Middle-East Journal of Scientific Research 24 (7): 2235-2238, 2016
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2016.24.07.23674

Synthesis of Thin Films on Flexible Substrates: A Review

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Abstract: Preparation and characterization of thin films have been successfully deposited on various types of substrates including rigid substrate and flexible substrates. In this work, flexible substrates such as cloth, viewfoils, threads, titanium foil, molybdenum foil, polycarbonate, polyethylene terephthalate, polyimide and plastic foilwill be discussed as reported by many researchers. The spin coated CdTe films prepared on to polyimide substrate show an efficiency of 11 % under AM 1.5 illuminations. The obtained experimental results support that these films could be used in solar cell application.

Key words: Flexible substrate · Titanium foil · Plastic · Polymer · Thin films · Solar cells

INTRODUCTION

In the past, most of the chalcogenide thin films were prepared on rigid substrate such as fluorine doped tin oxide substrate [1-4], quartz [5-7], stainless steel [8-10], molybdenum soda lime glass [11-13], titanium substrate [14-17], tin oxide substrate [18-20], microscopy glass slide [21-39] and indium tin oxide coated glass substrate [40-49]. Recently, the flexible substrate was used by many researchers due to some reasons such as they are cheap, lightweight, durable and resistant to high temperature fabrication processes. It means that the fabrication of chalcogenide thin films on the glass substrates has been replaced by the flexible substrate. The obtained films could be used in the field of microelectronics, circuit board optics, sensors, outer space materials and photovoltaic cells.

The objective of this paper is to report the preparation of metal chalcogenide thin films onto flexible substrate. The obtained films were characterized by using various tools such as XRD, FTIR, SEM.

Literature Survey: Cadmium sulfide thin films have been deposited on different flexible substrates such as cloth, viewfoils and threads by using chemical bath deposition method as proposed by Shur *et al.*, 2002 [50]. The deposition process was carried out at bath temperatures of 60-70 °C from solutions containing cadmium citrate complex-ions and thiourea. The scanning electron microscopy (SEM) technique shows that the obtained chemical bath deposited films are nanocrystalline grains. In addition, the X-ray diffraction (XRD) data support these films are hexagonal structure with a very high degree of crystallinity.

The role of flexible substrates such as titanium foil (Ti) and molybdenum foil (Mo) in the growth of Cu_2ZnSnS_4 (CZTS) thin films was investigated by Sebnem *et al.,* 2015 [51]. According to X-ray diffraction patterns, the existence of rutile phase of TiO_2 could be identified in the Ti-CZTS films. Meanwhile, binary secondary phases of SnS could be detected in Mo-CZTS films. The obtained results show that titanium foil is preferred because of its low cost and with nearly equal coefficients of thermal expansion to that of CZTS films. Lastly, they suggest these films lightweight and flexible substrate is feasible for roll to roll manufacturing. Further, they conclude that these materials could be employed for solar cell applications.

Radio Frequency magnetron sputtering was used to prepare CdS films on flexible polymer substrates including polycarbonate and polyethylene terephthalate as suggested by Park *et al.*, 2014 [52]. They select this deposition method due to some reasons such as high deposition rates, high purity film and excellent uniformity on large area substrates. They observe that the optical transmittance was increased as the sputtering pressure was increased. In the XRD studies, they conclude that the crystallinity and the preferred orientation toward *c*-axis in hexagonal phase were improved as the sputtered CdS films were prepared at lower pressure.

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CdTe films solar cells have shown long term stable performance as described by Romeo *et al.*, 2004 [53]. The spin coated CdTe films prepared on to polyimide substrate show an efficiency of 11 % under AM 1.5 illuminations. They explain that flexible CdTe films are the best candidate for terrestrial and space applications. These films are low cost and easily deployable power generators in space. Additionally, these materials show good tolerance against proton and electron irradiation.

CDs and ZnS films have been successfully formed by using vacuum thermal evaporation method as described by Gupta *et al*., 2013 [54]. Polyethylene terephthalate (PET) was employed as flexible substrates during the deposition process due to its high mechanical strength. Fourier transforms infrared (FTIR) investigations support that the ions of cadmium sulfide and zinc sulfide have been attached to the polymer chain of polyethylene terephthalate. In terms of mechanical study, they can conclude that the glass transition temperature of CdS-PET films is larger than ZnS-PET films. They explain that it is due to the size of CdS particle is lower than ZnS particle as supported by using X-ray diffraction data.

CdS films were synthesized on transparent plastic foil substrate using pulsed laser deposition method as reported by Acharya *et al.*, 2007 [55]. They observe that the obtain films are good adhesion, good polycrystalline texture, flat surface and room temperature photosensitivity with a blue shifted peak at 2.54 eV. Finally, they conclude that these materials could be used for a photonic application.

Polyethylene terephthalate polymer was used as substrate during the deposition of zinc sulfide thin films as reported by Yoo *et al.*, 2013 [56]. They claim that band gap energy increases with reducing radio frequency powers. They also figure out that the band gap of zinc sulfide films deposited on flexible substrates is less than that of ZnS films on the rigid substrate by 0.28 eV. Lastly, they comment that transmittance of these films degrades because of surface defects and complex internal structure.

CONCLUSION

There are several flexible substrates have been used by many researchers in order to prepare metal chalcogenide thin films. The experiment findings support that these films could be used in solar cell and photonic applications.

ACKNOWLEDGMENTS

Inti International University is gratefully acknowledged for the financial support of this work.

REFERENCES

1. Bhattacharya, C. and J. Datta, 2007. Synthesis of nanostructured Cd-Se-Te films thorugh periodic voltammetry for photoelectrochemical applications. J. Solid State Electrochem.,11: 215-222.
2. Pistone, A., A.S. Arico, P.L. Antonucci, D. Silvestro and V. Antonucci, 1998. Preparation and characterization of thin film ZnCuTe semiconductors. Sol. Energy Mater. Sol. Cells, 53: 255-267.
3. Jain, K., R.K. Sharma, S. Kohli, K.N. Sood and A.C. Rastogi, 2003. Electrochemical deposition and characterization of cadmium indium telluride thin films for photovoltaic application. Curr. Appl. Phys., 3: 251-256.
4. Mahalingam, T., S. Thanikaikarasan, R. Chandramohan, M. Raja, C. Sanjeeviraja, J.H. Kim and Y.D. Kim, 2007. Effects of bath temperature in electrodeposited $FeSe_2$ thin films. Mater. Chem. Phys., 106: 369-374.
5. Yamaguchi, T., Y. Yamamoto, T. Tanaka and A. Yoshida, 1999. Preparation and characterization of (Cd,Zn)S thin films by chemical bath deposition for photovoltaic devices. Thin Solid Films, 343-344: 516-519.
6. Sahraei, R., G.M. Aval and A. Goudarzi, 2008. Compositional, structural and optical study of nanocrystalline ZnS thin films prepared by a new chemical bath deposition route. J. Alloys Compd., 466: 488-492.
7. Wagh, B.G. and D.M. Bhagat, 2004. Some studies on preparation and characterization of cadmium sulphide films. Curr. Appl. Phys., 4: 259-262.
8. Patil, V.B., G.S. Shahane, D.S. Sutrave, B.T. Raut and L.P. Deshmukh, 2004. Photovoltaic proeprties of n-$CdS_{1-x}Te_x$ thin film/polysulphide photoelectrochemical solar cells prepared by chemical bath deposition. Thin Solid Films, 446: 1-5.
9. Pawar, S.M., A.V. Moholkar, K.Y. Rajpure and C.H. Bhosale, 2008. Photoelectrochemical investigations on electrochemically deposited CdSe and Fe-doped CdSe thin films. Sol. Energy Mater. Sol. Cells, 92: 45-49.

10. Natarajan, C., M. Sharon, C. Levy-Clement and M. Neumann-Spallart, 1994. Electrodeposition of zinc selenide. Thin Solid Films, 237: 118-123.
11. Qiu, S.N., C.X. Qiu and I. Shih, 1996. Diffusion length measurements on electrodeposited $CuInSe_2$ cells. Appl. Surf. Sci., 92: 306-310.
12. Kuranouchi, S., T. Nakazawa, A. Ashida and N. Yamamoto, 1994. Cadmium sulfide thin films prepared by chemical bath deposition method. Sol. Energy Mater. Sol. Cells, 35: 185-191.
13. Ndiaye, B., C. Mbow, M.S. Mane and C. Sene, One step electrodeposited $CuInSe_2$ absorber layers for efficient PV cells. Rev. Energies Renouvelables, 15: 609-620.
14. Dalchiele, E.A., S. Cattarin and M.M. Musiani, 1998. Preparation of $CdIn_2Se_4$ thin films by electrodeposition. J. Appl. Electrochem., 28: 1005-1008.
15. Lukinskas, A., V. Jasulaitiene, P. Lukinskas, I. Savickaja and P. Kalinauskas, 2006. Electrochemical formation of nanometric layers of tin selenides on Ti surface. Electrochim. Acta, 51: 6171-6178.
16. Loizos, Z., A. Mitsis, N. Spyrellis, M. Froment and G. Maurin, 1993. Cadmium chalcogenide semiconducting thin films prepared by electrodeposition from boiling aqueous electrolytes. Thin Solid Films, 235: 51-56.
17. Riveros, G., H. Gomez, R. Henriquez, R. Schrebler, R.E. Marotti and E.A. Dalchiele, 2001. Electrodeposition and characterization of ZnSe semiconductor thin films. Sol. Energy Mater. Sol. Cells, 70: 255-268.
18. Asenjo, B., A.M. Chaparro, M.T. Gutierrez and J. Herrero, 2006. Electrochemical growth and properties of $CuInS_2$ thin films for solar energy conversion. Thin Solid Films, 511-512: 117-120.
19. Subramanian, B., T. Mahalingam, C. Sanjeeviraja, M. Jayachandran and M.J. Chockalingam, 1999. Electrodeposition of Sn, Se, SnSe and the material properties of SnSe films. Thin Solid Films, 357: 119-124.
20. Chaparro, A.M., C. Maffiotte, M.T. Gutierrez and J. Herrero, 2000. Morphological and compositional study of CBD-ZnSe thin films by microscopy techniques and angle resolved XPS. Thin Solid Films, 358: 22-29.
21. Mane, R.S. and C.D. Lokhande, 1997. Studies on chemically deposited cadmium sulphoselenide (CdSSe) films. Thin Solid Films, 304: 56-60.
22. Ximello-Quiebras, J.N., G. Contreras-Puente, J. Aguilar-Hernandez, G. Santana-Rodriguez and A.A.C. Readigos, 2004. Physical properties of chemical bath deposited CdS thin films. Sol. Energy Mater. Sol. Cells, 82: 263-268.
23. Cetinorgu, E., C. Gumus and R. Esen, 2006. Effects of deposition time and temperature on the optical properties of air-annealed chemical bath deposited CdS films. Thin Solid Films, 515: 1688-1693.
24. Guillen, C., M.A. Martinez and J. Herrero, 1998. Accurate control of thin films CdS growth process by adjusting the chemical bath deposition parameters. Thin Solid Films, 335: 37-42.
25. Long, F., W.M. Wang, Z.K. Cui, L.Z. Fan, Z.G. Zou and T.K. Jia, 2008. An improved method for chemical bath deposition of ZnS thin films. Chem. Phys. Lett., 462: 84-87.
26. Johnston, D.A., M.H. Carletto, K.T.R. Reddy, I. Forbes and R.W. Miles, 2002. Chemical bath deposition of zinc sulphide based buffer layers using low toxicity materials. Thin Solid Films, 403-404: 102-106.
27. Roy, P., J.R. Ota and S.K. Srivastava, 2006. Crystalline ZnS thin films by chemical bath deposition method and its characterization. Thin Solid Films, 515: 1912-1917.
28. Avellaneda, D., G. Delgado, M.T.S. Nair and P.K. Nair, 2007. Structural and chemical transformations in SnS thin films used in chemically deposited photovoltaic cells. Thin Solid Films, 515: 5771-5776.
29. Ho, S.M., K. Anuar and W.T. Tan, 2013. Thickness dependent characteristics of chemically deposited tin sulfide films. Universal J. Chem., 1: 170-174.
30. Valenzuela-Jauregui, J.J., R. Ramirez-Bon, A. Mendoza-Galva and M. Sotelo-Lerma, 2003. Optical properties of PbS thin films chemical deposited at different temperatures. Thin Solid Films, 441: 104-110.
31. Amusan, J.A., 2008. Effect of annealed temperature on absorptivity of chemically deposited lead sulphide thin films. Res. J. Appl. Sci., 3: 1-4.
32. Seghaier, S., N. Kamoun, R. Brini and A.B. Amara, 2006. Structural and optical properties of PbS thin films deposited by chemical bath deposition. Mater. Chem. Phys., 97: 71-80.
33. Anuar, K., S.M. Ho, K.S. Lim and N. Saravanan, 2011. SEM, EDAX and UV-Visible studies on the properties of Cu_2S thin films. Chalcogenide Lett., 8: 405-410.

34. Anuar, K., A.H. Abdullah, S.M. Ho and N. Saravanan, 2010. Influence of deposition time on the properties of chemical bath deposited manganese sulfide thin films. Av. Quim., 5: 141-145.
35. Anuar, K., S.M. Ho, W.T. Tan and C.F. Ngai, 2011. Influence of triethanolamine on the chemical bath deposited NiS thin films. Am. J. Appl. Sci., 8: 359-361.
36. Kassim, A., S.M. Ho, A.H. Abdullah and S. Nagalingam, 2010. XRD, AFM and UV-Vis optical studies of PbSe thin films produced by chemical bath deposition method. Trans. C Chem. Chem. Eng., 17: 139-143.
37. Anuar, K., W.T. Tan, K.A. Dzulkefly, M.J. Haron, S.M. Ho, M. Shanthi and N. Saravanan, 2010. Preparation and characterization of PbSe thin films by chemical bath deposition. Jurnal Kimia, 4: 1-6.
38. Anuar, K., M. Jelas, M. Y Rosli, W.T. Tan, H.A. Abdul, S.M. Ho and N. Saravanan, 2010. Chemical bath deposition of NiSe thin films from aqueous solutions. Kuwait J. Sci. Eng., 37: 63-73.
39. Ho, S.M., 2014. Influence of complexing agent on the growth of chemically deposited $Ni_3Pb_2S_2$ thin films. Oriental J. Chem., 30: 1009-1012.
40. Castro-Rodriguez, R., A.I. Oliva, V. Sosa, F. Caballero-Briones and J.L. Peria, 2000. Effect of indium tin oxide substrate roughness on the morphology, structural and optical properties of CdS thin films. Appl. Surf. Sci., 161: 340-346.
41. Anuar, K., W.T. Tan, H.A. Abdul, N. Saravanan and S.M. Ho, 2010. Deposition and characterization of Cu_4SnS_4 thin films by chemical bath deposition method. Macedonian J. Chem. Chem. Eng., 29: 97-103.
42. Nweze, C.I., S.O. Ezeonu, D. Egeonu, C. Udeze and J. Ahaneku, 2015. Effect of the applied voltage on the optical properties of zinc sulphide thin films deposited on conducting glasses using electrodeposited method. J. Multidisciplinary Eng. Sci. Technol., 2: 1537-1541.
43. Anuar, K., N. Saravanan, S.M. Ho and K. Noraini, 2010. XRD and AFM studies of ZnS thin films produced by electrodeposition method. Arabian J. Chem., 3: 243-249.
44. Saravanakkumar, D., M. Kashif, V. Rethinasami, B. Ravikumar, S. Pandiarajan, A. Ayeshamariam, S. Sivaranjani, M. Bououdina and S. Ramalingam, 2014. Synthesis and characterization of zinc selenide (ZnSe) thin films electrodeposited on ITO and SnO_2 substrates. J. Ovonic Res., 10: 175-184.
45. Anuar, K., N. Saravanan, W.T. Tan, S.M. Ho and D. Teo, 2010. Chemical bath bdepsoition of nickel sulphide (Ni_4S_3) thin films. Leonardo J. Sci., 16: 1-12.
46. Han, W., L.Y. Cao, J.F. Huang and J.P. Wu, 2009. Influence of pH on PbS thin films prepared by electrodeposition. Mater. Technol. Adv. Performance Mater., 24: 217-220.
47. Anuar, K., S.M. Ho, S. Atan and N. Saravanan, 2010. X-ray diffraction and atomic force microscopy studies of chemical bath deposited FeS thin films. Studia UBB. Chemia, 55: 5-11.
48. Li, K., X. Meng, X. Liang, H. Wang and H. Yan, 2005. Electrodeposition and characterization of PbSe films on indium tin oxide glass substrates. J. Solid State Electrochem., 10: 48-53.
49. Anuar, K., W.T. Tan, N. Saravanan, L.K. Khor and S.M. Ho, 2010. Effects of deposition tie on the chemical bath deposited CuS thin films. J. Nepal Chem. Soc., 25: 2-8.
50. Shur, M.S., S. Rumyantsev, R. Gaska, B.Q. Wei, R. Vajtai, P.M. Ajayan and J. Sinius, 2002. Structural and transport properties of CdS films deposited on flexible substrates. Solid State Electron, 46: 1417-1420.
51. Sebnem, Y., A.O. Mehmet, G.A. Fatime, C. Ayten, K. Metin, A. Gulnur, T. Enver, Y. Ekrem and O. Lutfi, 2015. Growth of Cu_2ZnSnS_4 absorber layer on flexible metallic substrates for thin film solar cell applications. Thin Solid Films, 589: 563-573.
52. Park, Y., E.K. Kim, S. Lee and J. Lee, 2014. Growth and characterization of CdS thin films on polymer substrates for photovoltaic applications. J. Nanosci Nanotechnol., 14: 3880-3883.
53. Romeo, A., G. Khrypunov, F. Kurdesau, D.I. Batzner, H. Zogg and A.N. Tiwari, 2004. High efficiency flexible CdTe solar cells on polymer substrates. Tech. Digest the international PVSEC-14, Bangkok, Thailand, pp: 715-716.
54. Gupta, S., K. Sharma and N.S. Saxena, 2013. Temperature dependent mechanical analysis of chalcogenide (CdS, ZnS) coated PET films. ISRN Polymer Science,http://dx.doi.org/10.1155/2013/952612.
55. Acharya, K.P., J.R. Skuza, R.A. Lukaszew, C. Liyanage and B. Ullrich, 2007. CdS thin films formed on flexible plastic substrates by pulsed laser deposition. J. Phys. Condensed Matter, 19, http://dx.doi.org/10.1088/0953-8984/19/19/196221.
56. Yoo, D., M. Choi, C. Chung, S. Heo, D. Kim and C. Choi, 2013. Characteristics of radio frequency sputtered ZnS on the flexible polyethylene terephthalate (PET) substrate. J. Nanosci. Nanotechnol., 13: 7814-7819.