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Optical, Electrical Properties and Surface Morphology of Thermal Evaporated Zinc Telluride (ZnTe) Thin Films for Photovoltaic Applications

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Abstract - ZnTe bilayer thin films were deposited onto soda-lime glass by a thermal vacuum evaporation technique using the NANO 36 thermal evaporator under a vacuum pressure of 2.9×10^{-5} torr. The optical characteristics of the film were measured using an AVANTEX UV spectrophotometer in the wavelength range from 239.534 nm to 999.495 nm. Also, the electrical characteristics of the thin films were investigated using KEITHLEY four-point probe techniques. The investigation of the optical properties of the thin films as-deposited and annealed at different temperatures showed high transmission in the NIR region with good absorption in the visible and UV regions. The extrapolated band gap energies were 2.60 eV and 3.20 eV for annealed and as-deposited samples, respectively. electrical resistivity decreased as the annealing temperature increases. The images of the film as-deposited and on annealing have a uniform distribution on the glass slides.

Keywords— Hetero-junction, Evaporator, ZnTe and Band gaps

I. Introduction

Solar energy is the most importan among the renewable energy sources due to the unlimited supply of energy provided by the sun at no cost [1, 2]. However, solar energy is converted to electrical energy by a device called a solar cell [3]. Solar cells made from silicon are called first-generation solar cells. They have high efficiency, but the major disadvantage of these cells is that they are very costly to manufacture [4]. The second-generation cell is called a thin-film solar cell, which has some advantages over the first-generation solar cell. These advantages include having a very thin thickness and minimum material usage, which reduces the cost of the cell; being easy to design; and being lightweight [5]. The thin-film solar cells are considered the hope of humanity in the solar market because they are relatively inexpensive [6]. A thin-film solar cell is formed by sandwiching two electronically dissimilar materials, i.e., a p-type absorber layer and an n-type window layer, together [7]. Among the p-type absorber layers is cadmium telluride (CdTe), but cadmium is a toxic element that requires caution during the manufacturing process of the CdTe absorber layer [8]. However, a nontoxic p-type layer should be developed. Zinc telluride (ZnTe) is a family of group II-VI compound semiconductors [9]. The compound semiconductors of group II-VI play an important role in the fabrication of photovoltaic and other optoelectronic devices such as light-emitting diodes [10, 11]. The cubic, zinc-blend p-type structure of ZnTe has a lattice constant a = 6.1034. It is a semiconductor material with an absorption coefficient [12]. It is a p-type semiconductor with a direct bandgap energy of 2.21 to 2.26 eV at room temperature with a low electron affinity of 3.53 eV. [13] Different methods of deposition have been employed by different researchers to synthesize ZnTe thin films: metal-organic chemical vapour deposition (MOCVD) [14], spray pyrolysis [15], electrodeposition [16], thermal [17]. Due to the peculiarity of the thermal evaporation technique capable of forming multiple layers on a single substrate, making it easy to monitor the deposition rate and thickness of the film with a quartz crystal thickness monitor equipped with a vacuum coating unit, there was no wastage of materials and the time-saving technique was necessitated for this study.

Many studies on ZnTe thin films have been conducted. An investigation into the structural and optical properties of nanocolumnar ZnTe thin films grown using the glancing angle technique was conducted [12] and determined that the band gap energy of the samples was modified at higher deposition angles, which is promising to be applicable in optoelectronic devices. Also, the properties of arsenic–doped ZnTe thin films as a back contact for CdTe solar cells were studied by [14], and the results showed the undoped films were essentially insulting, while the doped layers showed a significant increase in conductivity with increasing in concentration. [18] studied the effect of annealing temperature on the structure and optical properties of ZnTe films prepared using the thermal evaporation method. From XRD investigation, it was found that the deposited films were near the single crystalline structure of the cubic type at a crystallization direction (111) and high intensity, with the non-availability of the hexagonal phase and other different directions in the alloy, as well as the persistence of weak peaks of element Te. [19] studied the effect of post-deposition annealing on the optical absorption and photoconductivity of pure ZnTe and pure MgP thin films deposited by vacuum.

II. MATERIAL AND METHOD

ZnTe films were deposited onto soda-lime glass. before the deposition, the glass substrates were cleaned thoroughly with liquid detergent; then washed with distilled water, and finally purified ultrasonically in acetone. The cleaned substrates were dried in hot air for 20 minutes. Zn-Te bilayers were growed by vacuum thermal evaporation with pressure 2.10 x 10^{-5} torr in a NANO 36 thermal evaporation chamber supplied by Kurt J. Lesker company. The high purity Zn (99.99%, shots-1-2 mm size from Sigma Aldrich, UK) and Te (99.99+%, pellets < 4 mm, Sigma Aldrich, UK) were placed in two different boats in the vacuum system. The glass substrates were placed in the substrate holder above the boats carrying the materials. The Zn layer is first deposited and later Te layer is deposited to get bilayers of Zn-Te thin films. The deposition rate of 10 Å/s was maintained to deposit 250 Å and 651 Å of Zn and Te, respectively. After the deposition, a substrate was annealed at 150°C, the second was annealed at 180°C for 15 minutes in a UNISCOPE SM9053 laboratory oven, while the third one was not annealed.

A. Characterization of The Film

A1. Optical Characteristics

Transmittances of both annealed and as-deposited layers were measured using AVANTEX UV spectrophotometer in the wavelength range from 239.534 nm to 999.495 nm. The absorbance coefficients were determined from Lambert's law

$$I = I_0 e^{(-\propto t)} \quad (1)$$

, where I / I_o = Transmittance (T), t is the thickness of the film deposited and α is absorbance coefficient.

$$\propto = -ln\frac{T}{t} \quad (2)$$

The reflectance and transmittance were plotted against incident wavelength to determine the percentages transmitted and reflected. The bandgap of the film is determined by plotting $(\alpha h\nu)^2$ against $(h\nu)$ in eV, where h is Planck's constant of value 6.62×10^{-34} Js and ν = c / λ , where c is the speed of light, 3×10^8 ms^{-1} and λ is the incident wavelength.

A2. The Electrical Characteristics

The electrical characteristics of the as-deposited as well as annealed ZnTe thin films were examined using a KEITHLEY four-point probe technique. The connection was arranged in such a way that the voltage across the transverse distance of the films and the corresponding values of the current was obtained. The sheet resistivities ρ of the film's temperature were calculated using the expression:

$$\rho = (\pi t ln2)\frac{v}{I} = 4.53Rt \quad (3)$$

, where V is the potential difference (voltage) across the transverse distance of the film. I is the corresponding values of the current and t is the thickness of the film deposited.

The conductivities were calculated using

$$\sigma = \frac{1}{\rho}\,(\Omega m)^{-1} \quad (4)$$

A3. The Morphological Property

The surface morphology of the as-deposited, as well as annealed ZnTe thin films, were observed by ASPEX 2030 Scanning Electron Microscope (SEM), operated at accelerating 16 kV potential with 500 magnifications were done for each sample.

III. RESULTS AND DISCUSSION

A1. Optical Properties

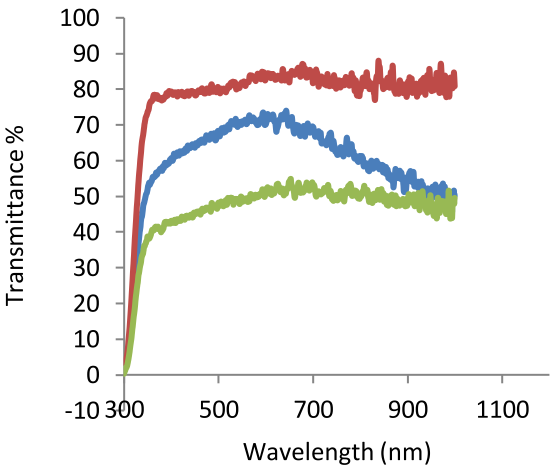

Fig. 1. The transmittance spectral of ZnTe thin film. Solid lines represent at 180 °C (red), 150 °C (blue) and as-deposited film (green).

The optical transmittance in Fig. 1 for ZnTe thin films reveals that transmittance increases smoothly from 300 nm to a maximum value of 700 nm in the visible region of wavelength and becomes almost consistent in the infra-red region. This agrees with the reports of [9, 20]. The spectral shows that as-deposited has a maximum 50% transmittance, annealed at 150°C has a maximum of 70% while annealed at 180°C has a maximum of 85%. The transmittance increases as annealing temperature increases this agrees with the report [18] The optical band gap energies were extrapolated from Fig. 2 found to be 2.60 eV, 2.70 and 3.20 eV for the films annealed at 180°C, 150°C and as-deposited film, respectively. This shows that the bandgap energy decreased from 3.20 eV (as deposited) to 2.60 eV on annealing. This agrees well with the reports of [21, 22]. However, the band gap energies are higher than the theoretical value of 2.26 eV. The higher value of tellurium deposited than zinc could be a factor for this deviation. Similar very high band gap energy between 2.75 eV and 3.15 eV was reported by [23]. High transmittance and bang gap energy are the requirements of the buffer layer of thin film solar cells.

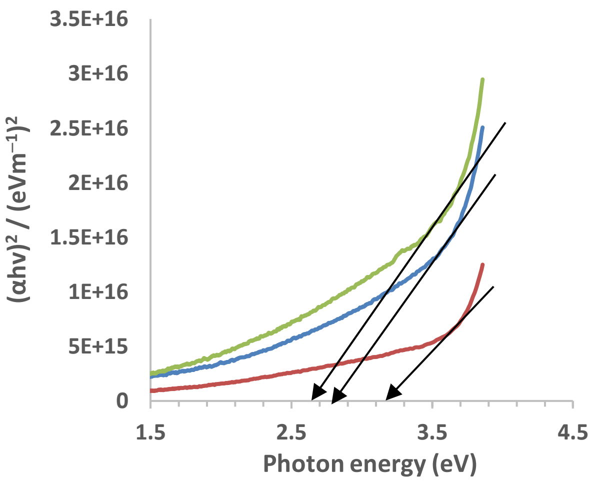

Fig. 2. The graph of $(\alpha h\nu)^2$ against photon energy. Solid lines represent at 180 °C (green), 150 °C (blue) and as-deposited film (red).

A2. The Electrical Parameters

The resistivities and conductivities of the films as-deposited and annealed are shown in Table I. The resistivity of the ZnTe thin films for as-deposited and annealed at 150°C and 180°C are 9.070 Ωm, 4.707 Ωm and 0.427 Ωm respectively. This showed that the resistivity decreased as the annealing temperature increased. This agrees with the report of [24] because the resistivity of semiconductors is inversely proportional to the temperature.

Table I: The Electrical results.

Sample	ZnTe (as deposited)	ZnTe (150°C)	ZnTe (180°C)
Voltage/×10^{-3} V	400	401	135
Current/×10^{-9} A	18	35	130
Resistivity (Ωm)	9.070	4.707	0.427
Conductivities $(\Omega m)^{-1}$	0.110	0.212	2.342

A3. Surface Morphology

The images of as-deposited and annealed at a different temperature of the films when viewed with a scanning electron microscope (SEM) at magnifications of 500 for each sample are shown in Fig. 3. The images of the film as-deposited and on annealing have a uniform distribution on the glass slides but with a small presence of monotonic grains that leads to a slight increase in the roughness of the thin films with the increasing of the annealing temperature this agrees with the image reported by [11, 19].

IV. CONCLUSION

ZnTe thin films were successfully deposited on glass substrates by the stacked elementalayer method using a NANO 36 thermal evaporator in a high vacuum at about 10 – 5 torr. The investigation of the optical properties of the thin films as-deposited and annealed at different temperatures showed high transmission in the NIR region with good absorption in the visible and UV region. The extrapolated band gap energies were high between 2.60 eV and 3.20 eV and the resistivity of the film decreased as the annealing temperature increases. The images of films, when viewed with the scanning electron microscope, showed that the surface is very smooth and covered over the substrate surface. These properties indicate that the films can be used as a replacement of CdS buffer layer in the fabrication CdTe, CIGS ($Cu(In,Ga)Se_2$) of thin film solar cells.

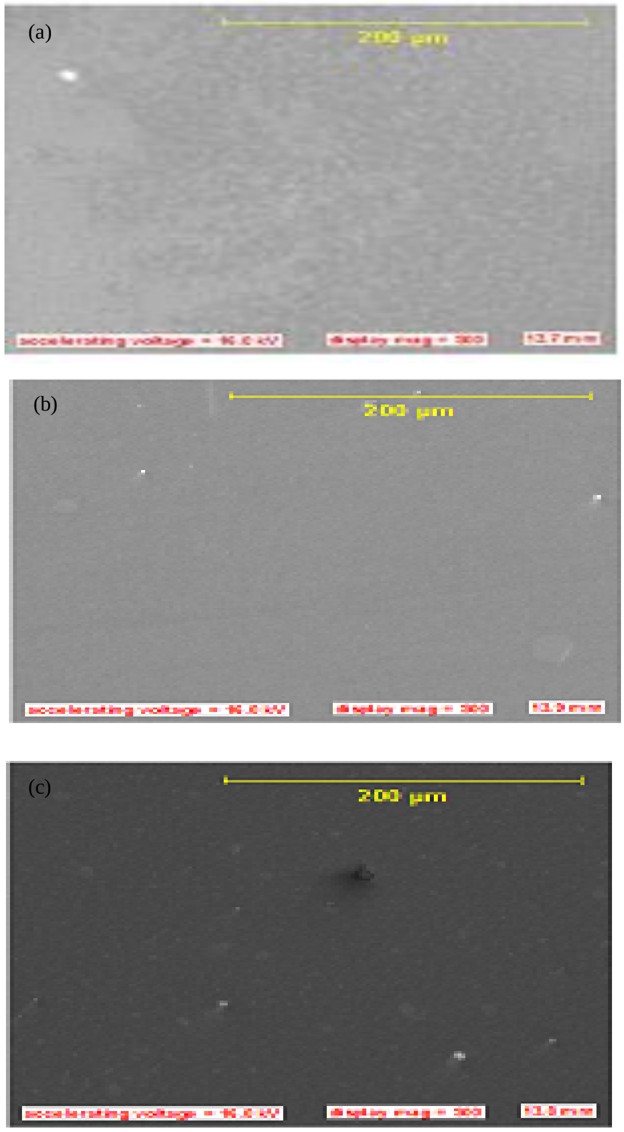

Fig. 3. SEM images of ZnTe (a) as-deposited, (b) annealed at 150°C and (c) annealed at 180°C.

REFERENCES

[1] R. J. Mustafa, M. R. Gomaa, M. Al-Dhaifallah and H. Rezk, "Environmental Impacts on the Performance of Solar Photovoltaic Systems," *Sustainability*, vol. 12, no. 2, pp. 1–17, 2020.

[2] S. Sharma, K. K. Jain and A. Sharma, "Solar Cells: In Research and Applications—A Review," *Mater. Sci. Appl.*, vol. 6, no. 12, pp. 1145–1155, 2015.

[3] A. M. Bagher, "Types of Solar Cells and Application," *Am. J. Opt. Photonics*, vol. 3, no. 5, pp. 94-113, 2015.

[4] M. Imamzai, M. Aghaei and Y. H. Thayoob, "A Review on Comparison between Traditional Silicon Solar Cells and Thin- Film CdTe Solar Cells," *in Proc.s Nation. Graduate Conf.*, pp. 8–10, 2012.

[5] S. Siebentritt, "Chalcopyrite Compound Semiconductors for Thin Film Solar Cells," *Curr. Opin. Green Sustain. Chem.*, vol. 4, pp. 1–7, 2017.

[6] A. Acevedo-Luna, R. Bernal-Correa, J. Montes-Monsalve and A. Morales-Acevedo, "Design of Thin Film Solar Cells based on A Unified Simple Analytical Model," *J. Appl. Res. Technol.*, vol. 15, no. 6, pp. 599–608, 2017.

[7] K. L. Chopra, P. D. Paulson and V. Dutta, "Thin-film Solar Cells: An Overview," *Prog. Photovoltaics Res. Appl.*, vol. 12, no. 23, pp. 69–92, 2004.

[8] J. Y. Muhammad, A. B. Waziri, A. M. Shitu, U. M. Ahmad, M. H. Muhammad, Y. Alhaji, A. T. Olaniyi and A.l A. Bala, "Recent Progressive Status of Materials for Solar Photovoltaic Cell: A Comprehensive Review," *Sci. J. Energy Eng.*, vol. 7, no. 4, pp. 77–89, 2019.

[9] M. Abbas, N. A. Shah, K. Jehangir, M. Fareed and A. Zaidi, "Physical Properties of ZnTe Semiconductor Thin Films Prepared by High Vacuum Resistive System," *Mater. Sci. Pol.*, vol. 36, no. 3, pp. 364–369, 2018.

[10] C. H. Hsu, C. Tseng, Y. Yu, P. C. Yang, C. Lai, J. S. Lin and H. Yang, "Effect of Annealing Temperature on Electrical Properties of ZnTe Layers Grown by Thermal Evaporation," *Adv. Mater. Res.*, vol. 608–609, pp. 1314–1317, 2013.

[11] T. Potlog, N. Maticiuc, A. Mirzac, P. Dumitriu and D. Scortescu, "Structural and Optical Properties of ZnTe Thin Films," *Proc. Int. Semicond. Conf. CAS*, vol. 2, pp. 321–324, 2012.

[12] R. Zarei, M. H. Ehsani and H. R. Dizaji, "An Investigation on Structural and Optical Properties of Nanocolumnar ZnTe Thin Films Grown by Glancing Angle Technique," *Mater. Res. Express*, vol. 7, no. 2, pp. 1–10, 2020.

[13] D. G. Diso, F. Fauzi, O. K. Echendu, A. R. Weerasinghe and I. M. Dharmadasa, "Electrodeposition and Characterisation of ZnTe Layers for Application in CdTe based Multi-layer Graded Bandgap Solar Cells*," J. Phys. Conf. Ser.*, vol. 286, no. 1, 2011.

[14] O. Oklobia, G. Kartopu and S. J. C. Irvine, "Properties of Arsenic-Doped ZnTe Thin Films as A Back Contact for CdTe Solar Cells," *Materials*, vol. 12, no. 3706, pp. 1–16, 2019.

[15] Y. D. Tembhurkar, "Study of Optical Band Gap Energy of II-VI Solid Solution Thin Films of CdZnS2 Prepared by Spray Pyrolysis," *Int. J. Sci. Res.*, vol. 5, no. 12, pp. 1939–1941, 2016.

[16] I. L. Ikhioya, "Optical and Electrical Properties of ZnTe Thin Films Using Electrodeposition Technique," *Int. J. Innov. Appl. Stud.*, vol. 12, no. 2, pp. 369–373, 2015.

[17] H. Tamura, "Effect of Substrate Temperature on Structural and Morphological Parameters of ZnTe Thin Films," *J. Chem. Inf. Model.*, vol. 53, no. 9, p. 287, 2008.

[18] S. M. Ali, A. A. A. Shehab and S. A. Maki, "Study of the Influence of Annealing Temperature on the Structural and Optical Properties of ZnTe Prepared by Vacuum Thermal Evaporation Technique," *Ibn AL-Haitham J. Pure Appl. Sci.*, vol. 31, no. 1, pp. 50–57, 2018.

[19] C. S. A. Raj, F. P. Xavier, A. Appl and S. Res, "Effect of Post Deposition Annealing on the Optical Absorption and Photoconductivity Studies of Pure ZnTe and Pure MgPc Thin Films Formed by Vacuum Deposition," *Sch. Res. Libr.*, vol. 5, no. 2, pp. 167–171, 2013.

[20] A. Islam, S. Choudhury, and T. Begum, "Structural and Optical Characterization of Vacuum Evaporated Zinc Selenide Thin Films," *Eur. Sci. J.*, vol. 10, no. 15, pp. 241–253, 2014.

[21] S. Shanmugan and D. Mutharasu, "Optical Properties and Surface Morphology of Zinc Telluride Thin Films Prepared by Stacked Elemental Layer Method," *Medziagotyra*, vol. 18, no. 2, pp. 107–111, 2012.

[22] S. Arora, "Structural and Optical Properties of Zn_x/Te_{1-X} Layered Thin Film on Glass Substrate," *Int. Robot. Autom. J.*, vol. 3, no. 4, pp. 324–326, 2017.

[23] S. S. Kale, R. S. Mane, H. M. Pathan, A. V Shaikh, O. Joo and S. Han, "Preparation and Characterization of ZnTe Thin Films by SILAR Method," *Appl. Surf. Sci.*, vol. 253, pp. 4335–4337, 2007.

[24] Y. Sugawa, J. Ohta and T. Ohgai, "Semiconductor Properties of ZnTe Thin Films Electrodeposited from Aqueous Solutions," *TMS 2015 144th Annu. Meet. Exhib.*, pp. 359–364, 2015.