



Properties of $\text{Cu}_2\text{ZnSnS}_4$ Thin Films Fabricated by Dip Coating Technique for Solar Cell Application

¹Sabiha Dilruba, ²Tabassum Perveen Ananna, ³Afrina Sharmin, ⁴M. S. Bashar, ⁵Zahid Hasan Mahmood

^{1,2}Institute of Energy, University of Dhaka, Dhaka, Bangladesh.

^{3,4}Institute of Fuel Research and Development (IFRD), BCSIR, Dhaka, Bangladesh.

⁵Department of Electrical and Electronic Engineering, University of Dhaka, Dhaka, Bangladesh.

Abstract: This paper is a part of the work done in making the prospects of solution processed CZTS more fruitful where achieving controlled phase and stoichiometric film of CZTS is the key issue in the development of CZTS for solar cells of the future. The chemical composition ratios of $\text{Cu}/(\text{Zn}+\text{Sn})$ were varied keeping Zn/Sn and $\text{S}/(\text{Cu}+\text{Zn}+\text{Sn})$ ratios fixed to study the impact of metal salt variation. Aqueous precursors containing copper (II) chloride dehydrate ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$), zinc (II) chloride (ZnCl_2), tin (II) chloride (SnCl_2) and thiourea ($\text{CS}(\text{NH}_2)_2$) were used. The films were deposited by dipping glass substrates into the solution prepared by 45–50°C dissolving cation metal salts and thiourea in 2-methoxyethanol and monoethanolamine. The dip coated films were baked and annealed respectively at a constant temperature. Comprehensive structural, morphological and optical characterization has been accomplished using x-ray diffraction, SEM, EDS and UV-Vis spectroscopy techniques. It was observed from XRD pattern that $\text{Cu}/(\text{Zn}+\text{Sn})$ higher ratio shows good quality Kesterite structure of CZTS with preferred orientation of (112), (220) and (312) planes. The direct band-gap of 1.5 eV were found in some sample, and absorption coefficients were found also $>10^4 \text{ cm}^{-1}$ which establish the characteristic signature of dominant CZTS phase in the film.

Keywords: CZTS ($\text{Cu}_2\text{ZnSnS}_4$), Thin films, Dip-coating method, Sol-gel, Annealing, Band gap, X-ray diffractometer.

I. Introduction

Solar energy, made from sunlight by solar cells, is naturally clean, carbon-free and renewable. It has the promising possibility to fulfill the terawatt energy demand of the world, provided it is available at par with grid electricity. The established solar cells made from silicon (Si) or cadmium telluride (CdTe) or copper indium gallium selenide (CIGS) generate electricity that is still too costly. Hence, there is a frantic inquiry for new materials for solar cells which will generate cost-effective electricity [1]. One such promising candidate is earth-abundant, low-cost and non-toxic kesterite copper zinc tin sulfide. CZTS is a mineral which has been found in nature [2]. However, CZTS material usually appears in kesterite phase because of its thermodynamical stability compared to the stannite-type [3]. Recently considerable work has been done on the quaternary compound semiconductor, $\text{Cu}_2\text{ZnSnS}_4$ (CZTS) to make it a good absorber layer for thin film solar cells [4-5] and thermoelectric power generators [6]. Copper zinc tin sulfide (CZTS) is a classic example of p-type semiconductor bearing a direct band gap of 1.5 eV as well as absorption coefficient greater than 10^4 cm^{-1} in the chromatic spectrum [7]. These factors together led to a quick development in the CZTS based thin film PV research in last few years, which is evident from the rise of record power conversion efficiency to 12.6 % [8] in a very short span. Although, this is quite impressive, the value is still far below the Shockley-Queisser limit for a single junction cell based on CZTS (~30%) [9].

The CZTS film in a thin film solar cell (photovoltaic device) performs as the p-type photoactive absorber layer. The absorber layer is the most critical part of a cell because the major processes required for photovoltaic effect happen here. The processes of absorption of solar radiation, generation of electron-hole pairs and departure of charges take place in this layer. Hence, effect of light on conductivity (photoconductivity) of CZTS films is meaningful in this regard as dark conductivity. Band gap of the absorber should be small enough to permit absorption of a significant portion of solar spectrum and at the same time large enough to deprecate the reverse saturation current density. Direct band gap semiconductors (1–1.7 eV) with a high absorption coefficient are preferred for this determination [10]. Therefore, in general, p-type semiconductors are selected as absorber layers. Many groups have employed wet chemical methods for CZTS thin film depositions such as spray pyrolysis [11], Sol-gel [12], spin coating [13], electrodeposition [14], Successive Ionic Layer Adsorption and Reaction (SILAR) [15], dip coating [16] etc. to obtain device quality CZTS thin films.

Sol process is linked with the sol-gel method since after producing the sol; a consecutive gel can be formed in one-step. The sol-gel process is the formation of an oxide network through polycondensation reactions of a molecular precursor in a liquid [17]. The final particles can be amorphous or crystalline. Generally, the sol or colloidal suspensions of particles are ruled by the van der Waals forces or hydrogen bonds. Sol-gel synthesis permits us to produce multi-component systems with a controlled stoichiometry by mixing sols of different compounds [18]; preventing problems of co-precipitation; and realizing an intimate mixing of reagents at atomic level, thus producing small particles.

Dip coating means submerging of a substrate into a tank containing coating material, removing the piece from the tank, and allowing it to drain. The process is carried out with well-defined speed under regulated temperature and atmospheric conditions. The coating thickness is counted by the withdrawal speed, by the solid content and the viscosity of the liquid. Because of simplicity, this method highly depends on automation. Many factors contribute to determining the final state of the dip coating of a thin film [19]. Various types of dip-coated films of different constructions and thicknesses can be fabricated by controlling many factors such as submersion time, the number of dipping cycles, solution composition, concentration and temperature, and environment humidity. The dip coating technique can give uniform, high-quality films even on bulky, complex shapes [20]. The dip coating is an untroublesome, low-cost technique with feasibility to accelerate for commercial production. Mainly it consists of two steps; (i) dip casting of substrate into the precursor solution and (ii) thermolysis of the film. These steps are completed multiple times in order to achieve the desired thickness. Moreover, during repetition of this process, voids and porosity may develop into the structure, which requires a post-growth annealing [21].

Recently, there are some reports about the research of CZTS thin films dip coating method. Furthermore, P. Prabeesh prepared $\text{Cu}_2\text{ZnSnS}_4$ thin films by dip coating technique using non-toxic chemicals and studied the effect of sulfurization at 550°C for 30 minutes [22]. Fischereder et al. [23] have used a toxic pyridinebased solution containing Cu, Zn and Sn salts along with thioacetamide as a sulphur source. However, pure CZTS films were made only by annealing the precursor film above 250°C in vacuum air. Thiourea is another common source of sulphur that can easily form development with Cu, Zn and Sn, which yield sulphides on thermal decomposition [24]. Tapas Kumar et al deposited phase pure CZTS films by dip coating from a methanolic solution of metal-thiourea complex [25]. Yuxin et al layered CZTS films by this way by ethylene glycol and metal-thioacetamide method [26]. Ferhat et al prepared the effect of pH on structural, optical and electrical properties of CZTS thin film absorber layered by dip method [27]. Patel et al has done CZTS thin films by dip coating by thiourea as the sulphur basis and studied the result of annealing in sulphur atmosphere at different temperatures [28].

In the present work $\text{Cu}_2\text{ZnSnS}_4$ thin films have been prepared using copper(II) chloride dehydrate ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$), zinc (II) chloride (ZnCl_2), tin (II) chloride (SnCl_2) and thiourea ($\text{CS}(\text{NH}_2)_2$) as the precursor material and 2-methoxyethanol as the solvent material using simple dip coating method. Here we varied the Cu/(Zn+Sn) ratios keeping Zn/Sn and S/(Cu+Zn+Sn) ratios fixed so that we can observe the proper variation that takes place in the characterization. Properties that we witnessed were crystallographic structure, morphology and optical properties of the CZTS nanocrystalline thin films in detail.

II. Experimental Details

A. Sample preparation

Soda-lime glass (SLG) substrates of 2.5 cm x 2.5 cm were washed with detergent and distilled water earlier to the deposition of CZTS thin films. They were ultrasonically cleaned with methanol and DI water again followed by flow of nitrogen to dry. The sol-gel solution for CZTS absorber layers was prepared containing copper(II) chloride dehydrate ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$), zinc (II) chloride (ZnCl_2), tin (II) chloride (SnCl_2) and thiourea ($\text{CS}(\text{NH}_2)_2$). The solution of 3.335M metal ions and 6.665 M thiourea was dissolved in 35 ml of 2-methoxyethanol. The mixture was stirred on the hotplate and magnetic stirrer at $45\text{--}55^\circ\text{C}$ for $\frac{1}{2}$ h. Meanwhile, the mono-ethanolamine was added a few drop about ~3 ml to the stabilizer. Then, the mixture incubated at room temperature at least 24 hours to yield a homogenous clear yellow solution. Finally, the mix from the sol-gel process was deposited on soda lime glass (SLG) substrates. Dip coater, PTL-MM01 was used to deposit the CZTS film on the cleaned soda lime glass substrates for withdrawing speed about 150 mm per minute. Then the wet films were dried in an oven, Binder ED53 Drying Oven at 200°C for 10 min. When heating is completed then the sample is put into the environment for natural cooling at 10 minutes and again the process was repeated for 3 times to obtain a suitable thickness of CZTS. The samples were denoted as A-3, B-3, C-3, and D-3 for the Cu/(Zn+Sn) ratio changes from 0.7 to 1. After that, the samples were annealed, Thermoconcept, KLS 10/12 at 250°C for 15 min.

Table 1 : Chemical statement of base solution

Cu/(Zn + Sn)	Zn/Sn	Metal ion	S/metal ion	Stirred	No. of deposition times	Name of sample
1	1.15	3.335M	2M	30 min	3	A-3
0.9	1.15	3.335M	2M	30 min	3	B-3
0.8	1.15	3.335M	2M	30 min	3	C-3
0.7	1.15	3.335M	2M	30 min	3	D-3

Where A, B, C, D is the variation of Cu/(Zn + Sn) ratio and 3 is denoted for the deposition times.

B. Characterization technique:

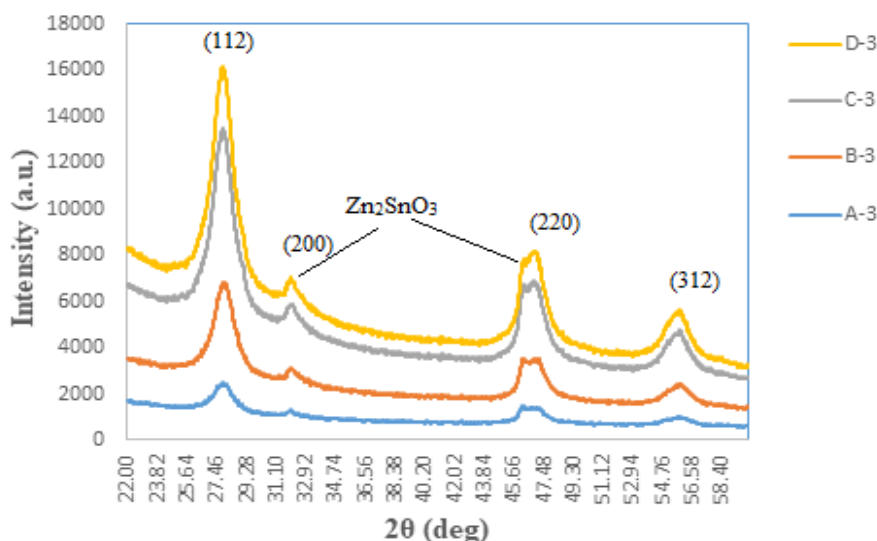
The phases and crystal orientation analysis were identified by using X-ray diffraction, GBC EMMA 147 XRD with Cu K α 1 radiation ($\lambda = 1.5406 \text{ \AA}$) collected from $2\theta = 22^\circ - 60^\circ$. The optical absorption and optical band gap calculate by transparent spectra on the wavelength range of 400 – 1200 nm measured by UV Vis spectrophotometer, GBCCintra-2020 UV-Vis Spectrophotometer. The thickness of the samples was measured by Stylus profiler, Bruker's Dektak XT in this research work. The film morphology was investigated by scanning electron microscopy (SEM, Zeiss, EVO 18). The elemental composition of CZTS was determined by energy-dispersive X-ray spectroscopy, EDX (EDAX, AMETEK).

III. Results and Discussion

A. Structural properties

The XRD patterns of sample A, B, C, D for 3 times deposited CZTS films prepared by dip coating technique are shown in Figure 2. Broad peaks were obtained at the 2θ positions 28.00° , 47.28° , 55.24° for the annealed films which corresponds to the (112), (220), (312) planes of CZTS thin films and they are characteristic of tetragonal kesterite structure of $\text{Cu}_2\text{ZnSnS}_4$ (ICDD card no: 26-0575)[29]. The films annealed at 250°C were identified by using XRD as a kesterite CZTS compound with Zn_2SnO_3 [30] which corresponds to the (200) and (220) planes. The films showed poor adhesion to the substrate because of the low temperature of annealing.

Figure 1: XRD pattern of sample A, B, C, D for 3 times deposited CZTS films



B. Morphological Characterization

The surface SEM micrograph is shown in Figure 2 and EDX composition in Figure 3. From the SEM images it is observed that the texture structures are formed for the CZTS thin films, together with particular cavities and voids can be seen over the entire surface of the CZTS thin film [Figure 2].

It is seen that as the copper content decreases and that of zinc increases there are certain change in the formation of particles [Figure 3 and table 2].

Figure 2: SEM images of CZTS films with various Cu/(Zn+Sn) ratios

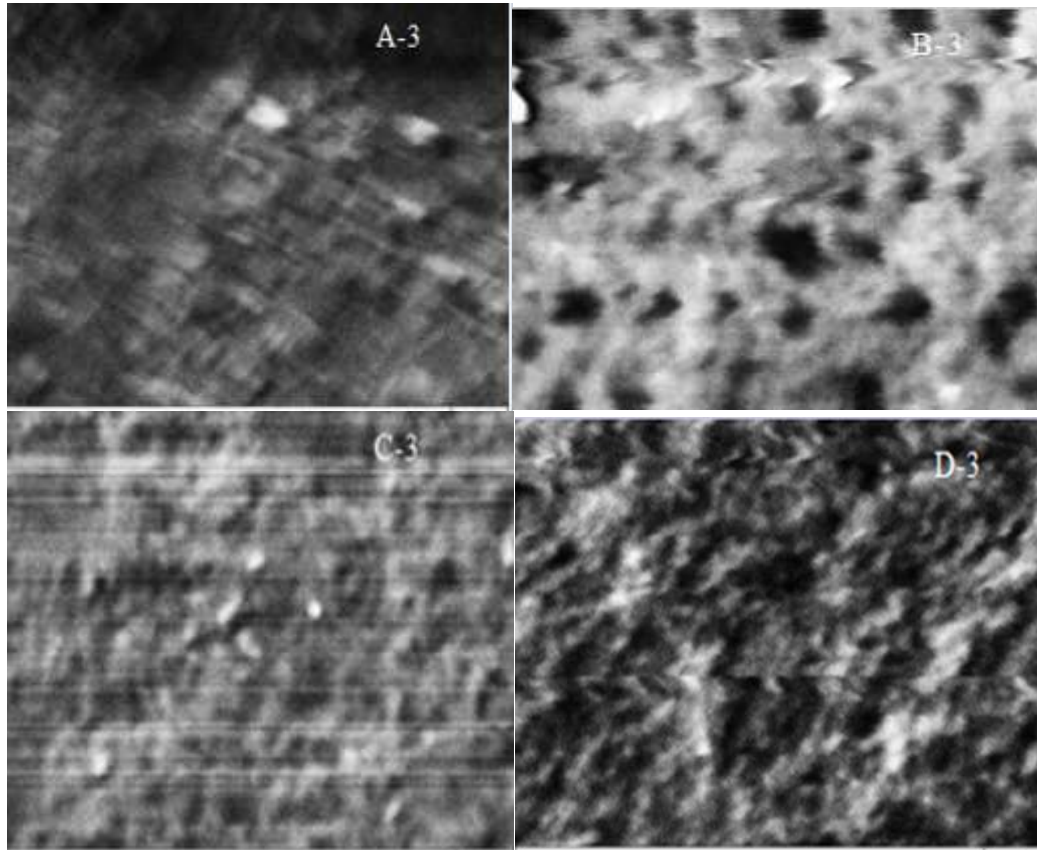
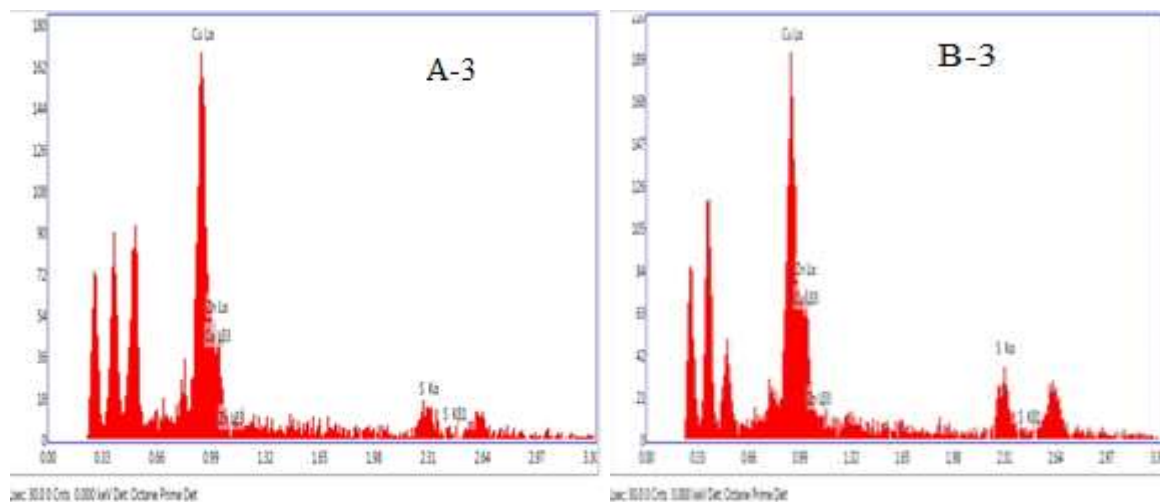


Figure 3: EDX spectrum of CZTS thin film for 3 times deposited



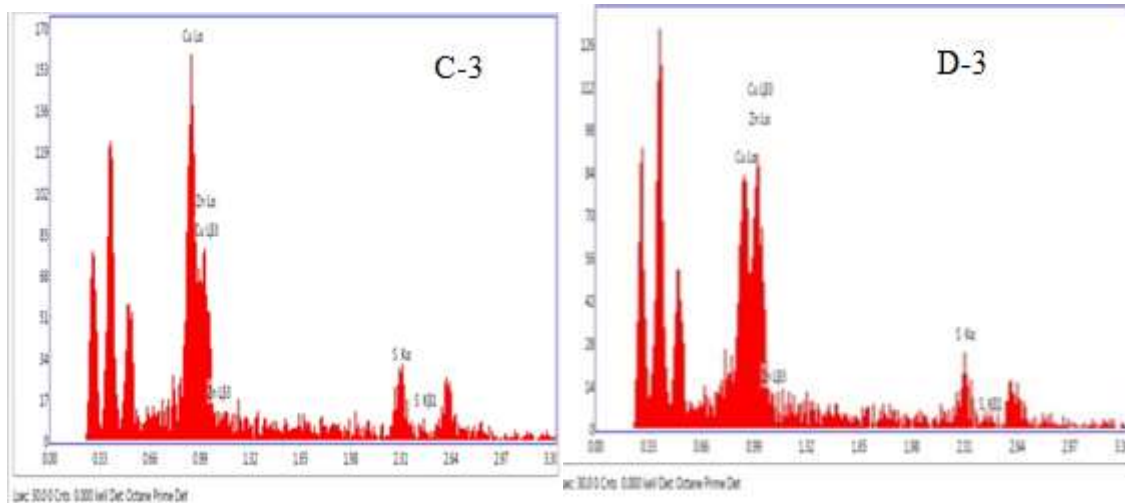


Table 2: Chemical composition (At %) of the CZTS films analysis

Sample	Cu	Zn	Sn	S
A-3	25.69	10.41	14.25	49.65
B-3	24.84	10.52	14.13	50.51
C-3	23.59	10.93	14.19	51.29
D-3	22.84	10.84	15.17	51.15

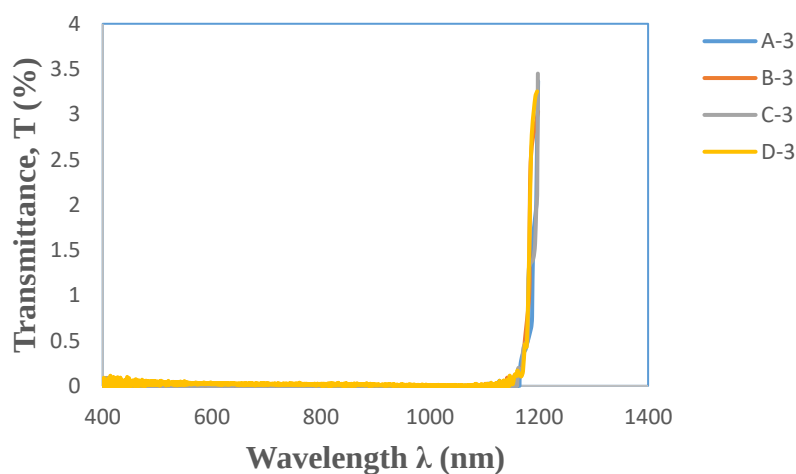
C. Measurement of Thickness

The measurements acquired by the surface profilometer indicated that the thickness of the film deposited by dip coating were found to 3.65, 3.55, 3.40, 3.14 μm respectively. It can be observed that thickness is proportionally increased with the Cu/(Zn+Sn) ratio.

D. Optical properties

The optical properties were studied by employing UV –VIS Spectrophotometer and acquiring the transmittance spectra for different Cu/(Zn+Sn) ratio which is recorded for wavelengths of 400nm to 1200 nm. It has been observed that the samples exhibit poor transmittance in the visible region for low-temperature annealing. In the case of CZTS thin film absorber layer, low transmittance is desired so the samples variation were usually the same in transmittance vs wavelength curve. The other optical characteristics manifested variation so comparable result can be found.

Figure 4: Transmittance Vs Wavelength of CZTS Thin Film for 3 times deposited CZTS films



The absorption coefficient (α), of CZTS films was calculated from the transmittance data as demonstrated in Figure 5[31].

$$\alpha = \left(\frac{1}{d}\right) \ln \left(\frac{1}{T}\right) \quad (1)$$

Where d is film thickness and T is transmittance, the absorption coefficient is $5.4 \times 10^4 \text{ cm}^{-1}$, $5.5 \times 10^4 \text{ cm}^{-1}$, $5.8 \times 10^4 \text{ cm}^{-1}$ and $6.3 \times 10^4 \text{ cm}^{-1}$ respectively of samples A-3, B-3, C-3 and D-3 in the wavelength 400nm.

The absorption coefficient for different samples decreases with increasing thickness and the optical band gap of CZTS films is calculated as shown in Figure 6 from the according to Tauc's formula[32].

$$(\alpha h\nu) = A(h\nu - E_g)^m \quad (2)$$

Where A is a constant, the exponent " m " can takes values $\frac{1}{2}$ for direct allowed, 2 for indirect allowed, $\frac{3}{2}$ for direct forbidden and 3 for indirect forbidden. The band gap energy was determined by plotting $(\alpha h\nu)^2$ versus the $h\nu$ of Figure 6, thus, the direct band gaps (E_g) of CZTS annealed at 250°C during 15 minute were estimated to be 1.50 eV, 1.49 eV, 1.48 eV and 1.48 eV respectively of samples A-3, B-3, C-3, and D-3.

The band gap increases with the increase in thickness and the ratios of $\text{Cu}/(\text{Zn}+\text{Sn})$. Finally the calculated band gap energy of all sample corresponds well with that reported in the literature (1.4-1.6 eV)[33] but the band gap of sample A-3, B-3, C-3, D-3 are near to the optimum for photovoltaic applications.

Figure 5: Absorption coefficient of CZTS Thin Film for 3 times deposited

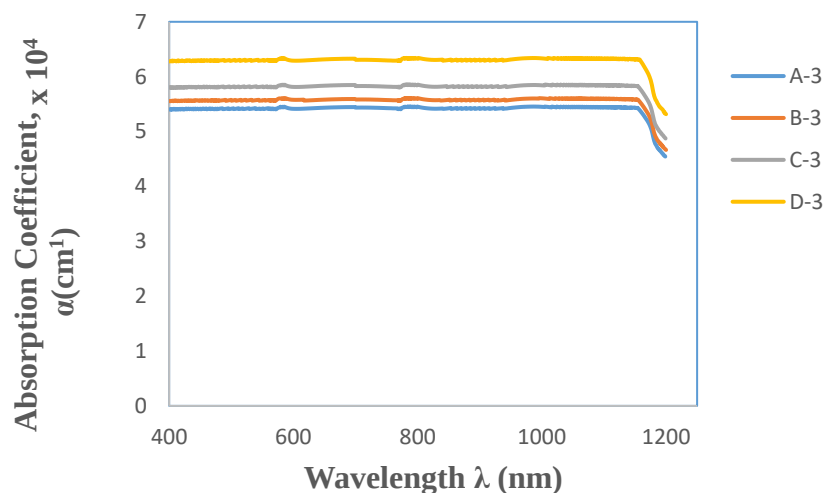
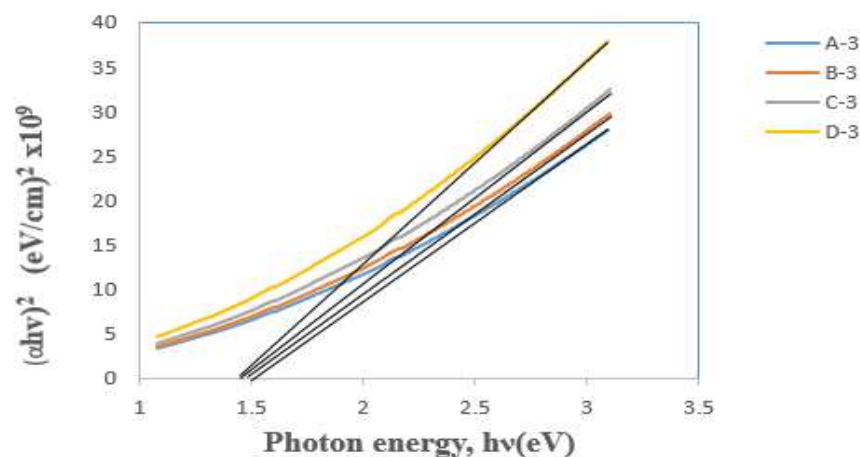


Figure 6: The values of the energy gap $(\alpha h\nu)^2$ in terms of $h\nu$, for 3 times deposited CZTS films



The extinction coefficient (k), was calculated from α using the relation[34]

$$k = \alpha \lambda / 4\pi \quad (3)$$

It is seen from Figure 7 that the extinction coefficient ranges between the extremes of 0.18 and 0.55 for all the samples of 3 times deposited in the wavelength range of 400nm - 1200 nm.

The behavior of curves seems to be similar where the value of " k " increases, with increasing wavelength. As " k " is directly proportional to the absorption (eq.3). Also, since the absorption coefficient of the CZTS is very high (10^4 cm^{-1}), so " k " will be high.

Figure 7: Extinction coefficient of CZTS thin films for 3 times deposited

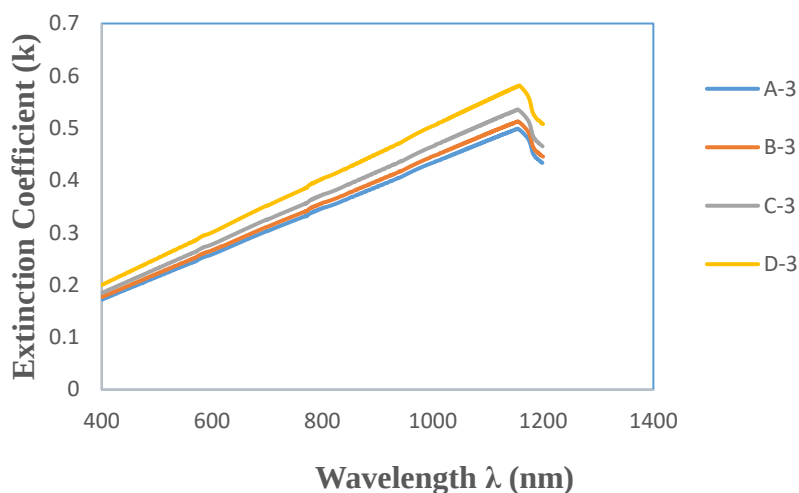
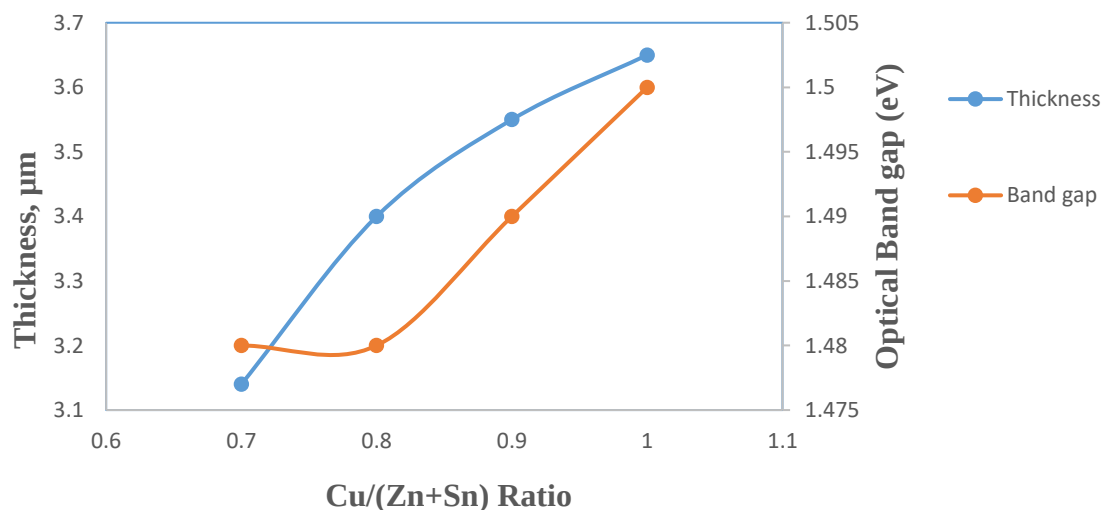


Table 3: Optical properties of CZTS with various Cu/(Zn+Sn) ratios

Sample name	A-3	B-3	C-3	D-3
Thickness (μm)	3.65	3.55	3.40	3.14
Optical band gap (eV)	1.50	1.49	1.48	1.48
Absorption coefficient (cm ⁻¹)	5.4x10 ⁴	5.5x10 ⁴	5.8x10 ⁴	6.3x10 ⁴

Figure 8: Thickness and optical bandgap as function of the Cu/(Zn+Sn) Ratio



Here it can be seen that film thickness is proportionally increased with band gap as a function of Cu/(Zn+Sn) Ratio. It is evident that most of the samples exhibited band gap close to ~1.5 eV which is good for solar cell.

IV. Conclusion

CZTS thin films were explained by sol-gel method associated with the dip coating technology. The ability to manipulate the structural and optical properties of CZTS in terms of XRD, Band gap, absorption coefficient was varying Cu/(Zn+Sn) ratios ranging from 0.7 to 1 and Zn/Sn and S/(Cu+Zn+Sn) ratios of 1.15 and 2. Dip coating of the precursors and annealing under an air atmosphere were useful as a simple process for kesterite CZTS thin-film preparation on soda lime glass. The films showed poor adhesion to the substrates because of low-temperature annealing and had secondary phase in the film. The x-ray diffraction shows that CZTS has a kesterite structure with a privileged orientation along the (112) plane. Here the Cu/(Zn+Sn) ratio also varied and band gap energy found in the range 1.4-1.5 eV which were suitable for photovoltaic applications. Structural and optical both properties demonstrated better output when Cu/(Zn+Sn) ratio is increased. Here it can be seen that thickness increases with the band gap and decreases for the absorption coefficient, for this reason, the extinction coefficient also decreases with thickness because α is proportional to k .

References

- [1] H. Azimi, Y. Hou, C.J. Brabec, *Energy Environ. Sci.* 7, 1829 (2014)
- [2] S. A. Kissin, "A Reinvestigation of the stannite (Cu₂FeSnS₄)—kesterite (Cu₂ZnSnS₄) pseudobinary system," *Canadian Mineralogist*, vol. 27, pp. 689–697, 1989.
- [3] S. Schorr, "Structural aspects of adamantine like multinary chalcogenides," *Thin Solid Films*, vol. 515, no. 15, pp. 5985–5991, 2007
- [4] L. A. Wahab, M. B. El-Den, A. A. Farrag, S. A. Fayek and K. H. Marzouk. 2009, *J. Phys. Chem. Solids*, Vol. 70, p. 604.
- [5] J. Zhang, L. Shao, Y. Fu and E. Xie. 2006, *Rare metals*, Vol. 25, p. 315.
- [6] M. Liu, F. Huang, L. Chen and I. Chen. 2009, *Appl. Phys. Lett.*, Vol. 94, p. 202103.
- [7] K. Ito, *Copper zinc tin sulfide-based thin-film solar cells* (Wiley, Chichester, 2015)
- [8] W. Wang, M. Winkler, O. Gunawan, T. Gokmen, T. Todorov, Y. Zhu, D. Mitzi, *Advanced Energy Materials* 4 (2014) 1301465.
- [9] W. Shockley, H. Queisser, *Journal of Applied Physics* 32 (1961) 510-519.
- [10] R.H. Bube, *Photovoltaic materials, series on properties of semiconductor materials*, vol1 (Imperial College Press, London, 1998)
- [11] O. Galán, M. Courel, M. Rodriguez, D. Olarte, M. Frutis, E. Saucedo, *Solar Energy Materials and Solar Cells* 132 (2015) 557-562.
- [12] B. Long, S. Cheng, Y. Lai, H. Zhou, J. Yu, Q. Zheng, *Thin Solid Films* 573 (2014) 117-121.
- [13] G. Ilari, C. Fella, C. Ziegler, A. Uhl, Y. Romanyuk, A. Tiwari, *Solar Energy Materials and Solar Cells* 104 (2012) 125-130.
- [14] E. Mkawi, K. Ibrahim, M. Ali, M. Farrukh, A. Mohamed, *Solar Energy Materials and Solar Cells* 130 (2014) 91-98.
- [15] K. Patel, D. Shah, V. Kheraj, *Journal of Alloys and Compounds* 622 (2015) 942-947.
- [16] Y. Sun, K. Zong, H. Zheng, H. Wang, J. Liu, H. Yan, M. Zhu, *Materials Letters* 92 (2013) 195-197.
- [17] G. Korotcenkov. *Handbook of Gas Sensor Materials: Properties, Advantages and shortcoming for applications* (2), new trends and technologies. Integrated analytical systems, (2), 396, (2014).
- [18] R. D'Angelo, C. L. Azanza Ricardo, A. Mittiga, P. Scardi, M. Leoni. A water- and sulphurization- free solution route to Cu₂-xZn_{1+x}SnS₄. *J. Sol-Gel Sci. Technol.* 72, 490-495, (2014).
- [19] Rahaman, M.N. (2007). *Ceramic Processing*. Boca Raton: CRC Press. pp. 242–244. ISBN 0-8493-7285 2.
- [20] Quére, David (1999). "FLUID COATING ON A FIBER". *Annual Review of Fluid Mechanics*. 31 (1): 347–384. ISSN 0066-4189. doi:10.1146/annurev.fluid.31.1.347.
- [21] Kinjal Patel, Vipul Kheraj, Dimple V. Shah, C.J. Panchal, Neelkanth G. Dhare "Cu₂ZnSnS₄ thin-films grown by dip-coating: Effects of annealing" *JALCOM* 36088 .
- [22] P. Prabeesh, P. Saritha I. Packia Selvam and S N Potty "Fabrication Of Czts Thin Films By Dip Coating Technique For Solar Cell Applications "
- [23] Fischereder A, Rath T, Haas W, Amenitsch H, Albering J, Meischler D, Larissegger S, Edler M, Saf R, Hofer F, Trimmel G (2010) Investigation of Cu₂ZnSnS₄ formation from metal salts and thioacetamide. *Chem Mater* 22:3399
- [24] Madarasz J, Bombicz P, Okuya M, Kaneko S (2001) Thermal decomposition of thiourea complexes of Cu(I), Zn(II), and Sn(II) chlorides as precursors for the spray pyrolysis deposition of sulfide thin films. *Solid State Ionics* 439:141
- [25] T. K. Chaudhuri, D. Tiwari, Earth-abundant non-toxic Cu₂ZnSnS₄ thin films by direct liquid coating from metal–thiourea precursor Solution, *Sol. Energy Mater. Sol. Cells*. 101 (2012) 46-50.
- [26] Y. Sun, K. Zong, H. Zheng, H. Wang, J. Liu, H. Yan, M. Zhu, Ethylene glycol-based dip coating route for the synthesis of Cu₂ZnSnS₄ thin film. *Mater. Lett.* 92 (2013) 195-197.
- [27] F. Aslan, A. Göktaş, A. Tumbul, Influence of pH on structural, optical and electrical properties of solution processed Cu₂ZnSnS₄ thin film absorbers. *Mater. Sci. Semicond. Process.* 43 (2016) 139-143.
- [28] K. Patel, V. Kheraj, D. V. Shah, C. J. Panchal, N. G. Dhare, Cu₂ZnSnS₄ thin-films grown by dip-coating: Effects of annealing. *J. Alloys. Compd.* 663 (2016) 842-847.
- [29] ICDD, card no: 26-0575
- [30] N. Nakayama, K. Ito, *Applied Surface Science* 92 (1996) 171-175.
- [31] D.E. Milovzorov, AM. Ali, T. Inokuma, Y. Kurata, T. Suzuki, S. Hasegawa "Optical properties of silicon nanocrystallites in polycrystalline silicon films prepared at low temperature by plasma-enhanced chemical vapor deposition" *Thin Solid Films* 382 Z200 I. 47_55.
- [32] I. Tauc, R. Grigorovic, and A. Vancu "Optical properties and Electronic structure of Amorphous Germanium" (1996) *phys. Stat. sol.* 15, 627.

- [33] D. Seo, S. Lim "Effect of sulfur and copper amounts in sol-gel precursor solution on the growth, crystal properties, and optical properties of Cu₂ZnSnS₄ films" (2013) *J Mater Sci: Mater Electron* DOI 10.1007/s10854-013-1314-z.
- [34] S. Islam, M. A. Hossain, H. Kabir, M. Rahaman, M. S. Bashar, M. A. Gafur, A. Kabir, M. M. R. Bhuiyan, F. Ahmed, N. Khatun, "Optical, Structural and Morphological Properties of Spin Coated Copper Zinc Tin Sulfide Thin Films". *Int. J. Thin. Fil. Sci. Tec.* 4, No. 3, 155-161 (2015).

Acknowledgements

This research was supported by the Solar cell Fabrication Lab of IFRD (Institute of Fuel Research and Development (IFRD), Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka.