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The influence of radiation-induced defects on thermoluminescence and optically stimulated luminescence of α-Al_2O_3:C

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ABSTRACT

It is known that when α-Al_2O_3:C is exposed to excessive amounts of ionising radiation, defects are induced within its matrix. We report the influence of radiation-induced defects on the thermoluminescence (TL) and optically stimulated luminescence (OSL) measured from α-Al_2O_3:C after irradiation to 1000 Gy. These radiation-induced defects are thermally unstable in the region 450–650 °C and result in TL peaks in this range when the TL is measured at 1 °C/s. Heating a sample to 700 °C obliterates the radiation-induced defects, that is, the TL peaks corresponding to the radiation induced defects are no longer observed in the subsequent TL measurements when moderate irradiation doses below 10 Gy are used. The charge traps associated with these radiation-induced defects are more stable than the dosimetric trap when the sample is exposed to either sunlight or 470-nm blue light from LEDs. TL glow curves measured following the defect-inducing irradiation produce a dosimetric peak that is broader and positioned at a higher temperature than observed in glow curves obtained before the heavy irradiation. In addition, sample sensitization/desensitization occurs due to the presence of these radiation-induced defects. Furthermore, both the activation energy and the kinetic order of the dosimetric peak evaluated when the radiation-induced defects are present in the sample are significantly lower in value than those obtained when these defects are absent. The radiation-induced defects also affect the shape and total light sum of the OSL signal as well as the position and width of the resultant residual phototransferred thermoluminescence main peak.

1. Introduction

α-Al_2O_3:C is a material of great dosimetric importance due to its high sensitivity to ionising radiation, low detectable dose threshold, wide range of linear dose response, low fading rate, low background noise, simple annealing procedure and high resistance to radiation [1–4]. Its extreme sensitivity to ionising radiation is ascribed to high concentration of luminescence-active point defects consisting mainly of an oxygen vacancy localizing an electron (F^+ centre, emission wavelength, λ_{em} = 330 nm) and oxygen vacancy with two electrons trapped nearby (F centre, λ_{em} = 420 nm). Both F^+ and F centres are intrinsic in as-grown α-Al_2O_3 and their concentration is enhanced when α-Al_2O_3:C is doped with carbon [1]. When Al_2O_3 is exposed to heavy irradiation of say energetic electrons or neutrons, its structure may not only change but defects may also be induced as a result [2,3]. Some previously reported radiation-induced defects in α-Al_2O_3:C and its precursor α-Al_2O_3 include complex aggregates of F_2 centres in different charged states as F_2, F^{+2} and F_2^{2+} [4,5]. F_2, F^{+2} and F_2^{2+} are aggregates of two oxygen vacancies that have trapped four, three and two electrons, respectively. Kortov et al. [4] go further to claim that it is the F^+ centres and not the F centres that are involved in the formation of these aggregates.

In this paper, we present the influence of radiation-induced defects in α-Al_2O_3:C on the TL and OSL measured after the defect-inducing irradiation.

2. Experimental details

Samples were aluminium oxide disks measuring 5 mm in diameter and 1 mm in thickness (Rexon

TLD Systems, Ohio, USA) and were annealed once at 900 °C for 15 min before use. All measurements were carried out in the Risø TL/OSL DA-20 Reader that measures both TL and OSL.

The luminescence detection unit consists of an EMI 9235QB photomultiplier tube (PMT) and a 7-mm thick Hoya U-340 detection filter (transmission 270–380 nm FWHM). However, to attenuate excessive luminescence intensities hazardous to the PMT at very high doses, we used an absorptive neutral density filter

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(NDF), a Hoya ND-03 of 1% transmission and a transmission wavelength of 400–700 nm. The irradiation unit is a built-in $^{90}Sr/^{90}Y$ β-source with a nominal dose rate of 0.1028 Gy/s. For CW-OSL measurements, a set of blue LEDs (peak wavelength, λ_p = 470 nm, FWHM = 20 nm) that delivers a maximum power density of 80 $mWcm^2$ at the sample position was used.

The following protocols, labelled Protocol 1 and Protocol 2, were used to investigate the effects of the heavy irradiation on TL and OSL, respectively. For this, samples were irradiated to 1000 Gy.

2.1. Protocol 1

This protocol was used to investigate the effects of heavy irradiation on TL.

Stage 1

1. A preheat at 1 °C/s to 700 °C to remove any background dose
2. Irradiation to a test dose of 1.0 Gy (used to monitor changes in TL)
3. TL at 1 °C/s to 400 °C

Steps 2–3 were repeated 10 times to monitor sensitivity changes. The TL measurements in step 3 shall be referred to as **TL A**.

Stage 2

4. Irradiation to 1000 Gy (intended to induce defects)
5. A preheat at 1 °C/s to 400 °C (to clear the main peak)
6. Irradiation to a test dose of 1.0 Gy (used to monitor changes in TL)
7. TL at 1 °C/s to 400 °C

Steps 6–7 were repeated 10 times to monitor sensitivity changes. The TL measurements in step 7 shall be referred to as **TL B**.

Stage 3

8. A preheat at 1 °C/s to 700 °C (intended to remove radiation induced defects)
9. Irradiation to a test dose of 1.0 Gy (used to monitor changes in TL)
10. TL at 1 °C/s to 400 °C

Steps 9–10 were repeated 10 times to monitor sensitivity changes. The TL measurements in step 10 shall be referred to as **TL C**.

Each irradiation was preceded by a 120-s pause to ensure that the sample was irradiated at room temperature.

To isolate the influence of the radiation induced defects on TL, Stage 2 of Protocol 1 was modified by preheating the sample to 700 °C instead of 400 °C (step 5) immediately after 1000 Gy irradiation i.e. the modified protocol involves two separate preheats to 700 °C, the other being at the beginning of Stage 3. This modified version of Protocol 1 shall be referred to as modified Protocol 1. Both Protocol 1 and modified Protocol 1 were repeated for TL readouts measuring to 500 °C.

2.2. Protocol 2

This protocol was used to investigate the influence of radiation-induced defects on OSL measured following the defect-inducing irradiation:

Stage 1

1. A preheat at 1 °C/s to 700 °C (intended to remove any background dose)
2. Irradiation to a test dose of 1.0 Gy (to monitor changes in OSL)
3. OSL at 30 °C for 200 s using 470-nm blue LEDs set at 90% optical power
4. TL at 1 °C/s to 500 °C (intended to record residual phototransferred TL (RPTTL))

Steps 2–4 were repeated 10 times to monitor sensitivity changes. The OSL measurements at step 3 and RPTTL measurements at step 4 shall be referred to as **OSL A** and **RPTTL A**, respectively.

Stage 2

5. Irradiation to 1000 Gy (intended to induce defects)
6. A preheat at 1 °C/s to 500 °C (intended to clear the main peak)
7. Irradiation to a test dose of 1.0 Gy (to monitor changes in OSL)
8. OSL at 30 °C for 200 s using 470-nm blue LEDs set at 90% optical power
9. TL at 1 °C/s to 500 °C (intended to record RPTTL)

Steps 7–9 were repeated 10 times to monitor sensitivity changes. The OSL measurements at step 8 and RPTTL measurements at step 9 shall be referred to as **OSL B** and **RPTTL B**, respectively.

Stage 3

10. A preheat at 1 °C/s to 700 °C (intended to remove radiation-induced defects)
11. Irradiation to a test dose of 1.0 Gy (to monitor changes in OSL)
12. OSL at 30 °C for 200 s using 470-nm blue LEDs set at 90% optical power
13. TL at 1 °C/s to 500C (intended to record residual RPTTL)

Steps 11–13 were repeated 10 times to monitor sensitivity changes. The OSL measurements at step 12 and RPTTL measurements at step 13 shall be referred to as **OSL C** and **RPTTL C**, respectively.

Every irradiation in Protocol 2 was also preceded by a 120-s pause to ensure that irradiation took place at room temperature.

3. Results and discussion

3.1. Thermoluminescence peaks following heavy beta-irradiation

An annealed sample was beta-irradiated to 1000 Gy then heated to 300 °C at 1 °C/s to record a TL glow curve. The sample was thereafter reheated from room temperature to 700 °C at 1 °C/s to record another TL glow curve. A third TL measurement from room temperature to 700 °C at 1 °C/s was made following irradiation to 1.0 Gy. The results are shown in Fig. 1.

Fig. 1(a) shows a semi-logarithmic plot of the TL glow-curve measured to 300 °C. This is denoted as Run 1. There are peaks at 48, 78, 149, and 282 °C. The prominent peak at 149 °C is the one used for dosimetry. Fig. 1(b) shows results for the second set of measurements made immediately after that shown in Fig. 1(a). The glow curve, labelled Run 2, was measured immediately after Run 1 shown in Fig. 1(a). This glow curve shows obvious peaks at 45, 198, 281 and 560 °C. There is also a broad peak between 330 and 490 °C. The third measurement, shown as Run 3 in Fig. 1(b),