High Sensitivity of LiF:Mg,Cu,P Thermoluminescent Dosimeter and Its Application for Low Dose Measurement In Medical Field

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Abstract. *The high sensitivity of thermoluminescent dosimeter (TLD) is required in the medical field for measurement of radiation dose for patient and workers who need high accuracy in diagnose. During this time, LiF TLD has become a choice and have dominated its use in determining dose and as quality assurance, especially for LiF:Mg,Cu,P have been applicated to measure low dose radiation, such as accepted dose of pediatric patients and estimation for out of field dose. It's also used as extremity dosimeter for determination of eye doses. In addition to many advantages, there are also some disadvantages mainly the decrease in sensitivity due to the heat treatment and it is can cause inaccuate of the dose-response. Other important variables to be considered are annealing procedure, heating rate, and ROI (region of interest) determination in readout of TLD response. By using the calibrator machine OB-85 with ^{137}Cs as gamma source, the selected LiF:Mg,Cu,P TLD was exposed on the surface of phantom with 30x30x15 cm dimensions at a distance of 200 cm. The result of research, in the several cycles use of TLD obtained deviation of sensitivity for each TLD are 7.99 to 15.80% for LiF:Mg,Cu,P, 0.49 to 10.59 % for ^{6}LiF:Mg,Cu,P and 13.07 to 30.46 % for ^{7}LiF:Mg,Cu,P with uniformity of TLD response lower than 5%.To obtain more accurate and precision measurements with a high confidence level it needto concern about the uniformity of TLD response and optimization of annealing techniques.*

Keywords*:phenomenon, LiF:Mg,Cu,P, high sensitivity, thermoluminescent dosimeter, accurate, precision*

Introduction

The phenomenon of thermoluminescence (TL) widespread that the electrons excitement caused by ionizing radiation and trapped on trap in the forbidden energy gap, will emit light when heated to a certain temperature.The high sensitivity of LiF phosphor with activators Mg and Ti (LiF:Mg,Ti)is the most commonly used as thermoluminescence dosimeter (TLD) to measure the radiation dose received on patient and also used as a quality assurance (QA) (Rah et al, 2009). And ithas dominated the fulfillment of dosimeter needs in a variety of medical applications including radiation therapy, diagnostic radiology, and radiotherapy mailed dosimetry (Moscovitch, 2007). But lately, the LiF:Mg,Cu,P TLD which is hypersensitive thermo-luminescent dosimeter has a sensitivity 23 times higher than LiF:Mg,Ti TLD started being used to patient dose monitoring, especially in pediatric patients and low doses monitoringor dose measure-ments with high accuracy (Sofyan, 2012).

The variation of sensitivity for LiF:Mg,Ti TLD according from the factory standards (Thermo Electron) is estimated about ± 15% and both types of LiF TLD (LiF:Mg,Ti and LiF:Mg,Cu,P) is very sensitive to heat treatment usually occurs in annealing process and readout TLD responses, especially for LiF:Mg,Cu,P TLD (Rah et.al, 2009 & Moscovitch, 2007).And based on reports of many authors, that LiF:Mg,Cu,P TLD has known many advantages when should determine dose with high precision. However, heat stimulation in annealing process can not be avoided and it can cause the TLDs sensitivity decreased significantly (Tsai,2011, Lupke, 2006). Although the annealing process for TLD in accordance with recommended temperature using oven at 240°C for 10 minutes, but the results of M. Lupke research has reported that TLDs sensitivity is still decreasing. The decrease of relative sensitivity for LiF:Mg,Cu,P TLD with annealing temperature at 240 °C for 10 minutes respectively 97%, 90% and 73% for cycle 10, 30 and 50. And meanwhile, forannealing temperature at 237°C the reduction of TLD sensitivity over smaller (Lupke, 2006).

In addition, the relationship between TL intensity with the depth of trap and the energy required to excite the electrons from traps to be important.The depth of electron trap is amount of energy (E) required by an electron to escape from trap in the conduction band or lattice defects contained on forbidden band. The lattice defects or impurities in each TLD potentially creating localized energy in the forbidden band gap and in certain circumstances can be trapping the electrons. The ability of electrons to escape from the trap is determined by frequency S of the charge in the trap and trap energy E(eV). Based on hypothesis used of previous researchers that the probability of whole electron retrapping is very low than recombination probability, then value of the TL intensity ($I(T)$) from TLD that receive thermally stimulate are shown in equation (1) (Alawiah,2015).

$$I(T) = n_0 \cdot S \cdot \exp\left(-\frac{E}{kT}\right) \cdot \exp\left(-\frac{s}{\beta}\int_{T_0}^{T} \exp\left(-\frac{E}{kT'}\right) dT'\right) \quad \text{...... (1)}$$

Where n_0 is the original population offilled electron traps, S is the luminescence efficiency or amount of electron interacts per second with lattice (s^{-1}), k is Boltzmann's constant (8.616×10^{-5} eV/K), β is heating rate, T_0 is the initial temperature, T' is a dummyvariable representing temperature, E is trap energy or the activation energy and s is the frequency factor which is related tothe local lattice vibration frequency, and value of T is $T=T_0+\beta t$.

The value of n_0 depends to radiation dose but independent to heating cycle, and while it the temperature T_M is not dependent on the amount of trapped electrons but relates to trap energy E. Thus, the relationship between energy E with maximum temperature $T_M$as peak position and the width of peak can be expressed as in equation 2.

$$E \cong \frac{kT_M^2}{\omega} \qquad \text{...........(2)}$$

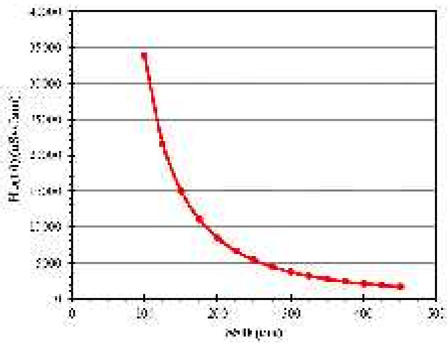
With ω is the full width at half maximum intensity of the glow peak.

The decreased of TLDs sensitivity can affect the values of dose response, so that it becomes as important variable that must be considered in its application in medical field, such as annealing procedure, the heating rate, the determination of ROI (region of interest)on the readout of TLD response. In the last decade (Romanyukha et.al (2016), Vincenti et al (2014), Carinou et al (2011), Sibony et al (2014), Bilski et al (2014)), studies related to the sensitivity decreased of LiF:Mg,Cu,P TLDs and the effect of heat stimulation with several causes have been widely performed. Therefore, this study aimed to get a dosimetry system using LiF:Mg,Cu,P to determine an accurate and precision dose received by patients and workers who are directly exposed to radiation due to consequence of the work. So that the radiation workers especially in the interventional radiology, the received dose on eye organs and other sensitive organ needs to get more serious attention.From these results, it is expected to improve the radiation safety and support the achievement of the principles of radiation protection.

Materials and Methods

Thermoluminescent Dosemeters

LiF TLD (LiF:Mg,Cu,P and LiF:Mg,Ti) chips which has dimensions 3.2 mm sq. x 0.89 mm provided commercially by Harshaw/Thermo Fisher Scientific Inc., USA. All TLDs irradiated on phantom 30 cm sq. x 15 cm with SSD (sample surface distance) at 200 cm from calibrator machine OB-85 as ^{137}Cs gamma sources in Secondary Standard Dosimetry Laboratory (SSDL) PTKMR. The data reference for gamma source (^{137}Cs) used in this R & D to TLD irradiation is obtained based on calculation (March 17, 2016) shown in Figure 1.



Gambar 1. Output curve of calibrator machine OB-85 of gamma sources at SSD 200 cm on March 17, 2016.

TLD reader of Harshaw 3500from Thermo Fisher Scientific Inc., USA. has been used to readout the responses of LiF TLD. In reading process of responses for two types of TLD must be done by using the time-temperature profile (TTP) which different and adapted to the characteristics of each TLD. Based on TTP, heating rate and maximum temperature of TLD are 10°C/sec and 300°C with required time in 33 second for LiF:Mg,Ti TLD, and 10°C/sec and 220°C in 23 second for LiF:Mg,Cu,P TLD. Especially for the high sensitive LiF:Mg,Cu,P TLD, the maximum temperature for readout of TLDs response to be lower than recommended. The heat treatment on LiF:Mg,Cu,P TLD can cause a decrease in TLD sensitivity, then readout process of TLD responses and annealing processes should be concern seriously.The readout process for TLD responses will starting on temperature of 50°C and under N_2 gas flows which aims to reduce or eliminate effect from oxidation and potential tribo-luminesence (Alawiah, 2015).

The Annealing process

All TLD must be annealed before use, in order the electrons that are likely still trapped will escape, thus TLD be considered to be clean from electrons trapped. Furthermore, TLD will ready to be used on next cycles to measure the magnitude of the response to a given radiation exposure. To avoid the possible errors in application, TLD must be received same treatment, such as treatment in the annealing process, radiation exposure, temporary storage room conditions and readout of TLD response.

In this study, the annealing processes for LiF:Mg,Ti TLD conducted on 400°C using furnace for 1 hour and continued with oven at temperatures of 210°C for 1 hour. Different treatment for the highly-sensitive TLD (LiF:Mg,Cu,P), annealing process only performed on 210°C for 10 minutes by oven in order not to decrease the sensitivity of TLD (Sofyan, 2012). The result of Lupke M. et al (2006), the sensitivity loss of LiF:Mg,Cu,P TLD annealed at 240 °C for 10 minutes (manufacturer's recommendations) achieve 10% for 10 cycle times of annealing (Lupke, 2006).

Results and Discussions

In this study has been used three types of LiF:Mg,Cu,P TLD and one type for TLD LiF:Mg,Ti namely TLD-100H (or LiF:Mg,Cu,P), TLD-600H (or ^{6}LiF:Mg,Cu,P) dan TLD-700H (or ^{7}LiF:Mg,Cu, P). TLD-100H contains Li as element of naturally occurring isotopes by 7.5% ^{6}Li and 92.5% ^{7}Li.TLD-600H and TLD-700 Hare enriched with ^{6}Li (95.6% ^{6}Li and 4.4% ^{7}Li) and ^{7}Li (99.93% ^{7}Li and 0.07% ^{6}Li), respectively (Moscovitch, 2007). Differences in concentrations of Li at any type of TLD can cause different response to exposure to gamma radiation and X-rays.

In application, such as measurement of radiation doses received by patient accurately with using TLD is needed in the medical fields. The difference in responses on each TLD and the probability sensitivity decrease due to thermally stimulated can causes the level of accuracy for measurement results into reduced. And the heat stimulation to TLD cannot be avoided, because it is necessary to obtain the luminescence of electrons in spite of trapping, and also to annealing process.In this study, LiF:Mg,Cu,P TLDs used has passed the selection process for uniformity of response with difference less than 5%. The difference of responses for TLD that receives same treatment in few cycles of use has shown in Figure 1. In Figure 1 shown that the same TLD in 6 cycles of discharging provide different responses.This difference can caused by dosimetry characteristics of TLD such as uniformity in batch manufacture, remainder of radiation dose in each TLD, reproducibility at low to medium of radiation doses etc. In addition, in generally the TLD responses is an integral of the emission light emitted while receive the thermally stimulate.

In several cycles use of TLD like Fig. 1 the deviation of sensitivity for each TLD are 7.99 to 15.80% for LiF:Mg,Cu,P, 0.49 to 10.59 % for ^{6}LiF:Mg,Cu,P and 13.07 to 30.46 % for ^{7}LiF:Mg,Cu,P. Because of the differences of sensitivity can caused by several factors that can affect the value of TLD responses, then the mainly due to the probability of uniformity from concentration of impurities TLD. From previous study

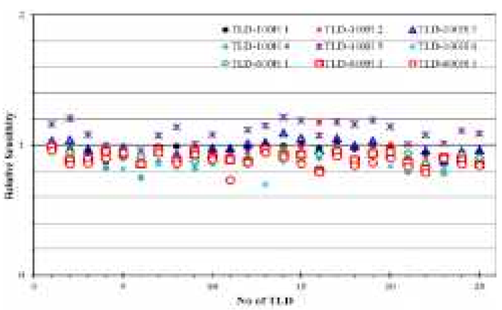


Figure 2. The difference responses of LiF:Mg,Cu,P TLD for same treatment.

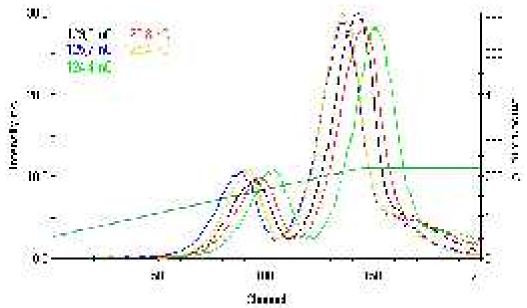


Figure3. TLD with difference glow peak

(Tang et al, 2013; Sadel et al,2013), we can be known about the influence of impurities on the nature of TL that occurred due to differences in impurity concentration in manufacture process for same or different batches. The Mistakes can lead inaccuracy in data analysis of the dose received may not be avoidable. High dose accuracy that can be obtained by entering this error factor as part of another set of correction factors.

The curve of glow peak for LiF:Mg,Cu,P TLD based on manufacturer's data is at a temperature of 220°C (channel 144). However, in this study was obtained the glow peak given on each TLD are relatively not equal (Figure 3). Thus, the ROI position in readout process for TLD response is difficult to determine absolutely. On the other side, to monitor of radiation dose received by workers mainly extremities dose (such as eye and critical organs dose) using high sensitive TLD must be done.The steps taken to get the value of TLD response consistently is total value of the response with ignoring the value of TLD responses on shallow traps.

The difference of peak curves position on Fig. 3 is illustrates the energy required to remove the electrons trapped from its traps.The depth of the position of the trapped electrons, the equivalence of heat energy required stimulation.

Conclusions

LiF:Mg,Cu,P TLD is very high sensitive TLD, and from this study were obtained 20 times more sensitive than LiF:Mg,Ti TLD, so it needs to be careful in handling. Such as in readout of TLD response, the position of TLDs on a planchet can affect the shape of glow curve. Because the glow curve is description of the energy required to excitation process of electrons from trap, then difference shape of glow curve can cause the results of dose determination becomes inaccurate and imprecise.

To obtain more accurate and precision measurements with a high confidence level it need to concern about the uniformity of TLD response and optimization of annealing techniques. The differences that occur in the several of cycles repeated for same TLD, the correction factor cannot be ignored. From this research, the deviation of sensitivity for each TLD are 7.99 to 15.80% for LiF:Mg,Cu,P, 0.49 to 10.59 % for ^{6}LiF:Mg,Cu,P and 13.07 to 30.46 % for ^{7}LiF:Mg,Cu,P.

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Discussion

Q : Dwi Ramadhani – PTKMR

1. It is possible to use the TLD that you mention in your article for Mamuju inhabitans?
2. It is also possible to compare the TLD results measurement to biological dosimeter like Chromosomal Aberration?

A : Hasnel Sofyan

1. Yes, it is possible. In our study, we used the TLDs LiF:Mg,Cu,P-shaped chips are very sensitive in measuring dose radiation. Based on the manufacturer's recommendations, this TLD used for monitoring of environment radiation dose. So, this TLD can also be used to monitoring of dose received on the Mamuju inhabitants.
2. Yes, but before using we must do calibrated the TLD against biological dosimeter.