Comparative Study of the RL/OSL Responses of NanoDot OSLD and myOSL Commercial Sensors using Prototype Reader

A. K. M. M. Rahman[1*], R. Khatun[2], S. Akter[2], A. N. Monika[3], R. A. Sharmin[3], M. M Ahasan[3] and M. Begum[4]

[1,2]*Atomic Energy Centre, Dhaka, Bangladesh Atomic Energy Commission, 4 Kazi Nazrul Islam Avenue, Dhaka-1000, Bangladesh*
[3]*Nuclear Medical Physics Institute, Atomic Energy Research Establishment, Bangladesh Atomic Energy Commission, Ganakbari, Savar, Dhaka, Bangladesh*
[4]*Institute of Nuclear Science and Technology, Atomic Energy Research Establishment, Bangladesh Atomic Energy Commission, Ganakbari, Savar, Dhaka, Bangladesh*

Abstract

The aim of this work is to compare the relevant Radioluminescence (RL) and Optically Stimulated Luminescence (OSL) responses of the nanoDot OSLD and myOSL sensors with an in-house developed reader system. Using PMMA optical communication fibres the RL/OSL signals have been guided from the LINAC beam-delivery room. The RL characteristics of the BeO based myOSL was observed constant level of luminescence for the dose rate 140 cGy/min (providing better consistency compared to Al_2O_3:C based nanoDot OSLD). It is therefore safe to say that the BeO type dosimeter is more suitable for real-time dose measurements. On the other hand, the OSL (counts/s) for nanoDot Al_2O_3:C is about 24 times higher sensitive than that of myOSL BeO dosimeter under green stimulation light. The OSL signals from both the commercial sensor media, captured in this study using prototype reader, show excellent quantitative agreement with those from other sensors using commercial such as microSTAR, myOSL readers. The information contained herein, this work will help to pursue RL/OSL experimentation in this exciting and vital area of dosimetry research.

Keywords: Optically stimulated luminescence, radioluminescence, nanoDot OSLD, BeO, prototype reader, fibre-optic coupled dosimeter

1. Introduction

The fibre-coupled luminescence dosimetry (FOCD) is the state-of-the-art system based on RL/OSL techniques in the field of medical dosimetry, where the luminescence generating material is attached to a long fibre cable for getting real time information [1]. Among various possible luminescent sensors, Al_2O_3:C and BeO are practically the only commercial passive (offline) OSL dosimeters used for medical, environmental and personnel dosimetry [2-3]. These badge-type dosimeter systems are designed commercially for single point assessments. The RL/OSL fibre mounted sensor arrangements (as herein FOCD) have been described by Gaza et al. [4].

Theoretically, the OSL is the light emitted from a pre-irradiated material when subjected to an appropriate optical stimulation. This emitted light signal is proportional to the absorbed dose of radiation [5]. The wavelength of the emitted light signal is the characteristic of the OSL material. There is no correlation between the wavelengths of stimulating light and the emitted OSL signal. The wavelength of emitted OSL light is different from that of the stimulating light; the wavelength could be longer or shorter. Overall, a good OSL material should have properties such as having emission band lying between 350 and 425 nm, and defects with high photo- ionization cross section in the region of green- blue (450-550 nm). The OSL emission is highly influenced by the intensity of the stimulating optical light source. On the other hand, the instantaneous radiation dose verification can be achieved through conditioning of RL signal. Out of the observable phenomena, RL occurs during the interaction (radiative transition occurred) of ionizing radiation with sensor media. It is a reliable source of real-time dosimetry. In order to be useful for such purposes, materials need to be sensitive and have characteristics of RL signals that are consistent, distinguishable and linearly responsive with incoming radiation. Generally the intensity of RL yield (measured in photon counts) is proportional to the dose rate of incident radiation, making it suitable for real-time dosimetry.

Besides commercial passive dosimetry system, the FOCD based dosimetry systems are to facilitate features such as real-time sensing and fast readouts [6]. Up to this date, among the different methods reported to achieve FOCD based system, the RL technique has shown to meet most of the requirements in radiotherapy dosimetry [7]. Since RL dosimetry provides for in-situ monitoring of the dose-rate (Gy/min), direct feedback can be provided to the medical physicists and radiation oncologists. Any malfunction in the radiation sources can be immediately identified, enabling rapid safety precaution intervention [8].

For a particular dose rate, RL intensity over the entire irradiation session should be constant. However, two specific aspects might represent limiting factors in the case of RL dosimetry of many scintillating materials for the effective use in radiation dosimetry (i) the “stem effect”, that is the spurious luminescence originating as a consequence of the irradiation of signal carrier fibre, and (ii) the “memory effect”, that is the RL sensitivity increase during prolonged exposition to ionizing radiation. Various materials having unique characteristics have been used as RL/OSL dosimeter in FOCD techniques. The RL signal from Al_2:O_3:C crystal demonstrates a plateau effect (stem effect) [9-10]. Some other crystalline phosphors (such as, $KMgF_3$:Ce, MgS, CaS, SrS, rare-earth doped SrSe etc) have also been reported to have shown RL sensitivity, albeit, inconsistent [11-12]. The major contribution of the

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*Corresponding author: *mizanbaec14@gmail.com*

plateau effect is from fluorescence resulted owing to limitations of the physical structure of the crystal [13]. Several works [14-16] have sought to deal with the growth in photon counts from Al_2O_3:C in an irradiation period by using mathematical modelling or other techniques such as pre-irradiating the Al_2O_3:C crystal with a certain level of dose (such as 20 Gy). Conversely in an experiment has shown almost constant RL intensity of BeO during the exposure of superficial X-rays with a steady state dose rate [13].

This study is expected to be useful to reveal important RL and OSL dosimetric characteristics of two different commercial nanoDot OSLD and my OSL sensors in radiotherapy dosimetry. In present study Al_2O_3:C based nanoDot OSLD and BeO based myOSL film chips were used as dosimeter sensors attaching to the tip of a polymethyl-methcrylate (PMMA) fibre cable, allowing at a distance characterization of the RL and OSL by using in-house assembled prototype RL/OSL reader [17] system under clinical photon beam LINAC irradiation.

2. Materials and Methods

2.1 Active probe preparation

The Al_2O_3:C (effective atomic number 11.28) based nanoDot OSLD film marketed by Landaeur Inc. USA, is made up of a photosensitive aluminium oxide powder coating on a 0.2 mm thick white polystyrene film roll [18]. This film is encapsulated inside a water-equivalent light-tight plastic case of density 1.03 gm/cm^3 [19].

Similarly Beryllium Oxide (BeO) based commercial myOSL dosimeter, marketed by RadPro International GmbH, Germany, is a wonderful OSL materials with high dosimetry characteristic. BeO is tissue equivalent (effective atomic number 7.2) and therefore highly suitable for personal dosimetry [20]. It is also made up of a photosensitive Beryllium Oxide powder coating on a 0.2 mm thick white polystyrene film roll. This is also encapsulated inside a light tight opaque water equivalent cassette.

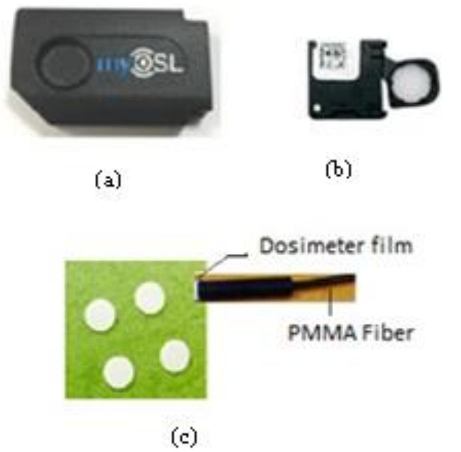

Fig. 1: Steps of probe preparation (a) BeO Oxide based commercial myOSL dosimeter, (b) Carbon dopped Al_2O_3:carbon based nanoDot OSLD and (c) Reduce sized (2mm) films probe

In the present work the probes were prepared by separating both type of the films from the case and resizing the circular film strips from a diameter of 5mm to 2mm, subsequently locating these on the tip of the PMMA fibre (Super Eska SK-40, Mitsubishi Rayon Co., Ltd, Japan). The general probe preparation procedure is shown in Fig. 1. The active volume of the probes was then wrapped with opaque Teflon tape for minimizing signal depletion due to extraneous light exposure.

2.2 Irradiation setup and instrumentation for RL/OSL signal conditioning

The dosimeter probe made from nanoDot and myOSL chips mentioned above was placed in a 10 x 10 cm^2 field within a solid-water^{TM} (Gammex, USA) phantom, at a depth dose maximum position d_{max} being found at 1.5 cm for 6 MV photon beam (high-energy X-ray) radiation. To provide for irradiation, a clinical linear accelerator (Varian 2100C/D) was used to generate a 6 MV X-ray photon beam at a dose-rate of 140 MU/min at 0° gantry angle was used. The source to surface distance was fixed at 100 cm for mitigating against detection of secondary (scattered) electron contamination from the collimator system. The PMMA optical fibre was located at the edge of the radiation field in order to minimize any potential RL signal from the PMMA optical fibre itself, otherwise known as the stem effect (primarily as a result of Cerenkov radiation). The other end of the PMMA optical fiber was connected to a reader setup, placed in the radiotherapy control room.

During capture of RL signal, the LED source is not energized. It is noted that the green LED (centred at 515 nm, 30 mW) is used to carry light through the PMMA fibre, and then be focused with stimulant light through a convex lens towards the dichroic colour beam-splitter, diagonally fitted to a rectangular dichroic mirror block. The light then passes to the dosimeter for generating OSL signal. The OSL or RL signal is then carried back from the dosimeter via the same PMMA fibre and focused to the beam-splitter through another converging lens. The RL/OSL signal is then reflected by the beamsplitter and guided towards a photomultiplier tube (300-700 nm) through the band-pass filter (315-445 nm) placed in front of the PMT. The signal-carrier PMMA fibres are connected from both sides to the dichroic cage via SMA-connectors. A photon-counting unit, placed between the workstation and PMT, acts as a signal conditioning bridge, sending RL/OSL data to a National Instruments (NI) Labview interface [17]. This relatively

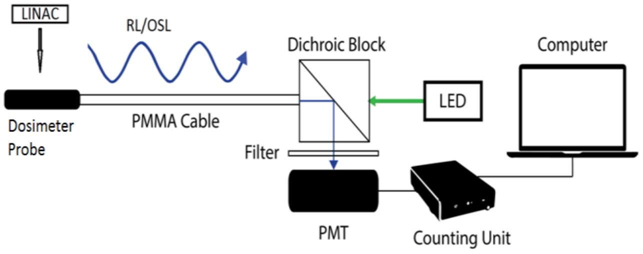

Fig. 2: A schematic of RL/OSL reader

simple reader arrangement also has the facility controlled from a standard laptop computer. A schematic of RL/OSL reader is illustrated in Fig. 2. Using Microsoft XL, the data are stored as TAB files, for subsequent processing.

3. Results and Discussion

3.1 RL responses of nanoDot Al_2O_3:C and myOSL BeO

The typical RL intensity response of Al_2O_3:C and BeO sensors as a function of irradiation time is compared in Fig. 3. For any choice of dose-rate, RL intensity over the entire duration of an irradiation period is expected to be constant [21]. The prolonged irradiation time is chosen 170s in present study. To provide for irradiation, a clinical linear accelerator (Varian 2100C/D) was used to generate a 6 MV X-ray photon beam at a dose-rate of 140 MU/min (in this case 1 MU/min = 1cGy/min) at 0° gantry angle. In both cases the photon counts were acquired at gate time of 200 ms.

It is observed from Fig. 3, the photon counts for Al_2O_3:C change significantly between the start and end of the irradiation period, while the RL response of Al_2O_3:C increases over time. In contrast, BeO maintains almost a constant RL intensity level over the same irradiation period of time. In addition, under the same dose rate the RL intensity of Al_2O_3:C is significantly higher than that of BeO sensor. The apparently spurious signal (non constant) from Al_2O_3:C is a result of the long scintillating decay time of the Al_2O_3:C crystal. The consistent level of RL intensity of the BeO can be considered an additional advantages over nanoDot Al_2O_3:C chips. Thus the RL signal of myOSL BeO sensor is seen to offer considerable potential for real-time radiation dosimetry owing to an ability to be coupled to an optical waveguide. The reason for the differences observed is due to the band gap of the materials of each sample type.

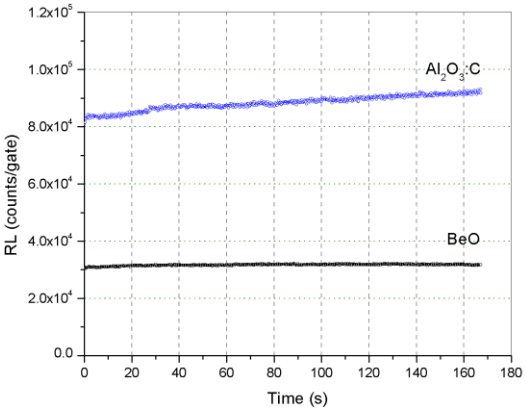

Fig. 3: RL responses of nanoDot Al_2O_3:C and myOSL BeO

3.2 Controlled depletion study of the studied commercial dosimeters

In order to verify the precision of measurements of the in-house developed reader system using nanoDot Al_2O_3:C and myOSL BeO dosimetric materials, the time between successive stimulations was set at 5 second interval (LED light off period) for control exhaustion of dosimetric traps. The experiment was performed in the laboratory by pre-irradiated (8 Gy) sample attached to a 0.5 m long and 1 mm core diameter PMMA optical fibre. The sample was periodically stimulated with the 515 nm (centred) green light for duration of 15s, repeated for 3 times. As a consequence to terminating each stimulation, the OSL initial intensity reaches lower level compared to successive previous OSL height due to a fraction of the charge trapped in the main dosimetric traps being depleted during each closely controlled stimulation. In Fig. 4 records the successive and highly reproducible fractional de-trapping, depleting from the initial OSL intensity. In each read out session, the amount of trapped charge depletes by a small fraction. That's why, the 2^{nd} OSL peak intensity is less compare to 1^{st} read out session and 3^{rd} peak is also less compare to 2^{nd} one. The phenomenon is visible in Fig. 5 for myOSL BeO sensor also. Under the same experimental condition the OSL (counts/s) is for nanoDot Al_2O_3:C is about 24 times higher sensitive than that of myOSL BeO dosimeter. Of course, the overall reader stability depends on the components of a specific reader and also on the dosimeter, readout protocol and analytical methods. Owing to the high sensitivity of OSL materials, counting statistics are not the dominant source of uncertainty in OSL dosimetry [22]. However, from the above experiments, it

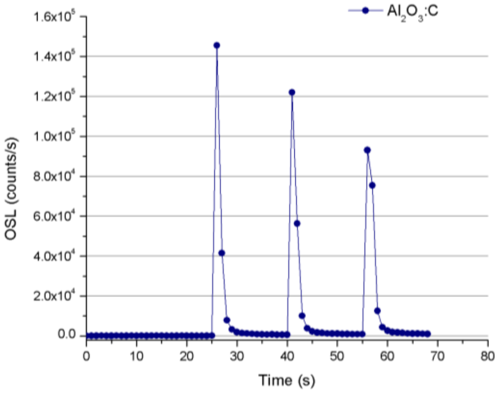

Fig.4. Controlled depletion OSL study of Al_2O_3:C

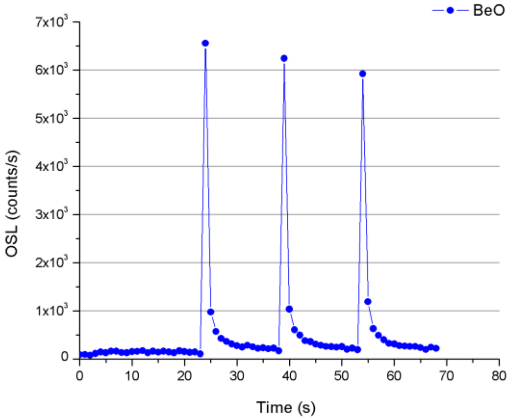

Fig. 5: Controlled depletion OSL study of BeO

can be predicted how such a system will behave in real-time OSL measurements. Because, the OSL procedure will involve periodic "pulsing" of the light stimulation at the same time as conduct of periodic irradiation, continuously monitoring the luminescence emission.

On the basis of results from the above and in support of clinical LINAC applications it is apparent that the present in-house prototype reader [17] offers excellent and versatile OSL measurements performance for viable OSL sensors.

4. Conclusion

The finding from the present work indicates that the two radiation measurement mechanisms, the RL and OSL, are independent of each other. This observation is supported by various previous studies, for instance [23]. The results also demonstrated that the reader has a strong potential for both RL and OSL dosimetry. The OSL and RL response curves show that the RL is much more material dependent than the OSL. Over prolonged periods the recorded RL response of BeO was consistent, making the material suitable for real-time dose measurements, even if its sensitivity is much lower compared to Al_2O_3:C. The information contained herein will help to pursue experimentation and exploration in this exciting and important area of radiation dosimetry research.

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