International Journal of Luminescence and Applications (ISSN: 2277-6362)
Vol. 5, No. 2, June 2015. Article ID: 105. pp.264-267.

Comparative Studies on Gamma and Ion Beam Induced Luminescence in Sol Gel Derived Yttrium Oxide

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Abstract— *The yttrium oxide (Y_2O_3) was synthesized by low temperature sol gel method. The synthesized product was annealed at 900^{o}C for 2 hour and pellets were prepared. The pellets were irradiated with 100 MeV swift Si^{8+} ions with different ion fluence and γ-rays. These were characterized by Photoluminescence (PL) and Thermoluminescence (TL) at room temperature. A broad PL emission with peak at ~335-645 nm upon 250 nm excitation was observed in pristine sample. However, PL intensity was found to enhanced in SHI irradiated samples. TL response of SHI irradiated samples shows prominent glow with peak at 390 K, 383 K and 630 K were observed. TL response of γ-rayed Y_2O_3 were also studied and compared. The TL kinetic parameters calculated using glow curve shape method and exhibit a second order kinetics.*

Keywords— *Gamma rays; Swift heavy ions; Photoluminescence; Thermoluminescence.*

PACS— *07.85.-m; 78.70.-g; 78.55.-m; 78.60.Kn.*

1. INTRODUCTION

Nanocrystalline yttrium oxide (Y_2O_3) was known for their interesting properties such as high radiation resistance, high melting point and thermal conductivity. It is a suitable material for photonic waveguide due to its high band gap (5.72 eV), with a very high refractive index (~2) and a wide transmission range (280–8000 nm) [1]. Consequently, they are the best host materials for different host for various applications such as display devices, optoelectronics, space and craft dosimetry [2]. Energetic swift heavy ion (SHI) interact with target materials and loss its energy through electronic processes which dominates at an energy of about 1 MeV/ nucleon or more and nuclear processes which dominates at an energy of 1 KeV/ nucleon [3]. It creates point defects, defects clusters and ion tracks in the irradiated materials along the projected range [4, 5]. Defects are largely responsible for enhancement of luminescence properties. In the present work, we report a comparative study of 100MeV swift Si^{8+} and γ-ray irradiation on the luminescence properties of nanocrystalline yttrium oxide.

2. EXPERIMENTAL

Nanocrystalline Y_2O_3 powder used in the present work was synthesized by the low temperature sol gel method and pellets of these sample was prepared based on the procedure discussed elsewhere [6]. The pellets were irradiated with 100 MeV swift Si^{8+} ions for fluence 1×10^{10} ions cm^{-2}. This experiment was performed using 15 UD Pelletron Accelerator at the Inter University Accelerator Centre, New Delhi, India. The PL of pristine and irradiated samples was recorded using a Hitachi F-2700 fluorescence spectrophotometer. TL measurements are performed at an heating rate of 5 Ks^{-1} using a Harshaw-3500 TLD reader.

3. RESULTS AND DISCUSSION

Figure 1 shows the PL spectra of pristine, 100 MeV Si^{8+} and gamma irradiated nanocrysatalline Y_2O_3 samples recorded at room temperature. The PL spectra of these samples indicate broad emission in the range about ~335-645 nm upon 250 nm excitation. It consists of overlapping of couple of emission bands. They are attributed to oxygen vacancy defects such as F and F^+-centers and Y^{3+}- O^{2-} donor acceptor pair [7, 8]. Bordun studied the influence of oxygen vacancies on luminescence spectra of Y_2O_3. He concluded that the luminescence bands with maxima at 365 and 428 nm are due to presence of oxygen vacancies related to radiative recombination [9]. Osipov and coworkers studied luminescence of pure yttria [10]. They reported cathodoluminescence spectra with peak at 465 nm and the emission is ascribed to recombination of associative Y^{3+}-O^{2-}donor acceptor pair. SHI irradiated sample with fluence of 1×10^{10} ions cm^{-2} shows highest luminescence emission and these indicates large number of defects generation in the material. Emission peak positions were shifted towards the lower energy side after ion and gamma irradiation. It might be due to modification of band gap of the material [11]. After energetic ion

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irradiation on samples, the crystallite size reduces because energetic ions impart more damage to the sample.

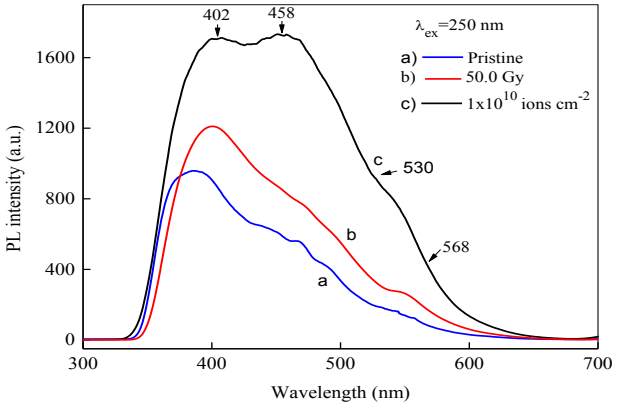

Fig. 1: PL spectra of pristine, 100 MeV swift Si^{8+} ion and γ-ray irradiated Y_2O_3.

Figure 2 shows TL glow curves of γ-rayed and SHI irradiated sol gel synthesized nanocrystalline Y_2O_3.Three TL glows with peaks at ~383, 424 and 557 K were observed in 50 Gy γ-rayed Y_2O_3 samples while four TL glows with peaks at ~390, 424, 557 and 630 K were observed in 100 MeV swift Si^{8+} ions irradiated Y_2O_3. A new TL glow at 630 K is observed in ion irradiated samples. This TL glow at 630 K in ion irradiated sample is attributed to deep traps and it was dominating of all other TL glows.

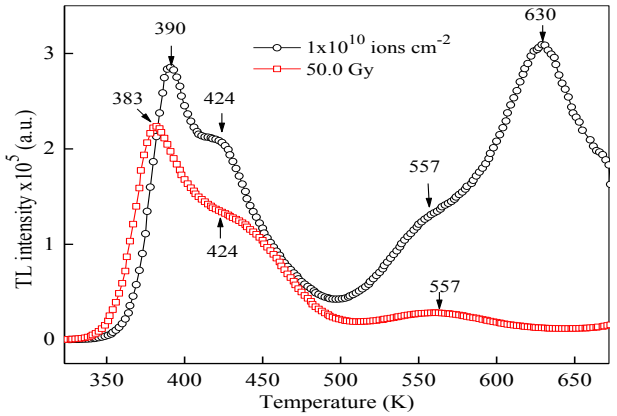

Fig. 2: TL glow curves of 100 MeV swift Si^{8+} ion and γ-ray irradiated Y_2O_3.

4. KINETIC PARAMETERS

To understand the TL mechanism of the material requires the knowledge of kinetic parameters (trapping parameters), i.e. activation energy (E) of the traps involved in TL emission, order of kinetics (b) and frequency factor (s) associated with the glow peaks of TL. Here, E is the energy required for the release of charge carrier from the trap to reach its excited state and 's' is the rate of electron ejection. The order of kinetics b is a measure of the probability that a free electron gets retrapped or recombination with holes. To obtain these parameters, the glow curves are deconvoluted using a glow curve deconvolution (GCD) technique [6,7]. The detail GCD technique is discussed by kitis et al [6]. They reported the TL glow curve equation of general order kinetics given below which is used for glow curve deconvolution.

$$I(T) = I_m . b^{b/(b-1)} . \exp\left(\frac{E}{kT}.\frac{T-T_m}{T_m}\right) \times \left[(b-1).(1-\Delta).\frac{T^2}{T_m^2} \times \exp\left(\frac{E}{kT}.\frac{T-T_m}{T_m}\right) + Z_m\right]^{-b/(b-1)} \quad (2)$$

where, $\Delta = \frac{2kT}{E}$; $\Delta_m = \frac{2kT_m}{E}$;

$$Z_m = 1 + (b-1).\Delta_m$$

where, k is Boltzmann constant (8.6×10^{-5} eV K^{-1}), β is the linear heating rate (5 Ks^{-1}) and I_m is glow peak intensity and T_m is glow peak temperature. The above equation inserted with an Excel spreadsheet. For the fitting procedure, one has to insert initial, arbitrary but meaningful values for the parameters I_m, T_m, E and b for each single glow peak. When the curve fitting procedure is completed, it gives the net values of I_m, T_m, E and b. In addition, the frequency factor and figure-of merit (FOM) values are found. The expression for the frequency factor and figure-of merit is given by [2];

$$\frac{\beta E}{kT_m^2} = s \exp\frac{-E}{KT_m}\left[1 + (b-1)\Delta_m\right] \quad (3)$$

$$\text{FOM} = \frac{\sum \left|TL_{exp} - TL_{the}\right|}{\sum TL_{the}} \quad (4)$$

Here TL_{exp} and TL_{the} represent the TL intensity of experimental and theoretical glow curves respectively. The FOM for the present curve fitting found to be 1.05 and 1.82 % for gamma and ion irradiation samples respectively. This indicates that, a good agreement between theoretically generated and experimentally recorded TL glow curves. The above traps parameters are tabulated in Table 1.

Deconvoluted TL curves of gamma and 100 MeV Si^{8+} irradiated nanocrystalline powder sample for a dose of 50.0 Gy and 1×10^{10} ions cm^{-2} are shown in figure 3(a) and 3(b) respectively. The deconvolution of the experimental glow curves has revealed TL glows with peak at 380, 405, 440, 465, 530, 561 and 594 K for gamma and TL glow with peaks at 389.8, 417.8, 440, 468, 534, 572 and 628.5 K for ion irradiated Y_2O_3. It is found that the all glow peaks obey the second order kinetics and activation energies are increased with increasing TL glow peak position. It is indicating that the traps are located in different traps level in the band gap of material. The trap parameters are tabulated in table1. SHI irradiated TL trap parameter/activation energy shows high values when compared to that of gamma irradiated TL.

Table 1: Trap parameters corresponding to different TL glow peaks in nanocrystalline Y_2O_3

Irradiation	*Peaks*	*T_m (K)*	*Order of kinetics*	*Activation Energy (eV)*	*Frequency factor (s^{-1})*	*FOM (%)*
	T_{m1}	380	1.6	1.35	4.24×10^{17}	
50 Gy	T_{m2}	405	2	1.37	5.16×10^{16}	
	T_{m3}	440	2	1.40	4.33×10^{15}	1.05
	T_{m4}	465	2	1.42	8.87×10^{14}	
	T_{m5}	530	2	1.45	1.73×10^{13}	
	T_{m6}	561	2	1.50	7.77×10^{12}	
	T_{m7}	594	1.5	1.55	3.50×10^{12}	
1×10^{10} ions cm^{-2}	T_{m1}	389.8	1.55	1.40	6.58×10^{17}	
	T_{m2}	417.8	2	1.42	6.05×10^{16}	
	T_{m3}	440	2	1.45	1.68×10^{16}	1.82
	T_{m4}	468	2	1.47	2.49×10^{15}	
	T_{m5}	534	2	1.50	4.13×10^{13}	
	T_{m6}	572	2	1.55	1.17×10^{13}	
	T_{m7}	628.5	1.2	1.60	1.56×10^{12}	

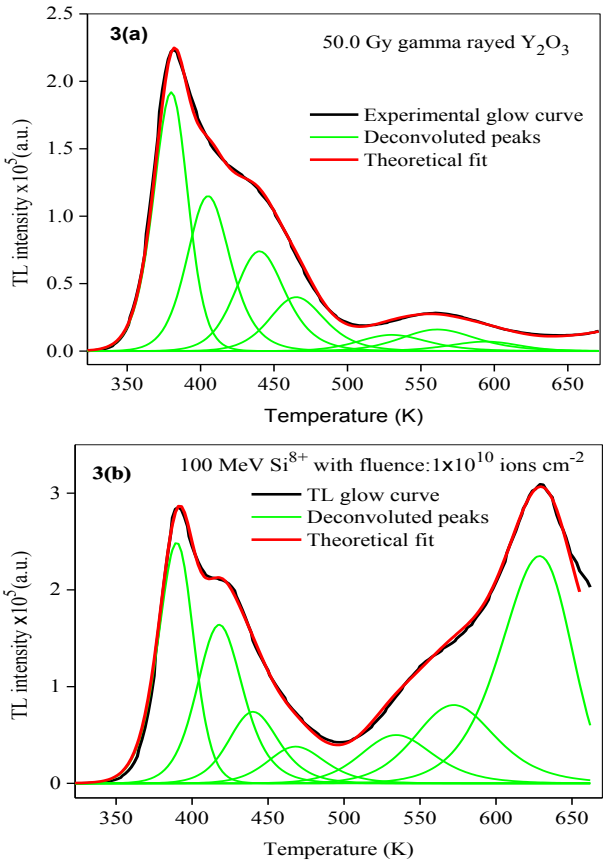

Fig. 3: Deconvoluted TL glow curve of (a) 50 Gy gamma (b)100 MeV swift Si^{8+} ion irradiated nanocrystalline Y_2O_3.

5. CONCLUSION

The modification of luminescence properties induced by 100 MeV Si^{8+} ions and gamma of sol gel synthesized nanocrystalline Y_2O_3 have been investigated. The impacts of SHI, lead to the destruction of the Y^{3+}-O^{2-} in Y_2O_3. PL emission are attributed to oxygen vacancy defects such as F and F^+-centers and Y^{3+}- O^{2-} donor acceptor. Deep level traps were created by induced swift heavy ions. TL glow curves exhibit second order kinetics due to probability of retrapping centers is high.

ACKNOWLEDGMENTS

The authors express their sincere thanks to Dr. D.K. Avasthi, Materials Science Group, Dr. S.P. Lochab, Health Physics Group, Inter University Accelerator Centre, New Delhi, India for their constant encouragement and help during the experiment. Also, one of the authors (NJS) is grateful to Inter University Accelerator Centre, New Delhi, for providing fellowship under UFR (No. 48303) scheme.

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