PERMEABILITY AND MICROWAVE ABSORPTION PROPERTIES OF DYSPROSIUM SUBSTITUTED MAGNESIUM FERRITE

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Abstract: $MgDy_{0.03}Fe_{1.97}O_4$ ferrite material prepared by chemical combustion method. Frequency and thermal variation of complex permeability and loss tangent of the prepared ferrite materials was studied by using a Hioki LCR-Q meter. The real part of initial permeability increases where as imaginary part of initial permeability and loss factor of the ferrites material decreases with increasing frequency. Also the permeability of the resulting ferrites increases while loss factor decreases with increasing sintering temperature. The microwave absorption properties of dysprosium substituted magnesium ferrite have been carried out by using Field Fox vector network analyzer in frequency range 2MHz to 6GHz.The prepared ferrite material shows reflection loss of -17.15dB and voltage standing wave ratio (VSWR) is 1.37 at 4.08 GHz.

Keywords: Dy-Mg ferrite, Combustion, Permeability

1. Introduction

Magnesium ferrite is soft magnetic semiconducting materials have number of applications in magnetic technology, adsorption sensors and catalysis [1]. The performance of magnesium ferrites at higher frequencies is good due to its high resistivity, low magnetic and electric losses [2, 3]. Effect of rare earth ion doping into spinel structure produces structural distortions which induces strains and hence modifies its magnetic as well as electrical properties [4-7]. Recently researchers have synthesized nano-sized ferrite material due to its important structural, electrical and magnetic properties for different applications in sensors,magnetic storage, electronic and microwave devices.

V. Naidu etal [8, 9] have been reported physical properties of metal ion substitutions such as Sm-Gd, Ce-Gd on magnesium ferrite. The structural and magnetic properties of dysprosium substituted magnesium ferrite were reported by Bamzai etal [10]. They have studied magnetic hysteresis loop and explain the ferromagnetic nature of dysprosium doped magnesium ferrite. Rezlescu etal [11] have studied the effect of rare earth ions on magnetic and electrical properties of nickel zinc ferrite. They have showed that the substitutions of iron ions by rare earth ions provide clearly improved temperature characteristics of the initial permeability. A. Loganathan etal [12] prepared pure and Sr-substituted $MgFe_2O_4$ by co-precipitation method and showed that structural, optical and magnetic properties of prepared ferrite strongly dependent on calcination temperature. Juhua Luo etal [13] studied magnetic and microwave absorption properties of rare earth ions doped strontium ferrite. They have shown that Er doped strontium ferrite got better microwave absorption performance at frequency 13.8GHz. Alagarsamy etal [14] synthesized Mg doped ferrite with Samarium, Dysprosium through sol-gel method. They have showed that prepared ferrite material used for microstrip patch antenna had an acceptable microwave performance with VSWR ≤ 2, return loss of 9.799 dB at frequency 3.5 GHz. The main objective of present work to study frequency and thermal variation of permeability as well as microwave absorption performance of dysprosium substituted magnesium ferrite material.

2. Experimental

The composition $MgDy_{0.03}Fe_{1.97}O_4$ was synthesized by chemical auto combustion route, in which metal nitrates are used as an oxidizing agent and fuel glycine as a reducing agent [15].The as-burnt powder was mixed with small amount of polyvinyl alcohol and uniaxially pressed at 6 tones/inch to form torroid shaped sample with inner diameter 1cm, outer diameter 2cm and thickness 15mm. The samples were sintered at 950^0C and 1050^0C for 1hour respectively. Powders acquired after combustion and sintering were characterized by X-ray powder diffraction using an X-ray diffractometer. The microstructural aspects were studied with a scanning electron microscope. The initial permeability and complex permeability with temperature and frequency variation were calculated by using Ls and Q factor values obtained from Hioki

(3532-50) LCR-Q meter. For study of microwave absorber properties, the prepared Mg-Dy ferrite powder were punched in to a rectangular shape with length 3 cm, breadth 2.5 cm and thickness 2 mm [16,17]. The scattering parameters such as reflection of wave for ferrite material were measured using Field Fox vector network analyzer in frequency range 2MHz to 6GHz.

3. Result and discussion

The X-ray diffraction pattern of the $MgDy_{0.03}Fe_{1.97}O_4$ sintered at 1050^0C is as shown in figure 1.

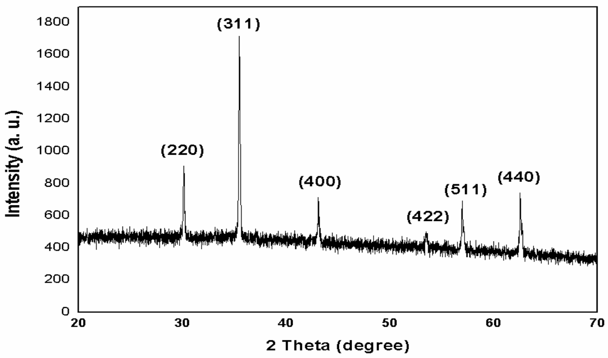
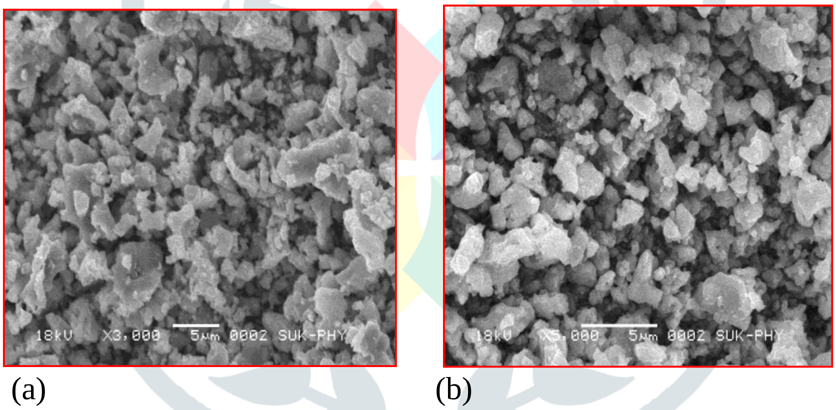


Figure 1: XRD pattern of $MgDy_{0.03}Fe_{1.97}O_4$ for sintering temperature 1050°C

All peaks of the XRD pattern of sample can be clearly indexed, which correspond to cubic spinel structure. Microstructural analysis represents the grain growth of the sample, which influences the magnetic properties of the materials. From microphotographs, it is seen that ferrite sintered at 1050^0C have a more spherical morphological grains as compared to that the ferrite sintered at 950^0C is as shown in figure 2.



(a) (b)

Figure 2: SEM photographs of $MgDy_{0.03}Fe_{1.97}O_4$ for sintering temperature (a)950^0C and (b)1050^0C

It is clear that the ferrite is well prepared with fine and spherical grains at sintering temperature 1050^0C. So that improve the initial permeability of prepared sample sintered at 1050°C and may be used in the magnetic devices.

The variation of initial permeability (μ_i) and its real (μ'), imaginary (μ'') parts with frequency for the composition $MgDy_{0.03}Fe_{1.97}O_4$ sintered at temperatures 950^0C and 1050^0C are shown in figure 3, 4 and 5.

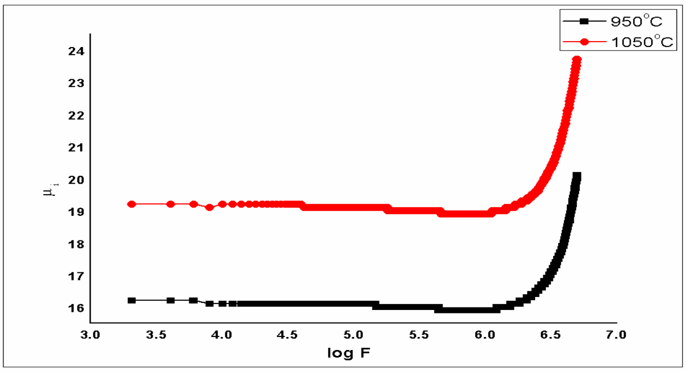


Figure.3: Variation of initial permeability (μ_i) for $MgDy_{0.03}Fe_{1.97}O_4$ with frequency

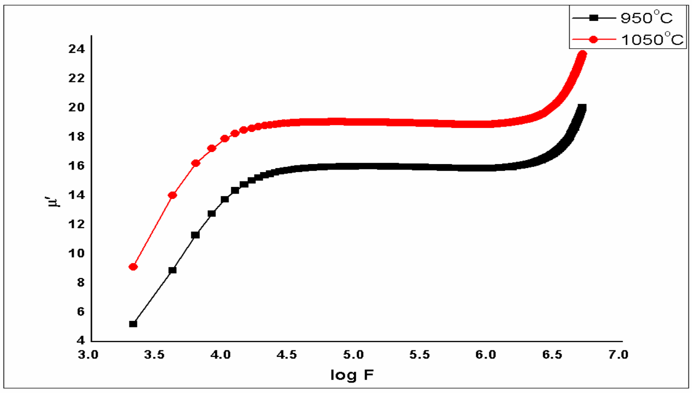


Figure 4 Variation of real part of initial permeability (μ') for $MgDy_{0.03}Fe_{1.97}O_4$ with frequency

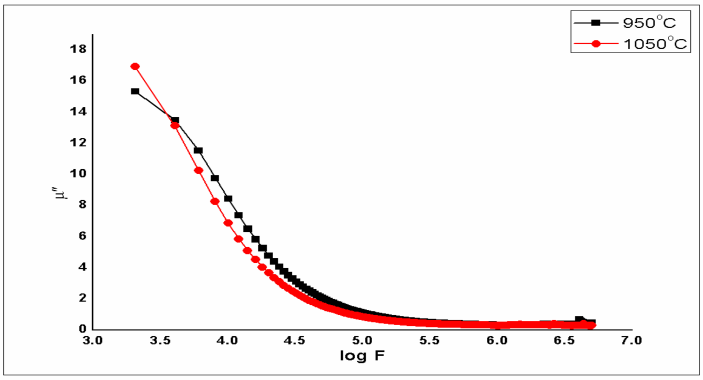


Figure 5.Variation of imaginary part of initial permeability (μ") for $MgDy_{0.03}Fe_{1.97}O_4$ with frequency.

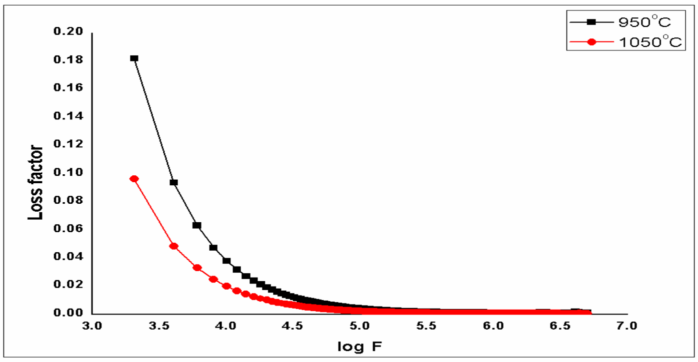


Figure 6.Variation of loss factor for $MgDy_{0.03}Fe_{1.97}O_4$ with frequency

From figure 4, it is seen that initially real part of permeability increases with frequency and then its value almost remains constant between the frequency range10KHz to 1MHz, then again increases for higher frequencies. While imaginary part of initial permeability initially gradually decreases and then its value remains constant between the frequency range150KHz to 6MHz is as shown in figure 5. Also from figure 3 and 4, it is seen that the permeability increases with increasing sintering temperature [18].During sintering process, the rare earth ions enter partially into lattice and hence form an isolating thin layer around the grains; reduces number of inner pores [12]. Increasing sintering temperature causes decreasing magnetic anisotropy there by reducing the internal stresses and crystal anisotropy, so that permeability increases with increase in sintering temperature [19, 20].Variation of loss factor with frequency for the composition $MgDy_{0.03}Fe_{1.97}O_4$ sintered at temperatures 950^0C and 1050^0C are shown in figure 6. It is observed that, the loss factor initially decreases suddenly with increase in frequency upto 100KHz, and above it loss factor remains constant with increasing frequency. Loss factors at different frequencies of the samples under investigation are presented in the Table 1. It is revealed that, loss factor decreases with increasing sintering temperature.

Table 1: Frequency dependence initial permeability, real part of permeability, imaginary part of permeability and loss factor (LF) at temperature (a) 950ºCand (b) 1050ºC for the $MgDy_{0.03}Fe_{1.97}O_4$ferrite.

(a)

Frequency	μ_i	μ'	μ''	LF*10^{-3}
2 KHz	16.20	5.22	15.34	181.53
10 KHz	16.15	13.77	8.45	37.99
100 KHz	16.07	16.03	1.11	4.32
1 MHz	15.91	15.90	0.35	1.37
5 MHz	20.07	15.91	0.49	1.22

(b)

Frequency	μ_i	μ'	μ''	LF *10^{-3}
2 KHz	19.24	9.14	16.93	96.24
10 KHz	19.19	17.92	6.87	19.96
100 KHz	19.10	19.08	0.86	2.36
1 MHz	18.92	18.92	0.32	0.90
5 MHz	23.74	23.73	0.30	0.54

Thermal variation of initial permeability and complex permeability of $MgDy_{0.03}Fe_{1.97}O_4$ are shown in figure 7, 8 and 9. From this figures, it is found that the value of permeability slightly increases with increasing temperature but near to Curie temperature permeability suddenly increases and at Curie temperature sharp decrease in permeability is observed. It represents that, the prepared material changes its ferromagnetic state to paramagnetic state at Curie temperature. Sharp decrease at Curie temperature indicates more homogeneity of prepared material with single cubic phase. It is also confirmed from XRD analysis that prepared material is cubic single phase. Curie temperature of $MgDy_{0.03}Fe_{1.97}O_4$ sintered at temperatures 950^0C and 1050^0C is nearly about 310^0C. It is seen that with increase in sintering temperature, there is no any remarkable trend obtained in Curie temperature. Such type of behavior also explained in substitutions of iron ions by rare earth ions in nickel zinc ferrite [11].Variation of loss factor with temperature for $MgDy_{0.03}Fe_{1.97}O_4$ sintered at temperatures 950^0C and 1050^0C are shown in figure 10. From this figure, it is clear that loss factor remains constant with increasing temperature but at Curie temperature loss factor suddenly increases. Hence it is seen that for low loss factor the ferrite material must be used in below its Curie temperature value.

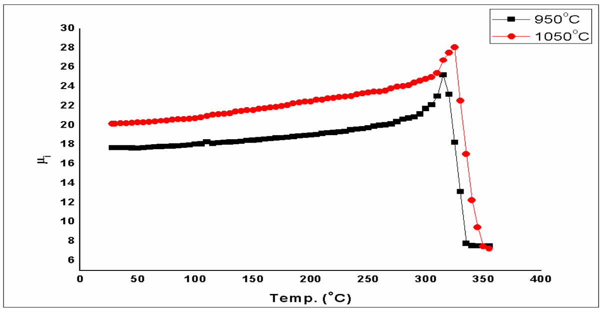


Figure 7 Thermal variation of initial permeability (μ_i)of $MgDy_{0.03}Fe_{1.97}O_4$

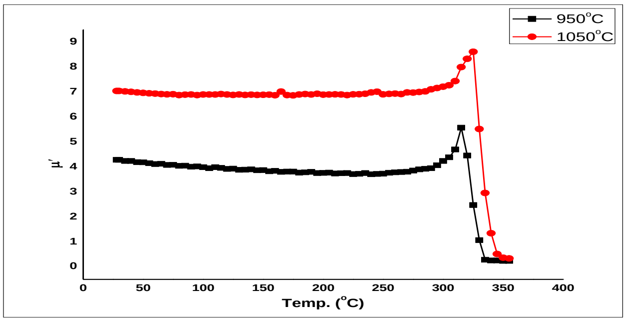


Figure 8.Thermal variation of real part of initial permeability (μ') of $MgDy_{0.03}Fe_{1.97}O_4$

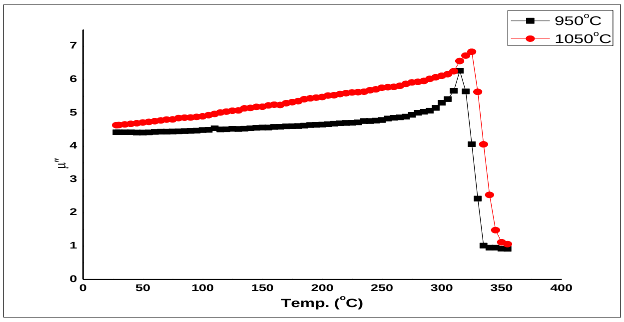


Figure 9.Thermal variation of imaginary part of initial permeability (μ'') of $MgDy_{0.03}Fe_{1.97}O_4$

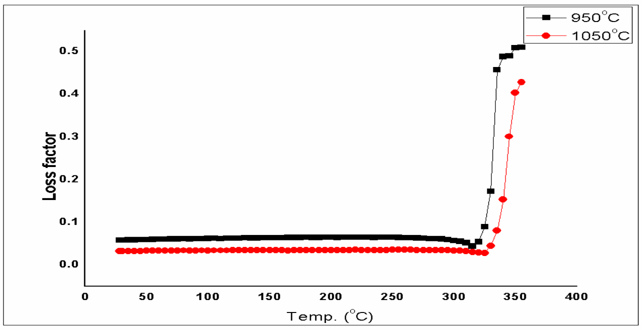


Figure 10. Thermal variation of loss factor for $MgDy_{0.03}Fe_{1.97}O_4$

The frequency dependence reflection of wave and VSWR for $MgDy_{0.03}Fe_{1.97}O_4$ ferrite material is as shown in figure 11 and 12.Electromagnetic wave absorber can transform the undesired waves into heat; hence it is used as to reduce serious electromagnetic interference problem [16]. The prepared ferrite material $MgDy_{0.03}Fe_{1.97}O_4$ shows reflection coefficient -17.15 dB and VSWR is 1.37 at 4.08 GHz. Similar type of behavior explained in Mg doped ferrite with Samarium, Dysprosium synthesized by sol-gel method [14]. Thus it is found that prepared material of $MgDy_{0.03}Fe_{1.97}O_4$ exhibited the best electromagnetic absorbing performance at 4.08GHz.

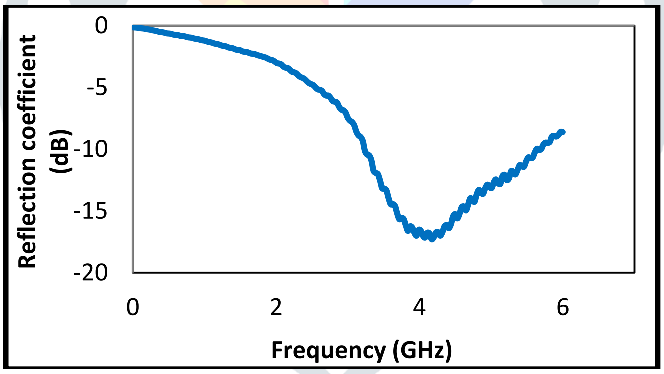


Figure 11. Frequency dependence reflection coefficient for $MgDy_{0.03}Fe_{1.97}O_4$

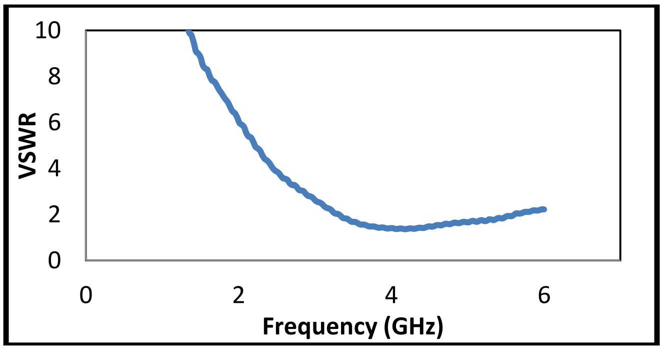


Figure 12. Frequency dependence VSWR for $MgDy_{0.03}Fe_{1.97}O_4$

4. Conclusion

Ferrite material with chemical formula of $MgDy_{0.03}Fe_{1.97}O_4$, were successfully synthesized by a chemical combustion route. The X-ray diffraction confirmed formation of cubic single phase ferrite material. Microstructural analysis represents the grain growth of the ferrites with increasing sintering temperature. The $MgDy_{0.03}Fe_{1.97}O_4$ powder prepared at sintering temperature 1050^0C exhibit good crystal structure and improved initial permeability. The initial permeability was found to increase and loss factor decreases at higher frequency. It is observed that loss factor decreases with increasing frequency as well as temperature. A good quality absorber should have a large reflection coefficient. The results showed that the prepared ferrite material have VSWR is 1.37 and return lossof -17.15 dB at frequency 4.08 GHz. Hence this ferrite material used as an electromagnetic wave absorber at frequency 4.08 GHz.

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References

[1] S. K. Pradhan, S. Bid, M. Gateshki, V. Petkov, Microstructure characterization and cation distribution of nanocrystalline magnesium ferrite prepared by ball milling, *Materials chemistry and Physics*, 93, 224-230, 2005.

[2] Kong. L. B., Li. Z. W., Lin. G. Q., Gan. Y. B., Magneto-dielectric properties of Mg-Cu-Co ferrite ceramics: II. Electrical, dielectric and magnetic properties, *J. Am. Ceram. Soc.*, Volume 90, Issue 7, 2104-2112, 2007.

[3] Koseoglu Y., Kavas. H., Aktas. B., Surface effects on magnetic properties of supermagnetic magnetite nanoparticles, *Physica Status Solidi. (a)*Volume 203, Issue 7, 1595- 1601, 2006.

[4] J. Jing, L. Liang-Chao, X. Feng, Preparation, characterization and magnetic properties of PANI/La substituted LiNi ferrite nanocomposities, *Chinese Journal of Chem*istry, 24, 1804-1809, 2006.

[5] J. Jing, L. Liang-Chao, X. Feng, Structural analysis and magnetic properties of Gd doped LiNi ferrites prepared using rheological phase reaction method, *J. Rare Earths*, 25, 79-83, 2007.

[6] C. B. Kolekar, P. N. Kamble, A. S. Vaingankar, Thermoelectric power in Gd substituted CuCd ferrites, *J. Bull. Mater.Sci.* 18(2), 133-140, 1995.

[7] Smitha Thankachan, ManjuKurian, Divya S. Nair, Sheena Xavier, E. M. Mohammed, Effect of rare earth doping on structural, magnetic, electrical properties of magnesium ferrite and its catalytic activity, *International Journal of Engineering Science and Innovative Technology*, Vol.3, Issue4, 1-9, 2014.

[8] V. Naidu, S. Vijayaragavan, R. Legadevi, A. Senthil Kumar, Synthesis of nanosized SmGd doped magnesium ferrite and their permittivity and hysteresis studies, *International journal of computer applications* 30(7), 13-23, 2011.

[9] V. Naidu, S. K. A. Ahamed KanduSah-ib, M. Suganthi, Chandra Prakash, Study of electrical and magnetic properties in nanosized CeGd doped magnesium ferrite, *International journal of computer applications* 27(5), 40-45, 2011.

[10] K. K. Bamzai, Gurbinder Kour, B. Kaur, S. D. Kulkarni, Effect of cation distribution on structural and magnetic, properties of Dy substituted magnesium ferrite, *Journal of Magnetism and Magnetic Materials*, 327,159-166, 2013.

[11] N. Rezlescu, E. Rezlescu, C. Pasnicu and M. L. Craus, Effects of the rare earth ions on some properties of a nickel zinc ferrite, *J. Phys.:Condens. Matter* 6, 5707-5716, 1994.

[12] A. Loganathan, K. Kumar, Effects on structural, optical and magnetic properties of pure and Sr-substituted $MgFe_2O_4$nanoparicles at different calcination temperatures, A*ppl. Nanosci*, 6, 629-639, 2016.

[13] JuhuaLuo and Hongkai Mao, Magnetic and microwave absorption properties of rare earth ions doped strontium ferrite and its nanocomposites with polypyrrole, *Journal of Magnetism and Magnetic Materials*, Volume 381, 365-371, 2015.

[14] S. Alagarsamy, Vasant Naidu, P. Immanuel Vinoth, M. Pandimadevi, Design and evaluation of E-shaped microstrip patch antenna for wimax application, *International Journal of Computer Applications*, Volume 45, No. 15, 34-36, 2012.

[15] Jeevan S. Ghodake, Dielectric behavior of dysprosium substituted magnesium ferrite, *Materials Science Research India*,Vol. 15, No. (1), 48-54, 2018.

[16] M. S. Kim and Jae GuiKoh, Microwave absorbing characteristics of NiCoZn ferrite by using a co-precipitation method, *Journal of the Korean Physical Society*, Vol. 53, No.2, 737-741,2008.

[17] J. S. Ghodake, Rahual C. Kambale, T. J. Shinde, P. K. Maskar, S. S. Suryavanshi, Magnetic and microwave absorbing properties ofCo2+ substituted nickel – zinc ferrites with the emphasis on initial permeability studies, *Journal of Magnetism and Magnetic Materials*, 401, 938-942, 2016.

[18] Beitollani A, Hoor M, Effect of sintering temperature on the microstructure and high frequency magnetic properties of $Ni_{0.467}Zn_{0.07}Co_{0.015}Fe_{0.511}O_4$ ferrite, *Journal of Materials Science: Materials in Electronics* 14,477-482, 2003.

[19] Verma A, Goal T. C., and Mendiratta R. G., Frequency variation of initial permeability of Ni-Zn ferrites prepared by the citrate precursor method, *Journal of Magnetism and Magnetic Materials*, Vol.210, No. (1-3), 274-331, 2000.

[20] J. S. Ghodake, T. J. Shinde, R. P. Patil,, S. B. Patil, S. S. Suryavanshi, Initial permeability of Zn-Ni-Co ferrite, *Journal of Magnetism and Magnetic Materials* 378,436-439, 2015.