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Metal Chalcogenide Thin Films for Photoelectrochemical Cell Applications: A Review

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Abstract: Metal chalcogenide thin films represent an important family of semiconductor materials in photoelectrochemical cell. Binary and ternary thin films hold promise in photoelectrochemical cell applications such as they are efficient absorbers in the visible and near infrared regions of solar spectrum. In this work, the fabrication of photoelectrochemical cell by using various types of thin films as photoelectrode will be discussed. Then, the conversion efficiency and fill factor of obtained films will be investigated.

Key words: Thin films · Photoelectrochemical cells · Metal chalcogenide · Conversion efficiency.

INTRODUCTION

Thin films are prepared by different deposition techniques including physical deposition technique and chemical deposition method. Recently, metal sulphide [1-18], metal selenide [19-30] and metal telluride [31-34] thin films have received considerable attention in the field of solar cells, optical waveguides, temperature sensors, filters, optoelectronic devices and laser devices. Interest in the development of photoelectrochemical cell (PEC) has grown because of demand for clean energy. This type of solar cell does not emit gases such as NO_x, SO_x and carbon dioxide. Furthermore, thin film electrodes are prepared on a substrate which can produce great ohmic contact and display excellent adhesion to the semiconductor. Therefore, it can be considered has the potential to solve environmental problems by converting solar energy into chemical energy. Nowadays, PEC has led to an extensive research in the search for suitable semiconductor materials as mentioned by many researchers. It is important to choose simple and economically deposition methods in order to prepare good quality of films, which will be served as photoanode semiconductor (working electrode).

In this paper, photoelectrochemical cell will be fabricated by using various types of thin films which serve as photoelectrode. Then, the PEC characteristics have been studied by measuring ideality factor both in dark and light conditions, fill factor and power conversion efficiency.

Literature Survey: Photoelectrochemical (PEC) cell contains counter electrode and working electrode. Generally, counter electrode can be made of metal such as platinum. Meanwhile, the photoactive semiconductor could be served as the working electrode. In PEC cell, both electrodes were immersed in the electrolyte containing redox couples.

Deposition of Bi_2S_3 films onto fluorine doped tin oxide glass substrate was carried out at room temperature under alkaline conditions as proposed by Buba *et al*., 2015 [35]. For the preparation of these films, thioacetamide and $Bi(NO_3)_3$ were employed as S^{2-} and Bi^{3+} ions source respectively. PEC studies were investigated by using thin films as negative electrode and graphite as the counter electrode. They conclude that the fill factor (0.047) and conversion efficiency (30 %) are observed to be small because of low series and high shunt resistance. Lastly, Mott-Schottky plot displays the n-type electrical conductivity of the obtained films.

Iron sulfide thin films are most powerful candidates for photoelectrochemical applications as recommended by Reddy and Vedavathi, 2012 [36]. These films consist of abundant and non-toxic elements. Polycrystalline (orthorhombic structures) films of FeS_2 were prepared using chemical bath deposition method in the presence of ferric chloride, thiourea and triethanolamine. They report

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that these films have a high absorption in the visible range. Further, they explain that FeS_2 films are semiconductor materials with a minority carrier diffusion length much larger than absorption length and higher carrier mobility.

Photoelectrochemical cells using n-type zinc selenide thin film electrodes in aqueous electrolytes (iodide-triiodide redox couple) have been described by Mahapatra *et al*., 2011 [37]. In their works, the SnO_2 coated glass substrates were employed for depositing semiconducting material. They point out that the conversion efficiency and fill factor were 0.2 % and 0.4, respectively from the current-voltage behaviors under illumination intensity of 40 mW/cm^2. Further, they explain that the lower efficiency because of high resistance of the cell and electrolyte absorption.

Electrodeposition method has many advantages such ash inexpensive, simple and convenient for large area deposition. It has been used to prepared zinc sulphide films from solutions containing sodium thiosulphate, zinc sulphate and ethylenediaminetetraacetic acid. The photoelectrochemical cell combination was n-ZnS|1M(Na_2S-NaOH-S)|graphite as designed by Bhalerao *et al.,* 2013 [38]. They found that the obtained films display n-type conductivity from the current voltage characteristics.

Arrested precipitation technique was used to prepare molybdenum bismuth telluride films as reported by Manauti *et al*., 2012 [39]. As mentioned by researchers, this technique has many benefits including low cost, high control ability with silicon micro fabrication process as well as room temperature fabrication. Finally, they claim that the conversion efficiency and fill factor were 0.115% and 0.295, respectively as indicated in PEC test.

Hexagonal phase of CdSe films were prepared on indium tin oxide coated glass substrate at room temperature using electro deposition method. Mahato *et al*., 2015 [40] observe that the films are semiconducting as indicated in electrical properties. The PEC cell was fabricated by them which consisted of CdSe|NaOH (1M)+S(1M)+Na_2S(1M)|Graphite. The obtained PEC results indicate that conversion efficiency was 1.16%. Further, they reveal that cadmium selenide films have two different zones of metallic character under both dark and illumination conditions.

Bismuth telluride thin films have been synthesized using electrochemical method as developed by Patil *et al*., 2015 [41]. The fern shaped Bi_2Te_3 films could be detected in their experiment. They found that surfactant aids in the growth of well leveled porous and spongy films. Lastly, they claim that the conversion efficiency recorded for these films was 0.083 %. In other words, these films have been proved to be materials for photoelectrochemical cell application.

The cost effective electro deposition method has been used to prepare cadmium sulphide and CdS-Bi_2S_3 films as proposed by Mahapatra and Panda, 2015 [42]. The PEC cell configuration is photoanode|NaOH (1M)+S(1M)+Na_2S(1M)| Pt as developed. The conversion efficiency and fill factor for CdS and mixed CdS-Bi_2S_3 films were found to be 5.16 % and 0.46 and 7.26% and 0.49, respectively. They explain that the improved performance of the mixed semiconductor electrode because of some reasons such as reduce in band gap, higher flat band potential and higher shunt resistance.

Ternary Ag-Sn-S films were prepared onto indium tin oxide glass substrate as reported by Yeh and Cheng, 2015 [43] using chemical bath deposition method. The aqueous solutions such as $AgNO_3$, $SnCl_2$, NH_4NO_3, tri-sodium citrate and ethylenediaminetetraacetic acid disodium salt were used during the deposition process. They proposed that the pH was adjusted to pH 1 in order to reduce the formation of metal complexes. They conclude that power conversion efficiency increases with increasing $SnCl_2$ concentration and reducing $AgNO_3$ concentration. The maximum conversion efficiency was 9.6 % for films prepare using 4 mL of $AgNO_3$ and 6 mL of $SnCl_2$, indicating decrease in hole-electron recombination.

The $Cd_{1-x}Co_xS$ films of varying composition ($0<x<0.5$) were synthesized on stainless steel substrates by a liquid phase chemical bath deposition method. The obtained films were used as the active photoelectrode and sulfide/polysulfide electrolyte was served as a redox couple in the photoelectrochemical cell as developed by Deshmukh *et al.,* 2012 [44]. Maximum energy conversion efficiency and fill factor of 2.94% and 47.1%, respectively have been made feasible which electrode composition is 0.1.

CONCLUSION

In this work, metal sulphide, metal selenide and metal telluride thin films have been successfully used as photoanode semiconductor in photoelectrochemical cell.The photoelectrochemical cell was fabricated in aqueous electrolytes which containing working and counter electrode.

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