



UNIVERSITI PUTRA MALAYSIA

**EMI SUPPRESSION CHARACTERISTICS OF PURE
AND IMPURE Ni-Zn FERRITIES AND Mg-Zn FERRITIES**

EWE LAY SHENG

ITMA 2001 1

**EMI SUPPRESSION CHARACTERISTICS OF PURE AND IMPURE Ni-Zn
FERRITES AND Mg-Zn FERRITES**

By

EWELAY SHENG

**Thesis Submitted in Fulfilment of the Requirement for the Degree of Master
of Science in the Institution of Advance Material
Universiti Putra Malaysia**

November 2001



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

**EMI SUPPRESSION CHARACTERISTICS OF PURE AND IMPURE Ni-Zn
FERRITES AND Mg-Zn FERITES**

By

EWE LAY SHENG

November 2001

Chairman : Assoc. Prof. Dr. Mansor Hashim
Faculty : Institut Teknologi Maju

Electromagnetic Interference (EMI) is a wave pollution, which interrupts the functioning of electronic circuits. Therefore, EMI wave absorbing materials are needed to suppress the wave pollution. One of the best solutions to overcome this problem is by using ferrites as EMI suppressors. This work is hoped to give a better understanding on how the purity of constituent oxides affects the suppression capability of ferrites. Moreover, it is also hoped to contribute in understanding how a good EMI suppressor can be made. A total of 12 toroidal samples with the composition of $Ni_xZn_{1-x}Fe_2O_4$ and another 12 toroidal samples with the composition $Mg_xZn_{1-x}Fe_2O_4$ were prepared via the conventional ceramic processing method, where $x = 0.1, 0.15, 0.2, 0.25, 0.3, 0.35$. These samples were prepared to be ferrites with purities $\sim 99.99\%$ and $\leq 99.1\%$ which denoted pure and impure ferrites respectively. Subsequently, these samples were sintered in air at 1300°C . The measured parameters to study the magnetic properties were density, permeability, relative loss factor, impedance, resistivity, microstructure and XRD analysis. It was found that the overall magnetic properties for pure Ni-Zn Ferrites and Mg-Zn Ferrites were only slightly better than those of impure Ni-Zn



ferrites and Mg-Zn Ferrites; the parameter values did not differ very much. Therefore, it is more economic if the impure materials are used for ferrite production instead of pure materials, which are more expensive.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia bagi memenuhi keperluan ijazah Master Sains

CIRI-CIRI PENUMPASAN EMI FERIT Ni-Zn DAN Mg-Zn TULEN DAN KURANG TULEN

Oleh

EWE LAY SHENG

November 2001

Pengerusi :Prof. Madya Dr. Mansor Hashim
Fakulti :Institut Teknologi Maju

Inteferens electromagnet (EMI) adalah satu pencemaran gelombang yang mengganggu pengoperasian litar-litar elektronik. Oleh sebab itu, bahan penyerap gelombang EMI diperlukan untuk menumpaskan pencemaran ini. Salah satu cara penyelesaian untuk mengatasi masalah ini ialah dengan menggunakan ferit sebagai penumpas EMI. Projek ini diharapkan akan memberi pemahaman yang lebih baik bagaimana ketulenan oxida yang digunakan mempengaruhi keupayaan penumpasan ferit. Tambahan pula, ia juga diharapkan dapat menyumbang kepada pemahaman mengenai bagaimana suatu penumpas EMI yang baik dapat dihasilkan. Sejumlah 12 sampel toroid dengan komposisi $Ni_xZn_{1-x}Fe_2O_4$ dan juga 12 sampel toroid dengan komposisi $Mg_xZn_{1-x}Fe_2O_4$ telah disediakan dengan kaedah lazim pemprosesan seramik, di mana $x = 0.1, 0.15, 0.2, 0.25, 0.3, 0.35$. Sampel-sampel ini telah disediakan sebagai bahan ferit yang mempunyai ketulenan $\sim 99.99\%$ dan $\geq 99.1\%$ masing-masing dan ditandakan sebagai ferit tulen dan tidak tulen. Seterusnya, sampel-sampel ini

disinterkan dalam udara pada suhu 1300°C. Parameter yang diukur untuk mengkaji sifat magnet adalah ketumpatan, ketelapan, factor kehilangan relatif, impedans, kerintangan, analisis mikrostruktur dan XRD. Didapati bahawa secara keseluruhannya, sifat-sifat magnet bagi Ni-Zn Ferit and Mg-Zn Ferit yang tulen adalah hanya sedikit lebih baik daripada sifat-sifat magnet bagi Ni-Zn Ferit and Mg-Zn Ferit yang tidak tulen. Nilai yang diukur mempunyai perbezaan yang tidak banyak. Oleh itu, adalah lebih ekonomik jika bahan yang kurang tulen digunakan untuk menghasilkan penumpas jika dibandingkan dengan bahan tulen, yang lebih mahal.

ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge my supervisor, **Dr. Mansor Hashim**, for giving me the platform to pursue my studies and to give me the opportunity to explore my 'insights' of ferrite science, besides the constant support through out this work. I would also like to extend my sincere appreciation to all my supervisors, particularly Professor Kaida Khalid and Dr Jumiah Hassan for helping me during my studies.

Particular thanks are also owed to my parents, my sisters and my brother for their encouragement. I would like to thank Dr. Zolman, Norhana Yahya, Shidah, Zahi and others for helping me in every way throughout the course of this work.

Most importantly, I thank my husband for his rare kind of support and love.



TABLE OF CONTENTS

	Page
ABSTRACT	2
ABSTRAK	4
ACKNOWLEDGEMENTS	6
APPROVAL	7
DECLARATION	9
LIST OF TABLES	12
LIST OF FIGURES	14
LIST OF PLATES	16
LIST OF SYMBOLS & ABBREVIATIONS	18
 CHAPTER	
I	GENERAL INTRODUCTION
	Basic Concepts
	Ferrimagnetism
	Magnetic Soft Ferrites
	Magnetic Parameters
	EMI Suppression
	Material for EMI Suppression
	Type of EMI Suppressor
	The Basic and Objective of Work
	History and Future Trend in Ferrite Technology
II	LITERATURE REVIEW
	Introduction
	Some Aspects of EMI Suppression
	Some Aspects of NiZn-Based Ferrites
	Some Aspects of MgZn-Based Ferrites
	Microstructural Aspects of Ferrites
III	FERRITES CRYSTAL STRUCTURE AND PROPERTIES
	Basic Composition of Ferrite
	Ionic Charge Balance and Crystal Structure
	Site Preferences of the Ions
	Normal Spinels
	Inverse Spinel
	The Hysteresis (B-H) Loop



	Magnetic Properties of Ferrites	53
	Intrinsic Properties	54
	Extrinsic properties	57
IV	METHODOLOGY	
	Introduction	61
	Powder Preparation	61
	Weighing	64
	Blending	66
	Presintering	66
	Grinding	68
	Addition of Binder, Lubricant and ZnO	69
	Sintering	71
	Electrical Impedance Measurements	72
	Inductance of a Toroid	72
	Resistivity	74
	Relative Permeability, Relative Loss Factors, Curie Temperature	75
	Density	76
	Microstructure Analysis	77
V	RESULTS AND DISCUSSION	78
	Density	79
	Permeability	82
	Relative Loss Factor	89
	Resistivity	95
	Impedance	98
	Microstructure Analysis	102
	XRD Analysis	116
VI	CONCLUSION	121
	Suggestions	121
	BIBLIGRAPHY	123
	APPENDICES	130
	VITA	153



LIST OF TABLES

Table		Page
1.1	Saturation Flux Density, Resistivity for Several Magnetic Materials	21
1.2	Effective Bohr Magneton Numbers for Mostly Divalent and Trivalent Ions of the Iron Group	23
1.3	Number of Sessions and Papers on Power Ferrites at ICF Conference	26
1.4	Generators of Electromagnetic Inteference	30
1.5	The Types of Materials to Use Determined by Frequency of Interference	35
1.6	Production of Ferrite Powder	36
3.1	Intrinsic and Extrinsic Factors of ferrites	53
5.1	The Density of Pure and Impure Ni-Zn Ferrites and Mg-Zn Ferrites	130
5.2	The Permeability if Impure Ni-Zn Ferrites	131
5.3	The Permeability of Pure Ni-Zn Ferrites	132
5.4	The Permeability of Impure Mg-Zn Ferrites	133
5.5	The Perneability of Pure Mg-Zn Ferrites	134
5.6	The RLF of Impure Ni-Zn Ferrites	135
5.7	The RLF of Pure Ni-Zn Ferrites	136
5.8	The RLF of Impure Mg-Zn Ferrites	137
5.9	The RLF of Pure Mg-Zn Ferrites	138



5.10	The Resistivity of Pure and Impure Ni-Zn Ferrites and Mg-Zn Ferrites	139
5.11	The Impedance of Impure Ni-Zn Ferrites	140
5.12	The Impedance of Pure Ni-Zn Ferrites	141
5.13	The Impedance of Impure Mg-Zn Ferrites	142
5.14	The Impedance of Pure Mg-Zn Ferrites	143
5.15	Grain Size for Pure and Impure Ni-Zn Ferrites and Mg-Zn Ferrites	144



LIST OF FIGURES

Figure		Page
1.1	Schematic Representation of Magnetic Materials	24
3.1	Crystal Lattice of Spinel Structure	46
3.2	Gradual Change in Direction of Moments Inside a Domain Wall	50
3.3	Typical Hysteresis Loop of a Ferrite	51
3.4	Four Main Types of Hysteresis Loop	51
3.5	Curie Temperature	55
4.1	Flow Chart of Sample Preparation	63
4.2	Digital Balance	64
4.3	Electric Furnace	68
4.4	Sieve and Crush	69
4.5	Mould	70
4.6	Pressing Machine	70
4.7	Measurement of Impedance, Z , using Impedance Analyzer HP4195A	72
4.8	Toroid View	73
4.9	Impedance Analyzer (HP 4192A)	73
4.10	The Silver Coated Toroidal Sample in Resistivity Measurement	74
4.11	The Basic Circuit Configuration for Hysteresis Measurement	76
4.12	Density Measurement of the Archimedes Principle	77



5.1	Density of Pure and Impure Ferrites Pure	79
5.2	Density of Pure and Impure Mg-Zn Ferrites	80
5.3	Permeability (0-60000) vs. Frequency of Impure Ni-Zn Ferrite	82
5.4	Permeability (0-40) vs. Frequency of Impure Ni-Zn Ferrites	83
5.5	Permeability (0-9000) vs. Frequency of Pure Ni-Zn Ferrites	83
5.6	Permeability (0-45) vs. Frequency of Pure Ni-Zn Ferrites	84
5.7	Permeability (0-35) vs. Frequency of Impure Mg-Zn Ferrites	84
5.8	Permeability (0-35) vs. Frequency of Pure Mg-Zn Ferrites	85
5.9	RLF (0-60) vs. Frequency of Pure Ni-Zn Ferrites	89
5.1	RLF (0-60) vs. Frequency of Impure Ni-Zn Ferrites	90
5.11	RLF (0-60) vs. Frequency of Pure Mg-Zn Ferrites	90
5.12	RLF (0-60) vs. Frequency of Impure Mg-Zn Ferrites	91
5.13	Resistivity of Pure and Impure Ni-Zn Ferrites	95
5.14	Resistivity of Pure and Impure Mg-Zn Ferrites	95
5.15	Impedance vs. Frequency of Pure Ni-Zn Ferrites	98
5.16	Impedance vs. Frequency of Impure Ni-Zn Ferrites	99
5.17	Impedance vs. Frequency of Pure Mg-Zn Ferrites	99
5.18	Impedance vs. Frequency of Impure Mg-Zn Ferrites	100
5.19	XRD Patterns for Ferrites	117

LISTS OF PLATES

Plate		Page
1	S1 Pure (Ni-Zn Ferrites)	102
2	S2 Pure (Ni-Zn Ferrites)	103
3	S3 Pure (Ni-Zn Ferrites)	103
4	S4 Pure (Ni-Zn Ferrites)	104
5	S5 Pure (Ni-Zn Ferrites)	104
6	S6 Pure (Ni-Zn Ferrites)	105
7	S1 Impure (Ni-Zn Ferrites)	105
8	S2 Impure (Ni-Zn Ferrites)	106
9	S3 Impure (Ni-Zn Ferrites)	106
10	S4 Impure (Ni-Zn Ferrites)	107
11	S5 Impure (Ni-Zn Ferrites)	107
12	S6 Impure (Ni-Zn Ferrites)	108
13	M1 Pure (Mg-Zn Ferrites)	108
14	M2 Pure (Mg-Zn Ferrites)	109
15	M3 Pure (Mg-Zn Ferrites)	109
16	M4 Pure (Mg-Zn Ferrites)	110
17	M5 Pure (Mg-Zn Ferrites)	110
18	M6 Pure (Mg-Zn Ferrites)	111
19	M1 Impure (Mg-Zn Ferrites)	111



20	M2 Impure (Mg-Zn Ferrites)	112
21	M3 Impure (Mg-Zn Ferrites)	112
22	M4 Impure (Mg-Zn Ferrites)	113
23	M5 Impure (Mg-Zn Ferrites)	113
24	M6 Impure (Mg-Zn Ferrites)	114



LIST OF SYMBOLS AND ABBREVIATIONS

EMI	electromagnetic interference
H	applied field
μ_B	Bohr magneton
H_c	coercive force
A	cross sectional area
T_c	Curie temperature
ρ^*	density
f	frequency
γ	gyromagnetic ration
μ''	imaginary part of permeability or magnetic loss parameter
B	induction
L	inductance
μ_i	initial permeability
μ_B	Bohr magneton
D_i	inner diameter
σ	internal stress
l	length
$\tan\delta$	loss tangent
N	number of wire turns
D_o	outer diameter
μ_0	permeability of free space

PVA	polyvinyl alcohol
Q	quality factor
μ'	real part of permeability
RLF	relative loss factor
B_r	remanent induction
R	resistance
ρ	resistivity
B_s	saturated induction
M_s	saturation magnetization
T	temperature
Ω	Ohm
XRD	x-ray diffraction
W	weight
K	anisotropy constant
t	thickness

CHAPTER I

GENERAL INTRODUCTION

Oxide ceramics that exhibit ferrimagnetic behaviour play an important role in the electronics industry and are commonly known as ferrites. Today's technology of high frequency recording, power supplies, telecommunications, televisions and entertainment electronics would have been very different were it not for many useful properties of ferrites.

Ferrites are mixed metal oxides containing iron oxide as their main component. There are three classes of commercial ferrites, each one having a specific crystal structure. The first type is soft ferrites with cubic spinel structure such as NiZn-ferrites, MnZn-ferrites and MgMnZn- ferrites. The second type is soft ferrites with the garnet structure such as microwave ferrites and yttrium iron garnets. The third one is hard ferrites with the magnetoplumbite (hexagonal) structure such as Ba and Sr hexaferrites.

Like ferromagnetic materials, ferrimagnetic ceramics exhibit spontaneous magnetization in the absence of an external field, consist of self-saturated domains, and show the characteristic hysteresis behaviour (Cullity, 1972;Smit and Wijn, 1959;Heck, 1974). The major difference between these classes of materials (one primarily metals and the other ceramics) is that the resistivity of ferrites, depending on composition, is at least six to twelve orders of magnitude higher than that of ferromagnetic materials like permalloys and silicon irons. This has given ferrites a distinct advantage as



magnetic materials of choice in high frequency applications, although their saturation magnetization is approximately one fifth to one eighth that of silicon irons (Table 1.1). In addition, the crystal structures of ferrites are quite different depending on variations in their chemical compositions, giving the technologist access to a wide range of properties. Ceramic processing techniques allow the economic fabrication of devices in various shapes and sizes.

Table 1.1: Saturation flux density, resistivity, for several magnetic materials

Material	Flux density	Resistivity
Iron (100% Fe)	2.158	9.6×10^{-6}
Silicon-Iron (4% Si)	2	60×10^{-6}
Cobalt (99.95 % Co)	1.9	6.3×10^{-6}
Nickel (99.6 %)	0.608	8.7×10^{-6}
FeO.Fe ₂ O ₃	0.6	4×10^{-6}
MnO.Fe ₂ O ₃	0.52	10^4
NiO.Fe ₂ O ₃	0.35	8×10^5
CuO.Fe ₂ O ₃	0.17	10^5
MgO.Fe ₂ O ₃	0.14	10^7
MnZn Ferrite	0.4-0.63	10^2-10^3
NiZn Ferrite	0.3-0.4	10^6
MgMn Ferrite	0.06-0.22	10^4-10^6
MgZn Ferrite	0.24-0.27	10^7-10^8
BaO.6Fe ₂ O ₃	0.41	10^4-10^5
5Fe ₂ O ₃ .3Y ₂ O ₃ (YIG)	0.17	$10^{10}-10^{12}$

Data from various sources including Heck (1974), Landolt-Bornstein (1970). The high value of flux density for MnZn ferrite is quoted from Kugimiya and Hirota (1989)

Depending on their coercivity (H_c), ferrites are said to be either soft if $H_c \sim 1,000$ A/m⁻¹ or hard if $H_c > 10,000$ A/m⁻¹. Soft ferrites may be subdivided further into two categories, one suitable for nonmicrowave applications (frequency $\ll 100$ MHz), and the other suitable for microwave applications (frequency $\gg 100$ MHz).

This work focused primarily on soft ferrites used in EMI suppressor typically operating in the frequency range of 0.1 MHz to 250 MHz. A few basic concepts necessary to understand the behaviour of ferrimagnetic materials are described here.

Basic concepts

The magnetic properties of solids have their origin in the two types of electron motion, orbital and spin. Each has a magnetic moment associated with it. The fundamental quantity, the *Bohr magneton* μ_B , is a measure of the magnetic moment caused by the spin of the electron, and is equal to 1.1645×10^{-29} Vsm (Cullity, 1972).

The magnetic moment associated with orbital and spin motion is a vector quantity, parallel to the axis of spin and normal to the plane of orbit, respectively. The net magnetic moment of the atom, therefore, is the vector sum of all its electronic moments. In most magnetic materials containing elements of the first group of transition metals the resultant orbital moment of electrons is much smaller than the spin moment. A comparison between the calculated and experimental values of the net magnetic moments for several divalent and trivalent metal ions is shown in Table 1.2.



Table 1.2: Effective Bohr magneton numbers for mostly divalent and trivalent ions of the iron group

Ion	Configuration	Calculated	Experimental
Ti ³⁺ , V ⁴⁺	3d ¹	1.73	1.8
V ³⁺	3d ²	2.83	2.8
Cr ³⁺ , V ²⁺	3d ³	3.87	3.8
Mn ³⁺ , Cr ²⁺	3d ⁴	4.9	4.9
Fe ³⁺ , Mn ²⁺	3d ⁵	5.92	5.9
Fe ²⁺	3d ⁶	4.9	5.4
Co ²⁺	3d ⁷	3.8	4.8
Ni ²⁺	3d ⁸	2.83	2.8

Note: Values calculated as if the orbital moments were not there, Kittel (1969).

Ferrimagnetism

In metals such as iron, nickel, and cobalt (transition metals) having unfilled subvalence shells, the magnetic moments of the inner shell (the d shell) electrons remain uncompensated. This results in each atom acting as a small magnet. In addition, within each crystal the atoms are sufficiently close and the magnetic moments of individual atoms are sufficiently strong. This leads to strong positive quantum-mechanical exchange interaction and long range ordering of magnetic moments, which manifests itself as ferromagnetism. There are three conditions that must be met simultaneously before a substance shows ferromagnetic behavior (Heck, 1974):

- 1) There must be an unfilled electron shell within the atom.
- 2) There must be uncompensated electronics spins in this unfilled inner shell.
- 3) The ions of the atoms must form a crystal lattice having a lattice constant at least three times the radius of the unfilled electron shell.

If the adjacent moments are aligned antiparallel (Figure 1.1) as a result of strong negative interaction, and only one type of magnetic moment is present, the neighboring atomic moments cancel each other resulting in net zero magnetization. The material is

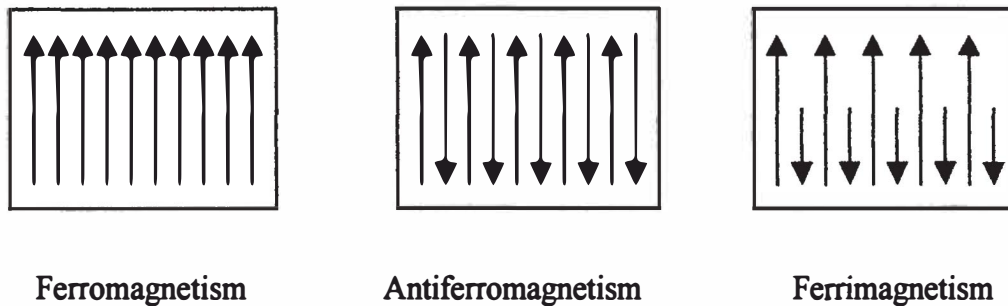


Figure 1.1: Schematic representation of magnetic moments

then said to exhibit antiferromagnetism. This situation can be interpreted as the result of simultaneous existence of two sublattices. A sublattice is a collection of all of the magnetic sites in a crystal with identical behavior, with all moments parallel to one another and pointing in the same direction, which are spontaneously magnetized and have the same intensity. Typical examples of antiferromagnetic materials are the metals Cr and α -Mn.

Sublattices (two or more) can also have spontaneous magnetizations in opposite directions but with different intensities. For instance, when a material contains magnetic ions of different species and magnetic moments, or of the same species occupying crystallographically inequivalent sites, the resultant moments of the sublattices lie parallel or antiparallel to one another and the dominant exchange interaction is mediated by the neighboring non-magnetic ions. Such materials have a spontaneous magnetization, which is weaker than in materials whose magnetic