DOI:10.7598/cst2016.1163
ISSN:2278-3458

Chemical Science Transactions
2016, **5(2),** 279-284

REVIEW ARTICLE

Synthesis and Characterization of Electrodeposited Zinc Oxide Nanostructures for Dye Sensitized Solar Cells – A Review

HO SOONMIN

Faculty of Science, Technology, Engineering and Mathematics,
INTI International University, Putra Nilai, 71800, Negeri Sembilan, Malaysia
soonmin.ho@newinti.edu.my

Received 27 October 2015 / Accepted 20 November 2015

Abstract: This review paper focuses on the preparation of zinc oxide nanostructures using electrodeposition method for dye sensitized solar cells. Electrodeposition method has been selected in this study due to many advantages if compared to other deposition techniques. During the deposition process, the nucleation rate can affect the structure and morphology of films. As results, experiment findings indicate that the nanoporous films with large surface area could be successfully produced using this method.

Keywords: Thin films, Dye sensitized solar cell, Semiconductor, Chalcogenide metal, Semiconductor

Introduction

Recently, dye sensitized solar cell is emerged as one of the most promising alternative renewable energy sources for converting light energy into electrical energy. Generally, it contained counter electrode[1], redox electrolyte and dye-modified wide band semiconductor electrode such as zinc oxide[2] nanostructure. ZnO films have been prepared by several deposition techniques including hydrothermal technique[3-6], chemical bath deposition[7-9], sol gel technique[10], spin coating[11], pulsed laser deposition[12], spray pyrolysis[13-16], thermal evaporation[17], dip-coating method[18,19] and radio frequency magnetron sputtering[20] as reported in many literature reviews. Dye sensitized solar cell has many benefits such as low production cost[21,22], simple manufacturing process, flexibility[23] and high conversion efficiency[24].

In this work, electrodeposition method has been selected to prepare zinc oxide thin films in dye sensitized solar cell application. The growth conditions will be analyzed, interpreted and discussed in this paper. Lastly, their performance in dye sensitized solar cells application is also reported.

Literature review

Lin *et al.,*[25] reported the zinc oxide films with sheet like nanoporous morphology using electrodeposition technique. These films were deposited on indium tin oxide (ITO) glass

using zinc nitrate (from 0.01 M to 0.1 M) and sodium dodecyl sulfate (SDS). The FESEM micrographs indicate that ZnO films consisted of hexagonal columns at higher concentration of zinc nitrate from 0.05 M to 0.1 M in the absence of SDS solution. However, the micrographs show sheet like structures for the films prepared in the presence of SDS solution. This is attributed to the SDS is a peculiar surfactant and catalyzed the self-assembled growth of lamellar nanostructures. On the other hand, Lima *et al.*,[26] suggested that is a direct relationship between morphology and zinc precursor concentration. It has been shown that more porous could be observed as the concentration of zinc was reduced in scanning electron microscopy (SEM) analysis.

The ZnO films were deposited onto indium tin oxide glass by Christian *et al.,*[27]. They found that short deposition time led to strong back reaction of photogenerated electrons from non-covered indium tin oxide glass to the electrolyte. They also conclude that the performance of solar cell is mainly depends on the pore size and pore geometry. For example, by increasing the pore size from 20-25 nm to 35-45 nm, higher coverage of the surface of substrate could be observed, and leading to a higher open circuit voltage.

The influences of potential and time on the properties of ZnO films were investigated by Ahmed *et al.,*[28]. In SEM investigation, they conclude that well defined shape of flower like ZnO morphology was prepared at the potential of -1200 mV *versus* SCE (saturated calomel electrode) for 1 hour. In addition, the UV-Visible spectrometry measurements also confirmed the good crystallinity with band gap of 3.37 eV.

ZnO films have been prepared using electrodeposition method onto fluorine doped SnO_2 glass by Haller *et al.,*[29]. The obtain films indicate tilted pores of various orientations in scanning electron microscopy studies. The x-ray diffraction (XRD) patterns display that the films is highly oriented along the c-axis of the wurtzite structure perpendicularly to the surface of substrate. Meanwhile, in optical properties investigations, these films transmit close to 80% of the incident light in the visible wavelength range.

Long ZnO nanowires and hierarchiral ZnO nanostructures were prepared by Kim *et al.,*[30]. They observe that ZnO nanostructures indicated very good corrosion resistance in an acidic dye solution and showed higher power conversion efficiency if compared to ZnO nanowires. On the other hand, they also suggest that the length of the long ZnO nanowires increased with increasing anodization time at a constant voltage with a growth rate of 50-80 µm per hour.

ZnO films were prepared using electro deposition by Mozaffari *et al.,*[31]. They observe that the growth mechanism of the ZnO films takes place in two important steps, namely nucleation and growth of nanoparticles. Their experiment results depict the formation of ZnO nanostructures which reaches its maximum at the deposition time of 1 hour. They also claim that at higher concentration of zinc, a large amount of ZnO was covered on the surface of substrate.

Zinc nitrate and polyvinylpyrrolidone were used to prepare ZnO films by Chen *et al.,*[32]. They claim that the grain size and morphology were depending on the concentration of polyvinylpyrrolidone. In their experiment findings, ZnO films with grain sizes of 20-40 nm were observed in the concentration of 4g/L. The band gap of these films was 3.3 eV and had hexagonal wurtzite structure. Finally, the highest solar-to-electric energy conversion efficiency of 5.08% was obtained by using the electrodeposited double-layer ZnO films.

ZnO nanostructures were deposited on fluorine doped tin oxide substrate at 70 °C using electrodeposition method by Kung *et al.,*[33]. The electrolytic bath contained zinc nitrate

and sodium acetate solutions. A metal-free dye, coded as D149, was used in this research. Cell performance was measured using a light source and AM 1.5 filter. I-V curves of a dye sensitized solar cells fabricated by a ZnO thin films were analyzed. A conversion efficiencyof 4.65% was achieved for a dye sensitized solar cells (0.2376 cm^2) with the photoanode, consisting of the double-layer film, under 100 mW/cm^2 illumination in the wavelength range of 400-800 nm as reported in their experiment results.

Yukako *et al.,*[34] have reported that indoline dye (D149) was applied for electrodeposited porous ZnO nanostructures. They claim the control of adsorption time and use of co-adsorbing cholic acid was essential to achieve high efficiencies. They conclude that the use of cholic acid improved the cell performance as it prevents aggregation and reduces the amount of D149 adsorbed.

There are some disadvantages could be observed in dye sensitized solar cells. For example, the use of the liquid electrolyte, that is not very stable at varying temperatures. Furthermore, this electrolyte solution consists of volatile organic solvents and must be carefully sealed. Currently, chalcogenide metal thin film solar cells are considered as an option for large scale developments. Scientists are now actively participated in exploring various types of thin films such as binary, ternary and quaternary thin films as given below in order to achieve better performance of the solar cells.

Binary, ternary and quaternary thin films are;

Binary thin films: Zinc sulfide[35], Zinc selenide[36], Bismuth sulfide[37], Zinc telluride[38], Copper sulfide[39], Lead selenide[40], Tin sulfide[41], Nickel sulfide[42], Manganese sulfide[43], Iron sulfide[44], Indium sulfide[45], Cadmium sulfide[46], Cadmium telluride[47], Antimony sulfide[48], Cobalt sulphide[49], Cadmium selenide[50], Lead sulphide[51]

Ternary thin films: Copper tin sulfide[52], Zinc indium selenide[53], Zinc cadmium sulfide[54], Copper indium selenide[55], Antimony copper sulfide[56], Copper indium sulfide[57], Nickel lead sulfide[58], Lead iron sulfide[59], Gallium copper selenide[60], Cadmium bismuth sulfide[61]

Quaternary thin films: Copper indium aluminium selenide[62], Copper zinc tin sulfide[63]

Conclusion

This review paper emphasizes on the electrodeposited ZnO nanostructures for the dye-sensitized solar cells. These films were characterized by x-ray diffraction, scanning electronic microscopy, atomic force microscopy and photoluminescence. The properties of thin films were affected by the different deposition parameters as shown in experimental results.

Acknowledgement

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

Reference

1. Masood H, Afshar G and Vahid J, *Mater Sci Semiconductor Proces.*, 2013, **16(5)**, 1352-1359; DOI:10.1016/j.mssp.2012.11.010
2. Kim S S, Yum J H and Sung Y E, *Solar Energy Materials Solar Cells*, 2003, **79(4)**, 495-505; DOI:10.1016/S0927-0248(03)00065-5
3. Bayram K, Taylan G, Ilknur B, Merve S and Sebahattin T, *Appl Surface Sci.*, 2014, **318**, 32-36; DOI:10.1016/j.apsusc.2013.12.065
4. Rahman M Y A, Roza I, Umar A A and Salleh M M, *J Alloys Compds*, 2015, **648**, 86-91; DOI:10.1016/j.jallcom.2015.05.283

5. Meng Y, Lin Y, Lin Y and Yang J, *J Solid State Chem.*, 2014, **210(1)**, 160-165; DOI:10.1016/j.jssc.2013.11.020
6. Lin Y, Lin Y, Wu J, Tu Y, Zhang X and Fang B, *Ceram Int.*, 2015, **41(10)**, 14501-14507; DOI:10.1016/j.ceramint.2015.07.089
7. Auttasit T and Lee M, *Superlattices Microstruct.*, 2012, **52(5)**, 987-996; DOI:10.1016/j.spmi.2012.08.002
8. Prashant B, Ahmed E and Babasaheb S, *Solar Energy*, 2014,**105**, 445-454; DOI:10.1016/j.solener.2014.03.024
9. Karst N, Rey G, Doisneau B, Roussel H, Deshayes R, Consonni V, Ternon C and Bellet D, *Mater Sci Engg B*, 2011, **176(3)**, 653-659; DOI:10.1016/j.mseb.2011.02.009
10. Pauporte T and Magne C, *Thin Solid Films*, 2014, **560**, 20-26; DOI:10.1016/j.tsf.2013.11.121
11. Susmitha K, Kumar M N, Rajkumar G, Giribabu L and Raghavender M, *Solar Energy*, 2015, **118**, 126-133; DOI:10.1016/j.solener.2015.03.054
12. Vijayalakshmy S and Subramanian B, *Electrochimica Acta*, 2014, **137**, 131-137; DOI:10.1016/j.electacta.2014.05.141
13. Premaratne K, Kumara G R A, Rajapakse R M G and Karunarathne M L, *J Photochemistry Photobiology A: Chem.*, 2012, **229(1)**, 29-32; DOI:10.1016/j.jphotochem.2011.12.010
14. Parthiban R, Balamurugan D and Jeyaprakash B G, *Mater Sci Semiconductor Processing*, 2015, **31**, 471-477.
15. Bedia FZ, Bedia A, Maloufi N, Aillerie M, Genty F and Benyoucef B, *J Alloys Compounds*, 2014, **616**, 312-318; DOI:10.1016/j.jallcom.2014.07.086
16. Pankaj S and Lal B, *International J Hydrogen Energy*, 2012, **37(6)**, 4863-4870; DOI:10.1016/j.ijhydene.2011.12.064
17. Ghislain J F, Yamin F, Moussa S and Huang X, *Mater Sci Semiconducting Processing*, 2013, **16(3)**, 652-658; DOI:10.1016/j.mssp.2012.12.005
18. Dimitrios K, Elias S and Evangelos V, *J Power Sources*, 2012, **219**, 9-15; DOI:10.1016/j.jpowsour.2012.07.034
19. Chou C S, Chou F C and Kang J Y, *Powder Technol.*, 2012, **215-216**, 38-45; DOI:10.1016/j.powtec.2011.09.003
20. Gong L, Liu Y, Gu X, Lu J, Zhang J, Ye Z, Chen Z and Li L, *Mater Sci Semiconductor Processing*, 2014, **26**, 276-281; DOI:10.1016/j.mssp.2014.05.016
21. Suri P, Panwar M and Mehra R M, *Mater Sci Poland*, 2007, **25(1)**, 137-144.
22. Arpita J, Partha P D, Shruti A A and Devi P S, *Solar Energy*, 2014, **102**, 143-151; DOI:10.1016/j.solener.2014.01.011
23. Hamadanian M, Ghomi JS, Hosseinpour M, Masoomi R and Jabbari V, *Science Semiconductor Proces.,* 2014, **27**, 733-739; DOI:10.1016/j.mssp.2014.08.017
24. Thomas W H, Rebecca A J, Alex B F M, Hal V R and Joseph T H, *Energy Environ Sci.*, 2008, **1**, 66-78; DOI:10.1039/B809672D
25. Lin Y, Yang J and Meng Y, *Ceramics International*, 2013, **39**, 5049-5052; DOI:10.1016/j.ceramint.2012.11.103
26. Lima F A S, Vasconcelos I F and Cantu M, *Ceramics International*, 2015, **41(8)**, 9314-9320; DOI:10.1016/j.ceramint.2015.03.271
27. Christian D, Till V G, Bernd M S, Torsten O and Michael W, *Materials*, 2014, **7(4)**, 3291-3304; DOI:10.3390/ma7043291

28. Ahmed NA, Hammache H, Makhloufi I, Eyraud M, Sam S, Keffous A and Gabouze N, *Vacuum*, 2015, **120**, 100-106; DOI:10.1016/j.vacuum.2015.04.009
29. Haller S, Rousset J, Renou G and Lincot D, *EPJ Photovoltaics*, 2011, **2**, DOI:10.1051/epjpv/2011021
30. Kim YT, Park J, Kim S, Park D and Choi J, *Electrochimica Acta*, 2012, **78**, 417-421; DOI:10.1016/j.electacta.2012.06.022
31. Mozaffari S A, Ranjbar M, Kouhestanian E, Amoli HS and Armanmehr M H, *Mater Sci Semiconductor Processing*, 2015, **40**, 285-292; DOI:10.1016/j.mssp.2015.06.081
32. Chen Z, Tang Y, Zhang L and Luo L, *Electrochemica Acta*, 2006, **51(26)**, 5870-5875; DOI:10.1016/j.electacta.2006.03.026
33. Kung C, Chen H, Lin C, Lai Y, Vittal R and Ho K, *Progress Photovoltaics: Res Appl.,* 2014, **22(4)**, 440-451.
34. Yukako S, Wang X, Miura H, Matsui M and Yoshida T, *J Photochem Photobiol A: Chem.*, 2010, **216(1)**, 1-7; DOI:10.1016/j.jphotochem.2010.08.015
35. Anuar K, Nani R and Ho S M, *Int J Adv Engg Sci Technol.*, 2011, **7(1)**, 169-172.
36. Anuar K, Ho S M, Tan W T, Kelvin and Saravanan N, *Eur J Appl Sci.*, 2011, **3(3)**, 75-80.
37. Ubale A U, *Mater Chem Phys.*, 2010, **121**, 555-560; DOI:10.1016/j.matchemphys.2010.02.021
38. Skhouni O, El-Manouni A, Mollar M, Schrebler R and Mari B, *Thin Solid Films*, 2014, **564**, 195-200; DOI:10.1016/j.tsf.2014.06.002
39. Anuar K, Ho S M, Tee W T, Lim K S and Saravanan N, *Res J Appl Sci, Engg Technol.*, 2011, **3(6)**, 513-518.
40. Anuar K, Ho S M and Saravanan N, *Turkish J Sci Technol.*, 2011, **6(1)**, 17-23.
41. Anuar K, Ho S M, Atan S and Haron M J, *Res J Chem Environ.*, 2011, **15(3),** 45-48.
42. Anuar K, Ho S M, Tan W T and Ngai C F, *Am J Appl Sci.*, 2011, **8(4)**, 359-361; DOI:10.3844/ajassp.2011.359.361
43. Anuar K and Ho S M, *Int J Chem Res.*, 2010, **1**, 1-5.
44. Anuar K, Ho S M, Atan S and Saravanan N, *Studia Universitatis Babes-Bolyai Chemia*, 2010, **55(3)**, 5-11.
45. Asenjo B, Guilln C, Chaparro A M, Saucedo E, Bermudez V, Lincot D, Herrero J and Gutirrez M T, *J Phys Chem Solids*, 2010, **71(12)**, 1629-1633; DOI:10.1016/j.jpcs.2010.09.011
46. Caballero-Briones F, Calzadilla O, Chale-Lara F, Rejon V and Pena J L, *Chalcogenide Lett.*, 2015, **12**, 137-145.
47. Chen H M, Guo F Q and Zhang B H, *J Semiconductors*, 2009, **30**, 053001-1-053001-4.
48. Ezema F I, Ekwealor A B C, Asogwa P U, Ugwuoke P E, Chigbo C and Osuji R U, *Turkish J Phys.,* 2007, **31(4)**, 205-210.
49. Sartale S D and Lokhande C D, *Indian J Pure Appl Phys.*, 2000, **38**, 48-52.
50. Panthan H M, Sankapal B R, Desai J D and Lokhande C D, *Mater Chem Phys.*, 2003, **78(1)**, 11-14; DOI:10.1016/S0254-0584(02)00198-0
51. Raniero L, Ferreira C L, Cruz L R, Pinto A L and Alves R M P, *Physica B: Condensed Matter*, 2001, **405(5)**, 1283-1286; DOI:10.1016/j.physb.2009.11.068
52. Anuar K, Zulkefly K, Atan S, Tan W T, Ho S M and Saravanan N, *Indian J Engg Mater Sci.*, 2010, **17**, 295-298.
53. Babu P, Reddy M V, Revathi N and Reddy K T R, *J Nano Electronic Phys.*, 2011, **3**, 85-91.
54. Song W C and Lee J H, *J Korean Phys Soc.*, 2009, **54**, 1660-1665.
55. Bari R H, Patil L A, Sonawane P S, Mahanubhav M D, Patil V R and Khanna P K, *Mater Lett.*, 2007, **61(10)**, 2058-2061; DOI:10.1016/j.matlet.2006.08.015

56. Ekuma C, Nnabuchi M, Nwabueze A and Owate I, *Ceramic Trans.*, 2010, **222**, 243-249.
57. Guan R, Wang X and Sun Q, *J Nanomater.*, 2015, Article ID 579489, DOI:10.1155/2015/579489
58. Ho S M, *Oriental J Chem.*, 2014, **30(3)**, 1009-1012; DOI:10.13005/ojc/300311
59. Joshi R K, Subbaraju G V, Sharma R. and Sehgal H K, *Appl Surface Sci*, 2004, **239(1)**, 1-4; DOI:10.1016/j.apsusc.2004.03.240
60. Lee H, Lee J, Hwang Y and Kim Y, *Curr Appl Phys.*, 2014, **14(1)**, 18-22; DOI:10.1016/j.cap.2013.10.001
61. Mishra S S D, Saini K K, Kant C and Pal M, *Mater Chem Phys.*, 2014, **146(3)**, 324-329; DOI:10.1016/j.matchemphys.2014.03.031
62. Badrul M, Rachmat A W, Eun S L and Kyoo H K, *J Ceramic Proces Res.*, 2007, **8**, 252-255.
63. Lin Y, Ikeda S, Septina W, Kawasaki Y, Harada T and Matsumura M, *Solar Energy Materials Solar Cells*, 2014, **120**, 218-225; DOI:10.1016/j.solmat.2013.09.006