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Temperature lags of luminescence measurements in a commercial luminescence reader

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ABSTRACT

The temperature recorded in thermoluminescence and optically stimulated luminescence equipments is not the temperature of the sample but that of the heating element on which the thermocouple is attached. Depending upon the rate of heating, a temperature difference appears between the samples and the heating element, termed as temperature lag, which could have serious effects on the curve shapes and trapping parameters. In the present work the temperature lag effect is studied in a newly developed luminescence equipment measuring both thermoluminescence and optically stimulated luminescence. It is found that the temperature lag could be large for heating rates above 2 K/s and it is strongly dependent upon the sample holder. A simple approximation method is proposed in order to both predict as well as correct for temperature lag effects in luminescence measurements.

1. Introduction

Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL) research tools are widely applied in the fields of radiation dosimetry and archaeological dating. Currently developed equipments can record both TL and OSL glow curves [1]. The exact knowledge of sample's temperature is very important, not only for TL but also for OSL measurements. The temperature is measured using a thermocouple, which however, records the temperature of the heating strip and not the one of the sample. The temperature difference between the heating element and the sample is known as temperature lag, whereas the temperature differences within the sample are known as thermal gradient. Betts and Townsend [2] had modeled in detail all these effects for the case of contact heating TL readers, while Betts et al. [3] have performed detailed measurements of the effects. Although the methodology used by [3] analyzed thoroughly the effects in every detail, it is technically very difficult and neither easily repeatable nor applicable. Piters and Bos [4], Pradhan [5] and Furetta et al. [6] had shown the serious effects of the temperature lag on TL glow-curves and on the trapping parameters evaluation.

Kitis and Tuyn [7] have proposed a method-approximation in order to correct for temperature lag and thermal gradients, using only TL measurements. The temperature lag correction is based on the following equation:

$$T_{mgj} = T_{mgi} - c \cdot \ln\left(\frac{\beta_i}{\beta_j}\right) \qquad (1)$$

where T_{mgj} and T_{mgi} are the peak maximum temperatures received at heating rates β_j and β_i, respectively and c a constant. This aforementioned equation was derived for all cases of kinetics, namely first, second and general, by considering the glow peaks obtained for two different rates of heating $\beta_i < \beta_j$ with the glow peak due to the higher heating rate being shifted towards the higher temperature keeping its integral stable and reducing slightly its peak height. Consequently, Eq. (1) was derived by considering the intensities of the two glow peaks at the same fraction of their maximum intensity and applying the corresponding kinetic order model [7]. In order to apply this specific method, one has to go through three distinctive steps.

Step 1: Evaluation of the constant c in Eq. (1), using two very slow heating rates, so that the temperature lags are negligible. For example, for heating rates $\beta_1/\beta_2 = 0.5$ giving peak maximum temperatures T_{mg1} and T_{mg2}, the constant will be:

$$c = \frac{T_{mg2} - T_{mg1}}{0.693} \qquad (2)$$

Step 2: From Eq. (1) and the evaluated constant c, the T_m at every high heating rate is estimated relative to the lower one.

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Step 3: If the peak maximum temperature of a glow-peak received with a high heating rate is T_{mg} and T_m is the respective value derived from step 2, then the temperature lag will be:

$$\Delta T = T_{mg} - T_m \tag{3}$$

The aim of the present work is to assess temperature lag effects appearing in a widely used TL/OSL reader, which will be described below. The dosimeter selected for this study is LiF:Mg,Ti (TLD-100). The reason is that this material is a reference material widely accepted in TL radiation dosimetry, and therefore its glow-curve properties and its physical parameters have been extensively studied.

2. Experimental procedure

The Harshaw LiF:Mg,Ti chips of dimensions 3 × 3 × 0.9 cm were used in the present work. The measurements were performed using the RISØ TL/OSL reader (model TL/OSL-DA-15) equipped with a 0.1 Gy/s $^{90}Sr/^{90}Y$ β-ray source [1]. The reader is fitted with an EMI 9635QA PM Tube.

All TL measurements were performed using a combination of a Pilkington HA-3 heat absorbing and a Corning 7–59 blue filter. Seven different heating rates were applied, ranging between 0.25 and 16 K/s, namely 0.25, 0.5, 1, 2, 4, 8 and 16 K/s. Maximum heating temperature was 350 °C in all cases except for the two latter cases where TLD-100 was heated up to 400 °C. The test dose attributed was 0.5 Gy. The study was performed on both sample holders available, namely stainless steel cups and discs, both purchased from RISØ laboratory.

3. Experimental results and discussion

3.1. Method of analysis

The main interest in the present work is the behavior of all glow-peak maximum temperatures as a function of the heating rate, but not the glow-curve intensity and trapping parameters which were extensively studied [4,5,8–11].

All the experimental glow-curves of LiF:Mg,Ti obtained were fitted using a first order kinetics function [12]:

$$I(T) = I_m \cdot \exp\left[1 + \frac{E}{kT}\cdot\frac{T - T_m}{T_m} - \frac{T^2}{T_m^2}\right]\cdot \exp\left[\frac{E}{kT}\cdot\frac{T - T_m}{T_m}\cdot(1-\Delta) - \Delta_m\right] \tag{4}$$

where Δ *is* $2kT/E$, Δ_m the value of Δ at T_m, E (eV) the activation energy, I_m the TL intensity at the peak maximum temperature T_m and k (eV/K) the Boltzmann constant.

All curve fittings were performed using the MINUIT computer program [13], while the goodness of fit was tested using the Figure Of Merit (FOM) of Balian and Eddy [14] given by:

$$\mathrm{FOM} = \sum_i \frac{|Y_{\mathrm{Exper}} - Y_{\mathrm{Fit}}|}{A} \tag{5}$$

where Y_{Exper} is the experimental glow-curve, Y_{Fit} is the fitted glow-curve and A is the area of the fitted glow-curve.

3.2. LiF chips in cup holders

A curve fitting example of LiF:Mg,Ti is presented in Fig. 1. The glow-peaks on which the interest is concentrated are the glow-peaks 2, 3, 4 and 5, already shown in the Figure. According to the de-convolution analysis, the experimental T_{mg} values as a function of the heating rate were obtained. The values of T_{mg} for the lower heating rates of 0.25 and 0.5 K/s were used in order to evaluate the constant c of Eq. (1) for each glow-peak. Once the constant c was evaluated then the corrected values of T_m from Eq. (1) were obtained. The results for glow-peaks 2, 3, 4 and 5 are shown in Fig. 2. The open circles, for all glow-peaks, represent the experimental values without any correction. The solid circles, for all glow-peaks, represent the corrections procedure of Eq. (1) described in introduction section. It can be easily observed that for heating rates up to 1 K/s there are not differences between un-corrected T_{mg} and corrected T_m values. However, for higher heating rates the difference between un-corrected and corrected T_m values, which defines the temperature lag, becomes obvious.

The crosses in Fig. 2 represent the T_m values resulted from a simulation study as following. The activation energies and frequency factors of all glow-peaks are evaluated from the curve fitting analysis. By considering, as in above case, that at the lowest heating rate of 0.25 K/s the temperature lag is negligible, then the (E, s) values obtained (presented in Table 1) can be used to evaluate theoretically the peak maximum positions through the usual first order Randall-Wilkins equation [15]. In fact this simulation is the obvious method to evaluate temperature lag, provided that very accurate values of (E, s) are known. The results of the simulation, which are represented by the crosses, show the excellent agreement achieved between the correction method of Eq. (1) and those of the theoretical simulation.

The glow-peak 5 is the most extensively studied glow-peak and many results concerning its trapping parameters are summarized in the GLOCANIN inter-comparison program [9,10]. The values of its trapping parameters evaluated in the present work as a function of the heating rate are listed in Table 2. The temperature lag

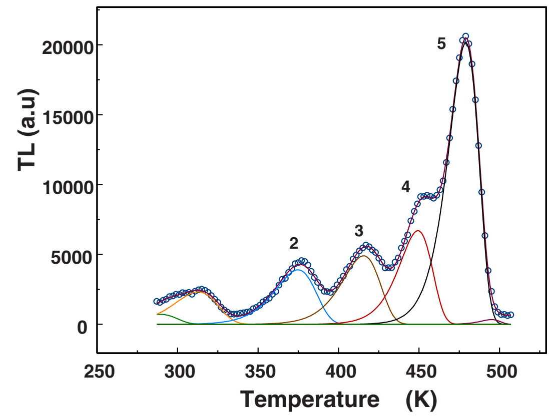

Fig. 1. Glow-curve of LiF:Mg,Ti de-convolved into its individual glow-peaks.

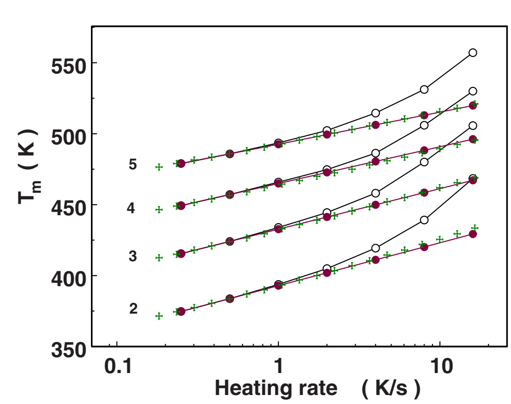

Fig. 2. T_m as a function of the heating rate for glow-peaks 2, 3, 4 and 5. Open circles represent the experimental values. Solid circles are the corrected values according to Eq. (1) while crosses correspond to the simulated values.