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Fabrication and optical characterization of zinc telluride thin films using electrodeposition technique

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Abstract

A well adherent thin film of Zinc Telluride (ZnTe) has been deposited on Flourine doped Tin oxide glass substrates from acidic baths containing Zinc heptahydrate and Tellurium dioxide. Films of different thicknesses with their molar concentrations were obtained. A mini Schimadzu UV-VIS Spectrophotometer was used to determine the optical absorbance of the films over the wavelength range of 300-900nm at room temperature. There is a decrease in absorbance as the molar concentrations of the precursors increases; while transmittance and energy band gap shown an increase. The band gap values obtained varied between 2.10eV and 2.7eV, for as deposited films. Also, photoelectrochemical cell (PEC) measurement reveals that ZnTe thin films exhibit p-type conductivity.

Keywords: Fabrication; Optical; Thin Film; Electrodeposition; Fluorine Tin Oxide (FTO)

1. Introduction

Semiconducting materials play an indispensable role in contemporary electronics. In the early days of radio and television, transmitting and receiving equipment relied on vacuum tubes, but these have been almost completely replaced in the last four decades by semiconducting materials, including transistors, diodes, integrated circuits and other solid-state devices (Young and Freedman, 2008). Such devices have found wide applications because of their compactness, reliability, power efficiency, and low cost. As discrete components, they have found use in power devices, optical sensors, and light emitters, including solid-state lasers. They have a wide range of current- and voltage handling capabilities and, more important, lend themselves to integration into complex but readily manufacturable microelectronic circuits. They are, and will be in the foreseeable future, the key elements for the majority of electronic systems, serving communications, signal processing, computing, and control applications in both the consumer and industrial markets.

The potential applications of chalcogenide based materials in electronic and optoelectronic devices are vast, but have received little attention until recently due to the cheap and wide availability of silicon based alternatives. Chalcogenide II-VI, compound semiconductors, such as Zinc Telluride (ZnTe) has generated a lot of interest among scientists because of its extensive use in the fabrication of solid state devices such as solar cells, thin film transistors. optoelectronics and electroluminescent displays (Tan, 2006).

Zinc telluride, ZnTe, is a binary semiconductor compound with a large and direct energy gap, 2.25-2.26 eV, at room temperature (Feutelais et al, 1997). Its wide range of potential applications in thermoelectricity, optoelectronic materials, photoelectrodes in solar cells, photodetectors, photovoltaic (PV) heterojunction structures and quantum well structures are well recognized (Mahalingam et al, 2002). ZnTe films were extensively studied for the applications as

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back contact material (p-type semiconductor) for CdTe in CdTe/CdS heterojunction solar cells (Toma and Antohe, 2014). The wide direct band gap makes ZnTe as one of the interesting materials for manufacturing of green light emitting diodes (LED) as well as other microelectronic and optoelectronic devices (Syed et al, 2015). Also, ZnTe exhibits unique electrical properties and high transparency in the infrared region which are very useful in infrared optoelectronics (Hossain et al, 2010). Because of its high electrooptic coefficient, ZnTe film is useful in the generation and detection of terahertz (THz) radiation (Walther et al, 2005) with application in imaging.

Extensive work has been conducted for the electrodeposition of zinc telluride from acidic aqueous electrolytes with $ZnSO_4$ or $ZnCl_2$ as precursors for Zn species (Bozzini et al, 2000). In this paper ZnTe thin films were fabricated using electrodeposition growth technique by varying the concentrations of the precursors salt; the fabricated ZnTe thin films were characterized using optical analysis and the variation in the energy gap of ZnTe thin-films as its composition varies were determined. Zinc telluride films electrodeposited on FTO substrate were characterized by UV-spectrophotometer to investigate their optical properties. Optical properties are directly related to structural and electronic properties of solids, and hence very important in device applications.

2. Experimental Method

2.1. Preparation of Tellurium dioxide (TeO_2) solution

A 2.00g of Tellurium dioxide (TeO_2) was weighed into a beaker. The salt was dissolved in small amount of de-ionized water and then transferred into 500ml glass beaker. 30ml of concentrated H_2SO_4 was later added to the solution. The reason for using concentrated acid is due to the inability of TeO_2 powder to dissolve completely in water. The solution was continuously stirred and de-ionized water was gradually added to the concentrated TeO_2 solution. As the gradual addition of water takes place, a clear solution was observed. The prepared TeO_2 solution was later placed on magnetic stirrer for continuous stirring and heating for ~25 minutes so as to aid complete dissolution of the TeO_2 powder. The pH of the dissolved TeO_2 solution was 1.0 which is very acidic.

2.2. Preparation of Precursors, Substrate selection and Surface cleaning

11.5g, 17.0g, 34.0g and 52g each of $ZnSO_4.7H_2O$ was dissolved in 400ml of de-ionized water measured in a separate 500ml beakers. The solution was magnetically stirred until $ZnSO_4.7H_2O$ dissolved properly.

FTO-coated glasses were used as conducting substrates due to their numerous advantages over ITO. The substrates were cut into desired dimension of 2.4cm by 5.0cm before cleaning. The cleaning was first done by dipping the substrates inside soap solution for 30 minutes. A clean cotton bud was used to clean the surface to remove oil or dirt from the surface. A further rinsing action using de-ionized water was carried on the glass/FTO substrates after washing with soap. The surface was finally rinsed in organic solvents (Benzene and Acetone), washed in de-ionized water and air dried before being applied as the working electrode in the electrodeposition technique set up.

2.3. Preparation of ZnTe electrolytic bath

The precursors used for the growth of ZnTe thin films were 0.1M, 0.15M, 0.3M and 0.45M $ZnSO_4.7H_2O$ as Zn^{2+} source. 2.5ml of TeO_2 as Te source were added into each of the precursors and stirred thoroughly until a clear solution was obtained. All chemicals used for electrodeposition were analytical reagent grade. The growth temperature and pH of the bath used for the optimisation of the growth voltage were 80^oC and 3.5±0.02 respectively. The pH of the bath was adjusted accordingly by adding ammonia or H_2SO_4 solution. The 2.10±0.02 pH was the initial pH used for ZnTe characterisation before optimising the pH to grow a nearly stoichiometric ZnTe layer for electronic device application. Electroplating of ZnTe was carried out in potentiostatic mode using a 2-electrode system set-up.

2.4. Reaction Mechanism

The deposition process is based on the slow release of Zn^{2+} and Te ions in solution which then condense on the substrate. The deposition of ZnTe occurs when the ionic product of Zn^{2+} and Te exceeds the solubility product of ZnTe. $ZnSO_4.7H_2O$ is used as the Zn^{2+} source and TeO_2 as Te ions through hydrolysis in an acidic medium according to the following equations:

$$TeO_2 + H_2O \rightarrow H_2TeO_3$$

$$H_2TeO_3 + 4H^+ + 4e^- \rightarrow Te + 3H_2O$$

$$ZnSO_4.7H_2O \rightarrow Zn^{2+} + SO_4^{2-} + 7H_2O$$

$$Zn^{2+} + Te + 2e^{-} \rightarrow ZnTe$$

3. Results and discussion

3.1. Optical absorption

The optical absorption measurements were carried out at room temperature in order to obtain the optical properties of the ED-ZnTe thin films. The measurements were carried out on ZnTe layers grown at cathodic potential 1700mV in the wavelength range 300–800 nm. As-deposited thin films were reddish in colour and adherent. Below show the absorption spectra of deposited thin films of ZnTe with molarities 0.10, 0.15, 0.30, and 0.45mol.

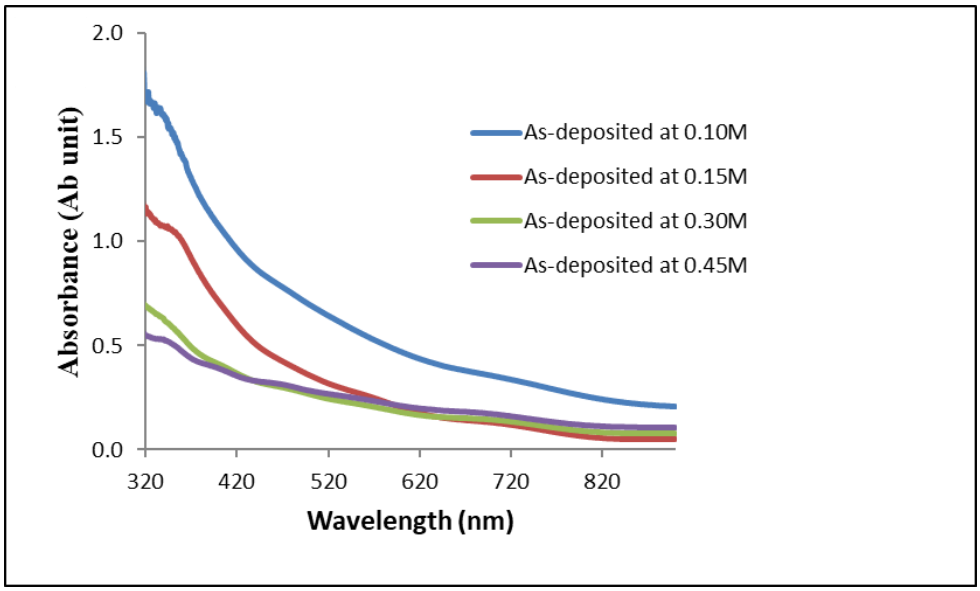

Figure 1 Absorbance spectra of ZnTe layers showing absorbance dependence of As-deposited

It can be observed that above the 400 nm wavelength, the values of absorbance of the samples are low and lie between 0 and 1.0.

Transmission data was obtained from the absorption spectra by the relation:

$$T = 10^{-A}$$

where T, is the transmittance and A is the absorbance. The Figure below shows the transmission spectra of ZnTe thin films for as-deposited.

An increase in the transmission values over the whole spectral range is observed with increasing molarities of the precursors as the wavelength increases, especially within the visible region down to the near infra red (i.e 400-800 nm). For instance, at 400 nm, transmittance increased from 5 % through 15 %, 35 % to 40 % at 0.10M, 0.15M, 0.30M and 0.45M respectively.

The optical band gap of the thin films was estimated from absorption coefficient data as a function of wavelength by using the Tauc Relation (Mahalingam *et al*., 2002) for direct band gap materials, which is given by

$$\alpha h\upsilon = A(h\upsilon - E_g)^{\frac{1}{2}}$$

Where hυ, is the photon energy, E_g, the optical band gap and A is a constant.

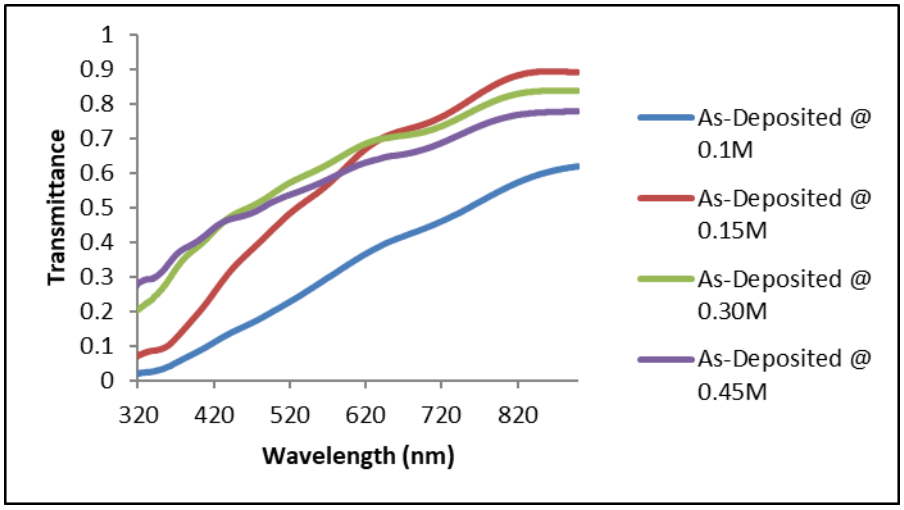

Figure 2 Transmittance spectra of ZnTe layers for as-deposited ZnTe.

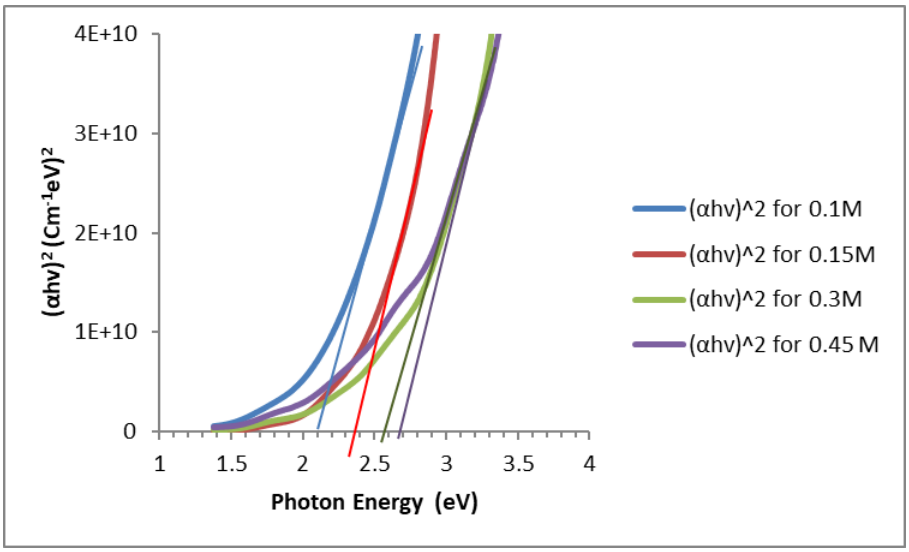

Figure 3 Energy band gap estimation of ZnTe layers grown at 1700mV with different molar concentrations of the precursors.

Figure 3 illustrates how the estimated energy bandgaps from optical absorption measurements vary with the molar concentrations for as deposited ZnTe layers. The samples show an increase in band gap with increasing molar concentration of the precursors (Zinc). The AD-ZnTe layers have energy bandgaps in the range (2.10–2.70) eV. At 0.1M, the E_g of as deposited ZnTe layers falls within 2.26 eV; this value happens to fall in the vicinity of the bandgap of bulk value of stoichiometric ZnTe layers. This signifies that the deposition of ZnTe using 0.1M of Zinc salt at cathodic potential of 1700 mV can be used in growing near stoichiometric ZnTe layers.

3.2. Photoelectrochemical cell measurements

PEC cell measurements were carried out so as to determine the electrical conductivity type of the ED-ZnTe layers. The result of the PEC signal observed for AD-ZnTe layers deposited at 1700mV showed p- type electrical conduction.

4. Conclusion

Zinc Telluride thin films have been prepared using electrodeposition technique by varying the molar concentration of the Zinc salt. It was observed that the absorbance decreased with increasing Zinc concentration. It implies that at lower concentration larger percentage of the light was absorbed by the sample. Hence, ZnTe layers grown at 0.1M are good absorber layers in device fabrication. The transmittance of the films is high in visible and infrared regions. All samples have peak transmittance in infrared region but the transmittance of sample with molar concentration of 0.45M film is

very high compared to other samples which make the material a good candidate in the production of blue and green light emitting device and it can also be used as buffer window layer in solar cell device architecture.

It was found that the energy bandgap increases with increase in Zn concentration. The optical band gaps of the films were between 2.1 and 2.7 eV at different molar concentrations. Therefore, the band gap of the fabricated semiconductor was successfully tuned at different molar concentrations of the precursor.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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