
UV-Vis	Ultraviolet Visible NIR Spectroscopy
M_s	Magnetic saturation
H_c	Coercivity
2θ	Theta degree
ρ	Resistivity
I -V	Current-voltage
Wt %	Weight percent
a.u	Arbitrary unit
σ	Conductivity
H	Magnetic field strength
E_g	Optical bandgap energy
E_p	Photon energy
nB	Magnetic moment per formula unit
M_{oct}	Magnetic moment octahedral
M_{tet}	Magnetic moment tetrahedral

D	Crystallite size
β	Angular line width at half maximum intensity
θ_b	Bragg angle
A	Absorption
I_o	Incident light intensity
I	Transmitted light intensity
hv	Photon energy
t	Thickness
N_a	Avogadro number
Fe_2O_3	Iron oxide
M	Molar mass

CHAPTER 1

INTRODUCTION

1.1 Background of study

Ferrites ceramic that have both electrical and magnetic properties been considered as highly important in electronic technological materials. Among the various types of ferrites, spinel ferrites are widely used in electrical and magnetic applications. Ferrites constitute a class of materials that has been perceived to have imperative potential in applications region from millimetre wave integrated circuitry to attractive recording. In contrast to technology of bulk ferrite for example, microwave magnetic devices and transformer cores, these potential applications in ferrite films perform to the guarantee of critical bulk ferrite properties. Ferrites are one of the magnetic ceramic materials which all are ferromagnetic oxides somehow have different in crystals structure. Ferrites have known as a spinel structure (Suzuki *et al.*, 2001), and recognized as iron oxides group that incorporates to garnets, spinels, orthoferrites and hexaferrites. Ferrites molecular formula is $M^{2+}OFe_2^{3+}O_3$ where M represent the divalent metal. For the example Cu, Fe, Mn, Co, Zn, Ni, Mg and so on (Huq *et al*., 2013).

Soft ferromagnetic materials find extensive applications as a result of their ability to enhance the flux produced by an electrical current. Consequently, the uses of soft materials are closely connected with electrical applications such as electrical power generation and transmission, radio signals receiver, microwaves, inductors, relays and electromagnets (Chavan *et al*., 2010). The new applications such as radio, television, video tape recorders, carrier telephone, computer circuitry and microwave devices (Sugimoto *et al*., 1999). Hence, the requirements of ferrites have also changed. The properties such as a strong in magnetic coupling, a high resistivity, and low loss at high frequencies. Their important potential have led to extensive intention in finding of fabrication and characterization in thin film of ferrite materials to particular applications (Suzuki *et al.*, 2001).

In 2000's, the electronic devices miniaturizing, nanostructured thick and thin films have been fabricating in term spinel ferrites. Nanocrystalline ferrite thin film with spinel cubic structure have been a subjects of huge investigation because of their potential applications in high density magneto-optic recording devices, ferrofluids, colour imaging and magnetic refrigeration (Gupta, Verma, *et al.,*2007). In view of storage applications, some ferrite thin films have been studied as potential perpendicular recording and magneto-optical media material. Barium ferrite and cobalt ferrite films are particularly promising because of their large coercivity, as well as their high corrosion resistance, good mechanical stability, and low noise (Suzuki *et al*., 2001). More recently, high-permeability insulating ferrites have been identified as candidate materials for flux guides and sensors in thin film recording heads. While microwave devices using bulk ferrites can be traced back to the 1950s, the development of ferrite thin films will provide several advantages for microwave and millimeter wave devices. For example, the propagation characteristics of magnetostatic wave devices can be significantly improved by films that can provide better uniformity of effective internal field compared with bulk crystals. Recent studies of ferrite thin films have focused on understanding the microstructure and its implications on the electronic and magnetic properties. Studies range from spinel and hexaferrite thin films for perpendicular recording media, integrated inductors, and micromagnetic devices to garnet structure ferrite films for magneto-optical applications. Despite variations in crystalllinity and crystal structure, the fundamental issues of structure-property relationships in ferrite thin films remain the same in these studies. Ferrite thin films under study range from nanocrystalline or polycrystalline to epitaxial thin films. Given a particular growth process, it has often been difficult to reproduce results from one laboratory to the next; however, the development and refinement of deposition techniques have resulted in the convergence of results. In polycrystalline and epitaxial ferrite thin films, electroplating, magnetron sputtering, pulsed laser deposition, evaporation, and molecular beam epitaxy have been used extensively.

1.2 Problem statement

Ni-Zn ferrite is commercially important materials because of their excellent electrical and soft magnetic properties. Technique involving preparation in ferrite film can simply prepared at low temperature. But, nickel-zinc substituted nickel ferrite thin films using sol-gel and spin-coating technique have not been reported in detail for its structural, magnetic, electrical and magnetic properties. Considering the significant of nickel ferrite thin film for wide applications, it worth to study the relationship between microstructure, magnetic properties, electrical and optical properties of thin film ferrite with nominal $Ni_{0.3}Zn_{0.7}Fe_2O_4$. Most of the previous research focussed on various annealing temperature, different substrate used, and dependent of thicknesses with increased the zinc contents. While, this research proposes are to establish and understand the relationship of the microstructure, magnetic, and optical properties in $Ni_{0.3}Zn_{0.7}Fe_2O_4$ ferrite thin film.

The hypothesis of each objective are listed as following:

1. The grain size and thickness of the film would increase with annealing temperature. That would result Ms increases while Hc decreases.

2. As the annealing temperature increase, the direct and indirect energy bandgap would decrease. That would increase the resistivity.

1.3 Objectives

The main objective of this project is to synthesis and characterization of NiZn ferrite thin film prepared by spin coating technique. In order to optimize the sol-gel spin coating NiZn thin film, the following objectives have been performed, which are:

1. To study the morphology and magnetic proeprties of $Ni_{0.3}Zn_{0.7}Fe_2O_4$ ferrite thin film.

2. To study the effect of annealing temperature of $Ni_{0.3}Zn_{0.7}Fe_2O_4$ ferrite thin film on optical and electrical properties.

1.4 Thesis structure

The thesis consists five chapters which include Introduction, Literature Review, Theory, Results Discussion and Conclusion. An introduction to NiZn ferrite thin films and its applications is given in Chapter 1. The research background of study, problem statement and the objectives of this project also discuss in this chapter. The theoretical explain in Chapter 2. Literature review on synthesis method, characterization of Ni-Zn ferrite film on structural, magnetic, electrical and optical is included in Chapter 3. The research experimental works used in this research is presented in Chapter 4. This chapter explain the starting materials used to prepare the film, film deposition and samples characterization. In Chapter 5, discussion and results of data of the experiment are listed, analysed and interpreted in the forms of graphs, tables, diagrams as well as in pictures.
In Chapter 6, conclusion and recommendations for future research are present.

REFERENCES

Bae, S.Y., Kim, C.S., Oh, Y.J. (1999). Magnetic properties of sol-gel derived Ni–Zn ferrite thin films on yttria stabilized zirconia buffered Si(100). *Journal of Applied Physics*, *85*(8), 5226–5228.

Bakr, N. A., Salman, S. A., Khudhair, H. F. (2016). Structural and optical properties of zinc doped nickel ferrite $Ni_{(1-x)}Zn_{(x)}$ Fe_2O_4 thin films prepared by chemical spray pyrolysis method. *Journal of Chemical, Biological and Physical Sciences 6*(1), 280–293.

Bakry, A. (2008). Influence of film thickness on optical properties of hydrogenated amorphous silicon thin films. *Egyptian Journal of Solids*, (31), 11–22.

Banks. (1961). *Goldman (Ed.) Handbook of Modern Ferromagnetic Materials*. Massachusetts: Kluwer Academic Publisher.

Batoo, K., Ansari, M. (2012). Low temperature fired Ni-Cu-Zn ferrite nanoparticles through auto-combustion method for multilayer chip inductor applications. *Nanoscale Research Letters*, *7*(1), 112.

Bilecka, I., Kubli, M., Amstad, E., Niederberger, M. (2011). Simultaneous formation of ferrite nanocrystals and deposition of thin films via a microwave-assisted nonaqueous sol-gel process. *Journal of Sol-Gel Science and Technology*, *57*(3), 313–322.

Brinker, C. J., Frye, G. C., Hurd, a. J., Ashley, C. S. (1991). Fundamentals of sol-gel dip coating. *Thin Solid Films*, *201*(1), 97–108.

Brinker, C. J., Schunk, P. R. (1992). Non-crystalline solids. *Review of sol-gel thin film formation sol-gel dip-coating*, *148*, 424–436.

Chappert, J., Frankel, R. B. (1967). Study of ferrimagnetic ordering in nickel ferrite and chromium-substituted nickel ferrite. *Physical Review Letters*, *19*(10), 570.

Chavan, S. M., Babrekar, M. K., More, S. S., Jadhav, K. M. (2010). Structural and optical properties of nanocrystalline Ni-Zn ferrite thin films. *Journal of Alloys and Compounds*, *507*(1), 21-25.

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

Cullity, B. D. (1972). *Introduction to Magnetic Materials*. Massachusetts: Addison-Wesley Pub. Company.

Cullity, B. D., Graham, C. D. (2009). *Introduction to magnetic materials* (2^{nd} ed.). New Jersey: John Wiley & Sons Inc.

Desai, M., Prasad, S., Venkataramani, N., Samajdar, I., Nigam, A. K., Keller, N., Rossi, A. (2002). Anomalous variation of coercivity with annealing in nanocrystalline NiZn ferrite films. *Journal of Applied Physics*, *91*(101), 7592–7594.

Dey, S., Roy, A., Das, D., Ghose, J. (2004). Preparation and characterization of nanocrystalline disordered lithium ferrite by citrate precursor method. *Journal of Magnetism and Magnetic Materials*, *270*(1-2), 224–229.

Dixit, G. (2012). Structural, magnetic and optical studies of nickel ferrite thin films. *Advanced Materials Letters*, *3*(1), 21–28.

Dixit, G., Singh, J. P., Srivastava, R. C., Agrawal, H. M., Choudhary, R. J., Gupta, A. (2010). Annealing effect on the structural and magnetic properties of nickel ferrite thin films. *Surface and Interface Analysis*, *42*(3), 151–156.

El-Sayed, A. M. (2003). Electrical conductivity of nickel-zinc and cr substituted nickel-zinc ferrites. *Materials Chemistry and Physics*, *82*(3), 583–587.

Gabal, M. A., Al-Luhaibi, R. S., Al-Angari, Y. M. (2013). Effect of zn-substitution on the structural and magnetic properties of Mn-Zn ferrites synthesized from spent Zn-C batteries. *Journal of Magnetism and Magnetic Materials*, *348*, 107–112.

Gao, P., Rebrov, E. V., Verhoeven, T., Schouten, J. C., Kleismit, R., Kozlowski, G., Subramanyam, G., Turgut, Z. (2010). Structural investigations and magnetic properties of sol-gel $Ni_{0.5}Zn_{0.5}Fe_2O_4$ thin films for microwave heating. *Journal of Applied Physics*, *107*(4), 0–8.

Goldman, A. (1999). *Handbook of Modern Ferromagnetic Materials*. Massachusetts: Kluwer Academic Publishers.

Goldman, A. (2006). *Modern Ferrite Technology* (2^{nd} ed.). Pittsburgh: Springer Science and Business Media, Inc.

Gupta, N., Verma, A., Kashyap, S. C., Dube, D. C. (2005). Dielectric behavior of spin-deposited nanocrystalline nickel-zinc ferrite thin films processed by citrate-route. *Solid State Communications*, *134*(10), 689–694.

Gupta, N., Verma, A., Kashyap, S. C., Dube, D. C. (2007). Microstructural, dielectric and magnetic behavior of spin-deposited nanocrystalline nickel-zinc ferrite thin films for microwave applications. *Journal of Magnetism and Magnetic Materials*, *308*(1), 137–142.

Hajalilou, A., Mazlan, S. A. (2016). A review on preparation techniques for synthesis of nanocrystalline soft magnetic ferrites and investigation on the effects of microstructure features on magnetic properties. *Applied Physics*

A, *122*(7), 680.

Hankare, P. P., Patil, R. P., Jadhav, A. V., Pandav, R. S., Garadkar, K. M., Sasikala, R., Tripathi, A. K. (2011). Synthesis and characterization of nanocrystalline Ti-substituted zn ferrite. *Journal of Alloys and Compounds*, *509*(5), 2160–2163.

Horowitz, F., Dawnay, E. J. C., Fardad, M. A., Green, M., Yeatman, E. M. (1997). Towards better control of sol-gel film processing for optical device applications. *Journal of Nonlinear Optical Physics & Materials*, *06*(01), 1–18.

Hu, C., Gao, Z., Yang, X. (2008). One-pot low temperature synthesis of MFe_2O_4 (M=Co, Ni, Zn) superparamagnetic nanocrystals. *Journal of Magnetism and Magnetic Materials*, *320*(8), 70–73.

Huq, M. F., Saha, D. K., Ahmed, R., Mahmood, Z. H. (2013). Ni-cu-zn ferrite. A Brief Review. *Journal of Scientific Research*, *5*(2), 215–234.

Ibrahim, N. B., Al-Shomar, S. M. (2013). Effect of annealing temperature on the structural and optical properties of nanocrystalline ZnO thin films prepared by sol-gel method. *Sains Malaysiana*, *42*(12), 1781–1786.

Idza, I. R., Hashim, M., Rodziah, N., Ismayadi, I., Norailiana, A. R. (2012). Influence of evolving microstructure on magnetic hysteresis characteristics in polycrystalline nickel-zinc ferrite, $Ni_{0.3}Zn_{0.7}Fe_2O_4$. *Materials Research Bulletin*, *47*(6), 1345–1352.

Jain, A., Sagar, P., Mehra, R. (2007). Changes of structural, optical and electrical properties of sol-gel derived ZnO films with their thickness. *Materials Science-Poland*, *25*(1), 233–242.

Joshi, G. P., Saxena, N. S., Mangal, R., Mishra, A., Sharma, T. P. (2003). Band gap determination of Ni-Zn ferrites. *Bulletin of Materials Science*, *26*(4), 387–389.

Kale, A., Gubbala, S., Misra, R. (2004). Magnetic behavior of nanocrystalline nickel ferrite synthesized by the reverse micelle technique. *Journal of Magnetism and Magnetic Materials*, *277*(3), 350–358.

Kale, R. B., Lokhande, C. D. (2005). Influence of air annealing on the structural, morphological, optical and electrical properties of chemically deposited ZnSe thin films. *Applied Surface Science*, *252*(4), 929–938.

Kambale, R. C., Adhate, N. R., Chougule, B. K., Kolekar, Y. D. (2010). Magnetic and dielectric properties of mixed spinel Ni-Zn ferrites synthesized by citrate-nitrate combustion method. *Journal of Alloys and Compounds*, *491*, 372–377.

Kayani, Z. N., Riaz, S., Naseem, S. (2011). Preparation and characterization of $SrBi_2$ Ta_2O_9 (SBT) thin films, *49*(1), 49–57.

Khairy, M., Gouda, M. E. (2014). Electrical and optical properties of nickel ferrite/polyaniline nanocomposite. *Journal of Advanced Research*, *6*(4), 555–562.

Khusayfan, N. M. (2013). Study of structure and electro-optical characteristics of indium tin oxide thin films. *Advances in Condensed Matter Physics, 2013*, 408182.

Kingery, W. D., Bowen, H. K., Uhlmann, D. R. (1976). *Introduction to Ceramics* (2nd ed.). New York: John Wiley & Sons.

Klug, H. P., Alexander, L. E. (1974). X-Ray Diffraction Procedures. *For Polycrystalline and Amorphous Materials* (2nd ed.). New York: John Wiley & Sons.

Kondo, K., Chiba, T., Yamada, S. (2003). Effect of microstructure on magnetic properties of Ni-Zn ferrites. *Journal of Magnetism and Magnetic Materials*, *254-255*, 541–543.

Koops, C. G. (1951). On the dispersion of resistivity and dielectric constant of some semiconductors at audio frequencies. *Physical Review*, *83*(1), 121–124.

Kumar, N., Prasad, S., Misra, D. S., Venkataramani, N., Bohra, M., Krishnan, R. (2008). The influence of substrate temperature and annealing on the properties of pulsed laser-deposited YIG films on fused quartz substrate. *Journal of Magnetism and Magnetic Materials*, *320*(18), 2233–2236.

Kumbhar, S. S., Mahadik, M. A., Mohite, V. S., Hunge, Y. M., Rajpure, K. Y., Bhosale, C. H. (2015). Effect of Ni content on the structural, morphological and magnetic properties of spray deposited Ni–Zn ferrite thin films. *Materials Research Bulletin*, *67*, 47–54.

Kumbhar, S. S., Mahadik, M. A., Mohite, V. S., Rajpure, K. Y., Bhosale, C. H. (2014). Synthesis and characterization of spray deposited nickel-zinc ferrite thin films. *Energy Procedia*, *54*, 599–605.

Labde, B. K., Sable, M. C., Shamkuwar, N. R. (2003). Structural and infra-red studies of $Ni_{1+x}Pb_xFe_{2-2x}O_4$ system. *Materials Letters*, *57*, 1651–1655.

Lisfi, A., Williams, C. M. (2003). Magnetic anisotropy and domain structure in epitaxial $CoFe_2O_4$ thin films. *Journal of Applied Physics*, *93*(103), 8143–8145.

Liu, Y., Li, Y., Zhang, H., Chen, D., Mu, C. (2011). Structural and magnetic properties of nizn-ferrite thin films prepared by radio frequency magnetron sputtering. *Journal of Applied Physics*, *109*(7), 1–4.

Louh, R., Reynolds, T. G., Buchanan, R. C. (2004). Ferrite Ceramics. *Ceramics Materials* (3rd ed.). New York: Marcel Dekker Inc.

Maensiri, S., Masingboon, C., Boonchom, B., Seraphin, S. (2007). A simple route to synthesize nickel ferrite ($NiFe_2O_4$) nanoparticles using egg white. *Scripta Materialia*, *56*(9), 797–800.

Mate, V., Grygar, A., Kadlecova, J. (2000). Sol-gel processing and magnetic properties of nickel zinc ferrite thick films. *Ceramics International*, *26*, 507–512.

Mathews, N. R., Morales, E. R., Cortes-Jacome, M. A., Toledo, J. A. (2009). TiO_2 thin films Influence of annealing temperature on structural, optical and photocatalytic properties. *Solar Energy*, *83*(9), 1499–1508.

Nakashima, S., Fujita, K., Tanaka, K., Hirao, K., Yamamoto, T., Tanaka, I. (2007). First-principles XANES simulations of spinel zinc ferrite with a disordered cation distribution. *Physical Review B: Condensed Matter and Materials Physics*, *75, 174443*.

Nandapure, A. I., Kondawar, S. B., Sawadh, P. S., Nandapure, B. I. (2012). Effect of zinc substitution on magnetic and electrical properties of nanocrystalline nickel ferrite synthesized by refluxing method. *Physical B: Physics of Condensed Matter*, *407*(7), 1104–1107.

Néel, L. (1948). Magnetic properties of ferrites ferrimagnetism and antiferromagnetism. *Annals of Physics Paris*, *3*, 137–198.

Nie, S. J., Geng, H., Wang, J. B., Wang, L. Sen, Wang, Z. W., Xu, R., Peng, D. L. (2013). The structure and magnetic properties of nizn-ferrite films deposited by magnetron sputtering at room temperature. *Advanced Materials Research*, *690-693*, 1702–1706.

Nlebedim, I. C., Melikhov, Y., Jiles, D. C. (2014). Temperature dependence of magnetic properties of heat treated cobalt ferrite. *Journal of Applied Physics*, *115*(4), 4–8.

Ozgur, U., Alivov, Y., Morkoc, H. (2009). Microwave ferrites, part 1: Fundamental properties. *Journal of Materials Science: Materials in Electronics*, *20*.

Patel, S. G., Oza, A. T. (2004). Infrared spectra of charge transfer complexes of metal-free phthalocyanine. *Journals of Pure and Applied Physics*, *42*(6), 79–88.

Patil, D. R., Chougule, S. S., Lokare, S. A., Chougule, B. K. (2008). Electrical properties of $NiFe_2O_{4+(1-x)}Ba_{0.7}Sr_{0.3}TiO_3$ composites. *Journal of Alloys and Compounds*, *452*(2), 414–418.

Patil, P. S., Kadam, L. D., Lokhande, C. D. (1996). Preparation and characterization of spray pyrolysed cobalt oxide thin films. *Thin Solid Films*, *272*(1), 29–32.

Patil, R. P., Delekar, S. D., Mane, D. R., Hankare, P. P. (2013). Synthesis, structural and magnetic properties of different metal ion substituted nanocrystalline zinc ferrite. *Results in Physics*, *3*, 129–133.

Pratibha, R., Godbole, R. V., Phase, D. M., Chikate, R. C., Sunita, B. (2015). Ferrite thin films: Synthesis , characterization and gas sensing properties towards liquid petroleum gas. *Materials Chemistry and Physics*, *149*-150, 333-338.

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

Rebrov, E. V., Gao, P., Verhoeven, T. M., Schouten, J. C., Kleismit, R., Turgut, Z., Kozlowski, G. (2011). Structural and magnetic properties of sol–gel $Co_{2x}Ni_{0.5-x}$ $Zn_{0.5-x}Fe_2O_4$ thin films. *Journal of Magnetism and Magnetic Materials*, *323*(6), 723–729.

Shinde, T. J., Gadkari, A. B., Vasambekar, P. N. (2008). DC resistivity of Ni-Zn ferrites prepared by oxalate precipitation method. *Materials Chemistry and Physics*, *111*(1), 87–91.

Smit, J., Wijn, H. P. J. (1959). *Ferrites*. New York: John Wiley & Sons.

Standley, K. J. (1972). *Oxide Magnetic Materials* (2^{nd} ed.). Clarendon Press.

Subbarao, E. C., Singhal, L. K., Merriam, M. F., Chakravorty, O., Raghavan, V. (1972). *Experiments in Materials Science*. New York, N.Y. : McGraw-Hill.

Sugimoto, M. (1999). The past, present, and future of ferrites. *Journal of the American Ceramic Society*, *82*(2), 80–269.

Sun, S., Zeng, H., Robinson, D. B., Raoux, S., Rice, P. M., Wang, S. X., Li, G. (2012). Monodisperse MFe_2O_4 (M= Fe, Co, Mn) nanoparticles. *Journal of the American Chemical Society*, *4*(1), 133–137.

Sutka, A., Strikis, G., Mezinskis, G., Lusis, A., Zavickis, J., Kleperis, J., Jakovlevs, D. (2012). Properties of Ni-Zn ferrite thin films deposited using spray pyrolysis. *Thin Solid Films*, *526*(3), 65–69.

Suzuki, Y. (2001). Epitaxial Spinel Ferrite Thin Films. *Annual Review of Materials Research*, *31*(4), 265–289.

Takayama, A., Okuya, M., Kaneko, S. (2004). Spray pyrolysis deposition of NiZn ferrite thin films. *Solid State Ionics*, *172*(1-4), 257–260.

Viswanathan, B., Murthy, V. R. K. (1990). *Ferrite Materials: Science and Technology (1^{st} Ed.)*. New Delhi: Narosa Publishing House.

Wohlfarth, E. P. (1980). *Ferromagnetic materials: A Handbook on the Properties of Magnetically Ordered Substances* (1^{st} ed.). Amsterdam: Elsevier Science.

Xin, Z., Xiao-Hui, S., Dian-Lin, Z. (2010). Thickness dependence of grain size and surface roughness for dc magnetron sputtered Au films. *Chinese Physics B*, *19*(8), 086802.

Xu, L., Li, X., Chen, Y., Xu, F. (2011). Structural and optical properties of ZnO thin films prepared by sol-gel method with different thickness. *Applied Surface Science*, *257*(9), 4031–4037.

Yakuphanoglu, F., Arslan, M. (2004a). The fundamental absorption edge and optical constants of some charge transfer compounds. *Optical Materials*, *27*(1), 29–37.

Yakuphanoglu, F., Arslan, M. (2004b). The fundamental absorption edge and optical constants of some charge transfer compounds. *Optical Materials*, *27*(1), 29–37.

Yan, F., Zhao, G., Chen, Y., Song, N., Zhao, N., You, C. (2013). One-step synthesis of $Ni_{0.5}Zn_{0.5}Fe_2O_4$ fine-patterned films via photosensitive sol-gel route. *Ceramics International*, *39*(7), 7721–7725.

Zahi, S., Daud, A. R., Hashim, M. (2007). A comparative study of nickel-zinc ferrites by sol-gel route and solid-state reaction. *Materials Chemistry and Physics*, *106*(2-3), 452–456.

Zhang, Y., Zhang, W., Peng, C. (2008). Strong ultraviolet luminescence of ZnO thin films with nanowall-network structures. *Optics Express*, *16*(14), 10696–700.