Journal of Non-Crystalline Solids xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Non-Crystalline Solids

journal homepage: www.elsevier.com/locate/jnoncrysol

The physical properties of phosphate calcium glass doped with titanium oxide nanoparticles

Mohamed Anwar K. Abdelhalim[a,*], Bandar Mora Al-Shamrani[b]

[a] Department of Physics and Astronomy, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia
[b] Medical Physics Section, Department of Radiodiagnostic and Medical Imaging, King Fahad Armed Forces Hospital, P.O. Box 9862, Jeddah 21159, Saudi Arabia

ARTICLE INFO

Keywords:
Thermoluminescent
Phosphate glass
Dosimetry
P_2O_5CaO glass
TiO_2

ABSTRACT

The present study was aimed to prepare and investigate the phosphate calcium glass doped with different concentrations of titanium oxide nanoparticles. The structures of $xTiO_2$ (100 − x) P_2O_5CaO glasses, with x = 0, 5, 10, 15, 20, and 25 were studied by the X-ray diffraction (XRD) and the scanning electron microscope (SEM). The time-dependent fading behavior of TL characteristics was investigated. The kinetic parameters, such as kinetics order, activation energy, and frequency factor, related to the glow peak were determined using the TolAnal software. The thermoluminescence (TL) characteristics of these irradiated glasses with gamma radiation doses, were studied in the temperature range 50–400 °C, and with a heating rate of 30 °C/s. The gamma irradiation was performed in the range of 1–500 Gy. The glow curves of the blank sample $50P_2O_5$ 50CaO, exhibited a dosimetric peak at temperature of nearly about 200 °C, and the high-temperature peak was at 300 °C; while after the addition of TiO_2, only one peak was observed at 300 °C. The sample $37.5P_2O_5$ – 37.5CaO - $26TiO_2$ induced the generation of TL signals upon irradiation, and with the highest TL response. The linear dose response was observed up to 500 Gy

1. Introduction

The glass dosimeters play a considerable role in different applications, such as industrial, medical, and food irradiation purposes. Because of the optical transparency of the glass, the glass dosimeters become of great interest, thus resulting in an overall improvement in the efficiency of the phosphorus.

A large number of studies have been dedicated to the improvement of the luminescence properties of the glass systems [1–8]. The phosphate glasses are often used as biomaterials; because of their chemical composition similarity to that of the natural bones, and it have several advantages over borate and silicate glasses, due to their thermal expansion coefficients, ultraviolet transmission, and melting temperatures [9–11].

Recently, many studies have focused on the applications of phosphate glasses in medicine and clinical dosimetry, as biomaterials [12–16]. The studies on P_2O_5CaO TiO_2 as a biomaterial glass has been studied extensively [17,18]. The recent studies on the various luminescent nanomaterials have shown that these materials were of potential use especially in the ionizing radiation dosimetry, with the TL technique which can measure the high doses that saturate the conventional microcrystalline phosphors [19–21]. The aim of the present study was to synthesize and characterize the P_2O_5CaO TiO_2 glass system which can be applied as standard gamma radiation dosimeter.

2. Materials and methods

2.1. Glass preparation

Phosphorus Pentoxide (P_2O_5) nanopowder as a glass (nearly 100% purity and APS is $^{<}$100 nm), added to calcium oxide (CaO) nanopowder as a glass modifier (nearly 100% purity and APS is $^{<}$100 nm) [22], and activated with different amounts of titanium oxide (TiO_2) nanopowders (purity of nearly 100% and APS is 10–26 nm), 0, 5, 10, 15, 20, 25 mol% as shown in Table 1. All the chemical compositions were purchased from Nanoshel Company (Intelligent Materials Pvt. Ltd.), and used in this study. The different kinds of the glass systems were prepared by the melt-quenching technique. Each batch of samples was weighed to 5 g, and the mixture was heated gradually until it reaches 1100 °C, to remove the water concentration, and then was remained at 1100 °C for 1–3 h, depending on the dopant concentration using the silica crucibles without covers in air [22]. These melts were quenched at the room

* Corresponding author.
E-mail address: mabdulhleem@ksu.edu.sa (M.A.K. Abdelhalim).
URL: http://fac.ksu.edu.sa/mabdulhleem (M.A.K. Abdelhalim).

http://dx.doi.org/10.1016/j.jnoncrysol.2017.04.039
Received 4 March 2017; Received in revised form 17 April 2017; Accepted 23 April 2017

Table 1
Nominal chemical composition of the glass series (mol%).

Furnace temperature and time (°C/h)	P_2O_5	CaO	TiO_2	Glass sample
1100/1	50	50	0	A
1100/1	47.5	47.5	5	B
1100/2	45	45	10	C
1100/2	42.5	42.5	15	D
1100/3	40	40	20	E
1100/3	37.5	37.5	25	F

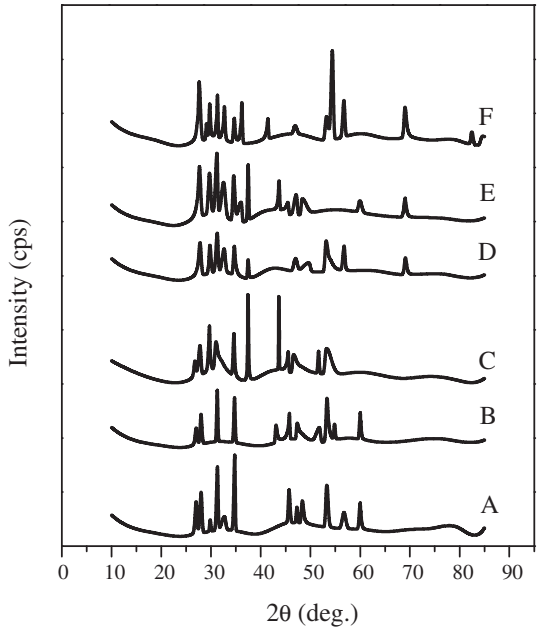

Fig. 1. XRD pattern of samples (A, B, C, D, E and F).

temperature in the air by pouring onto a stainless steel plate. The sample was crushed to get the powder form, and was pressed to the chips diameter of 5 mm and thickens of 1 mm. The glass samples were then placed into Perspex sample holder, and were sealed in a black paper in order to protect them from the ambient light [22].

2.2. The characterization of glass

X-ray diffraction patterns were obtained using a Rigaku (Ultima IV) diffractometer with a constant 12 mm footprint on the sample [22]. All the runs were over a 2θ range, 10–85° and at 0.01° sampling width using a Cu Kα (λ = 1.5406 A°) radiation source, and at 40 kV–40 mA (40 kV–40 mA for vitreous samples). To investigate the surface morphology, a Scanning electron microscope (SEM) of type Jeol JSM 6380 LAof 3.0 nm resolutions, 0.5–30 kV accelerating voltage, and × 5 to 300,000 magnification order was used [22].

2.3. The irradiation of samples

The glass samples were irradiated by gamma radiation using Cobalt-60 (Central Laboratory, College of Science, King Saud University) [22]. The irradiation of samples was performed in the range of 1–500 Gy for approximately 30 min. After the irradiation, the samples were read out with a standard reader with hot planchet capabilities (Model 3500 TLD Reader, MICRON/Harshaw, 6801 Cochran Road, Solon, OH 44139, USA) and commercial reader control software (WinREMS version PL-26732.003, MICRON/Harshaw, 6801 Cochran Road, Solon, OH 44139, USA) [22].

3. Results and discussion

3.1. Glass characterization

3.1.1. X-ray diffraction (XRD) analysis

The structure of the synthesized compound was investigated using the XRD patterns (Fig. 1), in which the intensity was performed as a function of the scattering angle 2θ°. The obtained results were matched with the International Center for Diffraction data (ICDD) [22].

3.1.2. Scanning electron microscope (SEM)

The SEM micrographs were recorded for the powdered samples. The sample's compounds show irregular morphology, non-uniform shape, and the size is approximately varying within the range 263–600 nm (Fig. 2).

3.1.3. Effective atomic number (Zeff)

The Zeff was calculated theoretically and tabulated as shown in Table 2. The different samples A, B, C, D, E, and F are near to the Zeff of the bone with a nearly value of 11.6–13.8 [23]. It has been reported that the radiation-interaction characteristics of mixture or compounds that are similar to the bone, the soft tissue, and/or any other body constituents, can be identified for the dosimetric purposes [24]. Therefore, this justifies our Zeff result, which can be used for personal and environmental monitoring.

3.2. Thermoluminescence properties

3.2.1. Annealing procedures

To eliminate the effects of previous exposure without causing any damage to the phosphor, the annealing was performed. The annealing procedures were applied to the blank sample (A: without activator). The TL signal measured before irradiation was a very weak signal. The temperatures used were 100, 200, 300 and 400 °C, and the annealing time was kept constant at 1 h for each temperature. The blank sample (A) was exposed to 1 Gy using Cobalt-60 source, and then readout. Fig. 3 shows the TL response of the blank sample (A) at different annealing temperatures from 100 to 400 °C [22]. The optimum post-irradiation annealing condition was observed at 400 °C for 1 h, using an external furnace. The readings were taken three times for each point, and the same steps were also carried out with the other samples [22].

3.2.2. Time temperature profile (TTP)

Fig. 4 shows TL curves for the blank sample (A) under different heating rates after being irradiated by 1 Gy. The stability in the shape of the TL glow curves was observed, and the TL peak was shifted to a higher temperature, showing the increase in the TL intensity by elevating the heating rate, and the highest TL response was observed at the heating rate 30 °C/s [22].

Table 3 shows the TTP applied throughout this work, with the heating rate 30 °C s^{-1}; Starting from 50 °C and to reach the maximum temperature 400 °C, the estimated time was 13.33 s.

3.2.3. TL glow curves

Figs. 5 and 6 show the glow curves and TL response (the total integral of the glow curve) for samples A, B, C, D, E, and F at 100 Gy [22]. It shows good TL response for sample F with one glow peak at 310 °C; by comparing the glow curve for the blank sample (A) with the glow curve of the sample (F), it shows that the addition of TiO_2 to the sample (F) induced one peak instead of 2 peaks, which are considered very suitable for the dosimetry purposes. Fig. 7 shows typical glow curves recorded at different irradiation doses 1, 5, 10, 50, 100, 200, 500 Gy for the sample (F).

The Gamma rays create trapping centers in the material, increases with increasing the gamma doses. It also acts as an exciting source to the material, raising the electrons from the valence band, which are