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The real-time gamma radiation dosimetry with TeO_2 thin films

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ABSTRACT

A detailed study of the effect of gamma radiation on the current–voltage characteristics of the TeO_2 thin films of different thicknesses, prepared by thermal evaporation in a vacuum, has been carried out for a much wider range of the gamma radiation doses than made here-to-fore. Subsequently, for the thin films of different thicknesses at different applied voltages, the variations of the current density with dose have been obtained. The current density increases near linearly with the gamma radiation dose up to a critical radiation dose, a dose value higher for the thicker films and decreases thereafter. The sensitivities of these TeO_2 thin films at different applied voltages have been found to be in the range 1.2–37.0 nA/cm^2/μGy. Correspondingly, the detection limits have also been estimated and have been found to be in the range 0.22–2.16 mGy. Clearly, the TeO_2 thin films have high potential for their use as real-time gamma radiation dosimeters in monitoring the gamma radiation doses under a variety of practical situations involving low level to high level of the doses.

1. Introduction

The properties of solid materials including the thin films of metal oxides and polymers undergo changes (Ibrahim and Soliman, 1998; Clough, 2001; Atanassova et al., 2001; Colby et al., 2002; Arshak and Korostynska, 2003a) whenever exposed to any kind of ionizing radiation. For metal oxide thin films, the effect depends on both the radiation dose and the parameters of the thin films including the film thickness. Attempts are being made to investigate the effect of gamma radiation on structural, optical and electrical properties of the thin films of metal oxides and polymers with the aim of determining the suitability of these thin films in the post-exposure as well as in the real-time gamma radiation dosimetry (Arshak and Korostynska, 2003a, b, 2006a; Arshak et al., 2004, 2006). Effect of gamma radiation on the structural, optical and electrical properties of the thin films of tellurium dioxide (TeO_2) has also been the subject of several investigations in the recent past (Arshak and Korostynska, 2003b, 2006a, b; Arshak et al., 2004, 2006). It is now an established fact that the degradation is much more severe for the higher radiation doses and thinner films (Arshak et al., 2004). Present work aims to study in detail the effect of gamma radiation on the current–voltage characteristics of the TeO_2 thin films of different thicknesses for a much wider range of the gamma radiation doses than made here-to-fore. The work further aims to obtain, for each film thickness and at each of the several applied voltages, the dose dependence of the current density and then to determine the sensitivity representing the change in the current density for unit change of the gamma radiation dose for the linear part of the current density versus dose plot as well as the expected detection limits correspondingly.

2. Experimental details

Employing thermal evaporation in a vacuum ($\sim 10^{-5}$ mbar), samples having coplanar structure as shown in Fig. 1 for the TeO_2 thin films of thicknesses 300, 450, 600, 900, 1200 and 1500 nm were prepared on the glass substrates, which were thoroughly cleaned in an ultrasonic cleaner before use. Two rectangular layers of aluminum, each of thickness of about 150 nm and having inner edge-to-edge separation of 3 mm, were deposited on each of the glass substrates to act as electrical contacts. A coil-shaped tungsten filament was used for the evaporation of aluminum. On the top of each pair of aluminum contacts, the TeO_2 thin film of a thickness 300 or 450 or 600 or 900 or 1200 or 1500 nm was deposited from a tungsten boat. In this manner, several samples of each film thickness were prepared. A disc-type ^{60}Co gamma radiation source of activity 20.5 μCi was used to expose these thin film structures to various levels of the gamma radiation dose at room temperature. In each gamma irradiation, the separation between source and thin film structure was kept about 0.4 mm giving dose rate of about 0.5 Gy/h as determined using a radiation dosimeter having a halogen quenched G–M detector with energy compensating filter

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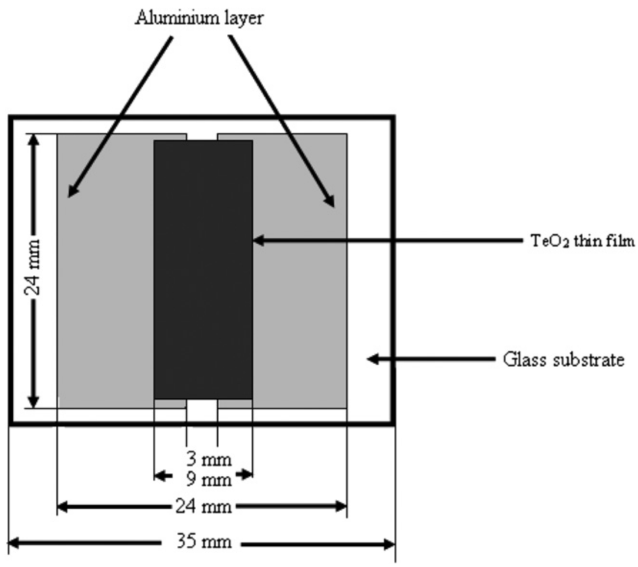

Fig. 1. Coplanar structure of a TeO_2 thin film for the current–voltage measurements.

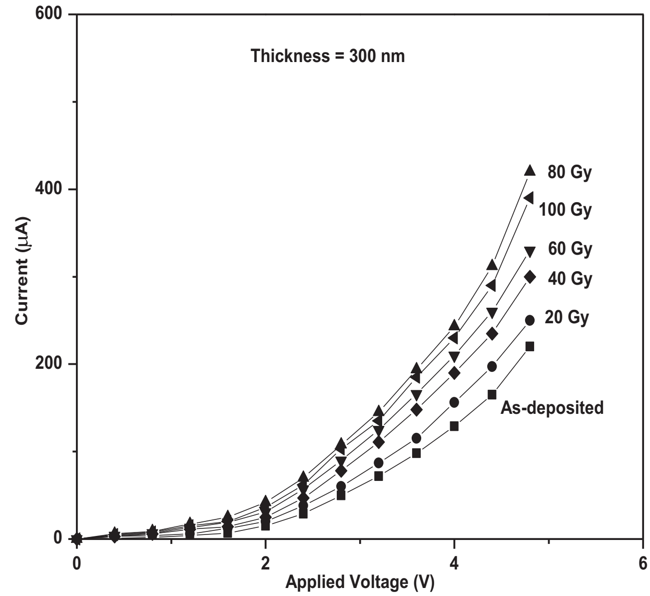

Fig. 2. Typical current–voltage characteristics for the TeO_2 thin films of thickness 300 nm, exposed to different levels of the gamma radiation dose.

(Model: RM701 of Nucleonix Systems, India). By varying the separation between source and G–M detector of the radiation dosimeter, the variation of dose rate with the distance from source was obtained. From these data, subsequently, the dose rate corresponding to the distance of 0.4 mm from the source was estimated by extrapolation and was found to be 0.5 Gy/h having an uncertainty of about 8%. Naturally, different gamma radiation doses were obtained by varying the exposure time. The current–voltage characteristics were then recorded for the thin films of different thicknesses mentioned above, exposed to different levels of the gamma radiation dose. Subsequently, these data were analyzed to obtain variations of the current density (i.e., the current per unit area of cross section of the thin film) with the gamma radiation dose at different voltages applied to the coplanar structure of the thin films of different thicknesses. For the linear part of each of the current density versus dose plots, so obtained, the sensitivity representing the change in the current density for unit change of the gamma radiation dose was estimated. Correspondingly, the detection limit was defined as the gamma radiation dose required for producing a unit change in the current through a TeO_2 thin film of a particular cross sectional area (i.e., the minimum detectable dose with a current meter of sensitivity 1 nA connected across a TeO_2 thin film of a particular cross sectional area). The actual cross sectional area of a thin film detector was obtained by multiplying the detector thickness (300 or 450 or 600 or 900 or 1200 or 1500 nm) with the detector width of 1.8 cm, which was same for all the thin film detectors in the present study. Thus, the detection limits of the gamma radiation dose for the TeO_2 thin films of different thicknesses at different applied voltages were also estimated. The stability of the background current (i.e., the stability of the current in the as-deposited thin films at different applied voltages) due to any temperature variation is expected to affect the detection limit of a thin film detector. However, no appreciable change in the current was observed in our measurements for a temperature variation of about ± 5 °C around the room temperature of 25 °C, the temperature at which all the current–voltage measurements were carried out.

3. Results and discussion

The typical current–voltage characteristics for the coplanar structure of the TeO_2 thin films of thickness 300 nm, exposed to different levels of the gamma radiation dose, are shown in Fig. 2. From the current–voltage characteristics recorded for three identical TeO_2 thin film structures of film thickness 300 nm, exposed to a certain level of the gamma radiation dose, the mean current–voltage characteristics was obtained and is shown in Fig. 2 as the typical current–voltage characteristics at that gamma radiation dose. Following this procedure, all the curves shown in Fig. 2 were obtained. The typical variations in these data were in the range from 5% to 7%. From these data, the variations of the current density with the gamma radiation dose were obtained for different voltages applied to the thin film structure and are shown in Fig. 3. Clearly, the current density increases quite linearly with the gamma radiation dose up to a dose of 80 Gy at different applied voltages studied here. Beyond the gamma radiation dose of 80 Gy, however,

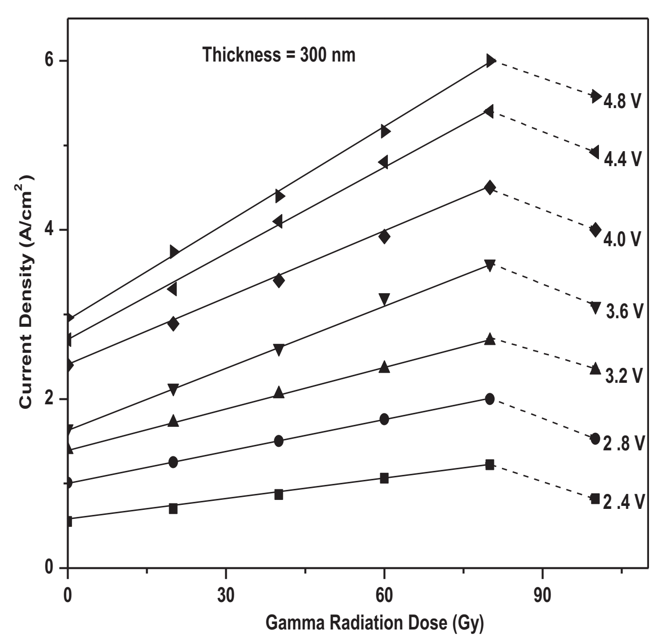

Fig. 3. Variation of the current density with gamma radiation dose for the TeO_2 thin films of thickness 300 nm at the applied voltages 2.4–4.8 V.