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Influence of Dy^{3+} Doping on the Structural and Magnetic Properties of YIG Nanoparticles

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Abstract: In this work, influence of dysprosium (Dy) doping on the structural and magnetic properties of Yttrium Iron Garnet (YIG) nanoparticles has been studied and results are presented. Dy doped YIG nanoparticles ($Y_{3-x}Dy_xFe_5O_{12}$, x = 0.2) are synthesized by standard sol-gel auto combustion method using citric acid as a fuel. Pure and Dy doped YIG nanoparticles were structurally characterized by X-ray diffraction technique at room temperature. X-ray analysis proves the formation of single phase cubic garnet structure. The lattice constant found to be increasing after Dy doping. Using XRD data, X-ray density, unit cell volume and particle size were deduced and their variation with Dy doping is studied. The magnetic properties like saturation magnetization, coercivity etc were studied through hysteresis loop technique. It is observed that, the saturation magnetization decreases after Dy doping.

Keywords: Yttrium iron Garnet, Dy^{3+} doping, Sol-gel auto combustion, XRD.

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I. INTRODUCTION

Ferrites in garnet structure having the formula $A_3B_5O_{12}$ are important class of magnetic materials. Usually, A is rare earth cation like Dy, Gd, La, Nd, Sm etc or Y and B is a transition metal ion i.e. Fe. The crystal structure of garnet possesses three kinds of cation sites or sub lattices namely dodecahedral ‘c’, octahedral ‘a’ and tetrahedral‘d’. The dodecahedral sites are normally occupied by the rare earth cation, while the tetrahedral and octahedral sites are occupied by transition metal Fe. They belong to the cubic structure with space group of Ia3d.

In the family of rare earth garnets, Yttrium iron garnets ($Y_3Fe_5O_{12}$) is the most representative, chemically stable and well known compound for various applications [1]. It is used widely in electronic devices like phase shifters, magneto-optical, wireless communication, sensing and other areas [2]. Their structural, electrical and magnetic properties are depends on the synthesis methods, condition of annealing and grinding, type and nature of dopant. The method of preparation strongly influences the structural and magnetic properties of garnets. YIG usually prepared by ceramic method which involves high temperature (1200°C). This method also produces some intermediate phases which affect the product quality. In order to overcome these problems, wet chemical method like sol-gel auto combustion method is effectively used. The most advantageous of sol-gel auto combustion method is that it produces fine powder of nanometric dimensions, homogeneous and it requires low temperature (120°C). In literature, several reports are available on the synthesis of YIG nanopowders using sol-gel auto combustion techniques. The literature survey reveals that, citric acid is of good chelating agent [3].

In the literature, though the structural and magnetic properties of pure YIG and Dy doped YIG are reported [4-5], it is interesting to investigate structural, magnetic and other properties as method of preparation, synthesis conditions, synthesis parameters plays a important role in governing the properties of YIG nanoparticles. Thus, the aim of the present work is to synthesize pure and Dy doped YIG nanoparticles by maintaining pH, metal to nitrate ratio, annealing temperature etc by sol-gel auto combustion method with citric acid as a chelating agent. The structural and magnetic properties were investigated to understand the effect of Dy doping in YIG.

II. EXPERIMENTAL

Materials

Dysprosium nitrate (Dy $(NO3)_3$ $6H_2O$), Yttrium nitrate (Y $(NO_3)_2{\cdot}6H_2O$), ferric nitrate (Fe $(NO_3)_3{\cdot}9H_2O$) and citric acid were used as a raw materials for sol-gel auto combustion synthesis of YIG nanoparticle. All the reagents used for the synthesis were of analytical grade (AR) and used as received without further purification.

Preparation

Dy doped YIG nanoparticle were synthesized by sol-gel auto combustion method using citric acid as a fuel. The stoichiometric proportions of metal nitrates to fuel (citric acid) ratio as 1:3 were taken into separate glass beakers. The mixed solution was stirred for 20 - 25 minutes to dissolve completely into distilled water. After complete dissolution they were mixed together. Ammonia was added drop-wise into the solution to adjust pH value at 7 and stabilize the nitrate-citric acid solution. Then the neutralized solution was constantly magnetically stirred and heated at 90°C - 100°C for 6 h on a hot plate. On the formation of sol-gel, very viscous gel the temperature was further raised up to 110°C so that the auto combustion of the dried gel started and finally powder was obtained.

Characterizations

The prepared Dy doped YIG nanoparticles were characterized by X-Ray diffraction (XRD) technique. The room temperature XRD pattern was recorded in the 2θ range of 20° and 80° with the appropriate wavelength. Using XRD data, various structural parameters such a crystallite size, lattice constant, unit cell volume, X-ray density etc parameters were calculated. The magnetic properties of prepared Dy doped YIG nanoparticles were studied by vibrating sample magnetometer at room temperature. Using the recorded data, the saturation magnetization, remenent magnetization and coercivity values were deduced.

III. RESULTS AND DISCUSSION

3.1 X-ray diffraction

Fig. 1 depicts X-ray diffraction of Dy doped YIG prepared by sol-gel auto combustion method. X-ray diffraction pattern shows the reflections (321), (400), (420), (431), (422), (521), (532), (444), (640), (642), (800), (840) and (842). Al these reflections belongs to cubic garnet structure. All the reflections are intense and slightly broader. The analysis of XRD pattern confirms the formation of single phase cubic garnet structure.

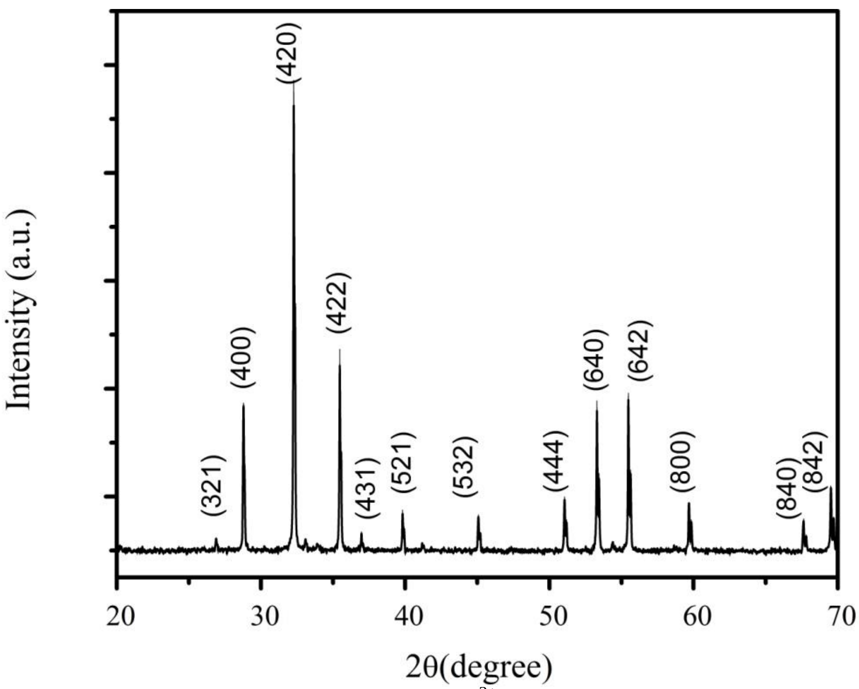

Fig. 1 X-ray diffraction pattern of Dy^{3+} doped YIG nanoparticles

To confirm the nanocrystalline nature, the crystallite size was calculated using the Scherrer's formula. The crystallite size of the undoped and Dy doped YIG nanoparticles are of the order of 9.3 nm and 9.4 respectively, which confirms the nanocrystalline nature of both the sample.

Using the interplanar spacing 'd' and Miller indices (hkl) value the lattice constant of the pure and Dy doped YIG nanoparticles were calculated. The values of lattice constant are given in table 1. It is found that the lattice constant was increase after Dy doping.

Using the XRD data the lattice constant, X-ray density and unit cell volume was calculated and their values are listed in table 1. It is observed from table 1 that, all these structural parameters are in good agreement with that of the literature values [6].

Table 1 Values of crystallite size (t), lattice constant (a), unit cell volume (V), X-ray density (d_X), saturation magnetization (M_S), remenance magnetization (M_r) and coercivity (H_C) of pure and Dy doped YIG nanoparticles

Sample/Parameters	t (nm)	a (Å)	V (Å^3)	d_X (gm/cm^3)	M_S (emu/gm)	M_r (emu/gm)	H_C (Oe)
$Y_3Fe_5O_{12}$	**10**	**12.356**	**1886.40**	**5.197**	**24.33**	**0.018**	**33.81**
$Y_{2.8}Dy_{0.2}Fe_5O_{12}$	**9.4**	**12.365**	**1890.52**	**5.289**	**23.062**	**0.035**	**53.55**

3.2 Magnetic analysis

Fig. 2 depicts the room temperature M-H plot of the Dy doped YIG nanoparticles. Using the M-H plot the values of saturation magnetization (M_S), remenance magnetization (M_r) and coercivity (H_C) were determined and tabulated in the table 1. The lower value of remenance magnetization and coercivity shows the superparamagnetic nature of the sample. It is also observed that, the values of saturation magnetization decreased after Dy doping. However, the value of remenance magnetization and coercivity was increased after Dy doping.

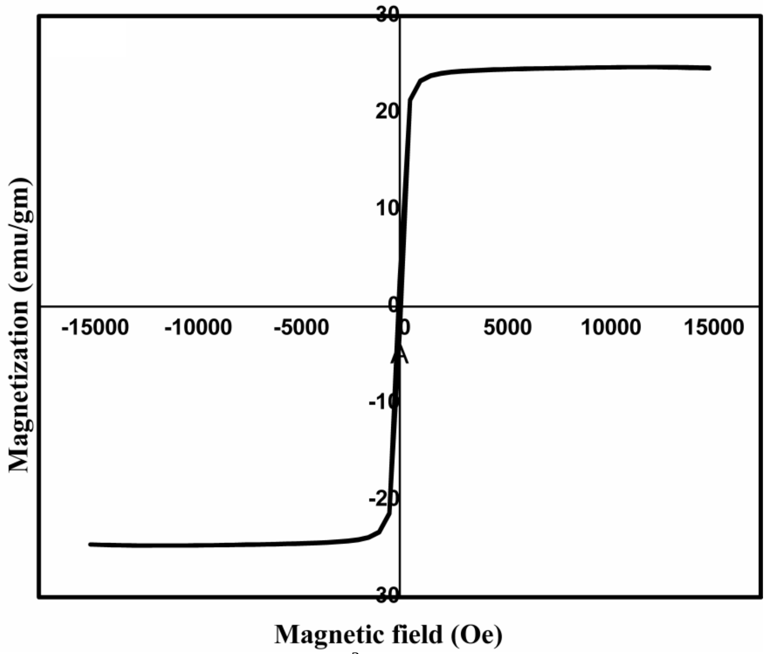

Fig. 2 M-H plot of Dy^{3+} doped YIG nanoparticles

IV. CONCLUSIONS

Pure and Dy doped yttrium iron garnet (YIG) nanoparticles were successfully synthesized using sol-gel auto combustion method. X-ray analysis confirms the formation of single phase cubic spinel structure as well as nanocrystalline nature for both the samples. The lattice constant, X-ray density and other structural parameters are found to be in the reported range. The superparamagnetic nature was observed in M-H hysteresis curve. The magnetization values were decreased after Dy doping in YIG nanoparticles.

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