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Effects of different types of nuclear radiations on optically stimulated luminescence

Ayşe Güneş TANIR,* Mustafa Hicabi BÖLÜKDEMİR, Tülay Neşe KIZILIRMAK
Department of Physics, Faculty of Sciences, Gazi University, Teknikokullar, Ankara, Turkey

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Abstract: This study aims to investigate the effects of different nuclear radiation fields on an optically stimulated luminescence (OSL) dosimeter using Al_2O_3:C material. The Al_2O_3:C material was exposed to α- and β-particles and γ-photons, and the luminescence signals were measured by stimulation with a blue light emitting diode. It is concluded that the OSL technique is suitable for obtaining an adequate blue light stimulated luminescence signal in α, β, and γ radiation fields, and if the source activity was low, the statistical distributions were large.

Key words: $\alpha - \beta - \gamma$ Radiations, blue light stimulated luminescence, dose effects

1. Introduction

Optically stimulated luminescence (OSL) was first suggested as a method of dosimetry by Antonov-Romanovskii et al. in 1956 [1], and its use as a dosimetery technique has become widespread recently. High resolution imaging of radiation fields using OSL is already a successful tool in personal radiation dosimetry as well as in computer radiography and diagnostic imaging, and it also has strong potential for making precise measurements in radiotherapy doses across the range of 0.1–200 Gy [2,3]. While different materials have been used for dosimetry purposes, none of them have been tested to decide which materials can be used as a radiation dosimeter, especially in the medical fields. Using Al_2O_3:C material in OSL dosimetry applications gives an important advantage in that this material does not need to be heated, thus eliminating the problems caused by the thermal quenching of the luminescence efficiency [4,5].

There are many studies on OSL properties [6–12]. In most of them, the signal was measured using green light stimulation. Recently Umisedo et al. [13] reported on the comparison between blue and green light stimulated luminescence and showed that blue stimulation provides faster readout times and a higher initial OSL intensity than green light stimulation.

Although the behavior of luminescence signals as a function of nuclear radiation dose and temperature has been investigated by many researchers, their dosimetric properties should be studied again in detail before they are used routinely for dose measurements, especially in the case of medical or personal dosimeter techniques. The optimum experimental conditions also need to be determined, particularly in medical fields.

In this work, the decay shape, dose and activity effects, and dose response of the blue light stimulated luminescence (BSL) signal from Al_2O_3:C exposed to different types of nuclear radiation were investigated.

*Correspondence: gunes@gazi.edu.tr

2. Experimental

The luminescence signal from Al_2O_3:C (TLD-500) was read using the ELSEC 9010 OSL system developed by Spooner et al. [14]. An automated ELSEC 9010 reader system has a ring of 24 blue light OSL attachments. These blue light emitting diode (LEDs; $\sim 470 \Delta 30$ nm) from WENRUN were installed in the system designed by Bölükdemir [15]. They have a power output of about 6 cd at a 20 mA current and an emission angle of 25°. A green long-pass Schott GG-420 filter was fitted in front of the blue LEDs to minimize the amount of directly scattered blue light reaching the PM photocathode. In 24 diodes, the total power delivered to the sample was measured as 21.6 mW/cm^2 at a distance of 16 mm.

Two different beta sources were used to expose the material: the first was a ^{90}Sr-^{90}Y beta source having a dose rate of 0.28 Gy/s and the other was a point source having an activity of 2812 particles/s. Other point radiation sources used in this study were ^{137}Cs, ^{226}Ra, and ^{204}Tl. The BSL signal from Al_2O_3:C materials versus the irradiation time were plotted for the Cs-137, Ra-226, and Tl-204 point sources.

Detection was done through 3 Hoya U-340 filters (3 mm). Luminescence was detected using a Thorn-EMI 9235QA PM tube having a dark count rate of about 40 cps at room temperature (RT). Al_2O_3:C materials (diameter: 5 mm, thickness: 1 mm) were used in the measurements. The Al_2O_3:C disks were annealed at 900 °C before use in order to eliminate deep traps [11].

3. Results and discussion

3.1. Thermal and dose stability

The Al_2O_3:C aliquot was first tested to observe background luminescence. Five aliquots were left to bleach under the visible light and heated at 400 °C for 30 min. Each aliquot was then measured for 1050 s. The measured luminescence counts were found to be 52 count/s, 47 count/s, 44 count/s, 45 count/s, and 53 count/s. The average background was 48.2 count/s. Additionally, the following steps were used to test the stability of the luminescence signal: the Al_2O_3:C aliquot was exposed to a 0.4 Gy beta dose, measured for 20 s without preheating treatment, and then bleached. The same procedure was repeated 9 times using the same aliquot. The decay curves were found to be similar (Figure 1). These decay curves show the dose stability of the BSL signal from the Al_2O_3:C material [11].

The same bleached aliquot was reexposed to 0.4 Gy beta doses and the signal measured at RT. This process was repeated for 73, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, and 400 °C. The BSL decay curves for different temperatures are shown in Figure 2. The BSL intensities reach their maximum value during the first 5 s. The BSL intensities at 73, 100, 125, 150, and 175 °C remain about the same, but they decrease sharply after 175 °C (Figure 2). BSL from Al_2O_3:C is nearly stable at temperatures up to 175 °C. The readout temperature should be restricted to values between $\sim$100 °C and $\sim$175 °C. As can be seen from Figure 2, the blue light stimulated luminescence decay time is only 20 s and an unstable signal occurred just after stimulation. As is known, it is essential for dosimeter studies that the luminescence signal be thermally stable. The thermal stability of green light stimulated luminescence signal from Al_2O_3:C was investigated by Markey et al. [16] and Bulur and Göksu [6]. They reported that green light stimulated luminescence from Al_2O_3:C is quite stable at temperatures of up to $\sim$100 °C.

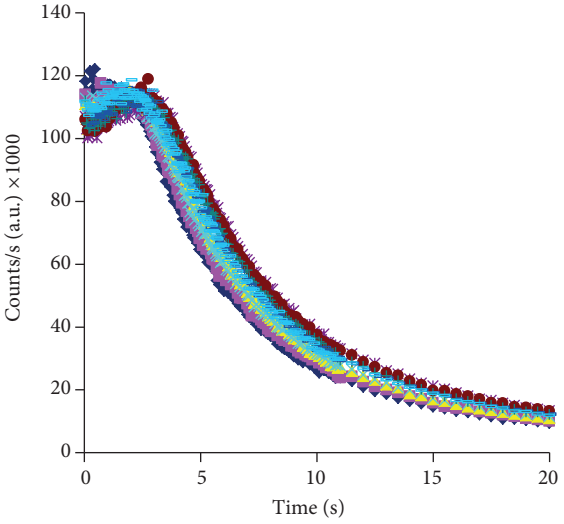

Figure 1. The dose stability of BSL decay curves from Al_2O_3:C.

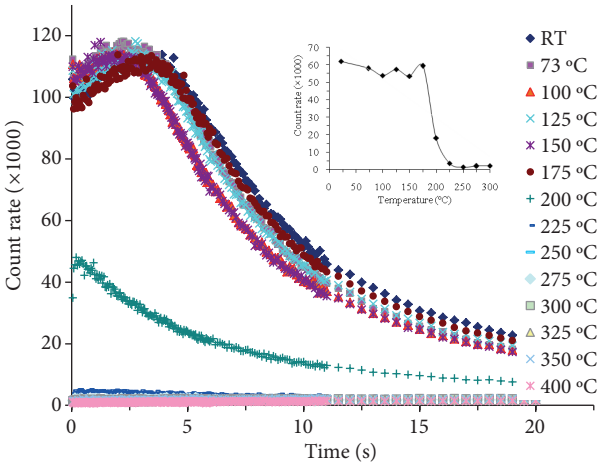

Figure 2. BSL decay curves from Al_2O_3:C for different temperatures. Inset: The intensities decrease after 175 °C.

3.2. Dose response to nuclear radiations

The 5 Al_2O_3:C aliquots that were bleached were exposed to 0.1 Gy beta doses using a ^{90}Sr-^{90}Y source and were left for 10 min at RT. To remove the unstable components, the aliquots were preheated to 100 °C for 5 min and then also left for 30 min at RT. BSL measurements were taken with 20 s reading times. The average counts were determined. The same 5 aliquots were bleached and the same procedures were repeated for 0.15 Gy, and similar steps were applied for 0.2, 0.4, 0.6, and 0.8 Gy. The BSL decay curves were plotted (Figure 3). As can be seen, as the dose increased, the peaks of the curves broadened. The luminescence count rate is plotted as a function of beta radiation doses in Figure 4. Figure 4 shows the dose response curves plotted by

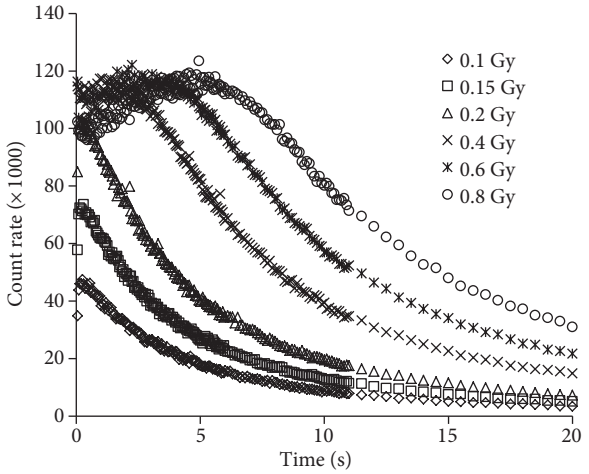

Figure 3. BSL decay curves from Al_2O_3:C for different beta radiation doses.

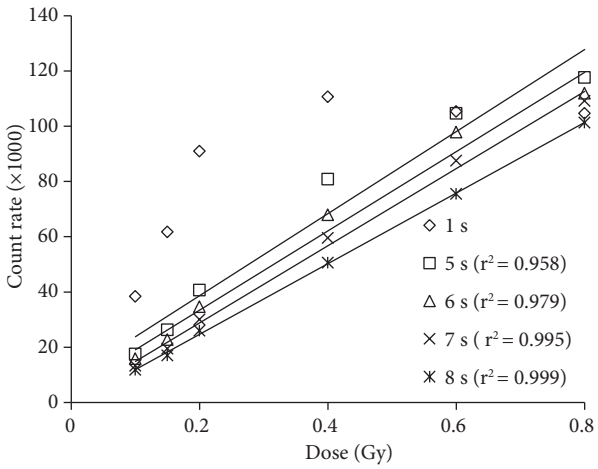

Figure 4. Dose response curves for different readout time. The counts measured at 1 and 2 s do not linearly increase as a function of dose.

using count rates measured at different reading times. As can be seen, the best fit for the strength of the linear relationship occurs at 7 or 8 s. The dose response curves plotted using the signals at 1 and 2 s did not fit a convenient linear curve. The signals after 7 s were used for dose calculations; thus, the results were obtained as accurately as possible.

One of the same 5 aliquots was irradiated by gamma rays from Cs-137 and another aliquot by alpha, gamma, and beta particles from Ra-226 point sources. These aliquots were put on the Cs-137 and Ra-226 point sources, left for 2 days, and then measured. These processes were repeated for 3 days, 4 days, and 5 days. Figure 5 shows the dose response curves for Cs-137 and Ra-226. The initial increases were not displayed in the decay curves measured for either Cs-137 or Ra-226. The dose response curves from both sources were found to be linear lines (Figure 5). As can be seen, the luminescence signals from Ra-226 are significantly higher than those of Cs-137.

3.3. Activity-dependent effects

Each of the 4 bleached aliquots was put on the 4 different point radiation sources. These were Cs-137 (activity [A] = 29,711 decay/s), Sr-90 (A = 2812 decay/s), Co-60 (A = 28083 decay/s), and Tl-204 (A = 30007 decay/s). Each aliquot was left on the radiation source for 27 days. BSL signals from the aliquots were measured for 50 s. The decay curves are shown in Figure 6. Although Co-60 and Cs-137 gamma sources possess nearly the same activity, the luminescence counts from the aliquots exposed to Cs-137 were found to be more stable than those from the aliquot exposed to the Co-60 source. This behavior can be explained by them each having different gamma energies. The gamma energy of the Cs-137 source (0.662 MeV) was lower than that of the Co-60 source (average: 1.25 MeV). Because the gamma ray energy of Co-60 is also higher than 1.02 MeV, pair production could be in evidence and so the charges localize at different level traps.

Tl-204 and Sr-90 are both sources of beta radiations. The activity of Sr-90 is significantly lower than that

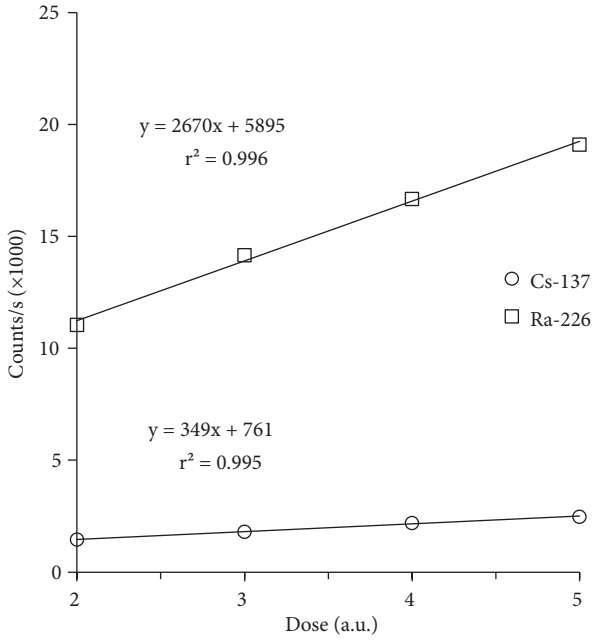

Figure 5. Dose response curves for Cs-137 and Ra-226. As is known, the exposure is directly proportional to dose.

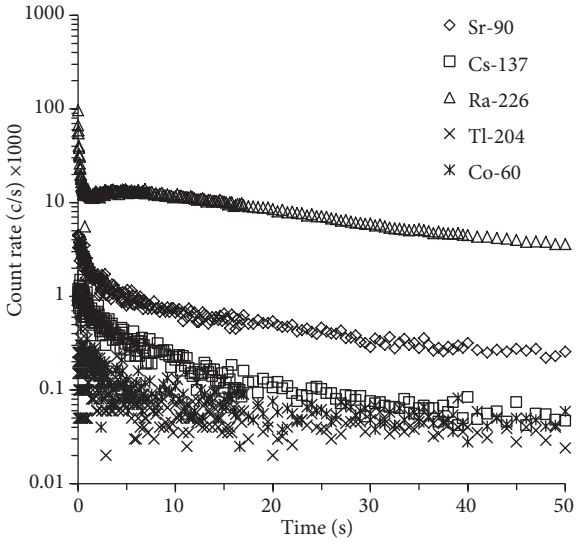

Figure 6. BSL decay curves from Al_2O_3:C aliquots exposed to different point adiation sources.

of Tl-204. However, as can be seen from Figure 6, while the statistical distributions of the luminescence counts from the aliquot exposed to Tl-204 have large deviations, the signals from the aliquot exposed to Sr-90 are more stable. The maximum beta energy of Sr-90 is 0.546 MeV. As the Tl-204 source decays, it emits beta particles (0.764 MeV) and captures electrons (0.347 MeV). As in the above conclusion, the beta energy of Tl-204 is also higher than that of Sr-90 and the statistical deviations of trapped charges are larger. As a result, both the energy and the activity of the radiation source used for exposure should be taken into consideration in order to decrease statistical errors in the use of Al_2O_3:C as a dosimeter.

4. Conclusion

Al_2O_3:C is suitable for obtaining adequate blue light luminescence intensity in α, β, and γ radiation fields. The luminescence intensity from Al_2O_3:C exposed to the alpha source was found to be higher than that from other sources. The statistical distribution is large considering that the source has low activity.

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