



Dielectric Behavior of Dysprosium Substituted Magnesium Ferrite

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Abstract

Dysprosium substituted Magnesium ferrite were successfully prepared by chemical combustion method. The as synthesized powder was presintered in air at 600 °C for 1hr and finally sintered at 950 °C for 1hr. From X-ray powder diffraction pattern of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$, confirmed single phase structure. Crystalline size of synthesized material was obtained from X-ray powder diffraction (311) peak, it is found to be 46.38nm. The frequency and temperature variation of dielectric constant, dielectric loss and loss tangent were determined by using instrument Hioki LCR meter. The frequency variation of dielectric constant shows normal dielectric properties of ferrites. The loss tangent with frequency shows similar properties as dielectric constant.



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Introduction

Nanocrystalline ferrites have very good electric, dielectric and magnetic properties and number of applications from radio frequencies to microwave frequencies. The dielectric constant, dielectric loss, loss tangent and resistivity of ferrites are necessary to know for high frequency electrical applications¹. The properties of electrical insulating materials are depends upon preparation method, chemical composition and type of additives². Magnesium ferrite is a soft magnetic n - type semiconducting

material, have high Curie temperature, high resistivity and environmental stability; hence it is most suitable for sensing applications³. Magnesium ferrites are widely used as catalysts have many applications in adsorption sensors, electric and magnetic technologies^{4,5}.

Rare earth element substituted into spinel type structure of ferrite, which can modify electrical as well as magnetic parameters of ferrites⁶. Rare earth doped ferrite material have high resistivity

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and good electrical insulators. K. K. Bamzai *et al.*,⁴ have investigated structural and magnetic parameters of dysprosium - magnesium ferrite. They have observed formation of secondary phase for substitution of small concentration of rare earth ion. N. Rezlescu *et al.*,⁷ have studied substitution of small amount of rare earth ions instead of iron, produces modification of magnetic and electrical properties. N. Sivakumar *et al.*,⁸ have studied electrical behavior of magnesium ferrite synthesized by ceramic route followed by mechanical milling. They have reported the anomalous behavior of real dielectric constant which is based on the presence of both n type and p type charge carriers. Hemaunt Kumar *et al.*,⁹ have reported electrical parameters of dysprosium doped cobalt ferrite. They have showed that as frequency increases the value of electrical parameters decreases. Smitha Thankachan *et al.*,⁶ have synthesized rare earth doped magnesium ferrite by sol-gel method. They have reported rare earth doped samples exhibit high conductivity than undoped magnesium ferrite.

The dielectric permittivity of ferrite material depends upon material synthesized process, calcination and sintering temperatures. The main aim of the present work to investigate the dielectric parameters of Dysprosium substituted Magnesium ferrite synthesized by combustion method.

Materials and Methods

Magnesium – Dysprosium ferrites having composition $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ were prepared by combustion method. In this method, we have used oxidizing agents are metal nitrates and combustion agent is glycine¹⁰. The flow chart for method of synthesized material is as shown in figure 1. The as synthesized powder was presintered in air at 600 °C for 1hr. Add binder such as polyvinyl alcohol in to presintered powder and it is uniaxially pressed at six tones per inch, to form pellet shaped material having thickness 1.5 centimeter and diameter 1 centimeter. Finally, prepared pellet shaped material and powder was sintered at 950 °C for 1hr.

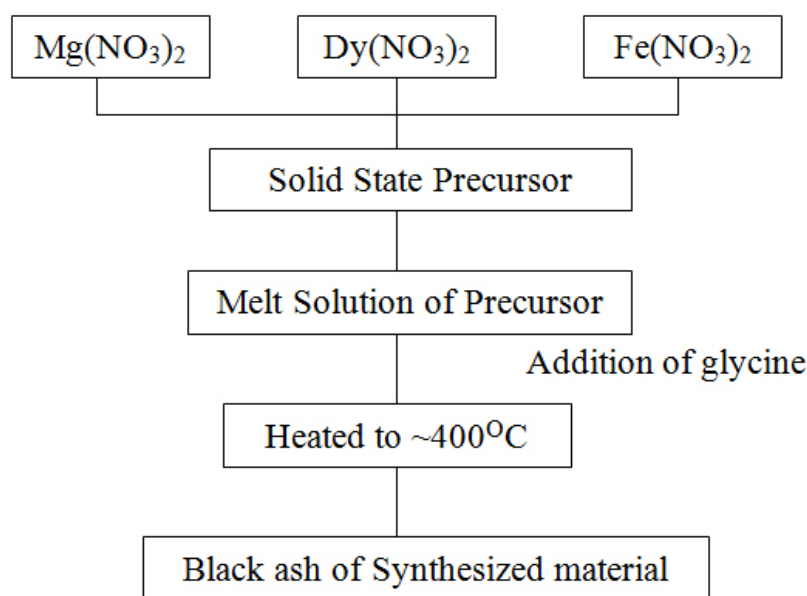


Fig. 1.:The flow chart for method of synthesized material

Pellet of sample $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ were used for measurement of dielectric behavior by using Hioki's LCR meter at different frequency and temperature. For measurement of dielectric parameter, silver conducting materials was coated on both surfaces of pellets. The dielectric parameter such as real

dielectric constant, complex dielectric constant (dielectric loss) and loss tangent were studied with frequency for different temperature by using Hioki's LCR meter. The dielectric constant (ϵ') of the pellet shaped ferrite material was calculated by using the formula⁹,

$$\epsilon' = c \times d / \epsilon_0 A$$

Where, ϵ_0 is permittivity of the free space, c is capacitance of pellet shaped ferrite material, d is thickness of the pellet, and A is area of the pellet.

The loss tangent or dissipation of the dielectric ($\tan\delta$) material was determined by the relation:

$$\tan\delta = 1 / Q$$

The dielectric loss (ϵ'') of the pellet shaped ferrite material is $\epsilon'' = \epsilon' \tan\delta$

Result and Discussions

X-ray diffractograms of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ sintered at temperature 950 °C is as shown in figure 2. The XRD pattern can be easily indexed to cubic spinel crystal of magnesium ferrite (JCPDS 73 - 1960). From XRD pattern it is identified that $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ have cubic crystal structure. The lattice constant of ferrite material was calculated by using the formula, $a = d\sqrt{h^2 + k^2 + l^2}$; Where a is the lattice constant; d is the interplaner spacing; h , k , and l are Miller indices of the crystal planes. The lattice parameter was observed from XRD data is 8.14Å°. The average crystallite size determined by Debye-Scherrer's equation using FWHM of the (311) reflection and it is found to be 46.38nm.

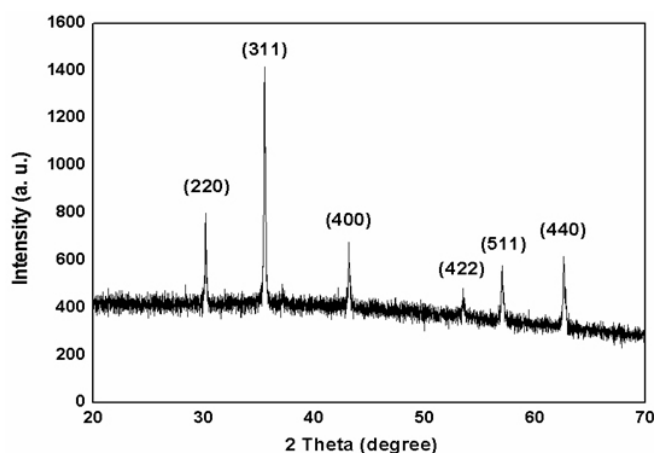


Fig. 2: XRD spectra of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$

Dielectric behavior of ferrites depends upon cation distribution on tetrahedral (A) sites and octahedral (B) sites in the spinel structure. Magnetism ferrites are good nanostructured electrical materials and its dielectric behavior was depends upon grain size and method of synthesis⁸. Frequency variation curve of dielectric constant and dielectric loss of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ at various temperatures are represented in fig.3 and 4. It is observed that for lower frequencies the value of dielectric constant decreases rapidly while at higher frequency it becomes steady. This is normal behavior of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ ferrites and such type of behavior also discussed by several researchers in different ferrite system^{9,11,12,13}. The changes in dielectric constant at low frequencies can be discussed with the Maxwell – Wagner's interfacial polarization effect^{14,15,16}. The conduction process in ferrite materials can be explains with the hoping of

charge carriers between pair of ions Fe^{3+} and Fe^{2+} . The ferrite material has heterogeneous structure. It consists of two layers; in which large conducting layer of grains separated by thin layer of conducting grain boundaries^{1,16,17}. When electrons come to the grain boundary due to hopping mechanism; such electrons crowded at the grain boundary and produces space charge polarization. But electrons moves reverse in their motion, as increase the frequency of field therefore corresponding probability of electron reaching to layer of grain boundary decreases, as a result decreases space charge Polarization. Hence dielectric constant of material decreases rapidly as frequency of field increases.

Figure 5 and 6 shows thermal variations of dielectric constant of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ sintered at temperature 950 °C for different frequencies. In figure 5 and 6, it

is seen that as temperature increases the value of dielectric constant increases for all frequencies. Also it is found that this temperature variation in dielectric constant is very large at low values of frequencies while for higher value of frequency the variation is very small. The observed values of temperature dependence dielectric data of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ at sintering temperature 950°C for 10 kHz, 100 kHz and 1000 kHz are summarized in Table 1. The dielectric permittivity of material is mainly depends upon dipolar, electronic, ionic and interfacial polarizations. Mainly dipolar and interfacial polarizations are

temperature dependent. But as temperature increases the interfacial polarization increases while dipolar polarization decreases. Hence at low frequencies dielectric constant increases with increase in temperature which is depends upon interfacial polarization. But dielectric constant at higher frequencies depends upon electronic as well as ionic polarizations but its temperature dependent contributions are insignificant. Therefore for higher frequencies, constant and low value of dielectric constant is observed^{1,18}.

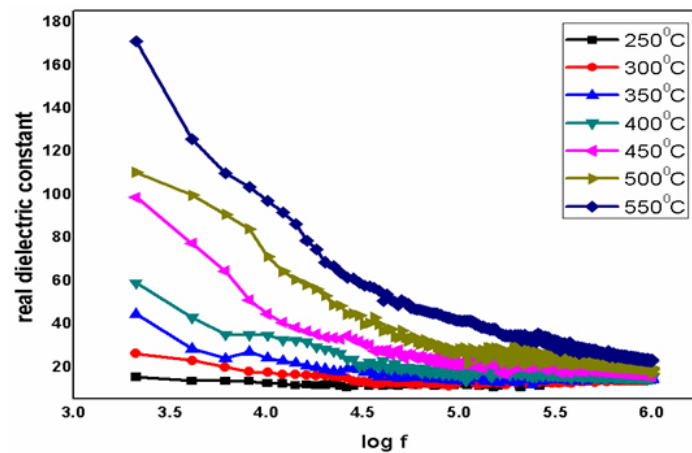


Fig. 3: Real dielectric constant of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ with frequency

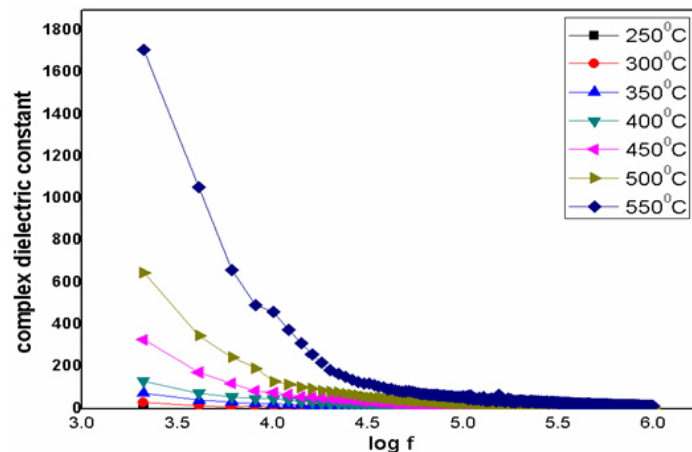
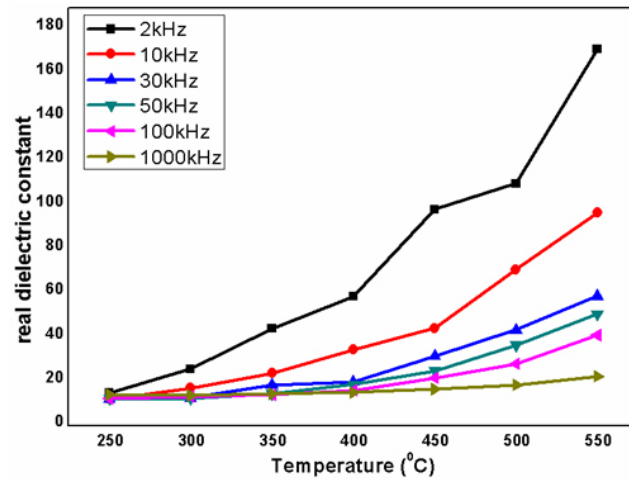
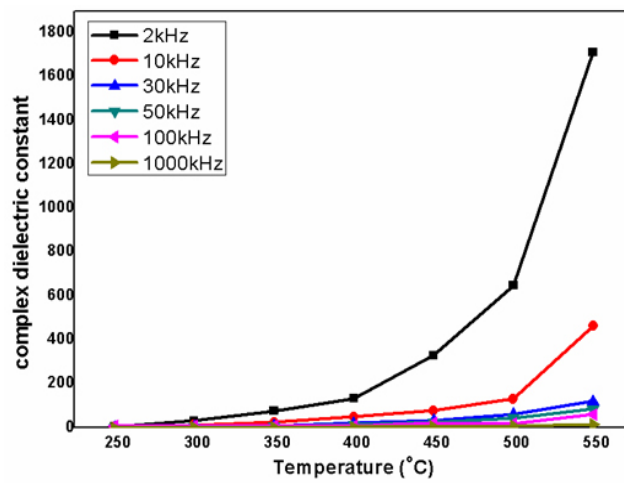


Fig. 4: Complex dielectric constant of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ with frequency

Fig. 5: Real dielectric constant of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ with temperatureFig. 6: Complex dielectric constant of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ with temperatureTable 1: Temperature dependence dielectric data of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$

Temp. °C	Real dielectric constant			Complex dielectric constant			Dielectric loss tangent		
	10kHz	100kHz	1000kHz	10kHz	100kHz	1000kHz	10kHz	100kHz	1000kHz
300	17.23	13.28	13.97	11.80	7.55	0.69	0.68	0.57	0.05
350	23.96	14.16	14.62	23.97	9.63	1.19	1.00	0.68	0.08
400	34.66	16.18	15.25	49.76	7.24	2.78	1.43	0.45	0.18
450	44.35	21.79	16.77	77.71	22.6	4.95	1.75	0.67	0.29
500	71.09	28.19	18.62	131.4	19.1	8.20	1.85	0.68	0.44
550	96.81	41.19	22.67	463.5	60.8	15.21	4.76	1.47	0.67

Dielectric loss tangent represents dielectric absorption in a material. Figure 7 and 8 shows dielectric loss tangent with frequency and temperature. Dielectric loss tangent with frequency and temperature shows similar behavior as dielectric constant. The value of loss tangent depends upon structural homogeneity, iron content and stoichiometry¹⁹. The dielectric loss tangent at lower frequencies decreases

rapidly with increase in frequency but for higher frequencies dielectric loss tangent decreases slowly. The variation of loss tangent with temperature of Dysprosium substituted Magnesium ferrite increases as temperature increases is as shown in figure 8. Similar results are reported for dysprosium doped cobalt ferrites¹³, nickel – zinc ferrite and Gd doped nanocrystalline cobalt ferrite²⁰.

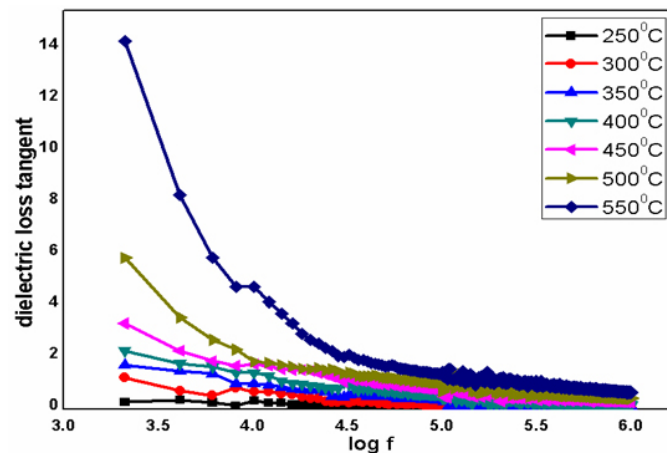


Fig. 7: Dielectric loss tangent of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ with frequency

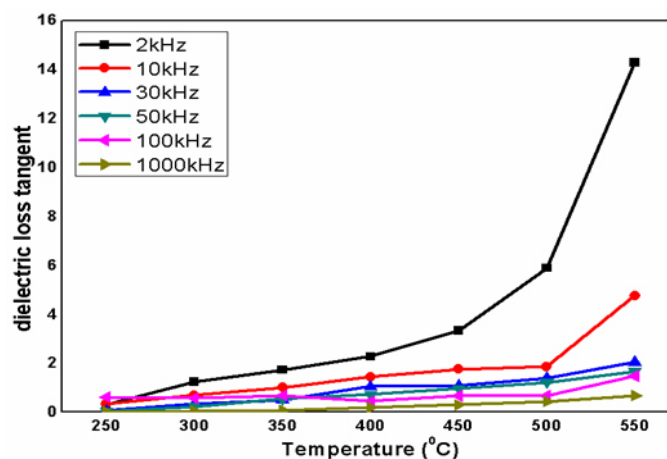


Fig. 8: Dielectric loss tangent of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$ with temperature

Conclusions

Dysprosium substituted Magnesium ferrite were successfully prepared by combustion route. From X-ray spectrograph of $\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$, confirmed cubic single phase structure of synthesized material. Crystallite size obtained from X-ray powder diffraction (311) peak and it is found to be 46.38 nm. The dielectric constant with frequency of

$\text{MgDy}_{0.03}\text{Fe}_{1.97}\text{O}_4$, shows a normal dielectric nature. Dielectric constant at low frequencies changes considerably with increasing temperature which is discussed with the Maxwell-Wagners type of interfacial polarization. Dielectric constant and loss tangent increases as temperature increase. The loss tangent with temperature and frequency shows similar behavior as dielectric constant.

References

- 1 Santosh s Jadhav, Sagar E. Shirsath, B. G. Toksha, D. R. Shengule, K. M. Jadhav, *Journal of optoelectronics and Advanced Materials*, Vol. No. 10, p 2644-2648 (2008).
- 2 R. V. Mangalaraja, S. Ananthakumar, P. Manohar, F.D.Gnanam, *Journal of Magnetism and Magnetic Materials* 253 56-64 (2002).
- 3 M. M. Deraz and Omar H. Abd-Elkader, *Int.J. Electrochem. Sci.* 8 8632 – 8644 (2013).
- 4 K. K. Bamzai, Gurbinder Kour, Balwindar Kaur, Manju Arora, Manju Arora, R. P. Pant, *Journal of Magnetism and Magnetic Materials* 345, 255- 260 (2013).
- 5 S. K. Pradhan, S. Bid, M. Gateshki, V. Petkov, *Materials chemistry and Physics* 93 224-230 (2005).
- 6 Smitha Thankachan, Binu P. Jacob, Sheena Xavier, and E. M. Mohammad *Phys. Scr.* 87, 7pp (2013).
- 7 Rezlescu N, Rezlescu E, Panicu C and Craus M. L., *Journal of Physics: Condensed Matter.* 6, 5707-5716 (1994).
- 8 N. Sivakumar, A. Narayanasamy, J. M. Greneche, R. Murugaraj, Y. S. Lee, *Journal of Alloys and Compounds* 504, 395- 402 (2010).
- 9 Hemaunt Kumar, Jitendra Pal Singh, R. C. Srivastava, P. Negi, H. M. Agrawak and K. Asokan, *Journal of Nanoscience*, Volume 2014, Article ID 862415, 10 (2014).
- 10 R. C. Kambale, P. A. Shaikh, C. H. Bhosale, K. Y. Rajpure, and Y. D. Kolekar, *Smart Mater. Struct.* 18, 115028 (2009).
- 11 Binu P. J., Smitha T, Sheena and Mohammed EM, *Journal of Alloys Compounds* 578, 314-319 (2013).
- 12 E. Ateia, M. A. Ahmed and R. M. Ghouniem, *International Journal of Modern Physics B* 29, 13pages (2015).
- 13 Sheena Xavier, *Xavierian Research Journal* 2(2) 59-66 (2014)
- 14 A. Sutka, K A Gross, G. Mezinskis, G Bebris and M Knite *Phys. Scr.* 83, 025601 (6pp) (2011).
- 15 Heywang W J., *Am. Ceram. Soc.* 47 484 (1964).
- 16 Koops C. G., *Phys Rev.* 83 121 (1951).
- 17 K. W. Wagner, *Ann. Physics*, 40, 817 – 855 (1913).
- 18 L. L. Hench, J. K. West, *Principles of Electronics Ceramics*, Wiley, New York, p.189 (1990).
- 19 S Nasir and M Anis-ur-Rehman *Phys. Scr.* 84 025603, 7pp) (2011).
- 20 Erum Pervaiz and I. H. Gul, *Journal of Physics: Conference Series* 439, 012015 (2013).