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Thermoluminescence Properties of Gamma and C^{5+} Ion Beam Irradiated $Sr_2(1\text{-}X)(Dy,Na)_X znwo_6$ Phosphors

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ABSTRACT

The thermoluminescence study of $Sr_{2(1-x)}(Dy,Na)_xZnWO_6$ phosphors irradiated with γ-ray (Co^{60}) and 75keV C^{5+} ion beam were investigated. The TL glow curves of γ-rays and C^{5+} ion beam irradiate phosphors show similar nature. The glow curve has three distinguishable overlapping components of glow peaks. The relative intensities of component glow peaks are different for both type of irradiation. Glow curves were analyzed by deconvolution and calculation of trapping parameters using Chen's peak shape method for understanding the nature of trapping centers which results different glow peaks.

Keywords: Thermoluminescence, C^{5+} ion beam, Double perovskite tungstate, Phosphors.

I. INTRODUCTION

Thermoluminescence (TL) is emission of light from the material as consequences of heating a material which is previously exposed to ionizing radiation. The glow curve (graph of TL emission intensity vs. temperature) yields important information about the nature of the traps in the luminescent material. TL is an extensive technique used for dosimetry of ionizing radiations as in this process, the intensity of glow peak reflects the absorbed dose **[1-7]**. Phosphor material show different response to different types of ionizing radiation, this is due to different spatial dose distribution **[8]**.

Heavy ion beams have been used for diagnostic and therapeutic purposes for a long time now. The application of radiotherapy is based on the fundamental principle of achieving precise dose localization in the target lesion while causing minimal damage to surrounding normal tissues. Energy deposition of carbon ion beams increases with penetration depth up to the sharp maximum at the end of their range, known as the Bragg peak. Because the original peak is too narrow and sharp to completely cover the target lesion, broadening of the narrow peak according to the size of the lesion is used in cancer treatment **[8,9]**. This result in carbon ion beams allowing a highly localized deposition of energy that can be utilized for increasing radiation doses to tumors while minimizing irradiation to adjacent normal tissues. Nevertheless, the dose of these energetic ions needs to be measured with great precision and accuracy, especially when dealing with human beings. This has triggered investigations to use thermoluminescent dosimeters (TLDs) for dose verification in heavy ion irradiation. In this respects Numan Salah have investigated Carbon ions irradiation on nano and microcrystalline $CaSO_4$:Dy a well-known TLD material **[10]**.

The tungstates with double perovskite structure offers various interesting physical properties such as electrical **[11]**, magnetic **[12]**, optical **[13]** and photocatalytic **[14]** properties, which has attracted researchers' attention since 50 years **[15,16]**. As the Dy^{3+} doped Sr_2ZnWO_6 phosphors shows excellent photo luminescent properties. Thus, in this context we extend our previous work **[17]**, and investigate the TL properties of $Sr_{2(1-x)}(Dy,Na)_xZnWO_6$ phosphors using γ-rays from Co^{60} source and C^{5+} ion beam.

II. METHODS AND MATERIAL

The pure and Dy^{3+} doped samples of Sr_2ZnWO_6 were synthesized by solid state reaction method at 1250°C. The detailed procedure is in our previous work reported somewhere else **[17]**.

The TL measurements of as synthesized phosphor were carried out upon the exposure of γ-rays and C^{5+} ion beam at the Inter-University Accelerator Center (IUAC), New Delhi, India. Fixed mass (5 mg) of phosphor samples were exposed to various γ-doses (10Gy – 1kGy) from Co^{60} source having dose rate of 6.66 $kGyh^{-1}$ at room temperature, and TL glow curve of the phosphor of the samples were recorded.

For TL studies of C^{5+} ion beam exposure the samples were pelletized by using 1 cm diameter Die punch and 150 mg weight of sample, 5 tons of pressure was given for making pellet, the pellets were prepared without any binder. For irradiation, the pellets of sample were mounted on a copper target ladder. The copper ladder prevents heating of the sample during Swift Heavy Ion (SHI) irradiation. For irradiation the ladder was kept inside the evacuated irradiation chamber. The ion beams were magnetically scanned on a 10 mm X 10 mm area of sample surface for a uniform irradiation and the beam spot size used was 2.5 mm^2. The samples in the form of pellets were irradiated at room temperature by C^{5+} ion beam at 75 MeV energies for different ion fluence in the range 15 X 10^{10} to 30 X 10^{12} ions/cm^2, using a 16 MV Tandem Van de Graff type electrostatic accelerator (15 UD pelletron) at the IUAC. The full details of this setup are given by Kanjilal et al. **[18]**.

The glow curves (GC) of all irradiated phosphor materials were recorded using Harshaw TLD reader (model 3500). The heating rate (5°/sec) was kept constant during recording of each GC.

III. RESULTS AND DISCUSSION

The study of TL properties of as prepared phosphor was carried out by two irradiation source viz. γ-rays and C^{5+} ion beam. Figure 1 shows the glow curve of γ-ray (1kGy) irradiated $Sr_{2(1-x)}(Dy,Na)_xZnWO_6$ (x = 0, 0.005, 0.01, 0.02) phosphors.

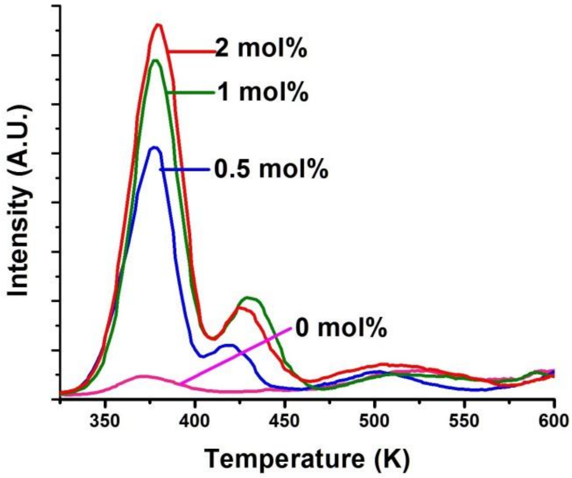

Figure 1. TL GC of 1kGy γ-ray irradiated $Sr_{2(1-x)}(Dy, Na)_xZnWO_6$ phosphors.

The nature of glow curve for doped samples is of complex nature and consisting of three distinguishable and overlapping glow peaks. The glow curve has prominent glow peak at low temperature at 378 K one small shoulder peak at moderate temperature at 427 K and broad peak at higher temperature at 508 K. The relative intensity of these glow peaks are different, lower temperature glow peak has highest intensity amongst all three glow peaks. The undoped samples show only two peaks in glow curve similar to one at low temperature and other at high temperature peak in doped one, but second shoulder glow peak is absent. These glow peaks are the results of at least three different types of the trapping centers in the phosphor material. Out of these shallow and deep traps are corresponds to defect centers in the host lattice which results in respective low temperature and high temperature glow peaks. Whereas, the shoulder peak is attributed to the defect structure, that is associated with the doping ion. The intensity of the each glow peak is found to be increase with Dy^{3+} ion concentration and no concentration quenching is observed up to 2 mol% concentration.

The variation of TL intensity with different γ-dose (10Gy - 1000Gy) were carried out for $Sr_{1.96}(Dy, Na)_{0.02}ZnWO_6$ phosphor and is shown in Figure 2. It is observed that the TL intensity of low temperature glow peak and shoulder peak is increases linearly with γ-dose and the high temperature peak shows insignificant variation of TL intensity with variation of γ-dose.

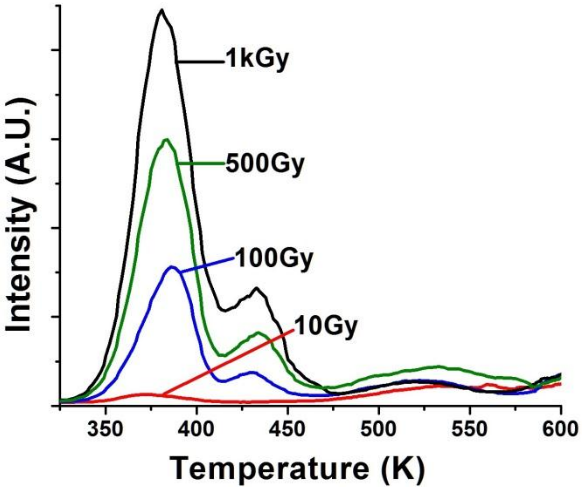

Figure 2. γ-dose response curve of $Sr_{1.96}(Dy,Na)_{0.02}ZnWO_6$ phosphor.

To study the TL response for 75 keV C^{5+} ion beam irradiation source only 2 mol% Dy^{3+} doped phosphor was used. The said phosphor was irradiated with different C^{5+} ion beam dose for different time. The glow curves of $Sr_{1.96}(Dy,Na)_{0.02}ZnWO_6$ phosphor irradiated with 75 keV C^{5+} ion beam for different time are shown in Figure 3.

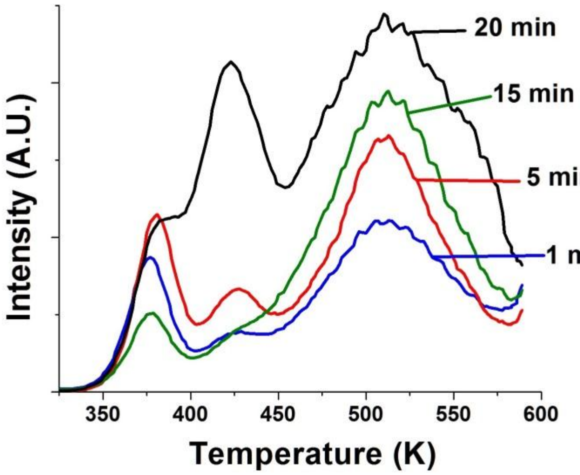

Figure 3. TL glow curve of $Sr_{1.96}(Dy,Na)_{0.02}ZnWO_6$ phosphor irradiated with 75 keV C^{5+} ion beam for different time.

The nature of glow curves of C^{5+} ion irradiated sample is similar to γ-irradiated sample; it consists of three glow peaks almost at same temperature (i.e. 378, 423, and 512 K), only the difference is the relative intensities of the individual peaks are different. In contrast to the glow curve of γ-irradiated sample, in this case high temperature peak is dominant in glow curve. The TL intensity of low temperature peak first increase with irradiation time and then saturate after 15 min of irradiation whereas, the glow peak at moderate temperature and at high temperature increase with irradiation time. This indicate that the heavy ion beam create larger amount of deep traps than shallow traps which is incorporation with literature [**7**].

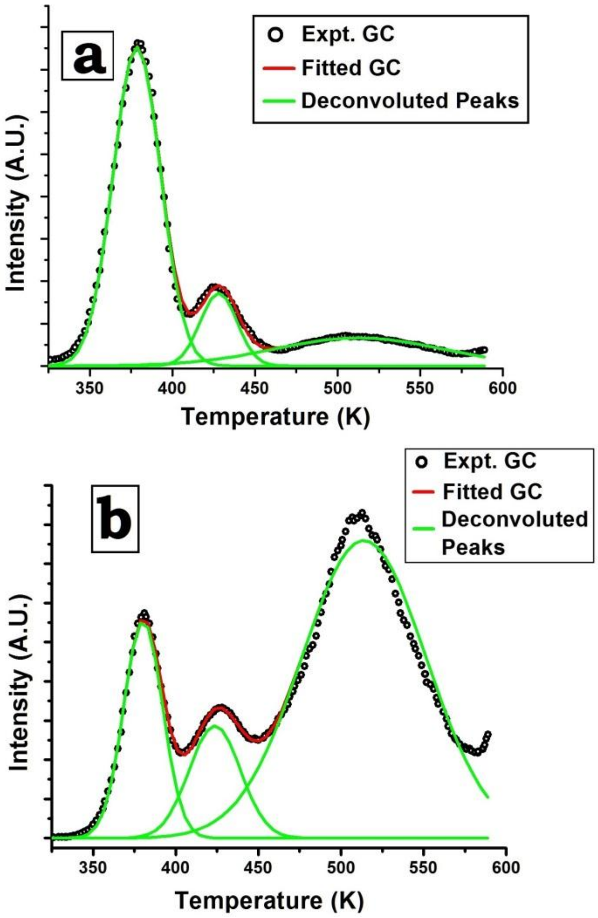

Figure 4. Glow curve deconvolution of $Sr_{1.96}(Dy,Na)_{0.02}ZnWO_6$ phosphor irradiated with (a) γ-ray (1kGy) and (b) C^{5+} ion beam (5 min).

In order to find the number of traps and related kinetic parameter, the GC of $Sr_{1.96}(Dy,Na)_{0.02}ZnWO_6$ phosphor irradiated with γ-ray (1kGy) and C^{5+} ion beam were deconvoluted into three peaks as shown in Figure 4. The qualities of fitting were tested by calculating of figure of merit (FOM) by the formula:

$$FOM = \frac{\sum_i |y_i - y(x_i)|}{\sum_i y_i} \times 100\%$$

where y_i is the content of the channel i and $y(x_i)$ is the value of fitting function in the center of channel i.

The kinetic parameter {activation energy (E), frequency factor (s)} obtained from GC analysis reveals the great information, there are different methods to calculate the kinetic parameters but in this work Chen's **[19]** of peak shape method is utilized. The activation energy and frequency factor is calculated by the formula which is given as follows:

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

And

$$s = \frac{\beta \Delta_m}{T_M (1 + \frac{2(b-1)}{\Delta_m})} \exp \Delta_m$$

Where α is τ, δ or ω. The values of c_α, b_α, and Δ_m are summarized as below:

$$c_\tau = 1.510 + 3.0(\mu - 0.42);\ c_\delta = 0.976 + 7.3(\mu - 0.42);$$

$$c_\omega = 2.52 + 10.2(\mu - 0.42);\ b_\tau = 1.58 + 4.2(\mu - 0.42);$$

$$b_\delta = 0;\quad b_\omega = 1;\quad \Delta_m = \frac{E}{kT_M}$$

In present study the FOM is found to be 0.0132 (γ-ray) and 0.0115 (C^{5+} ion beam) and the activation energy and frequency factor of each deconvoluted peak is summarized in Table 1.

Table 1. Trapping parameter of deconvoluted glow peaks of doped $Sr_{1.96}(Dy,Na)_{0.02}ZnWO_6$ phosphor.

Irradiation Type	Trapping Parameter	Peak		
		P_1	P_2	P_3
γ-ray	T_m (K)	378	427	508
	E (eV)	0.902	1.081	1.159
	s (sec^{-1})	9.729 X 10^{12}	5.042 X 10^{14}	9.729 X 10^{12}
C^{5+} ion beam	T_m (K)	378	423	512
	E (eV)	0.890	0.950	1.065
	s (sec^{-1})	1.481 X 10^{11}	9.167 X 10^{12}	7.752 X 10^{10}

The activation energy and frequency factor for different glow peaks is found to be nearly equal with slight change, this indicate that the electron traps resulting due to both type of the irradiation is same.

IV. CONCLUSION

In summary, the TL properties of double perovskite structured tungstate Sr_2ZnWO_6 doped with Dy^{3+} ion using γ-ray (Co^{60}) and 50keV C^{5+} ion beam as irradiation source is presented. The complex glow curve show similar nature for both type of radiation sources. The glow curve shows three glow peak on one at low temperature (378 K) one at moderate temperature (427 K) and one at higher temperature (508 K). The TL intensity of glow curve is found to be highest in 2 mol% Dy^{3+} doped phosphor sample. The phosphor sample shows linear response to γ-ray but non-linear response to C^{5+} ion beam. The values of kinetic parameter show that similar types of defects were formed in the phosphor material for both of the radiations.

V. ACKNOWLEDGEMENT

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