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Thermoluminescence investigations of sol–gel derived and γ-irradiated rare earth (Eu and Nd) doped YAG nanophosphors

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ABSTRACT

Nanocrystalline YAG doped with Eu^{3+} and Nd^{3+} has been synthesized by a sol–gel technique. The prepared nanophosphors were calcined and characterized by XRD, SEM. The XRD analysis revealed well-defined cubic phase. Electron microscopy showed spherical morphologies with an average size of 15–20 nm. The thermoluminescence (TL) properties of as prepared nanophosphors were investigated after γ-irradiation using ^{60}Co source at room temperature. It has been found that there is a prominent TL glow peak at 290–295 °C for the as prepared doped samples. The TL glow curve showed variation in TL peak intensity as the concentration of dopant is changed. Kinetic data and trap depth for the synthesized samples were calculated by a peak shape method. It has been found that TL response is nonlinear in the range 0.29–1.16 kGy. This paper discusses about the optimal doping concentration of Eu and Nd in YAG nanophosphors.

1. Introduction

Rare earth (RE) doped yttrium aluminum garnet (YAG) has been thoroughly investigated for application in various fields, such as lasers, scintillators, cathode ray tubes (CRT), field-emission displays (FEDs), plasmas display panels (PDPs), and optical windows, due to its attractive optical property, outstanding chemical stability, low creep rate, and high thermal resistance [1–4]. Luminescent materials based on YAG are stable under conditions of high irradiation with an electron beam [5,6]. The structural and luminescent properties of several rare earth doped YAG have been extensively studied during the last decade [7–11].

Thermoluminescence (TL) is very sensitive technique for detection of traps or defects. Several studies have been reported on the optical properties of YAG nanoparticles, but very limited studies have been done to explore the thermoluminescence properties (TL) of YAG which is necessary for dosimetric applications. Rodríguez-Rojas et al. studied the thermo-luminescence characterization of Tb^{3+} and Ce^{3+} doped nanocrystalline $Y_3Al_5O_{12}$ exposed to UV-irradiation and found it suitable for UV-irradiation dosimeter and photonics application [12]. However to the best of our knowledge nothing has been so far reported about TL characteristics and dose response of γ-irradiated sol–gel derived YAG: Eu^{3+} and YAG: Nd^{3+} nanophosphors.

In this paper, sol–gel synthesis and systematic study of the nanocrystalline Eu^{3+} and Nd^{3+} have been done. The optimal doping concentration, effect of increase in irradiation on TL has been studied and possible mechanism for TL has been discussed.

2. Experimental

2.1. Materials and methods

A.R. grade chemicals were used in the present investigation. Tin (IV) chloride tetrahydrate ($SnCl_4 \cdot 4H_2O$, Scitech), ammonium hydroxide (NH_4OH 25%, Merck), sodium hydroxide (NaOH, R&M Chemicals), europium oxide (Eu_2O_3) etc. were procured commercially and used without any further purification. The solutions were prepared with ultra-pure water obtained by a SQ-Ultra Pure Water Purification System, Germany.

2.2. Synthesis of YAG:RE nanophosphors

In the present investigation Eu^{3+} and Nd^{3+} doped $Y_3A1_5O_{12}$ nanophosphors were synthesized by a sol–gel method. The schematic

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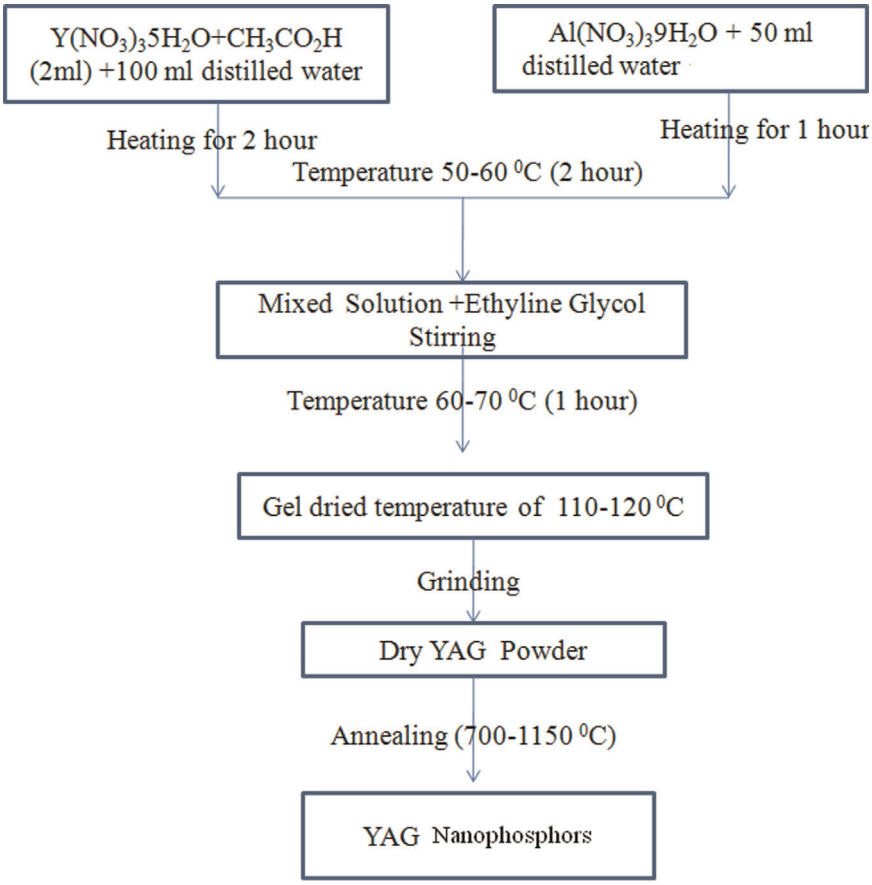

Scheme 1. Schematic representation of formation YAG:RE(Eu/Nd) nanophosphors.

diagram of the process is shown in Scheme 1. In this method two different solutions were taken for the synthesis of the desired nanophosphors. In first solution, appropriate amount of yttrium nitrate ($Y(NO_3)_3 \cdot 5H_2O$) was dissolved in 2 mL of acetic acid (CH_3COOH) followed by addition of 100 mL ultra-pure water and was stirred for 2 h at 50–70 °C. In second solution, aluminum nitrate ($Al(NO_3)_3 \cdot 9H_2O$) was dissolved in 50 mL of ultra-pure water. Subsequently both solutions were mixed and complexed with 2 mL of 1,2-ethanediol $C_2H_6O_2$ (ethylene glycol) and stirring was continued at 60–70 °C until a gel (foam) was formed. The gel was dried at 100–130 °C and then grinded to obtain a fine powder. This powder was annealed at 700–900 °C for 6 h and the temperature was raised to 1150 °C for 4 h. After this, the sample was allowed to cool at room temperature, and was finally grinded. For doped samples appropriate amount of Eu^{3+} and Nd^{3+} was added during the initial stirring of yttrium precursor solution and the subsequent process was repeated as described above.

2.3. Characterization

The X-ray diffraction (XRD) patterns were recorded to characterize the phase of the nanophosphors using a Rigaku miniflex powder diffractometer with a Cu Kα radiation source ($\lambda = 1.5406$ Å) at 40 kV and 150 mA 2θ range of 20–60° at step size of 0.02° (2θ). The SEM was recorded by CARL ZEISS EVO 60 Model-CA7625. The obtained nanophosphors were exposed to ^{60}Co γ-rays in the dose range of 0.26–1.16 kGy at room temperature. The TL glow curves of the samples were measured by using a Nucleonix model 1009 I TL reader with a heating rate of 5 °C/s in temperature range from 50 to 400 °C. Every time 2 mg of irradiated phosphor was taken for TL measurements.

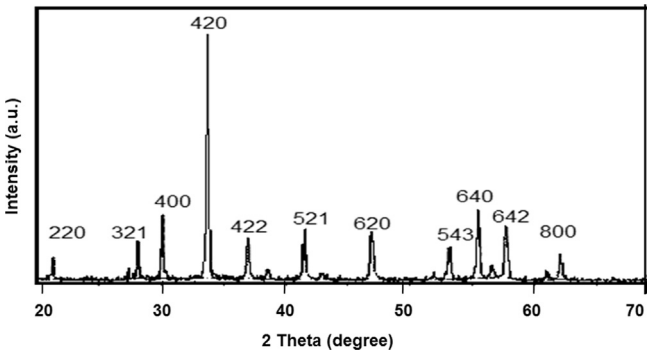

Fig. 1. XRD diffraction patterns of YAG nanophosphors.

3. Results and discussion

3.1. Phase characterization

The recorded XRD pattern of the $Y_3A1_5O_{12}$ nanophosphors is shown in Fig. 1. The XRD spectrum for $Y_3A1_5O_{12}$ indicates that sample was amorphous and has a well-defined monophasic polycrystalline YAG structure. All XRD peaks were indexed in terms of a garnet structure according to the standard JCPDS card no. 33-40. The unit cell parameters are in good agreement with the standard values. The main peak of the cubic $Y_3A1_5O_{12}$ structure is centered at $2\theta = 33.317°$ and corresponds to the crystalline plane with Miller indices of (4,2,0). The observed interplaner spacing of $Y_3A1_5O_{12}$ nanophosphors is 2.660 Å (d_{420}). The average nanocrystallites size is calculated from full width at half-maximum of major XRD peaks using the Debye–Scherrer's formula