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TL–OSL correlation studies of $LiMgPO_4$:Tb,B dosimetric phosphor

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ABSTRACT

The recently synthesized $LiMgPO_4$:Tb,B (LMP) is a highly sensitive Optically Stimulated Luminescence (OSL) phosphor for dosimetric applications. Studies were carried out to assess the correlation between thermoluminescence (TL) and OSL of this phosphor. Measurements like Residual TL (R-TL), Continuous Wave OSL (CW-OSL) and Linearly Modulated OSL (LM-OSL) of LMP were carried out and various curves thus obtained were de-convolved using Computerized Curve Deconvolution (CCD) program. The deconvolution of CW-OSL and LM-OSL curves showed five different first order components in LMP. It was observed that OSL signal of LMP has its origin from five traps having different photo-ionization cross-sections. Same traps were found to be responsible for both TL and OSL in this phosphor. Bleaching decay rates were calculated for each R-TL glow peaks and compared with the decay rates of individual OSL components. The value of decay rates of R-TL and OSL matches well. Experimental verification of presence of individual OSL components using t_{bleach}–t_{max} method was carried out.

1. Introduction

OSL has emerged as a popular dosimetric technique during the past 10 years, after the development of crystalline α-Al_2O_3:C phosphor. OSL based dosimeter is being used increasingly due to the fact that it has various advantages over TL based dosimeter such as faster and multiple readout, absence (no role) of thermal quenching, high sensitivity, possible use of phosphor in plastic binders etc. In an effort to find alternative OSL phosphor to alumina (α-Al_2O_3:C), several other OSL materials have been synthesized such as $LiMgPO_4$:Tb,B (LMP) [1], KBr:Eu [2], $(NH_4)2SiF_6$:Tl [3], MgO:Tb [4], $NaMgF_3$:Eu^{2+} [5], $LiAlO_2$:Tb/Ce [6,7], $ZnAl_2O_4$:Tb [8], $Y_3Al_5O_{12}$:C [9], $MgAl_2O_4$:Tb [10] etc.

Dhabekar et al. observed that LMP is a promising OSL dosimetric phosphor and could be an alternative to α-Al_2O_3:C. The OSL vs. dose response of LMP phosphor is linear up to 1 kGy, therefore this phosphor can also be used in food irradiation dosimetry where delivered doses are of the order of 500 Gy depending upon nature of the product. The minimum detectable dose of LMP is 20 μGy. The synthesis technique of LMP phosphor is simple, cost effective with readily available raw material and is amenable to large-scale production of the phosphor. Since LMP has the potential to be used in personnel, environmental, medical and high dose dosimetry (food irradiation), characterization of LMP is of high importance to explore its various applications in OSL dosimetry. TL–OSL correlation study in LMP is one of them.

OSL signal arises from radiative recombination of charge carriers, de-trapped from all optically sensitive traps. Deconvolution of OSL signal is necessary to get information of individual traps. By analyzing the TL glow curves and the OSL decay curves into their individual glow-peaks and components respectively, a relation between specific glow-peaks and OSL components can be established.

TL–OSL correlation studies on various phosphors are reported in literature. Chougaonkar and Bhatt [11] reported that all three thermoluminescence (TL) peaks appearing contribute to the blue light stimulated luminescence (BLSL) in CaF_2:N and the individual contribution from first, second and third TL peak was ~63%, ~25% and ~12%, respectively. Polymeris et al. [12] established a relation between specific glow-peaks and OSL components in CaF_2:N by deconvoluting the residual TL (R-TL) glow curves and the OSL decay curves into their individual glow-peaks and components respectively. The OSL signal of CaF_2:N was found to consist of four individual components, two of them are qualitatively and quantitatively connected to two of its TL glow-peaks [12]. The correlation between TL peaks and LM-OSL components in different samples of alumina crystal was reported by Dallas et al. [13]. They have compared individual components, which were obtained after the deconvolution of the TL glow curve and LM-OSL curve using the equation given by Kitis et al. [14] and Polymeris et al. [15] respectively. Bulur and Yeltik et al. [16] reported the presence of two components in CW-OSL and LM-OSL curve of BeO using deconvolution technique. The t_{bleach}–t_{max} experiment analogous to the T_m–T_{stop} in TL was suggested by Kitis and Pagonis et al. [17] to find the different individual constituents of LM-OSL curve.

Munish Kumar et al. have reported a preliminary study on CW-OSL and LM-OSL kinetics of LMP [18]. LMP exhibits three major TL

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peaks and the individual contribution to OSL from first, second and third TL peak was ~33%, ~45% and ~22%, respectively. CW-OSL curve could not be fitted with a single exponential decay curve. Munish Kumar et al. also reported that all three major TL peaks contribute in the OSL process. Dose dependent studies (up to 12 Gy studied) of LM-OSL curve in LMP showed that the peak position of LM-OSL curve was independent of dose, which is a typical characteristic of LM-OSL curve following first order kinetics.

Thus correlation study involves the deconvolution of the residual TL (R-TL) curves, CW-OSL and LM-OSL curve, followed by the comparison of the bleaching decay rates for individual R-TL glow-peaks and decay rates of LM-OSL and CW-OSL curves. These procedures have been adopted in this work to correlate the TL and OSL components of LMP.

In this paper, the correlation between the individual components of TL and OSL curve in LMP is obtained. Experimental verification of presence of individual OSL components using t_{bleach}–t_{max} method is also reported.

2. Material and methods

For TL–OSL measurements, LMP with grain size less than 53 μm was selected. TL and OSL measurements were carried out using an automatic Riso TL–OSL-DA-15 reader system [19]. It can accommodate up to 48 disks and has an attached β^- irradiator (^{90}Sr/^{90}Y source, dose rate: 1.22 Gy min^{-1}). To prevent scattered stimulation light from reaching the PMT, detection filters are employed. The Riso reader is equipped with a 7.5 mm Hoya U-340 detection filter, which has a peak transmission around 340 nm (FWHM = 80 nm). TL measurements were carried out without the filter in the emission side. CW-OSL and LM-OSL measurements were carried out at room temperature. The stimulation intensity was 80 mW/cm^2 (100%) during CW-OSL measurement. The LM-OSL was recorded by varying the stimulation light intensity from 0% to 100% (80 mW/cm^2) power for various acquisition times.

Following three sets of experiments were carried out.

2.1. CW-OSL and LM-OSL measurements

The LMP was irradiated for 20 mGy of β^- radiation and CW-OSL measurement was carried out for time period of 250 s. To correlate the CW-OSL data theoretically to LM-OSL data [20], LM-OSL measurement time period '*T*' was kept equal to the double of that of CW-OSL (i.e. *T* = 500 s).

2.2. t_{bleach}–t_{max} method

This experiment was carried out to separate the LM-OSL curve of LMP into their constituents. LMP was optically bleached for 5 s (t_{bleach}) and complete LM-OSL was recorded and time corresponding to the maximum LM-OSL intensity (t_{max}) was noted. The process was repeated for a gradually increasing bleaching time t_{bleach} in the step of 5 s up to 400 s and graph was plotted between the t_{bleach} and t_{max}.

2.3. Residual TL method

The correlation between TL and OSL components was determined experimentally by R-TL method as suggested by Dallas et al. [21]. In this experiment, TL measurement of LMP was carried out after different optical bleaching period starting from 5 s to 100 s. It involved the following steps. (i) LMP sample was irradiated with a test dose of 300 mGy, (ii) CW-OSL was recorded for the simulation time of 5 s, (iii) residual TL was recorded for temperature up to 573 K with heating rate of 0.5 K/s, (iv) steps (i)–(iii) were repeated for different bleaching times (5 s, 10 s, 25 s, 50 s, 75 s, 100 s).

3. Results and discussion

The deconvolution of LM-OSL, CW-OSL and residual TL (R-TL) curve was carried out to compare their decay rates.

3.1. LM-OSL and CW-OSL correlation

LM-OSL curve was de-convolved using general order LM-OSL kinetic equation [15,17].

$$^{b}I_{\text{LM}} = I_{\text{m}}\frac{t}{t_{\text{m}}}\left[\frac{b-1}{2b}\frac{t^2}{t_{\text{m}}^2}+\frac{b+1}{2b}\right]^{\frac{-b}{b-1}} \tag{1}$$

where *b* is kinetic order, I_{m} is peak LM-OSL intensity, t_{m} is the time corresponding to I_{m}. There were three parameters *b*, t_{m} and I_{m} in each LM-OSL components, which were varied to fit the theoretical LM-OSL with the experimental LM-OSL curve. The de-convolved LM-OSL curve is shown in Fig. 1. The numbers of individual LM-OSL were varied from one to six and Figure of Merit (FOM) was evaluated each time. It was observed that FOM was the least for LM-OSL curve with five components. Kitis and Pagonis et al. [17] had suggested that the FOM of less than 2% and with the least possible number of components is acceptable for best fit of the curve. In this work the least FOM (1.1%) was obtained when the experimental LM-OSL curve was fitted with five individual components. The expression for the total LM-OSL curve is as given below

$$I_{\text{LM}} = I_{\text{Lm1}} + I_{\text{Lm2}} + I_{\text{Lm3}} + I_{\text{Lm4}} + I_{\text{Lm5}}$$

where

$$I_{\text{Lmi}} = I_{\text{mi}}\frac{t}{t_{\text{mi}}}\left[\frac{b_{\text{i}}-1}{2b_{\text{i}}}\frac{t^2}{t_{\text{mi}}^2}+\frac{b_{\text{i}}+1}{2b_{\text{i}}}\right]^{\frac{b_{\text{i}}}{b_{\text{i}}-1}}$$

The initial anomaly in the fitting of LM-OSL curve is due to nonlinear ramping in the stimulated LED light [13,21]. The presence of five components in the LM-OSL curve is consistent with the observation of Munish Kumar et al. [18], where they claim that LM-OSL curve follows first order kinetics with more than single component. The values of t_{m} for all five LM-OSL components are summarized in

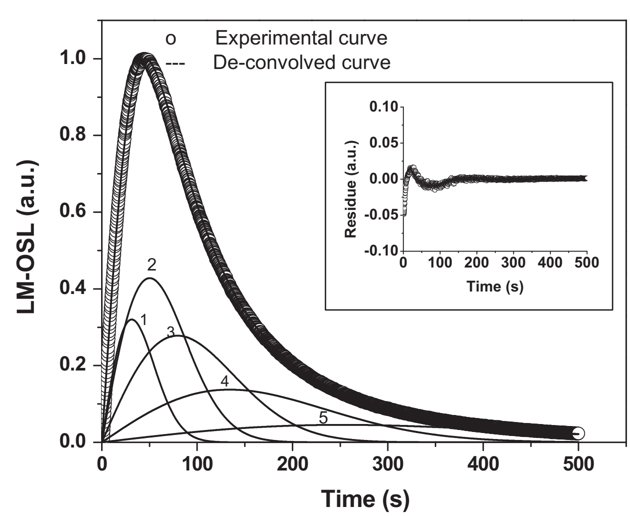

Fig. 1. A typical LM-OSL curve of LMP recorded for 500 s. Solid line shows the individual components obtained after deconvolution. Numerical 1–5 represents the individual peaks. The figure inset shows the residual plot.