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"Research Note"

CHARACTERIZATION OF A NEW PREPARED $Li_2B_4O_7$: Mn DOSIMETER FOR γ- IRRADIATION HIGH-DOSE DOSIMETRY*

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Abstract – A lithium borate thermoluminescence dosimeter with 0.3 wt% of manganese impurity concentration was prepared for high dose levels in the range of 1-30 kGy for gamma irradiation applications. The TLD reader was used for read out purposes from ambient temperature to about 400°C with a heating rate of 6°C/sec. The pre- and post- irradiation anneal temperature was 300°C for 1.5 and 1 hours respectively. The effects of absorbed dose, dose rate, storage time, as well as the temperature and humidity versus pre- and post-irradiation storage time have been studied. The main glow peak was found to occur at 375°C, and the dosimeter response in the range of 1-30 kGy was linear. No significant fading effect of the dosimetric peak was observed after 8 weeks of storage, and the effects of ambient temperature and humidity were less than ±5% at 95% confidence level.

Keywords – Dosimetry, thermoluminescence, dose response, dose rate, glow curve

1. INTRODUCTION

Thermoluminescence dosimeters such as the manganese activated lithium borate have attracted a great interest because of their low atomic number, approach to tissue equivalence, simple glow curve and low cost. Lithium borate has been used as a practical radiation dosimeter [1]. Most of the earlier publications pertain to the use of lithium borate with 0.1 wt% of manganese impurity in medical applications, while in this work, lithium borate with 0.3 wt% of manganese impurity has been prepared for high-dose applications (1-30 kGy) [2-4].

The glow peak, dose response, dose rate, as well as the response variation due to pre- and post-irradiation storage time, temperature and humidity have been determined according to the ISO/ASTM standards [5, 6].

2. EXPERIMENTAL

The dosimeter was prepared by fusing a mixture of 23 wt% of lithium carbonate (Li_2CO_3), 77 wt% of boric acid (H_3BO_3), and 5 ml solution containing $MnCl_2$, $4H_2O$ with 0.3 wt% of manganese impurity. It was dried for 12 hours at 100 ºC, and then fired at 950 ºC for 30 min in a 200 ml platinum crucible. After 20 minutes, the mixture was shaken and fired at 950 ºC for an additional 20 minutes, stirred again, and poured into a second platinum crucible. The cooled crystalline mass was grounded and sieved through a

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No. 80 over 200 mesh sieve, and then was kept in desiccators in a dark condition at room temperature [2, 7].

Irradiations were carried out in the ^{60}Co field of a Gammacell 220 irradiator with a dose rate of 1.35 Gy/s calibrated by a Fricke dosimeter. The lower dose rates of 0.13 and 0.48 Gy/s were achieved by insertion of two cylindrical lead shield attenuators in the Gammacell chamber.

All irradiations were performed at room temperature (22-24°C). The samples were surrounded by a 4 mm Plexiglas container to achieve electron equilibrium.

The TOLEDO – 654 and Harshaw model 4000 TLD Readers were used for read-out purposes and recording the glow curves, respectively, using the linear heating rate of 6°C/sec from ambient temperature to about 400 °C in a purified nitrogen atmosphere [8]. The applied pre-irradiation annealing temperature was 300 °C for 1.5 hours, followed by 300°C pre-read out annealing treatment for 1 hour [4]. For each absorbed dose, at least 8 to 10 samples containing 5 mg of phosphor powder were read and the average response and standard deviation were determined [5, 6].

3. RESULTS AND DISCUSSIONS

a) Glow curve

The obtained glow curve of the prepared dosimeter at 1kGy applied dose has been shown in Fig.1. The increased content of manganese impurity (0.3 wt%) shifts the main glow peaks to higher temperatures with a main high-temperature peak at about 375 °C [2]. This is comparable with the reported values by Pradhan et al, with a main peak at 370 °C and a secondary peak at 210 °C [4]. The secondary peaks were totally removed in the prepared dosimeter because of the post-irradiation, high-temperature annealing and cooling down treatment. This overcomes the fading effect for long term dose measurements. The high-temperature part of the glow curve of the dosimeter is significant for high absorbed dose applications.

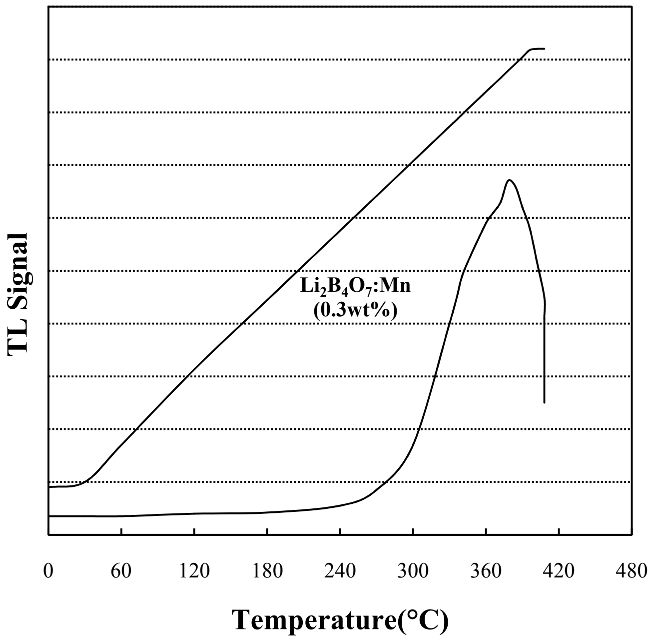

Fig. 1. Glow curve of the $Li_2B_4O_7$: Mn dosimeter having a concentration of 0.3wt% manganese, after pre-read out anneal treatment at 300 °C for 1hr for the applied dose of 1kGy

b) Dose response

The relationship of the measured dose responses as a function of absorbed doses of 1 to 30 kGy has been shown in Fig. 2. The linearity region of the dose response extended to 30 kGy. The coefficient of variation (CV%) of the dose responses for all measured values were found to be about ± 7%, [5, 6].

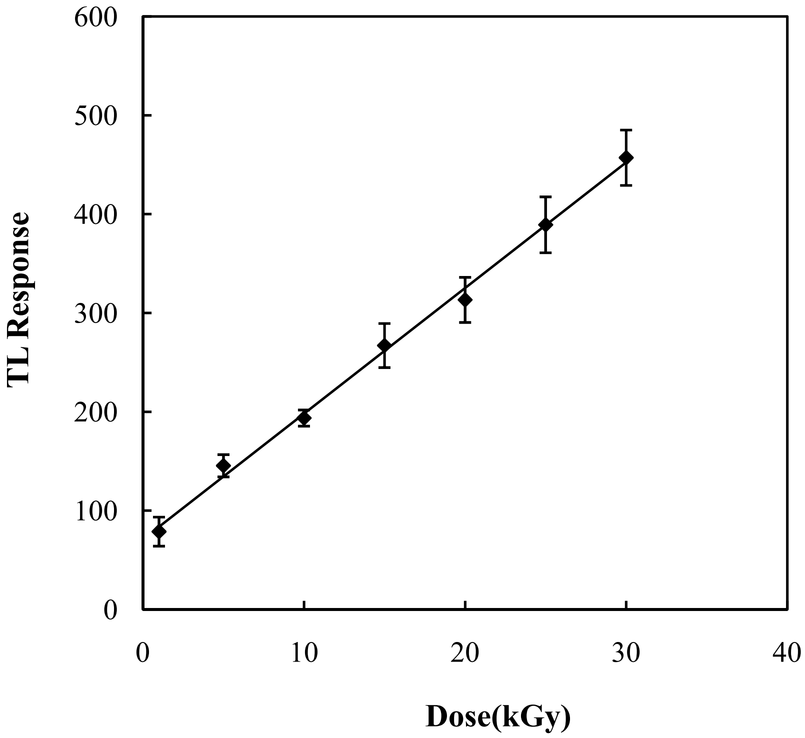

Fig. 2. Calibration curve of $Li_2B_4O_7$:Mn (0.3wt%) dosimeter as a function of absorbed dose

c) Post- irradiation stability

Post-irradiation stability of the irradiated dosimeters for 1 and 10 kGy absorbed doses were studied for 8 week periods in dark condition [5]. The normalized net response variations over the storage period have been shown in Fig. 3. The dosimeter that received a dose of 1kGy showed nearly uniform and fixed responses for a period of 6 weeks, whereas for the 10 kGy absorbed dose, a decrease of about 6% has been observed at the end of the 8 week storage periods. It seems that post-irradiation stability is dose dependent and the response variation is observed by increasing the applied doses.

d) Dose rate dependence

Dose rate effect was studied for the irradiation dose of 10 kGy at 23 °C in the range of 0.13 to 1.35 Gy/s in the Gammacell [5]. The results have been shown in Fig. 4. Dose rate dependence of the responses of the irradiated dosimeters for all dose rates was found to be less than ±5%.

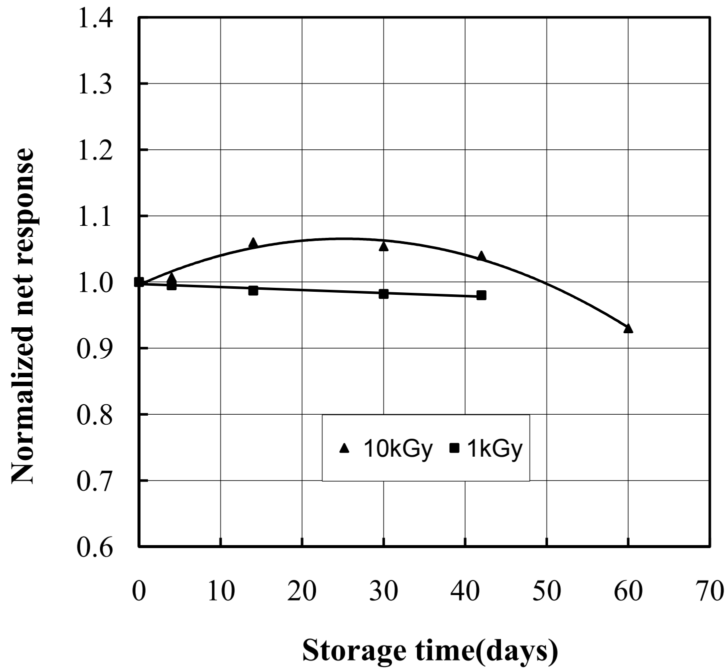

Fig. 3. Normalized net responses of the irradiated $Li_2B_4O_7$:Mn (0.3wt%) dosimeters at 1 and 10 kGy as a function of storage time

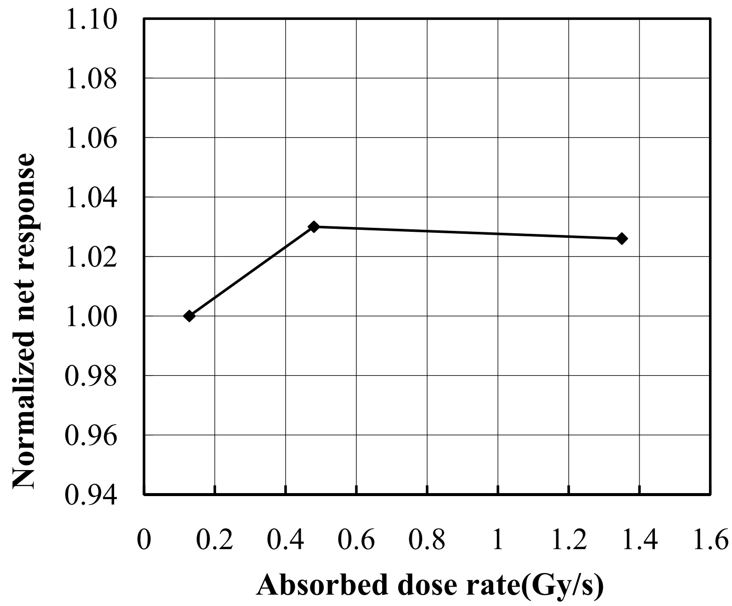

Fig. 4. Dose rate dependence of the irradiated $Li_2B_4O_7$:Mn dosimeter at 10 kGy

e) Effect of storage temperature

Pre- and post- irradiation stability of the exposed dosimeters at 5 kGy was explored at temperatures of 5 °C, 25 °C, and 50 °C. All unirradiated dosimeters, as well as the irradiated one, were kept in dark condition for a 10 day period [5]. The obtained results have been shown in Fig. 5.

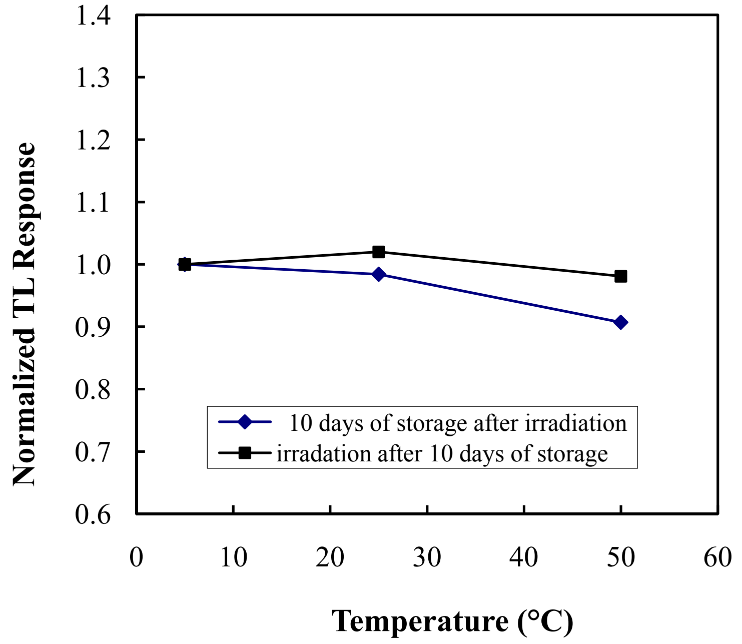

Fig. 5. Normalized net TL responses of the irradiated $Li_2B_4O_7$:Mn dosimeters as a function of storage temperatures, prior to and after irradiation at 5kGy

No significant effect of temperature was observed on the responses of the dosimeters kept in 5 °C and 25 °C ambient temperatures, but the responses of the dosimeters kept at 50 °C decreased to about 4% and 8% for pre-and post-irradiation storage periods, respectively [9]. In general, the effect of the ambient temperature on the responses of the pre-irradiation stored dosimeters is less than 5%, but for post-irradiation storage at high temperatures, a correction factor of about 0.3%/°C should be applied.

f) Effect of storage humidity

The effect of the storage humidity on the dosimeter responses has been studied at room temperature with relative humidity of about 48% and in water (100%), prior to and after irradiation at 5 kGy. All dosimeters were kept in dark condition in these atmospheres for a 10 day period [5].

No significant effect of humidity was observed on the responses of the dosimeters because of the high-temperature pre-read-out annealing treatment (300°C/1hr). In general, the humidity variations were less than ±5% at 95% confidence level [9].

4. CONCLUSION

Based on the obtained results, the prepared $Li_2B_4O_7$: Mn dosimeters with a 0.3 wt% of manganese impurity concentration have produced the intended objectives of linear dose response (1-30 kGy); low dose rate effects, low and moderate effects of pre- and post-irradiation storage temperatures in the range of 5-25°C and 25-50°C respectively, as well as a low humidity effect of less than 5%. The obtained correction factor can be used for post-irradiation high-temperature effect. The dosimeter has also shown good post- irradiation stability and fading characteristics at room temperature for about 8 weeks. According to the well-behaved response of the dosimeter and low response variation due to the environmental parameters, it can be concluded that the prepared dosimeter can be used for dose measurements in high dose applications.

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