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Thickness dependence of optical parameters for ZnTe thin films deposited by electron beam gun evaporation technique

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Abstract

Zinc telluride thin films with different thicknesses have been deposited by electron beam gun evaporation system onto glass substrates at room temperature. X-ray and electron diffraction techniques have been employed to determine the crystal structure and the particle size of the deposited films. The stoichiometry of the deposited films was confirmed by means of energy-dispersive X-ray spectrometry. The optical transmission and reflection spectrum of the deposited films have been recorded in the wavelength optical range 450–2500 nm. The variation of the optical parameters, i.e. refractive index, n, extinction coefficient, k, with thickness of the deposited films has been investigated. The refractive index dispersion in the transmission and low absorption region is adequately described by the single-oscillator model, whereby the values of the oscillator strength, oscillator position, dispersion parameter as well as the high-frequency dielectric constant were calculated for different film thickness. Graphical representations of the surface and volume energy loss function were also presented.

Keywords: ZnTe; Structure properties; Optical properties

1. Introduction

II–VI compounds are widely used in solid-state devices such as infrared detector (IR), photo-voltaic cells, nuclear radiation detectors and windows for IR laser, etc. These are the important semiconductors for opto-electronic devices. This group is much more important for photo-conductive and photo-electric devices [1]. Zinc telluride (ZnTe) compound is one of the elements of the group II–VI having wide range of applications. It has been used for photovoltaics and photoelectrochemical solar cell applications because of its optimum energy gap of 2.26 eV at room temperature [2] and low affinity of 3.53 eV [3]. In addition ZnTe has been recently used in opto-electronic detection of terahertz (THz) radiation [4,5].

In the recent years, researchers become interested to prepare ZnTe in thin film form employing different techniques, such as thermal evaporation [6–8], hot wall evaporation [9], rf sputtering [10], molecular beam epitaxy [11], and electrodeposition [12]. The published data has driven a good idea about the structural and electrical properties of the deposited films [6,8,13,14]. However, in spite of the optical properties of ZnTe thin films the data reported about its optical properties still lack details. The optical properties of ZnTe films deposited at substrates temperature of 573 K by thermal evaporation of Zn and Te sources onto Corning glass substrates were investigated [15]. Furthermore, the optical properties of pure ZnTe films and those doped with Cu [16] or Ag [17] in the spectral region 500–2000 nm has also been reported. However, according to literatures, there has been less attention paid to study the thickness effect on the optical properties of ZnTe films. The thickness is an important parameter in determining the efficiency of optical devices, e.g. interference filter, buffer layers for IR detectors, as back contact for thin films solar cell and opto-electronic devices all of which depend on the variation in optical properties with film thickness.

The objective of the present work is to obtain the relationship between the optical properties and thickness of

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ZnTe films. Information about the effect of film thickness on the optical parameters such as dielectric constants, refractive index and absorption are essential in the characterization of materials that are used in fabrication of opto-electronic devices and also for optimization of the efficiency of the thin film solar cells.

2. Experimental techniques

Thin films of different thicknesses were deposited onto Corning 7059 glass substrates using ZnTe powder purchased from Aldrich. An electron beam gun evaporation system (Type Leybold-Heraeus Combitron CM-30, Germany) was used for deposition of ZnTe films at vacuum pressure of $\sim 8\times10^{-7}$ mbar. The deposition rate was almost maintained constant during the evaporation process at nearly $\sim 8\,\mathrm{nm\,s^{-1}}$. The thickness, t, of the deposited film was monitored during evaporation process using quartz crystal thickness monitor (Type Edwards FTM5). The deposition was carried out at room temperature.

The structure of the deposited films was determined using X-ray diffractometry (Type Philips X'Pert) with Ni-filtered, CuK_α radiation operated at 30 mA and 40 kV. Transmission electron microscope (Type JEOL TEM-1230) was used to examine the microstructure of the deposited films. For this purpose, ZnTe films deposited on carbon films supported by copper grids to produce plan-view samples thin enough for electron transmission in the transmission electron microscope (TEM). The elemental chemical composition was determined by means of energy-dispersive X-ray spectrometer (EDS), interfaced to a scanning electron microscope.

A double-beam spectrophotometer (Type JASCO Corporation, model V-570), with automatic computer data acquisition and photometric accuracy of $\pm0.002\%$ absorbance and $\pm0.3\%$ transmittance, was employed at normal light incidence to record the optical transmission and reflection spectra of the deposited films over the wavelength range 450–2500 nm. The measurements were made on various parts of the deposited films, scanning the entire sample and a very good reproducibility of spectra was generally achieved. All the optical measurements reported in the present work were performed at room temperature.

3. Results and discussions

3.1. Structural characterization

The crystal structure of the deposited films was determined by X-ray diffraction (XRD) technique. A typical XRD pattern of as-deposited ZnTe films is shown in Fig. 1. The spectra showed the various diffraction peaks at 2θ values 25.32°, 42.07°, 49.67° and 67.46°, respectively. The peaks were identified to originate from (1 1 1), (2 2 0), (3 1 1) and (3 3 1) plane, respectively, which corresponds to ZnTe cubic phase. This result was confirmed by comparing the peak positions (2θ) of the XRD patterns with the standard X-ray powder diffraction data file [18]. Fig. 1 also indicates that the intensity and broadening of the peak (1 1 1) gradually increases with the increase of film thickness, which may be due to the improvement of particle size at higher film thickness. The lattice parameter "a" for $(h\,k\,\ell)$ has been calculated by the following expression [19]:

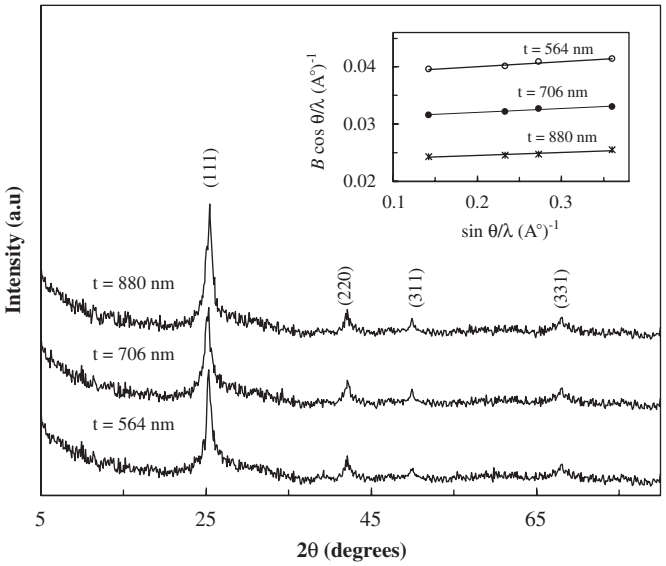

Fig. 1. X-ray diffraction patterns of different thickness ZnTe films. Inset shows the plot of $\beta\cos\theta/\lambda$ versus $\sin\theta/\lambda$.

$$d=\frac{a}{\sqrt{(h^2+k^2+\ell^2}} \tag{1}$$

where d is the interplanar spacing of the atomic plane whose Miller indices are $(h\,k\,\ell)$.

Information on the particle size and strain for the thermally evaporated ZnTe films was obtained from the full-width at half-maximum of the diffraction peaks. The full-width at half-maximum β can be expressed as a linear combination of the contributions from the particle size, D and strain, ξ through the relation [20]

$$\frac{\beta\cos\theta}{\lambda}=\frac{1}{D}+\frac{\zeta\sin\theta}{\lambda} \tag{2}$$

The plot of $\beta\cos\theta/\lambda$ versus $\sin\theta/\lambda$ (see inset of Fig. 1) allows us to determine both strain and particles size from slope and intercept of the graph. The estimated values for different film thickness are listed in Table 1.

To assess the microstructure of the deposited films, we performed TEM study. Fig. 2(a)–(c) shows the TEM micrograph and the corresponding electron diffraction patterns for a group of ZnTe samples with different thinner thicknesses prepared for electron microscopy studies. The diffraction patterns for different film thicknesses consist of well-defined continuous rings of different intensities, confirming the polycrystalline structure of ZnTe cubic phase. It is also evident from the TEM micrograph that the particles are uniformly distributed for different film