Indian Journal of Pure & Applied Physics
Vol. 47, June 2009, pp. 402-405

Effect of heating rate on TL glow curves – Theoretical and experimental studies

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Received 24 February 2009; accepted 30 April 2009

In the absence of thermal quenching but at the same radiation dose, the area under the glow curve at different heating rates is conserved only in TL - time plots and is not conserved in TL-temperature plots. Further at a given heating rate, the glow peak height is same in time as well as in temperature plots and the glow peak height increases with the increase of the heating rate. However to conserve area in TL - temperature plots, the TL intensity when divided by the respective heating rate lead to the decrease of glow peak height in TL/β-temperature plots, which is the artifact of the normalization process. The effect of heating rate on TL glow curves has been investigated theoretically as well as experimentally. The ambiguity prevalent in literature regarding the effect of heating rate on TL glow peak height and area under the glow curves when glow curves are plotted in time or temperature scales has been attempted to resolve. It is suggested that researchers should always present un-normalized as well as normalized TL glow curves if the glow curves (for TL sample exposed to same radiation dose) are recorded at different heating rates.

Keywords: Thermoluminescence glow curves, Heating rate

1 Introduction

The effect of heating rate on thermoluminescence (TL) glow curves is well known theoretically as well as experimentally[1-4]. Many researchers[5-8] (including the recently published books of Furetta[7-8]) have reported the decrease of glow peak height/maximum TL intensity with the increase of heating rate whereas some workers have also reported the increase of glow peak height with the increase of heating rate[9-13]. Recently Rasheedy *et al.*[9] have studied the effect of the heating rate on the TL glow curves in time and temperature plots for linear heating and have raised the issue of non-conservation of area in TL-temperature plots which was sorted out by Kumar *et al.*[14,15], however the facts were explained only physically and were not supported by theoretically and experimentally obtained TL glow curves. According to Pradhan[12], the experimental results observed by him on the effect of heating rate on glow peak height were similar to those observed by Akselrod *et al.*[11] but in contradiction to the results of Kitis *et al*[6]. In this paper an attempt has been made to clarify this situation and the results are supported theoretically as well as experimentally.

2 Theory

The intensity of thermoluminescence (TL) I as obtained from Randall-Wilkins equation is given by :

$$I = n_0 s \exp(-E/kT)\exp\left(-\int_{T_0}^{T} \frac{s\exp(-E/kT)}{\beta} dT\right) \quad \text{... (1)}$$

where, n_0 is the number density of trapped electrons (m^{-3}), E is the activation energy (eV), s is the frequency factor or attempt to escape factor (Hz), T_0 is the starting temperature and $T = T_0 + \beta t$ is the linear heating profile, β = dT/dt is the constant heating rate (Ks^{-1}) and k is the Boltzman's constant (eV K^{-1}). In the Eq. (1), I represent TL intensity, which (I as such) when plotted against time or temperature leads to TL-time or TL temperature plots[1-2].

In the glow curve (plot of TL intensity with temperature/time) there is maximum in TL intensity for some temperature T_m (or time t_m required to attain temperature T_m), which can be obtained by equating the derivative of the Eq. (1) equal to zero, i. e. (dI/dT) = 0 at $T = T_m$

$$\frac{\beta E}{kT_m^2} = s\exp(-E/kT_m) \quad \text{... (2)}$$

By using Eq. (2) in Eq. (1), the maximum value of TL intensity/peak height I_m at T_m or t_m is :

$$I_m = \frac{n_0 \beta E}{kT_m^2}\exp\left(-\int_{T_0}^{T_m} \frac{s\exp(-E/kT)}{\beta} dT\right) \quad \text{... (3)}$$

Using $T = T_0 + \beta\ t$ and $\beta = dT/dt$ transformation in Eq. (3), the value of I_m obtained at time T_m is same as is at t_m. However the peak height I_m does not increase in direct proportion with the increase in β as can be seen from the Eq. (3).

3 Theoretical and Experimental Results

The Eq. (1) is solved numerically for various linear heating rates. The values of other parameters involved in Eq. (1) (chosen arbitrarily for demonstration) are E = 1.1eV, $s = 10^{11}$ Hz, T_0 = 300 K and $n_0 = 10^{23}\ m^{-3}$. The TL intensity resulting from the simulation of Eq. (1) is function of time as well as temperature. Time and temperature are correlated to each other through the relation $T = T_0 + \beta\ t$. However the resulting TL intensity I (to be plotted along Y-axis) is same relative to both the time as well as temperature. The theoretically generated plots are shown in Fig. 1(a and b) for I versus time and I versus temperature respectively. In the absence of thermal quenching at a fixed dose, it has been found that with the increase of the heating rate[13-15]: (i) glow peak height increases, (ii) peak position comes earlier, (iii) area under the glow curve is independent of the heating rate, (iv) full width at the half maximum (FWHM) decreases. Further, Fig. 1(b) shows corresponding TL glow curves in temperature scale. It is seen that (i) glow peak height increases with the increase of the heating rate and their respective peak heights are same as those of corresponding time scale glow curves, (ii) peak position shifts toward higher temperature, (iii) area under the glow curve is not conserved and is a function of heating rate, (iv) FWHM increases.

To verify above theoretical results, the experimental study was also carried out. The experimentally obtained TL glow curves were recorded using locally made TL reader, which is computer interfaced, so data acquisition facility is there. In addition to this, the integrated counts are also displayed on the digital panel meter (DPM). The data acquired for various heating rates but at the same dose are plotted in Fig. 2(a and b) respectively in time and temperature for α-Al_2O_3:C phosphor (190°C peak). Studies were also carried out for the dosimetry peak of $CaSO_4$:Dy and it was found that above mentioned theoretical results hold. It has been found that with the increase of the heating rate, the glow peak height increases and is same in time as well as in the corresponding temperature plots. Further from Fig. 2a, it follows that the area under the glow curve is same and is independent of the heating rate (assuming no thermal quenching for simplicity). Further in Fig. 2(b), it has been found that the area increases with the increase in the heating rate, which was also predicted theoretically.

The reason for the non-conservation of area in temperature scale can be had from previous studies[1,2,10,13-15] and from these studies it follows that $\int_{T_0}^{T_f} I dT = \beta \int_0^{t_f} I dt$ (here I is same as represented by the Eq. (1) or experimentally obtained counts, which can be plotted against time or temperature depending upon the users choice). As $T = T_0 + \beta\ t$ so at $t = t_0 = 0$, $T = T_0$ and at $t = t_f$, $T = T_0 + \beta t_f = T_f$, so temperature scale area will always be β times the time scale area of TL glow curves (except for $\beta = 1\ Ks^{-1}$). However as described earlier that the integrated counts

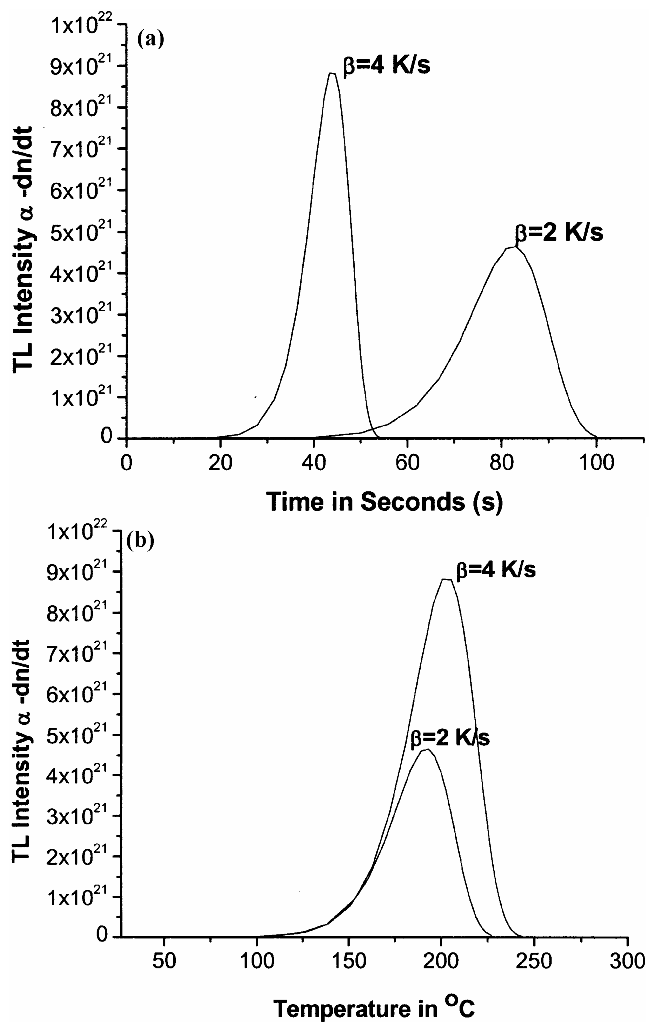

Fig. 1 — Plot of TL intensity (theoretical) with respect to: (a) time, (b) temperature. The parameters assumed are, activation energy, E = 1.1 eV, frequency factor, $s = 10^{11}$ Hz, T_0 = 300 K and number of trapped electrons, $n_0 = 10^{23}\ m^{-3}$

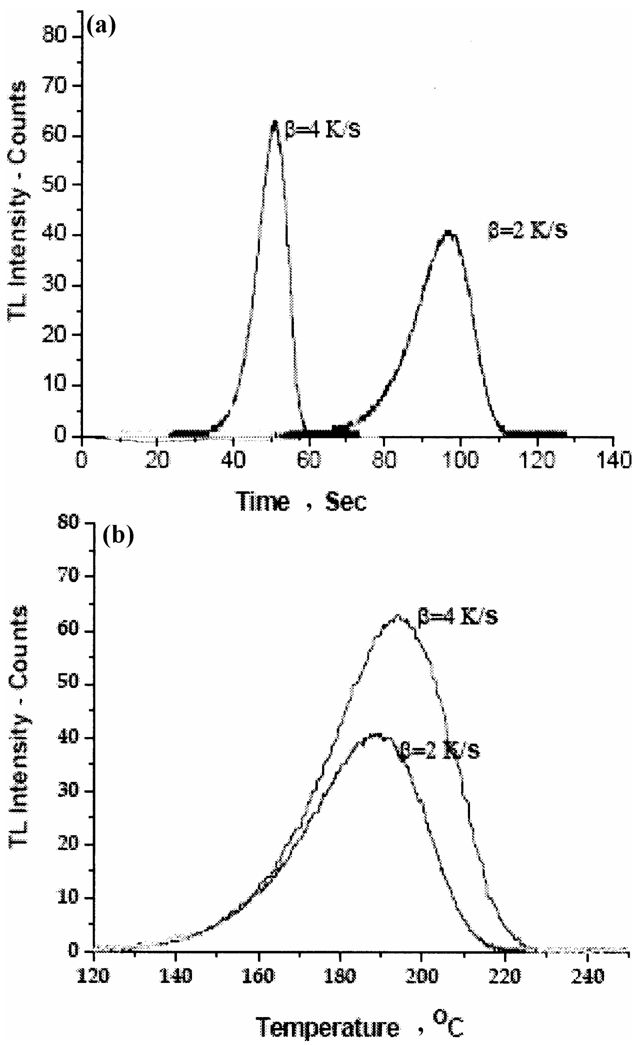

Fig. 2 — TL glow curves (experimental) for α-Al_2O_3:C at two different heating rates plotted in: (a) time, (b) temperature. The dose (beta) given to the sample was 5 mGy

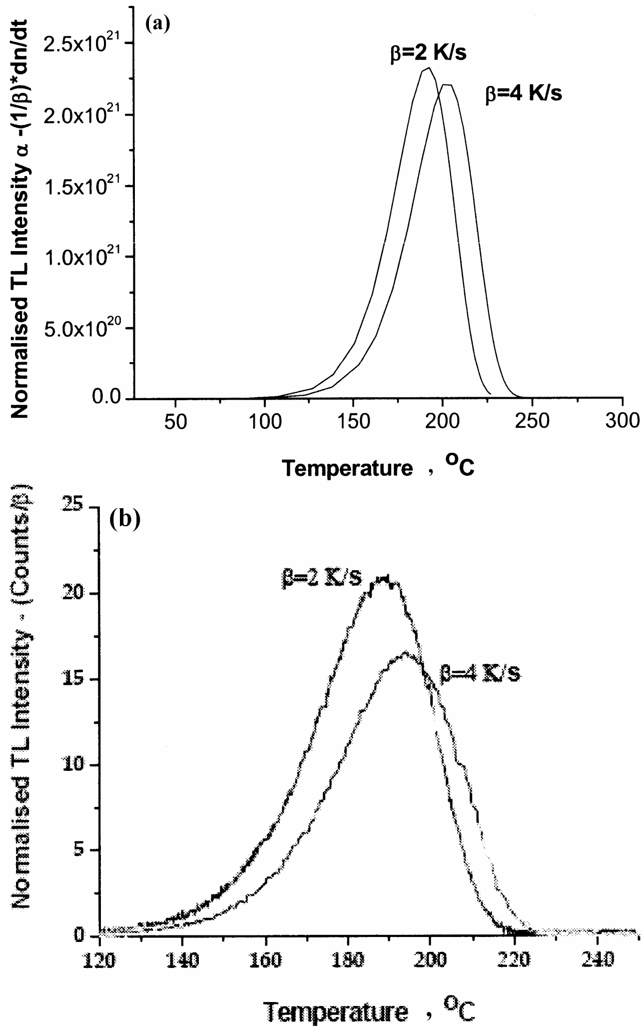

Fig. 3 — Normalized TL glow curves: (a) (TL/β) corresponding to Fig. 1b, (b) (experimental-TL/β) corresponding to Fig. 2b.

displayed on the DPM are same (within statistical fluctuations) even for different heating rates: implying that plot of TL output with time represents the exact picture. Further in the plot of I versus temperature, area is not conserved because the temperature scale is obtained from the time scale by multiplying the time scale by β i.e. $T = T_0 + \beta\, t$, which makes I as function of time but the dependence of I on temperature is functional. However for area conservation, one can normalize/divide I (obtained from Eq. (1) or experimental counts) by the respective heating rate but this normalization will lead to the decrease of peak height which is the artifact of the normalization process. Such normalized glow curves corresponding to [Figs (1b and 2b)] are shown in Fig. 3(a and b), respectively.

4 Conclusions

The area under the glow curve (no thermal quenching) for different heating rates at a fixed dose is conserved in TL - time plots and is not conserved in TL-temperature plots but for a given heating rate, the glow peak height is same in time as well as in temperature plots and the glow peak height increases with the increase of the heating rate. However to conserve area in TL-temperature plots, the TL intensity (I) when divided by the respective heating rate lead to the decrease of glow peak height in I/β-temperature plots, which is the artifact of the normalization process. This is supported by the fact that during experiment the counts displayed on DPM are same (within statistical fluctuations) for the TL glow curves recorded at different heating rates but at the same dose (no thermal quenching). It is recommended that normalized and un-normalized TL counts and temperature plots should be presented when TL glow curves are recorded at various heating rates even though the imparted radiation dose is same.

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