Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings 5 (2018) 13874–13878

materialstoday: PROCEEDINGS

www.materialstoday.com/proceedings

SACT 2016

Improved the chrage transfer for highly efficient photoelectrochemical water oxidation: the case of WO_3 and $BiVO_4$

C. Wiriyachailerd[a], M. Horprathum[b], P. Eiamchai[b], C. Ponchio[a,c,*]

[a]*Department of chemistry, Faculty of science and technology, Rajamangala University of Technology Thanyaburi, Pathumtani 12110, Thailand*
[b]*National Electronics and Computer Technology Center, 112 Pahol Yothin Rd., Pathumthani 12120, Thailand*
[c]*Advance Materials Design and Development (AMDD) Research Unit, Institute of Research and Development, Rajamangala University of Technology Thanyaburi, Klong 6, Thanyaburi, Thailand*

Abstract

The tungsten oxide (WO_3) and bismuth vanadate ($BiVO_4$) thin films were successfully deposited on indium doped tin oxide (ITO) by dc reactive magnetron sputtering and spin coating technique, respectively. The physical structural were characterized by field-emission scanning electron microscopy (FE-SEM) and X-ray diffractometry (XRD). The photoelectrocatalytic water oxidation of ITO/WO_3 and ITO/WO_3/$BiVO_4$ electrodes were compared under visible light irradiation. The double layer of WO_3/$BiVO_4$ thin film are present the enhancing efficiency of water oxidation comparing with single WO_3 layer. The results showed the improvement of charge transfer by using heterojunction nanostructure semiconductor electrode in order to suppress the recombination effect and enhance an efficient of water splitting.

Selection and/or Peer-review under responsibility of SACT 2016.

Keywords: Charge transfer; Photoelectrochemical; Water oxidation; Tungsten oxide; Bismisth vanadate

1. Introduction

A photoelectrocatalytic water splitting has been usually used by semiconductors as a photoelectrode. Therefore, a selections of semiconductors considering is very important for improve the photoelectrocatalytic activity. A tungsten oxide (WO_3) has been investigated for water oxidation from water splitting under visible light irradiation [1-3]. To enhance the efficiency,which that designs of nanostructured WO_3 [4-6] combined with the suitable

* Corresponding author. Tel.: +668-7362-9105; fax: +66-2160-1143.
E-mail address: chatchai@rmutt.ac.th

semiconductor for used to enhance of charge transfer process [7-9]. Especially the combination of nanostructured morphology and suitable semiconductors as is interfacial heterojunction are an interesting topics to improve the high efficiency of water splitting.

This article describe the nanostructured WO_3 by dc reactive deposition of sputtering technique [10] and combine with $BiVO_4$ spin-coated [11] on indium doped tin oxide (ITO) substrate. The film morphology and crystalline structure of the film composition were studied by field-emission scanning electron microscopy (FE-SEM), X-ray diffractometry (XRD), respectively. The photoelectrocatalytic activity for water oxidation of fabricated electrode was studied by amperometry method under visible light irradiation. The comparison between pure and couple semiconductors were studied in order to confirm the charge transfer enhancement of heterojunction semiconductor.

2. Experiment

The 250 nm-thick tungsten oxide (WO_3) thin films were deposited on silicon wafers and indium doped tin oxide (ITO) coated glass substrates (12Ω/□) by dc reative sputtering technique with a 3 inch-diameter tungsten (W) target (purity 99.995%). The distance from substrate to target and substrate rotation speed were fixed at 7 cm and 10 rpm, respectively. The substrate normal was positioned at an angle of 45 with respect to the vapor incident flux in order to obtain the optimal film uniformity. The discharge was generated at a constant dc power of 150 W. The chamber obtained a vacuum state by mechanical pump and a turbo pump vacuum with a base pressure of 8.5 x 10^{-6} mbar. After a based pressure, the W target were reactively sputtered in a mixture of 99.999% argon and 99.999% oxygen. The flow rate of the oxygen and argon were controlled with mass flow controller at 24 and 8 sccm, repectively. The bismsuth vanadate ($BiVO_4$) were prepared by spin coating technique which the condition of 1,000 rpm for 60 second after that repeated until the 5 layers. Fig. 1 shows schematic diagram of preparation double layer $WO_3/BiVO_4$ thin film.

The physical morphology and film thickness of the WO_3 and $BiVO_4$ thin film were characterized by field-emission scanning electron microscopy (FE-SEM, Hitachi S-4700) . The crystalline structure of the fabricated thin films were confirmed by X-ray diffractometer (TTRAX III-RIGAKU) with Cu-$K_{\alpha 1}$, TTRAX III-RIGAKU. The Cu-Kα radiation was operated at 50 kV, 300 mA with a scanning speed of 2θ per minute at a 2θ step of 0.02°. The photoelectrocatalytic activity for water oxidation of fabricated electrodes were studied by amperometry in solution of 0.5 M sodium sulfate under visible light irradiation.

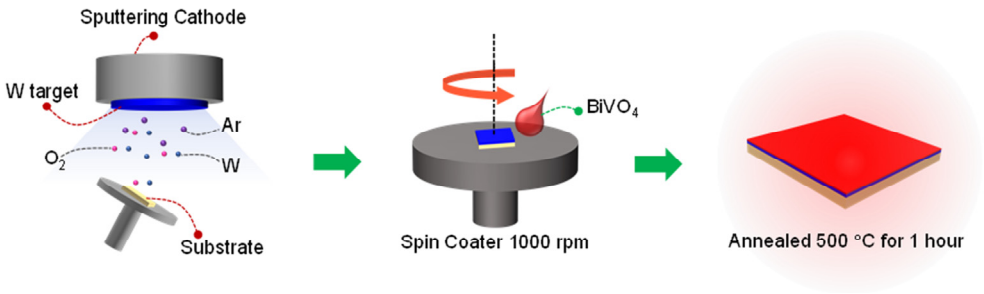

Fig. 1. schemetic diagram of develop multilayer $WO_3/BiVO_4$ thin film.

3. Results and discussion

3.1. Thin films morphology

The cross sections and surface to pology from the FESEM micrographs (Fig. 2(a)-(b)) showed dense morphology of WO_3 film with the thickness layer of 250 nm prepared by the dc reactive magnetron sputtering technique. The total thickness of multilayer was increased to 330 nm after spin coated $BiVO_4$ on WO_3 thin film which showed the particles dispersed on the dense film of WO_3 (Fig. 2(c)). Fig. 2(d) showed the surface roughness morphology of

WO_3 thin films was increased by the present of $BiVO_4$. The results from the coated film demonstrated morphology improvement of dense WO_3 film by $BiVO_4$, that would be suitable for water adsorption.

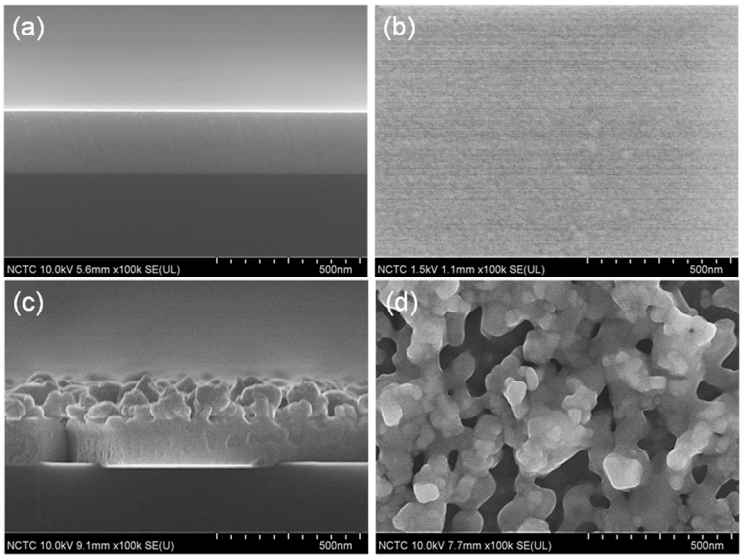

Fig. 2. Morphology of (a) cross sectional of WO_3, (b) top view of WO_3, (c) cross sectional of $WO_3/BiVO_4$ after annealed and (d) top view of $WO_3/BiVO_4$ after annealed on silicon wafers.

3.2. Crystalline structure

The XRD patterns of the annealed WO_3 and $BiVO_4$ deposited on silicon wafers were shown in Fig. 3. The results showed that the as-deposited WO_3 film were amorphous without observable crystallinity (Fig. 3(b)). After the sample was annealed at 500°C, the XRD patterns monoclinic (Fig. 3(c),(d)) [12]. Therefore, the XRD results confirmed the formation of the WO_3 and $BiVO_4$ materials on the substrates based on the proposed preparation process.

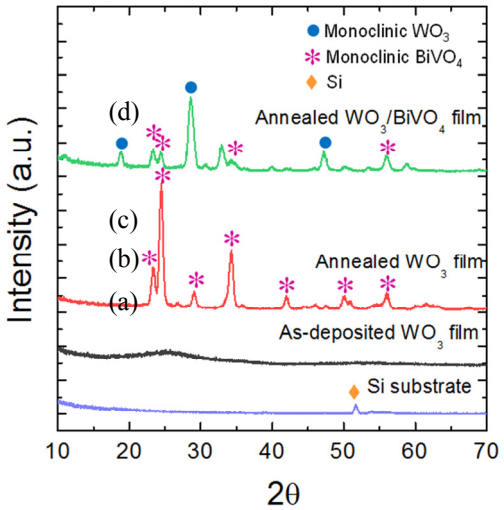

Fig. 3. The XRD patterns of (a) Silicon wafer, (b) WO_3 as-deposition, (c) WO_3 after annealed and (d) $WO_3/BiVO_4$ after annealed at 500°C.

3.3. Photoelectrocatalytic properties

The amperometric method was used to study the photocurrent actinties from water oxidation of ITO/WO_3/$BiVO_4$ electrode in a 0.5 M Na_2SO_4 solution under visible light irradiation ($\lambda > 420$ nm). Fig. 4 showed the photocurrent results of the prepared ITO/WO_3/$BiVO_4$ sample in comparison with the ITO/WO_3 sample as a referent. The amperographs showed significant enhancement of the anodic photocurrent from the ITO/WO_3/$BiVO_4$ electrodes. The results indicated that the combination of the $BiVO_4$ structures with the WO_3 thin films could greatly improve the photoelectrocatalytic activity for water oxidation of pure WO_3 due to the function of charge separation and roughness surface morphology improvement.

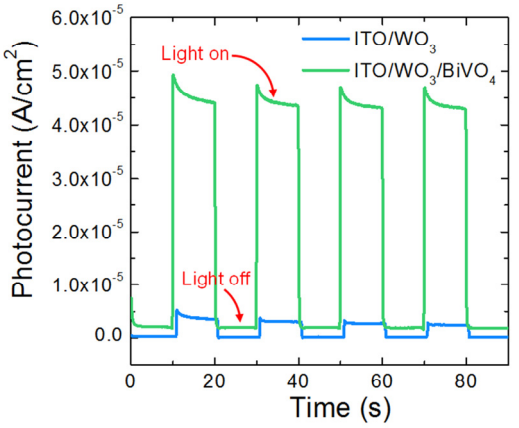

Fig. 4. Amperographs of ITO/WO_3 and ITO/WO_3/$BiVO_4$ electrodes at 1.0 V vs. Ag/AgCl in 0.5 M Na_2SO_4 solution under visible light irradiation.

We could demonstrate the fundamental technique to improve the photoelectrocatalytic activity for water oxidation by use the heterojunction of suitable couple semiconductor. Fig. 5 showed the schematic diagram of the charge transfer process at the heterojunction semiconductor ITO/WO_3/$BiVO_4$ electrode under visible light irradiation. A combination of the composited WO_3 and and $BiVO_4$ semiconductors would readily yield corresponding bound energy level which helped generate electron transfer from the conduction band of WO_3 and $BiVO_4$ into the electrode. At the same time, the generated hole transfer from the valance band of WO_3 to that of $BiVO_4$ caused a number of holes occurred at electrode surface that high efficiency to oxidize the water to O_2 in solution [13].

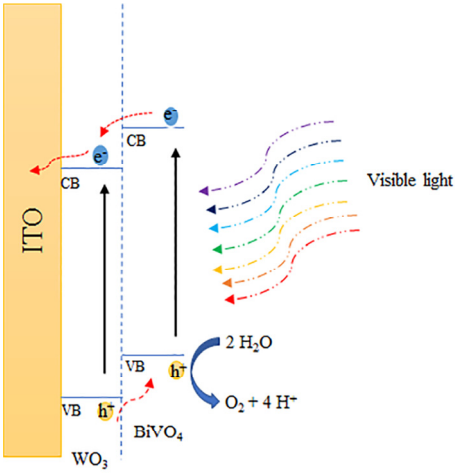

Fig. 5. Schematic diagram of charge transfer process of ITO/WO_3/$BiVO_4$ electrode for water oxidation under visible light irradiation.

4. Conclusion

In summary, the ITO/WO_3/$BiVO_4$ composited electrodes were fabricated by the GLAD sputtering and spin coating technique. The SEM images confirmed the roughness morphology improvement of dense WO_3 film by $BiVO_4$ at the outward direction for water adsorption. The crystalline structure of the composited WO_3 and $BiVO_4$ on the substrate were confirmed by the XRD results. The $BiVO_4$ at the outer side of composited WO_3/$BiVO_4$ electrode could had enhance the photocurrent actinties from water oxidation by the function of the charge separation and surface roughness improvements. There are suitable for applied with other couple semiconductor in order to enhance the photoelectrocatalytic activity under visible light irradiation.

Acknowledgments

This work was carried out with the help of Optical Thin-Flim Technology Laboratory (OLT): Thin films group, the National Electronics and Computer Technology Center (NECTEC) for supporting their facilities. Researcher would like to thank to department of chemistry, faculty of science and technology, Rajamangala University of Technology Thanyaburi (RMUTT) for facility and especially thank to Research and Researchers for Industries-RRI (MSD58I0038) for financial support.

References

[1] G. Liu, X. Wang, X. Wang, H. Han, and C. Li, Journal of Catalysis (293) 2012 61-66.
[2] G. Liu, J. Han, X. Zhou, L. Huang, F. Zhang, X. Wang, et al., Journal of Catalysis (307) 2013 148-152.
[3] C. Janáky, K. Rajeshwar, N. R. de Tacconi, W. Chanmanee, and M. N. Huda, Catalysis Today (199) 2013 53-64.
[4] Y. Nukui, N. Srinivasan, S. Shoji, D. Atarashi, E. Sakai, and M. Miyauchi, Chemical Physics Letters (635) 2015 306-311.
[5] Y. Fang, W. C. Lee, G. E. Canciani, T. C. Draper, Z. F. Al-Bawi, J. S. Bedi, et al., Materials Science and Engineering: B (202) 2015 39-45.
[6] W. L. Kwong, H. Qiu, A. Nakaruk, P. Koshy, and C. C. Sorrell, Energy Procedia (34) 2013 617-626.
[7] L. J. Minggu, K. H. Ng, H. A. Kadir, and M. B. Kassim, Ceramics International (40) 2014 16015-16021.
[8] C. W. Lai and S. Sreekantan, International Journal of Hydrogen Energy (38) 2013 2156-2166.
[9] C. W. Lai and S. Sreekantan, Journal of Alloys and Compounds (547) 2013 43-50.
[10] A. Wisitsoorat, M. Z. Ahmad, M. H. Yaacob, M. Horpratum, D. Phakaratkul, T. Lomas, et al., Sensors and Actuators B: Chemical (182) 2013 795-801.
[11] C. Ponchio, S.-y. Kishioka, Y. Murakami, A. Y. Nosaka, and Y. Nosaka, Electrochimica Acta (55) 2010 592-596.
[12] C. Ponchio, Y. Murakami, S.-y. Kishioka, A. Y. Nosaka, and Y. Nosaka, Electrochimica Acta (54) 2009 1147-1152.
[13] J. Su, L. Guo, N. Bao, and C. A. Grimes, Nano Lett (11) 2011 1928-1933.