UNIVERSITI PUTRA MALAYSIA

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FSAS 2001 5

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DEVELOPMENT OF MnZn FERRITE AS A TRANSFORMER CORE MATERIAL FOR SWITCH-MODE POWER SUPPLIES (SMPS)

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Thesis Presented in Fulfilment of the Requirement for the Degree of Master of Science in the Faculty of Science and Environmental Studies
Universiti Putra Malaysia
July 2001

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

DEVELOPMENT OF MnZn FERRITE AS A TRANSFORMER CORE MATERIAL FOR SWITCH-MODE POWER SUPPLIES (SMPS)

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July 2001

Chairman: Associate Prof. Mansor Hashim, Ph.D.

Faculty: Science and Environmental Studies

In electronics, magnetic transformer using ferrite cores are widely applied. In the recent years the rapid growth in popularity of Switched Mode Power Supplies (SMPS) units has led to a corresponding demand for high frequency ferrite cored power transformer. The main motivation for using ferrite transformer cores is the dramatic reduction of eddy current losses when compared with traditional iron core transformer. This study has been carried out to improve processing and understand the loss mechanisms of manganese zinc (MnZn) ferrite to meet the SMPS requirements.

The preparation of the samples was typical for MnZn ferrite production utilizing wet method technique. The experimental work was divided into three parts namely the effect of composition, the effect of atmosphere control and the effect of additives.

The effect of composition showed that MnZn ferrite sample with chemical composition of $(MnO)_{0.335}(ZnO)_{0.130}$ $(Fe_2O_3)_{0.535}$ yield high initial permeability, μ_i values. The effect of controlling of the sintering atmosphere with the same composition did not achieve the desired result. μ_i dropped and Relative Loss Factor decreased. The effect of additives showed that In_2O_3 addition suppresed grain growth and V_2O_5 cause duplex structure, which is the main reason, the μ_i declined.

This can be concluded that to improve the magnetic characteristics is by controlling the microstructure by having an appropriate and proper controlling sintering scheme.

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

PENGHASILAN FERIT MnZn UNTUK TERAS TRANSFORMER BAGI BEKALAN KUASA MOD SUIS (BKMS)

Oleh

MASDHIAH MASPOL

Julai 2001

Pengerusi: **Prof. Madya Mansor Hashim, Ph.D.**

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Di dalam bidang elektronik, penggunaan teras transformer daripada bahan ferit telah diaplikasikan secara meluas. Pada tahun-tahun kebelakangan ini pertumbuhun mendadak oleh penggunaan Bekalan Kuasa Mod Suis (BKMS) telah menyebabkan permintaan yang tinggi dalam menghasilkan transformer berfrekuensi tinggi. Motivasi utama ialah transfomer ferit mampu mengurangkan kehilangan tenaga disebabkan arus pusar jika dibandingkan dengan transformer yang diperbuat daripada besi. Kajian ini dijalankan bertujuan memperbaiki kaedah pemprosesan dan mengkaji mekanisma kehilangan bagi memenuhi ciri-ciri yang diperlukan oleh mangan zink (MnZn) ferit bagi SMPS.

Penyediaan sampel-sampel MnZn ferit ialah dengan kaedah basah. Eksperimen yang dijalankan terbahagi kepada tiga bahagian iaitu kesan komposisi, kesan pengawalan atmosfera persinteran dan kesan bahan tambah.

Keputusan menunjukkan bahawa dengan sampel MnZn ferit berformula kimia $(MnO)_{0.335}(ZnO)_{0.130}(Fe_2O_3)_{0.535}$ memberikan nilai ketelapan awal, μ_i yang tinggi. Walaubagaimanapun kesan pengawalan atmosfera persinteran bagi sampel yang sama tidak menunjukkan hasil yang dikehendaki. μ_i menurun begitu juga dengan kehilangan. Kesan penambahan Indium menyekat pertumbuhan butiran manakala Vanadium menyebabkan kesan Dupleks yang menjadi sebab utama μ_i menurun.

Dengan ini dapat disimpulkan bahawa untuk memperbaiki hasil yang dikhendaki ialah dengan mengawal mikrostruktur melalui pengawalan kitaran persinteran yang sesuai dan betul.

ACKNOWLEDGEMENTS

First and foremost, I would like to extend my deepest praise to Allah s.w.t that has given me strength, determination and courage to complete my project.

I would like to extend my gratitude and indebtedness to my supervisor, Associate Professor Dr. Mansor Hashim for giving me this path to pursuit my knowledge of this technological ferrites. I would also like to express my sincere appreciation to Dr. Jumiah Hassan, Dr. Jamil Suradi and Dr. Azmi Zakaria for their valuable comments and suggestions of my work in this thesis.

I would like to thank the following person from Chemistry Department, En. Kamal Margona, En. Ismail Yassin and En. Abas Abdul Rahman for their kind assistance in apparatus set-up. I also wish to thank the staff from Physics Department who had rendered their help in various ways during my research work.

A special thanks goes to all my friends for their help, advice and support. Last but not least, to my family especially my parents for their loving and prayers in making this report succeed.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	cross sectional area, cm^2
a_o	grain diameter, microns
AC	alternating Current
B_s	saturation magnetization
B_r	remanent induction, remanence
d	density (g/cm^2)
DC	direct current
Do	outer diameter
Di	inner diameter
f	frequency (Hertz)
Fe	iron
H_c	coercive force
In	indium
K	temperature, Kelvin
Lp	parallel inductance
Mn	manganese
N_2	nitrogen
Np	number of turns in primary winding
Ns	number of turns in secondary winding
n	number of unpaired electrons in an atom
Oe	oersted
O_2	oxygen

PO_2	oxygen partial pressure
PVA	polyvinyl alcohol
Q	quality factor
R	resistance
RLF	relative loss factor
SEM	scanning electron microscopy
SMPS	switch-mode power supply
T_c	curie temperature
μ_o	permeability of free space
μ_i	initial permeability
μ'	real permeability
μ''	imaginary part of permeability
ρ	resistivity, Ohm-cm
XRD	x-ray diffraction
Zn	zinc

CHAPTER 1

INTRODUCTION

SMPS in General

The so-called Switch-Mode Power Supply (SMPS) is a class of power supply that is made up of switching stages to process electric power.

Switched Mode Power Supplies may have the combination of capacitor, filter (electromagnetic interference suppressor), rectifier, transformer, choke, diode and transistor to operate. Transformer core material was the object of study in this research.

Transformer as a Component of SMPS

The power transformers that transform the high frequency input voltage to the usable voltage are at the hearth of the SMPS system. The transformer is required to transform (reduce or increase) the mains AC voltage to a level that is better suited to the desired DC output voltage level and to provide electrical isolation between the input and output of the power supply.

Since 1970s, the 50 Hz linear power transformers with iron cores have been gradually replaced by low conductive ferrite. In this way a considerable size reduction of the magnetic core was realized to operate at higher frequencies. It was not until the 1980's that the advent of transistor-switched power supplies created a need for a ferrite material operating at much higher flux levels. The frequency range for early power ferrite was 16-25 kHz. During 1980-1984, the Switched-Mode Power Supply market grew very rapidly as did for power ferrite transformer. Now power supplies operating at 1 MHz and above are commercially available.

Basis of Work

In this project, MnZn ferrites has been selected as a material of study in the fabrication of transformer core for SMPS application because in power application, materials with large magnetic moments are needed. The magnetic metal ions with the most unpaired spins are chosen. Mn with electron configuration ([Ar] $3d^5$) gives MnZn ferrites $5\mu_B$ which is the highest magnetic moment measured among other ferrites. With this characteristic, MnZn ferrite has the ability to conduct high amplitude permeability, which is one of SMPS requirement other than high saturation flux density and low magnetic losses. The limitation of MnZn ferrites application at higher frequencies is because of its eddy current losses.

Because of the easy exchange valence ions, fabrications of MnZn ferrites need a very complicated task especially in the sintering process. The problem encountered is a strict control of oxygen partial pressure while sintering; during soaking period and cooling cycle, because any non-equilibrium during this process will cause zinc losses and α-Fe_2O_3 precipitation together with β-Mn_2O_3, which cause inhomogeneities and stresses that will affect the desired magnetic properties.

Statement of Objectives

The objective of this project is to investigate whether varying the metal cations in a chemical composition, changing the sintering condition and study the effect of additives onto a MnZn ferrite specimens could improve a material having high magnitude of permeability and the reduction of the specific magnetic losses through the characterization of magnetic, electrical and microstructure properties.

The aim of this study is to obtain a MnZn ferrite properties appropriate for transformer for SMPS application, utilizing our scientific knowledge in Solid State Science and to have a reproducible material for industrial needs.

In this report, five chapters will be presented. A very general outline of this study to be carried out has been given. In Chapter II we will review some of the past results, which is relevant and be a helpful reference to the project. The basic theory for spinel ferrite and measurement involved will be given in Chapter III and the experimental details will be described in Chapter IV. The results obtained and conclusions will be discussed and presented in Chapter V.

CHAPTER II

LITERATURE REVIEW

Introduction

Since the need of transformer to be high permeability, any relevant studies that relate to this matter will be reviewed. The study of technique to be used and some results of the effect of Indium and Vanadium addition that will be helpful reference in this research will be given in this chapter.

Past Study

Other compositions of ferrites like NiZn and MgZn ferrite are usually sintered in air. Economos (1955) was the first who investigate effects of firing atmosphere of manganese ferrite. MnZn ferrites need a strict control of atmosphere during firing, because one reason is of the variable ion valency. In MnZn ferrite, the oxygen diffusion rates are still rapid enough during the first stages of the cool. It is still possible at that stage to control the oxidative state through the atmosphere to ensure that properties are not be destroyed by further oxidation or reduction during the cooling period. As it is further cooled, the possibilities of equilibration are reduced with the decreased diffusion rates. Thus a well controlled oxygen partial pressure (Po_2) in a Nitrogen (N_2) atmosphere is required.

This will refer to an equilibrium phase diagram of a MnZn ferrite shows a weight changes with oxygen as a function of atmosphere oxygen content and temperature for the system of $(MnO)_{0.268}(ZnO)_{0.183}(Fe_2O_3)_{0.549}$ (Slick, 1971). The diagram shows the importance of atmosphere on the oxidation state in the spinel phase and the hematite phase boundary. From this diagram, cooling will be exercise along an iso-composition line and then quickly cooling through the phase boundary at the lowest temperature when the kinetic are sluggish. This figures agrees well with the universal equilibrium atmosphere diagram first shown by Blank (1961) and working more detail by Morineau and Paulus (1975).

Properties Control

A several studies by researchers to improve properties of MnZn ferrites have been made. (Michalowsky et al, 1993) indicate that to gain high quality of MnZn ferrite, a precise control of the microstructure is required especially the grain size distribution, the chemical composition and the grain interfaces or grain boundaries.

(Rosales et al , 1995) found that to prepare high permeability of MnZn ferrites is very complicated task that homogeneity must be carefully monitored. It refers to the stoichiometry of composition through the whole specimen.