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# Effect of gamma radiation on electrical and optical properties of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films

**S L SHARMA*** **and T K MAITY**
Department of Physics & Meteorology, Indian Institute of Technology, Kharagpur 721 302, India

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**Abstract.** **We have studied in detail the gamma radiation induced changes in the electrical properties of the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of different thicknesses, prepared by thermal evaporation in vacuum. The current–voltage characteristics for the as-deposited and exposed thin films were analysed to obtain current versus dose plots at different applied voltages. These plots clearly show that the current increases quite linearly with the radiation dose over a wide range and that the range of doses is higher for the thicker films. Beyond certain dose (a quantity dependent on the film thickness), however, the current has been observed to decrease. In order to understand the dose dependence of the current, we analysed the optical absorption spectra for the as-deposited and exposed thin films to obtain the dose dependences of the optical bandgap and energy width of band tails of the localized states. The increase of the current with the gamma radiation dose may be attributed partly to the healing effect and partly to the lowering of the optical bandgap. Attempts are on to understand the decrease in the current at higher doses. Employing dose dependence of the current, some real-time gamma radiation dosimeters have been prepared, which have been found to possess sensitivity in the range 5–55 $\mu$Gy/$\mu$A/cm$^2$. These values are far superior to any presently available real-time gamma radiation dosimeter.**

**Keywords.** **Thin films; tellurium dioxide; indium oxide; dosimeter; sensitivity.**

## 1. Introduction

The trend of radiation awareness has greatly improved over the last two decades or so. This has become so because of the fact that ionizing radiations (such as X-rays, gamma rays, beta particles, alpha particles, fission fragments, etc) are finding more and more applications in several fields including industry, medicine, military, research, nuclear power production, etc. Unfortunately, almost everywhere radiation exposure may occur and strict monitoring of radiation levels is very essential to ensure that the surrounding environment remains harmless for the workers involved. To ease monitoring of the radiation levels, it is important to develop novel cost-effective radiation sensors with real-time response that would initiate an immediate alert signal in case of emergency. Gamma radiation dosimeters can be of a variety of types according to their physical detection principles and materials used. A simple hand-held real-time radiation dosimeter is usually not available, though it is highly needed. Generally, policemen take response to an emergency situation but they may not be aware that the situation might be involving some radioactive materials and they will not even think about bringing a Geiger–Mueller counter based radiation dosimeter due to its large size. Naturally, availability of a simple hand-held real-time radiation dosimeter will bring improvement in the situation drastically.

The exposure of every solid material to ionizing radiations produces changes in the microstructural properties of the material, which in turn affects the optical, electrical and other physical properties of the material (Ibrahim and Soliman 1998; Atanassova *et al* 2001; Clough 2001). Efforts are on world over to investigate the influence of gamma radiation on thin films and thin film structures of different metal oxides and polymers, in order to find out the suitability of using thin films and thin film structures of different metal oxides and polymers as post-exposure as well as real-time gamma radiation dosimeters (Colby *et al* 2002; Arshak *et al* 2004, 2006; Arshak and Korostynska 2006; Kumar *et al* 2006; Maity and Sharma 2008; Sharma *et al* 2008). Naturally, a deep understanding of the physical properties of these thin films and thin film structures under the influence of gamma radiation is quite important from the viewpoint of design of novel real-time gamma radiation dosimeters possessing high sensitivity (i.e. large change in the output signal for small change in the radiation dose). The effect of gamma radiation on the microstructural, optical and electrical properties of thin films of tellurium dioxide ($TeO_2$) as well as thin films of the mixture of tellurium dioxide and indium oxide ($TeO_2$–$In_2O_3$) has been the subject of several experimental investigations in the recent past (Arshak and

*Author for correspondence (shivji@phy.iitkgp.ernet.in)

Korostynska 2003a, 2006; Arshak *et al* 2006; Kumar *et al* 2006; Maity and Sharma 2008; Sharma *et al* 2008). Also, Arshak and Korostynska (2003b) have recently reported that $In_2O_3$ plays an important role in regard to increasing the free carrier concentration whenever it is doped into metal oxides such as $TiO_2$, $TeO_2$, NiO, etc. Naturally, there is a strong necessity of further studying the effect of gamma radiation on different physical properties of thin films of $TeO_2$–$In_2O_3$ mixture having varying compositions.

The effect of ionizing radiations depends on both the radiation dose and the parameters of the films including film thickness. It is already an established fact that the degradation is much more severe for the higher radiation doses and thinner films (Arshak and Korostynska 2006). Present work aims to study in detail the gamma radiation induced changes in the electrical properties of thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of different thicknesses for a much wider range of gamma radiation doses than done here-to-fore. The work has been carried out in order to understand the dose dependence of the current for the thin films of different thicknesses and then to determine the thickness dependence of the range of gamma radiation doses over which the current versus dose plot remains linear or near linear. Further, work has been carried out with the idea of determining sensitivity (in terms of the radiation dose required to produce unit change in the output current) for each of the film thicknesses studied here. In order to understand these variations, we have also studied the effect of gamma radiation on the optical properties of thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ for a much wider range of gamma radiation doses. These measurements are expected to play a very important role in the design of real-time gamma radiation dosimeters of different sensitivities which can be used to monitor ionizing radiations under a variety of practical situations.

## 2. Experimental

Employing thermal evaporation in a vacuum, thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thicknesses 300, 450 and 600 nm were prepared on suitably prepared glass substrates. During film deposition, the vacuum inside the chamber was of the order of $10^{-5}$ mbar. At room temperature, a disc-type $^{60}Co$ gamma radiation source was used to expose these thin films to various levels of gamma radiation dose. Thin films, having planar configuration as described earlier (Kumar *et al* 2006), were prepared for electrical measurements. Two rectangular layers of aluminium, each of thickness, 150 nm and separated by a linear gap of 3 mm, were deposited on each of the suitably prepared glass substrates to act as electrical contacts. A tungsten filament in the form of a coil was used for the evaporation of aluminium contacts. On the top of each pair of aluminium contacts, a thin film of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness 300 or 450 or 600 nm was deposited from a tungsten boat. In this manner, several samples of each of the three thicknesses mentioned above were prepared. The current versus applied voltage plots for the as-deposited thin films as well as for the thin films of the three thicknesses mentioned above exposed to different levels of gamma radiation dose were then recorded. Subsequently, for each of the three film thicknesses, these plots were analysed to obtain variations of the current density with gamma radiation dose at different voltages in the voltage range 2–5 V applied to the thin film structure. For each of the current density versus gamma dose plots, so obtained, the slope (representing change in the current density per unit change in the gamma radiation dose) has been estimated for the linear or near linear portion of the plot. Subsequently, the sensitivity for each of the three film thicknesses at each voltage applied to the thin film structure has been estimated. In order to understand these electrical measurements, we have also recorded optical absorption spectra for the as-deposited thin films as well as for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness 220 nm exposed to different levels of gamma radiation dose using Perkin-Elmer Lambda 45 UV-Visible Spectrometer for the wavelengths in the range 270–770 nm. Subsequently, these optical absorption spectra have been analysed to obtain dose dependence of the optical bandgap and that of the energy width of band tails of the localized states.

## 3. Results and discussion

The typical plots of the current versus applied voltage for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness 300 nm, recorded for the as-deposited thin films as well as for the thin films exposed to different levels of gamma radiation dose, are shown in figure 1. Subsequently, these plots were analysed to obtain variations of the current density with gamma

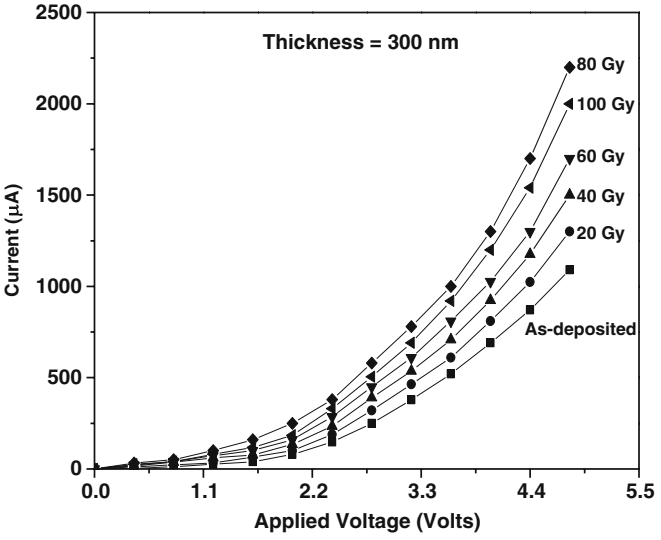


**Figure 1.** Typical current vs applied voltage plots for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 300 nm, exposed to different levels of gamma radiation dose.

radiation dose at different voltages applied to the thin film structure. These variations of the current density with the gamma radiation dose at different voltages applied to the thin film structure in the voltage range 2–5 V are shown in figure 2. Clearly, at different applied voltages, the current density has been found to increase quite linearly with the gamma radiation dose over a dose range of 0–80 Gy. Beyond the gamma radiation dose of 80 Gy, however, the current density has been observed to show a reverse trend at all applied voltages. For each of the current density versus gamma dose plots, so obtained, the slope (representing current density per unit gamma radiation dose) has been estimated for the linear portion of the plot. The slopes for the linear portions of these plots have been found to be in the range 42–210 mA/cm$^2$/Gy. The corresponding sensitivities of the film at different applied voltages have been found to be in the range 4·7–23·8 μGy/μA/cm$^2$. For the sake of comparison, the variations of the current density with the gamma radiation dose for the $TeO_2$ thin films of thickness 300 nm at different voltages applied to the thin film structure in the voltage range 2–5 V are shown in figure 3, a figure obtained for the recently published results of Maity and Sharma (2008). Clearly, for the $TeO_2$ thin films of thickness, 300 nm, also at different applied voltages, the current density has been found to increase quite linearly with the gamma radiation dose over a dose range of 0–80 Gy. Beyond the gamma radiation dose of 80 Gy, however, the current density has been observed to show a reverse trend at all applied voltages. The slopes for the linear portions of these plots have been found to be in the range 8·5–37·0 mA/cm$^2$/Gy and the corresponding sensitivities of the $TeO_2$ film of thickness, 300 nm, at different applied voltages have been found to be in the range 27·0–117·6 μGy/μA/cm$^2$. Clearly, the sensitivity of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 300 nm, is 5–6 times better than that of $TeO_2$ thin films of the same thickness, 300 nm.

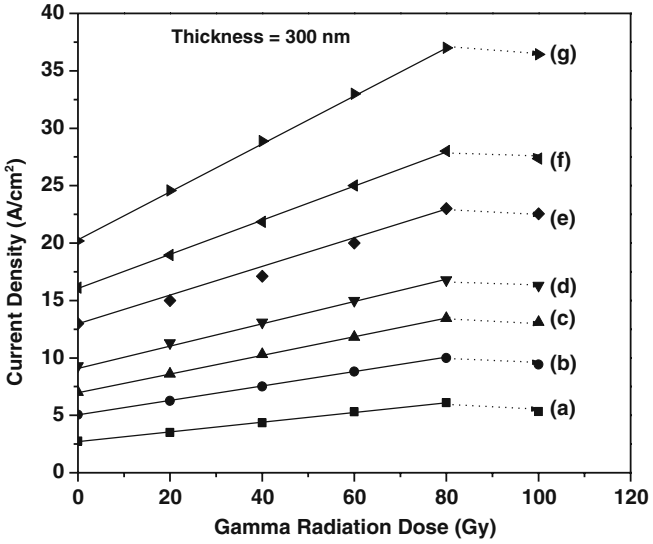


**Figure 2.** Plots of the current density vs gamma radiation dose for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 300 nm, for applied voltages (V) of (a) 2·4, (b) 2·8, (c) 3·2, (d) 3·6, (e) 4·0, (f) 4·4 and (g) 4·8.

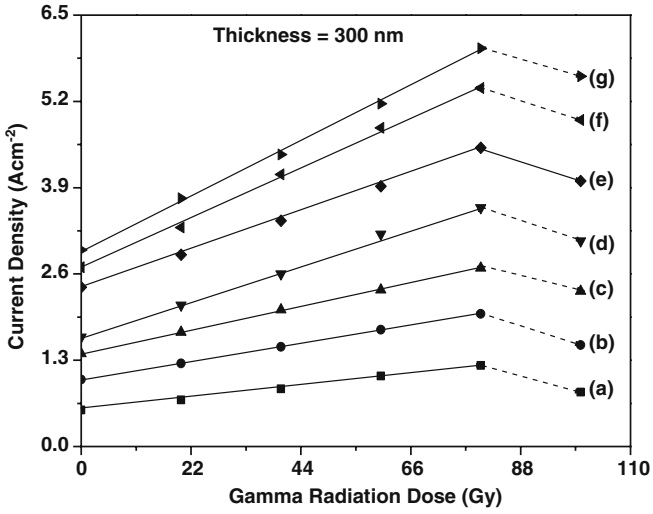


**Figure 3.** Plots of the current density vs gamma radiation dose for the $TeO_2$ thin films of thickness, 300 nm, for applied voltages (V) of (a) 2·4, (b) 2·8, (c) 3·2, (d) 3·6, (e) 4·0, (f) 4·4 and (g) 4·8.

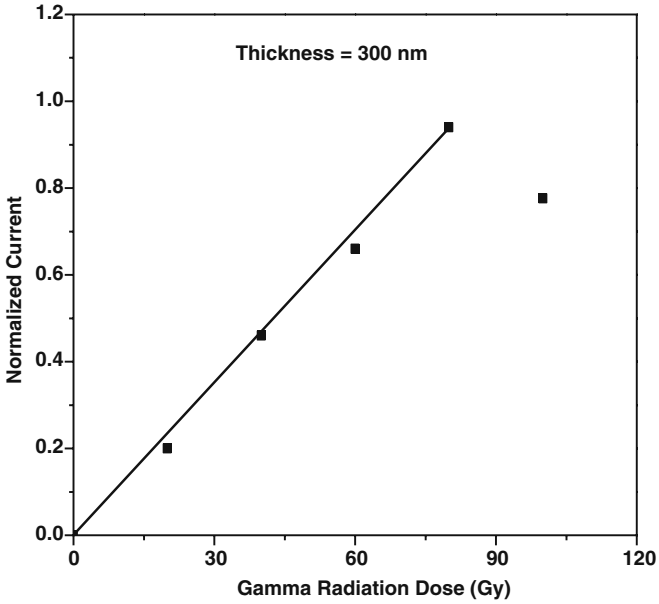


**Figure 4.** Typical variation of the normalized current with gamma radiation dose for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 300 nm, at an applied voltage of 3·5 V.

In order to understand relative change in the current due to gamma radiation exposure of different levels, a quantity called normalized current, $I_N$, is defined as

$$I_N = \frac{I - I_0}{I_0}, \tag{1}$$

where $I$ denotes the current for the thin films exposed to a certain level of radiation dose and $I_0$ the current for the as-deposited thin films. Figure 4 shows typical variation of the normalized current with the gamma radiation dose at a voltage of 3·5 V applied to the thin film structure of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 300 nm. Clearly, the normalized current increases quite linearly with the gamma radiation dose up to a dose of 80 Gy. Beyond the dose of 80 Gy, however, the normalized current has also been observed to show a reverse trend. A comparison of figure 4 with figure 6 of Maity and Sharma (2008) clearly shows that the dose dependence of the normalized current for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 300 nm, is quite similar to that for the $TeO_2$ thin films of the same thickness, 300 nm.

Figure 5 shows typical plots of the current versus applied voltage for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 450 nm, recorded for the as-deposited thin films as well as for the thin films exposed to different levels of gamma radiation dose. The corresponding variations of the current density with the gamma radiation dose at different voltages applied to the thin film structure in the voltage range 2–5 V are shown in figure 6. Clearly, at different applied voltages, the current density has been found to increase quite linearly with the gamma radiation dose over a dose range of 0–120 Gy. Beyond the gamma radiation dose of 120 Gy, however, the current density has been observed to show a reverse trend at all applied voltages. The slopes for the linear portions of these plots have been found to be in the range 39–208 mA/cm$^2$/Gy. The corresponding sensitivities of the film at different applied voltages have been found to be in the range 4·8–25·6 μGy/μA/cm$^2$. For the sake of comparison, the variations of the current density with gamma radiation dose for the $TeO_2$ thin films of thickness, 450 nm, at different voltages applied to the thin film structure in the voltage range, 2–5 V, are shown in figure 7, a figure obtained for the recently published results of Maity and Sharma (2008). Clearly, for the $TeO_2$ thin films of thickness, 450 nm, also at different applied voltages, the current density has been found to increase quite linearly

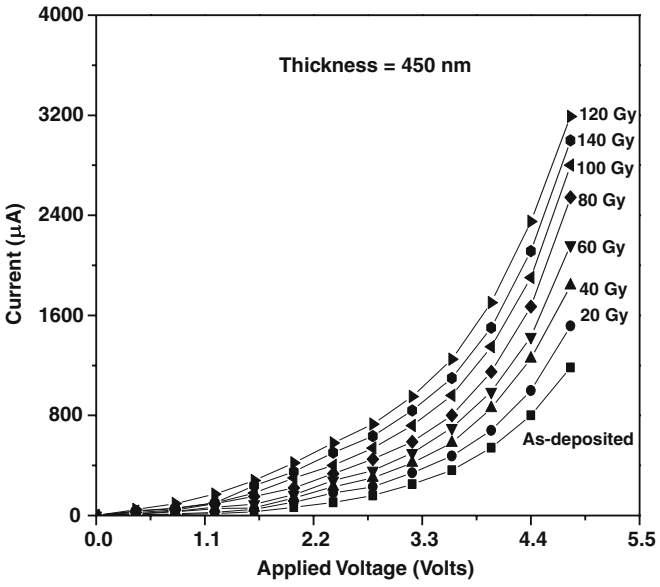


**Figure 5.** Typical current vs applied voltage plots for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 450 nm, exposed to different levels of gamma radiation dose.

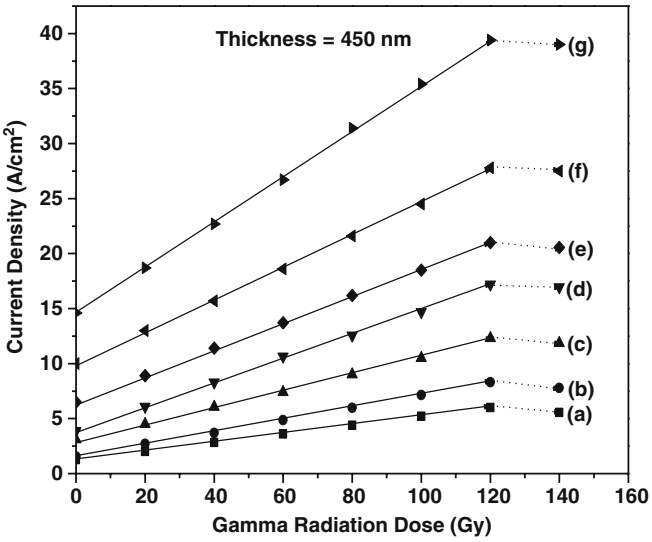


**Figure 6.** Plots of the current density vs gamma radiation dose for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 450 nm, for applied voltages (V) of (a) 2·4, (b) 2·8, (c) 3·2, (d) 3·6, (e) 4·0, (f) 4·4 and (g) 4·8.

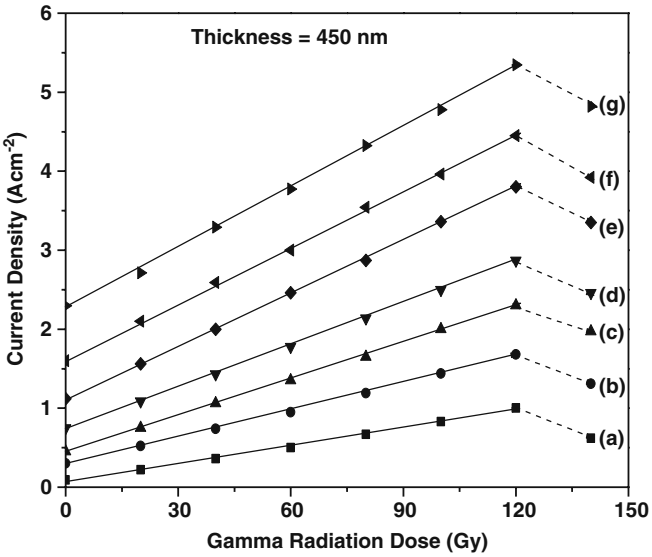


**Figure 7.** Plots of the current density vs gamma radiation dose for the $TeO_2$ thin films of thickness, 450 nm, for applied voltages (V) of (a) 2·4, (b) 2·8, (c) 3·2, (d) 3·6, (e) 4·0, (f) 4·4 and (g) 4·8.

with the gamma radiation dose over a dose range of 0–120 Gy. Beyond the gamma radiation dose of 120 Gy, however, the current density has been observed to show a reverse trend at all applied voltages. The slopes for the linear portions of these plots have been found to be in the range 8·0–25·5 mA/cm$^2$/Gy and the corresponding sensitivities of the $TeO_2$ film of thickness, 450 nm, at different applied voltages have been found to be in the range 39·2–125·0 μGy/μA/cm$^2$. Clearly, the sensitivity of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 450 nm, is 5–8 times better than that of $TeO_2$ thin films of the same thickness, 450 nm.

Figure 8 shows typical variation of the normalized current with gamma radiation dose at a voltage of 3·5 V applied to the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 450 nm. Clearly, the normalized current increases quite linearly with gamma radiation dose up to a gamma radiation dose of 120 Gy. Beyond 120 Gy, however, the normalized current has also been observed to show a reverse trend. A comparison of figure 8 with figure 8 of Maity and Sharma (2008) clearly shows that the dose dependence of the normalized current for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 450 nm, is quite similar to that for the $TeO_2$ thin films of the same thickness, 450 nm.

The typical plots of the electrical current vs applied voltage for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 600 nm, recorded for the as-deposited thin films as well as for the thin films exposed to various levels of gamma radiation dose, are shown in figure 9. The corresponding variations of the current density with the gamma radiation dose at different voltages applied to the thin film structure in the voltage range 2–5 V are shown in figure 10. Clearly, at different applied voltages, the current density has been found to increase quite linearly with the gamma radiation dose over a dose range of 0–160 Gy. Beyond the gamma radiation dose of 160 Gy, however, the current density has been observed to show a reverse trend at all applied voltages. The slopes for the linear portions of these plots have been found to be

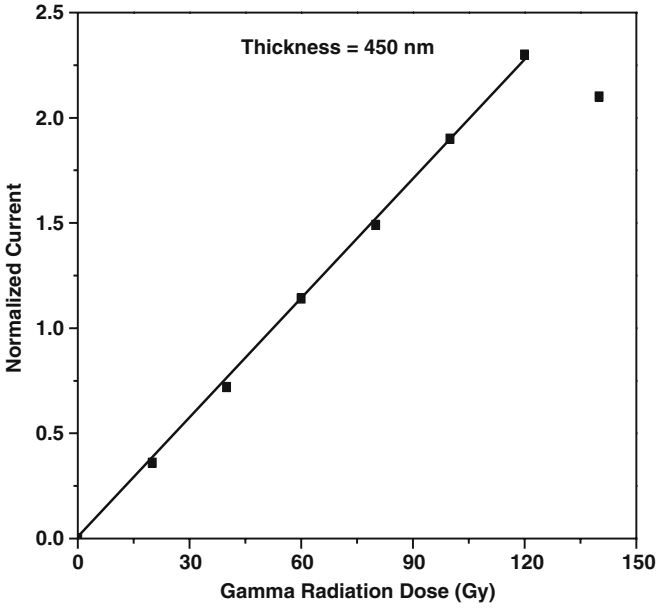


**Figure 8.** Typical variation of the normalized current with gamma radiation dose for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 450 nm, at an applied voltage of 3·5 V.

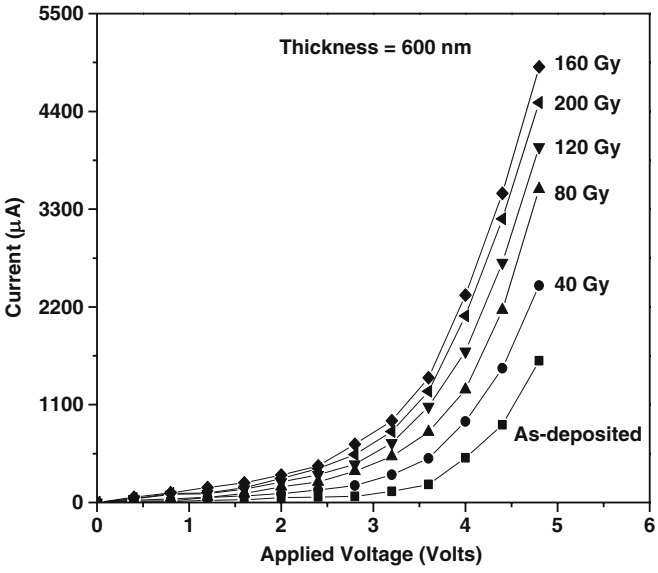


**Figure 9.** Typical current vs applied voltage plots for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 600 nm, exposed to different levels of gamma radiation dose.

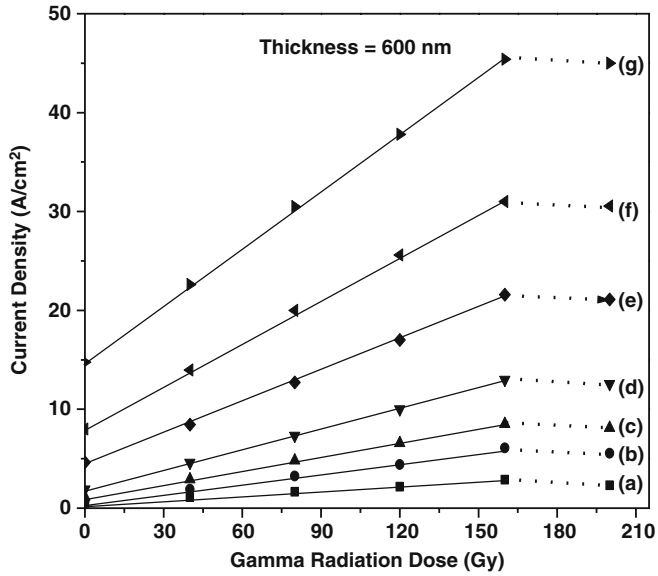


**Figure 10.** Plots of the current density vs gamma radiation dose for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 600 nm, for applied voltages (V) of (a) 2·4, (b) 2·8, (c) 3·2, (d) 3·6, (e) 4·0, (f) 4·4 and (g) 4·8.

in the range 18–191 mA/cm$^2$/Gy. The corresponding sensitivities of the film at different applied voltages have been found to be in the range 5·2–55·5 μGy/μA/cm$^2$. For the sake of comparison, variations of the current density with gamma radiation dose for the $TeO_2$ thin films of thickness, 600 nm, at different voltages applied to the thin film structure in the voltage range 2–5 V are shown in figure 11, a figure obtained for the recently published results of Maity and Sharma (2008). Clearly, for the $TeO_2$ thin films of thickness, 600 nm, also at different applied voltages, the current density has been found to increase quite linearly with the gamma radiation dose over a dose range of 0–160 Gy. Beyond the gamma radiation dose of 160 Gy, however, the current density has been observed to show a reverse trend at all applied voltages. The slopes for the linear portions of these plots have been found to be in the range 4·2–24·5 mA/cm$^2$/Gy and the corresponding sensitivities of the $TeO_2$ film of thickness, 600 nm, at different applied voltages have been found to be in the range 40·8–238·0 μGy/μA/cm$^2$. Clearly, the sensitivity of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 600 nm, is 5–8 times better than that of $TeO_2$ thin films for the same thickness, 600 nm.

Figure 12 shows typical variation of the normalized current with the gamma radiation dose at a voltage of 3·5 V applied to the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 600 nm. Clearly, the normalized current increases quite linearly with the gamma radiation dose up to a gamma radiation dose of 160 Gy. Beyond the dose of 160 Gy, however, the normalized current has also been observed to show a reverse trend. A comparison of figure 12 with figure 10 of Maity and Sharma (2008) clearly shows that the dose dependence of the normalized current for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 600 nm, is quite similar to that for the $TeO_2$ thin films of the same thickness, 600 nm.

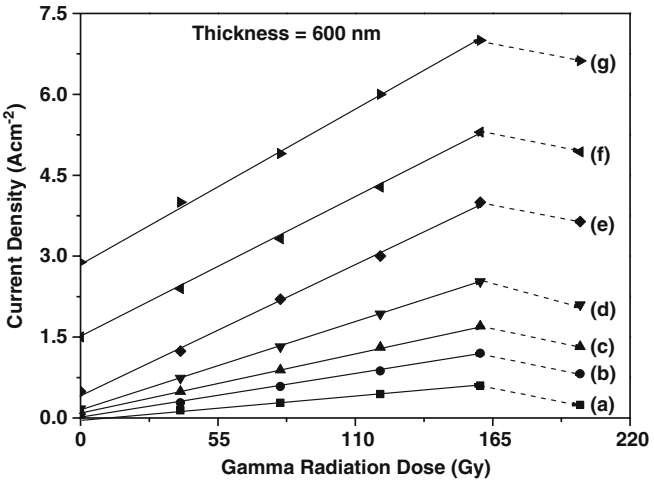


**Figure 11.** Plots of the current density vs gamma radiation dose for the $TeO_2$ thin films of thickness, 600 nm, for applied voltage (V) of (a) 2·4, (b) 2·8, (c) 3·2, (d) 3·6, (e) 4·0, (f) 4·4 and (g) 4·8.

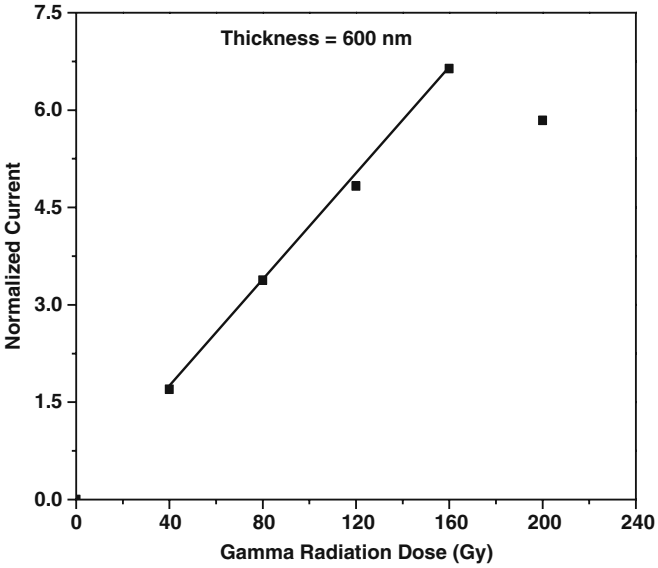


**Figure 12.** Typical variation of the normalized current with gamma radiation dose for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 600 nm, at an applied voltage of 3·5 V.

In order to understand the above results on the electrical properties, we have analysed the optical absorption spectra recorded for the as-deposited thin films as well as for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 220 nm, exposed to different levels of gamma radiation dose and have obtained the dose dependence of the optical bandgap as well as that of the energy width of the band tails of localized states. The said analysis has been carried out in the framework of Maity and Sharma (2008), a framework based on the Urbach's empirical formula for the absorption coefficient near the band edge (Urbach 1953), Mott's concept in regard to the creation of localized energy states in the normally forbidden energy gap (Mott 1969) and Mott–Davis model for the optical bandgap of thin films (Mott and Davis 1979). From the absorption coefficient versus photon energy plots for the as-deposited thin films as well as for the films exposed to different levels of gamma radiation dose, the values of $\Delta E$ (the energy width of the band tails of localized states) were calculated from the slopes of the straight-line portions (Urbach 1953). With $\Delta E_0$ as the energy width of the band tails of localized states for the as-deposited thin films, the variation of the normalized energy width $\Delta E_N$ $(= (\Delta E - \Delta E_0)/\Delta E_0)$ of the band tails of localized states with the dose is shown in figure 13. The energy width of the band tails of localized states has been found to increase with the gamma radiation dose up to a dose of about 75 Gy. This increase in the energy width of the band tails of localized states can be attributed to the induced defects due to the exposure to gamma radiation. As the as-deposited thin films are generally amorphous in nature, the atomic arrangement in terms of nearest neighbours departs only slightly from the ideal crystalline state. Furthermore, since the amorphous thin films contain relatively rigid

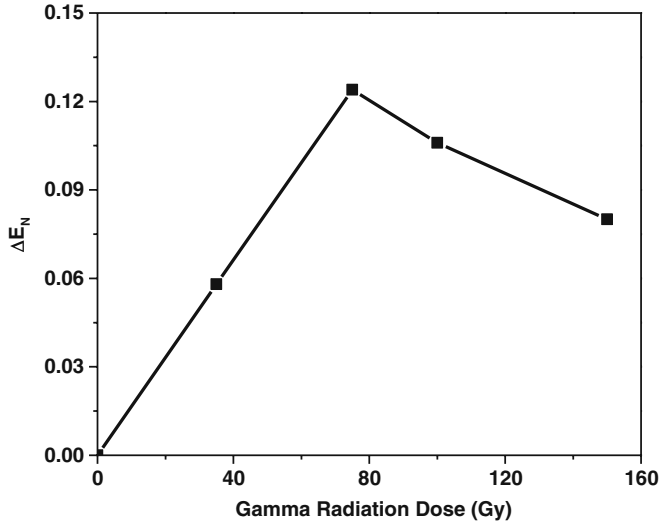


**Figure 13.** Variation of the normalized energy width of band tails of the localized states with the gamma radiation dose for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 220 nm.

chemical bonds, the deviation from the crystalline state is small resulting in the requirement of excessive energy to distort this rigidity. This excessive energy leads to the formation of short-range order (Mott 1969) or creation of localized energy states in the normally forbidden energy gap. Whenever gamma radiation interacts with the thin film, induced defects will be formed and the density of the localized states increases resulting in increase in the energy width of the band tails of localized states. Arshak and Korostynska (2002) have also reported that the energy width of the band tails of localized states for the $TeO_2$ thin films of thickness, 50 nm, increased with the increase of radiation dose up to a certain value. They, however, did not report for higher doses of gamma radiation. The energy width of the band tails of localized states for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 220 nm, in the present study has, however, been found to decrease with further increase in the gamma radiation dose beyond 75 Gy.

The values of the optical bandgap, $E_{\text{opt}}$, for the as-deposited thin films as well as for the thin films exposed to different levels of gamma radiation dose have been estimated from the $(\alpha_\nu h\nu)^2$ versus photon energy, $h\nu$ plots using the Mott and Davis (1979) model for the direct allowed transition using the equation:

$$\alpha_\nu h\nu = B\left(h\nu - E_{\text{opt}}\right)^{1/2}, \tag{2}$$

where $h\nu$ denotes the energy of the incident photon and $B$ a constant. The optical bandgap for the as-deposited thin films has been found to be about 2·7 eV and the variation of the optical bandgap with the radiation dose is shown in figure 14. Clearly, the optical bandgap decreases from 2·7 to 2·5 eV for the gamma radiation dose of 75 Gy. This decrease in the optical bandgap is basically due to the increase in the energy width of the band tails of localized states. During gamma irradiation, the defects are created within the thin film. At the same time, the defects also get annihilated even under the normal room temperature conditions (Deng *et al* 1999). This creation and annihilation of defects coexist together and at higher doses of gamma radiation, the number of defects created due to irradiation becomes much more than the number of defects annihilated. Arshak and Korostynska (2002) have also reported a similar decrease in the optical bandgap with the increase of gamma radiation dose up to a certain dose for the $TeO_2$ thin films. They, however, did not report for the doses higher than certain dose. The optical bandgap for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 220 nm, in the present work has, however, been found to increase with further increase in the gamma radiation dose beyond 75 Gy. In a recent publication, Arshak *et al* (2006) have also reported a similar observation for thin films of mixture of $MnO/TeO_2$.

The nature of optical properties of thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$, described above, is quite similar to the dose-response of most materials used in thermoluminescence dosimetry (Horowitz 2001). These materials usually show a linear, then super-linear, followed by saturating response and further increase in radiation dose results in the high structural disorder. The high structural disorder at very high radiation doses reduces the sensitivity of material parameters to further exposure of radiation. The increase in optical bandgap for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 220 nm, for the gamma radiation doses beyond 75 Gy may be attributed

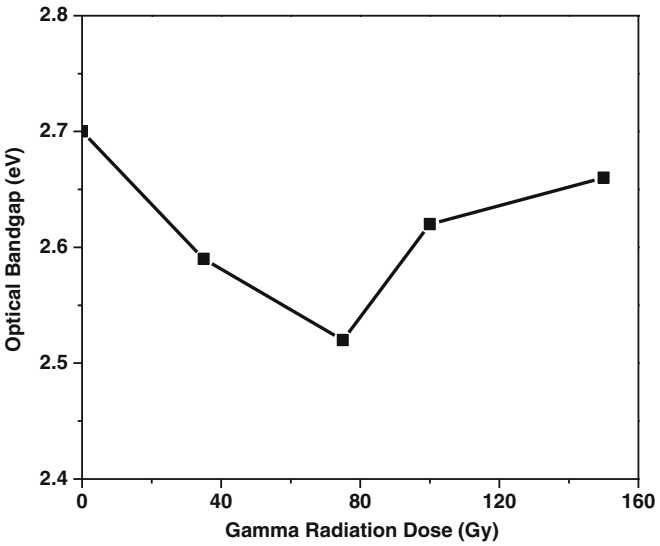


**Figure 14.** Variation of the optical bandgap with gamma radiation dose for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thickness, 220 nm.

**Table 1.** Sensitivity (in μGy/μA/cm$^2$) for the $TeO_2$ and $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films.

| Applied voltage | Sensitivity for $TeO_2$ thin films of thickness | | | Sensitivity for $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness | | |
|---|---|---|---|---|---|---|
| | 300 nm | 450 nm | 600 nm | 300 nm | 450 nm | 600 nm |
| 2·4 V | 117·6 | 125·0 | 238·0 | 23·8 | 25·6 | 55·5 |
| 2·8 V | 83·3 | 82·6 | 135·1 | 16·1 | 17·8 | 27·0 |
| 3·2 V | 62·5 | 66·6 | 102·0 | 12·5 | 13·3 | 20·4 |
| 3·6 V | 40·0 | 55·5 | 73·5 | 8·0 | 9·1 | 13·5 |
| 4·0 V | 33·3 | 45·4 | 47·1 | 7·6 | 8·2 | 9·1 |
| 4·4 V | 29·4 | 41·6 | 44·6 | 6·7 | 6·8 | 6·9 |
| 4·8 V | 27·0 | 39·2 | 40·8 | 4·7 | 4·8 | 5·2 |

to a similar high structural disorder at very high radiation doses.

Present studies have clearly shown that the gamma radiation dose up to which the current keeps increasing near linearly depends upon the thickness of thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ and that it is 80 Gy for thin films of thickness, 300 nm, 120 Gy for thin films of thickness, 450 nm and 160 Gy for thin films of thickness, 600 nm. For the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ of thicknesses 300, 450 and 600 nm, however, the current has been observed to decrease beyond the gamma radiation doses of 80, 120 and 160 Gy, respectively. Recently, Arshak *et al* (2004) have also reported for thin films of some metal oxides that the sensitivity of thin films for low radiation doses is much higher than that of the thick films and that the thick films sustain up to much higher radiation doses than the thin films.

The current for the thin films of $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ has been observed to increase near linearly with dose up to a certain gamma radiation dose (critical dose) and the value of this dose is higher for the thicker films. This increase in the current may be attributed to the healing effect (Zaykin and Aliyev 2002). During the process of film deposition, some intrinsic defects are always formed. The interaction of gamma radiation induces defects during its passage through the thin film resulting into disorder in the microstructure of the film. At small doses, these thin films have fine homogeneous grain structure without any big pores and the number of defects (induced plus residual intrinsic) is smaller than the number of intrinsic defects due to the recombination of defects. The recombination of defects reduces the resistivity of thin film, giving rise to an increase in the current. The critical dose dependence on the film thickness can also be understood in terms of the healing effect (Zaykin and Aliyev 2002). Accordingly, thicker films require much higher radiation doses for healing in comparison to thinner films.

The near linear increase of current with the gamma radiation dose can also be understood in terms of a simple charge transfer model (Arshak and Korostynska 2006), according to which the Fermi level shifts upward in the exposed thin films as compared to that in the as-deposited thin films which then results in lowering of the optical bandgap. In turn, the filling of the hole-states causes the current to increase with the increase in the gamma radiation dose up to a certain dose. The current is, however, observed to decrease with increase in the radiation dose above a certain dose level which may be partly attributed to the increase in the optical bandgap (see figure 14).

The near linear variation of the current with the gamma radiation dose up to a certain critical dose (a quantity that depends upon the film thickness) can be considered as a working region for real-time gamma radiation dosimetry. For understanding the importance of the present work, table 1 lists the values of the sensitivity for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thicknesses, 300, 450 and 600 nm, along with the values of the sensitivity for the $TeO_2$ thin films of thicknesses, 300, 450 and 600 nm. Accordingly, (i) a real-time gamma radiation dosimeter prepared from the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 300 nm, at a typical voltage of 3·6 V will have a sensitivity of 8·0 μGy/μA/cm$^2$ which is nearly five times better than that prepared from the $TeO_2$ thin films of thickness, 300 nm, (ii) a real-time gamma radiation dosimeter prepared from the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 450 nm, at a typical voltage of 3·6 V will have a sensitivity of 9·1 μGy/μA/cm$^2$ which is nearly six times better than that prepared from the $TeO_2$ thin films of thickness, 450 nm and (iii) a real-time gamma radiation dosimeter prepared from the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of thickness, 600 nm, at a typical voltage of 3·6 V will have a sensitivity of 13·5 μGy/μA/cm$^2$ which is nearly six times better than that prepared from the $TeO_2$ thin films of thickness, 600 nm.

## 4. Conclusions

The current–voltage characteristics for the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films clearly show that the current increases quite linearly with gamma radiation dose up to a certain critical dose (a quantity dependent upon the film thickness) and that the current decreases for the doses above this value. The

increase in the current may be attributed partly to the healing effect (Zaykin and Aliyev 2002) and partly to the lowering of the optical bandgap. Attempts are on to understand the decrease in the current at higher doses. Employing the dose dependence of the current, some real-time gamma radiation dosimeters based on the $(TeO_2)_{0.9}$ $(In_2O_3)_{0.1}$ thin films of different thicknesses have been prepared, which have been found to possess sensitivity in the range 5–55 $\mu Gy/\mu A/cm^2$. Clearly, these values are far superior to any presently available real-time gamma radiation dosimeter. Further work is in progress for developing real-time gamma radiation dosimeters possessing still better sensitivities.

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