ISMP2016 IOP Publishing

IOP Conf. Series: Journal of Physics: Conf. Series **851** (2017) 012001 doi:10.1088/1742-6596/851/1/012001

Response of optically stimulated luminescence dosimeters subjected to X-rays in diagnostic energy range

Y Musa[1,2], S Hashim[1], M K A Karim[1,3], K A Bakar[4], W C Ang[1], N Salehhon[1]

[1]Department of Physics, Universiti Teknologi Malaysia, Johor, Bahru Johor, 81300, Malaysia
[2]Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Kaduna State, P.M.B. 1014, Nigeria
[3]Department of Diagnostic Imaging, National Cancer Institute, Precint 7 62250 Putrajaya, Malaysia
[4] Department of Radiology, Hospital Sultanah Aminah, Johor, Bahru Johor, 80100, Malaysia

E-mail: yahaya_ms@yahoo.com

Abstract. The use of optically stimulated luminescence (OSL) for dosimetry applications has recently increased considerably due to availability of commercial OSL dosimeters (nanoDots) for clinical use. The OSL dosimeter has a great potential to be used in clinical dosimetry because of its prevailing advantages in both handling and application. However, utilising nanoDot OSLDs for dose measurement in diagnostic radiology can only be guaranteed when the performance and characteristics of the dosimeters are apposite. In the present work, we examined the response of commercially available nanoDot OSLD (Al_2O_3:C) subjected to X-rays in general radiography. The nanoDots response with respect to reproducibility, dose linearity and signal depletion were analysed using microStar reader (Landauer, Inc., Glenwood, IL). Irradiations were performed free-in-air using 70, 80 and 120 kV tube voltages and tube currents ranging from 10 – 100 mAs. The results showed that the nanoDots exhibit good linearity and reproducibility when subjected to diagnostic X-rays, with coefficient of variations (CV) ranging between 2.3% to 3.5% representing a good reproducibility. The results also indicated average of 1% signal reduction per readout. Hence, the nanoDots showed a promising potential for dose measurement in general X-ray procedure.

1. Introduction

Optically stimulated luminescence (OSL) is one of the modern optical techniques for detection and measurement of ionising radiation that is applicable to various areas including medical, environmental and personal dosimetry. Due to its vast applications, the use of OSL technique is on the increase due to dramatic growth in the use of artificial sources of ionising radiation especially in medicine. Measurement of organ doses in diagnostic radiology is important in order to assess the risk-to-benefit associated with the radiation. Thermoluminescence dosimeters (TLDs) were the most commonly used dosimeters for organ and tissue dose estimation, but OSL dosimeters have recently been recommended for dosimetry applications due to its promising dosimetric properties which include stable sensitivity, high precision and accuracy, high speed of readout, possibility of multiple re-analysis and dose accumulation among others [1]. Both optically stimulated luminescence (OSL) and thermoluminescence (TL) begin by irradiation with primary source of ionising radiation in which energy may be deposited in the material in the form of trapped charge carriers (i.e. electrons and holes). But the released trapped charge can then be stimulated by absorption of optical photons of appropriate wavelength, causing OSL, or by absorption of heat, causing TL. The Al_2O_3:C based OSL dosimeter can be stimulated with a wide spectrum of light ranging from 400 to 700 nm and emission in a broad band of wavelengths with a peak centred at 410 – 420 nm [2]. The basis of detection of ionising radiation using OSL is illustrated in figure 1, which involve three stages. In stage (a), the dosimeter is exposed to ionising radiation in which the energy deposited may give rise to excitations and ionizations. Stage (b) is the period characterized by a metastable concentration of trapped electrons and holes and it corresponds to the period in which the dosimeters are transported back to the laboratory and stored before measurement. The information stored in the dosimeter can be read by light stimulation in which light of certain wavelength λ_{stim} stimulates the electrons to the conduction band which leads to recombination of electrons and holes. Subsequently, defect is created in the excited state and relaxes to the ground state by emission of photon with wavelength λ_{OSL} [3].

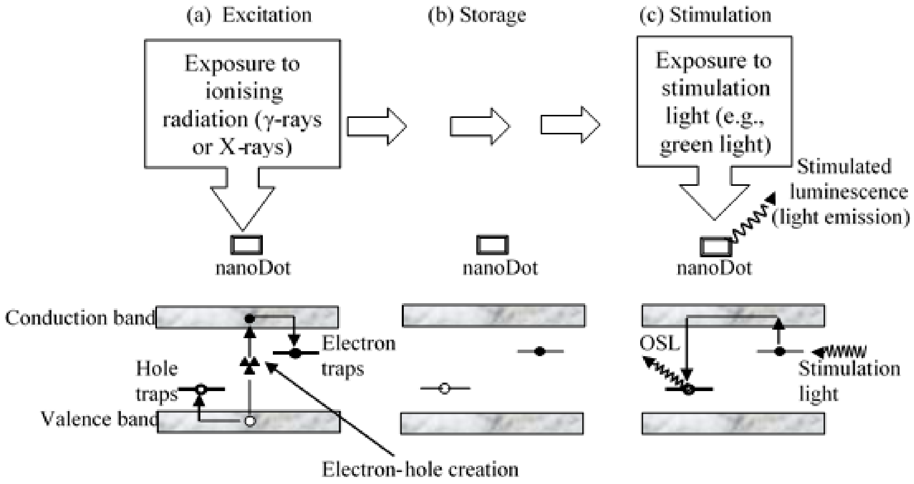

Figure 1. Schematic diagram illustrating the stages of OSL process

X-rays remain the most commonly used artificial source of radiation for radiological examinations in medicine which contributed enormously to the diagnosis of countless number of diseases, having the largest contribution (> 90%) to the combined doses from all artificial sources of radiation [4], [5]. But the amount of radiation used in diagnostic radiology requires quantification to ensure that the correct ration of radiation is used which allows an assessment of the risk involved. Radiation dosimetry is however required to estimate the dose delivered to patient and optically stimulated luminescence is found to be one of the most successful techniques for radiation dosimetry in recent years [6]. The dosimetric properties of OSL dosimeters have recently been characterised and demonstrated a good performance within the diagnostic energy range, 40 – 140 kV [7]–[9]. Based on literature survey, there are few studies on the performance of OSL dosimeters in diagnostic general X-ray compared to studies associated to radiation therapy [9]. The purpose of this work is to evaluate the reproducibility, linearity and signal depletion of the OSL dosimeters using X-rays in diagnostic energy range to ascertain the possibility of utilising these dosimeters for dose measurements.

2. Materials and method

The OSL dosimeters used in the present work were InLight nanoDots (Al_2O_3:C) by Landauer Inc (Glenwood, IL), which are among the recent advances in OSL dosimeters useful for dose measurements in diagnostic radiology [7], [9]. The nanoDots were irradiated using a general X-ray facility (Siemens Multix-top Model) installed at the Diagnostic Imaging Department, Hospital Permai, Johor. Each nanoDot contain one OSL element in a single slide, basically designed for storing the detector element in a black light-tight case which protects it from visible light. The size of the nanoDot is illustrated in figure 2, with the detector element pushed out of the case alongside its adapter.

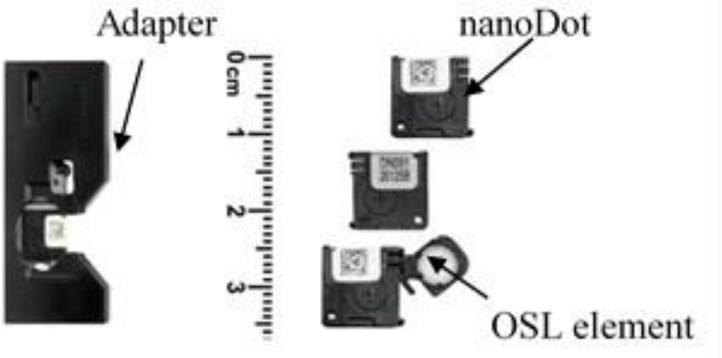

Figure 2. InLight nanoDot dosimeter

Measurements were carried out using microStar reader, which is a portable InLight reader available to measure clinical radiation doses in both patients and employees. The reader consists of an array of green light emitting diodes (LEDs) as a high intensity stimulating source and operates in continuous-wave optically stimulated luminescence (CW-OSL) mode to measure the OSL signal [10]. The reader was calibrated using the linear (standard) calibration method with a set of preirradiated nanoDots provided by the manufacturer and exposed free-in-air to known doses ranging from 0 – 1000 mGy using Cs-137 source having effective energy of 662 keV. The absorbed dose is calculated using equation 1.

$$Dose = \frac{PMT\ counts}{Calibration\ factor * Sensitivity} \tag{1}$$

2.1. Reproducibility test

The reproducibility test was performed using two set of dosimeters, one set was pre-irradiated with known doses of 10 and 1 Gy from Cs-137 source. The second set of dosimeters consist of 10 unexposed nanoDots having the same sensitivity, irradiated free-in-air with 70 kVp X-ray and 100 cm from the tube focus while varying the tube current from 10 to 100 mAs (see table 1). Each nanoDots was then read up to 10 times from which the mean and standard deviations were obtained.

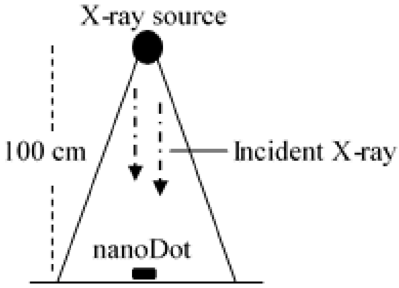

Figure 3. Schematic diagram of the nanoDot's irradiation set-up

2.2. Dose linearity

The linearity response was tested using two different tube voltages in general X-ray: 80 kVp and 120 kVp. For each kVp, ten nanoDots were irradiated by utilising one dosimeter per mAs setting while increasing the tube currents from 10 – 100 mAs as shown in table 1. Each dosimeter was read 3 times and average of the 3 readings was utilised.

Table 1. Irradiation regime of the nanoDots using general X-ray

Test	Beam Potential (kVp)	Tube current (mAs)
Reproducibility	70	10 – 100
Linearity	80 120	
Signal depletion	120	80

2.3. Signal depletion

The depletion test was performed by irradiating three nanoDots at 100 cm from the tube focus using 120 kVp/80 mAs setting. After 24 hours of post irradiation, the nanoDots were read up to 60 times sequentially per OSLD. The background signal of the OSLDs were measured following optical annealing before the irradiation.

3. Results and Discussion

3.1. Reproducibilty test

The reproducibility of each nanoDot was measured as the coefficients of variation (CV) of ten repeated readouts. For the two dosimeters exposed to known dose of 10 and 1Gy, the coefficients of variations were found to be 2.4% and 0.26% respectively, indicating a good reproducibility. While nanoDots irradiated with general X-ray unit also showed good reproducibility ranging between 2.3 % and 3.5% which describe the reliability of the nanoDots and microStar reader to reproduce their output with good precision. As shown in figure 4, at minimum tube current the OSLD seemed to have the highest coefficient of variation which may be attributed to the lowest dose received during the exposure, indicating better reproducibility and low standard deviation for higher mAs setting. Previous studies have also revealed nanoDot’s reproducibility between 2.9% and 3.6% for X-rays in diagnostic energy range and a maximum of 6.6% for doses below 1 mGy [7], [9].

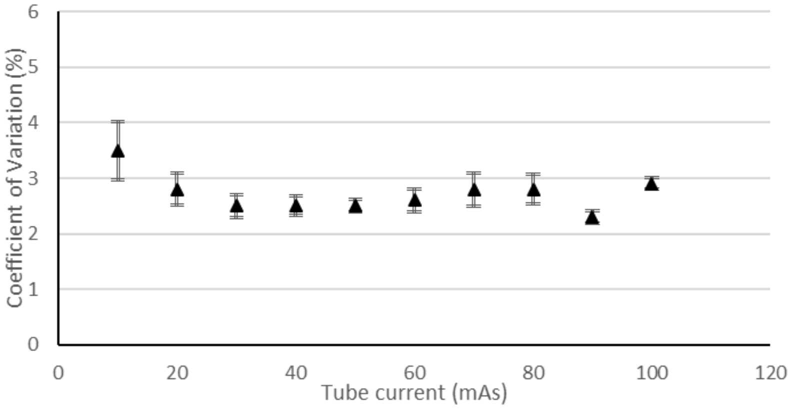

Figure 4. Coefficient of variation at different tube currents using 70 kVp X-ray. The error bars represent the standard deviation of the mean.

3.2. Dose linearity

As shown in figure 5, good linearity between the OSLD dose response and current-time product was obtained for both 80 and 120 kVp radiation qualities with values of R^2 found to be 0.9996 and 0.9992 respectively. This indicated that the nanoDots exhibit a linear response across the entire dose range (measured) and selected tube currents for the two radiation qualities. The OSLD dose response has earlier been reported to be linear for X-rays in diagnostic energy range [2], [3], [7], [9], [11]. Good linearity was also obtained between the PMT counts and measured dose for the two radiation qualities as shown in figure 6. The PMT counts were normalised to the minimum value and regression lines showed a nearly perfect fit with values of R^2 well above 0.99. The error bars in figures 5 and 6 represent the standard errors of the measurements

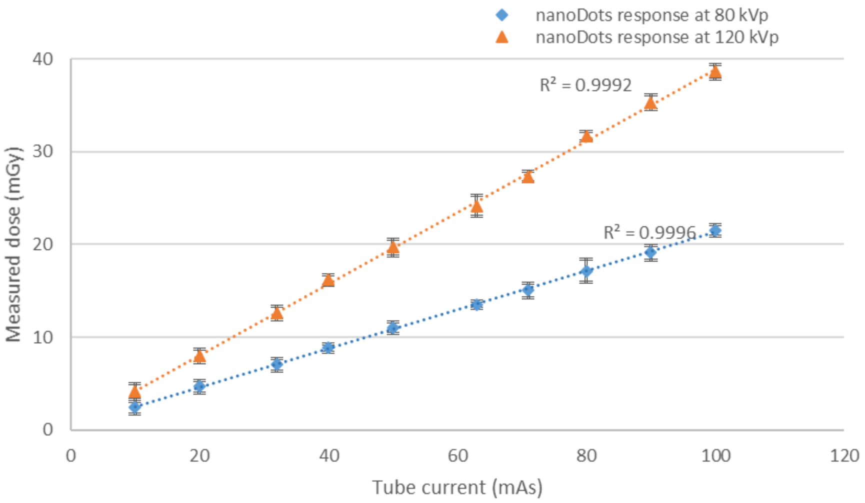

Figure 5. OSLD response when subjected to increasing current-time products.

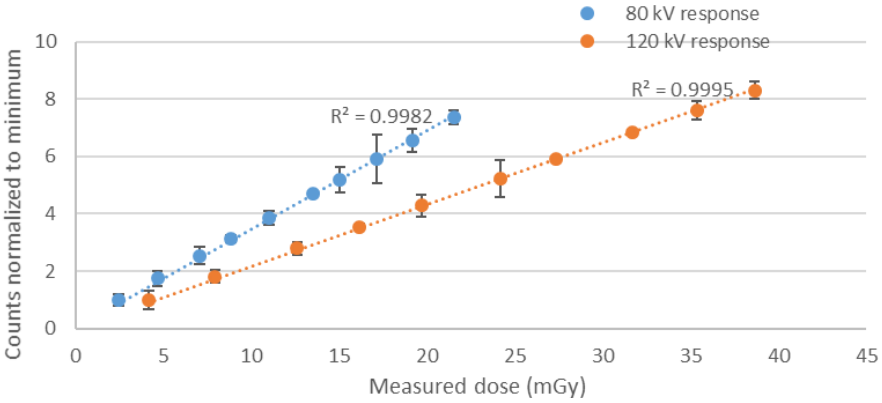

Figure 6. Counts versus measured dose showing the linear response of the nanoDots

3.3. *Signal depletion*

After 24 hours of post-irradiation, each nanoDot was read sixty times and the average of three sequential readouts. As shown in figure 7, each time the dosimeter was read, certain amount of its original OSL signal is reduced which may be attributed to the partial discharge of the trapped charges as earlier demonstrated [12]. Each data point on the horizontal axes represent the mean value obtained from the 3 nanoDots and the error bars represent their standard deviation. It can be seen from figure 7 that the both count and dose deplete in the similar trend with average of 1% signal loss per readout and 2.5% signal loss per 3 repeated readouts.

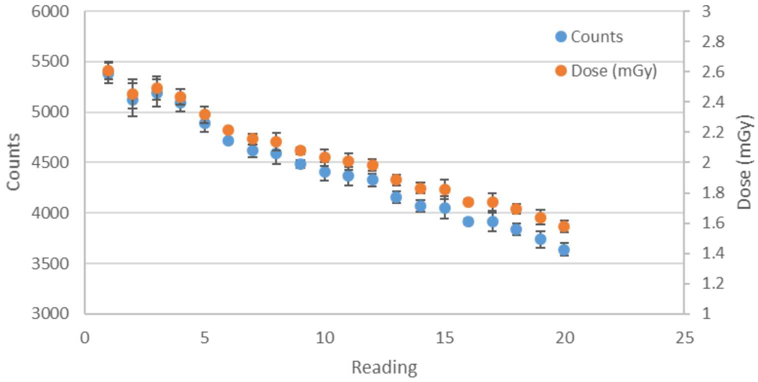

Figure 7. Depletion of OSL signal with respect to counts and measured dose.

4. Conclusion

We successfully examined the response of OSLDs (nanoDots) when subjected to X-rays in diagnostic energy range. The nanoDots are found to exhibit good linearity and reproducibility in the selected radiation qualities, with an average of less than 2.5% signal loss per 3 repeated readouts. This is an indication that the nanoDots could be utilised for radiation dosimetry in general radiography.

5. References

[1] McKeever SWS and Moscovitch M 2003 On the advantages and disadvantages of optically stimulated luminescence dosimetry and thermoluminescence dosimetry. *Radiat. Prot Dosimetry*. **104**(3):263–270.
[2] Jursinic PA 2010 Changes in optically stimulated luminescent dosimeter (OSLD) dosimetric characteristics with accumulated dose. *Med. Phys.* **37**(1):132–40.
[3] Yukihara EG and McKeever SWS 2011 Optically stimulated luminescence: Fundamentals and Applications. *John Wiley & Sons*, USA. ISBN:978-0-470-97706-4.
[4] IAEA 2007 Dosimetry in diagnostic radiology: an international code of practice TRS 457.
[5] Karim MKA, Suhairul H, Sabarudin A, Bradley DA, and Bahruddin NA 2016 Evaluating organ dose and radiation risk of routine CT examinations in Johor, Malaysia. *Sains Malaysiana*, **45**(4):567–73.
[6] Yukihara EG and McKeever SWS 2008 Optically stimulated luminescence (OSL) dosimetry in medicine. *Phys. Med. Biol.* **53**:R351–R79.
[7] Al-Senan RM and Hatab MR 2011 Characteristics of an OSLD in the diagnostic energy range. *Med. Phys.* **38**(7):4396–405.
[8] Endo A, Katoh T, Kobayashi I, Joshi R, Sur J and Okano T 2012 Characterization of optically stimulated luminescence dosemeters to measure organ doses in diagnostic radiology," *Dentomaxillofacial Radiol.* **41**(3):211–16.
[9] Lim CS, Lee S B, and Jin GH 2011 Performance of optically stimulated luminescence Al2O3 dosimeter for low doses of diagnostic energy X-rays," *Appl. Radiat. Isot.* **69**(10):1486–489.
[10] Bos AJJ and Wallinga J 2009 Optically stimulated luminescence signals under various stimulation modes assuming first-order kinetics. *Phys. Rev. B - Condens. Matter Material. Phys.* **79**(19):1-12.
[11] Akselrod MS, Botter-Jensen L and McKeever SWS 2006 Optically stimulated luminescence and its use in medical dosimetry. *Radiat. Meas.* **41**(1):S78–99.
[12] Jursinic PA 2007 Characterization of optically stimulated luminescent dosimeters, OSLDs, for clinical dosimetric measurements. *Med. Phys.* **34**(12):4594–604.

Acknowledgement

The authors wish to acknowledge the support from Research University Grant Scheme with project No. QJ130000.2517.13H39 and Ahmadu Bello University, Zaria, through the Needs Assessment Intervention Fund.