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Factors influencing the shape of CW-OSL signal obtained by stimulation of very deep traps in carbon-doped aluminium oxide: An experimental study

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ABSTRACT

The optically stimulated luminescence from carbon-doped aluminium oxide (α-Al2O3:C) displays a peak with time under certain measurement conditions. In this paper, we present factors that influence the peak-like shape of continuous-wave optically stimulated luminescence (CW-OSL) signal. The report is based on the experimental study of OSL signals obtained by stimulation of very deep traps in α-Al2O3:C. Methods exploiting post-irradiation annealing, variable dose and temperature dependent OSL measurements were used in the investigation. It is found that the rising part of the CW-OSL peak is obtained when the rate of retrapping at the most optically active trap (main trap) exceeds the rate of direct radiative recombination following optical release of charges from all optically active traps. This is possible if, during optical stimulation, the primary trap responsible for OSL i.e. the main trap, is substantially unoccupied and the very deep, donor traps are substantially filled up. The rate of charge retrapping itself is deduced to depend on the occupancy of the acceptor traps i.e. shallow, main and secondary traps; concentration of charge carriers in the very deep, donor traps; the post-irradiation annealing temperature and the temperature at which the OSL is measured.

1. Introduction

Continuous-wave optically stimulated luminescence (CW-OSL) is a steady-state method for measuring OSL whereby the intensity of the stimulation light is held constant throughout the stimulation period while the OSL signal is continuously monitored. Conventionally, the observed luminescence decays monotonically with optical stimulation time due to emptying of charges from traps and their subsequent recombination at luminescence centres. For first order kinetics i.e. no retrapping, the time-dependence of a CW-OSL decay curve can be approximated by a simple exponential or a summation of simple exponentials. Quartz, for example, produces a CW-OSL decay curve that can be deconvolved into three exponential components termed as fast, medium and slow components [1,2].

Depending on the experimental conditions, a peak-like CW-OSL signal, rather than a monotonically decaying one, is observed in some materials, for example, Al2O3:C [3,4], CaF2:N [5], BeO [6], quartz and feldspar [7]. Results of simulations based on the OSL model devised by Yukihara and McKeever [8] and McKeever, et al. [7] demonstrated that a peak observed in the CW-OSL curve can be attributed to trapping and thermal detrapping of charge from the shallow traps during optical stimulation. Poolton et al. [9] used the presence of the peak in the infrared (IR)-stimulated OSL curve obtained from feldspars after long green light exposure of an irradiated sample as evidence of localized, donor-acceptor type recombinations. Furthermore, McKeever [7] successfully used simulations and experimental measurements on quartz and feldspar at high dose, low optical stimulation intensity, and intermediate measurement temperatures to show that the OSL in these cases are capable of producing a peak-shaped OSL curve. The theoretical model used by Mckeever et al. [7] was based on the assumption that optical stimulation releases charges from traps into the conduction band from where they get recaptured by the traps or recombine radiatively or non-radiatively at recombination centres.

In the present work, we use an experimental approach to explore some factors that influence the peak-shaped nature of CW-OSL signal obtained by optical stimulation of very deep traps in α-Al2O3:C. Blue light and not green light was used during the study since blue light is more effective in releasing charge from deep traps in Al2O3:C [10].

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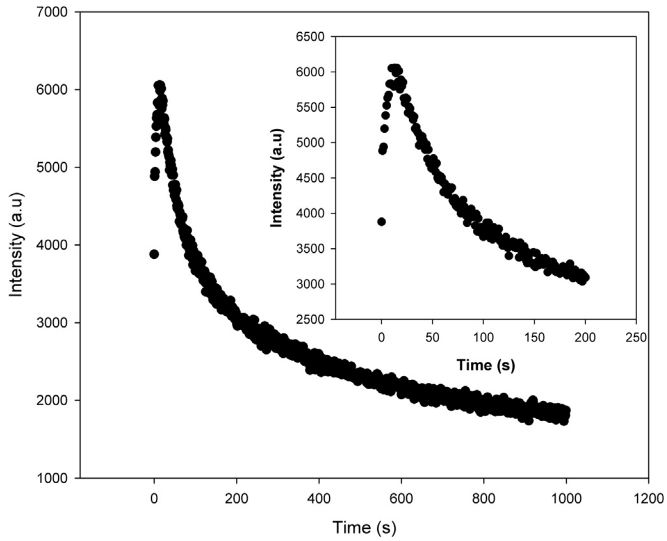

Fig. 1. A plot of CW-OSL signal obtained from blue light stimulation of very deep traps for 1000 s at 30 °C. The sample was first irradiated to 5.0 Gy followed by heating to 500 °C at 1.0 °C/s before exposing it to 470-nm blue LEDs. The inset shows the same plot for the first 200 s to provide a clearer view of the peak.

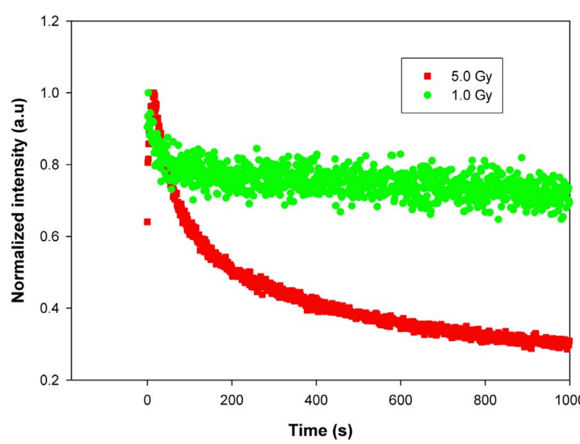

Fig. 2. Plots of CW-OSL signal for 1.0 Gy and 5.0 Gy irradiation doses. The sample was first irradiated then heated to 500 °C at 1.0 °C/s before exposing it to 470-nm blue LEDs. The signal was recorded at 30 °C for a stimulation period of 1000 s.

This work is intended to provide further insight into the charge transfer mechanisms during stimulated luminescence processes in α-Al2O3:C.

2. Experimental details

Samples used were carbon-doped aluminium oxide disks (Rexon TLD Systems, Ohio, USA) measuring 5 mm in diameter by 1 mm in thickness. All measurements were carried out in the Risø TL/OSL-DA-20 Reader. The irradiation unit is a built-in ^{90}Sr/^{90}Y source that delivers beta dose at a nominal rate of 0.1028 Gy/s. The luminescence detection unit consists of an EMI 9235 QB photomultiplier tube and a 7-mm thick Hoya U-340 filter (transmission 270–380 nm FWHM). The luminescence stimulation unit is comprised of 470-nm blue LEDs that delivers a maximum power intensity of 80 mW cm^2 at the sample position. Unless otherwise stated, optical power for the LEDs was set at 90% for a total stimulation time of 1000 s. All samples were annealed only once at 900 °C for 15 min before use to erase their irradiation history.

3. Results and discussion

3.1. The shape of the CW-OSL signal relative to optical stimulation of very deep traps

A previously annealed sample was irradiated to 5.0 Gy, heated linearly at 1.0 °C/s to 500 °C, and then optically stimulated for 1000 s using 470-nm blue LEDs at 30 °C to record OSL. Heating to 500 °C ensures that charge trapped during irradiation period is only available in very deep traps i.e. traps thermally accessible beyond 500 °C. Fig. 1 presents a plot of the OSL intensity versus stimulation time and, in the inset, the same feature for the first 200 s intended to better illustrate the peak-like profile. Fig. 1 shows that the CW-OSL signal obtained by optical stimulation of charge captured in very deep traps of α-Al2O3:C (following an irradiation dose of 5.0 Gy), is peak-shaped. Polymeris et al. [4] reported a similar result for α-Al2O3:C under 470-nm blue light stimulation following beta irradiation to 25.0 Gy and post-irradiation heating to 500 °C. The rising part of the curve represents the period during which the rate of charge retrapping into the most optically active traps i.e. main trap, is greater than the rate of detrapping from the optically active traps and subsequent recombination at the radiative luminescence centres. At the peak maximum, the retrapping rate is approximately equal to the rate of detrapping and subsequent direct recombination. Beyond the peak, the rate of detrapping and subsequent direct recombination exceeds charge retrapping.

We expect the retrapping rate to be more than the detrapping rate and subsequent direct recombinations if the most optically active trap is relatively less occupied and the very deep traps filled. What is relevant in Fig. 1 is that prior to optical stimulation, the main trap, that is, the most optically active trap in α-Al2O3:C, is unoccupied due to post-irradiation heating whereas the donor traps are significantly occupied due to the 5.0-Gy irradiation. We expect that the radiation history of the sample will influence the occupancy of the very deep traps. In the subsequent sections, we examine this proposal in greater detail.

3.2. Influence of charge concentration in very deep traps on the peak shape of the CW-OSL signal

The concentration of charges in very deep traps can be altered by irradiation dose, illumination light and post-irradiation annealing temperature. We now show how each one of these external influences affects the peak-shaped CW-OSL signal.

3.2.1. Effect of irradiation dose on the peak shape of the CW-OSL signal

For this study, a sample was irradiated to 1.0 Gy, heated at 1.0 °C/s to 500 °C to deplete the acceptor traps, then exposed to 470-nm blue LEDs for 1000 s at 30 °C. This procedure was repeated for 5.0 Gy irradiation dose. Fig. 2 shows the CW-OSL signals corresponding to the irradiation doses used.

Fig. 2 shows that an irradiation dose of 5.0 Gy produced a peak-shaped CW-OSL signal as expected (see Fig. 1) whereas a 1.0 Gy irradiation dose did not. In both cases i.e. 1.0 Gy and Gy, the main trap is unoccupied prior to optical stimulation. However, the occupancy of the very deep traps is greater for 5.0 Gy irradiation dose compared to 1.0 Gy irradiation dose. This is consistent with our earlier statement