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Effects of gamma irradiations on structural and electrical properties of indium oxide thin films prepared by thermal evaporation

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ABSTRACT

Effects of gamma irradiations on structural and electrical properties of the post-annealed indium oxide thin films of thickness 750 nm, prepared by thermal evaporation in vacuum, were studied. The thin films, exposed to various levels of the gamma radiation dose, were characterized by XRD, SEM and *I–V* measurements. Results show that the average grain size and the degree of crystallinity increase with the gamma radiation dose up to a certain dose and decrease thereafter. Results also show that the conductivity increases with the gamma radiation dose up to the same value of the dose and decreases thereafter. The dislocation density, however, shows the opposite trend of the dose dependence.

1. Introduction

Amongst the transparent conducting materials, indium oxide (In_2O_3) occupies a special place due to its wide range of applications in photovoltaic cells, thin film transistors, gas sensors, flat panel displays, light emitting diodes and electroluminescent devices [1,2]. Due to large band gap [3–5], the indium oxide thin films also appear to be quite promising material for the development of gamma radiation sensors and dosimeters. On passing through any metal oxide thin film, gamma radiation produces structural defects such as colour centres, oxygen vacancies, grain size and grain boundary modifications [6–12]. Correspondingly, the defect density undergoes a change that depends upon the level of the gamma irradiation. The generated defect states, in a natural way, produce changes in the structural, optical and electrical properties of the metal oxide thin films. In the past, several researchers [13–17] studied the properties of the indium oxide thin films prepared by different methods in order to develop electronic devices of various kinds. Also, some studies have recently been reported on the effects of gamma radiation on electrical and structural properties of the thin films of some metal oxides mixed with indium oxide [12,18,19]. However, there exists no study on the effects of gamma radiation on the structural and electrical properties of the thin films of pure indium oxide on glass substrates and requires attention [20–23]. The aim of the present work is to investigate the effects of gamma irradiation of various levels on the structure, surface morphology and electrical properties of the post-annealed indium oxide thin films of thickness 750 nm, prepared by thermal evaporation in vacuum, by XRD, SEM and *I–V* studies in order to determine the suitability of these thin films in the gamma radiation dosimetry.

2. Materials and methodology

The indium oxide thin films of thickness 750 ± 5 nm were prepared on thoroughly cleaned glass substrates, employing thermal evaporation in the vacuum $\sim10^{-5}$ mbar, from a tungsten boat containing required amount of indium oxide powder (Alfa Aesar: purity – 99.997%). The rate of growth and thickness of the films were monitored by a digital thickness monitor attached to the coating unit. The rate of growth of the films was about 24 nm/min. After deposition, these films were annealed at a temperature of about 400 °C for about one hour in open atmosphere inside a furnace before any other processing or measurement. A ^{60}Co gamma radiation source was used to expose these thin films to various levels of the gamma radiation dose at room temperature subsequently. The X-ray diffraction (XRD) patterns for the thin films, exposed to various levels of the gamma radiation dose, were then recorded using PAN analytical X-ray diffractometer (XRD Model: PW1729) with Cu-Kα radiation of wavelength 1.54 Å. From these XRD patterns, the dose dependences of the structural parameters of the thin films such as the FWHM, grain size, degree

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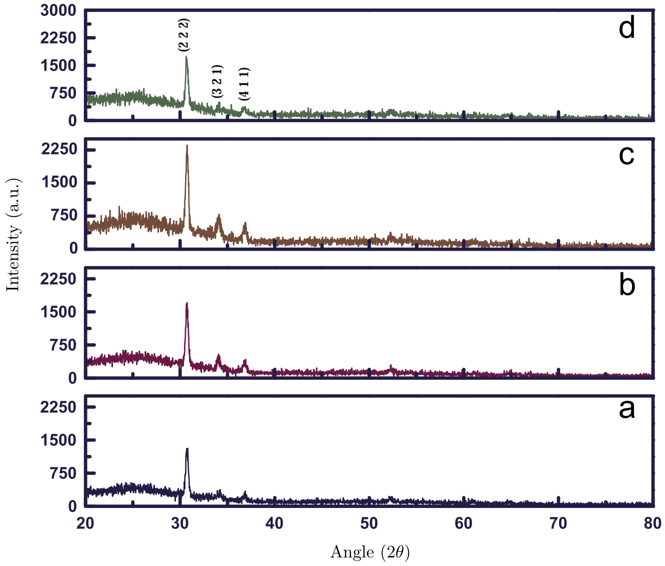

Fig. 1. The typical XRD pattern for the annealed indium oxide thin film of thickness 750 nm, exposed to the gamma radiation dose of (a) 0 Gy, (b) 90 Gy, (c) 180 Gy and (d) 360 Gy.

of crystallinity, micro-strain and dislocation density were calculated [5]. In order to further understand the gamma radiation induced changes in the surface morphology and microstructure, for the thin films exposed to various levels of the gamma radiation dose, the scanning electron microscope (SEM) images were also recorded using the JEOL-JSM-5800 scanning electron microscope. The effect of gamma irradiations of different levels on the electrical conductivity of the thin films [5] was studied by recording the current versus voltage (*I–V*) characteristics using Keithley electrometer (Model: 6517B Electrometer/High resistance meter).

3. Results and discussion

Fig. 1 shows the typical XRD patterns for the indium oxide thin films of thickness 750 nm, exposed to various levels of the gamma radiation dose. All these XRD patterns possess a diffraction peak due to the reflection from the (222) plane corresponding to the 2θ-value of about 30.6°, revealing the fact that the preferred orientation along (222) was common at all the gamma radiation doses. The intensity of this diffraction peak increases with the increase of the gamma radiation dose up to a dose of 180 Gy and decreases thereafter. Also, the FWHM of this diffraction peak decreases with the gamma radiation dose up to the same critical dose of 180 Gy and increases thereafter. The variation in the peak intensity is directly related to the degree of crystallinity whereas that in the FWHM to the grain size. Increase of crystallization in the thin films of the mixture of In_2O_3 and SiO with the gamma radiation dose up to a certain dose was reported by Arshak et al. [22] as well as by Arshak and Korostynska [23]. They, however, did not report for higher doses. Table 1 presents the summary of the structural parameters of the indium oxide thin films, calculated from the XRD data. Clearly, the average grain size and degree of crystallinity increase with the gamma radiation dose up to a dose of 180 Gy and both of them decrease thereafter. The dislocation density, however, decreases with the gamma radiation dose up to the same value of the dose and increases thereafter. Fig. 2 shows the typical SEM micrographs for the indium oxide thin films of thickness 750 nm, exposed to various levels of the gamma radiation dose. These SEM images clearly show that the average crystallite size increases with the gamma radiation dose up to a certain dose and decreases thereafter. Further, the values of the average grain size estimated from these SEM images are 24.32 ± 0.31 nm at 0 Gy, 30.62 ± 0.45 nm at 90 Gy, 32.57 ± 0.58 nm at 180 Gy and 27.97 ± 0.43 nm at 360 Gy, which match reasonably well with the values obtained from the XRD patterns. Clearly, the gamma radiation induced coalescence of small crystallites by grain boundary collapse in the region of low gamma radiation doses appear to lead to the formation of the large-sized crystallites that enhances the average crystallite size and the degree of crystallinity. At higher gamma radiation doses, however, it appears that the crystallites breakup into smaller crystallites as well as produce back the amorphous material leading to the net decrease in the average crystallite size as well as decrease in the degree of crystallinity.

Fig. 3 depicts the typical *I–V* characteristics for the indium oxide thin films of thickness 750 nm, exposed to various levels of the cumulative gamma radiation dose, measured by two-point probe method. The current versus voltage plots clearly confirm the semiconducting behaviour of the thin films at all the gamma radiation doses. It is also observed that the current increases linearly with the gamma radiation dose up to a dose of 180 Gy and decreases thereafter. The variation of the current with the gamma radiation dose can be understood in terms of the variation of the grain size as the two show quite similar dose dependences. With increase of the gamma radiation dose in the low dose region, the average grain size increases leading to the decrease in the grain boundary area, as can be seen from the XRD patterns and SEM micrographs. These structural changes cause a decrease in the scattering of the charge carriers and hence an increase in the conductivity of the films due to high leakage current through the high leakage paths. At higher gamma radiation doses, however, the average grain size decreases leading to the increase in the grain boundary area causing an increase in the scattering of the charge carriers and hence a decrease in the conductivity of the films. The strong linear dose dependence of the current up to a certain gamma radiation dose, however, provides a reasonably high scope for the development of the gamma radiation dosimetry applications such as involving in the teaching and research laboratories.

4. Conclusions

The radiation response of the post-annealed indium oxide thin films of thickness 750 nm, prepared by thermal evaporation in vacuum, has been investigated using ^{60}Co gamma source. The electrical conductivity, grain size and degree of crystallinity increase with the gamma radiation dose up to a certain dose and

Table 1
The structural parameters of the annealed indium oxide thin film, exposed to various levels of the gamma radiation dose.

Gamma dose (Gy)	Grain size (m)	Degree of crystallinity (%)	Microstrain $\times 10^{-3}$	Dislocation density $\times 10^{15}$ (lines/m^2)
0	25.32	11.0	4.6	1.45
90	30.96	11.5	4.4	1.14
180	32.73	12.0	4.2	0.98
360	28.22	10.5	4.4	1.25