

STUDY ON STRUCTURAL AND MAGNETIC PROPERTIES OF YTTERBIUM DOPED ZINC FERRITE PREPARED BY SOLID STATE METHOD

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Abstract

Rare earth, ytterbium doped Zinc ferrites: $Zn(Yb_xFe_{1-x})_2O_4$ with $x=0.0000, 0.0125, 0.0250, 0.0375$ and 0.0500 were prepared by the solid state method. Effect of Ytterbium doping on structural and magnetic properties of Zinc Ferrite is reported. The phase formation of the prepared samples was analyzed by X-ray diffraction. The appropriate variations in lattice parameters and cell volume confirmed the successful substitution of Fe^{3+} ions with Yb^{3+} ions at octahedral sites. The bulk density (D_b) and X-ray density (D_x) were also significantly varied by increased Yb^{3+} contents. XRD analysis reveal pure spinel phase in all the samples, without traces of secondary phases. The magnetic measurements were performed by using a soft magnetic Hysteresis Graphs Meter (DX-2012SD). It was found that saturation magnetic induction and coercivity followed decreasing trend with substitution of Fe^{3+} ions by Yb^{3+} ions.

Keywords: XRD, structural, magnetic, ytterbium doped zinc ferrite

Introduction

Spinel ferrites have received special attention over the last years as important magnetic compounds of vital technological interest due to their useful applications. These materials are successfully used in different fields like in high frequency devices, microwave devices, catalysis, photocatalysis and magnetically guided drug delivery. The general formula for spinel ferrites is AB_2O_4 , where A is divalent metal ion (eg. cobalt, nickel and zinc) B is usually iron usually substituted sometimes with other trivalence metals ions Rare earths.

The properties of these compounds are relied to the distribution of cations between tetrahedral (A) and octahedral (B) sites. Therefore, the structural and magnetic properties can be influenced by the synthesis methods, chemical-composition, particle size or doping and can be fine-tuned by changing the amount of doping Rare Earth elements.

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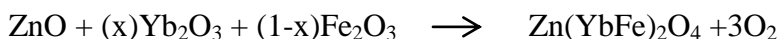
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Material and Method

Experimental procedure

Rare earth doped Zinc ferrites were prepared $Zn(Yb_xFe_{1-x})_2O_4$ with $x=0.0000, 0.0125, 0.0250, 0.0375$ and 0.0500 by the solid state method. The raw materials such as ytterbium oxide, zinc oxide and ferrite oxide were used as the source materials. The required amount of the ZnO , Yb_2O_3 and Fe_2O_3 were weighed with digital balance. The raw materials of ZnO , Yb_2O_3 and Fe_2O_3 were taken in stoichiometric proportions.

These oxide materials were mixed with standard weight percentages according to their stoichiometric calculation by using the following equation.



All compositions have been mixed in an Agate mortar and ground for 5 hours. After mixing and grinding, the mixture has been pre sintered at $900^\circ C$ for 5 hours in a furnace with heating rate of $20^\circ C/min$ and cooled to room temperature with the same rate. After that, the powder and the mixture has been ground with an Agate motor for 1hour. Then, the powder has been pressed into pellets and toriods by uniaxial hydraulic press at a pressure of 5tons.

The sintering temperature should start from $1000^\circ C$ which is $100^\circ C$ higher than the pre-sintering temperature. This condition is required for densification of Ferrite in standard solid state methods. Therefore, the sintering temperature was chosen as $1000^\circ C$ with time duration for 5 hours to densify $ZnFe_2O_4$ and Yb doped $ZnFe_2O_4$ magnetic ferrite by standard solid state method.

The ytterbium doped zinc ferrite samples were characterized by using X-ray Diffraction. The magnetic characterization was carried out using a soft magnetic Hysteresis Graphs Meter (DX-2012SD).

Results and Discussion

Structural Analysis

The XRD spectrum of the sample final sintered at 1000 °C as shown in Figure 1. As seen in XRD spectra cubic spinel structure of zinc ferrite was found to be stable at final sintering temperature. The lattice constant and crystallite size of $Zn(Yb_xFe_{1-x})_2O_4$ calculated data are shown in Table 1. The lattice parameter obtained for pure zinc ferrite is in good agreement with the reported value.

The diffraction peaks corresponding to (2 2 0), (3 1 1), (4 0 0), (4 2 2), (5 1 1) and (4 4 0) reflection planes and the absence of any extra peak show that all the samples have attained single phase cubic structure. This implies that the Yb^{3+} ions have been completely dissolved into the spinel lattice of zinc ferrite.

In order to fulfill the structural properties, the theoretical (X-ray) density was calculated using equation, $D_x = \frac{8M}{Na^3}$ where, D_x = X-ray density, M = the molecular weight (gm) of the sample, N = Avogadro's number (per mol), and a = the lattice parameter in angstrom and bulk density by equation, $D_b = \frac{m}{\pi r^2 h}$ Where, m = the mass of pellet, r = the radius of the pellets, h = the thickness of the pellets and D_b = the bulk density.

Table 2 shows the bulk density and apparent porosity of sintered temperature along with Yb compositions. The bulk density and X-ray density increased with increasing Yb content which indicated improvement in grain growth upon Yb substitution. The bulk density is found to be 62.92 % of X-ray density for the final sintering temperature of in average. Moreover, the bulk density increased with increasing Yb concentration, indicating improved densification by the substitution of Yb for $Zn(Yb_xFe_{1-x})_2O_4$ in the ferrite. This indicated that the rate of densification decreased with the decreasing Yb content. Moreover, the Yb played an important role during sintering of the ferrites. The porosity for all the compositions was calculated by equations $P = 1 - \frac{D_b}{D_x}$ where, P = porosity, D_b = bulk density and D_x = X-ray density.

The smaller values of “ D_b ” than those of “ D_x ” confirmed the presence of pore in all the compositions. The formation of pores was decreased with the increase in Yb concentration. Therefore, it agrees well with the variation of density with Yb concentration. According to literature, the increased densification in this case was due to the presence of excess Zn in the system. The excess Zn arose due to the Yb substitution for Fe in the ferrite.

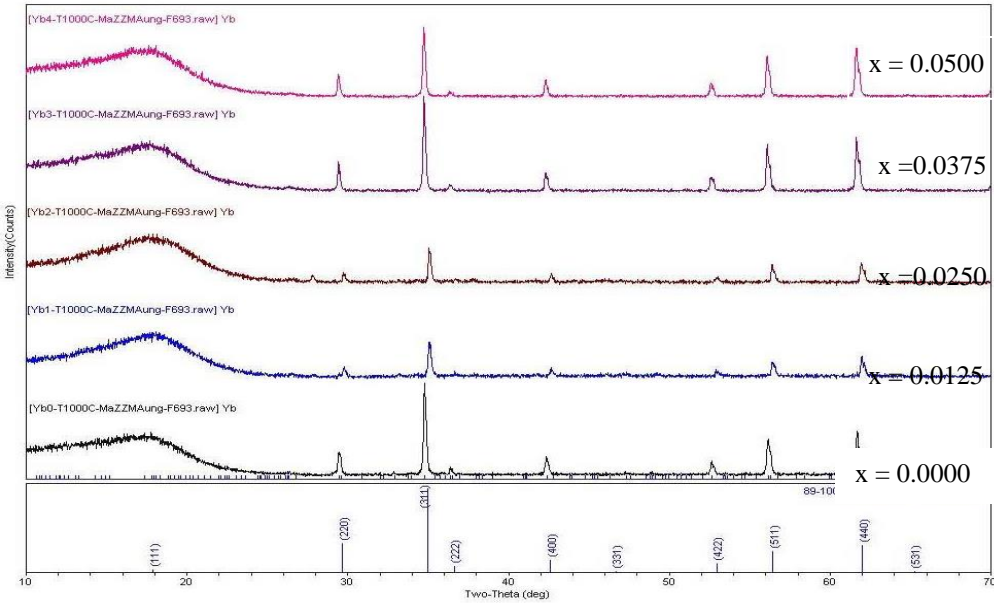


Figure 1: XRD patterns of $Zn(Yb_xFe_{1-x})_2O_4$ pellets sintered at 1000 °C

Table 1: Lattice constant and crystallite size of $Zn(Yb_xFe_{1-x})_2O_4$ sintered at 1000 °C

Sample of composition “x”	Lattice Constant (Å)	Crystallite size (nm)
0.0000	8.47	44.29
0.0125	8.47	41.09
0.0250	8.47	37.80
0.0375	8.55	36.78
0.0500	8.55	31.68

Table 2: Values of X-ray density, bulk density and porosity of Zn(Yb_xFe_{1-x})₂O₄ sintered at 1000 °C

No	Samples of composition “x”	Mol.wt. (g/mol)	X-ray density (g/cm ³)	Bulk density (g/cm ³)	Porosity
1	0.0000	241.07	5.27	3.62	0.31
2	0.0125	244.00	5.36	3.74	0.30
3	0.0250	246.93	5.41	3.75	0.29
4	0.0375	249.86	5.42	4.03	0.26
5	0.0500	252.79	5.48	4.16	0.24

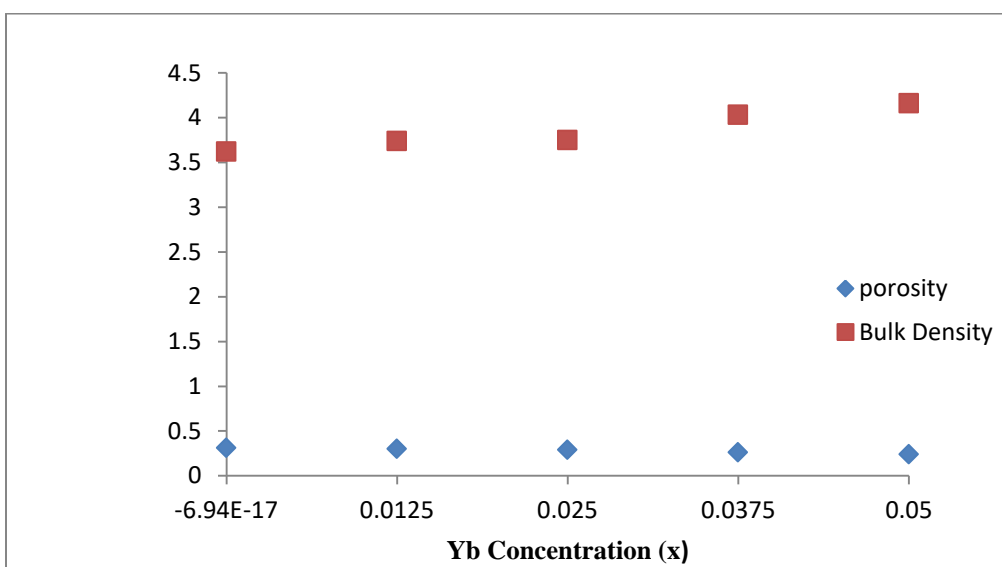


Figure 2: The variation of bulk density and apparent porosity with different Yb concentration (x) for Zn(Yb_xFe_{1-x})₂O₄ sintered at 1000 °C

The lattice constant of ytterbium-substituted zinc ferrite is observed to be larger than that of zinc ferrite. An increase in lattice constant with increase in Yb³⁺ ion content is expected because of the large ionic radius of Yb³⁺ (0.858 Å) compare to that of Fe³⁺(0.67 Å).

The ytterbium substitution zinc ferrite changes in the lattice constant and this may probably be the reason for the observed shift of XRD peaks with

ytterbium substitution. The theoretical (X-ray) density of zinc ferrite is in agreement with that of the zinc ferrite because it increases with increase in ytterbium concentration.

Magnetic Properties of $\text{Zn}(\text{Yb}_x\text{Fe}_{1-x})_2\text{O}_4$

The magnetic properties of $\text{Zn}(\text{Yb}_x\text{Fe}_{1-x})_2\text{O}_4$ were measured by using Soft Magnet DC Meter (DX-2012SD) under the static (DC) state. Table 3 shows the initial permeability (μ_i), maximum permeability (μ_m), saturation magnetic induction (B_s) and remanence (B_r) of sintered ferrites along with their coercive force which were measured at room temperature.

Moreover, it was observed that H_c increased by increasing doping contents of Yb^{3+} ions. It might be due to the effect of denser microstructure with Yb^{3+} ions substitution in spinel lattice. It is interesting to note that the corecivity significantly increased at $x = 0.0250$ of Yb substitution compared to that of undoped ones. It has also been reported that if the squareness ratio is greater than 0.5 ($B_r / B_s \geq 0.5$), then the compounds are in single magnetic domain and if this ratio is less than 0.5 ($B_r / B_s \leq 0.5$), then the compounds are in multi-magnetic domains. In this work, it was observed that the squareness ratios for all samples are greater than 0.5 and therefore it confirmed the formation of single domain structure in $\text{ZnYbFe}_2\text{O}_4$ ferrites. Therefore, in these $\text{ZnYbFe}_2\text{O}_4$ ferrites, decrease in B_s and increase in H_c with respect to doping contents made them electromagnets.

Table 3: Magnetic data for $\text{Zn}(\text{Yb}_x\text{Fe}_{1-x})_2\text{O}_4$ sintered at 1000 °C

Composition “x”	μ_i mH/m	μ_m mH/m	B_r (T)	B_s (T)	B_r/B_s	H_c (A/m)
0.0000	0.055	2.273	0.053	0.062	0.854	3.43
0.0125	0.040	1.682	0.037	0.044	0.840	3.48
0.0250	0.018	1.266	0.029	0.034	0.852	3.50
0.0375	0.018	1.266	0.029	0.034	0.852	3.50
0.0500	0.018	1.266	0.048	0.034	1.410	3.50

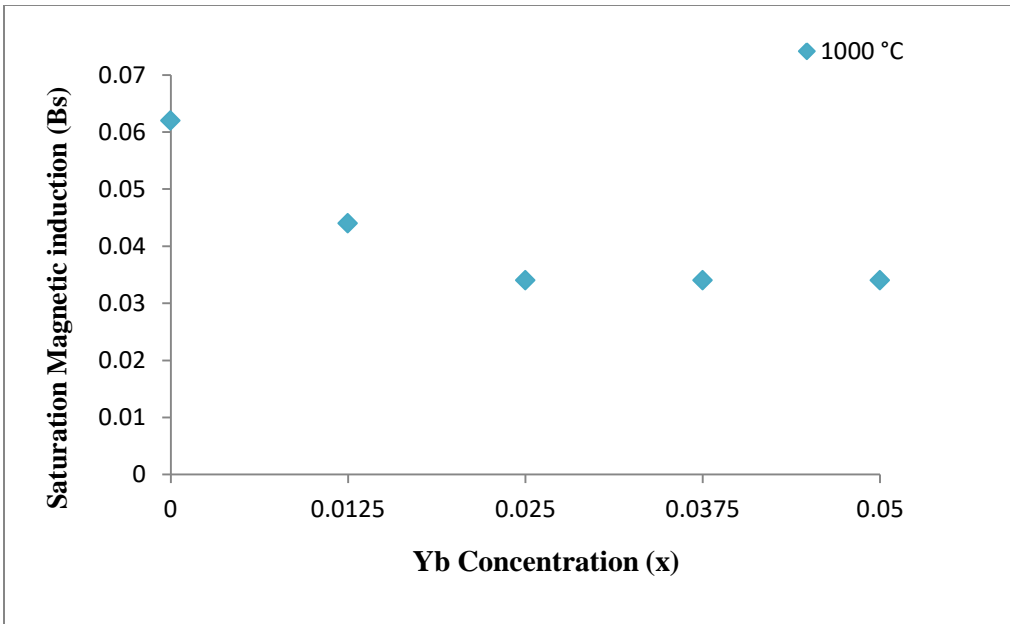


Figure 3: The variation of saturation magnetic induction of $\text{Zn}(\text{Yb}_x\text{Fe}_{1-x})_2\text{O}_4$ with different Yb concentration (x)

Conclusion

In this experiment of ytterbium doped on the zinc ferrite $\text{Zn}(\text{Yb}_x\text{Fe}_{1-x})_2\text{O}_4$ with $x=0.0000, 0.0125, 0.0250, 0.0375$ and 0.0500 were synthesized by using solid state method. XRD analysis confirmed the formation of single phase structure, without any secondary phase in all the compositions. The substitution of ytterbium in zinc ferrite has resulted in an increase in lattice constant. Moreover, it was observed that coercivity H_c increased by increasing doping contents of Yb^{3+} ions. It might be due to the effect of denser microstructure with Yb^{3+} ions substitution in spinel lattice. This is proved that the substitution of small amount of ytterbium rare earth (RE) ions in ferrite can also tune the magnetic properties.

The result obtained in this work suggested that $\text{Zn}(\text{Yb}_x\text{Fe}_{1-x})_2\text{O}_4$ crystalline ferrites are suitable materials for microwave devices applications

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