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Beta ray induced optically stimulated luminescence properties of calcium oxide phosphor

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This work presents the results on optically stimulated luminescence of calcium oxide (CaO). Polycrystalline CaO phosphors are irradiated with beta rays in the dose range 10 – 100 Gy. The optically stimulated luminescence (OSL) from CaO sample is strong, the decay is fast and entire signal decays within 50 s. OSL intensity increases linearly with beta dose. The life time and photo ionization cross section (PICS) of decay are in the range ~0.045, 1.5 and 41.391 s and 1.32×10^{-16}, 3.32×10^{-18} and 1.42×10^{-19} cm^2 for fast, medium and slow components, respectively. Further, the life time and PICS of fast, medium and slow LM-OSL components have been found to be 2.29, 6.0, 17.0 s and 2.56×10^{-18}, 9.77×10^{-19}, 3.45×10^{-19} cm^2, respectively. Both the OSL curves exhibits general order kinetics.

Keywords: Calcium oxide, Beta rays, Optically stimulated luminescence, Kinetic parameters

1 Introduction

Luminescence is extensively used to determine absorbed radiation dose in wide band gap insulators exposed to ionizing radiation. The study of optically stimulated luminescence (OSL) properties of phosphor materials is a major field of research in radiation dosimetry. OSL is a process resulting in light emission from an insulator or semiconductor previously exposed to ionizing radiation when the material is stimulated with visible photon[1,2]. OSL dosimetry is successfully used for radiation monitoring of personnel working with ionizing radiation sources, nuclear accidents, cosmic radiation in space, radiation facilities in health and power sectors, geochronology (dating of sediments) and environmental radiation monitoring[2]. In particular, OSL is effectively used in medical[3], personal[4], retrospective[5] and accidentdosimetry[6]. In addition to being of use for radiation dosimetry, the OSL signal contains information about the distribution of traps and recombination centers in the crystals. OSL signals can also provide insights to the charge excitation, movement of traps and their recombination in crystals. Suchinsights will leads to improve our understanding of the luminescence mechanism[7].

Calcium oxide (CaO) is a wide band gap material and band gap energy is about 6.1 eV and fundamental absorption edge starts with exciton transitions[8]. Though many potential applications of nanocrystalline CaO imply use of its optical properties, there are not many studies of its luminescence characteristics[9]. Inspite of previous studies, very little work was performed on undoped CaO nanophosphor. The present paper offers a brief analysis of basic results of investigations on OSL properties of CaO phosphors. The main objective of continuous wave OSL (CW-OSL) and linearly modulated OSL (LM-OSL) measurements are to determine photoionization cross section of traps that are active in the process and produce individual OSL curve components.

2 Materials and Methods

Calcium oxide phosphor was synthesized by solution combustion technique. The samples were annealed at 1200 °C for 2 h in muffle furnace. The synthesis procedure and characterization details were reported elsewhere[10]. In the present investigation, experiments are performed using RisØ TL/OSL reader (Model: TL/OSL-DA-20). The annealed samples are irradiated with ^{90}Sr/^{90}Y beta source which emits beta particles with a maximum energy of 2.27 MeV. The source strength is about 1.48 GBq,

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which gives a dose rate of approximately 0.08 Gy/s at the sample position. The beta irradiator is located above the sample carousel in RisØ TL/OSL reader.

OSL curves are recorded by stimulating with a cluster of 42 blue LEDs (NICHIA type NSPB-500AS) having a peak emission at 470 nm (FWHM = 20 nm) of power 80 mW/cm^2 (90% is used in the present experiments). Hoya U-340 (7.5 mm thick, Ø = 45 mm) detection filter is used in front of photo multiplier tube (Bialkali EMI 9235QB, which has maximum detection efficiency between 200 and 400 nm) while recording OSL decay curves. CW-OSL curves are recorded with constant stimulation intensity and the stimulation intensity is linearly ramped to record LM-OSL[11].

3 Results and Discussion

3.1 Continuous wave optically stimulated luminescence

In CW-OSL, the luminescence is recorded very fast and looks like a decay curve. Also in CW-OSL, the background count rate or net background is nearly constant. Hence, CW-OSL is useful in dosimetric applications due to short recording time. Figure 1 represents CW-OSL decay curves of 1200 °C annealed CaO phosphor exposed to β – rays in the range 10 – 100 Gy stimulated with blue light. The OSL from annealed CaO sample is strong, the decay is fast and the entire signal decays within 50 s. It is found that, the initial OSL intensity increases linearly with beta dose, this is one of the fundamental requirement of a good dosimeter. The increase in intensity with dose is due to increase in number of traps responsible for OSL[1]. The dose response curve is shown as inset of Fig. 1.

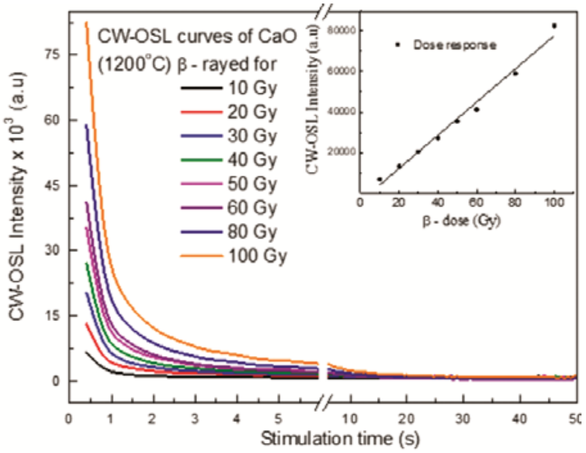

Fig. 1 – CW-OSL decay curves of beta irradiated CaO phosphor (Inset: Dose response).

The photo ionization cross section (PICS) of a trap is an important property in detecting the appropriate wavelength for optical stimulation[2]. PICS is related to retrapping probability (*b*) and maximum stimulation intensity. OSL originates from various trap levels having different PICS. These trap levels and retrapping process lead to different OSL decay components. CW-OSL curve can be fitted with sum of three exponentials. Deconvoluted CW-OSL decay curves are given in Fig. 2. The figure of merit and goodness of fit (GOF) for this analysis are 2.00 and 0.99%, respectively, which are in the acceptable limit. Life time, order of kinetics and PICS of three OSL components of deconvoluted decay curves for various beta doses are calculated and given in Table 1. It is found that, the life time associated with the traps responsible for OSL decay components are less at higher dose. This implies that, the phosphor is highly sensitive to beta particles. Further, all the three components exhibits general order kinetics and corresponding PICS values are in theoretically acceptable range[12].

3.2 Linearly modulated optically stimulated luminescence

In the case of LM-OSL, the recording of luminescence is slow but peak shaped curve is obtained. Well separated multiple peaks can also be obtained if optically sensitive traps having different values of PICS are participating in the OSL process. The peak height of LM-OSL curve is decided by number of traps (also called as trap density) participating in OSL processand recombination efficiency, whereas the peak position is decided by optical stimulation rate, retrapping and recombination cross-sections and radiation dose. LM-OSL is very useful in characterization of traps participating in OSL process. Figure 3 shows LM-OSL curves of

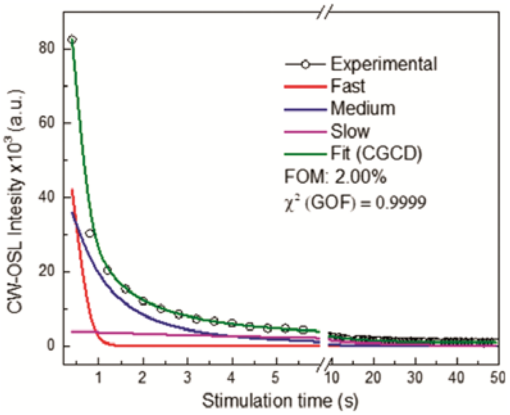

Fig. 2 – Deconvoluted CW-OSL decay curves of beta irradiated CaO.

Table 1 – CW-OSL kinetic parameters of β – rayed calcium oxide phosphors.

Dose (Gy)	Lifetime (s)			Order of kinetics			Photo ionization cross section (cm^2)		
	Fast	Medium	Slow	Fast	Medium	Slow	Fast	Medium	Slow
10	0.044	1.764	41.391	1.68	1.18	1.00	1.32×10^{-16}	3.32×10^{-18}	1.42×10^{-19}
50	0.028	1.067	10.431	1.28	1.59	1.00	2.07×10^{-16}	5.48×10^{-18}	5.62×10^{-19}
100	0.037	1.000	10.000	1.29	1.44	1.88	1.60×10^{-16}	5.86×10^{-18}	5.86×10^{-19}

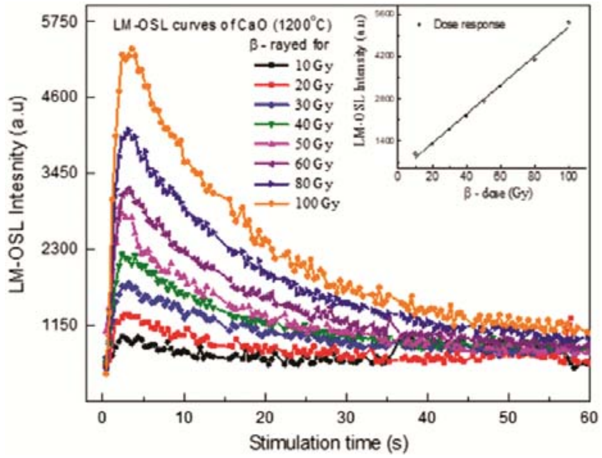

Fig. 3 – LM-OSL decay curves of beta irradiated CaO phosphor (Inset: Dose response).

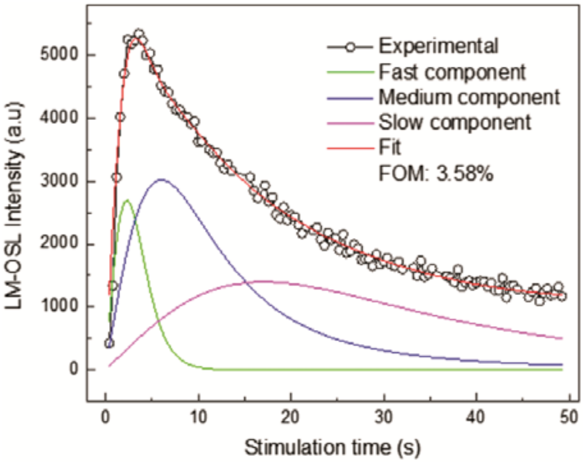

Fig. 4 – Deconvoluted LM-OSL decay curves of beta irradiated (100 Gy) CaO.

1200 °C annealed CaO phosphor exposed to beta rays in the dose range 10 – 100 Gy. It is found that, area under the curve increases with beta dose. Variation of LM-OSL peak intensity maxima as function of dose is shown as inset of Fig. 3. This dose response is also linear like CW-OSL dose response.

LM-OSL curves generally comprise of several overlapping peaks. The analysis and separation of these complex curves into their constituent components can be attained using computerized glow curve deconvolution (CGCD) analysis. Figure 4 shows the deconvoluted LM-OSL curves of beta irradiated (100 Gy) calcium oxide phosphor. The LM-OSL decay curves are deconvoluted using equation[13].

$$I(T) = I_{\mathrm{m}} \frac{t}{t_{\mathrm{m}}} \left[\frac{b-1}{2b} \frac{t^2}{t_{\mathrm{m}}^2} + \frac{b+1}{2b} \right]^{\mathrm{b}/_{1-\mathrm{b}}}$$

where I_{m} is the intensity maximum, T_{m} is time corresponding to maximum intensity and b is retrapping probability.

The decay curves are deconvoluted in to three components namely fast, medium and slow component. FOM of this analysis is 3.58%. Here, fast component exhibit general order kinetics. Whereas, medium and slow components exhibit second order kinetics. The life time and PICS of fast, medium and slow LM-OSL components are found to be 2.29, 6.0, 17.0 s and 2.56×10^{-18}, 9.77×10^{-19}, 3.45×10^{-19} cm^2, respectively.

4 Conclusions

CW and LM-OSL properties of 1200 °C annealed CaO phosphor are studied under beta irradiation. Both the OSL curve exhibits linear dose response over a dose range 10 to 100 Gy. OSL curves are deconvoluted in to three components for analysis. The kinetic parameters obtained are in theoretically acceptable rage. CaO phosphor is a polycrystalline powder and have the advantages of simple preparation and low cost. These results demonstrated that, CaO material has a strong potential for OSL dosimetry. However, further work is needed in order to fully characterize this material for radiation dosimetric applications.

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