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A review on the Penternary compound thin films

Ho Soonmin

Faculty of Science, Technology, Engineering and Mathematics,INTI International University, Negeri Sembilan, MALAYSIA.

Address For Correspondence:
Ho Soonmin, Faculty of Science, Technology, Engineering and Mathematics,INTI International University, Negeri Sembilan, MALAYSIA.
E-mail: soonmin.ho@newinti.edu.my

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ABSTRACT

Background: Thin films such as binary, ternary, quaternary and penternary compound have got an enormous interest among the researchers. This is due to they have a great potential for reaching high efficiency at low production cost in solar cell industry. Solar cell can convert the sun energy into electricity. Silicon is a semiconductor material and is a key ingredient in solar cell. However, there are some disadvantages of silicon based solar cells including good silicon feedstock is very expensive and the cost of making a single pure crystal is time consuming. **Objective:** In this work, the main objective is to investigate the preparation and characterization of penternary compound thin films by using different deposition techniques. Currently, researchers are looking for cheaper absorbing materials to replace silicon based solar cells. **Results:** In the past,a variety of thin films such as binary, ternary and quaternary thin films have been successfully produced by many researchers using various deposition techniques. Here, the preparation of penternary thin film such as $Cu(In,Ga)(S,Se)_2$ and $Cu_2ZnSn(SSe)_4$ films was described and reported. Researchers claim that the best solar cell can be fabricated and successfully reach up to 10 % and 12.4 % of power conversion efficiency for $Cu(In,Ga)(S,Se)_2$ and $Cu_2ZnSn(SSe)_4$ thin films, respectively. **Conclusion:** In this work, solution deposition method, electrodeposition method and evaporation technique have been used to prepare penternary thin films such as $Cu(In,Ga)(S,Se)_2$ and $Cu_2ZnSn(SSe)_4$ thin films. The obtained films were characterized by using different tools. The obtained experimental findings show that these thin films could be employed as absorbing materials in photovoltaic application.

INTRODUCTION

Thin films can be defined as a very thin layer of a substance (between a few nanometers to about 100 micrometers) on a supporting material. Thin films technology can be applied to various substrates such as indium tin oxide (ITO) coated glass, microscope glass slide, fluorine doped tin oxide (FTO) coated glass, soda lime glass and tin oxide (SnO_2) coated glass substrate. Researchers found that the obtained films can be tailored to meet the special requirements of a particular application by choosing the deposition technique, substrate materials and deposition materials. In a few decades ago, the concept of thin film based photovoltaic cell was developed due to the main reason such as cost reduction has always been an objective of the solar cell idea. Nowadays, a variety of binary films, ternary films and quaternary films have been developed by using different deposition techniques as reported by many researchers (Table 1).

In this work, preparation of penternary thin films wasdescribed. These films are semiconductor compounds composed of five elements. The properties of these films will be studied by using various tools. Finally, the obtained data will be analyzed and reported.

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Table 1: Chalcogenide metal thin films

Thin films	Deposition technique	Researcher(s)
SnSe	Chemical bath deposition	Anuar *et al* (2012)
SnS	Chemical bath deposition	Anuar *et al* (2011)
	Chemical bath deposition	Anuar *et al* (2011)
PbS	Chemical bath deposition	Ho *et al* (2013)
ZnS	Spray pyrolysis	Dedova *et al* (2005)
	Spray pyrolysis.	Zeng *et al* (2013)
Cu_2S	Chemical bath deposition	Anuar *et al* (2011)
ZnSe	Chemical bath deposition	Anuar *et al* (2011)
PbSe	Chemical bath deposition	Anuar *et al* (2010a)
Ni_4S_3	Chemical bath deposition	Anuar *et al* (2010b)
CdSe	Successive ionic layer adsorption and reaction method	Panthan *et al* (2002)
In_2S_3	Chemical bath deposition	Gopinath *et al* (2013)
FeS_2	Chemical bath deposition	Anuar *et al* (2010c)
Cu_2Te	Electro deposition	He *et al* (2015)
CuS	Chemical bath deposition	Anuar *et al* (2010d)
	Spray pyrolysis	Isac *et al* (2007)
CdS	Flash evaporation method	Murali *et al* (2008)
CdS	Successive ionic layer adsorption and reaction method	Guzeldir *et al* (2012)
$CdS_{0.5}Se_{0.5}$	Chemical bath deposition	Khomane (2013)
$Ni_3Pb_2S_2$	Chemical bath deposition	Ho (2014)
Ag-In-S	Chemical bath deposition	Lin *et al* (2008)
Cu_4SnS_4	Chemical bath deposition	Anuar *et al* (2010e)
CdS:Fe	Flash evaporation method	Dizaji *et al* (2012)
CdZnSe	Chemical bath deposition	Deo *et al* (2014)
$Pb_{1-x}Mn_xS$	Chemical bath deposition	Joshi *et al* (2006)
$CdSe_{0.6}Te_{0.4}$	Electro deposition	Shinde *et al* (2013)
	Chemical bath deposition	Shinde *et al* (2014)
Cu_3SnS_4	Chemical bath deposition	Alias *et al* (2014)
CdMnS	Chemical bath deposition	Oriaku *et al* (2008)
$CuInSe_2$	Chemical bath deposition	Bari *et al* (2006)
Cu_2ZnSnS_4	Chemical bath deposition	Kumar *et al* (2014)
	Chemical bath deposition	Shinde *et al* (2012)
	Chemical bath deposition	Subramaniam *et al* (2014)
Ag-Zn-Sn-S	Chemical bath deposition	Yeh and Cheng (2014)

Literature Survey:

Cu(In,Ga)$(S,Se)_2$ or CIGSS thin films could be applied in solar cells. These absorber materials have a great potential for reaching high efficiency at low production cost. The investigation of internal wave propagation and photon absorption rate was carried out by Richter *et al*. (2013) by using technology computer aided design simulator. Molybdenum films are employed as metallic back electrode during experiment. They conclude that the reflectance of the $MoSe_2$/air interface with mean square error equals to 2.42 in order to get the excellent results for the solar cell application.

Physical vapor deposition (PVD) method was used to produce Cu(In,Ga)$(S,Se)_2$thin films. This method shows more environmentally friendly if compared to other deposition techniques, but it operates at very high temperatures and vacuum conditions. Mario and William (2005) reported that the band gap of 1.5 eV for various sulphur and gallium contents. Also, they claim that the best solar cell can display near 10 % of power conversion efficiency.

Atom probe tomography (APT) has contributed to major advances in materials science such as determine chemical composition and capable for three dimensional imaging.This technique has been used by Keller *et al*. (2013) to investigate the properties of co-evaporated Cu(In,Ga)$(S,Se)_2$films. The APT results show that the selenium concentration was underestimated if compared to energy dispersive analysis X-ray (EDX) results. They further claim that the atomic percentage of selenium was about 45-47 %. Lastly, they figure out that APT results reveal very complex chemical properties of grain boundaries and interiors.

The solar cell consisting of glass/Mo/CIGSSe/CdS/i-ZnO/ZnO:Al was fabricated by Ingo *et al*. (2014). They also suggest that the smallest band gap of the films is significantly increased upon thinning the absorber. They further explain that an increase of the band gap lead to reduction of the saturation current density.

Electrodeposition method was used to prepare Cu(In,Ga)$(S,Se)_2$thin films as reported by Taunier *et al*. (2005). This technique is attracted in terms of cost and able to grow films over large areas of substrates. The experiment findings show that the obtained films are single phase over the whole composition range. They further point out that this method able to prepare large range of sulfur containing films. The results reflect that S/(S+Se) atomic ratio from 0 % to greater than 90 %. Lastly, they found that grain size reducing with increasing sulfur content.

On the other hand, lower toxicity solution based process for the preparation of the $Cu_2ZnSn(SSe)_4$thin films has been presented by Guo *et al*. (2015).The scanning electron micrograph (SEM) indicates that the average grain size is 0.5 to 2 μm for the selenized films. They explain further that these films display a typical bilayer structure with a thickness of 1640 nm. Lastly, the solar cell was fabricated by them. The results show power conversion efficiency (PCE) of 6.4 % with fill factor of 0.554. Other researchers such as Wang *et al*., 2013 (6.03 %), Jiang *et al*., 2013 (6.2 %), Schnabel *et al*., 2013 (7.5 %), Kim *et al*., 2014 (12.4%), Tian *et al*., 2014 (6.83 %)and Zhang *et al*., 2015 (7.86%) also report PCE value according to their experimental results.

Chen *et al*. (2014) described the preparation of $Cu_2ZnSnS_xSe_{4-x}$ films by using solution technique and heating process. They claim that well crystalline thin films lead to highest cell efficiency in dye sensitized solar cell. Lastly, they explain that the charge transport is improved when the porosity and grain boundaries are reduced with the enhanced crystallization.

In this work, the obtained experimental results show that penternary thin films could be used in solar cell application. In other words, metal chalcogenide thin films such as binary, ternary and quaternary thin films could be the best candidate as absorbing material in order to looking for cheaper semiconductor materials.

Conclusion:

In this work, preparation of $Cu(In,Ga)(S,Se)_2$and $Cu_2ZnSn(SSe)_4$thin films have been described by using various deposition methods. The experiment findings show that these films could be used in solar cell application.

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REFERENCES

Alias, M.F.A., I.S. Naji and B.Y. Taher, 2014. Influence of substrate temperatures on the optical properties of thin Cu_3SnS_4 films prepared by CBD. IPASJ International Journal of Electrical Engineering, 2: 1-7.

Anuar, K., W.T. Tan, K.A. Dzulkefly, M.J. Haron, S.M. Ho, M. Shanthi and N. Saravanan, 2010a. Preparation and characterization of PbSe thin films by chemical bath deposition. Jurnal Kimia, 4: 1-6.

Anuar, K., N. Saravanan, W.T. Tan, S.M. Ho and D. Teo, 2010b. Chemical bath deposition of nickel sulphide (Ni_4S_3) thin films. Leonardo Journal of Sciences, 16: 1-12.

Anuar, K., W.T. Tan, M. Jelas, S.M. Ho and S.Y. Gwee, 2010c. Effects of deposition period on the properties of FeS_2 thin films by chemical bath deposition method, Thammasat International Journal of Science and Technology., 15: 62-69.

Anuar, K., W.T. Tan, N. Saravanan, L.K. Khor and S.M. Ho, 2010d. Effects of deposition time on the chemical bath-deposited CuS thin films. Journal of Nepal Chemical Society, 25: 2-8.

Anuar, K., N. Saravanan, K. Zulkefly, S. Atan, W.T. Tan and S.M. Ho, 2010e. Influence of complexing agent (Na_2EDTA) on chemical bath deposited Cu_4SnS_4 thin films, Bulletin of the Chemical Society of Ethiopia, 24: 259-266.

Anuar, K., S.M. Ho, S. Atan and M.J. Haron, 2011a. The effect of the pH value on the growth and properties of chemical bath deposited SnS thin films. Research Journal of Chemistry and Environment, 15: 45-48.

Anuar, K., S.M. Ho, S. Atan, H. Jelas and N. Saravanan, 2011b. Chemical bath deposition of SnS thin films: AFM, EDAX and UV-Visible characterization. Oriental Journal of Chemistry, 27: 1375-1381.

Anuar, K., S.M. Ho, K.S. Lim and N. Saravanan, 2011c. SEM, EDAX and UV-Visible studies on the properties of Cu_2S thin films. Chalcogenide Letters, 8: 405-410.

Anuar, K., S.M. Ho, W.T. Tan, Kelvin and N. Saravanan, 2011d. Composition, morphology and optical characterization of chemical bath deposited ZnSe thin films. European Journal of Applied Sciences, 3: 75-80.

Anuar, K., S.M. Ho, W.T. Tan, S.M. Ho and N. Saravanan, 2012. Temperature-dependent surface topography analysis of SnSe thin films using atomic force microscopy. Asian Journal of Research in Chemistry, 5: 291-294.

Bari, R.H., L.A. Patil and P.P. Patil, 2006. Structural, optical and electrical properties of chemically deposited nonstoichiometric copper indium diselenide films. Bulletin of Materials Science, 29: 529-534.

Chen, H., D. Kou, Z. Chang, W. Zhou, Z. Zhou and S. Wu, 2014. Effect of crystallization of $Cu_2ZnSnS_xSe_{4-x}$ counter electrode on the performance for efficient dye-sensitized solar cells. ACS Applied Materials & Interfaces, 6: 20664-20669.

Dedova, T., M. Krunks, O. Volobujeva, I. Oja, 2005. ZnS thin films deposited by spray pyrolysis technique. Physica Status Solidi (C), 5: 1161-1166.

Deo, S.R., A.K. Singh, L. Deshmukh, L.J. Paliwal and R. Adhikari, 2014. Structural, morphological and optical studies on chemically deposited nanocrystalline CdZnSe thin films. Journal of Saudi Chemical Society, 18: 327-339.

Dizaji, H.R., M. Ghasemian and M.H. Ehsani, 2012. Structural and optical characterization of CdS:Fe thin films prepared by flash evaporation method. Surface Review and Letters, 19: doi: 10.1142/S0218625X12500126.

Gopinath, G.R., R.W. Miles and K.T. R. Reddy, 2013. Influence of bath temperature on the properties of In_2S_3 films grown by chemical bath deposition. Energy Procedia, 34: 399-406.

Guo, J., Y. Pei, Z. Zhou, W. Zhou, D. Kou and S. Wu, 2015. Solution processed $Cu_2ZnSn(S,Se)_4$ thin film solar cells using elemental Cu, Zn, Sn, S and Se powders as source. Nanoscale Research Letters, 10: DOI 10.1186/s11671-015-1045-6.

Guzeldir, B., M. Saglam and A. Ates, 2012. Deposition and characterization of CdS, CuS and ZnS thin films deposited by SILAR method. Acta Physica Polonica A, 121: 33-35.

He, W., H. Zhang, Y. Zhang, M. Liu, X. Zhang and F. Yang, 2015. Electrodeposition and characterization of CuTe and Cu_2Te thin films. Journal of Nanomaterials, http://dx.doi.org/10.1155/2015/240525.

Ho, S.M., K. Anuar and W.T. Tan, 2013. The role of bath temperature in aqueous acidic chemically PbS films. Journal of Basic and Applied Scientific Research, 3: 353-357.

Ho, S.M., 2014. Influence of complexing agent on the growth of chemically deposited $Ni_3Pb_2S_2$ thin films. Oriental Journal of Chemistry, 30: 1009-1012.

Ingo, R., K. Jan, P. Jurgen, D. Thomas and A. Alejandro, 2014. One dimensional simulation of sequentially processed $Cu(In_{1-x}Ga_x)(Se_{1-y}S_y)$ heterojunction solar cells with vertically graded absorber composition. Physica B, 439: 9-13.

Isac, L.A., A. Duta, A. Kriza, I.A. Enesca, M. Nanu, 2007. The growth of CuS thin films by spray pyrolysis. Journal of Physics: Conference Series, 61: 477-481.

Jiang, M., F. Lan, X. Yan and G. Li, 2013.$Cu_2ZnSn(S_{1-x}Se_x)_4$ thin film solar cells prepared by water based solution process. Physica Status Solidi, 8: 223-227.

Joshi, R.K., P. Kumar, H.K. Sehgal and A. Kanjilal, 2006. Study of solution grown variable band gap $Pb_{1-x}Mn_xS$ semiconductor nanoparticle films. Journal of the Electrochemical Society, 153: C707-C712.

Keller, J., R. Schlesiger, I. Riedel, J. Parisi, G. Schmitz, A. Avellan and T. Dalibor, 2013. Grain boundary investigations on sulfurized $Cu(In,Ga)(S,Se)_2$ solar cells using atom probe tomography. Solar Energy Materials & Solar Cells, 117: 592-598.

Khomane, A.S., 2013. Crystallographic and microscopic properties of ternary $CdS_{0.5}Se_{0.5}$ thin films. Optik, 124, 2432-2435.

Kim, J., H. Hiroi, T.K. Todorov, O. Gunawan, M. Kuwahara, T. Gokmen, D. Nair, M. Hopstaken, B. Shin, Y.S. Lee, W. Wang, H. Sugimoto and D.B. Mitzi, 2014. High efficiency $Cu_2ZnSn(S,Se)_4$ solar cells by applying a double In_2S_3/CdS emitter. Advanced Materials, 26: 7427-7431.

Kumar, A.V., N.K. Park and E.T. Kim, 2014. A simple chemical approach for the deposition of Cu_2ZnSnS_4 thin films. Physica Status Solidi, 211: 1857-1859.

Lin, L.H., C.C. Wu, C.H. Lai and T.C. Lee, 2008. Controlled deposition of silver indium sulfide ternary semiconductor thin films by chemical bath deposition. Chemistry of Materials, 20: 4475-4483.

Mario, G., and N.S. William, 2005. Five source PVD for the deposition of $Cu(In_{1-x}Ga_x)(Se_{1-y}S_y)_2$ absorber layers. Thin Solid Films, 480-481: 33-36.

Murali, K.R., C. Kannan, P.K. Subramanian, 2008. Photoelectrochemical properties of flash evaporated cadmium sulphide films. Chalcogenide Letters, 5: 195-199.

Oriaku, C.I., F.I. Ezema and J.C. Osuwa, 2008. Fabrication and optical constants of CdMnS ternary thin films deposited by chemical bath. Pacific Journal of Science and Technology, 10: 413-416.

Panthan, H.M., B.R. Sankapal, J.D. Desai and C.D. Lokhande, 2002. Preparation and characterization n of nanocrystalline CdSe thin films deposited by SILAR method. Materials Chemistry and Physics,78: 11-14.

Richter, M., C. Schubbert, P. Eraerds, I. Riedel, J. Keller, J. Parisi, T. Dalibor, A. Avellan, 2013. Optical characterization and modeling of $Cu(In,Ga)(Se,S)_2$ solar cells with spectroscopic ellipsometry and coherent numerical simulation. Thin Solid Films, 535: 331-335.

Schnabel, T., M. Low and E. Ahlswede, 2013. Vacuum free preparation of 7.5 % efficient $Cu_2ZnSn(S,Se)_4$ solar cells based in metal salt precursors. Solar Energy Materials & Solar Cells, 117: 324-328.

Shinde, S.K., D.P. Dubal, G.S. Ghodake and V.J. Fulari, 2014. Synthesis and characterization of chemically deposited flower like $CdSe_{0.6}Te_{0.4}$ thin films for solar cell application. Materials Letters, 126: 17-19.

Shinde, S.K., J.V. Thombare, D.P. Dubal and V.J. Fulari, 2013. Electrochemical synthesis of photosensitive nano-nest like $CdSe_{0.6}Te_{0.4}$ thin films. Applied Surface Science, 282: 561-565.

Shinde, N.M., C.D. Lokhande, J.H. Kim and J.H. Moon, 2012. Low cost and large area novel chemical synthesis of Cu_2ZnSnS_4 (CZTS) thin films. Journal of Photochemistry and photobiology A: Chemistry, 235: 14-20.

Subramaniam, E.P., G. Rajesh, N. Muthukumarasamy, M. Thambidurai, V. Asokan and D. Velauthapillai, 2014. Solar cells of Cu_2ZnSnS_4 thin films prepared by chemical bath deposition method. Indian Journal of Pure & Applied Physics, 52: 620-624.

Taunier, S., J. Sicx, P.P. Grand, A. Chomont, O. Ramdani, 2005.Cu(In,Ga)$(S,Se)_2$ solar cells and modules by electrodeposition. Thin Solid Films, 480-481: 526-531.

Tian, Q., G. Wang, W. Zhao, Y. Chen, Y. Yang, L. Huang and D. Pan, 2014. Versatile and low toxic solution approach to binary, ternary and quaternary metal sulfide thin films and its application in $Cu_2ZnSn(S,Se)_4$ solar cells. Chemsitry of Materials, 26: 3098-3103.

Wang, G., W. Zhao, Y. Cui, Q. Tian, S. Gao, L. Huang and D. Pan, 2013. Fabrication of a $Cu_2ZnSn(S,Se)_4$ photovoltaic device by a low toxicity ethanol solution process. ACS Applied Materials & Interfaces, 5: 10042-10047.

Yeh, L.Y. and K.W. Cheng, 2014. Preparation of the Ag-Zn-Sn-S quaternary photo electrodes using chemical bath deposition for photoelectrochemical applications. Thin Solid Films, 558: 289-293.

Zeng, X., S.S. Pramana, S.K. Batabyal, S.G. Mhaisalkar, X.D. Chen, K.B. Jinesh, 2013. Low temperature synthesis of wurtzite zinc sulfide (ZnS) thin films by chemical spray pyrolysis. Physical Chemistry Chemical Physics, 15: 6763-6768.

Zhang, R., S.M. Szczepaniak, N.J. Carter, C.A. Handwerker and R. Agrawal, 2015. A versatile solution route to efficient $Cu_2ZnSn(S,Se)_4$ thin film solar cells. Chemistry of Materials, 27: 2114-2120.