UNIVERSITI PUTRA MALAYSIA

EVOLUTION OF MORPHOLOGY, MAGNETIC PROPERTIES AND THEIR RELATIONSHIPS DURING SINTERING OF BARIUM FERITE ($BaFe_{12}O_{19}$), COBALT FERRITE ($CoFe_2O_4$) AND COBALT NICKEL FERRITE ($Co_{0.5}Ni_{0.5}Fe_2O_4$)

MOHD SHAMSUL EZZAD SHAFIE

ITMA 2015 16

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By

MOHD SHAMSUL EZZAD SHAFIE

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

September 2015

In appreciation of their love and sacrifices, this thesis is dedicated to Parents SHAFIE BIN AWANG and NORIZAH BINTI MAT

Beginning… PhD
Padang perahu di lautan
Padang hati di fikiran

Intermediate…PhD
Kupu-kupu terbang melintang
Hinggap menghisap bunga layu
Hati di dalam menaruh bimbang
Melihat ikan memanjat kayu

Orang selsema sakit berhingus
Lubang hidung rasa terkambus
Ibarat seperti telur kemungkus
Benci nak pandang rasa cemus

Anak ruan tidak terluang
Benang sutera di dalam tubuh
Hendak buang tidak terbuang
Sudah mesra di dalam tubuh

Ending..Phd
Murai gila jadi tekukur
Ajaib hairan hati tafakur

Kalau tuan pergi ke Kedah
Singgah lama di Kuala Muda
Kalau suatu diperolehi dengan mudah
Bagai irama hilang nada

Cahaya redup menyegar padi
Ayam berkokok mengirai tuah
Jikalau hidup tidak berbudi
Umpama pokok tidak berbuah

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

EVOLUTION OF MORPHOLOGY, MAGNETIC PROPERTIES AND THEIR RELATIONSHIPS DURING SINTERING OF BARIUM FERITE ($BaFe_{12}O_{19}$), COBALT FERRITE ($CoFe_2O_4$) AND COBALT NICKEL FERRITE ($Co_{0.5}Ni_{0.5}Fe_2O_4$)

By

MOHD SHAMSUL EZZAD SHAFIE

September 2015

Chairman: Associate Professor Mansor Hashim, PhD
Institute : Advanced Technology

In this study, the microstructural evolution during sintering of BaM, CoF and CoNiF ferrites is reported in terms of the effects of the sintering route and temperature, as well as densification behavior and grain-growth kinetics through regression coefficient plots. Three ferrite materials were selected due to outstanding properties in electronic applications and no detail study on evolution study for that material. These materials synthesized using mechanical alloying followed by sintering from 500 to 1400°C with 100°C increments. Two sintering modes were adopted: MSS and SSS. The particle size structural, microstructural and magnetic properties details of the samples were detained by appropriate use of transmission electron microscopy (TEM), X-ray diffractometry (XRD), scanning electron microscopy (SEM), vibrating sample magnetometry (VSM), and a B-H hysteresis graph.

This study proves that microstructure generally influences the magnetic properties as reflected by a threshold grain size, for the H_c, as the SD to MD magnetic transition point. At early sintering temperatures, microstructure shows widespread necking processes, proving the occurrence of densification. For hard ferrite BaM, a single phase was observed to form at a temperature of 1000°C which is higher than that for soft ferrite at 700°C. It is noted that strong magnetocrystalline anisotropy would cause significant difficulty to align magnetic moments in BaM, as indicated by H_c values for this phase. In intermediate sintering, approximately 800 to 1100°C for BaM and 700 to 1000°C for CoF and CoNiF, strong ordered magnetism is shown by the B-H loop shape. It is also believed that densification through grain boundary diffusion was dominant at this stage.

Increasing sintering temperature resulted in higher density, coarser microstructure, and further densification and grain growth. However, a substantial amount of powder surface reactivity was still preserved within the microstructure of the compact. Subsequently, during the dwell time at the highest temperature, densification and grain growth took place at higher rates resulting, finally in increased density, coarser microstructure and higher initial magnetic permeability. At this stage, grain boundary diffusion through lattice and volume diffusion dominated causing microstructure to grow abnormally with introduction of intraganular pores. Porosity was observed to increase at this stage.

The substitution of NiO into CoF enhances the sintering by increasing bulk diffusion due to the increased vacancy concentration which is accompanied by the solubility of Ni^{2+} in the ferrites. Ni^{2+} ions are cations that are soluble in the host lattice and enter regular positions on the tetrahedral or octahedral sites. The results for the MSS and SSS samples as obtained from their hysteresis magnetic loops, showed high saturation magnetization BaM ($100 < 4\pi Ms < 9800$ G), low remanence ($7 <$ Br, $<$ 2039 G) and H_c ($22 < Hc < 35$ Oe) values. The relative density-grain size plot of the sintering process demonstrates a crossover between the densification mechanisms from grain boundary diffusion to lattice diffusion with increasing sintering temperature. Most importantly, the M-H loops for BaM, CoF and CoNiF were each found to belong to three families of M-H curves which correspond to different states of magnetism.

Finally for the evolution study, it is strongly believed that there are a few factors found to sensitively influence the samples content of ordered magnetism: their ferrite-phase crystallinity degree, the fraction of grains above the critical grain size and large enough grains for domain wall accommodation.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

EVOLUSI RUPABENTUK, SIFAT MAGNETIK DAN HUBUNGAN MEREKA SEMASA PENSINTERAN BARIUM FERIT ($BaFe_{12}O_{19}$), KOBALT FERIT ($CoFe_2O_4$) KOBALT NIKEL FERIT ($Co_{0.5}Ni_{0.5}Fe_2O_4$)

Oleh

MOHD SHAMSUL EZZAD SHAFIE

September 2015

Pengerusi: Profesor Madya Mansor Hashim, PhD
Institut : Teknologi Maju

Dalam kajian ini, evolusi mikrostruktur semasa pensinteran BAM, COF dan CoNiF ferrites dilaporkan dari segi kesan laluan pensinteran dan suhu, serta juga keadaan pemadatan dan kinetik pertumbuhan bijirin melalui plot pekali regresi. Tiga bahan ferit dipilih kerana sifat cemerlang dalam aplikasi elektronik dan tiada kajian terperinci mengenai kajian evolusi untuk bahan tersebut. Bahan-bahan ini dihasilkan menggunakan pengaloian mekanikal diikuti oleh pensinteran dari 500-1400°C dengan 100°C kenaikan. Dua mod pensinteran telah diterima pakai : MSS dan SSS. Saiz zarah sifat-sifat struktur , mikrostruktur dan magnet butiran sampel telah diperolehi dengan penggunaan yang sesuai alat mikroskop pemancaran elektron (TEM) ,Pembelauan sinar- X (XRD) , mikroskop imbasan elektron (SEM) , magnetometry sampel bergetar (VSM) dan BH histerisis graf.

Kajian ini membuktikan bahawa mikrostruktur umumnya mempengaruhi sifat-sifat magnet seperti yang ditunjukkan oleh saiz ambang bijirin, untuk H_c , kerana titik peralihan magnet dari SD kepada MD. Pada suhu pensinteran awal, mikrostruktur menunjukkan proses perleheran yang meluas , membuktikan berlakunya pemadatan . Untuk ferit keras BaM , fasa tunggal diperhatikan terbentuk pada suhu 1000 °C yang lebih tinggi daripada itu untuk ferit lembut pada suhu 700 °C. Ia menyatakan bahawa anisotropi hablur magnetic kukuh akan menyebabkan kesukaran besar untuk menyelaraskan momen magnet di BaM , seperti yang ditunjukkan oleh nilai-nilai H_c untuk fasa ini. Dalam pensinteran pertengahan, kira-kira 800-1100 °C untuk BaM dan 700 1000 °C untuk COF dan CoNiF , kemagnetan kuat terarah ditunjukkan oleh bentuk gelung BH. Ia juga dipercayai bahawa pemadatan melalui sempadan bijian penyebaran adalah dominan pada peringkat ini.

Peningkatan suhu pembakaran menghasilkan ketumpatan yang lebih tinggi, mikrostruktur kasar, dan pemadatan serta pertumbuhan bijian. Walau bagaimanapun, sejumlah besar kereaktifan permukaan serbuk masih dikekalkan dalam mikrostruktur padat . Selepas itu , pada masa suhu dikekalkan, pemadatan dan bijirin pertumbuhan tertinggi berlaku pada kadar yang lebih tinggi, akhirnya ketumpatan meningkat, mikrostruktur lebih kasar dan kebolehtelapan magnet di permulaan yang lebih tinggi. Pada peringkat ini , penyebaran sempadan bijian melalui kekisi dan jumlah penyebaran dikuasai menyebabkan mikrostruktur berkembang secara biasa dengan kemunculan liang intraganular . Keliangan diperhatikan meningkat pada peringkat ini.

Penggantian NiO ke dalam COF menambahbaik pembakaran dengan meningkatkan penyebaran pukal kerana kekosongan kepekatan meningkat yang disertai oleh kebolehlarutan Ni^{2+} dalam ferrites. Ni^{2+} ion adalah kation yang larut dalam kekisi perumah dan memasuki kedudukan biasa pada tapak tetrahedron atau oktahedron. Keputusan bagi MSS dan SSS sampel yang diperolehi daripada gelung magnet histerisis mereka, menunjukkan tingginya nilai-nilai pemangnetan tepu BaM (100 $<4\pi$Ms <9800 G), remanence rendah (7 <Br, <2039 G) dan H_c (22 <Hc <35 Oe). Plot pemadatan saiz bijirin relatif untuk proses pensinteran menunjukkan salingkaitan antara mekanisma pemadatan dari penyebaran sempadan bijian kepada kekisi penyebaran dengan peningkatan suhu penbakaran. Paling utama, gelung M-H untuk BaM, COF dan CoNiF telah didapati setiapnya memiliki tiga keluarga lengkung M-H yang sesuai dengan keadaan-keadaan yang berbeza kemagnetan. Akhir sekali dalam kajian evolusi, amat dipercayai bahawa terdapat beberapa faktor yang didapati dengan secara sensitif mempengaruhi kandungan sampel kemagnetan terarah: darjah fasa penghabluran ferit, sebahagian kecil daripada biji-bijian melampaui saiz butiran kritikal dan bijirin cukup besar untuk pengisian dinding domain.

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for giving me company while I toiled hard.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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Signature: ______________________________

Name of Member of Supervisory Committee: Assoc. Prof. Dr. Khamirul Amin Matori

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LIST OF ABBREVIATIONS

XRD	X-ray diffraction
SEM	Scanning Electron Microscopy
EDX	Energy Dispersive X-ray
STEM	Scanning transmission electron microscopy
wt %	Weight percent
hkl	Miller indices
MUT	Material under test
JCPDS	Joint Committee on Power Diffraction Standard
BPR	Ball-to-powder weight ratio
MA	Mechanical alloying
a.u	Arbitrary unit
Fig.	Figure
χ	Magnetic susceptibility
H	Magnetic field strength
H_a	Anisotropy field
H_C	Coercivity
M	Mass magnetization
M_R	Remanent magnetization
M_S	Saturation magnetization
σ_R	Specific remanent magnetization
σ_S	Specific saturation magnetization
T_N	Néel temperature
2θ	2 theta degree
D_m	Mean grain diameter

γ	Magnetic domain wall energy proportional to the global anisotropy constant
M_{sv}	Magnetization per unit volume
M_{sm}	Magnetization per unit mass
MSS	Multisample sintering
SSS	Single sample sintering
BaM	Barium hexaferrite
CoF	Cobalt ferrite
CoNiF	Cobalt nickel ferrite
T_s	Sintering temperature
T_c	Curie temperature
PVA	Polyvinyl Alcohol
Q_a	Activation energy
D_{RD}	Relative density
G	Grain size
HEBM	High Energy Ball Milling
SP	Superparamagnetic
SPM	Superparamagnetic material
MD	Multi-Domain
SD	Single-Domain
PSD	Pseudo Single-Domain
D	Diffusion
G	Grain size
r_p	Pore radius
ρ_{xrd}	XRD density
ρ_{exp}	Experimental density

CHAPTER 1

INTRODUCTION

1.1 Current trend of magnetic nanomaterials research

Magnetic materials nowadays have been of great interest for their technological applications. The changing of grain size would adjust magnetic properties of ferrite (Ismail et al., 2014). The systematic studies on the correlations between magnetic properties and microstructure evolution of ferrite will provide fundamental understanding of magnetic properties. This study is focused on investigating the underlying mechanisms and correlating these to changes in structure and magnetic properties of the ferrite as a function of processing characteristics, sintering route and initial state starting powders. In this study, we apply two routes of sintering known as single sample sintering (SSS) and multi sample sintering (MSS). SSS has one compaction of nanoparticles and one sintering route while the MSS has different sample compaction of nanoparticles and different routes of sintering. It should be carefully noted from the beginning that the MSS scheme yields evolution changes statistically assumed to occur subsequently after the previous lower temperature. However, the SSS scheme yields evolution changes which are tone, not statistically assumed, changes occurring after the previous lower temperature. This is because in the MSS scheme there is only one sintering temperature for each sample, which in the SSS scheme there is only one sample which goes through the entire sequence of sintering temperatures.

1.2 Scope of this study

In this study, we describe synthesis of hard magnetic material via mechanical alloying processing. The chosen of material are confined to hard magnetic materials which are probably representative of hard magnetic ceramics. The all-important crystal structure, microstructure and the major hysteresis loop parameters of the materials are the main study focus in this work.

In particular, a considerable effort was made to understand the details of the evolution of microstructure and magnetic properties during the grain growth and subsequent sintering treatment. By studying the key mechanisms associated with the formation of grain evolution in the course of the sintering routes investigated in this work we hope to develop well-tailored and micro structurally guided approaches to the large scale production of ferrite magnetic material. However, very little attention has been paid to this aspect in the literature. Williamson-hall analysis adopted in this study for observing the nanoscale features such as strain broadening present inside the mechanically alloyed powder particles.

1.3 Problem Statement

The control of the magnetic properties relies on the control of the microstructure development in sintering. To control the microstructure development, the understanding of the relation between densification, grain and pore growth is clearly necessary. Thus, to have a good understanding of the behavior of ferrites, it is imperative to perform systematic investigations of their properties, in particular, the microstructural evolution during sintering (or their densification and grain growth). The microstructures developed during sintering are determined to a large extent by the powder characteristics (crystallite size and shape, size distribution, porosity, state of agglomeration, and chemical and phase composition) and by the green microstructure, which are intimately related to the processing method. The effects of these parameters on the microstructural evolution are reported and qualitatively discussed in terms of the densification and grain growth kinetics.

The investigations of the sintering phenomena are mainly concentrated on densification and microstructure development of ferrites. Although the densification process is one of the main phenomena in the sintering process, however, coarsening process, involving grain growth, pore growth, and diminution, is also an important process in sintering, and more importantly, the coarsening process will affect the densification. Therefore, in order to understand the sintering process well, the relationship between the densification and the growth of pore and grain should also be understood. To understand it, in this study we provide knowledge to answer the composition-microstructure relationships at various intermediate sintering conditions during the parallel evolutions of the morphology and the material properties. We also attempt to answer the following questions; do the changes of microstructure affect the magnetic properties? What would the magnetic properties evolve with the microstructure changes? what would happen to the ions of the materials during and parallel to the microstructure changes? do they also rearrange to contribute to magnetization of the materials?

1.4 Objectives

Based on reviews throughout publication from other researchers, no studies on the detail magnetic-properties relationship in barium hexaferrites, cobalt ferrite and cobalt nickel ferrite synthesized by mechanical alloying method have been carried out. The ultimate goal of this research is to critically track the evolution of magnetic properties parallel to the microstructural changes. Our objective in this study is to understand the evolution of magnetic properties parallel to the microstructural changes. The specific objectives are:

1) To prepare $BaFe_{12}O_{19}$, $CoFe_2O_4$ and $Co_{0.5}Ni_{0.5}Fe_2O_4$ prepared by mechanical alloying process.
2) To study the evolution of magnetic properties with microstructure changes involving mechanical alloying effect.
3) To study microstructure changes arising from mechanical alloying effects.

4) To study the effect of the sintering route on the microstructural evolution and magnetic properties of $BaFe_{12}O_{19}$, $CoFe_2O_4$ and $Co_{0.5}Ni_{0.5}Fe_2O_4$ ferrites.
5) To study the influence of microstructural changes of magnetic properties when the cobalt in cobalt ferrite is partially substituted by a partially nickel amount.

1.5 Significant of Study

Ferrite materials are known to provide the best combination of magnetic properties necessary for applications in the magnet industry. High performance ferrites materials, offering a high magnetization with a large H_c, exhibit outstanding magnetic behavior at room temperature. $BaFe_{12}O_{19}$, $CoFe_2O_4$ and $Co_{0.5}Ni_{0.5}Fe_2O_4$ materials have become the ideal candidates, as they possess a many applications nowadays. These materials are characterized by the relation magnetic-microstructure evolution, which bears the fundamental importance for structural and magnetic properties. Presently, the preparation and production of these materials are generally not yet fully systematic.

Thus, the enhancement of magnetic properties can be tailored by systematically controlling the sintering process through microstructural modifications, which depend on the formation of the specific atomic sublattices governed by establishment of the proper phase relationship in the materials systems. A lack of fundamental understanding of phase formation in the ferrite material with respect to temperature is a detriment to magnetic materials research and is a driving force for this work.
In this thesis we will derive the sintering path beginning with phenomena that happen in mechanical alloying related to strains as discussed using the Williamson-hall plot, diffusion mechanism by introducing activation energy, magnetic properties detailed behavior as exhibited by M-H (fundamental study) and B-H (potential practical study) loops and the trajectory path in sintering as explained by the regression coefficient of relative density. Finally the conclusions are based on the data analysis.

1.6 Thesis Outline

Chapter 1 introduces the objectives of the thesis, summarizes the main contributions, and outlines the thesis arrangement. Chapter 2 describes different experimental techniques used in these studies and microstructure-evolution study by other researchers. Chapter 3 discusses the basic theories as they affect ferrites and sintered materials. Specifically, the chapter reports the fundamentals of magnetization, the chemistry of spinel and hexagonal ferrites, sintering parameters and the mechanical alloying process. In Chapter 4, the characteristics measurement of the as-prepared ferrite and sintered ferrite is described. The discussion of the results obtained for the as-prepared ferrites and the microstructure-magnetic properties forms chapter five. Chapter 5 covers the discussion of the results obtained of the as-prepared ferrites and the microstructure-magnetic properties. Chapter 6 summarizes and concludes the research findings, in addition to some suggested recommendations. A list of the author’s publications is attached at the end of the thesis, sequentially preceded by the author’s biography appendices and references/bibliographies.

REFERENCES

A. Broese Van Groenou, P. F. Bongers, a. L. S. (1968). Review Paper Magnetism , Microstrueture and Crystal Chemistry of Spinel Ferrites. *Material Science Engineering*, *3*, 317–392.

Alarifi, a., Deraz, N. M., & Shaban, S. (2009). Structural, morphological and magnetic properties of NiFe2O4 nano-particles. *Journal of Alloys and Compounds*, *486*, 501–506. doi:10.1016/j.jallcom.2009.06.192

Andres, R. P., Averback, R. S., Brown, W. L., Brus, L. E., Goddard, W. a., Kaldor, A., … Wang, Y. (1989). Research opportunities on clusters and cluster-assembled materials—A Department of Energy, Council on Materials Science Panel Report. *Journal of Materials Research*, *4*(3), 704–736. doi:10.1557/JMR.1989.0704

B. Parvatheeswara Rao, K. H. R. (1997). Effect of sintering conditions on resistivity and dielectric properties of Ni – Zn ferrites. *Journal of Materials Science*, *2*, 6049–6054. doi:10.1109/CEIDP.1999.804648

B.H.Liu, J.Ding, Z.L.Dong, C.B.Boothroyd, J.H.Yin, J. B. Y. (2006). Microstructural evolution and its influence on the magnetic properties of CoFe2O4.pdf. PHYSICAL REVIEW B.

Bahmanrokh, G., Hashim, M., Ismail, I., Soltani, N., Vaziri, P., Shafie, M. S. E., & Navaseri, M. (2013). A simple method for measuring intrinsic blocking temperature in superparamagnetic nanomaterials. *Journal of Superconductivity and Novel Magnetism*, *26*(2), 407–414. doi:10.1007/s10948-012-1742-7

Bahmanrokh, G., Hashim, M., Matori, K. A., Navasery, M., Soltani, N., Bahmanrokh, G., … Navasery, M. (2014). Recording-media-related morphology and magnetic properties of crystalline CoPt3 and CoPt3-Au core-shell nanoparticles synthesized via reverse microemulsion Recording-media-related morphology and magnetic properties of crystalline CoPt 3 and CoPt 3 -Au cor. *Journal of Applied Physics*, *093907*. doi:10.1063/1.4894154

Barba, A., Clausell, C., & Felı, C. (2004). Sintering of (Cu0.25Ni0.25Zn0.50)Fe2O4 Ferrite. *Journal of American Ceramic Society*, *77*, 571–577.

Barba, Antonia, Clausell, Carolina, Feliu, Carlos, Monzo , Maria, Nunu, Luis, Heras, Delia, Balbastre, J. V. (2004). Study of NiZn Ferrite Permeability:Effect of relative Density and Microstructure. *Journal of American Ceramic Society*, *1318*, 1314–1318.

Batlle, X. (2002). Finite-size effects in fine particles : *Journal of Physics D: Applied Physics*, *15*.

Bawa Waje, S., Hashim, M., & Ismail, I. (2011). Effects of sintering temperature on grain growth and the complex permeability of Co0.2Ni0.3Zn0.5Fe 2O4 material prepared using mechanically alloyed nanoparticles. *Journal of Magnetism and Magnetic Materials*, *323*(11), 1433–1439. doi:10.1016/j.jmmm.2010.12.032

Bellad, S. S., Watawe, S. C., & Chougule, B. K. (1999). Microstructure and permeability studies of mixed Li-Cd ferrites. *Journal of Magnetism and Magnetic Materials*, *195*(November 1998), 57–64. doi:10.1016/S0304-8853(98)01073-7

Benito, G., Morales, M. P., Requena, J., Raposo, V., Vázquez, M., & Moya, J. S. (2001). Barium hexaferrite monodispersed nanoparticles prepared by the ceramic method. *Journal of Magnetism and Magnetic Materials*, *234*, 65–72. doi:10.1016/S0304-8853(01)00288-8

Bernard-Granger, G., Monchalin, N., & Guizard, C. (2007). Sintering of ceramic powders: Determination of the densification and grain growth mechanisms from the “grain size/relative density” trajectory. *Scripta Materialia*, *57*, 137–140. doi:10.1016/j.scriptamat.2007.03.030

Bhosale, D. N., Choudhari, N. D., Sawant, S. R., & Bakare, P. P. (1997). Initial permeability studies on high density Cu□Mg□Zn ferrites. *Journal of Magnetism and Magnetic Materials*, *173*, 51–58. doi:10.1016/S0304-8853(97)00178-9

Bhosale, D. N., Verenkar, V. M. S., Rane, K. S., Bakare, P. P., & Sawant, S. R. (1999). Initial susceptibility studies on Cu-Mg-Zn ferrites. *Materials Chemistry and Physics*, *59*, 57–62. doi:10.1016/S0254-0584(99)00028-0

Bid, S., & Pradhan, S. K. (2003). Preparation of zinc ferrite by high-energy ball-milling and microstructure characterization by Rietveld’s analysis. *Materials Chemistry and Physics*, *82*, 27–37. doi:10.1016/S0254-0584(03)00169-X

Biju, V., Sugathan, N., Vrinda, V., & Salini, S. L. (2008). Estimation of lattice strain in nanocrystalline silver from X-ray diffraction line broadening. *Journal of Materials Science*, *43*, 1175–1179. doi:10.1007/s10853-007-2300-8

Billas, I. M., Châtelain, a, & de Heer, W. a. (1994). Magnetism from the atom to the bulk in iron, cobalt, and nickel clusters. *Science (New York, N.Y.)*, *265*(September), 1682–1684. doi:10.1126/science.265.5179.1682

Bonetti, E., Campari, E. G., Del Bianco, L., Pasquini, L., & Sampaolesi, E. (1999). Mechanical behaviour of nanocrystalline iron and nickel in the quasi-static and low frequency anelastic regime. *Nanostructured Materials*, *11*(6), 709–720. doi:10.1016/S0965-9773(99)00359-1

Bonetti, E., Del Bianco, L., Signoretti, S., & Tiberto, P. (2001). Synthesis by ball milling and characterization of nanocrystalline Fe3O4 and Fe/Fe3O4 composite system. *Journal of Applied Physics*, *89*(2001), 1806–1815. doi:10.1063/1.1339855

Bueno, A. R., Gregori, M. L., & Nóbrega, M. C. S. (2007). Effect of Mn substitution on the microstructure and magnetic properties of Ni0.50−xZn0.50−xMn2xFe2O4 ferrite prepared by the citrate–nitrate precursor method. *Materials Chemistry and Physics*, *105*(2-3), 229–233. doi:10.1016/j.matchemphys.2007.04.047

Buri, A. M. and A. (1978). Kinectics of Devitrification and Differential Thermal Analysis. *Thermochimica Acta*, *25*, 155–160.

Burton, B. (1972). Interface reaction controlled diffusional creep: A consideration of grain boundary dislocation climb sources. *Materials Science and Engineering*, *10*(3), 9–14. doi:10.1016/0025-5416(72)90060-2

C. Suryanarayana and C.C. Koch. (2000). Nanocrystalline materials – Current research and future Directions. *Hyperfine Interactions*, *130*, 5–44.

Cabañas, M. V., González-Calbet, J. M., & Vallet-Regí, M. (1994). Synthesis of barium hexaferrite by pyrolysis of an aerosol. *Journal of Materials Research*, *9*(3), 712–716. doi:10.1557/JMR.1994.0712

Calderer, J., Molinàs, P., Sueiras, J., Llobet, E., Vilanova, X., Correig, X., … Rodríguez, a. (2000). Synthesis and characterisation of metal suboxides for gas sensors. *Microelectronics Reliability*, *40*, 807–810. doi:10.1016/s0026-2714(99)00306-6

Carp, O., Barjega, R., Segal, E., & Brezeanu, M. (1998). Nonconventional methods for obtaining hexaferrites. *Thermochimica Acta*, *318*, 57–62. doi:10.1016/S0040-6031(98)00352-9

Chen, N., Yang, X., Liu, E., & Huang, J. (2000). Reducing gas-sensing properties of ferrite compounds M Fe 2 O 4 ž M s Cu , Zn , Cd and Mg /. *Sensors (Peterborough, NH)*, 178–180.

Chen, Z., & Gao, L. (2007). Synthesis and magnetic properties of CoFe2O4 nanoparticles by using PEG as surfactant additive. *Materials Science and Engineering B: Solid-State Materials for Advanced Technology*, *141*(3), 82–86. doi:10.1016/j.mseb.2007.06.003

Chinnasamy, C. N., Jeyadevan, B., Shinoda, K., Tohji, K., Djayaprawira, D. J., Takahashi, M., … Narayanasamy, a. (2003). Unusually high coercivity and critical single-domain size of nearly monodispersed CoFe2O4 nanoparticles. *Applied Physics Letters*, *83*, 2862–2864. doi:10.1063/1.1616655

Chinnasamy, C. N., Senoue, M., Jeyadevan, B., Perales-Perez, O., Shinoda, K., & Tohji, K. (2003). Synthesis of size-controlled cobalt ferrite particles with high coercivity and squareness ratio. *Journal of Colloid and Interface Science*, *263*, 80–83. doi:10.1016/S0021-9797(03)00258-3

Costa, a C. F. M., Tortella, E., Morelli, M. R., & Kiminami, R. H. G. a. (2003). Synthesis , microstructure and magnetic properties of Ni – Zn ferrites, *256*, 174–182.

Dadkhah, M., Jafari, M., & Saboori, A. (2012). The effects of Magnesia nano particles and Magnesium Carbonate on sintering behavior of nano alumina, *0*(0000).

Demczyk, B. G., & Artman, J. O. (2000). Magnetic properties of magnetron sputtered Co-Cr thin films. *Journal of Physics D: Applied Physics*, *24*, 1627–1632. doi:10.1088/0022-3727/24/9/016

Devan, R. S., Kolekar, Y. D., & Chougule, B. K. (2006). Effect of cobalt substitution on the properties of nickel–copper ferrite. *Journal of Physics: Condensed Matter*, *18*, 9809–9821. doi:10.1088/0953-8984/18/43/004

Dho, J., Lee, E. K., Park, J. Y., & Hur, N. H. (2005). Effects of the grain boundary on the coercivity of barium ferrite. *Journal of Magnetism and Magnetic Materials*, *285*, 164–168. doi:10.1016/j.jmmm.2004.07.033

Ding, J. (1995). Hexaferrite magnetic materials prepared by mechanical alloying. *Journal of Magnetism and Magnetic Materials*, *150*(95), 417–420. doi:10.1016/0304-8853(95)00279-0

Ding, J., Chen, Y. J., Shi, Y., & Wang, S. (2000). High Coercivity in SiO2-doped CoFe2O4 Powders and Thin Films. *Appl. Phys. Lett.*, *77*, 3621–3623. doi:10.1063/1.1328374

Ding, J., Street, R., & Nishio, H. (1996). ~ Jemmal of , M maderlals Magnetic properties of Ba- and Sr-hexaferrite prepared by mechanical alloying. *Journal of Magnetism and Magnetic Materials*, *164*, 385–389.

Doms, L., Van den Enden, L., & Geise, H. J. (1983). A comparative study of the structure of 2,3-dimethyl-2-butene. *Journal of Molecular Structure: THEOCHEM*. doi:10.1016/0166-1280(83)80131-6

Drofenik, M., Kristl, M., Žnidaršič, A., Hanžel, D., & Lisjak, D. (2007). Hydrothermal synthesis of Ba-hexaferrite nanoparticles. *Journal of the American Ceramic Society*, *90*, 2057–2061. doi:10.1111/j.1551-2916.2007.01740.x

Dutta, H., Sinha, M., Lee, Y. C., & Pradhan, S. K. (2007). Microstructure characterization and phase transformation kinetics of ball-mill prepared nanocrystalline Mg-Zn-ferrite by Rietveld's analysis and electron microscopy. *Materials Chemistry and Physics*, *105*, 31–37. doi:10.1016/j.matchemphys.2007.04.019

Eckert, J., Holzer, J. C., Krill, C. E., & Johnson, W. L. (1992). Reversible grain size changes in ball-milled nanocrystalline Fe–Cu alloys. *Journal of Materials Research*, *7*, 1980–1983. doi:10.1557/JMR.1992.1980

ElementsXRay.pdf. (n.d.).

Fang, Q. Q., Bao, H. W., Fang, D. M., Wang, J. Z., & Li, X. G. (2004). The effect of Zn-Nb substitution on magnetic properties of strontium hexaferrite nanoparticles. *Journal of Magnetism and Magnetic Materials*, *278*, 122–126. doi:10.1016/j.jmmm.2003.12.328

Franco, a., e Silva, F. C., & Zapf, V. S. (2012). High temperature magnetic properties of Co1-xMgxFe2O4 nanoparticles prepared by forced hydrolysis method. *Journal of Applied Physics*, *111*(2012), 07B530. doi:10.1063/1.3677923

G. Mendoza-Suarez, J.A. Matutes-Aquino, J.I. Escalante-Garcia, H. Mancha-Molinar,D. RmH os-Jara, K. K. J. (2001). Magnetic properties and microstructure of Ba-ferrite powders prepared by ball milling. *Journal of Magnetism and Magnetic Materials*, *223*, 55–62.

Gedam, N. N., Padole, P. R., Rithe, S. K., & Chaudhari, G. N. (2009). Ammonia gas sensor based on a spinel semiconductor, Co0.8Ni0.2Fe2O4 nanomaterial. *Journal of Sol-Gel Science and Technology*, *50*, 296–300. doi:10.1007/s10971-009-1942-1

George, M., Mary John, A., Nair, S. S., Joy, P. a., & Anantharaman, M. R. (2006). Finite size effects on the structural and magnetic properties of sol–gel synthesized NiFe2O4 powders. *Journal of Magnetism and Magnetic Materials*, *302*, 190–195. doi:10.1016/j.jmmm.2005.08.029

Globus, a., & Duplex, P. (1966). Separation of susceptibility mechanisms for ferrites of low anisotropy. *IEEE Transactions on Magnetics*, *2*(3). doi:10.1109/TMAG.1966.1065867

Globus, a., Duplex, P., & Guyot, M. (1971). Determination of initial magnetization curve from crystallites size and effective anisotropy field. *IEEE Transactions on Magnetics*. doi:10.1109/TMAG.1971.1067200

Globus, a., & Monjaras, R. (1975). Influence of the deviation from stoichiometry on the magnetic properties of Zn-rich NiZn ferrites. *IEEE Transactions on Magnetics*. doi:10.1109/TMAG.1975.1058826

Gómez, B., Gordo, E., & Torralba, J. M. (2006). Influence of milling time on the processing of Fe-TiCN composites. *Materials Science and Engineering A*, *430*, 59–63. doi:10.1016/j.msea.2006.05.051

Goodenough, J. B., & Loeb, a. L. (1955). Theory of ionic ordering, crystal distortion, and magnetic exchange due to covalent forces in spinels. *Physical Review*, *98*(2), 391–408. doi:10.1103/PhysRev.98.391

Gopal Reddy, C. V., Manorama, S. V., & Rao, V. J. (1999). Semiconducting gas sensor for chlorine based on inverse spinel nickel ferrite. *Sensors and Actuators, B: Chemical*, *55*, 90–95. doi:10.1016/S0925-4005(99)00112-4

Gopalan, E. V., Al-Omari, I. a., Kumar, D. S., Yoshida, Y., Joy, P. a., & Anantharaman, M. R. (2010). Inverse magnetocaloric effect in sol-gel derived nanosized cobalt ferrite. *Applied Physics A: Materials Science and Processing*, *99*, 497–503. doi:10.1007/s00339-010-5573-8

Goya, G. F., & Rechenberg, H. R. (1999). Ionic disorder and Néel temperature in ZnFe2O4 nanoparticles. *Journal of Magnetism and Magnetic Materials*, *196-197*, 191–192. doi:10.1016/S0304-8853(98)00723-9

Hadjipanayis, G. C. (1999). Nanophase hard magnets. *Journal of Magnetism and Magnetic Materials*, *200*(April), 373–391. doi:10.1016/S0304-8853(99)00430-8

Han, Y. H., Suh, J. J., Shin, M. S., & Han, S. K. (1997). The Effect of Sintering Conditions on the Power Loss Characteristics of Mn-Zn Ferrites for High Frequency Applications. *Journal De Physique*, *7*, 10–11.

Haque, M. M., Huq, M., & Hakim, M. a. (2008). Densification, magnetic and dielectric behaviour of Cu-substituted Mg-Zn ferrites. *Materials Chemistry and Physics*, *112*, 580–586. doi:10.1016/j.matchemphys.2008.05.097

He, Q., Wang, H. Z., Wen, G. H., Sun, Y., & Yao, B. (2009). Formation and properties of Ba x Fe 3 − x O 4 with spinel structure by mechanochemical reaction of ␣ -Fe 2 O 3 and BaCO 3. doi:10.1016/j.jallcom.2009.06.142

Hernando, a., & González, J. M. (2000). Soft and hard nanostructured magnetic materials. *Hyperfine Interactions*, *130*(1), 221–240. doi:10.1023/A:1011096522429

Hernando, a., & Kulik, T. (1994). Exchange interactions through amorphous paramagnetic layers in ferromagnetic nanocrystals. *Physical Review B*, *49*(10), 7064–7067. doi:10.1103/PhysRevB.49.7064

Herzer, G. (1990). Grain Size Dependence of Coercivity and Permeability. *IEEE Transactions on Magnetics*.

Hesabi, Z. R., Simchi, a., & Reihani, S. M. S. (2006). Structural evolution during mechanical milling of nanometric and micrometric Al2O3 reinforced Al matrix composites. *Materials Science and Engineering A*, *428*, 159–168. doi:10.1016/j.msea.2006.04.116

Hu, G., Choi, J., Eom, C., Harris, V., & Suzuki, Y. (2000). Structural tuning of the magnetic behavior in spinel-structure ferrite thin films. *Physical Review B*, *62*(2), R779–R782. doi:10.1103/PhysRevB.62.R779

Huq, M. F., Saha, D. K., Ahmed, R., & Mahmood, Z. H. (2013). Ni-Cu-Zn Ferrite Research: A Brief Review. *Journal of Scientific Research*, *5*(2), 215–234. doi:10.3329/jsr.v5i2.12434

HYDROTHERMAL PROCESS INGS TO PRODUCE MAGNETIC PARTICULATES.pdf. (n.d.).

Ibrahim, I. R., Hashim, M., Nazlan, R., Ismail, I., Wan Ab Rahman, W. N., Abdullah, N. H., … Muhamad Zulkimi, M. M. (2014). Grouping trends of magnetic permeability components in their parallel evolution with microstructure in Ni0.3Zn0.7Fe 2O4. *Journal of Magnetism and Magnetic Materials*, *355*, 265–275. doi:10.1016/j.jmmm.2013.12.024

Ismail, I., & Hashim, M. (2012). Sintering temperature dependence of evolving morphologies and magnetic properties of Ni0.5Zn0.5Fe2O4 synthesized via mechanical alloying. *Journal of Superconductivity and Novel Magnetism*, *25*, 1551–1561. doi:10.1007/s10948-012-1468-6

Ismail, I., Hashim, M., Amin Matori, K., Alias, R., & Hassan, J. (2012). Dependence of magnetic properties and microstructure of mechanically alloyed Ni0.5Zn0.5Fe2O4 on soaking time. *Journal of Magnetism and Magnetic Materials*, *324*(16), 2463–2470. doi:10.1016/j.jmmm.2012.03.012

Ismail, I., Hashim, M., Ibrahim, I. R., Nazlan, R., Mohd Idris, F., Shafie, S. E., … Wan Rahman, W. N. (2013). Crystallinity and magnetic properties dependence on sintering temperature and soaking time of mechanically alloyed nanometer-grain Ni0.5Zn 0.5Fe2O4. *Journal of Magnetism and Magnetic Materials*, *333*, 100–107. doi:10.1016/j.jmmm.2012.12.047

Ismail, I., Hashim, M., Kanagesan, S., Ibrahim, I. R., Nazlan, R., Wan Ab Rahman, W. N., … Manap, M. (2014). Evolving microstructure, magnetic properties and phase transition in a mechanically alloyed Ni0.5Zn0.5Fe2O4 single sample. *Journal of Magnetism and Magnetic Materials*, *351*, 16–24. doi:10.1016/j.jmmm.2013.09.041

Ismail, I., Hashim, M., Matori, K. A., Alias, R., & Hassan, J. (2012). The transition from paramagnetic to ferromagnetic states as influenced by evolving microstructure of Ni 0.5Zn 0.5Fe 2O 4. *Journal of Superconductivity and Novel Magnetism*, *25*, 71–77. doi:10.1007/s10948-011-1201-x

Jahanbin, T., Hashim, M., Matori, K. A., & Waje, S. B. (2010). Influence of sintering temperature on the structural, magnetic and dielectric properties of Ni0.8Zn0.2Fe2O4 synthesized by co-precipitation route. *Journal of Alloys and Compounds*, *503*(1), 111–117. doi:10.1016/j.jallcom.2010.04.212

Jiang, H. G., Rühle, M., & Lavernia, E. J. (1999). On the applicability of the x-ray diffraction line profile analysis in extracting grain size and microstrain in nanocrystalline materials. *Journal of Materials Research*, *14*, 549–559. doi:10.1557/JMR.1999.0079

Kagotani, T., Fujiwara, D., Sugimoto, S., Inomata, K., & Homma, M. (2004). Enhancement of GHz electromagnetic wave absorption characteristics in aligned M-type barium ferrite Ba1−xLaxZnxFe12−x−y(Me0.5Mn0.5)yO19 (x=0.0–0.5; y=1.0–3.0, Me: Zr, Sn) by metal substitution. *Journal of Magnetism and Magnetic Materials*, *272-276*, E1813–E1815. doi:10.1016/j.jmmm.2003.12.878

Kale, a., Gubbala, S., & Misra, R. D. K. (2004). Magnetic behavior of nanocrystalline nickel ferrite synthesized by the reverse micelle technique. *Journal of Magnetism and Magnetic Materials*, *277*, 350–358. doi:10.1016/j.jmmm.2003.11.015

Kambale, R. C., Shaikh, P. a., Kamble, S. S., & Kolekar, Y. D. (2009). Effect of cobalt substitution on structural, magnetic and electric properties of nickel ferrite. *Journal of Alloys and Compounds*, *478*, 599–603. doi:10.1016/j.jallcom.2008.11.101

Kanagesan, S., Hashim, M., Jesurani, S., Kalaivani, T., Ismail, I., & Shafie, M. S. E. (2012). Particle morphology and magnetic properties of Ba0.5Sr0.5Fe12O19 powder calcined conventionally and by microwave heating. *Journal of Alloys and Compounds*, *543*, 49–52. doi:10.1016/j.jallcom.2012.07.118

Kanagesan, S., Jesurani, S., Velmurugan, R., Sivakumar, M., Thirupathi, C., & Kalaivani, T. (2012). Synthesis and magnetic properties of conventional and microwave calcined barium hexaferrite powder. *Journal of Materials Science: Materials in Electronics*, *23*(June), 635–639. doi:10.1007/s10854-011-0460-4

Kapse, V. D., Ghosh, S. a, Raghuwanshi, F. C., Kapse, S. D., & Khandekar, U. S. (2014). Talanta Nanocrystalline Ni 0 . 6 Zn 0 . 4 Fe 2 O 4 : A novel semiconducting material for ethanol detection. *Journal of Superconding and Novel Magnetism*, *78*, 1451–1462. doi:10.1016/j.talanta.2008.10.031

Kim, H. T., & Han, Y. H. (2004). Sintering of nanocrystalline BaTiO3. *Ceramics International*, *30*(December 2003), 1719–1723. doi:10.1016/j.ceramint.2003.12.141

Koch, C. C. (1997). Synthesis of nanostructured materials by mechanical milling: problems and opportunities. *Nanostructured Materials*, *9*, 13–22. doi:10.1016/S0965-9773(97)00014-7

Kodama, R., & Berkowitz, a. (1999). Atomic-scale magnetic modeling of oxide nanoparticles. *Physical Review B*, *59*(9), 6321–6336. doi:10.1103/PhysRevB.59.6321

Kodama, R., Makhlouf, S., & Berkowitz, a. (1997). Finite Size Effects in Antiferromagnetic NiO Nanoparticles. *Physical Review Letters*, *79*, 1393–1396. doi:10.1103/PhysRevLett.79.1393

Kolar, D. (2000). COMMISSION ON HIGH TEMPERATURE MATERIALS AND SOLID STATE CHEMISTRY * CHEMICAL RESEARCH NEEDED TO IMPROVE HIGH-TEMPERATURE PROCESSING OF ADVANCED CERAMIC MATERIALS (Technical Report) Chemical research needed to improve high-temperature processing of adva, *72*(8), 1425–1448.

Kou, X. C., Kronmüller, H., Givord, D., & Rossignol, M. F. (1994). Coercivity mechanism of sintered Pr17Fe75B8 and Pr17Fe53B30 permanent magnets. *Physical Review B*, *50*(6), 3849–3860. doi:10.1103/PhysRevB.50.3849

Krell, A., & Blank, P. (1996). The Influence of shaping method on the grain size dependence of strength in dense submicrometre alumina. *Journal of the European Ceramic Society*, *16*(11), 1189–1200. doi:10.1016/0955-2219(96)00044-1

Kronmüller, H., Durst, K.-D., & Sagawa, M. (1988). Analysis of the magnetic hardening mechanism in RE-FeB permanent magnets. *Journal of Magnetism and Magnetic Materials*, *74*(1988), 291–302. doi:10.1016/0304-8853(88)90202-8

Kulkarni, S. D., Deshpande, C. E., Shrotri, J. J., Gunjikar, V. G., & Date, S. K. (1989). Thermochemical characterization of ultrafine Sr-hexaferrite. *Thermochimica Acta*, *153*(4630), 47–61. doi:10.1016/0040-6031(89)85421-8

Lakshman, a, Rao, P. S. V. S., Rao, B. P., & Rao, K. H. (2005). Substituted Magnesium–Manganese Ferrites. *Journal of Physics D: Applied Physics*, *38*, 673–678. doi:10.1088/0022-3727/38/5/002

Lakshman, a., Rao, P. S. V. S., & Rao, K. H. (2004). Frequency dependence of initial permeability and magnetic loss factor of in3+ and Cr3+ substituted Mg-Mn ferrites. *Journal of Magnetism and Magnetic Materials*, *283*, 329–334. doi:10.1016/j.jmmm.2004.05.040

Lakshman, A., Rao, K. ., & Mendiratta, R. . (2002). Magnetic properties of In3+ and Cr3+ substituted Mg–Mn ferrites. *Journal of Magnetism and Magnetic Materials*, *250*, 92–97. doi:10.1016/S0304-8853(02)00359-1

Lee, J. G., Park, J. Y., & Kim, C. S. (1998). Growth of ultra-fine cobalt ferrite particles by a sol – gel method and their magnetic properties. *Journal of Materials Science*, *33*, 3965–3968. doi:10.1023/A:1004696729673

Lewis, J. a. (1997). Binder Removal From Ceramics. *Annual Review of Materials Science*, *27*, 147–173. doi:10.1146/annurev.matsci.27.1.147

Lisfi, a., & Williams, C. M. (2003). Magnetic anisotropy and domain structure in epitaxial CoFe2O4 thin films. *Journal of Applied Physics*, *93*(2003), 8143–8145. doi:10.1063/1.1541651

Lisjak, D., & Drofenik, M. (2007). The mechanism of the low-temperature formation of barium hexaferrite. *Journal of the European Ceramic Society*, *27*, 4515–4520. doi:10.1016/j.jeurceramsoc.2007.02.202

Liu, X., Wang, J., Gan, L. M., & Ng, S. C. (1999). Improving the magnetic properties of hydrothermally synthesized barium ferrite. *Journal of Magnetism and Magnetic Materials*, *195*, 452–459. doi:10.1016/S0304-8853(99)00123-7

Lu, K., & M. L. Sui. (1995). Thermal Expansion Behaviors in Nanocrystalline Materials With a Wide Size Range. *Acta Metall, Mater*, *43*(9), 3325 – 3332.

Maaz, K., Karim, S., Mashiatullah, a., Liu, J., Hou, M. D., Sun, Y. M., … Chen, Y. F. (2009). Structural analysis of nickel doped cobalt ferrite nanoparticles prepared by coprecipitation route. *Physica B: Condensed Matter*, *404*(21), 3947–3951. doi:10.1016/j.physb.2009.07.134

Mathe, V. L., & Sheikh, a. D. (2010). Magnetostrictive properties of nanocrystalline CoNi ferrites. *Physica B: Condensed Matter*, *405*(17), 3594–3598. doi:10.1016/j.physb.2010.05.047

Mathew, D. S., & Juang, R. S. (2007). An overview of the structure and magnetism of spinel ferrite nanoparticles and their synthesis in microemulsions. *Chemical Engineering Journal*, *129*, 51–65. doi:10.1016/j.cej.2006.11.001

Mekala, S. R., & Ding, J. (2000). Magnetic properties of cobalt ferrite / SiO 2 nanocomposite. *Journal of Alloys and Compounds*, *296*, 152–156.

Meyers, M. a., Mishra, a., & Benson, D. J. (2006). Mechanical properties of nanocrystalline materials. *Progress in Materials Science*, *51*, 427–556. doi:10.1016/j.pmatsci.2005.08.003

Mishra, D., Anand, S., Panda, R. K., & Das, R. P. (2004). Studies on characterization, microstructures and magnetic properties of nano-size barium hexa-ferrite prepared through a hydrothermal precipitation-calcination route. *Materials Chemistry and Physics*, *86*, 132–136. doi:10.1016/j.matchemphys.2004.02.017

Mohsen, Q. (2010). Barium hexaferrite synthesis by oxalate precursor route. *Journal of Alloys and Compounds*, *500*(1), 125–128. doi:10.1016/j.jallcom.2010.03.230

Moreno, N. O., Lopez, J. L., & Pfanes, H. (2001). Magnetic and structural properties of CoFe O thin " lms synthesized via a sol } gel process. *Journal of Magnetism and Magnetic Materials*, *230*, 1424–1425.

Mosleh, Z., Kameli, P., Ranjbar, M., & Salamati, H. (2014). Effect of annealing temperature on structural and magnetic properties of BaFe12O19 hexaferrite nanoparticles. *Ceramics International*, *40*(5), 7279–7284. doi:10.1016/j.ceramint.2013.12.068

Moulin, J., Champion, Y., Grenèche, J. M., & Mazaleyrat, F. (2003). Magnetic properties of MnZn ferrite with ultra-fine grain structure. *Journal of Magnetism and Magnetic Materials*, *254-255*, 538–540. doi:10.1016/S0304-8853(02)00858-2

Nakagawa, S., Sasaki, I., & Naoe, M. (2002). Magnetization processes of storage and back layers in double-layered perpendicular magnetic recording media observed using anomalous and planar Hall effects. *Journal of Applied Physics*, *91*(2002), 8354–8356. doi:10.1063/1.1456418

Nazarov, a. a., Romanov, a. E., & Valiev, R. Z. (1994). On the nature of high internal stresses in ultrafine grained materials. *Nanostructured Materials*, *4*(1), 93–101. doi:10.1016/0965-9773(94)90131-7

Nazionale, E., Atterniva, E., Ricerche, C., Casaccia, E., Nuovi, S., Nazionale, S. I., … Padova, I.-. (1998). Microstructural evolution of Al – Fe powder mixtures during high-energy ball milling, *3*, 2519–2527.

Nazlan, R., Hashim, M., Ibrahim, I. R., & Ismail, I. (2014). Dependence of magnetic hysteresis on evolving single-sample sintering in fine-grained yttrium iron garnet. *Journal of Superconductivity and Novel Magnetism*, *27*, 631–639. doi:10.1007/s10948-013-2328-8

Ng, W. K., Ding, J., Chow, Y. Y., Wang, S., & Shi, Y. (2000). A study on barium ferrite particles prepared by chemical coprecipitation. *Journal of Materials Research*, *15*(July), 2151–2156. doi:10.1557/JMR.2000.0310

Novák, P., & Rusz, J. (2005). Exchange interactions in barium hexaferrite. *Physical Review B*, *71*, 1–6. doi:10.1103/PhysRevB.71.184433

Pardavi-Horvath, M. (2000). Microwave applications of soft ferrites. *Journal of Magnetism and Magnetic Materials*, *215*, 171–183. doi:10.1016/S0304-8853(00)00106-2

Park, J. H., & Natesan, K. (1993). Oxidation of copper and electronic transport in copper oxides. *Oxidation of Metals*, *39*, 411–435. doi:10.1007/BF00664664

Patil, D. R., Lokare, S. a., Chougule, S. S., & Chougule, B. K. (2007). Dielectric and magnetic properties of xNiFe2O4+(1-x)Ba0.9Sr0.1TiO3 composites. *Physica B: Condensed Matter*. doi:10.1016/j.physb.2007.06.019

Petersson, A. (2004). Cemented Carbide Sintering : Constitutive Relations and Microstructural Evolution.

Pillai, V. (1995). Preparation of nanoparticles of silver halides, superconductors and magnetic materials using water-in-oil microemulsions as nano-reactors. *Advances in Colloid and Interface Science*, *55*, 241–269. doi:10.1016/0001-8686(94)00227-4

Polotai, A., Breece, K., Dickey, E., Randall, C., & Ragulya, A. (2005). A novel approach to sintering nanocrystalline barium titanate ceramics. *Journal of the American Ceramic Society*, *88*, 3008–3012. doi:10.1111/j.1551-2916.2005.00552.x

Pradhan, S. K., Bid, S., Gateshki, M., & Petkov, V. (2005). Microstructure characterization and cation distribution of nanocrystalline magnesium ferrite prepared by ball milling. *Materials Chemistry and Physics*, *93*, 224–230. doi:10.1016/j.matchemphys.2005.03.017

Pradhan, S. K., Sain, S., & Dutta, H. (2011). Microstructure Characterization of Nanocrystalline Magnesium Ferrite Annealed at Elevated Temperatures by Rietveld Method. *ISRN Ceramics*, *2011*, 1–8. doi:10.5402/2011/194575

Pullar, R. C. (2012). Hexagonal ferrites: A review of the synthesis, properties and applications of hexaferrite ceramics. *Progress in Materials Science*, *57*(7), 1191–1334. doi:10.1016/j.pmatsci.2012.04.001

Rafferty, a., Prescott, T., & Brabazon, D. (2008). Sintering behaviour of cobalt ferrite ceramic. *Ceramics International*, *34*, 15–21. doi:10.1016/j.ceramint.2006.07.012

Ragulya, a. V. (1998). Rate-controlled synthesis and sintering of nanocrystalline barium titanate powder. *Nanostructured Materials*, *10*(3), 349–355. doi:10.1016/S0965-9773(98)00075-0

Rajendran, M., Pullar, R. C., Bhattacharya, A. K., & Das, D. (2001). Magnetic properties of nanocrystalline CoFe2O4 powders prepared at room temperature: Variation with crystallite size. *Journal of Magnetism and Magnetic Materials*, *232*, 71–83. Retrieved from http://wrap.warwick.ac.uk/12036/

Rangappa, D., Naka, T., Ohara, S., & Adschiri, T. (2010). Preparation of Ba-hexaferrite nanocrystals by an organic ligand-assisted supercritical water Process. *Crystal Growth and Design*, *10*, 11–15. doi:10.1021/cg900941p

Rao, K. S., Kumar, a. M., Varma, M. C., Choudary, G. S. V. R. K., & Rao, K. H. (2009). Cation distribution of titanium substituted cobalt ferrites. *Journal of Alloys and Compounds*, *488*, 6–9. doi:10.1016/j.jallcom.2009.08.086

Sabbaghizadeh, R., Hashim, M., Gholamipour, R., Bahmanrokh, G., Shamsul, M., & Shafie, E. (2013). Influence of Annealing Temperature on the Magnetic Properties of Rapidly Quenched (Nd , Pr) 2 - (Fe , Co , Ga , Ti , C) 14 B / α - Fe Nanocomposite Ribbons. *Advances in Materials Science and Engineering*, *2013*, 2–7.

Sadhana, K., Praveena, K., Matteppanavar, S., & Angadi, B. (2012). Structural and magnetic properties of nanocrystalline BaFe12O19 synthesized by microwave-hydrothermal method. *Applied Nanoscience*, *2*, 247–252. doi:10.1007/s13204-012-0100-1

Sankaranarayanan, V. K., Pankhurst, Q. a., Dickson, D. P. E., & Johnson, C. E. (1993). An investigation of particle size effects in ultrafine barium ferrite. *Journal of Magnetism and Magnetic Materials*, *125*, 199–208. doi:10.1016/0304-8853(93)90838-S

Sato Turtelli, R., Atif, M., Mehmood, N., Kubel, F., Biernacka, K., Linert, W., … Sikora, M. (2012). Interplay between the cation distribution and production methods in cobalt ferrite. *Materials Chemistry and Physics*, *132*(2-3), 832–838. doi:10.1016/j.matchemphys.2011.12.020

Schrefl, T. (1994). Interactive and cooperative magnetization magnetic materials, *129*, 66–78.

Search, H., Journals, C., Contact, A., Iopscience, M., & Address, I. P. (2000). Contact us My IOPscience Magnetic properties of nanostructured ferrimagnetic zinc ferrite Magnetic properties of nanostructured ferrimagnetic zinc ferrite, *7795*.

Sedlar, M., & Pust, L. (1995). Preparation of cobalt doped nickel ferrite thin films on optical fibers by dip-coating technique. *Ceramics International*, *21*, 21–27. doi:10.1016/0272-8842(95)93267-7

Seip, C. T., Carpenter, E. E., O'Connor, C. J., John, V. T., & Li, S. L. S. (1998). Magnetic properties of a series of ferrite nanoparticles synthesized in reverse micelles. *IEEE Transactions on Magnetics*. doi:10.1109/20.706388

Shafie, M. S. E., Hashim, M., Ismail, I., Kanagesan, S., Fadzidah, M. I., Idza, I. R., … Sabbaghizadeh, R. (2014). Magnetic M – H loops family characteristics in the microstructure evolution of BaFe 12 O 19. *Journal of Materials Science: Materials in Electronics*, (25), 3787–3794. doi:10.1007/s10854-014-2090-0

Shang, H., Wang, J., & Liu, Q. (2007). Synthesis and characterization of nanocrystalline BaFe12O19 obtained by using glucose as a fuel. *Materials Science and Engineering A*, *456*, 130–132. doi:10.1016/j.msea.2006.12.011

Sharma, P., Rocha, R. a., de Medeiros, S. N., & Paesano, a. (2007). Structural and magnetic studies on barium hexaferrites prepared by mechanical alloying and conventional route. *Journal of Alloys and Compounds*, *443*, 37–42. doi:10.1016/j.jallcom.2006.10.022

Singh, M., & Sud, S. P. (2001). Controlling the properties of magnesium – manganese ferrites. *Materials Science and Engineering B*, *83*, 180– 184.

Singhal, S., Barthwal, S. K., & Chandra, K. (2007). Cation distribution in the nano size aluminium substituted cobalt ferrites using XRD, magnetic and M??ssbauer spectral studies. *Indian Journal of Pure and Applied Physics*, *45*, 821–825. doi:10.1016/j.jmmm.2006.03.023

Singhal, S., Bhukal, S., Singh, J., Chandra, K., & Bansal, S. (2011). Optical, X-ray diffraction, and magnetic properties of the cobalt-substituted nickel chromium ferrites (CrCo x Ni 1-x FeO 4, x = 0, 0.2, 0.4, 0.6, 0.8, 1.0) synthesized using sol-gel autocombu. *Journal of Nanotechnology*, *2011*. doi:10.1155/2011/930243

Singhal, S., & Chandra, K. (2007). Cation distribution and magnetic properties in chromium-substituted nickel ferrites prepared using aerosol route. *Journal of Solid State Chemistry*, *180*, 296–300. doi:10.1016/j.jssc.2006.10.010

Sivasankaran, S., Sivaprasad, K., Narayanasamy, R., & Iyer, V. K. (2010). Synthesis, structure and sinterability of 6061 AA100−x–xwt.% TiO2 composites prepared by high-energy ball milling. *Journal of Alloys and Compounds*. doi:10.1016/j.jallcom.2009.11.051

Sonal singhal, J.singh, S.K Barthwal, K. C. (2005). Preparation and characterization of nanosize silver anti. Journal of Solid Science Chemistry.

Stewart, S. J., Figueroa, S. J. a, Ramallo López, J. M., Marchetti, S. G., Bengoa, J. F., Prado, R. J., & Requejo, F. G. (2007). Cationic exchange in nanosized ZnFe2O4 spinel revealed by experimental and simulated near-edge absorption structure. *Physical Review B - Condensed Matter and Materials Physics*, *75*, 3–6. doi:10.1103/PhysRevB.75.073408

Su, H., Zhang, H., Tang, X., & Xiang, X. (2004). High-permeability and high-Curie temperature NiCuZn ferrite. *Journal of Magnetism and Magnetic Materials*, *283*, 157–163. doi:10.1016/j.jmmm.2004.05.017

Suryanarayana, C. (2001). Mechanical alloying and milling. *Progress in Materials Science*, *46*, 1–184. doi:10.1016/S0079-6425(99)00010-9

Suryanarayana, C. (2002). The structure and properties of nanocrystalline materials: Issues and concerns. *Jom*, *54*, 24–27. doi:10.1007/BF02709088

Suryanarayana, C., & Norton, M. G. (1998). X-ray Diffraction: A Practical Approach. *Microscopy and Microanalysis : The Official Journal of Microscopy Society of America, Microbeam Analysis Society, Microscopical Society of Canada*, *4*, 513–515. doi:10.1017/S143192769800049X

Suzuki, Y., van Dover, R., Gyorgy, E., Phillips, J., & Felder, R. (1996). Exchange coupling in single-crystalline spinel-structure (Mn,Zn)Fe2O4/CoFe2O4 bilayers. *Physical Review B*. doi:10.1103/PhysRevB.53.14016

Teixeira, A. M. R. D. F., Ogasawara, T., & Nóbrega, M. C. D. S. (2006). Investigation of sintered cobalt-zinc ferrite synthesized by coprecipitation at different temperatures: a relation between microstructure and hysteresis curves. *Materials Research*, *9*(3), 257–262. doi:10.1590/S1516-14392006000300003

Thang, P. D., Rijnders, G., & Blank, D. H. a. (2005). Spinel cobalt ferrite by complexometric synthesis. *Journal of Magnetism and Magnetic Materials*, *295*, 251–256. doi:10.1016/j.jmmm.2005.01.011

Topal, U., Ozkan, H., & Sozeri, H. (2004). Synthesis and characterization of nanocrystalline BaFe12O19 obtained at 850°C by using ammonium nitrate melt. *Journal of Magnetism and Magnetic Materials*, *284*, 416–422. doi:10.1016/j.jmmm.2004.07.009

Turilli, G., Paoluzi, a., Lucenti, M., & Pareti, L. (1992). Influence of the particle size and intrinsic magnetic characteristics on the coercivity of sintered magnets. *Journal of Magnetism and Magnetic Materials*, *104-107*, 1143–1144. doi:10.1016/0304-8853(92)90524-R

Upadhyay, C., Verma, H. C., & Anand, S. (2004). Cation distribution in nanosized Ni-Zn ferrites. *Journal of Applied Physics*, *95*(2004), 5746–5751. doi:10.1063/1.1699501

Varadinov, R., Nikolov, V., Peshev, P., Mitov, I., & Neykov, K. (1991). New solvents for the growth of substituted BaFe12O19 single crystals from high-temperature solutions. *Journal of Crystal Growth*, *110*, 763–768. doi:10.1016/0022-0248(91)90634-H

Venkateswarlu, K., Chandra Bose, a., & Rameshbabu, N. (2010). X-ray peak broadening studies of nanocrystalline hydroxyapatite by WilliamsonHall analysis. *Physica B: Condensed Matter*, *405*(20), 4256–4261. doi:10.1016/j.physb.2010.07.020

Verma, a, Goel, T. ., Mendiratta, R. ., & Alam, M. . (1999). Dielectric properties of NiZn ferrites prepared by the citrate precursor method. *Materials Science and Engineering: B*, *60*, 156–162. doi:10.1016/S0921-5107(99)00019-7

Verma, A., & Chatterjee, R. (2006). Effect of zinc concentration on the structural, electrical and magnetic properties of mixed Mn-Zn and Ni-Zn ferrites synthesized by the citrate precursor technique. *Journal of Magnetism and Magnetic Materials*, *306*, 313–320. doi:10.1016/j.jmmm.2006.03.033

Waje, S. B., Hashim, M., Yusoff, W. D. W., & Abbas, Z. (2010). X-ray diffraction studies on crystallite size evolution of CoFe2O4 nanoparticles prepared using mechanical alloying and sintering. *Applied Surface Science*, *256*, 3122–3127. doi:10.1016/j.apsusc.2009.11.084

Wang, H. Z., He, Q., Wen, G. H., Wang, F., Ding, Z. H., & Yao, B. (2010). Study of formation mechanism of barium hexaferrite by sintering curve. *Journal of Alloys and Compounds*, *504*, 70–75. doi:10.1016/j.jallcom.2010.05.050

Wang, J., Chen, Q., & Che, S. (2004). Magnetic properties in BaFe12O19 nanoparticles prepared under a magnetic field. *Journal of Magnetism and Magnetic Materials*, *280*, 281–286. doi:10.1016/j.jmmm.2004.03.045

Wang, L., & Li, F. S. (2001). K ssbauer study of nanocrystalline Ni } Zn ferrite. *Journal of Magnetism and Magnetic Materials*, *223*, 233–237.

Wang, X. H., Chen, P. L., & Chen, I. W. (2006). Two-step sintering of ceramics with constant grain-size, I. Y 2O 3. *Journal of the American Ceramic Society*, *89*, 431–437. doi:10.1111/j.1551-2916.2005.00763.x

Watawe, S. C., Sarwade, B. D., Bellad, S. S., Sutar, B. D., & Chaugule, B. K. (2000). Microstructure and magnetic properties of Li-Co ferrites, *65*, 173–177.

Williamson, G. ., & Hall, W. . (1953). X-ray line broadening from filed aluminium and wolfram. *Acta Metallurgica*, *1*, 22–31. doi:10.1016/0001-6160(53)90006-6

Y.c.Wang, J.Ding, J.B.Yi, B.H.Liu, T.Yu, Z. X. S. (2004). High-coercivity Co-ferrite thin films on „ 100…-SiO2 substrate.pdf. *Applied Physics Letters*, 84,2596 (2004).

Yongfei, W., Qiaoling, L., Cunrui, Z., & Hongxia, J. (2009). Preparation and magnetic properties of different morphology nano-SrFe12O19 particles prepared by sol-gel method. *Journal of Alloys and Compounds*, *467*, 284–287. doi:10.1016/j.jallcom.2007.12.037

Zhang, D. L. (2004). Processing of advanced materials using high-energy mechanical milling. *Progress in Materials Science*, *49*, 537–560. doi:10.1016/S0079-6425(03)00034-3

Zhang, H., Li, L., & Zhou, J. (2001). Low-Temperature Sintering, Densification, and Properties of Z-type Hexaferrite with Bi2O3 Additives. *Journal of the American …*, *94*, 2889–2894. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1151-2916.2001.tb01110.x/abstract

Zhang, H., Rong, C., Zhang, J., Zhang, S., & Shen, B. (2002). Coercivity of isotropic nanocrystalline Pr12Fe82B6 ribbons. *Physical Review B*, *66*, 1–5. doi:10.1103/PhysRevB.66.184436

Zhao, L., Yang, H., Zhao, X., Yu, L., Cui, Y., & Feng, S. (2006). Magnetic properties of CoFe2O4 ferrite doped with rare earth ion. *Materials Letters*, *60*, 1–6. doi:10.1016/j.matlet.2005.07.017

Zhao, W. Y., Zhang, Q. J., Li, L. C., & Guan, J. G. (2005). Microstructure and magnetic properties of non-stoichiometric M-type hexaferrite with barium surplus. *Journal of Magnetism and Magnetic Materials*, *295*, 21–27. doi:10.1016/j.jmmm.2004.12.034

Zhong, W., Ding, W., Zhang, N., Hong, J., Yan, Q., & Du, Y. (1997). Key step in synthesis of ultrafine BaFei2019 by sol-gel technique. *Journal of Magnetism and Magnetic Materials*, *168*, 196–202.

Zhou, B., Zhang, Y.-W., Yu, Y.-J., Liao, C.-S., Yan, C.-H., Chen, L.-Y., & Wang, S.-Y. (2003). Correlation between structure and intervalence charge-transfer transitions in nanocrystalline CoFe2-xMxO4 (M=Mn,Al,Sc) thin films. *Physical Review B*, *68*, 1–8. doi:10.1103/PhysRevB.68.024426

Zlatkov, B. S., Nikolic, M. V., Aleksic, O., Danninger, H., & Halwax, E. (2009). A study of magneto-crystalline alignment in sintered barium hexaferrite fabricated by powder injection molding. *Journal of Magnetism and Magnetic Materials*, *321*, 330–335. doi:10.1016/j.jmmm.2008.09.014

LIST OF PUBLICATIONS

Shafie, M. S. E., Hashim, M., Ismail, I., Kanagesan, S., Fadzidah, M. I., Idza, I. R., Sabbaghizadeh, R. (2014). Magnetic M – H loops family characteristics in the microstructure evolution of BaFe 12 O 19. *Journal of Materials Science: Materials in Electronics*, (25), 3787–3794.

Bahmanrokh, G., Hashim, M., Ismail, I., Soltani, N., Vaziri, P., **Shafie, M. S. E**., & Navaseri, M. (2013). A simple method for measuring intrinsic blocking temperature in superparamagnetic nanomaterials. *Journal of Superconductivity and Novel Magnetism*, *26*(2), 407–414.

Ismail, I., Hashim, M., Ibrahim, I. R., Nazlan, R., Mohd Idris, F., **Shafie, M. S. E**., Wan Rahman, W. N. (2013). Crystallinity and magnetic properties dependence on sintering temperature and soaking time of mechanically alloyed nanometer-grain Ni0.5Zn 0.5Fe2O4. *Journal of Magnetism and Magnetic Materials*, *333*, 100–107.

Kanagesan, S., Hashim, M., Jesurani, S., Kalaivani, T., Ismail, I., & **Shafie, M. S. E**. (2012). Particle morphology and magnetic properties of Ba0.5Sr0.5Fe12O19 powder calcined conventionally and by microwave heating. *Journal of Alloys and Compounds*, *543*, 49–52.

Sabbaghizadeh, R., Hashim, M., Gholamipour, R., Bahmanrokh, G., **Shamsul, M**., & Shafie, E. (2013). Influence of Annealing Temperature on the Magnetic Properties of Rapidly Quenched (Nd , Pr) 2 - (Fe , Co , Ga , Ti , C) 14 B / α -Fe Nanocomposite Ribbons. *Advances in Materials Science and Engineering*, *2013*, 2–7.

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