A study of structural and electrical properties of Zinc Ferrite Ceramic

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Abstract

A Zinc ferrite sample with $ZnFe_2O_4$ chemical composition was synthesized in 1000℃ using conventional solid state synthesis method. X–ray diffraction (XRD), standing electron microscopy (SEM) and LCR meter were used for the characterization of the zinc ferrite nanoparticles. X–ray diffraction pattern indicated the formation of the cubic phase $ZnFe_2O_4$. SEM micrograph revealed different morphological features of obtained zinc ferrites. The dielectric properties of $ZnFe_2O_4$ ceramic were interpreted by means of C–f, D–f and Er–f characteristics using LCR meter.

Key Words: $ZnFe_2O_4$, XRD, SEM, LCR meter

Introduction

Ferrite magnetic materials are the most important materials in modern technology. Spinel ferrites with the general formula AB_2O_4 are very important magnetic materials because of their interesting magnetic and electrical properties with chemical and thermal stabilities. Ferrite has a cubic structure of normal spinel–type and is a soft magnetic n–type semiconducting material.

The metal spinel ferrites belong to the face centred (fcc) close packing structure of AB_2O_4 type. In the ferrite compounds, zinc ferrite ($ZnFe_2O_4$) exhibits superparamagnetic behavior and it has a potential application in many fields. Superparamagnetism is a form of magnetism which appears in small ferromagnetic or ferrimagnetic nanoparticles.

The properties of ferrites include high electrical resistivity and sufficiently low dielectric properties over a wide ranges of frequencies. The dielectric properties of ferrites according to several factors, such as method of preparation, heat treatment, sintering conditions, chemical composition, type of dopants and crystallite size. The electrical conductivity and dielectric behavior of spinel ferrites are very sensitive to the type of substituent and sintering conditions, such as temperature, time and heating rate.

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Experimental Details

$ZnFe_2O_4$ nanoparticles were prepared by means of solid-state reaction method. For preparing the $ZnFe_2O_4$ sample, pure ZnO and Fe_2O_3 were chosen as starting materials. After being weighted, these powder materials were mixed to form $ZnFe_2O_4$ 50g each with equal ratio in mass. This mixed powders were ground by an agate motor to obtain the homogeneous and fine powders. After being mixed, the powders were annealed at 1000℃ for 8h. After being annealed, the powder were ground again to get the fine powder. The phase identification of the samples was done by using X-ray diffraction technique and scanning electron microscopy. The powder sample of as-prepared zinc ferrite ($ZnFe_2O_4$) was made pellet by using SPECAC hydraulic press using 5 ton (~70MPa). After that it was annealed at 1000℃ for 3h. Frequency dependence of the dielectric properties of $ZnFe_2O_4$ ceramic were also studied.

Results and Discussions

The structure of zinc ferrite crystalline powders was analyzed by RIGAKU MULTIFLEX X-ray diffractometer using Ni filtered CuK_α radiation to analyze the dimensions or lattice parameters of those powders. The measurement was taken from 10° to 70° with 2θ diffraction angles. The basic ingradients were mixed and heat treated at 1000℃ for single phase $ZnFe_2O_4$. Thus, the information was revealed from the analysis of XRD data. Figure 4.1 showed the XRD patterns of $ZnFe_2O_4$ for heat treatment at 1000℃.

The collected XRD data of the diffraction angles (°), atomic spacing (Å), miller indices (hkl) and peak height (%) for identified peak are tabulated in Table (4.1).

The diffraction line of (311) plane is the highest in intensity. The plane (peak) is dominated on others peak. The maximum peak was roughly proportional to the ray intensity. In figure (4.1), XRD patterns were found to be consistent with that of standard $ZnFe_2O_4$ of cubic structure. The lattice parameters of the samples are evaluated by using crystal utility of the equation of

$$\frac{1}{d} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2} = \frac{4\sin^2\theta}{\lambda^2}$$

where, θ is the diffraction angle, (hkl) is the miller indices, a,b,c are the lattice parameters and λ is the wavelength of incident X-ray. The lattice parameters of the sample are obtained as a = b = c = 8.43 Å. The crystallite size of the sample was estimated by using the Scherrer formula,

$$t = \frac{0.9\lambda}{B\cos\theta}$$

where, t is the crystallite size (nm), λ is the wavelength of incident X-ray (Å), θ is diffraction angle of the peak under consideration at FWHM (°) and B is observed FWHM (radian). In this experiment, the FWHM of the strongest peak (I = 100%) of (311) plane in the collected XRD pattern was used to calculate the crystallite size. The crystallite size of the samples is obtained as 76.47 nm and it indicates that the sample was nanosized $ZnFe_2O_4$ material.

Table (4.1) XRD data of zinc ferrite powders

Sr No.	2θ (degree)	d (Å)	(h k l)	I (%)	FWHM	t (nm)
1.	18.23	4.86	111	7.7	0.13	60.49
2.	29.96	2.98	220	37.3	0.12	68.53
3.	35.27	2.54	311	100.0	0.11	76.48
4.	36.89	2.43	222	7.2	0.13	65.43
5.	42.86	2.11	400	17.9	0.11	79.76
6.	46.89	1.94	331	1.7	0.27	31.95
7.	53.15	1.72	422	9.4	0.18	50.19
8.	56.65	1.62	511	37.8	0.13	68.37
9.	62.20	1.45	440	32.6	0.13	71.37
10.	65.44	1.42	531	2.6	0.14	68.93
11.	66.46	1.40	442	2.0	0.50	18.99

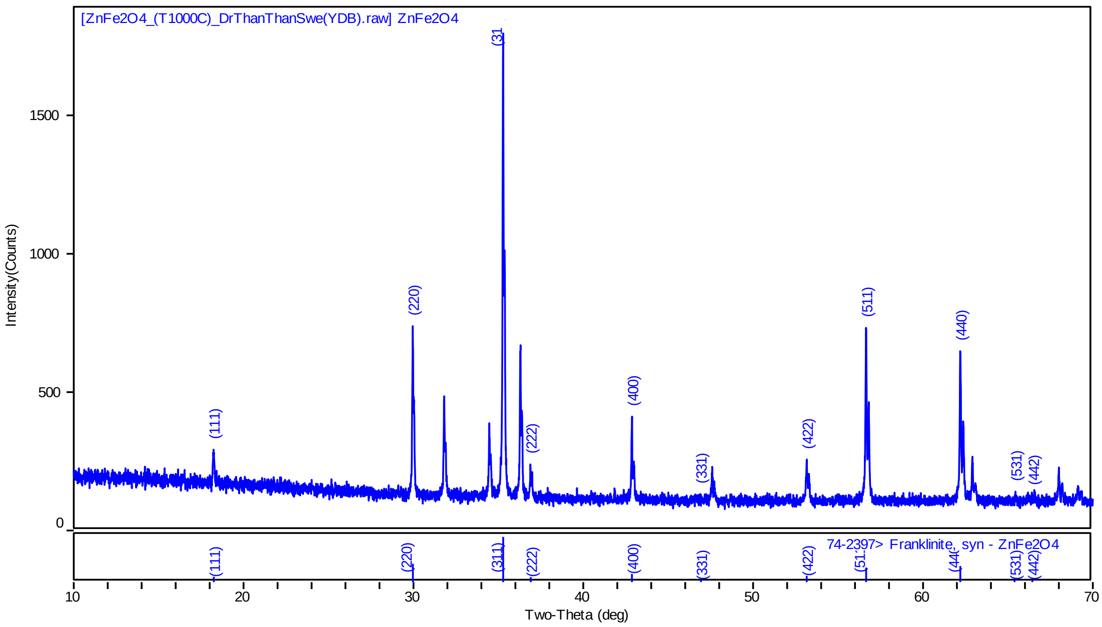

Figure (4.1) XRD pattern of $ZnFe_2O_4$ powders at 1000℃

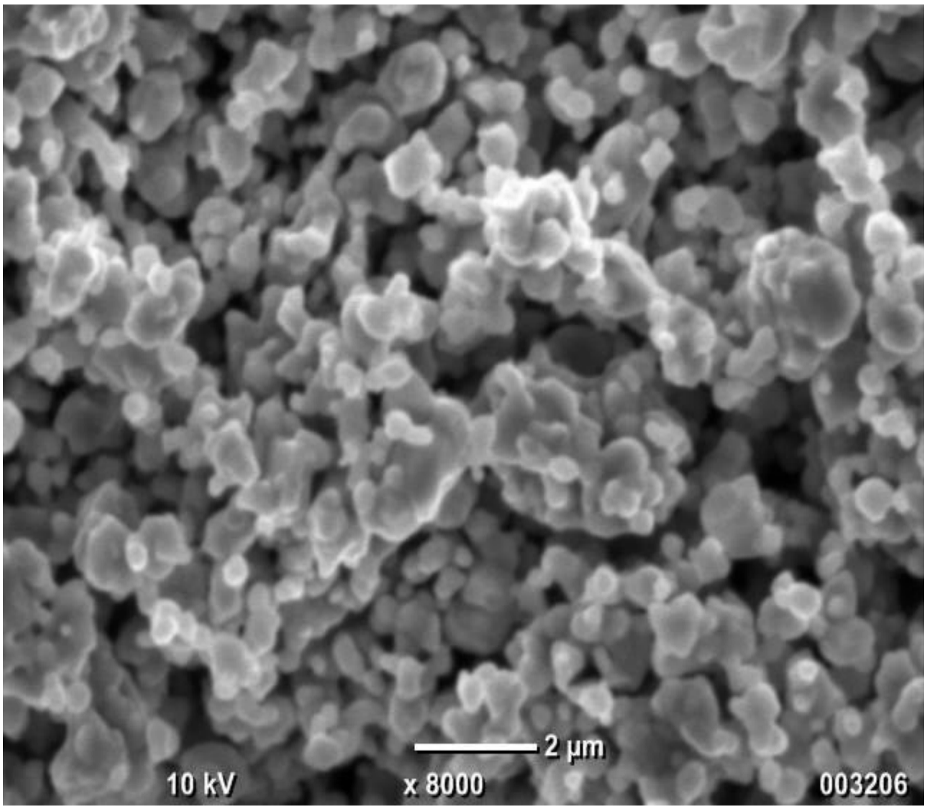

Figure (4.2) SEM micrograph for the studied sample.

Table (4.2) The values of capacitance, dissipation factor and dielectric constant for $ZnFe_2O_4$ ceramic

Frequency (kHz)	Capacitance (pF)	Dissipation factor	Dielectric constant
1	10.19	2.74	36.37
25	9.03	0.27	32.32
50	8.07	0.27	28.80
75	7.68	0.28	27.42
100	7.35	0.30	26.25

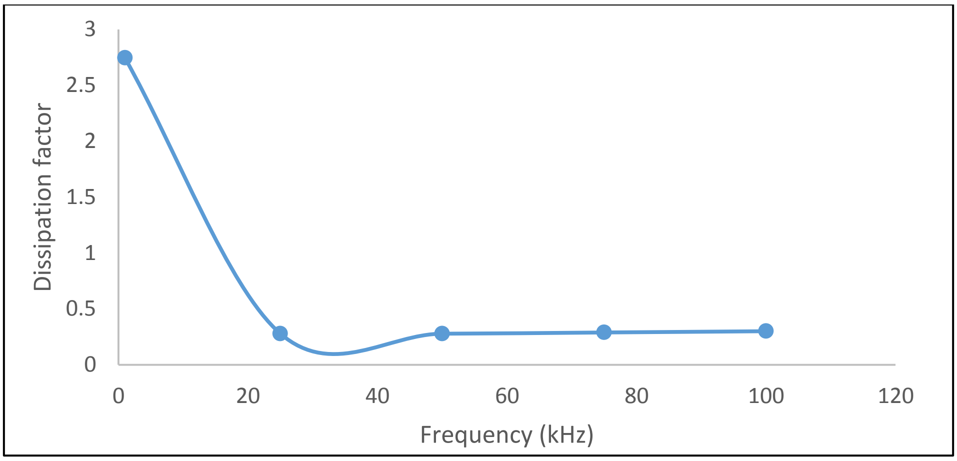

Figure (4.3) Dissipation factor versus frequency of $ZnFe_2O_4$ ceramic at 1000℃

Table (4.3) The values of resistance, resistivity and conductivity for $ZnFe_2O_4$ ceramic

Frequency (kHz)	Resistance (MΩ)	Resistivity (kΩm)	Conductivity (μSm^{-1})
1	5.23	169.83	6.03
25	2.49	79.04	12.65
50	1.41	44.72	22.35
75	0.95	30.36	32.93
100	0.72	22.90	43.66

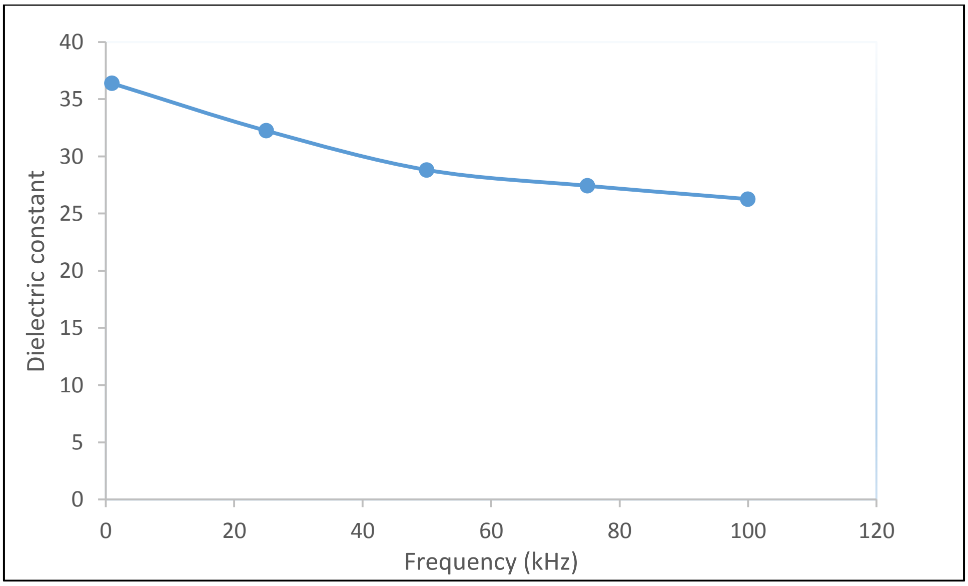

Figure (4.4) Dielectric constant versus frequency of $ZnFe_2O_4$ ceramic at1000℃

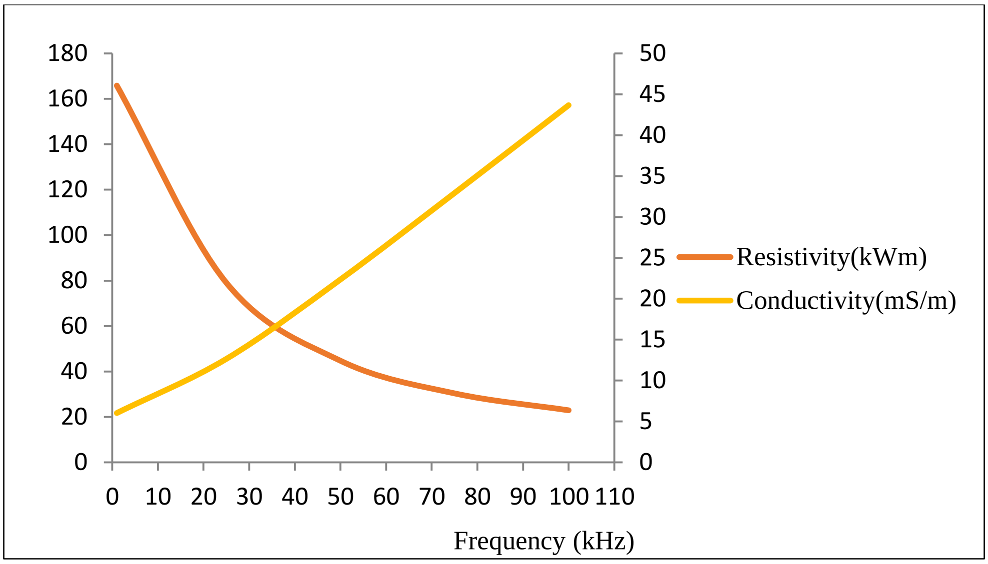

Figure (4.5) Resistivity and Conductivity versus frequency of $ZnFe_2O_4$ ceramic at 1000°C

Conclusion

Zinc Ferrite ($ZnFe_2O_4$) nanoparticles have been prepared by the use of solid state reaction method. Structural properties of the samples have been characterized by powder X-ray diffraction (XRD) method. This result obtained from the X-ray diffraction pattern, zinc ferrite powders are polycrystalline with a cubic structure and the lattice parameter 'a' was 8.43Å. The average crystallite size of the sample is obtained as about 60.04nm.

The surface morphology and microstructural properties of $ZnFe_2O_4$ powder were investigated using a Scanning Electron Microscopy (SEM). The surface was seen to be crack free and uniformly distributed. It was observed that some grains were separated by pores while others were distributed in continuity. The average grain size of $ZnFe_2O_4$ was found to be about 407.57 nm. It could be seen that the grain size of the sample was extremely fine. It was obvious that the grain distributed on the $ZnFe_2O_4$ powder was observed to be dense and smooth.

The dielectric properties of $ZnFe_2O_4$ nanoparticles were also studied. From capacitance frequency measurements, the values of capacitance decreased with the increase in frequency 1kHz to 100kHz. The variation of dissipation factor and dielectric constant decreased with the increase in frequencies. The resistivity decrease with the increase in frequencies and the conductivity increased with the increase in frequencies. $ZnFe_2O_4$ were suitable among several ferrite materials with good potentials for maximum frequency application.

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