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Phototransferred thermoluminescence and thermally-assisted optically stimulated luminescence dosimetry using α-Al_2O_3:C,Mg annealed at 1200 °C

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ABSTRACT

We report phototransferred thermoluminescence (PTTL) and thermally-assisted optically stimulated luminescence (TA-OSL) of α-Al_2O_3:C,Mg annealed at 1200 °C. PTTL is TL measured from an irradiated phosphor after its exposure to light. The other theme of this study, TA-OSL is the additional amount of luminescence optically stimulated from a sample over and above the amount that would be measured at room temperature. A sample irradiated to 10 Gy and preheated to 230 °C at 1 °C/s followed by illumination by 470 nm blue light produced four PTTL peaks at 53, 80, 102 and 173 °C. The PTTL peaks occur at the same positions as the corresponding conventional TL peaks. Their kinetic parameters are also similar. The intensity of the PTTL peaks increased with duration of illumination to a maximum within 200 s for doses between 1 Gy and 10 Gy. The dose response of each of the PTTL peaks at 80, 102 and 173 °C is linear within 1–15 Gy. The rate of fading is low and the peaks are reproducible. When the irradiated sample is optically stimulated at temperatures between 30 °C and 300 °C, after preheating to 500 °C, the intensity of its TA-OSL goes through a peak with temperature at 200 °C. Using the rising edge of the plot, activation energy of thermal assistance for a deep electron trap was estimated as (0.21 ± 0.02) eV. The TA-OSL dose response is sublinear from 10–250 Gy and saturates thereafter. The PTTL and TA-OSL analyses signify that the concentration of deep traps in α-Al_2O_3:C,Mg increased after annealing at 1200 °C. As a result, the sample produced better PTTL and TA-OSL response than when annealed at lower temperature.

1. Introduction

α-Al_2O_3:C,Mg is a high-sensitivity luminescence material initially introduced as an optical data storage and fluorescent nuclear track detector [1]. However, recent studies using thermoluminescence (TL) and optically stimulated luminescence (OSL) have shown that the material can also be used as a TL and OSL dosimeter [2–4]. The dose response of the main TL peak of α-Al_2O_3:C,Mg under beta irradiation is superlinear within 0.1–30 Gy followed by sublinearity up to 100 Gy [2]. The peak is reproducibile. However, a major drawback in using the material for TL or OSL dosimetry is that its luminescence signal fades at a faster rate than desired for a dosimeter. Kalita and Chithambo [3] explained that the release of the trapped electrons causing fading in α-Al_2O_3:C,Mg may be due to charge hopping between the electron traps.

Phototransferred TL (PTTL) and thermally-assisted OSL (TA-OSL) are two methods useful for study of luminescence from deep electron traps. These electron traps are not accessible at ambient temperatures and as such the electrons trapped here are stable at ambient conditions. PTTL is technically the TL measured from a phosphor after illumination of an irradiated sample by light of a specific wavelength [5]. On the other hand, TA-OSL is the luminescence measured from a sample under simultaneous thermal and optical stimulation and is specifically the extra amount of luminescence over the signal that would be measured at room temperature [6]. TA-OSL has been observed in α-Al_2O_3:C [7–9], α-Al_2O_3:C,Mg [10], feldspar [11] and quartz using various methods [12–15].

Previous studies of PTTL [16] and TA-OSL [10] in an un-annealed α-Al_2O_3:C,Mg showed that the concentration of deep traps in this material is low. This conclusion has been verified by a set of TL and OSL measurements carried out on samples irradiated to different doses [17]. Owing to such low concentration of deep traps in un-annealed α-Al_2O_3:C,Mg, the resulting PTTL and TA-OSL signals are too weak for use in dosimetry. Interestingly, it was recently observed that the distribution of electron traps in the sample was significantly affected by annealing at 1200 °C [18]. For example, an un-annealed sample showed glow peaks at 42, 72, 161, 193, 279, 330 and 370 °C [19,20] but an additional peak at 100 °C was observed when the sample was annealed at 700 °C and 900 °C [21]. The activation energy of the peaks is between 0.83 eV and 1.94 eV and all the peaks follow first-order kinetics [19,20]. In contrast, a sample annealed at 1200 °C shows glow peaks at

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54, 80, 102, 173, 238, 290, 330 and 387 °C. The activation energy of the peaks is between 0.77 eV and 2.07 eV [18]. The peak at 54 °C follows general order kinetics whereas the rest follow the first order kinetics [18]. The change in the distribution of electron traps, as reflected by the glow peaks, was attributed to dissociation of aggregate F_2^{2+}(2Mg) defects [18,21,22].

Since the distribution of electron traps in α-Al_2O_3:C,Mg is affected by annealing at 1200 °C, it is likely that there may also be some change in the concentration of deep traps and this can be studied by PTTL and TA-OSL. The aim of this work is to study the PTTL and TA-OSL of α-Al_2O_3:C,Mg after annealing at 1200 °C in order to explore its application in luminescence dosimetry.

2. Experimental details

α-Al_2O_3:C,Mg chips of size 5 × 2.5 × 1 mm (Landauer, Inc; Oklahoma, USA) were used. The samples were annealed at 1200 °C for 15 min before use. Luminescence was measured using a RISØ TL/OSL DA-20 Luminescence Reader. Signals were detected by an EMI 9235QB photomultiplier tube through a 7.5 mm thick Hoya U-340 filter (transmission band 290–380 nm FWHM). The samples were irradiated at ambient temperature using a $^{90}Sr/^{90}Y$ beta source at a nominal dose rate of 0.1028 Gy/s and all measurements were carried out in a nitrogen atmosphere to avoid spurious signals from air.

For PTTL measurement, an irradiated sample was preheated to a specific temperature to remove charges from electron traps associated with identified glow peaks below that temperature. After cooling to room temperature, the sample was illuminated by a set of 470 nm blue light emitting diodes (LEDs) set at a power density of 72 mW/cm^2, in order to induce transfer of charge from deep traps to the shallower ones emptied by preheating. After the illumination, a complete glow curve was then measured up to 500 °C to monitor the presence of any PTTL peaks.

In TA-OSL measurements, an irradiated sample was preheated to 500 °C to remove charges from electron traps corresponding to all glow peaks up to 500 °C. Continuous-wave OSL (CW-OSL) was then measured for 500 s at some elevated temperature using the same set of blue LEDs. Measurement temperatures were changed up to 300 °C.

3. Results and discussion

Fig. 1 shows a conventional TL glow curve measured from a sample annealed at 1200 °C at 1 °C/s following irradiation to 0.2 Gy. In order to better identify peaks beyond 200 °C, the TL was measured again but with the dose increased to 1 Gy and after preheating to 230 °C at 1 °C/s. The result is shown in the inset to Fig. 1. The glow curve consists of eight peaks at 54, 80, 102, 173, 238, 290, 330 and 387 °C labelled as I, II, IIA, III, IV, V, VI and VII respectively. The kinetic and dosimetric features of the conventional TL peaks I-VII have been reported elsewhere [18].

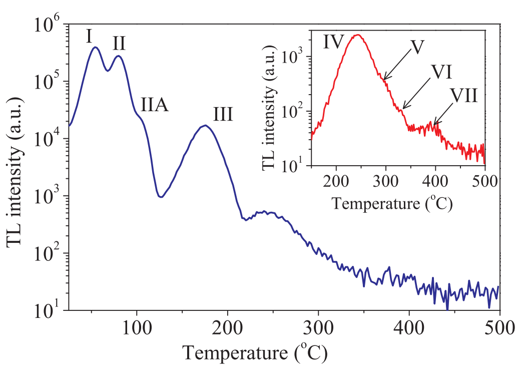

Fig. 1. A glow curve of α-Al_2O_3:C, Mg annealed at 1200 °C recorded at 1 °C/s following irradiation to 0.2 Gy. The inset shows a glow curve of the same sample irradiated to 1 Gy and recorded after preheat to 230 °C at 1 °C/s.

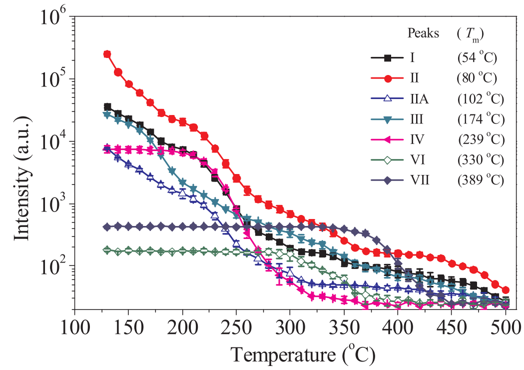

Fig. 2. The peak intensity for each of peaks I, II, IIA, III, IV, VI and VII against preheating temperature.

3.1. PTTL analyses

To study PTTL following a specific pre-heat, it is important to distinguish the traps which get depleted (donors) from those that get filled (acceptors) during the illumination. In order to identify the donors and acceptors, a step-annealing experiment was carried out.

3.1.1. Step-annealing experiment

Here the intensity of the glow peaks recorded after illumination are noted as a function of pre-heating temperature. In this experiment, a sample irradiated to 10 Gy was first preheated to 130 °C at 1 °C/s and after cooling, TL recorded following illumination for 100 s at 25 °C. The procedure was repeated on the same sample, freshly irradiated each time, but with the preheat temperature increased from 130 °C to 500 °C at 10 °C intervals. Fig. 2 shows a plot of the intensity of peaks I, II, IIA, III, IV, VI and VII against the preheating temperature. Each data point in Fig. 2 is an average from three identical measurements and the error bars represent their standard deviation. Peak V is omitted from Fig. 2 as it is embedded within the falling edge of peak IV and therefore its intensity could not be reliably monitored. The preheating temperature was chosen from 130 °C which is above the position of peaks I, II and IIA. At a high dose of 10 Gy used in the PTTL experiments, peaks I and II would be far too intense to be measured without a neutral density filter in front of the photomultiplier tube. The problem is that if one uses a neutral density filter this way, the intensity of the other peaks in the glow curve become suppressed to such an extent that they cannot be reliably detected.

Since the sample was first preheated to 130 °C, that is, beyond the maxima of peaks I, II and IIA, the existence of these peaks in the glow curve after illumination shows that they are reproduced as PTTL peaks. Therefore the electron traps corresponding to peaks I, II and IIA act as acceptors. The intensity of these peaks, however, decrease with the preheating temperature. This decrease is attributed to a reduction in the concentration of electrons at the donor traps. Regarding peak III, its intensity decreases gradually with preheating temperature up to 500 °C. The existence of this peak beyond its maximum (at 173 °C) indicates that the peak is an acceptor in PTTL. In contrast, the intensities of each of peaks IV, VI and VII gradually decrease to background when the preheating temperature exceeds their corresponding peak maxima at 238 °C, 330 °C and 387 °C respectively. Fig. 2 also shows that when the preheating temperature goes beyond the positions of peaks IV, VI and VII, the intensity of PTTL peaks I, II, IIA and III decrease rapidly. This behaviour suggests that the electron traps corresponding to peaks IV, VI and VII act as donors in the PTTL process. In addition, the presence of PTTL peak III after preheating to 500 °C implies the existence of some deep donor electron traps in the sample.