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THERMOLUMINESCENCE RESPONSE OF YTTERBIUM-DOPED AND UNDOPED OF SILICON OPTICAL FIBER SUBJECTED TO PHOTON IRRADIATION

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Radiation effects of photon irradiation in Ytterbium-doped silica optical fibers are still much less explored despite their importance in space-based application as radiation dosimetry. This study investigates and compares the thermoluminescence glow curve, response, linearity and sensitivity of Ytterbium-doped SiO_2 optical fibers with that of TLD-100. Samples are placed in solid phantom and irradiated to 6 MV photon beam with doses ranging from 0.5 Gy to 4.00 Gy. These beams were provided by Primus MLC 3339 Linear Accelerator (LINAC) available at Hospital Sultan Ismail, Johor Bahru. The glow curve were analysed to determine various properties of the TLD's. The results clearly showed the superiority of TLD-100 in terms of response and sensitivity to produce luminescence, followed by Yb-doped and Un-doped optical fibers. TLD-100 shows high sensitivity of about 659.1619 nC mg-1 Gy-1, while the Yb-doped optical fiber sensitivity is 0.3834 nC mg-1 Gy-1 and the Un-doped optical fiber sensitivity is 0.2248 nC mg-1 Gy-1. On the other hand, the sensitivity for TLD-100 is 1719.25 times higher than Yb-doped fiber and is 2932.21 times higher than that of Un-doped optical fiber.

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1. Introduction

Radiation dosimetry is a basic in medical which involves patient and other dosimetry. In the variety uses of radiation that can be used for application in radiotherapy, thermoluminescense dosimeter (TLD) has become a commonly technique for radiation dosimetry. Thermoluminescence is a process of excitation of electrons to higher energy levels by an incident radiation. Thereafter, the excitation of electrons trapped by imperfection in the crystal. By heating the crystal, the excitation energy is released as light (McKinlay,1981). According to (Oberhofer, Scharman, 1981; Yaakob et al, 2011), radiotherapy is one of the several modalities used in the treatment harmful disease especially in destroying cancer and this treatment is successful to increase the probability of maximum destroying tumour by giving high radiation dose to the cancer tissue. However, since dose is restricted in healthy tissue, the damage to that tissue should be restrained to within acceptable levels. The most clinically effective energy range for electrons in radiotherapy is 6 to 20 MeV. The electron beams among this energy range, can be used to treat superficial tumors that are less than 5 cm deep, with a characteristically sharp drop-off in dose rate beyond the treatment depth. Principal electron radiotherapy applications are the treatment of skin and lip cancers, chest wall irradiation for breast cancer, administering boost dose to nodes, and the treatment of head and neck cancers.

Besides, TL dosimeters are widely used for radiation detection in the fields of environmental, industrial and personnel applications, just to mention a few. The theory of TL

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dosimeter, and the abilities of different TL materials for use in several applications, has been summarized (Oberhofer and Scharmann, 1981; Cameron, 1968; McKinlay, 1981; Horowitz, 1984; McKeever, 1985). The main advantages of TL dosimeters are wide useful dose range, small physical size, reusability and economy, no need for high voltage or cables, i.e. stands alone character, and tissue equivalence (LiF) for most radiation types. These make TL detectors a useful tool for clinical dosimetry; since its first use for *in vivo* dosimetry during radiotherapy (Daniels, 1953). *In-vivo* dosimetry is one of the best methods for accurate dose delivery and quality check, while radiotherapy is performed by putting dosimeters on the patient's skin or natural body cavities. Thus, the using of TL detectors has become an important technique for clinical dosimetry. The TLD is based on the principle that the amount of light emitted by the phosphor material, which has been exposed to ionizing radiation, will depend on the radiation dose received by the material. The TL energy response is one of the important characteristics of TL material. The information on the energy and absorbed dose is very useful and great importance in choosing a particular TL material for any special application. In addition, a few thermoluminescense (TL) materials are tissue equivalent with an effective atomic number which is very close to that of soft biological tissue. For the purpose of personnel or medical dosimetry, the tissue equivalency is an essential consideration. A material is considered as "tissue equivalent" if it has a Z_{eff} value near the human tissue Z_{eff} value, which is 7.4, the Z_{eff} for a germanium-doped optical fiber is in the range of 11.9 - 13.4 (N. H. Yaakob, 2011). Recently, we have investigated the properties of Yb-Tb-doped SiO_2 optical fibre using 6 and 10 MV photon irradiation (Sahini *et al.*, 2014_a; Sahini *et al.*, 2014_b). Germanium and Aluminium-Doped Silicon Dioxide Optical Fibre Dosimeters for Radiotherapeutic Dose Measurement were investigated (Haliza et al., 2011).

This present studies are to work out new materials based on optical fiber and doped with Ytterbium to enhance the thermal stability and chemical durability of the Ytterbium doped optical fiber are taken commercially available. The Ytterbium doped optical fiber will be taken commercially and the characteristics of this doped optical fiber will be determined using X-ray diffraction (XRD) and Energy Dispersive Analysis X-ray (EDAX). The optical fiber will be irradiated with photon from Linear Accelerator (LINAC) and the TL response will be measured. The TL result will compare with those of the commercially available TLD-100. This work concerns the suitability of doped and undoped optical fiber as ionizing radiation dosimeters. The dosimetric capabilities of response Ytterbium doped Silicon Dioxide Optical Fiber will be investigated for megavoltage photons. Therefore, it is the aim of this project to study the fundamental dosimetry properties of Ytterbium doped Silicon Dioxide, SiO2 optical fiber and TLD-100 subjected to photon irradiation.

The irradiation on the core of the optical fiber has been conducted at dose levels ranging from 0.5 – 4.00 Gy of ionizing radiation sources, such as photons using Primus MLC 3339 linear accelerator machine (LINAC). These dosimeters were irradiated to 6 MV photon beam. The TL results obtained will be compared with the commercially available TL materials such as TLD-100. The determination of the dose response of Yb-doped optical fiber will be performed using 6 MV photon irradiation for 1-, 2-, 3- and 4 Gy. Readings of TL yield are obtained immediately after exposure will be examined using 6 MV photon irradiation for 1-, 2-, 3- and 4 Gy produced by LINAC.

2. Research methodology

Thermoluminescence materials

There are three major areas for the usage of fibers as light conductors. These are decorative, light and image transmission and communication. SiO_2 optical fibers are currently being investigated as TLD material. This research is focused on the thermoluminescence response of SiO_2, which has been doped commercially, Yb-125 and produced as single-mode telecommunication optical fibers. The doped SiO_2 optical fiber has a cladding diameter of 124.7 ± 1.0 μm and coating diameter of 250.0 ± 10.0 μm.

Lithium Fluoride (LiF)

The first basic TL material commercially known as TLD 100 has the composition of ~92.14% 7LiF and ~7.36% LiF incorporated with ~ 200 ppm Magnesium and ~10 ppm Titanium (Saint, 2000) is generally regarded as a standard TL dosimeter. TLD 100 characteristics that made it good TL dosimeters include the wide useful ranges (10μGy – 10Gy), low fading (5 – 10% per year) and sensitivity to small doses. TLD 100 arising factor that made it interesting is its tissue equivalence (Z*eff* = 8.04), which is an important factor in personnel dosimetry as well as medical application.

Silicon Dioxide Optical Fiber (SiO_2)

The commercially available doped SiO_2 optical fibers studied here in demonstrate very useful TL properties and represent an excellent candidate for use in TL dosimetry of ionizing radiations (Hashim et al., 2010). The presence of impurities or the addition of dopants to silica can greatly enhance the sensitivity of silica to radiation by providing an increased number of traps. In optical fiber for telecommunications, dopants are incorporated in the silica glass to modify its refractive index to obtain total internal reflection. The present work represents a preliminary study of photon irradiation response of commercially available Yb-doped SiO_2 optical fibers. In particular, interest focuses on the ability of such fibers to measure doses at the periphery of irradiation fields, such values represents a small fraction of the tumuor dose. Comparison of sensitivity has also been made using the standard photon TL material, TLD-100.

Prepared of Material

Before irradiating the TL material, the samples need to be prepared accordingly so that it will be suitable for the purpose of the study. To determine the TL response of Yb-doped optical fiber subjected to photon irradiation and TLD-100 were prepared. Generally, a TL material to be used for dosimetric purposes is expected to have characteristics such as high sensitivity, long term stability of the stored dosimetric information of room temperature concerning thermal and optical fading, large linearly between the TL signal and dose and also energy dependence. Most commercially available TL dosimeters have high glow peak temperature; deep electron traps so that they are stable for months or years. The Ytterbium is taken commercially available on the market already. Annealing test will be performed at temperature below 400 ^oC to determine the optimal pre-exposure annealing procedure for erasing background signal accumulated during transportation and storage for minimize the detection threshold. The material will be left to reach room temperature inside the furnace over 24 hour period to avoid thermal stress. After cooling, the material is then put inside a dissector to avoid it form oxidized. Fluorescent light exposure is being avoided.

It is known that the pre-irradiation heat-treatment is generally re-established the defect equilibrium that exists in the material before the irradiation. The heat treatment before irradiation can also empty the deep traps to avoid the influence of deep traps to avoid the influence of deep traps on the TL intensities of dosimetric peaks. Therefore, one of the first parameters investigated is the annealing procedure to be the used in order to get the highest sensitivity and eliminate the effects of the previous irradiation. The experiment will be carried using different annealing temperatures (annealing period is one hour for each temperature). The annealing temperatures will be used 100, 200, 300 and 400 ^oC. Each experimental point will be obtained using 10 samples submit to the same annealing procedure and same dose. The whole experiment is then will be repeated at various dose levels.

In preparation for irradiation, the outer polymer coating of the optical fibers was removed using a fibers stripper (Miller, USA). After the removal of the outer cladding, the optical fiber will be cleaned using a cotton cloth dampened with a small amount of methyl alcohol to completely remove any remnant polymer cladding.

Storage and Handling: Many aspects of the storage and handling of dosimeters can affect their TL sensitivity, stability and precision (McKinlay, 1981). Many aspects of the storage and handling of dosimeters can affect their TL sensitivity, stability and precision (McKinlay, 1981).

Environmental factors such as temperature, humidity, ultraviolet and visible radiation are the factors of concern in TLD routine storage. In this work, the TL materials will be kept in a suitable container and place of high temperature and ultraviolet radiation is avoided. During handling, it is ensured that the TL materials are not scratched or touched using hand. Each optical fiber and TLD100 will be placed inside a gelatine capsule for routine storage, handling and for irradiations. Each capsule contained 6 pieces of optical fiber. For TLD100, each capsule will be contained 3 chips.

Annealing: Before TLDs can be reused, they must undergo a re-zeroing anneal. Annealing is the thermal treatment used to erase any irradiation memory from the TL material. This is to stabilize the trap structure and to restore it to its condition prior to irradiation. The high temperature anneal is required to clear the luminescence traps of residual signal that may cause unwanted background readings during the subsequent use of the phosphor. The low temperature anneal is required to stabilize and aggregate low temperature traps in order to enhance the sensitivity of the main luminescence traps and to reduce the loss during use of radiation-induced signals due to thermal or optical fading. In annealing, the TL material was put in a TLD oven type LAB-01/400 or known as furnace. The furnace is connected to a computer and *Thermosoft* software is used to control the process in the furnace.

Annealing characteristics might vary for different TL materials. During annealing, TL material was heated to a certain temperature for a certain length of time and these characteristics vary with different TL material. In experimental aspect, the temperature and time for annealing is called Time Temperature Profile (TTP). The TTP was set using *Thermo-soft* software and at the main menu, the process of annealing is displayed in the form of graph.

Exposure to Radiation: The doped optical fiber will be exposed to the various radiation sources such as photon from linear accelerators (LINAC). Modern linear accelerators predominant teletherapy machine in major radiotherapy centers worldwide provide multiple electron beam energies. In association with this capability, there is no considerable demand to validate patient dose, dosimetrics system being required to provide good spatial resolution, high precision and accuracy, among other characteristics. In this study, all these samples will be exposed to 6MV photon emitted by PRIMUS MLC (LINAC) with dose between 0.5 Gy and 4.0 Gy. In an LINAC, the electrons are accelerated following straight trajectories in special evacuated structures called accelerating waveguides. Electrons follow the same linear path, relatively slowly and at different times; hence LINACS also fall into the class of cyclic accelerators. The high power radiofrequency (RF) fields used for electron acceleration in the accelerating waveguides are produced through the process of decelerating electrons by retarding potentials with special evacuated devices called magnetrons and klystrons.

Photons: In this study, the doped optical fiber and TLD-100 are inserted separately into the capsule and then put into a solid phantom. A solid phantom is placed on perspexes to reduce the radiation scatter. The two most commonly used solid phantom materials in radiotherapy dosimetry are polystyrene and polymethylmethacrylate (PMMA). Neither polystyrene nor PMMA are ideal water-equivalent materials. For dosimetry in this study, the PMMA are used.

The Yb-doped and TLD-100 rod is placed on the beam axis at a depth of 10 cm in a solid phantom, which has been irradiated with 6 MV photon beam from linear accelerator Primus MLC 3339.(LINAC Primus, Department of Radiotherapy and Oncology, Hospital Sultan Ismail, JB). The beam field size was set to 10 x 10 cm^2 and positioned at the standard Source-Surface Distance (SSD) of 100 cm. The dose delivered by LINAC machine is 50 to 400 MU (Monitor Unit) using a constant dose rate of 200 MU/min. 1 MU corresponds to a dose of 1 cGy delivered under the reference conditions that are at the depth of dose maximum on the central beam axis when irradiated with a 10×10 cm^2 field at a source to surface distance (SSD) of 100 cm. Each 50 MU dose is equivalent to 0.5 Gy and it took 15 seconds for completely expose.

Read-Out Process: After irradiation, readings were obtained by using TLD Reader and *WinREMS* software. In this study, Harshaw® 4500 TLD Reader which used hot nitrogen gas as the heat transfer medium. To measure the TL response, the TLD chips or Yb-doped fibers would be placed on the planchet in the TLD reader drawer. Different forms of TLD such as chip, rod, fiber or powder require different planchet.

Instrumentation: The optical fibre TL yield is read out using a Harshaw 3500 TL reader belonging to Department of Physics, Faculty of Scienes, Universiti Teknologi Malaysia (UTM). When using TLDs, the lower traps are often deliberately eliminated. One easy way to accomplish this is to wait 24 hours or more after the radiation exposure is given before reading the TLD. In calculating the thermoluminescence response from the TL, a background reading were subtracted. The background reading is usually small and is the result of several factors. Most of the background readings come from the natural TL of oxygen in the air. This was eliminated by reading the TLDs in a non-oxygen atmosphere. Another source of background TL reading is electronic noise from the TLD reader. This originates from spurious electrons released and multiplied in the PMT and is called the dark current.

Dark Current: Dark current is the signal produced in the photomultiplier (PMT) when light is absent. This is generally a function of the thermal emission of electrons from the 24 cathode. There can be a significant variation of dark current between PM tubes. Typically, dark currents are on the order of $10^{-2} – 10^{-4}$ mA. They can be reduced by cooling the PMT.

PMT Noise: PMT Noise readings measure the electronic background noise in the system. It is a reading taken with no dosimeter or any other light source within the PMT assembly. Its purpose is to measure electronic noise and determine if there are any light leaks in the system. When this reading is taken, the drawer should be in the “between” position and not in the “closed” position. In this state the gas is flowing, but it is not being heated and there is no dosimeter under the PMT. PMT readings are reported in pico-Coulombs and generally should not exceed 1200 picoCoulomb (pC).

Background Noise: Background noise is the reading produced by the reader when heat is being applied but there is no TL material in the planchet. It consists of any signal generated by contamination on the planchet, light leaks, PMT dark current or stray infrared radiation. To take a background noise reading, one pushes the read drawer all the way in and then follows the normal read procedure with no dosimeter. The nitrogen flow is used to reduce the background signals, and does so by reducing the oxygen induced TL signals.

3. Results and discussion

TL Glow Curve

The intensity of luminescence as a function of temperature which exhibits several maxima is called the thermoluminescence light emission and is displayed as a thermoluminescence glow curve. This glow curve varies with the mode of heating and heating temperature. The area under the curve represents the radiation energy deposited (Mayles *et al.*, 2007). Previously it was shown that the SiO_2 optical fiber presents two obvious glow peaks, one of which is dominant with a maximum between 200 and 250^{o}C. The glow curve of TLD-100 has five peaks at 65, 120, 160, 195 and 210^{o}C. Using the TLD-100 glow peaks as temperature references, it is found that the dominant optical fiber glow peak is at 230^{o}C (Espinosa *et al.*, 2006). Figure 1 presents the glow curve for Yb-doped optical fiber using 6 MV photon with 0.5 Gy dose while Figure 2 shows the glow curve for Undoped optical fibre using 6 MV photon with 0.5 Gy dose. Figure 3 displays a glow peak of TLD-100 using 6 MV photon with 0.5 Gy dose response, which has a different glow curve from the glow curve of optical fibers. Red line represents in the graph is the readout temperature was at 300°C from the time-temperature profile set up for the TLD reader. By comparing the glow curves of Yb-doped fibers and Un-doped fiber, it is clearly seen that Yb-doped shows better glow curve than of Un-doped optical fiber. In the case of the fibers, no clear glow peak is observed, maybe due to too low of energy that cause many background noise.

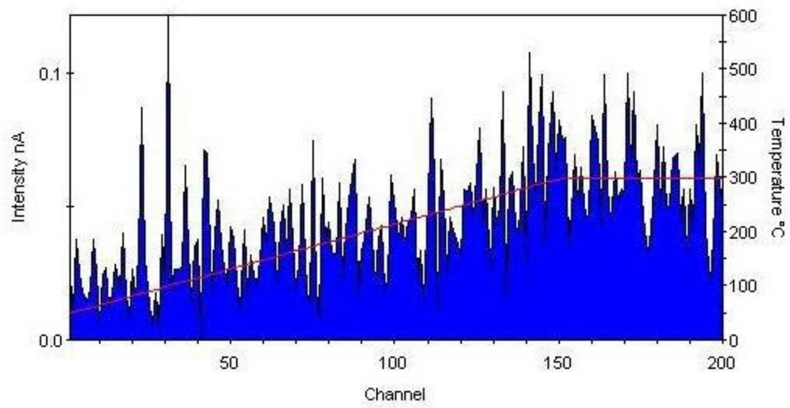

Fig 1: The glow curve for the Yb-doped optical fiber material following 6 MV \photon irradiations with 0.5 Gy dose

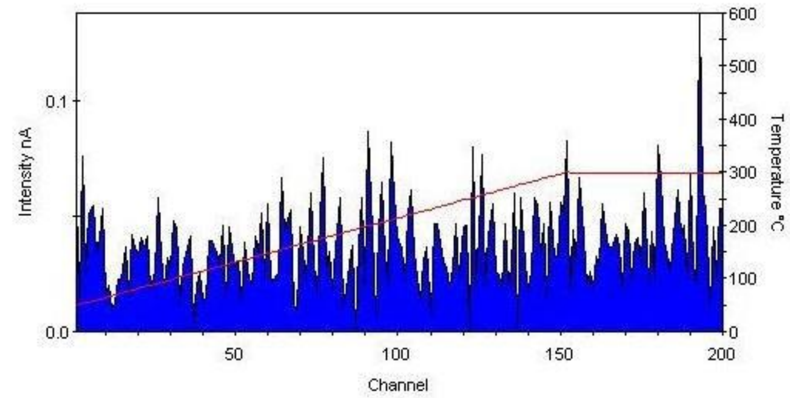

Fig. 2: The glow curve for Un-doped optical fiber material following 6 MV photon irradiations with 0.5 Gy dose.

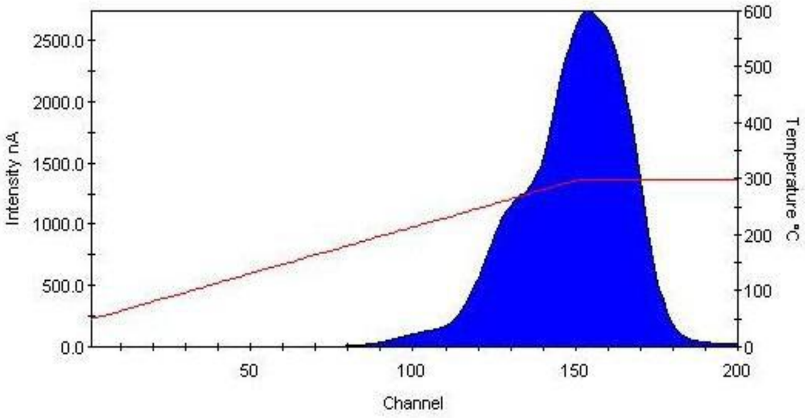

Fig. 3: The glow curve for TLD-100 rods following 6 MV photon irradiations with 0.5 Gy dose.

Response to Photon

There are ranges of dose available at the Department of Radiotherapy and Oncology, Hospital Sultan Ismail, where the irradiations took place the high doses ranging from 0.50 to 4.00 Gy are used for this research. This study continues with a summary of the results of TL response to photons, which list all the result for the dose responses to photon in tables for a better understanding. The dose response results will be explained in the following section.

Dose Response and Linearity: A linear relationship between the TL emission and the absorbed dose is a very important characteristic for any thermoluminescense dosimetric application and to characterize the response of the material. For many applications, it is commonly favored to have a linear dose TL signal relationship which is between the TL signal and the dose. The TL response of Yb-doped SiO_2 optical fibres, TLD-100 and Un-doped subjected to 6 MV photons irradiation versus doses in Gy can be seen in Figure 4, Figure 5 and Figure 6 respectively. This graph shows data obtained for the high dose response in the dose range of 0.50 – 4.00 Gy.

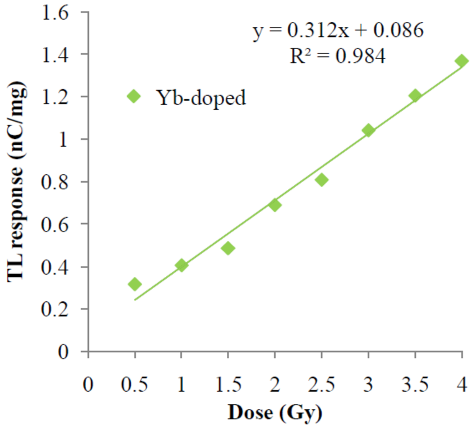

Fig 4. TL response in (nC/mg) versus dose in Gy of Yb-doped optical fiber for 6 MV photon irradiation.

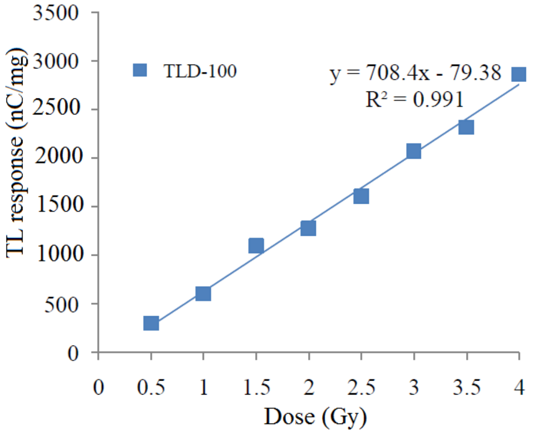

Figure 5. TL response in (nC/mg) versus dose in Gy of TLD-100 for 6 MV photon irradiation.

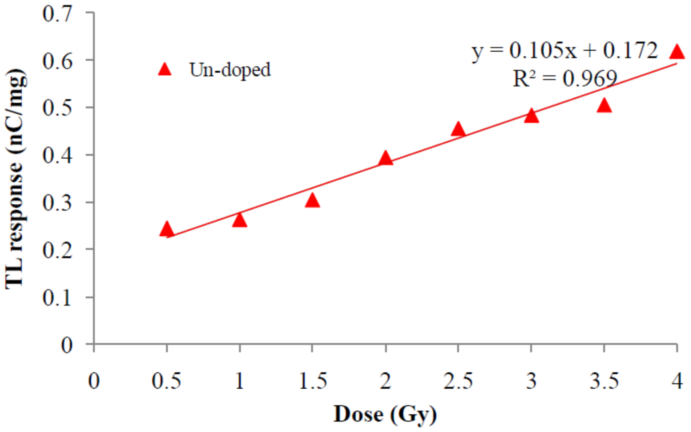

Fig. 6. TL response in (nC/mg) versus dose in Gy of un-doped (SiO_2) optical fibre for 6 MV photon irradiation.

A regression coefficient (R^2) for Yb-doped is 0.984, TLD-100 is 0.991 and Un-doped is 0.969. This indicates the occurrence of a little scatter in the TL values. The dose response is discussed in terms of the functional dependence upon absorbed dose of the measured TL signal; the TL signal being a function (*F*) of absorbed dose (*D*) and energy (E), i.e. *F (E, D)* (Suhairul, 2009). It can be seen from the graphs that all types of dosimeter signals exhibit good linearity for the range of doses used in this study. Also, if the dose is low, the TL response in (nC/mg) is also low for all dosimeters. This shows that each dosimeter is dependent on the dose. In fact, as can be seen from Figure 4,5,6 TLD-100 is the most high linear value when compared to other optical fiber dosimeter and it is followed by the Yb- and then Un-doped fibers. This occurs because of TLD-100 gives a higher TL response after the irradiation than others dosimeters.

Assuming a linear fit, a change in the TL yield per unit absorbed dose (in other words the slope) for Yb-doped optical fibers is 0.312 mg^{-1} Gy^{-1} (from Fig. 4), TLD-100 is 708.4 mg^{-1} Gy^{-1}(from fig.5) ,whereas the change in the TL yield per unit of absorbed dose for Un-doped optical fibers is 0.105 mg^{-1} Gy^{-1}(from fig.6). For the optical fiber, Yb-doped gives a higher TL response than Un-doped as shown in Figures 4 and 6.

Sensitivity

The sensitivity of a TL material is another important characteristic that can give a decision for the material response, and it can be described in term of TL yield per unit dose per unit mass of the sample. In this study the TL sensitivity is expressed as glow curve area per unit mass of dosimeter and per unit of a dose (nC mg-1 Gy-1) of 6 MV photon from linear accelerator. Table 1 present a summary of the sensitivities of Yb-, TLD-100 and Un-doped optical fiber.

Table 1: TL sensitivity (nCmg-1Gy-1) for Yb-doped optical fiber, TLD-100 and undoped optical fiber.

Dose (Gy)	Sensitivity (nC mg^{-1}Gy^{-1})		
	Yb-doped	TLD-100	Un-doped
0.5	0.6343	598.6147	0.4896
1.0	0.4061	600.905	0.2643
1.5	0.3246	728.7749	0.2036
2.0	0.3448	636.9198	0.1976
2.5	0.3236	641.519	0.1824
3.0	0.3471	690.0285	0.1613
3.5	0.3444	661.9855	0.1445
4.0	0.3423	714.5474	0.1547
Average	0.3834	659.1619	0.2248

In the current study, the sensitivity for Yb- and Un-doped were calculated as the average of the eight (nC mg^{-1}Gy^{-1}) readings that shown in Table 1. The sensitivity of Yb-doped was 0.3834 nC mg^{-1}Gy^{-1}. In contrast, the sensitivity of Un-doped was 0.2248 nC mg^{-1}Gy^{-1} . The Yb-doped TL dosimeter shows TL sensitivity, which is 1.7055 times more than that of Un-doped optical fiber for 6MV photon. A high sensitivity allows for determination at very low radiation doses.

The change in the TL yield per unit of absorbed dose is also known as the sensitivity. Thermoluminescence sensitivity is a measure of the amount of TL signal per unit of mass produced by a given material after exposure to a dose of radiation. On the other hand, the sensitivity for TLD-100 was 659.1619 nC mg^{-1}Gy^{-1} which is 1719.25 times better than Yb-doped fiber and is 2932.21 times better than that of Un-doped optical fiber using 6 MV photon irradiation for high dose responses. This indicates that the Yb-doped optical fiber is better than Un-doped optical fiber, where the Yb-doped fibers give a better TL response in this study. So, this shows that the highest sensitivity is for the TLD-100, followed by the Yb-doped and Un-doped fiber.

4. Conclusion

This study has investigated the thermoluminescence glow curves, TL dose response, linearity and sensitivity of doped SiO_2 optical fibers and undoped and TLD-100 when subjected to 6 MV photon irradiation. Subsequently, the results of doped SiO_2 optical fibers and TLD-100 have been compared each other. A linear dose response has been observed for 6 MV photon irradiation with a dose range from 0.50 Gy to 4.0 Gy**.** For 6 MV photons, the change in TL yield per unit absorbed dose (slope) for Yb-doped fibers was 0.312 mg-1 Gy-1, TLD-100 is 708.4 mg-1 Gy-1, while for Un-doped fibers was 0.105 mg^{-1} Gy^{-1}. The sensitivity for TLD-100 subjected to 6 MV is 1619 nC $mg^{-1}Gy^{-1}$, while the Yb-doped optical fibre sensitivity is 0.3834 nC mg^{-1} Gy^{-1} and the Un-doped optical fibre sensitivity is 0.2248 nC $mg^{-1}Gy^{-1}$. TLD-100, Yb- and Un-doped optical fiber yields a linear response to the absorbed dose for photons irradiation, although with differences in both the glow curve characteristics and radiation sensitivities. These three groups of samples have a high sensitivity give a good TL response at high dose. This study has clearly shown that the TLD-100 gives a higher TL response and higher sensitivity to produce luminescence than the other dosimeter. However, these optical fiber materials were still in the early stages of the study as a new radiation dosimeter. Thus, more research needs to be done to reduce the drawbacks that have been imposed upon optical fiber. Currently, many studies on optical fiber have had very good results and are encouraging. Because of its physical characteristics such as small sized, impervious to water and cost-effective, Yb-doped optical fiber has the potential to be a part in dosimetric material that can be widely used in many applications.

References

[1] J.R. Cameron, N. Suntharalingam, G.N Kenney, Thermoluminescent Dosimetry. Madison: University of Wisconsin Press . (1968),

[2] F. Daniels, C.A. Boyd, D. F Saunders, Science, **117**, 343 (1953).

[3] G. Espinosa, J.I. Golzarri, J. Bogard, J. Garcia-Macedo, Radiation Protection. Dosimeter, **18**, 1 (2006).

[4] Haliza et. al Germanium and Aluminium-Doped Silicon Dioxide Optical Fibre Dosimeters for Radiotherapeutic Dose Measurement**. (**2011).

[5] S. Hashim, D. A. Bradley, N. Peng, A.T. Ramli, H. Wagiran, Nucl. Instrum. Methods Phys. Res. A **619**, 291 (2010).

[6] Y.S. Horowitz, (ed.) Thermoluminescence and Thermoluminescent Dosimetry. Vol. I - III. Boca Raton, Florida: CRC Press. (1984).

[7] P. Mayles, A. Nahum, J. C. Rosenwald, Handbook of Radiotherapy Physic Theory and Practice. France. Taylor & Francis. (2007).

[8] S.W.S McKeever, Thermoluminescence of Solids. Cambridge: Cambridge University Press. (1985).

[9] A.F McKinlay, Thermoluminescence Dosimetry, Medical Physics Handbooks 5, Bristol: Adam Hilger Ltd. (1981).

[10] N. H. Yaakob, H. Wagiran, I. Hossain, A. T. Ramli, D.A Bradley, S. Hashim, H. Ali, Physics Research A **69,** 1189 (2011).

[11] M. Oberhofer, Scharmann. Applied Thermoluminescence Dosimetry. Bristol, United Kingdom. Adam Hilger Ltd Publication. (1981)

[12] Suhairul Hashim, The thermoluminescence response of doped Silicon Dioxide optical fibres to ionizing radiation. Doctor of Philosophy. Universiti Teknologi Malaysia. (2009).

[13] M S Sahini, H Wagiran, I Hossain, M A Saeed, H Ali,. Indian J Phys. **88,** 843 (2014).

[14] M S Sahini, I Hossain, H Wagiran, M A Saeed, H Ali, App. Rad. Isotope **92,** 18 (2014)