Performance of ZnO-doped recycled window glass as a thermoluminescence dosimeter

T Thumsa-ard, R Laopaiboon and J Laopaiboon*

Department of Physics, Faculty of Science, Ubon Ratchatani University, Ubon Ratchatani 34190, Thailand

* Corresponding author. E-mail: 2502jin@gmail.com

Abstract. Thermoluminescence properties of Thai commercial window glass provided by Guardian Industries Corporation (denoted as WG) were studied. WG was doped with varying concentrations of ZnO. The composition of glass is 90WG-10Na_2O-xZnO (where x = 0.000, 0.001, 0.010, 0.100, 1.000 mol%). Glass samples were recycled by using melt quenching technique and cut into the dimensions of 6×6×1 mm^3. After irradiated glass samples with X-ray at photon energy 160 keV in absorb dose rang 0-14 mGy, the glow curve structure, TL sensitivity, linearity and minimum detectable dose were investigated.

1. Introduction

Thermoluminescence (TL) is an ability of a semiconductor or an insulator to emit light when thermally stimulated after irradiation. The intensity of the light emitted by some materials depends on the radiation dose received by material, which makes these materials suitable as dosimeters. A TLD material used as dosimeter should show high sensitive for a very low dose, low hygroscopicity and linear dose response. In addition, it should be easy with very little cost. Precise measurements are required in studies of TL materials [1]. Various types of commercial glass (ordinary windows, cathode ray tubes, glass kitchenware) have been studied as potential accidental radiation dosimeters [2]. It was found that Thai transparent window glass provided by Gardian Industries Corporation can be a good dosimeter due to its dose response characteristic and easy preparation, linearity of TL response which major components are SiO_2, Na_2O, CaO, MgO, Al_2O, Fe_2O_3, TiO_2 and K_2O [3]. Recycling window glass process needs to add melting agent such as Na_2O to reduce melting point. The (100-x)WG-xNa_2O glass system with different concentrations of Na_2O was studied and it showed that the 90WG-10Na_2O glass sample produced the highest TL intensity. Thus this glass was selected as base glass [4].

Many researches were found that doping zinc oxides can improve its TL characteristics in other materials. For example, doping ZnO on borosilicate glass for studying the better thermoluminescence properties [5], doping ZnO on Fe nanoparticles for improving structural, EPR, photo and thermoluminescence properties [6], ZnS on Mn nanocrystalline powders for developing thermoluminescence properties [7] and more researches. Therefore, zinc oxides are one of the good activators to develop thermoluminescence properties in other materials.

The present studies intend to investigate new material based on commercial Thai transparent window glass for the use as thermoluminescence dosimeter when radiation accidents happen. One of the reasons to consider the use of window glass is that it is common in local, easy to prepare and estimate the radiation dose. In this work, glass has been chosen as the structure of phosphor since it

has been found to be a good dosimeter. In this work, glass is doped zinc oxides with varying concentrations for better thermoluminescence properties of window glass.

2. Materials and Methods

The Thai commercial window glass provided by Guardian Industries Corporation (denoted as WG) was used for starting materials. Melt quenching technique were applied for preparing the recycled window glasses (denoted as WG) in the compositions 90WG-10Na_2O-xZnO (where x = 0.001, 0.010, 0.100, 1.000 mol%). The required quantities of WG, Na_2O and ZnO were grinded together to ensure homogeneity. The mixtures in ceramic crucible were melted at 1250 °C for 4 hours in an electrically heated furnace. The melted glasses were poured into stainless steel molds and immediately annealed at 500 °C for 2 hours in order to remove any internal stresses and then cooled down to room temperature. Thereafter, glass samples were cut in to the dimensions of 6×6×1 mm^3. Then the sample irradiated with photon energy of 160 keV (X-ray tube model MD 1100 KELEX) in the absorb dose range 0-14 mGy. After irradiation exposure, the TL measurement were carried out immediately to avoid TL fading by using a TLD reader model Harshaw 3500

3. Results and discussion

3.1. Glow curve features

Glow curve is one of important features for better understanding of TL phenomena. They are usually plotted as light intensity against the heating temperature. The shape and the position of the glow curve reveal the type of trapping states and their fading characteristics of the corresponding material.

Figure 1. gives the glow curves of window glass mixed with Na_2O and doped with varying concentrations of ZnO exposed to 14 mGy of X-ray at photon energy 160 keV. There glow curve were investigated. It was observed that the TL glow curve characteristic of the glass samples depend on concentration of zinc oxides and demonstrated their main peaks in rang of 195-220 °C as shown in the second column in Table 1. It is well known that the ideal glow curve should have single sharp peak positioned between 180-250 °C [8].

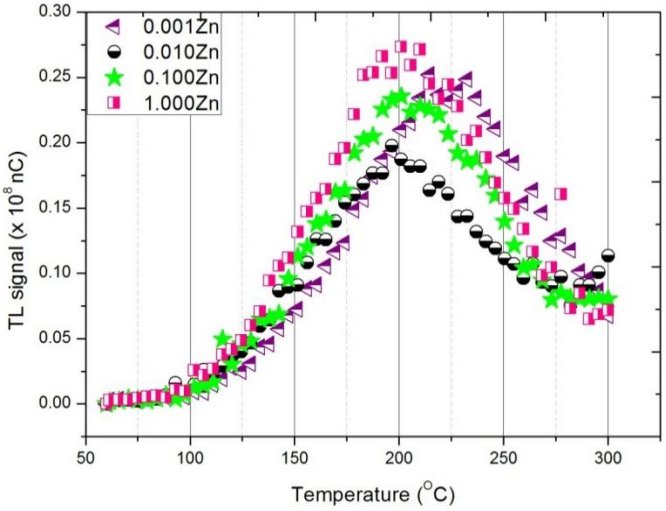

Figure 1. TL glow curve comparison of 90WG-10Na_2O-xZnO glass system (where x = 0.001, 0.010, 0.100, 1.000 mol%) after irradiated to 14 mGy of X-ray at photon energy 160 keV.

3.2. TL signal vs. dose

Another important characteristic in TL measurements is sensitivity of a TL material, which is the integrated area of its glow curve. The comparison of TL sensitivity of 90WG-10Na_2O-xZnO (where x = 0.001, 0.010, 0.100, 1.000 mol%) samples subjected to X-ray irradiation at photon energy 160 keV 14 mGy. It was found that TL sensitivity of window glass doped with varying concentrations of zinc oxides showed closely response in range from 1.933×10^9 nC to 2.266×10^9 nC as shown in the third column in Table 1.

Table 1. The experimental data of 90WG-10Na_2O-xZnO (where x = 0.001, 0.010, 0.100, 1.000 mol%) glass system

Galss sample	TL main peak (°C)	Sensitivity for 14 mGy (nC)	Linearity (R^2)
90WG-10Na_2O-0.001ZnO	220	1.933×10^9	0.9252
90WG-10Na_2O-0.010ZnO	200	2.207×10^9	0.8913
90WG-10Na_2O-0.100ZnO	195	2.033×10^9	0.8388
90WG-10Na_2O-1.000ZnO	200	2.266×10^9	0.9904

3.3. Linearity

One of important characteristics of any thermoluminescence dosimetric applications is linearity which is a linear relationship between the TL emission and the absorbed dose. Normally, the linearity range depends on the particular thermoluminescence material. The TL responses of the glass samples were studied over the dose range of 0-14 mGy and shown in Figure 2. Each data point represents the average of three individual readings and the error bars represent the standard deviation of mean for window glass doped with varying concentrations of zinc oxides. The result doesn't clearly reveal the best linearity property compared to all of the glass samples as shown in the last column in Table 1.

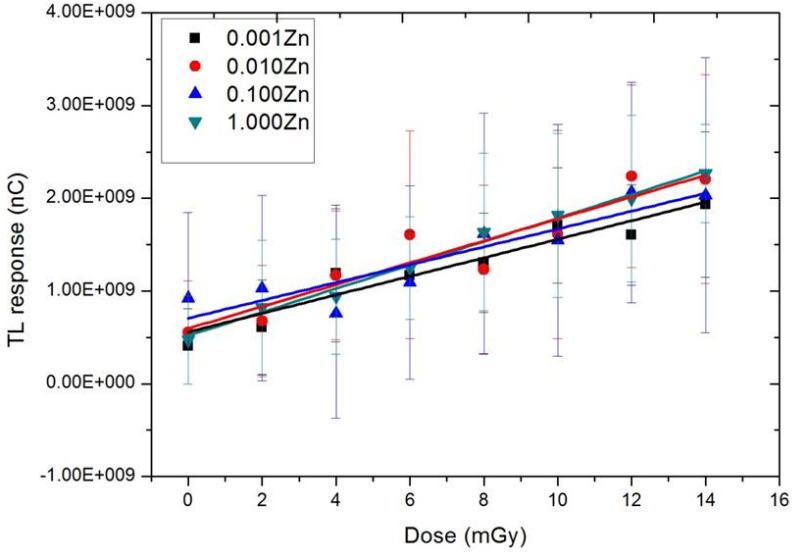

Figure 2. TL response versus X-ray dose of 90WG-10Na_2O-xZnO (where x = 0.001, 0.010, 0.100, 1.000 mol%) glass system

3.4. Minimum detectable dose

The minimum detectable dose (MDD) has been determined according to the expression [9]

$$MDD = (M + 3\sigma)\phi_C \quad (1)$$

Where M is the mean TL background signal obtained from samples non-irradiated and σ is The standard deviation of the mean background and ϕ_C is the TL system calibration factor express In 1/slope of linearity graph.

Table 2. The data for Minimum detectable dose calculation of 90WG-10Na_2O-xZnO (where x = 0.001, 0.010, 0.100, 1.000 mol%) glass system.

Galss sample	slope	Intrinsic Bkg.	SD of Intrinsic Bkg.	Calibration factor	MDD (mGy)
90WG-10Na_2O-0.001ZnO	1.0×10^{8}	8.09×10^{8}	4.34×10^{8}	1.11×10^{-8}	21.11
90WG-10Na_2O-0.010ZnO	1.0×10^{8}	1.11×10^{9}	6.02×10^{8}	1.00×10^{-8}	29.17
90WG-10Na_2O-0.100ZnO	9.0×10^{7}	1.84×10^{9}	1.03×10^{9}	1.11×10^{-8}	54.66
90WG-10Na_2O-1.000ZnO	1.0×10^{8}	9.46×10^{8}	7.12×10^{8}	1.00×10^{-8}	30.84

The minimum detectable dose of window glass mixed with Na_2O and doped with ZnO at various concentrations were compared in Table.1. It was found that the window glass mixed with Na_2O and doped with ZnO at concentration of 0.001 mol% shows the lowest minimum detectable dose (approximately 21.11 mGy) compared to the entire glass samples.

4. Conclusion

The results of this work demonstrated that the main TL glow peak of the window glass mixed with Na_2O and doped with varying concentrations of ZnO revealed in rang of 200-220 °C. The result doesn't clearly reveal the highest TL sensitivity and the best linearity property compared to all of the glass samples in this work. However, It was observed that the window glass mixed with Na_2O and doped with ZnO at concentration of 0.001 mol% shows the lowest minimum detectable dose (approximately 21.11 mGy) compared to the entire glass samples.

4. Acknowledgements

The authors gratefully acknowledge the financial support for this work from Science Achievement Scholarship of Thailand (SAST) and Glass Technology Excellent Center (GTEC), Department of Physics, Faculty of Science, Ubon ratchathani University for providing research grants and facilities.

References

[1] Aboud H, Wagiran H, Hussin R, Ali H, Alajerami Y and Saeed M 2014 *Appl. Radiat. Isot.* **90** 35
[2] Kharita M H, Yousef S and Bakr S 2012 *Nucl. Instrum. Methods Phys. Res. B* **278** 50
[3] Kucuk N, Kucuk I, Cakir M, Kayakels S 2013 *J. Lumin*. **139** 84
[4] Laopaiboon R and Bootjomchai C, 2015 *J. Lumin.* **158** 275
[5] Salamaa E, Soliman H A, Youssef G M and Hamad S 2017 *J. Lumin.* **186** 164
[6] Reddy A J, Kokila M K, Nagabhushana H, Sharma S C, Rao J L, Shivakumara C, Nagabhushana B M and Chakradhar R P S 2012 *Chem. Phys.* **133** 876
[7] Ortiz-Hernández A A, Garcí V H M, Arrieta M L P, Sígala J J O, Ibarra J J A, Vega-CarrilloR and Guajardo C F 2015 *Appl. Radiat. Isot.* **99** 105
[8] Lim T Y, Wagiran H, Hussin R and Hashim S 2015 *Appl. Radiat. Isot.* **102** 10
[9] Alajerami Y S M, Hashim S, Ghoshal S K, Bradley D A, Mhareb M and Saleh M A 2014 *J. Lumin.* **155** 141