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Research Article

Analysis of Structural and Electrical Properties of Vanadium Substituted Yttrium Iron Garnet

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ABSTRACT

The garnet having the general formula $Y_3V_xFe_{5-x}O_{12}$ (x= 0.0, 0.2 and 0.4) were synthesized using double sintering ceramic technique. The samples were characterized by X-ray diffraction technique. The X-ray diffraction studies of compositions revealed the formation of single phase cubic structure with lattice constant ranging from 12.364 to 12.381 Å up x=0.0 to x= 0.4. The IR spectra of all samples are taken in the range of 300-800cm^{-1}. IR spectra show typical absorption bands indicating the garnet nature of samples.

The aim of the present work is to develop sintered material of the vanadium substituted yttrium iron garnet ($Y_3Fe_{5-x}V_xO_{12}$) and to study the effect of vanadium substitution on the properties of yttrium iron garnet in meeting the requirement of device engineers. In the present study, we report our results on the structural and electrical properties of vanadium substituted yttrium iron garnet. ($Y_3Fe_{5-x}V_xO_{12}$) (x = 0.0 – 0.4) through X-ray diffraction, infrared spectroscopy and electrical resistivity measurements. The d.c. electrical resistivity measurements were carried out by means of two probe method. The samples in the form of pellet were placed between two electrodes.

1 Introduction

Yttrium iron garnet (YIG) $Y_3Fe_5O_{12}$ belongs to a group of magnetic oxides and has received a great deal of attention in laser, microwave devices and ultrasonic devices field. They are characterized by magnetic and magneto-optical properties. Yttrium iron garnet (YIG) is a microwave ferrite, which in polycrystalline form has specific characteristics.

Garnets are cubic oxides with space group O_h^{10} and they are characterized by the chemical formula $\{A_3\}[B_2]X(C_3)O_{12}$, where the different brackets reflect the various oxygen coordination of the A cations while the [ ] and ( ) indicate six fold and four fold coordination of the B and C cations, respectively. A can be one of the fourteen well known rare earth ions or Yttrium while B and C are the cations like Al, Ga, Cr, etc. [1]. Yttrium iron garnet is one of the well-known family of ferrimagnetic oxide magnetic materials. In the present study, we report our results on the structural and electrical properties of vanadium substituted yttrium iron garnet ($Y_3Fe_{5-x}V_xO_{12}$) (x = 0.0 – 0.4) through X-ray diffraction, infrared spectroscopy.

Pure and substituted yttrium iron garnet has been studied intensively by several researches with a view to understand their basic properties. Substituted yttrium iron garnets have been extensively used in wide band non reciprocal devices [2, 3]. Non-magnetic substitutions in yttrium iron garnet have provoked great interest for scientific studies of the effects caused by the magnetic dilutions [4, 5]. In general, non-magnetic cations occupy two non-equivalence sites with more or less pronounced preference for one site [6]. Non-magnetic ions usually occupy octahedral or tetrahedral site.

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2 Experimental Findings

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3 Result and Discussion:

The room temperature X-ray diffraction patterns (XRD) of vanadium doped yttrium iron garnet $Y_3Fe_{5-X}V_xO_{12}$ (where x = 0.0-0.4 in the step of 0.2) are shown in Fig.1 (a). The X-ray diffraction patterns of the garnet system shows the Bragg's peaks belonging to cubic garnet structure the cubic garnet structure can be easily observed in all the samples. All the observed reflections (321), (400), (420), (422), (431), (521), (611), (444), (640), (642), (800), (842), in the garnet system with the crystalline phases were well indexed using the JCPDS powdered diffraction file (card no.43-0507). The XRD patterns show sharp and intense Bragg reflections belonging to single phase cubic garnet structure. Using Miller indices and Bragg's law, the inter planner spacing'd' values were calculated and same are given in Table 1. It is observed from table 1 that'd' values increases with increase in vanadium composition x.

Table: 1 Miller indices (hkl) and Inter planner spacing (d) of $Y_3V_xFe_{5-x}O_{12}$.

Plane	**d(A)**		
(hkl)	x=0.0	x=0.2	x=0.4
(4 0 0)	3.09	3.09	3.09
(4 2 0)	2.76	2.76	2.77
(4 2 2)	2.52	2.52	2.53
(4 3 1)	2.42	2.43	2.42
(5 2 1)	2.26	2.26	2.26
(6 1 1)	2.01	2.01	2.00
(4 4 4)	1.78	1.78	1.79
(6 4 0)	1.72	1.72	1.72
(6 4 2)	1.65	1.65	1.65
(8 0 0)	1.56	1.54	1.55
(8 4 0)	1.38	1.38	1.38
(8 4 2)	1.35	1.35	1.35
(6 4 0)	1.72	1.72	1.72

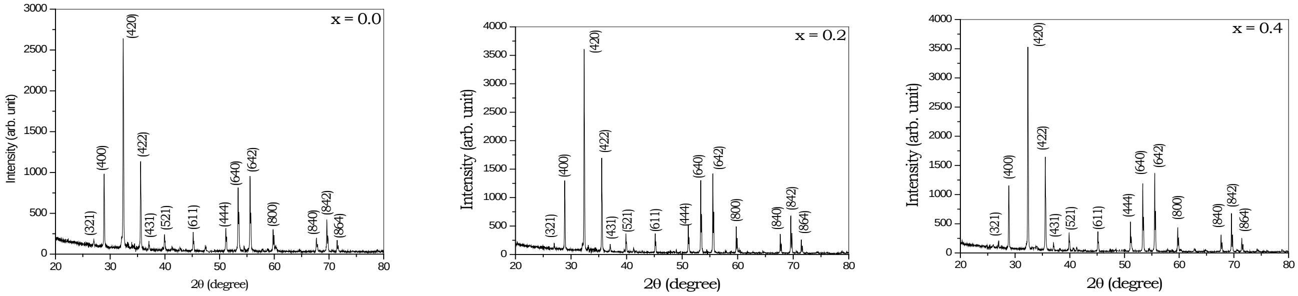


Fig. 1: XRD patterns of $Y_3V_xFe_{5-x}O_{12}$ (x= 0.0, x=0.2 and x=0.4

The lattice constant for all the samples of the series $Y_3Fe_{5-X}V_xO_{12}$ was calculated using the values of inter planner spacing and Miller indices. The values of lattice constant are presented in Table 2. The variation of lattice constant 'a' of yttrium iron garnet with vanadium substitution is nearly linear. The lattice constant for pure yttrium iron garnet (a=12.376 Å) fairly agrees well with the literature data [7]. The increase in lattice constant of the present system is due to the replacement of Fe^{3+} (0.67 A. U.) ions of smaller ionic radii by V^{3+} ions of larger ionic radii (0.74 A^0. U.) [8]. Normally, ions of larger radius, when substituted for smaller radius, the lattice constant of the system increase. Here, in the present work Fe^{3+} ions in $Y_3Fe_{5-X}V_xO_{12}$ garnet system were replaced by V^{3+} ions of larger radii this causes the increase in lattice constant of vanadium substituted yttrium iron garnet system.

Table: 2 Lattice constant (a), X-ray density (dx), bulk density (d_B) porosity (P) and particle size (t) of $Y_3V_xFe_{5-x}O_{12}$.

x	a (Å)	dx (gm/cm^3)	d_B (gm/cm^3)	P (%)	t (µm)
0.0	12.364	5.187	4.15	19.99	5.60
0.2	12.373	5.169	4.12	20.29	6.26
0.4	12.381	5.152	4.07	21.00	6.87

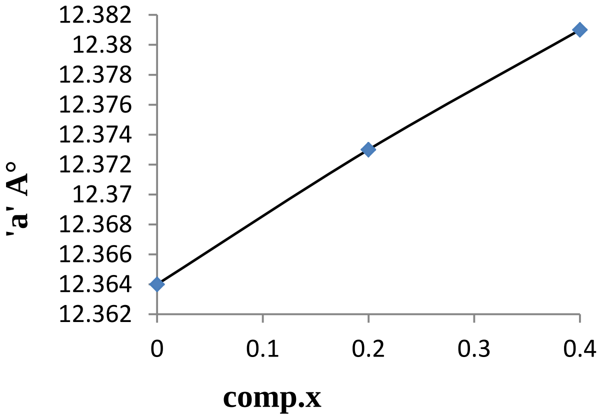


Fig. 2: Variation of lattice constant 'a' with composition (x) of $Y_3V_xFe_{5-x}O_{12}$ *(x = 0.0, 0.2 and 0.4*

The X-ray density of the present samples was estimated using the values of experimental lattice parameter and molecular weight. Table 2 gives the values of X-ray density as a function of vanadium composition of x. The X-ray density is inversely proportional to the unit cell volume (a^3) and therefore with increase in lattice constant X-ray density should decrease. The observed behavior of the X-ray density with vanadium composition x is in accordance with the theoretical consideration. Similar behavior of X-ray density was observed in [Al^{3+}] substituted yttrium iron garnet [6]

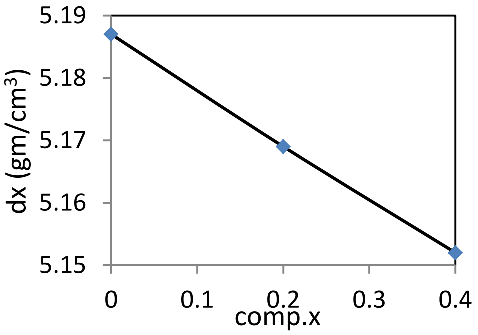


Fig. 3: Variation of X-ray density 'd_x' with composition 'x' of $Y_3V_xFe_{5-x}O_{12}$ *(x=0.0, 0.2 and 0.4).*

The bulk density of each investigated samples was calculated using the values of mass and volume and are given in Table 2 the bulk density decreases uniformly with the vanadium substitution. The linear decrease in bulk density may be due to increase in the volume with vanadium substitution.

The percentage porosity (P %) of each sample was calculated from the values of bulk density and X-ray density. Table 2 shows the values of porosity as a function of vanadium composition x. It can be seen from table 2 that percentage porosity increases with vanadium composition x. The high values of porosity are may be due to high sintering temperature effect.

The crystallite size (t) of all the samples under investigation were calculated from the full width at half maximum (FWHM) of the highest intensity peak (420) of the X-ray diffraction pattern using the Scherrer formula. The values of particle size for all the composition is listed in Table 2.

It is observed from Table 2 that crystallite size for all the samples is in micrometer range indicating the bulk polycrystalline nature.

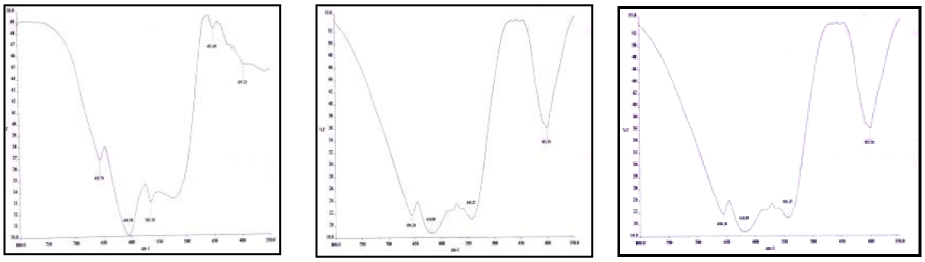
Infrared Spectroscopy

The infrared spectra of $Y_3Fe_{5\text{-}X}V_xO_{12}$ are shown in Fig 4. (a-c). The infrared spectra can provide the information regarding structure, bond strengths, imperfection and impurities. IR Spectra reveals that observation in wave number 300-800 cm^{-1} are very intense corresponding to allowed fundamental transitions.

IR spectra show absorption bands near 400 cm^{-1} and 600cm^{-1} assigned to the stretching mode YIG tetrahedron, Our results are similar to Al^{3+} substituted yttrium iron garnet synthesized via citrate gel process [9,10]. The IR bands at 655 cm^{-1}, 605 cm^{-1} can be assigned to new per modes whereas the bands at 397 and 424 cm^{-1} can be assigned to new two modes. Similar results are shown by M. Ristic et. al [11, 12].

Table 3: Vibrational band frequency of $Y_3V_xFe_{5\text{-}x}O_{12}$ for x= 0.0 to 0.4

x	ν1 (cm-1)	ν2 (cm-1)	ν3 (cm-1)	ν4 (cm-1)
0.0	655.04	605.15	564.87	424.68
0.2	656.04	616.06	542.95	399.29
0.4	656.05	617.56	541.52	403.02



(a) (b) (c)

Fig.4 (a-c): IR spectra of $Y_3V_xFe_{5\text{-}x}O_{12}$ of typical samples x = 0.0, 0.2 and 0.4.

Analysis of electrical resistivity

The D. C. electrical resistivity (ρ) measurements for all the samples of $Y_3In_xFe_{5\text{-}x}O_{12}$ garnet system were carried out in the temperature range of 300-725 K. Plots of log ρ Vs 1000/T are shown in Fig. 4.5 (a to d). It is observed from resistivity plots that, D.C. electrical resistivity decreases with increase in temperature. The plot exhibits a relatively sharp kink, which divides the curve in two parts. The resistivity plots obeys Arrhenius relation given by the equation,

$$\rho = \rho_0 \, e^{\frac{\Delta E}{KT}} \quad \ldots.4.3$$

Using the above relation and from the resistivity plot, the activation energy for two regions that is ferrimagnetic and paramagnetic was calculated and the values are given in table 4. It is observed form table 4.4 that, activation energy decreases with increase in In^{3+} ions. The experimental results on D.C. electrical resistivity studies closely matches with those reported in the literature [14, 15].

Table: 4 Activation energy in paramagnetic (E_p) and ferrimagnetic (E_f) region of $Y_3V_xFe_{5-x}O_{12}$.

x	E_p (eV)	E_f (eV)	ΔE (eV)
0.0	0.38	0.20	0.18
0.2	0.31	0.16	0.15
0.4	0.25	0.13	0.12

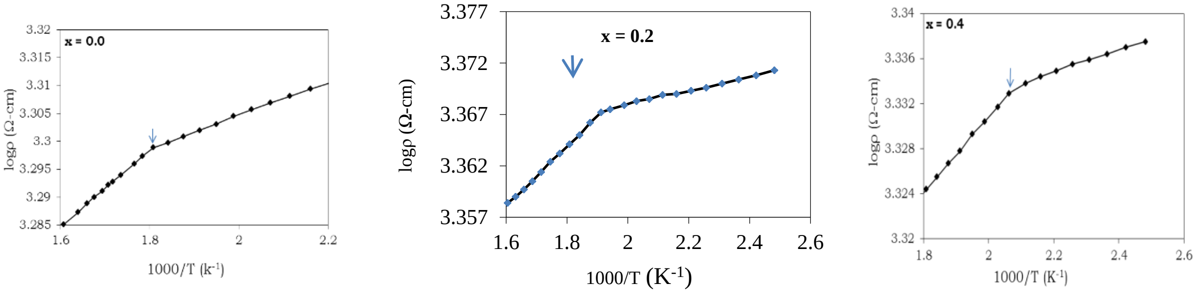


Fig. 5: Variation of logρ versus 1000/T of $Y_3V_xFe_{5-x}O_{12}$ (x=0.0, x=0.2 and x=0.4)

4 Conclusion:

Taking into consideration the observed experimental results on the structural properties, the following conclusions can be drawn. Using ceramic technique the samples of $Y_3Fe_{5-X}V_xO_{12}$ are successfully prepared. The single phase cubic garnet structure of the prepared samples of $Y_3Fe_{5-X}V_xO_{12}$ was confirmed by X- ray diffraction analysis. The Lattice constant found to be increases with V^{3+} substitution. The x-ray density and bulk density decreases with vanadium composition x. The IR spectra show vibrational band frequencies. Thus, the substitution of non-magnetic vanadium (V^{3+}) in Yttrium iron garnet (YIG) influences greatly the structural properties. The d.c. electrical resistivity decreases with temperature. The activation energy decreases with V^{3+} substitution.

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