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Investigation of Order of Kinetics for CW and LM OSL Processes in α-Al_2O_3:C

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Abstract— *Continuous wave (CW) and linearly modulated (LM) OSL curves were studied for α-Al_2O_3:C based single crystal detectors using RISO TL/OSL reader system. It was been found that CWOSL curve can be nearly described by single decaying exponential at lower doses. It was also found that the shape factor μ_g for experimental LMOSL curve was 0.589, which represents first order kinetics. The CWOSL curve was also transformed to LMOSL curve and the shape factor for the transformed LMOSL was found to be 0.576. The effect of optical bleaching on peak position for LMOSL curves was studied and it was found that peak position "t_m" is unaffected by optical bleaching. The phosphorescence and its TL like representation for α-Al_2O_3:C also indicates that it obeys first order kinetics. In view of above study, it is concluded that CW and LM OSL curves for α-Al_2O_3:C may be obeying first order kinetics especially at low doses.*

Keywords— *CW & LM OSL curves; order of kinetic; shape factor; optical bleaching; decay constants.*

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1. INTRODUCTION

CW and LM stimulation profiles are popular for the investigation of traps participating in the optically stimulated luminescence (OSL) phenomena. In CWOSL, the recorded luminescence appears like a decaying (exponential) curve whereas in LMOSL, the recorded luminescence is peak shaped. It is also possible to transform CWOSL curve to LMOSL curve. It may be noted that the CWOSL represents same physical information as LMOSL and both describe the same phenomenon under different stimulation profiles [1-4]. In this paper, results obtained from the CW OSL and LMOSL studies for α-Al_2O_3:C are presented and the transformation of CW to LM OSL curve are performed. α-Al_2O_3:C is selected as it is an ideal and popular OSL phosphor for kinetic studies.

2. CRITERIA FOR FIRST AND NON-FIRST ORDER KINETICS

Following tests are commonly used in the determination of order of kinetics for CW and LM OSL curves:

2.1 First Order Kinetics

A CWOSL curve follows first order kinetics if it could be fitted by single decaying exponential and the decay constant is always independent of radiation dose. Also the decay constant is further unaffected by optical bleaching. The graph between ln(I_{CW}) with respect to time is a straight line(I_{CW} is CWOSL intensity) [4-6].

For LMOSL curves, the peak position t_m is always independent of radiation dose as well as optical bleaching. The shape factor μ_g (defined by the ratio of [$\delta/\omega = (t_2-t_m)/(t_2-t_1)$] where t_m is the time corresponding to maximum intensity of the LM-OSL peak (I_m) and t_1 and t_2 are the value of the time for the rising and falling portions of the LM-OSL curve at $I_m/2$. lies in the range 0.55-0.58 for LMOSL curves following first order kinetics. It is important to note that the CW or LM OSL curves obeying first order kinetics exhibit linear dose response [4-6].

2.2 Non-First Order Kinetics

In this case, the decay pattern for CWOSL curve is not a perfect decaying exponential and the decay constant/pattern is dose as well as order of kinetics dependent. The decay constant for CWOSL curves is influenced by optical bleaching [4]. Further for LMOSL curves, the peak position t_m is dose dependent and shifts toward higher side in time with the decrease of radiation dose. Also under optical bleaching, the peak position t_m for LMOSL curves shift towards higher side in time. The value of the shape factor μ_g for second order kinetics lies in the range 0.65-0.68 for LMOSL curves whereas the shape/geometrical factor μ_g values in the range 0.59-0.65 correspond to order of kinetics between one and two [4-6]. It is worth mentioning that non-first order CWOSL curves may be fitted as sum of two, three or more first order exponential fits, however that may not be the actual situation always. Higher values of μ_g (>0.68) may represent LMOSL curve resulting from superposition of more than one LMOSL curves obeying first or non-first order kinetics or their mixture [4-6].

It must also be noted that the CWOSL as well as LMOSL curves may be broadened due to scattering of light inside the sample and higher the broadening thicker the sample.

This may change the decay constant for CWOSL curves or μ_g for LMOSL curves. Further in case of phosphors having multiple emission wavelengths, the acquired OSL curve may be quite different from the actual one and the results obtained from the kinetic analysis may not be explained. In addition, the effect of competing traps or recombination centres (radiative and non-radiative participating in TL only or TL & OSL as well) on the shape of OSL curves is not ruled out.

3. TRANSFORMATION TECHNIQUES

Transformation of CW to LM OSL curves is necessary to equate CW and LM stimulation processes and may be helpful in evaluating various kinetic parameters. Agreement between these techniques may indicate the validity of simple trap model however disagreement may result from large number of factors. Also, the transformation from CW to LM OSL is required because the CW OSL always appear to be a featureless decaying curve. The transformation technique suggested by Bulur is described below:

3.1 Bulur's Transformation Technique

The luminescence output in a CW OSL measurement for first order kinetics can be written as: $I(t) = n_0 b \exp(-bt)$, where n_0 is initial number of trapped electrons, b is a constant describing the decay of luminescence curve and is proportional to detrapping probability α and the stimulation light intensity I_0 ($b = \alpha I_0$). In order to convert the CW OSL curve to a LM OSL curve, one may introduce a new independent variable u, which is defined as:

$$u = \sqrt{2tP} \text{ or } t = \frac{u^2}{2P}$$

where u has the units of second like time t and the measurement period P of the LM OSL experiment. Substituting Eq. (2) to Eq. (1) and further multiplying by u/P one obtains:

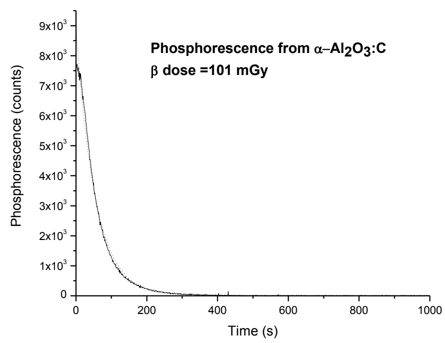
$$I(u) = n_0 \frac{b}{P} u \exp(-\frac{b}{2P} u^2)$$

This transformation suggested first by Bulur may be helpful for obtaining the LM OSL curve in cases where linear modulation of OSL is not easily achievable [1-3]. It can also be used to compare transformed LMOSL curves with actual experimental curves. Bulur also suggested that in order to use all the available data in the CW OSL curve, it is a good choice to have P = 2t where t is the total measurement time of the CW OSL data which can be deduced from equating the total light intensity impinging on the sample as well. Also the stimulation power and acquisition time for CW and LM OSL measurements should be such that total energy delivered to the sample is equal for two modes of optical stimulation [7-8].

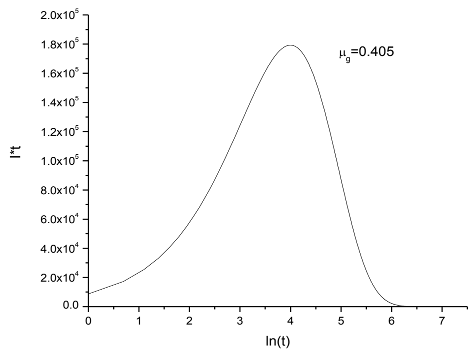
4. MATERIALS AND METHODS

The α-Al_2O_3:C crystal (5 mm diameter and 1 mm thickness) were used in this study The luminescence studies were performed using RISO TL/OSL system TL/OSL-DA-15 in which a cluster of 42 blue light emitting diodes (λ = 470 ± 30 nm) were used for stimulation. A green long pass GG-420 filter minimizes the directly scattered blue light from reaching the photomultiplier tube (EMI 9235QA). The blue light stimulated signal was detected using a 7.5 mm thick x 35 mm diameter HOYA U-340 (λ_p~340 nm, FWHM~80nm) filter. The LED cluster delivers ~25 mW cm^{-2} (maximum) power to the sample and the stimulation power can be linearly ramped to record LMOSL [4, 9-10]. Irradiations of the sample was carried out using a $^{90}Sr/^{90}Y$ source (dose rate: 1.22 Gy min^{-1}) housed in the system. A dose of 1.22 Gy was imparted to the phosphor every time unless otherwise mentioned. Freshly annealed α-Al_2O_3:C single crystals were exposed to a beta dose of 101 mGy. Phosphorescence arising from shallow trap was recorded immediately after exposure. CWOSL and LMOSL curves stimulated using blue LEDs were also recorded for above crystals. The effect of optical bleaching on CWOSL and LMOSL curves was also studied.

5. RESULTS AND DISCUSSIONS



(a)

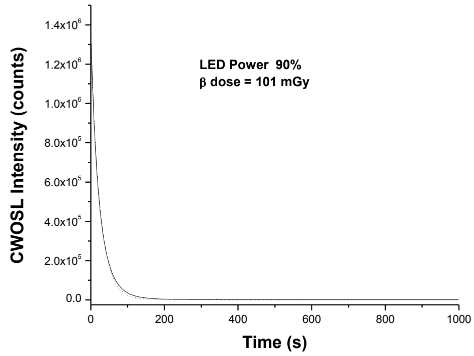


(b)

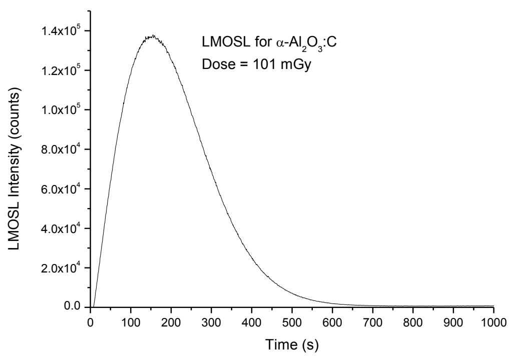
Fig. 1: (a) Phosphorescence decay curve recorded immediately after exposure of α-Al_2O_3:C crystal; (b) TL-like presentation of phosphorescence decay curve (shown in Figure 1(a)) for α-Al_2O_3:C.

Typical phosphorescence curve for α-Al_2O_3:C crystal recorded immediately after exposure is shown in Figure 1a whereas in Figure 1b, the TL-like presentation of phosphorescence decay curve is shown.

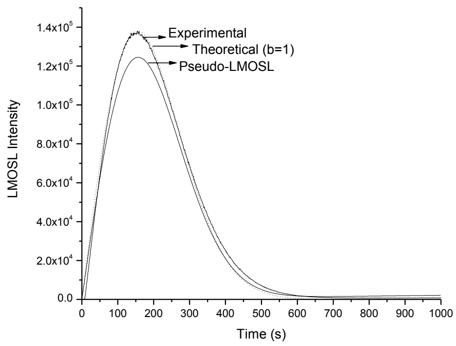
The phosphorescence recorded at room temperature from α-Al_2O_3:C follows exponential decay and arises from shallow traps. Further the TL-like presentation of phosphorescence decay curve (shown in Figure 1b) have shape factor ~0.405, which is indicative of first order kinetics.



(a)



(b)



(c)

Fig. 2: (a) Blue light (LED's) stimulated CWOSL curve for α-Al_2O_3:C; (b) Blue light (LED's) stimulated LMOSL curve for α-Al_2O_3:C; (c) Blue light (LED's) stimulated LM OSL curves for α-Al_2O_3:C. The theoretical as well as transformed LMOSL curves are also shown in the same Figure.

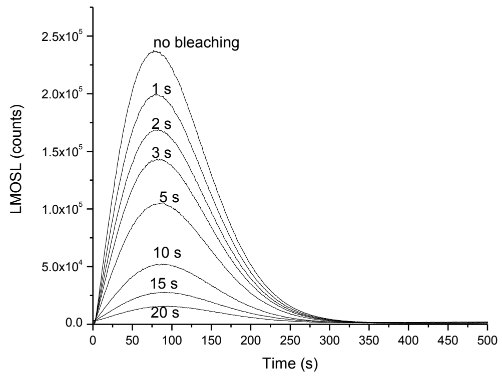


Fig. 3: Effect of optical bleaching on LMOSL. The LED power was kept at 90% for CW OSL whereas for LM OSL, the powder varied from 0 – 90 %.. The beta dose in both the cases was 101 mGy.

Further in Figures 2a and 2b, the CW and LM OSL curves stimulated using blue LED's are shown. In Figure 2c, Blue light (LED's) stimulated LM OSL curves for *α*-Al_2O_3:C. The theoretical as well as transformed LMOSL curves along with experimentally recorded LMOSL curve are shown in Figure 2c. In Figure 3, the effect of optical bleaching on peak position "t_m" for LMOSL curves is shown.

It has been found that CWOSL curve for α-Al_2O_3:C can be nearly described dominantly by single decaying exponential implying that CWOSL curve follows first order kinetics. It was also found that the shape factor μ_g for experimental LMOSL curve was 0.589 which represents first order kinetics. The experimental LMOSL curve could also be fitted using first order kinetics. The CWOSL curve was also transformed to LMOSL curve (Figure 2b) and the shape factor μ_g for LMOSL (transformed) curve was found to be 0.576. This is further tested from the effect of optical bleaching on peak position for LMOSL curves and it was found that peak position "t_m" is unaffected by optical bleaching carried out using blue LED's (Figure 3). It was also found that the value of the shape factor μ_g remained almost independent of the bleaching time within experimental errors. The above mentioned properties are typical characteristics of LMOSL curves obeying first order kinetics.

Also the decay constant for CWOSL curves was found to be nearly constant with optical bleaching. This is a typical characteristic of LMOSL curves obeying first order kinetics. Hence transformation of CW to LM OSL curve in α-Al_2O_3:C matches with the experimental LMOSL curve and the OSL process can be best described by first order kinetics.

From the above study, it has been found that the traps participating in luminescence for *α*-Al_2O_3:C follow first order kinetics. Further the CW and LM OSL from α-Al_2O_3:C can be described by assuming first order kinetics. Hence the OSL from α-Al_2O_3:C forms a simple example to test theory. Further studies assuming CWOSL as a sum of 2 or 3 first order decaying exponential components are in progress.

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