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The thermoluminescence properties and determination of trapping parameters of soda lime glass doped with erbium oxide

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ABSTRACT

The thermoluminescence properties and trapping parameters of soda lime glass doped with erbium oxide (Er_2O_3) were investigated. The glow curve and linearity evaluations of the glass samples were carried out by irradiation with 100 kV of X-ray tube photon energy at a dose of 14 mGy. The results for the glow curve and linearity show that the S-2 glass sample is more suitable for using as a dosimeter. The lower detection limit (D_{LDL}) of the S-2 glass samples was studied. Reproducibility of the S-2 glass samples was investigated by calculation of the detector variability index (DVI). Trapping parameters (activation energy and frequency factor) supported the results for the glow curve and fading of the glass samples. Physical properties of the glass samples were calculated. The results could explain the behavior of the modifier atoms when these were added into the network structures.

1. Introduction

Nuclear energy and radioactive sources are used widely for various applications; such as, agriculture, food preservation, radiotherapy, and many other industries. Therefore, the management of radiation protection is extremely important. Personnel monitoring is also important for workers associated with radiation. Thermoluminescence dosimeters (TLD) are one of the most highly efficient means of radiation dosimetry. New materials are now being implemented which allow more sensitivity and linearity in the radiation response of the TL signal output over a wide range of radiation doses. In the case of radiation accidents, retrospective dosimeters play a key role in measuring the amount of radiation at the beginning of the accident. The materials used for retrospective dosimeters should be common materials and personally portable. Watch glass and tooth enamel have successfully been used to assess the doses absorbed by people involved in major radiation accidents, such as the Chernobyl disaster [1–4]. Glass materials have been engaged due to valuable properties; such as, easy handling, chemical inertness, and excellent transparency. Moreover, a dosimeter made from glass possesses several advantages over other dosimeters, not least of which is its effective atomic number (Z_{eff}), which is comparable to that of human biological tissue [5–7].

Recently, commercial window glass was investigated to assess its potential for use as a radiation dosimeter. This is interesting since window glass is a common material. The results found that it has the potential to be developed for dosimetry [7]. However, its capacity in terms of signal storage and reproducibility required improvement. The oxides of some rare earth metals were expected to improve the stability of trapping electrons and the thermoluminescence behavior of materials [8–13]. Trivalent rare earth ions (RE^{3+}); such as, Dy^{3+}, Nd^{3+}, Sm^{3+}, etc., played a direct role in trapping electrons and caused an increase in the TL signal [14–17]. Moreover, the trivalent rare earth ions had a stability for storing electrons in the trap resulting in low fading of the TL signals [15,18]. The Er^{3+} ion is one of the rare earths, which can act as a very important dopant due to its optical transition in the range of being near-infrared. In addition, the trivalent oxide of erbium has highly suitable active ions for several hosts which apply f-f transition states [19]. Moreover, the structure of the host glass doped with Er^{3+} was investigated. The results revealed that the effect of Er^{3+} on the structural properties decreased the connectivity of the network glass for low Er_2O_3 concentrations while an increase in the Er_2O_3 concentration slightly increased the elastic moduli [20,21]. These findings indicate that the structure of the host glass is highly suitable with increased concentrations of Er_2O_3.

For this research study, the soda lime glasses from recycled window glass doped with Er_2O_3 was prepared. The new glass materials were investigated to assess their thermoluminescence properties. The statistical analysis to represent the reproducibility was carried out by using the coefficients of variation analysis method. Trapping parameters and physical properties of the glass samples were studied and discussed to better understand the interior of the glass structures.

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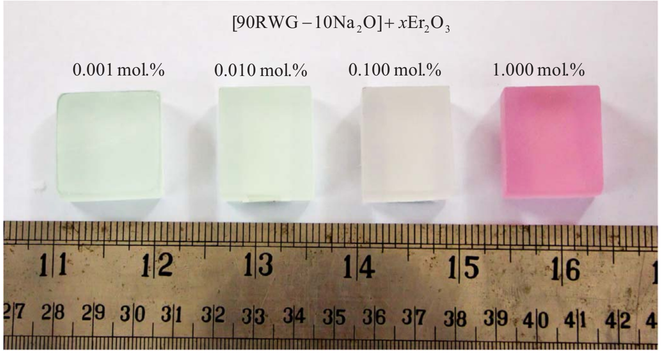

Fig. 1. Morphology of the glass samples with different concentrations of Er_2O_3.

2. Experimental details

The (90)RWG – (10)Na_2O – (x)Er_2O_3 glass system was prepared using a melt quenching technique, where the RWG is recycled window glass (soda lime glass) and x is 0.001, 0.01, 0.1 and 1 mol%. The RWG was prepared by cleaning and grinding into a powder. The analytical reagent grades of Na_2O and Er_2O_3 were used in this research. The chemical oxides (Na_2O and Er_2O_3) and RWG powder were weighed using an electric balance with accuracy in the order of 0.1 mg. The appropriate amounts of chemical were mixed thoroughly in ceramic crucibles. The mixtures were melted in an electric furnace at 1250 °C for about four hours to ensure homogeneity. The homogenous melted glasses were poured into preheated stainless steel molds and then immediately inserted into separate electric furnaces for annealing at 500 °C for two hours before being allowed to cool naturally to room temperature. The obtained glass samples were cut and polished in order to maximize flatness. The nominal compositions and physical observations of the prepared glass samples are given in Fig. 1 and Table 1.

For the thermoluminescence measurements, each sample was annealed using a dual step technique (400 °C for one hour and then 100 °C for two hours) before being irradiated with 100 kV of X-ray tube photon energy with a dose range of 0 – 14 mGy to carry out the thermoluminescence response and glow curve assessment. The X-ray machine band KELEX was used with the X-ray tube model MD1100. The X-ray tube had an inherent filtration by oil-insulation with a vacuum system and added filtration by lead-shielded housing to reduce to low photon energy. TL light emitted from the glass samples was detected by a TLD Reader of the brand Harshaw/Bicron Model 3500 Manual. The glow curves were recorded from 60 °C up to a maximum temperature of 300 °C with a heating rate of 10 °C/s. The region of interest facility available in the TLD reader was used to evaluate the responses of different glow peaks resulting from the Computerized Glow Curve Deconvolution (CGCD) procedure. The CGCD data were gathered by taking notes from the MS-DOS files to the Excel program. Each datum point was obtained from an average of five measurements.

Table 1
Chemical compositions and physical observations of the glass samples.

Glass samples	Chemical compositions (mol%)			Physical observations
	RWG	Na_2O	Er_2O_3	
S – 1	90	10	0.001	Colorless and homogeneous
S – 2	90	10	0.01	Colorless and homogeneous
S – 3	90	10	0.1	Light pink and homogeneous
S – 4	90	10	1	Pink and homogeneous

Archimedes' principle was used to determine the variation of the density of the glass samples. The density could be calculated using the equation:

$$\rho = \left(\frac{W_1}{W_1 - W_2}\right)\rho_L \qquad (g{\cdot}cm^{-3}) \tag{1}$$

where W_1 and W_2 are the weights of the glass samples in air and in immersion liquid respectively, and ρ_L is the density of the immersion liquid. The immersion liquid in this study was n-hexane. All of the samples were measured three times at room temperature. The estimated error in these measurements was ± 0.002 g cm^{-3}. Molar volume (V_a) was evaluated using the equation:

$$V_a = \frac{M_{glass}}{\rho} \qquad (cm^3\,mol^{-1}) \tag{2}$$

where M_{glass} is the molecular weight of the glass samples. The error in the molar volume was determined by repeating the density measurements three times and was equal to ± 0.102 cm^3 mol^{-1}.

The physical properties of the glass samples were investigated. The ion concentration (N) could be calculated using the equation [22]:

$$N = \frac{(mol\%\ of\ RE\ doped)(\rho)(N_A)}{M_{glass}} \qquad (ions\,cm^{-3}) \tag{3}$$

where N_A is Avogadro's number. After the ion concentration was determined, three other related physical properties were evaluated using the equations [22,23]:

$$\text{Polaron radius:}\, r_P = \frac{1}{2}\left(\frac{\pi}{6N}\right)^{1/3} \qquad (\text{Å}) \tag{4}$$

$$\text{Interatomic distance:}\, r_i = \left(\frac{1}{N}\right)^{1/3} \qquad (\text{Å}) \tag{5}$$

$$\text{Field strength:}\, F = \left(\frac{z}{r_P^2}\right) \qquad (cm^{-2}) \tag{6}$$

where z is the valence number of the rare earth ion.

3. Results and discussions

The glass samples were doped with Er_2O_3 from 0.001 mol% to 1 mol % along with physical observations as shown in Fig. 1 and Table 1. The morphology of all glass samples showed good homogeneity. The color of the glass samples was colorless doped with Er_2O_3 at 0.001–0.01 mol % and became pink when increasing the concentration of Er_2O_3 from 0.1 to 1 mol%. The glass samples were irradiated with 100 kV of X-ray tube photon energy at doses of 14 mGy. The glow curves of the measurements are shown in Fig. 2. The glass samples showed similar main glow curves for all concentrations at around 180 °C and 270 °C, respectively. From Fig. 2, it is clear that the Er_2O_3 caused significant changes in the TL intensity by the electron trap created by the Er^{3+} ion. The important role played by the Er^{3+} ion in the TL emission is in the trap filling process that may arise through the direct transfer of

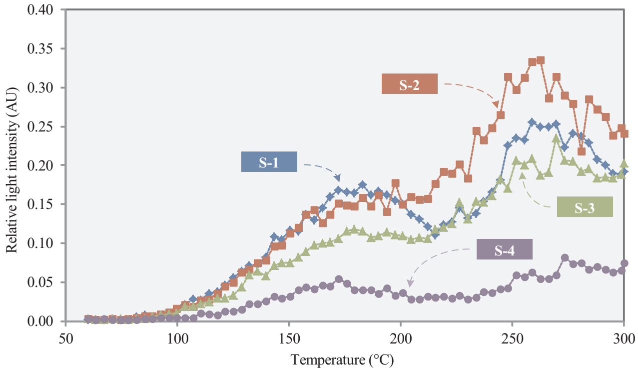

Fig. 2. Glow curve of the glass samples irradiated with X-ray tube photon energy of 100 kV at a dose of 14 mGy.