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On the feasibility of multiple assessment of dose using CW-OSL technique in Al_2O_3:C

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HIGHLIGHTS

- An approach based on CW-OSL technique is suggested for dose re-estimation in Al_2O_3:C.
- Calibration tables and curves are generated for different stimulation intensities and signal integration times.
- The behaviour of dose response curves for a successive readout numbers is found to be dose independent.
- Implications of these results with context to research and routine applications are discussed.

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ABSTRACT

The culmination of Continuous Wave OSL (CW-OSL) acquisition after initial few seconds offers improvement in dose detection threshold for Al_2O_3:C. Consequently, the traps from which dose information can be retrieved are still occupied by charge carriers and therefore can be stimulated multiple number of times for extracting OSL signal. This offers an approach for reassessment of the dose in an inadvertent circumstance of dose information being lost. Calibration tables and curves are generated for different stimulation intensities (ranging from 32 to 72 mW/cm^2) and signal integration times (ranging from 1 to 10 s) that can be used for re-estimation of the doses lying in the range of 1 mGy to 1 Gy. The qualitative as well as quantitative analysis of the observed trends with respect to stimulation intensity and signal integration time is carried out. The behaviour of dose response curves for successive readout numbers is also studied.

1. Introduction

Ever since its first use by Huntley et al. (1985), Optically Stimulated Luminescence (OSL) has witnessed a steady growth in its popularity as a means of measurement of ionizing radiation due to several advantages it offers over conventional TL technique. The most visible advantage lies in the fact that this method of dose readout is all optical and therefore does not involve heating of samples. This feature, besides eliminating the need to provide a reliable and reproducible heating scheme, also solves the associated problem of thermal quenching of the luminescence efficiency.

Another reason for the accelerated spread of this measurement methodology is the OSL phosphor α-Al_2O_3:C which owing to its high sensitivity to ionizing radiation and a superior chemical and thermal stability, has established itself as a reference phosphor that is being routinely used for personnel and environmental monitoring applications in several countries (Bøtter-Jensen et al., 2003; Yukihara and Mckeever, 2011).

Amongst different variants of OSL readout methodologies that are in practice e.g. Linearly Modulated (LM-OSL), Pulsed (P-OSL), Non Linearly modulated (NL-OSL), the Continuous Wave OSL (CW-OSL) technique has attracted a much wider following in dosimetric community due to its inherent operational simplicity, superior signal to noise ratio (SNR) and capability of fast readout (Mishra et al., 2011a, 2011b; Wallinga et al., 2008; Bulur, 1996). Nevertheless, when CW-OSL is employed for the low dose measurements, it becomes necessary to ensure that the background signal considerations are addressed through appropriate experimental design. Though filter combinations are deployed to isolate background arising from scattered stimulation light, it is not possible to completely eliminate the background by any choice of filters.

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Prompted by this, Akselrod and Mckeever (Akselrod and Mckeever 1999; McKeever and Akselrod 1999) attempted to address background issue by utilizing the technique of P-OSL introduced earlier by Markey et al. (1995). Their approach was based on the temporal discrimination between the stimulation light and the OSL emission. This was achieved by making use of a pulsed light source and a gated detection system that detected the OSL signal *between* the stimulation pulses. This methodology of P-OSL, besides realizing superior signal to noise ratio also offers a re-read capability through appropriate choices of power and period of optical stimulation.

Despite these advantages P-OSL technique has many associated difficulties. In particular, choice of P-OSL parameters like stimulation pulse width and separation between the pulses would differ significantly from one phosphor to another as it critically depends on intrinsic luminescence lifetime which is characteristic of a luminescent phosphor. For optimum operation the measurement parameters are required to be such that both the pulse width and the time between pulses are much less than the luminescence lifetime. This requirement introduces inflexibility and restricts choice of parameters.

Furthermore, even though this approach in principle precludes the need of optical filters, in practice, there exists a possibility of damage to Photo Multiplier Tube (PMT) in spite of gating that may compromise the stability and durability of the OSL reader. This necessitates one to revert back to the use of optical filters in front of PMT which consequently deteriorates SNR. Therefore, this idea has got limited efficacy as one cannot get rid of optical filtration and inadvertently ends up in a significant reduction of the measured OSL intensity which is undesirable. Owing to these difficulties involved and inherently complex instrumentation, P-OSL unlike CW-OSL is rarely used for research and routine applications.

In CW-OSL, based on our observation that the contribution of background and associated standard deviation increase linearly with time, and thereby for initial few seconds their contribution is minimal; we explored the possibility of restricting the readout time to few seconds and could demonstrate significant improvement in MMD (Rawat et al., 2014). For instance, at stimulation intensity of 72 mW/cm^2, MMD was found to be 37 μGy when area under CW-OSL curve for a readout time of 60 s was considered while it was 7 μGy when readout was restricted to 1 s, which amounts to an improvement by a factor of 5. Here it is important to emphasize that restricting CW-OSL read out time for initial few seconds preserves a substantial amount of OSL signal and thus collaterally offers a possibility of multiple readouts and thereby enabling dose re-estimation, an aspect which so far has not been explored. Prompted by this, in this communication, we present our results of dose re-estimation studies by employing the technique of CW-OSL on indigenously developed Al_2O_3:C phosphor for doses ranging from 1 mGy to 1 Gy. Henceforth throughout the paper we will use the term OSL in place of CW-OSL unless otherwise specified.

2. Materials and methods

The methodology for generating a typical calibration curve involves acquisition of OSL signal for a specific duration at a fixed stimulation intensity followed by repeated readouts while maintaining the same readout parameters. The time interval between consecutive readouts was chosen to be 10 min. The integrated OSL signal obtained from a particular readout constitutes a data point of this calibration curve. This curve is of utility for dose reconstruction at some later stage, whenever the need arises.

2.1. Sample preparation

All OSL measurements were performed on indigenously developed Al_2O_3:C (the process protected vide Patent application–No. 252/MUM/2013). This phosphor was embedded in polytetrafluoroethylene (PTFE, teflon) matrix and was cold pressed resulting into the formation of discs. Each disc weighed 100 mg (25 mg Al_2O_3:C and 75 mg Teflon) and admeasured 0.3 mm in thickness and 10 mm in diameter. The size distribution of Al_2O_3:C grains was opted to be in the range 35–50 μm so as to match with that of Teflon powder ensuring thus a reasonably homogeneous mixing. These cold pressed discs were subjected to a thermal treatment at 370 °C for 1 h which lead to enhancement in their mechanical integrity and strength thereby offering ease in handling Additionally, it rendered them a definite and precise geometry that ensured consistency and reproducibility of OSL readouts. The Teflon based Al_2O_3:C discs prepared in this manner were used for entire experimental studies. Out of the prepared discs the ones which were selected had OSL sensitivity variations within ±7%.

2.2. OSL reader system

All OSL measurements were carried out using a commercial OSL reader (Risø TL/OSL-DA-20 reader; Risø National Laboratory, Roskilde, Denmark) described by Bøtter-Jensen et al. (2000). Optical stimulation was carried out with blue Light Emitting Diodes (LEDs) (wavelength of 470 ± 20 nm) capable of delivering 80 mW/cm^2 stimulation intensity at sample position. A green long pass filter (GG-420) is incorporated in front of each LED cluster to minimize the amount of directly scattered blue light from reaching the detector system. The standard PMT used in the Risø TL/OSL luminescence reader is a bialkali EMI 9235QA, which has an extended UV response with maximum detection efficiency between 300 and 400 nm. To prevent scattered stimulation light from reaching the PMT, the Risø reader is equipped with a 7.5 mm Hoya U-340 detection filter, which has a peak transmission around 340 nm (FWHM 80 nm).

2.3. Irradiation

All irradiations were performed on freshly prepared telfon embedded Al_2O_3:C discs. The discs were irradiated to gamma rays of ^{137}Cs source having dose rate of 5 mGy/min at a distance of 40 cm. The doses delivered to these discs varied from 1 mGy to 1 Gy. A set of 3 discs were used for each dose and stimulation intensity. OSL signal at a given stimulation intensity is taken to be an average of 3 such discs.

2.4. Blue light stimulation

Though use of blue light stimulation of Al_2O_3:C provides faster readouts (CW-OSL curve decays faster), as compared to green, but it also creates a problem of complex and enhanced background owing to the stimulation of electrons from a deeper traps (>500 °C) to the conduction band (Umisedo et al., 2010). The problem becomes conspicuous, particularly in those cases where low dose measurements are involved using the detectors that have been previously exposed to high doses. This being detrimental to signal to noise ratio, hampers MMD. These aspects were taken care through the use of fresh set of dosimeters (that were not subjected to irradiation previously) every time.

2.5. Choice of readout parameters

2.5.1. Intensity of stimulation

In this study we have chosen stimulation intensities in the range 40–90% of maximum LED intensity (that corresponds to stimulation intensity of 80 mW/cm^2 at sample position) since our earlier