UNIVERSITI PUTRA MALAYSIA

MAGNETIC CHARACTERISTICS AND MICROSTRUCTURE OF SOME FERRITE ANTENNA AND INDUCTOR CORES DOPED WITH Co, Ca, AND Si.

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By

LOH PIT MUI

Thesis Presented in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Science and Environmental Studies,
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DEDICATIONS

To my beloved father and mother,

LOH HIN
LIM KIM MOI

To my brother and sisters,

LOH PIK LAN
LOH SOON SENG
LOH PIT KHIM

To my dearest friend

LEE BOON KOK

and the members of Ferrite Group in UPM.

WITHOUT WHOSE LOVE AND CONTINUED SUPPORT THIS THESIS WOULD NOT HAVE BEEN POSSIBLE.

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H	applied field
μ_B	Bohr magneton
H_c	coercive force
A	cross-sectional area
T_c	curie temperature
ρ	density
f	frequency
μ"	imaginary part of permeability or magnetic loss
L	inductance
B	induction
μ_i	initial permeability
D_i	inner diameter
l	length
$\tan\delta$	loss tangent
μ_o	magnetic constant
H_{max}	magnetic field for effective saturated induction
N	no. of wire turns

D_o	outer diameter
PVA	polyvinyl alcohol
Q	quality factor
μ'	real part of permeability
RLF	relative loss factor
B_r	remanence
R	resistance
σ	resistivity
B_s	saturated induction
M_s	saturation magnetisation
SEM	scanning electron microscopy
T	temperature
α_L	temperature coefficient of inductance
$\alpha_{\mu i}$	temperature coefficient of initial permeability
T_o	temperature compensation point
t	thickness
K_t	total first anisotropy constant
W	weight
XRD	X-ray diffraction

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

MAGNETIC CHARACTERISTICS AND MICROSTRUCTURE OF SOME FERRITE ANTENNA AND INDUCTOR CORES DOPED WITH Co, Ca, AND Si.

By

LOH PIT MUI

March, 1996

Chairman : Dr. Mansor Hashim
Faculty : Science and Environmental Studies

This work gives accounts of an attempt to produce two types of commercial ferrite material whose magnetic characteristics were to be studied in relation to some additives and the microstructure. Two compositions, MgZn- and NiZn-based ferrites, were prepared by the oxide method and characterised mainly in terms of magnetic properties and microstructure. The former composition was to be used as the material for antenna bars and the latter for high-frequency inductors. The antenna material was shaped into bars and toroids while the inductor material into rectangular plates and toroids. The properties of the two compositions were investigated as functions of the amount of additives (CaO and SiO_2 and CoO). The influence of sintering temperature

and forming pressure on magnetic and mechanical properties and average grain size was also studied. The experimental investigation consists of three parts.

Firstly, various compositions of MgZn-based ferrites were prepared and the properties upgraded by suitable additions of CaO and SiO_2. The inexpensive raw material powder MgO was used to substitute NiO in a composition of commercial NiZn-based ferrite commonly used for antenna bars. A MgZn-ferrite composition with properties matching the commercial material's properties was successfully obtained.

Secondly, the effect of directly-added CoO to MgZn- and NiZn-based ferrites was studied. The addition of CoO for these two original compositions decreased the initial permeability and minimised the variation of initial permeability with temperature. However, the frequency range and the Curie temperature increased with the increase of CoO content. The variations of the properties as a function of the amount of CoO were discussed in terms of the contribution of Co^{2+} ions to magnetocrystalline anisotropy.

Thirdly, intentional changes of microstructure for both original compositions were made by varying the forming pressure and sintering temperature. No significant changes on magnetic and mechanical properties and microstructure were found with the increase of forming pressure. However, the average grain size increased with the sintering temperature, thus, influencing the magnetic and mechanical properties of the samples. The initial permeability increased linearly with grain size.

Abstrak tesis yang dikemukakan kepada Senat Universiti Pertanian Malaysia bagi memenuhi keperluan Izajah Master Sains.

CIRI MAGNET DAN MIKROSTRUKTUR BEBERAPA ANTENA DAN TERAS INDUKTOR FERIT YANG DIDOPKAN DENGAN Co, Ca, DAN Si.

oleh

LOH PIT MUI

Mac, 1996

Pengerusi : Dr. Mansor Hashim
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Penyelidikan yang dijalankan bertujuan untuk menghasilkan dua jenis bahan ferit komersil yang mana ciri-ciri pemagnetan dihubungkait dengan beberapa jenis bahan penambah dan mikrostruktur. Dua komposisi ferit, masing-masing berasaskan MgZn dan NiZn telah disediakan dengan menggunakan kaedah pengoksidaan dan penciriannya dilakukan berasaskan kepada ciri-ciri magnet dan mikrostruktur. Komposisi yang pertama digunakan sebagai bahan untuk bar antena dan komposisi yang kedua untuk induktor berfrekuensi tinggi. Bahan antena yang dikaji adalah dalam bentuk bar dan toroid, sementara bahan induktor berbentuk plat segiempat dan toroid. Ciri-ciri bagi kedua-dua komposisi telah dikaji berfungsikan peratusan bahan penambah (CaO dan SiO_2 serta CoO). Di samping itu, kesan suhu pensinteran dan

kesan tekanan terhadap ciri-ciri pemagnetan dan mekanikal serta purata saiz butiran juga telah dikaji. Penyelidikan terbahagi kepada tiga bahagian.

Pertama, beberapa komposisi ferit berasaskan MgZn telah disediakan dan ciri-ciri magnetnya telah dipertingkatkan dengan penambahan peratusan CaO dan SiO_2 yang sesuai. Bahan mentah yang murah, MgO, telah digunakan untuk menggantikan NiO dalam komposisi komersil ferit berasaskan NiZn yang biasanya digunakan untuk bar antena. Komposisi ferit MgZn dengan ciri-cirinya selaras dengan ciri-ciri bahan yang komersil telah berjaya diperolehi.

Kedua, kesan penambahan CoO secara langsung ke dalam ferit berasaskan MgZn and NiZn juga telah fahami. Penambahan CoO kepada kedua-dua komposisi asal telah menyebabkan penurunan ketelapan awal. Di samping itu, ia juga telah meminimakan perubahan ketelapan awal dengan pertambahan suhu. Walau bagaimanapun, julat frekuensi telah dilebarkan dan suhu Curie meningkat dengan pertambahan kandungan CoO. Perbezaan ciri-ciri ini telah dibincangkan dengan merujuk kepada sumbangan ion-ion Co^{2+} kepada ketakisotropan magnetohablur.

Ketiga, perubahan mikrostruktur telah sengaja dilakukan keatas kedua-dua komposisi yang asal dengan mengubah suhu pensinteran dan tekanan. Walau bagaimanapun tidak didapati perubahan yang bermakna terhadap ciri-ciri magnet dan mekanik serta mikrostruktur dengan pertambahan tekanan. Namun demikian, purata saiz butiran sampel-sampel bertambah dengan pertambahan suhu pensinteran dan sekaligus mempengaruhi ciri-ciri magnet dan mekanik. Ketelapan awal didapati meningkat secara linear dengan saiz butiran, seperti yang dijangka.

CHAPTER I

GENERAL INTRODUCTION

Oxide ceramics which exhibit ferrimagnetic behaviour play an important role in the electronics industry and are commonly known as ferrites. Ferrites are the mixed metal oxides containing iron oxide as their main component. There are three important classes of commercial ferrites, each one having a specific crystal structure: (1) soft ferrites with the cubic spinel structure such as MgZn and NiZn ferrites; (2) soft ferrites with the garnet structure such as the microwave ferrites, for example, yttrium iron garnet; and (3) hard ferrites with the magnetoplumbite (hexagonal) structure such as Ba and Sr hexaferrites. This work investigates some aspects of the magnetic behaviour and microstructure of some spinel ferrites intended for application as loop antenna cores and high-frequency telecommunication inductor cores.

Historical Overview

Magnetite or ferrous ferrite, a naturally-occurring ferrite, has been known since more than 2000 years ago (Ishino et al., 1987). However, only after the beginning of 20th century (Hilpert, 1909; Forestier, 1928), it was found that some ferrites composed of ferric oxide and another metal oxide showed ferromagnetic properties and the chemical composition of spinel ferrites was clarified. Soon after this, all of the spinel ferrites being used at the time had been developed based on this research.

In 1930s, the first practical ferrite application was in inductors used in inductance-capacitance filters in frequency division multiplex equipment (Kato et al., 1933; Kawai, 1934; Snoek, 1936 and 1947). The combination of high resistivity and good magnetic properties made these ferrites an excellent core material for these filters operating at 50-450 kHz. The large-scale introduction of the television in the 1950s was a major opportunity for the fledgling ferrite industry (Owens, 1956). Ferrite cores were the material of choice in television sets for the high-voltage transformer and the picture-tube deflection system. In the 1970s, ferrite cores were used widely in telecommunication equipment, main-frame computer memories, recording heads, etc. (Hirota et al., 1980). Since the early 1980s, ferrite cores have been used in high-frequency power supplies (Roess, 1982; Bracke, 1983).

Problems in Ferrite Application

Although it is now some decades since spinel ferrites debuted as an important new category of magnetic materials and have attained great commercial importance, it was not long before full-fledged research and development efforts were underway. Therefore, many difficulties have been found to beset the research works in obtaining desired ferrite products.

The chemical aspects of spinel ferrites such as compositional variability and amounts of impurities have long been studied by various workers (Goldman, 1990; Standley, 1972; Snelling, 1988). It has been reported that the amount of an element present in a ferrite composition may affect not only the intrinsic properties but also the microstructure. Thus, apparently, to produce a good-quality product, a specialised working knowledge of ceramic science is needed for a judicious and scientifically reasoned choice of starting constituents that could yield desired properties. The purity level of the raw materials must also be considered as an important basic condition which influences the desired final performance in terms of all the magnetic and electrical properties of the product. This is because the impurities present in the raw materials may have an effect on the properties of a ferrite (Drofenik et al., 1984).

Preparation of spinel ferrites with optimum properties is considered to be most difficult and complex. The main problems involved are due to the fact that most of the