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Thermoluminescence characterization of γ-ray irradiated Dy^{3+} activated $SrAl_4O_7$ nanophosphor

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ABSTRACT

Dy doped strontium aluminate phosphor ($SrAl_4O_7$:Dy(15% molar concentration)) was synthesized by combustion method using urea as a reducer at initiating temperature of 600^{o}C. The absorption spectra shows the absorption edges at λ = 242 nm, thus the band gap of 5.11 eV. The Thermoluminescence (TL) property of Dy(15%) doped $SrAl_4O_7$ nanophosphor has been investigated for γ-irradiation. The TL glow curve of $SrAl_4O_7$:Dy (15%) phosphor with different γ-ray doses show the dose increases the TL-intensity while the temperature corresponding to maximum intensity remains nearly same. The maximum TL-intensity observes around 172.84 ^{o}C for the different doses. It was found that TL intensity strongly depends upon the γ-dose. It shows linear response upto 2.36 kGy. Hence Dy(15%) doped $SrAl_4O_7$ could be used for TL Dosimetry upto 2.36 kGy. Copyright © 2014 VBRI press.

Keywords: Keywords: Thermoluminescence; combustion synthesis; strontium aluminate.

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Introduction

The alkaline earth aluminates are an important class of phosphorescence materials because of their high quantum efficiency in visible region **[1]**, long persistence of phosphorescence, good stability, color purity and good chemical, thermal and radiation resistance **[2]**. Dy^{3+} ion is a good activator for preparation of electron-trapping luminescence materials **[3]**. Based on that some solid dosimeters such as BaB_4O_7:Dy^{3+} & SrB_4O_7:Dy^{3+} were produced **[4-5]**. A choice of the Dy^{3+} comes from the fact that one can readily estimate the coordination state around

Dy^{3+}, e.g., coordination symmetry and electronic state of chemical bond between Dy^{3+} and a ligand, on the basis of the relative intensity of emission lines caused by the 4 *f* –4*f* transitions of Dy^{3+} **[6]**.

Thermoluminescence is the emission of light from an insulator or semiconductor when they are thermally stimulated following the previous absorption of energy from radiation. It is very important and convenient method of investigating the nature of traps and trapping level in crystals **[7]**. It is used to detect the combination emission caused by thermal de-trapping of carriers. The energy corresponding to the glow peak is equal to the trap depth. The traps and carriers (electrons and holes) may be produced by irradiation, or created during sample processing. The synthesis of oxide phosphors has been achieved by a variety of routes. Combustion process is very simple, safe, energy saving and takes only a few minutes. The method makes use of the heat energy liberated by the redox exothermic reaction at a relative low igniting temperature between metal nitrates and urea as fuel. It was found that the $SrAl_2O_4:Eu^{2+}$ prepared at initiating temperature 600°C exists as a single phase monoclinic structure **[8]**. In this paper we have reported the Thermoluminescence behavior of γ-irradiated Dy doped (15% molar concentration) $SrAl_4O_7$ phosphor for possible application in γ-radiation dosimetry.

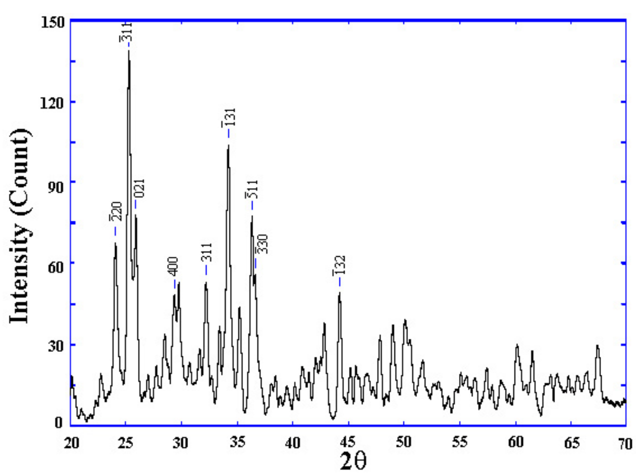

Fig. 1. X-ray diffraction pattern of $SrAl_4O_7$:Dy phosphor matched with JCPDS data file no. 25-1208.

Experimental

Analytical grade strontium nitrate $Sr(NO_3)_2$, aluminum nitrate $Al(NO_3)_3.9H_2O$, Dysprosium oxide Dy_2O_3 and urea $CO(NH_2)_2$ were used as the starting materials. Stoichiometric composition of the metal nitrates (oxidizers) and urea (fuel) were calculated using the total oxidizing and reducing valences of the components. First of all Dy_2O_3 was converted into $Dy(NO_3)_3$ by mixing it into 2 ml of concentrated HNO_3. Then weighed quantities of each nitrate and urea were mixed together and crushed into mortar for 1 hour to form a thick paste. The resulting paste was placed in a vertical cylindrical muffle furnace maintained at 600°C. Initially the mixture boiled and underwent dehydration followed by decomposition with the evolution of large amount of gases (oxides of carbon, nitrogen and ammonia). The process being highly exothermic continued and the spontaneous ignition occurred. The solution underwent smoldering combustion with enormous swelling, producing white foamy and voluminous ash. The flame temperature, as high as 1400 - 1600 °C, converts the vapor phase oxides into mixed aluminates. The flame persists for ~30 seconds. The foamy product can easily be milled to obtain the precursor powder.

Powder XRD data of the phosphor was collected on a Bruker D2 Phaser X-ray diffractor using Cu/Kα radiation (λ=1.54056 Å). Absorption spectra were recorded using Shimadzu UV-1700 UV-Visible spectrophotometer. The sample was irradiated with γ-rays using a ^{60}Co source having an exposure rate of 0.59 kGy/hr, it was wrapped in aluminum foil and kept in dark till the TL studies were carried out. A routine TL setup (Nucleonix TL 10091) was used for recording TL glow curves.

Results and discussion

XRD analysis

The x-ray diffraction patterns (**Fig. 1**) indicate that the crystal structure of $SrAl_4O_7$:Dy is mainly monoclinic and matches well to the JCPDS data file no. 25-1208. The diffraction intensity is maximum for (-311) plane having 2θ=25.279° and FWHM= 0.198 radians. The particle size was calculated using Scherrer formula and it was found to be 47.78 nm. The particle sizes for other planes are shown in **Table 1**.

Table 1. Particle size with crystal planes.

Planes	2Theta	FWHM	Size (nm)
-220	24.023	0.217	43.49
-311	25.279	0.198	47.78
021	25.888	0.227	41.72
400	28.468	0.136	70.02
311	32.241	0.197	48.77
-131	34.141	0.261	36.99
-511	36.651	0.447	21.75
-132	47.757	0.204	49.48

Optical absorption spectra

Fig. 2 shows the optical absorption spectra of $SrAl_4O_7$:Dy in the range of 190nm-500nm. No absorption occur for wavelength λ > 390nm (visible). By the absorption spectra of the sample the absorption edges was found at λ = 242 nm, thus the bandgap was found to be 5.11 eV.

Thermoluminescence studies

The TL response of γ-irradiated $SrAl_4O_7$:Dy (15%) was recorded in the temperature range between room temperature to 300°C. The TL glow curve of $SrAl_4O_7$:Dy (15%) phosphor with different γ-doses is shown in **Fig. 3**. It is clear from the figure that the dose increases the TL-intensity while the temperature corresponding to maximum intensity remains nearly same. The maximum TL-intensity corresponds to 172.84 °C, 173.4 °C, 170.6 °C, 170.2 °C and

171.3 °C for the dose value of 49.17 Gy, 147.5 Gy, 295 Gy, 885 Gy and 2360 Gy respectively.

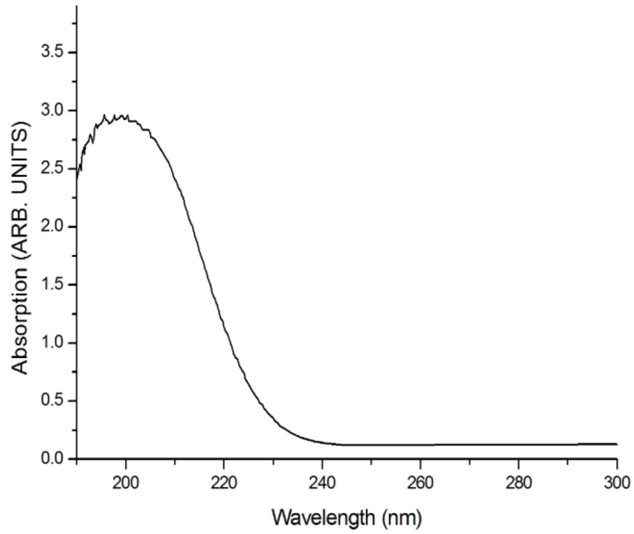

Fig. 2. Absorption spectra of $SrAl_4O_7$:Dy having absorption edge 242nm.

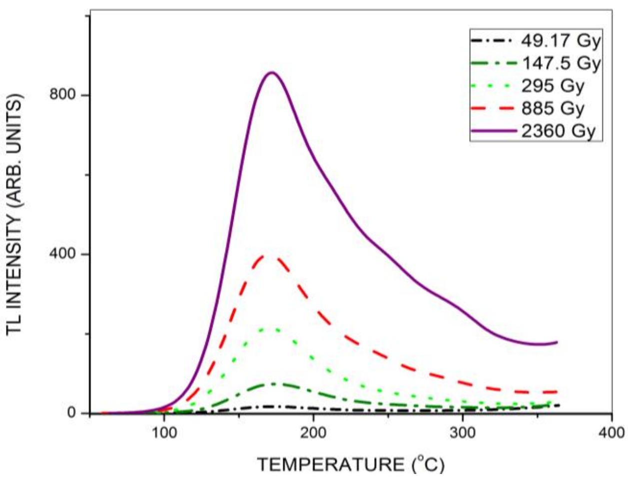

Fig. 3. TL Glow curve of $SrAl_4O_7$:Dy(15%) irradiated with different doses of γ radiation.

Table 2. Kinetic parameter as calculated by Chen's equation.

Dose (Gy)	Sametry Factor	E_t	E_d	E_w
49.17	0.63	0.97	0.60	0.57
147.5	0.61	1.01	0.70	0.67
295	0.59	1.02	0.75	0.71
885	0.64	1.10	0.68	0.67
2360	0.70	1.16	0.52	0.52

The order of kinetics was calculated by Chen's Method measuring the symmetry factor $\mu=\delta/\omega$, where δ is half width towards fall-off side of glow curve and ω is full width at half maximum of glow curve. They are calculated as $\delta = T_2-T_m$, $\omega = T_2-T_1$ and $\tau = T_m-T_1$, where T_m is peak temperature corresponding to maximum intensity, T_1 & T_2 are temperature on either side of T_m corresponding to half of maximum intensity. The trap depth was calculated by the Chen's equation-

$$E_\alpha = C_\alpha\left(\frac{kT_m^2}{\alpha}\right) - b_\alpha\left(2kT_m\right)$$

where E_α is trap depth and C_α and b_α are constants of Chen's equation, α was replaced by δ, ω and τ as per the case.

The calculated values of kinetic parameters are listed in **Table 2**. From the value of the geometrical factor it is clear that the peaks obey general order kinetics. The mean trap depth for the peak comes out to be 0.71 eV, 0.79eV, 0.83 eV, 0.82 eV and 0.73 eV for the doses 49.17, 147.5, 295, 885 and 2360 Gy respectively.The addition of Dy as activator produces deep traps at temperature at around 171 °C, which could be useful for dosimetric purpose due to its thermal stability.

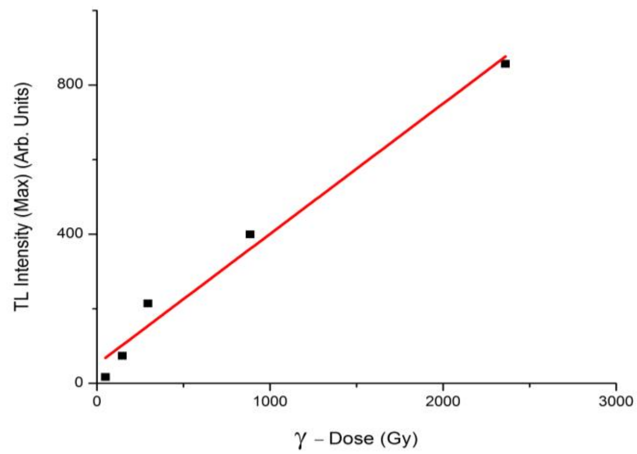

Fig. 4. Variation in Maximum TL intensity with γ-dose.

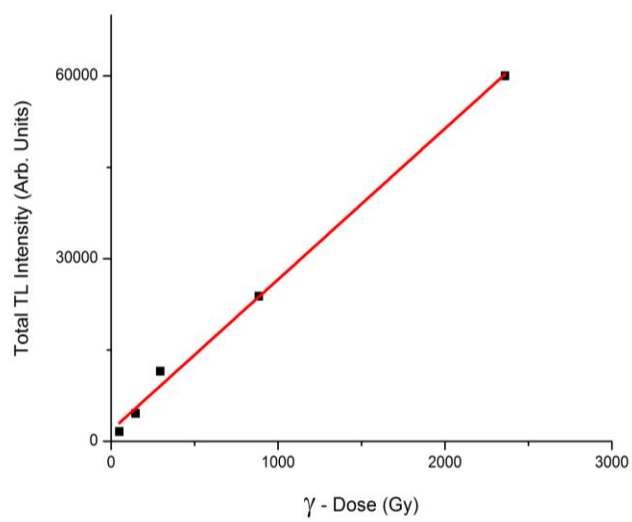

Fig. 5. Variation in Total TL-intensity with γ-dose.

The TL intensity is maximum for 2360 Gy dose, the variation in maximum TL-intensity with γ-dose is shown in **Fig. 4**. From the figure it is clear that maximum TL-intensity shows linear response upto the range 2.36 kGy and hence we suggest the application of $SrAl_4O_7$:Dy (15%) as γ-dosimeter. The Total-TL intensity (integral count) also shows same behavior with γ-dose shown in **Fig. 5**.

Conclusion

We have investigated the Thermoluminescence phenomena in the γ-irradiated $SrAl_4O_7$:Dy (15%) nano-phosphor (of size 47.78 nm). The phosphor was prepared by combustion method which appears to be a more feasible method for production. The absorption spectra show the absorption edges at λ = 242 nm, thus the band gap of 5.11 eV. The TL property of Dy(15%) doped $SrAl_4O_7$ nanophosphor has been investigated for γ-irradiation. It was found that TL intensity strongly depends upon the γ-dose. It shows linear response upto 2.36 kGy. Hence Dy(15%) doped $SrAl_4O_7$ could be used for TL Dosimetry upto 2.36 kGy.

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