International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.9, No.03 pp 390-395, 2016

Metal Selenide semiconductor thin films: A Review

Ho Soon Min*

***Faculty of Science, Technology, Engineering and Mathematics, INTI International University, 71800, Nilai, Negeri Sembilan, Malaysia.**

Abstract: Recent research has emphasized on the preparation of metal chalcogenide thin films such as metal sulfide, metal selenide and metal telluride by using various deposition techniques. Because of these thin films possess very useful physical properties and could be found in many technical applications. In this review paper, study of the properties of metal selenide thin films will be reported.
Keyword: thin films, semiconductor, chemical bath deposition, selenide, electro deposition.

Introduction:

Selenium is located in Group 6 of the periodic table. It could be found in water, soil and some foods. Human need small amount of selenium due to its antioxidant properties, therefore protect cells from damage. Nowadays, the preparation of the metal selenide thin films has been explored by number of deposition techniques. Generally speaking, these deposition techniques are classed as either physical or chemical method. Usually, thin films prepared by chemical deposition methods are less expensive than those prepared by the capital intensive physical deposition technique.

Polycrystalline thin films have received a great deal of attention because of their potential application in the area of electronic and optoelectronic devices. Recent research has focused on the synthesis of metal chalcogenide thin films such as metal sulfide (SnS_2(1), MnS_2(2), MnS (3), CuS (4), Bi_2S_3(5), Ni_4S_3(6), Cu_2S (7),CdS (8), FeS (9), FeS_2(10), ZnS(11), NiS(12), PbS(13), Sb_2S_3(14), $Ni_3Pb_2S_2$(15), Cu_4SnS_4(16-18), $SnS_{0.5}Se_{0.5}$(19),Cu_3SnS_4(20)), metal selenide and metal telluride (CdTe(21), Sb_2Te_3(22),ZnTe(23), Bi_2Te_3(24), $CdSe_{0.6}Te_{0.4}$(25), $Cd_{1-x}Zn_xTe$(26), $Zn_{1-x}Hg_xTe$(27), $GaCuTe_2$(28), Ag_2SeTe (29) and GeSbTe (30)) using various methods. These materials are of practical interest because of very useful optical, mechanical and electrical properties. Here, in this review paper, an investigation of the properties of metal selenide thin films will be reported.

Literature survey:

In recent years, synthesis and characterization of semiconductor thin films are of great importance. There are many reports available on the growth of different types of thin films by various techniques as shown below.

Many scientists have reported that the use of Sb_2Se_3 thin films in solar cells(31,32). Several deposition techniques such as successive ionic layer adsorption and reaction(33), thermal evaporation(34), chemical bath deposition(35) and electro deposition method(36)have been developed to produce these compounds. Rodriguez-Lazcano et al (35) have reported that the films are photosensitive, with dark and photoconductivity values are $2X10^{-8}$ and 10^{-6} $(\Omega cm)^{-1}$, respectively.

Cadmium selenide thin films have been prepared by various deposition methods such as chemical bath deposition(37), spray pyrolysis(38), vacuum evaporation(39), electro deposition (40) and thermal evaporation(41). Literature review reveals that the band gap and absorption coefficient value are 1.8 eV and $0.58X10^5cm^{-1}$, respectively. The conductivity of CdSe thin films is n-type(38,40), indicating that they can be utilized in solar cells, photo detection, light amplifiers and light emitting diodes applications.

Abundant literature is available on the preparation of tin selenide films such as chemical bath deposition(42), spray pyrolysis(43), reactive evaporation(44), thermal evaporation(45) and electro deposition method(46).Bindu and Nair (47) have reported that the band gap is in the range of 1 to 1.27 eV, while the electrical conductivity is 0.01-0.2 $\Omega^{-1}cm^{-1}$.Wahab et al (48) have reported that the absorption efficient was observed to be larger than 10^5cm^{-1}. On the other hand, the SnSe films were electrochemically deposited onto Au (111) substrates by Mustafa and Ilkay(46). They found that the stoichiometric SnSe films could be obtained at -0.5 V. Also, the films obtained are direct transition with band gap of 1.3 eV.

Zinc selenide thin films play important roles in optoelectronic devices. These films have been successfully prepared using chemical bath deposition(49), thermal evaporation(50), vacuum evaporation (51) and electrodeposition method(52). Several researchers have reported on the electro deposition of ZnSe films from aqueous solution on different substrates such as fluorine doped tin oxide(53), stainless steel, indium tin oxide (52) and zinc substrate. ZnSe thin films have a large value of band gap among the group II-VI compound. The band gap for these films was found to be 2.7 eV(54) with a direct transition.

Copper selenide films have a wide direct band gap in the range between 2.1-2.7 eV. As shown in literature reports, they are normally crystallized in hexagonal and orthorhombic (55) structure according to X-ray diffraction studies. Numerous methods have been employed to obtain these films such as chemical bath deposition(56), pulsed laser deposition(57), thermal evaporation(58) and electro deposition (59). Conductivity of 1 $X10^8\Omega^{-1}cm^{-1}$ and sheet resistance between 8-24Ω was obtained from experiment results indicating that CuSe filmscould be used in the solar cell production.

Nickel selenide thin films are important semiconducting materials and could be considered as one of the absorbent materials used in photoelectrochemical cell. They are direct transition semiconductors (60) and the band gap values obtained were estimated to be 2.11-2.52 eV. Hankare et al (61) have reported that the chemical bath deposited nickel selenide thin films revealed polycrystalline nature with hexagonal system. They also claimed that the band gap was 1.6 eV with p-type conduction. Meanwhile, Zainal et al (62) have found that the electro deposition in the presence of triethanolamine in aqueous solution was found to offer some improvement in the synthesis of NiSe films. Their photoelectrochemical analysis indicates outstanding photo activity for the films deposited at -0.7V.

As far as I know, over the last few decades, there have been a few research studies on the preparation of ternary [Table 1] and quaternary metal selenide [Table 2] thin films by using different deposition techniques.In future, extensive research should be carried out to grow various kinds of metal selenide thin films due to selenium is considered to be non-toxic substances. It is because of the obtained experiment findings not only broaden our knowledge on mesoscopic physics phenomena, but also on fundamental theories about the effect of its dimension, size and morphology.

Table 1: Ternary metal selenide thin films

Thin films	Technique	Reference
CdZnSe	Photoelectrochemical deposition	Ham et al, 2008(63)
$CuInSe_2$	Thermal evaporation	Nordin et al, 2014 (64)
CdSSe	Thermal evaporation	Kale et al, 2014 (65)
$CdIn_2Se_4$	Potentiostatic deposition	Balladores et al, 2014 (66)
$CuGaSe_2$	Aerosol Assisted Chemical Vapour deposition	Mahboob et al, 2014 (67)

Table 2: Quaternary metal selenide thin films

Thin films	Technique	Reference
$CuIn_{0.7}Ga_{0.3}Se_2$	Aerosol Assisted Chemical Vapour deposition	Mahboob et al, 2014 (67)
$CuIn(S,Se)_2$	Spin coating	Arnou et al, 2015 (68)
$Cu_2ZnSnSe_4$	Electro deposition	Jeon et al, 2014 (69)
CuZnSnSe	Vacuum evaporation	Sabli et al, 2013 (70)

Conclusion:

In this review paper, as well known, various deposition techniques have been used in preparing metal selenide thin films. The obtained research findings indicating that these films have potential application in solar cell, electronic andoptoelectronic devices.

Reference

1. Sankapal BR, Mane RS, Lokhande CD. Successive ionic layer adsorption and reaction (SILAR) method for the deposition of large area (~10cm^2) tin sulfide SnS_2 thin films. Materials Research Bulletin. 2000, 35; 2027-2035.
2. Anuar K, Tan WT, Ho SM, Abdul HA, Ahmad HJ, SaravananN. Effect of solution concentration on MnS_2 thin films deposited in a chemical bath. Kasetsart Journal: Natural Science.2010, 44; 446-453.
3. Anuar K, Ho SM.Deposition and characterization of MnS thin films by chemical bath deposition method. International Journal of Chemistry Research.2010, 1; 1-5.
4. Anuar K, Tan WT, Saravanan N, Khor LK, Ho SM.Effects of deposition time on the chemical bath-deposited CuS thin films. Journal of Nepal Chemical Society.2010, 25; 2-8.
5. Ahire RR, Sharma RP. Photoelectrochemical characterization of Bi_2S_3 thin films deposited by modified chemical bath deposition. Indian Journal of Engineering & Materials Sciences. 2006, 13; 140-144.
6. Anuar K, Nagalingam S, Tan WT, Ho SM, Darren T. Chemical bath deposition of nickel sulphide (Ni_4S_3) thin films. Leonardo Journal of Sciences. 2010, 16; 1-12.
7. Anuar K, Ho SM, Lim KS, Nagalingam S. SEM, EDAX and UV-Visible studies on the properties of Cu_2S thin films. Chalcogenide Letters. 2011, 8; 405-410.
8. Guzeldir B, Saglam M, Ates A. Deposition and characterization of CdS, CuS and ZnS thin films deposited by SILAR method. ActaPhysicaPolonica A. 2012, 121; 33-35.
9. Anuar K, Ho SM, Loh YY, Saravanan N. Structural and morphological characterization of chemical bath deposition of FeS thin films in the presence of sodium tartrate as a complexing agent. Silpakorn University Science and Technology Journal. 2011, 4; 36-42.
10. Anuar K, Tan WT, Saravanan N, Ho SM, GweeSY. Influence of pH values on chemical bath deposited FeS_2 thin films. Pacific Journal of Science and Technology.2009, 10; 801-805.
11. Anuar K, Ho SM, Abdul HA, Noraini K, SaravananN. Influence of the deposition time on the structure and morphology of the ZnS thin films electrodeposited on indium tin oxide substrates. Digest Journal of Nanomaterials and Biostructures.2010, 5; 975-980.
12. Anuar K, Ho SM, Tan WT, NgaiCF. Influence of triethanolamine on the chemical bath deposited NiS thin films. American Journal of Applied Sciences.2011, 8; 359-361.
13. Oriaku CI, Osuwa JC. Analysis of thin chalcogenide PbS films prepared from chemical bath. Pacific Journal of Science and Technology. 2008, 9; 461-467.
14. Nair MTS, Peria Y, Campos J, Garcia VM, Nair PK. Chemically deposited Sb_2S_3 and Sb_2S_3-CuS thin films. Journal of the Electrochemical Society. 1998, 145; 2113-2120.
15. Ho SM. (2014). Influence of complexing agent on the growth of chemically deposited $Ni_3Pb_2S_2$ thin films. Oriental Journal of Chemistry.2014, 30; 1009-1012.
16. Anuar K, Tan WT, Atan MS, Dzulkefly K, Ho SM, Jelas HM, Saravanan N. Cyclic voltammetry study of copper tin sulfide compounds. Pacific Journal of Science and Technology.2007, 8; 252-260.
17. Anuar K, Ho SM, Tan WT, Atan MS, Kuang D, Jelas HM, SaravananN. Effects of solution concentration on the properties of Cu_4SnS_4 thin films. Materials Science (Medziagotyra).2008, 14; 101-105.

18. Anuar K, Saravanan N, Tan WT, Atan S, Kuang Z, Haron MJ, Ho SM. Effect of Deposition Period and pH on Chemical Bath Deposited Cu_4SnS_4 Thin Films. Philippine Journal of Science.2009, 138; 161-168.
19. Subramanian B, Sanjeeviraja C, Jayachandran M. Materials properties of electrodeposited $SnS_{0.5}Se_{0.5}$ films and characterization of photoelectrochemical solar cells. Materials Research Bulletin. 2003, 38; 899-908.
20. Alias MFA, Naji IS, Taher BY. Influence of substrate temperatures on the optical properties of thin Cu_3SnS_4 films prepared by CBD. IPASJ International Journal of Electrical Engineering. 2014, 2; 1-7.
21. Hussain KMA, Mahmood ZH, Syed IM, Behum T, Faruqe T, Parvin J. Thermal vacuum deposition of cadmium telluride thin films solar cell material. American Journal of Materials Science and Application. 2014, 2; 91-95.
22. Gu D, Nminibapiel D, Baumgart H, Robinson H, Kochergin V. Atomic layer deposition of antimony telluride thin films using $(Me_3Si)_2Te$ with $SbCl_3$ as precursors. ECS Transactions.2011, 41; 255-261.
23. Shanmugan S, Mutharasu D. Optical properties and surface morphology of zinc telluride thin films prepared by stacked elemental layer method. Materials Science (Medziagotyra).2012, 18; 107-111.
24. Dheepa J, Sathyamoorthy R, Velumani S. Characterization of bismuth telluride thin films-flash evaporation method. Materials Characterization.2007, 58; 782-785.
25. Shinde SK, Thombare JV, Dubal DP, Fulari VJ. Electrochemical synthesis of photosensitive nano-nest like $CdSe_{0.6}Te_{0.4}$ thin films. Applied Surface Science. 2013, 282; 561-565.
26. Rajavel D, Zinck JJ. Metalorganic molecular beam epitaxial growth of high quality of $Cd_{1-x}Zn_xTe$ $(0<x<0.27)$ films. Applied Physics Letters.1993, 63; 322-324.
27. Mahalingam T, Kathalingam A, Velumani S, Lee SN, Moon HS, Kim YD. Electrosynthesis and studies on $Zn_{1-x}Hg_xTe$ thin films. Journal of New Materials for Electrochemical Systems.2007, 10;21-25.
28. Gopalam BSV, Murali KR. Electric conduction in copper gallium telluride thin films. Materials Chemistry and Physics. 1986, 15; 463-468.
29. Vijayan C, Soundararajan N, Chandramohan R, Dhanasekaran V, Sundaram K, Neyvasagam K, Mahalingam T. Morphological properties of Ag_2SeTe nanofilms prepared by thermal evaporation. Journal of Microscopy.2011, 243; 267-272.
30. Yoshihisa F, Yoshitaka S, Takashi K.Amorphous thin GeSbTe phase change films prepared by radical assisted metal organic chemical vapor deposition. Thin Solid Films.2015, 583; 55-59.
31. Liu XS, Chen C, Wang L, Zhong J, Luo M, Chen J, Xue DJ, Li DB, Zhou Y, Tang J. Improving the performance of Sb_2Se_3 thin film solar cells over 4% by controlled addition of oxygen during film deposition. Progress in Photo voltaic. 2015. DOI: 10.1002/pip.2627.
32. Zhou Y, Wang L, Chen SY, Qin SK, Liu XS, Chen J, Xue DJ, Luo M., Cao YZ, Cheng YB, Sargent EH, Tang J. Thin films Sb_2Se_3photovoltaics with oriented one dimensional ribbons and benign grain boundaries. Nature Photonics.2015, 9; 409-415.
33. Pathan HM, Lokhande CD. Deposition of metal chalcogenide thin films by successive ionic layer adsorption and reaction (SILAR) method. Bulletin of Materials Science. 2004, 27; 85-111.
34. Liu XS, Chen J, Luo M, Leng MY, Xia Z, Zhou Y, Qin SK, Xue DJ, Lv L, Huang H, Niu DM, Tang J. Thermal evaporation and characterization of Sb_2Se_3 thin film for substrate Sb_2Se_3/CdS solar cells. ACS Applied Materials & Interfaces.2014, 6; 10687-10695.
35. Rodriguez-Lazcano Y, Pena Y, Nair MTS, Nair PK. Polycrystalline thin films of antimony selenide via chemical bath deposition and post deposition treatments. Thin Solid Films. 2005, 493; 77-82.
36. Ngo TT, Chavhan S, Kosta I, Miguel O, Grande HJ, Zaera RT. Electro deposition of antimony selenide thin films and application in semiconductor sensitized solar cells. ACS Applied Materials Interfaces. 2014, 6; 2836-2841.
37. Nawfal YJ, Marwa TM, Noor AM. The optical and electrical properties of CdSe thin films prepared by CBD technique. Rafidain Journal of Science.2012, 23; 116-125.
38. Yadav AA, Barote MA, Masumdar EU., Studies on cadmium selenide (CdSe) thin films deposited by spray pyrolysis. Materials Chemistry and Physics. 2010, 121; 53-57.
39. Fujii M, Kawai T, Kawai S. Photoelectrochemical properties of cadmium chalcogenide thin films prepared by vacuum evaporation. Solar Energy Materials.1988, 18; 23-35.
40. Chowdhury RI, Islam MS, Sabeth F, Mustafa G, Farhad SFU, Saha DK, Chowdhury FA, Hussain S, Islam ABMO. Characterization of electrodeposited cadmium selenide thin films. Dhaka University Journal of Science. 2012, 60; 137-140.

41. Rajendra BV, Kasturi VB, Shivakumar GK. Photoconductivity in vacuum deposited cadmium selenide thin films. Indian Journal of Engineering & Materials Sciences. 2004, 11; 217-220.
42. Anuar K, Ho SM, Tan WT, SaravananN. Temperature-dependent surface topography analysis of SnSe thin films using atomic force microscopy. Asian Journal of Research in Chemistry. 2012, 5; 291-294.
43. Amaraj L, Jayachandran M,Anjeeviraja CS. Preparation and characterization of tin diselenide thin film by spray pyrolysis technique. Materials Research Bulletin. 2004, 39; 2193-2201.
44. John KJ, Pradeep B, Mathai E. Tin selenide (SnSe) thin films prepared by reactive evaporation. Journal of Materials Science. 1994, 29; 1581-1583.
45. Indirajith R, Srinivasan TP,Ramamurthi K, Gopalakrishnan R. Synthesis, deposition and characterization of tin selenide thin films by thermal evaporation technique. Current Applied Physics. 2010, 10; 1402-1406.
46. Mustafa B, Ilkay S.Electrodeposition and growth mechanism of SnSe thin films. Applied Surface Science.2011, 257; 2944-2949.
47. Bindu K, Nair PK. Semiconducting tin selenide thin films prepared by heating Se-Sn layers. Semiconductor Science and Technology. 2004,19;doi:10.1088/0268-1242/19/12/003.
48. Wahab YB, Hutagalung SD, Sakrani SB. Optical absorption in tin selenide thin films. Proc. SPIE 3175, Third International Conference on thin film physics and applications.1998, 295;doi:10.1117/12.300689.
49. Anuar K, Ho SM, Kelvin, Tan WT, SaravananN. Influence of pH on the morphology properties of ZnSe thin films studied by atomic force microscopy. European Journal of Scientific Research.2011, 66; 592-599.
50. Taj MK, Muhammad FM, Arshad M, Shah A, Raza Q, Amjid I, Aziz U. Synthesis of thermally evaporated ZnSe thin film at room temperature. Thin Solid Films.2011, 519; 5971-5977.
51. Antohe S, Ion L, Girtan M, Toma O. Optical and morphological studies of thermally vacuum evaporated ZnSe thin films. Romanian Reports in Physics.2013, 65; 805-811.
52. Nweze CI, Ekpunobi AJ. Electrodeposition of zinc selenide films on different substrates and its characterization. International Journal of Scientific & Technology Research.2014, 3; 201-203.
53. Gudage YG, Deshpande NG, Sagade AA, Sharma R. Room temperature electro synthesis of ZnSe thin films. Journal of Alloys and Compounds. 2009, 488; 157-162.
54. Castiblanco R, Vargas J, Morales J, Torres J, Pardo A. Determination of the optical properties of ZnSe thin films using the transfer matrix method. Journal of Physics: Conference Series.2014, 480; doi:10.1088/1742-6596/480/1/012025.
55. Ramesh K, Thanikaikarasan S, Bharathi B. Structural, morphological and optical properties of copper selenide thin films. International Journal of ChemTech Research.2014, 6; 5408-5411.
56. Garcia VM, Nair PK, Nair MTS. Copper selenide thin films by chemical bath deposition. Journal of Crystal Growth. 1999, 203; 113-124.
57. Xue MZ, Zhou YN, Zhang B, Yu L, Zhang H, Fu ZW. Fabrication and electrochemical characterization of copper selenide thin films by pulsed laser deposition. Journal of the Electrochemical Society.2006, 152; A2262-A2268.
58. Rajesh D, Chandrakanth RR., Sunandana CS. Annealing effects on the properties of copper selenide thin films for thermoelectric applications. IOSR Journal of Applied Physics, 2013, 4; 65-71.
59. Bhattacharya RN, Fernandez AM, Contreras MA, Keane J, Tennant AL, Ramanathan K, Tuttle JR, Noufi RN, Hermann AM.Electrodeposition of In-Se, Cu-Se and Cu-In-Se thin films. Journal of the Electrochemical Society.1996, 143; 854-858.
60. Anuar K, Tan WT, Abdullah AH, Jelas HM, Saravanan N, Ho SM, Yazid M. Chemical bath deposition of NiSe thin films from alkaline solutions using triethanolamine as complexing agent. Oriental Journal of Chemistry. 2009, 25; 813-816.
61. Hankare PP, Jadhav BV, Garadkar KM, Chate PA, Mulla IS, Delekar SD. Synthesis and characterization of nickel selenide thin films deposited by chemical method. Journal of Alloys and Compounds. 2010, 490; 228-231.
62. Zainal Z, Saravanan N, Mien HL. Electro deposition of nickel selenide thin films in the presence of triethanolamine as a complexing agent. Journal of Materials Science: Materials in electronics. 2005, 16; 111-117.
63. Ham SY, Jeon SY, Lee UK, Paeng KJ, Myung NS. Photoelectrochemical deposition of CdZnSe thin films on the Se-modified Au electrode. Bulletin of the Korean Chemical Society. 2008, 29; 939-942.

64. Nordin S, Zainal AT, Chang CB, Wan MMY, Zulkarnain Z, Hikmat S, Josephine LYC, Masatoshi F. Deposition and characterization of SnSe and $CuInSe_2$ thin films by thermal evaporation technique from synthesized SnSe and $CuInSe_2$ sources. Sains Malaysian. 2014, 43; 1061-1067.
65. Kale MS, Talele NT, BhavsarDS. Preparation and studies of nanostructured thin films of $(CdS)_{0.8}Se_{0.2}$. International Journal of Scientific and Research Publications. 2014, 4; 1-4.
66. Balladores Y, Marquez J, Martinez Y, Marquez OP, Manfredy L, Lopez-Rivera SA. Double potentiostatic deposition and characterization of $CdIn_2Se_4$ semiconductor. ARPN Journal of Science and Technology. 2014, 4; 439-446.
67. Mahboob S, Malik SN, Haider N, Nguyen CQ, Malik MA, Brien PO. Deposition of binary, ternary and quaternary metal selenide thin films from diisopropyldiselenophosphinato-metal precursors. Journal of Crystal Growth. 2014, 394; 39-48.
68. Arnou P, Cooper CS, Malkov AV, Bowers JW, Walls JM. Solution processed $CuIn(S,Se)_2$ absorber layers for application in thin film solar cells. Thin Solid Films. 2015, 582; 31-34.
69. Jeon JO, Lee KD, Oh LS, Seo SW, Lee DK, Kim HG, Jeong JH, Ko MJ, Kim BS, Son HJ, Kim JY. Highly efficient copper-zinc-tin-selenide (CZTSe) solar cells by electrodeposition. ChemSusChem, 2014, 7;DOI: 10.1002/cssc.201301347.
70. Sabli N, Talib ZA, Yunus WMM, Zainal Z, Hilal HS, Fujii M.CuZnSnSe thin film electrodes prepared by vacuum evaporation: Enhancement of surface morphology and photoelectrochemical characteristics by argon gas. Materials Science Forum 2013, 756; 273-280.

*****