



## EFFECT OF ALUMINIUM ON STRUCTURAL AND MAGNETIC PROPERTIES OF $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$ GARNET

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### ABSTRACT

Polycrystalline samples of aluminum substituted Yttrium – Europium rare earth garnet with generic formula  $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_x$  ( $x = 0.0, 0.2$  and  $0.4$ ) have been prepared by standard double sintering ceramic technology using AR grade oxides of respective ions ( $Y_2O_3$ ,  $Eu_2O_3$ ,  $Fe_2O_3$  and  $Al_2O_3$ ). The prepared samples were characterized by X-ray diffraction method (XRD). The analysis of room temperature X-ray diffraction patterns clearly indicates the formation of single phase cubic garnet structure. Using XRD data, the lattice constant was calculated for all the samples. The substitution of Al effects in decreasing the lattice constant. The decrease in lattice constant is attributed to difference in ionic radii of  $Fe^{3+}$  and  $Al^{3+}$  ions. The magnetic properties of all the samples were determined using hysteresis loop technique. The saturation magnetization and other magnetic parameter decreases due to substitution of  $Al^{3+}$  ions in place of  $Fe^{3+}$  ions.

### KEYWORDS: -

Y-Eu-Fe-Al Garnet, X-ray diffraction, Magnetization

## 1 INTRODUCTION

The compound with general formula  $R_3T_5O_{12}$  (where R stands for lanthanide Sm-Lu and Yttrium and T for Fe, Ge and Al etc.) are usually termed as garnet. These materials were first identified by Bertaut and Forrat [1] and independently by Geller and Gilleo [2].

Ferrite garnets are uncompensated anti-ferromagnets and exhibit many interesting anomalies which shed light on the nature of anti-ferromagnetization and on the relationship between physical property and crystal structure.

The ferrimagnetic oxide yttrium iron garnet (YIG) is an important magnetic material for a number of technical applications. Depending on the type of application, it is used in the form of bulk, single crystal, epitaxially grown thin film or polycrystalline sintered samples. These three forms are necessarily prepared in different ways and consequently they differ in number of physical properties, e.g. resistivity, optical absorption, lattice constant and photo magnetic properties [3].

Yttrium iron garnet (YIG) is a microwave ferrite and in polycrystalline form has specific characteristics. Yttrium iron garnet in solid solution have become technologically significant for making devices [4]. It is well known that the microstructure of these materials depends on the initial powders and methods used in the synthesis of garnets. They can be prepared by hot pressing [5], co-precipitation, hot spraying [6] etc. Yttrium iron garnet and substituted Yttrium iron garnet show wide variety of interesting magnetic properties [7, 8, 9].

Thus, the study of electrical and magnetic properties of pure yttrium iron garnet and substituted yttrium iron garnet is important from the theoretical and application point of view. The magnetic crystallographic properties of pure Yttrium iron garnet and substituted Yttrium iron garnet have been studied extensively by many workers [7, 10, 11].

To our knowledge very few reports of the structural, electrical and magnetic properties of substituted Yttrium iron garnet are available in the literature [12, 13 and 14].

In the present work, a systematic investigation of structural and magnetic properties of non-magnetic  $Al^{+3}$  substituted yttrium-europium garnet ( $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$ ) was carried out.

The structural and magnetic properties of  $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$  were investigated by means of X-ray diffraction and magnetization measurements.

## 2 EXPERIMENTAL DETAILS

The samples of the series  $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$  were prepared using high purity oxides of  $Y_2O_3$ ,  $Eu_2O_3$ ,  $Fe_2O_3$  and  $Al_2O_3$ . Appropriate quantities of the constituents were mixed thoroughly in agate pestle mortar for 4 hours. The resulting powders were ground and preheated at  $1100^{\circ}C$  at

24 hours. Then it was further mixed and ground for 2 hours. The powder was pressed into cylindrical pellets and fired at 1400°C for 24 hours. Finally, the pellets were cooled to room temperature at the rate of 2°C per minute.

X-ray diffraction patterns were recorded at room temperature using Philips X-ray diffractometer using Cr-K<sub>α</sub> radiation. XRD patterns were recorded in the 2θ range of 20° to 80°. Measurements of magnetization were taken at room temperature using hysteresis loop technique.

### 3 RESULTS AND DISCUSSION

#### 3.1 X-Ray diffraction

The room temperature X-ray diffraction patterns are shown in Fig. 1 for typical sample (x= 0.4). The X-ray diffraction pattern shows the reflections which belongs only to cubic garnet structure. The analysis of the X-ray diffraction data of the system Y<sub>2.8</sub>Eu<sub>0.2</sub>Fe<sub>5-x</sub>Al<sub>x</sub>O<sub>12</sub> showed the presence of single garnet phase. X-Ray diffraction patterns were indexed and all the samples were found to have a cubic garnet structure. Using Miller Indices of the XRD peak, inter-planer spacing 'd' values of all the samples were determined and represented in table 1.

The lattice constant of all the samples were determined from X-ray data and the values are listed in table 2. The lattice constant values are in good agreement with the results of other garnet system [15, 16]. It is evident from Table 2 that the lattice constant decreases linearly with Al substitution. This behaviour of lattice constant can be explained on the basis of difference in ionic radii of the constituent ions. In the present series of Y<sub>2.8</sub>Eu<sub>0.2</sub>Fe<sub>5-x</sub>Al<sub>x</sub>O<sub>12</sub> the magnetic Fe<sup>3+</sup> ions are replaced by non-magnetic Al<sup>3+</sup> ions. Since ionic radii of Al<sup>3+</sup> (0.51Å) ions is smaller than that of Fe<sup>3+</sup> ions (0.64Å), the lattice constant decreases with Al substitution, similar behaviour of lattice constant with composition was reported in the literature [17].

The X-ray density of the all the samples was calculated using the relation [18].

$$d_x = \frac{ZM}{NV} \text{ gm/cm}^3 \quad \text{----- (1)}$$

where,

Z is the number of molecule per unit cell,

M is the molecular weight,

N Avogadro's number and

V is the volume of the unit cell.

The values of X-ray density obtained by using the above relation are presented in Table 2. It is observed from Table 2 that X-ray density decreases with  $Al^{3+}$  substitutions. This is attributed to the fact that the decrease in mass overtakes decrease in lattice constant.

The bulk density of all the samples was measured using Archimedes principle. The values of the bulk density are presented in Table 2.

The percentage porosity (P) of all the samples was calculated using the following relation and the values are given in table 2.

$$P = \left(1 - \frac{d}{d_x}\right) \times 100 \%$$

where,

d is bulk density

$d_x$  is X-ray density

The values of porosity for all the samples are listed in table 2.

### **3.2 Magnetization measurements**

The saturation magnetization ( $\sigma_s$ ) for all the samples was obtained using hysteresis loop technique (M-H plots). The data of magnetization were recorded at room temperature. The M-H plot exhibit normal ferrimagnetic behaviour which reduces with substitution of  $Al^{3+}$  ions. The values of saturation magnetization are given in Table 3. It is evident from Table 3 that the saturation magnetization decreases systematically with the substitution of  $Al^{3+}$  ions. The decrease in saturation magnetization can be explained on the basis of A-B interaction. The substitution of non-magnetic  $Al^{3+}$  reduces active magnetic linkages there by reducing the saturation magnetization.

The saturation magnetization per formula unit in Bohr magneton, i.e. magneton number  $n_B$  ( $\mu_B$ ) was calculated for all the samples using hysteresis loop technique. The values of magneton number ' $n_B$ ' are summarized in Table 3. it is observed from Table 3 that saturation magnetization ' $\sigma_s$ ' and magneton number ' $n_B$ ' decreases with the addition of non-magnetic aluminum.

## **4 CONCLUSIONS**

From the experimental results obtained on  $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$  ( $x = 0.0, 0.2$  and  $0.4$ ), the following conclusions can be drawn.

The samples of  $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$  were successfully synthesized by double sintering ceramic method.

The single phase cubic garnet structure was confirmed for all the samples using X-ray diffraction method.

The lattice constant decreases with increasing  $Al^{3+}$  content 'x'.

The saturation magnetization and magneton number both decreases with  $Al^{3+}$  substitution.

**Table 1**

**Miller indices (hkl) and inter-planer spacing (d) for  $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$  system**

**(x= 0.0, 0.2 and 0.4)**

Plane (hkl)	Inter-planer spacing 'd' (Å)		
	X=0.0	X=0.2	X=0.4
(400)	4.001	4.004	4.018
(331)	4.400	4.433	4.437
(420)	4.469	4.478	4.489
(422)	4.899	4.908	4.922
(440)	5.699	5.698	5.705
(622)	6.640	6.643	6.649
(640)	7.223	7.229	7.243
(642)	7.491	7.504	7.517

**Table 2**

**Lattice Constant, X-ray density ( $d_x$ ), Bulk density (d) and porosity for  $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$  system (x= 0.0,0.2 and 0.4)**

Composition 'x'	Lattice Constant	X-ray density ' $d_x$ ' (g/cm <sup>3</sup> )	Bulk density 'd' (g/cm <sup>3</sup> )	Porosity 'p' %
0.0	12.340	5.303	5.113	2.270
0.2	12.325	5.282	5.024	4.868
0.4	12.308	5.263	5.236	0.510

Table 3

Saturation magnetization ( $\sigma_s$ ), magneton number  $n_B(\mu_B)$   $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$  system  
 (x= 0.0 to 0.4)

Composition 'x'	Saturation magnetization $\sigma_s$ (emu/g)	Magneton number $n_B$ ( $\mu_B$ )
0.0	31.080	4.17
0.2	27.195	3.62
0.4	24.346	3.22

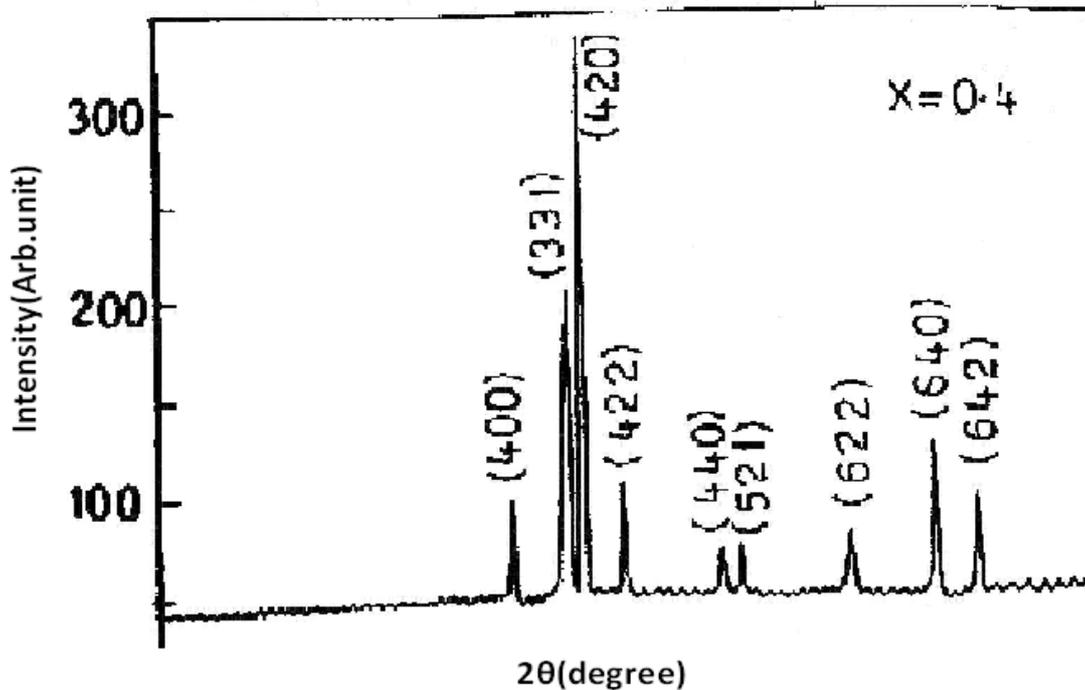


Fig.1 X-ray diffraction pattern of  $Y_{2.8}Eu_{0.2}Fe_{5-x}Al_xO_{12}$  system (x= 0.0, 0.2 and 0.4)

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