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Fabrication and characterisations of n-CdS/p-PbS heterojunction solar cells using microwave-assisted chemical bath deposition

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Abstract

n-CdS/p-PbS heterojunction solar cells were prepared via microwave-assisted chemical bath deposition method. A cadmium sulfide (CdS) window layer (340 nm thickness) was deposited on an indium tin oxide (ITO) glass. A lead sulfide (PbS) absorber layer (985–1380 nm thickness) with different molar concentrations (0.02, 0.05, 0.075, and 0.1 M) was then grown on ITO/CdS to fabricate a p–n junction. The effects of changing molar concentration of the absorber layer on structural and optical properties of the corresponding PbS thin films and solar cells were investigated. The optical band gap of the films decreased as the molarity increased. The photovoltaic properties (*J–V* characteristics, short circuit current, open circuit voltage, fill factor, and efficiency) of the CdS/PbS heterostructure cells were examined under 30 mW/cm^2 solar radiation. Interestingly, changing molar concentration improved the photovoltaic cells performances, the solar cell exhibited its highest efficiency (1.68%) at 0.1 M molar concentration.

Keywords: Nanocrystalline material; Solar cells; PbS; CdS

1. Introduction

Nanocrystallines PbS compound is an important material in the production of absorber layers for solar cell applications due to its unique properties (direct band gap of 0.41 eV and exciton Bohr radius of 18 nm) provide electrons and holes with strong quantum confinement, leading to an increase in the absorption of solar radiation in the near-infrared (NIR) region Nozik (2002), Szendrei et al. (2010), Popescu et al. (2006). Several studies devoted to this system have been reported in the literature. Henry et al. (2011) fabricated infrared active hybrid solar cells composed of mesoporous SnO_2 sensitized with PbS nanoparticles and infiltrated with organic hole-transporters. Patil et al. (2011) fabricated and liquefied petroleum gas (LPG) sensing performance of p-polyaniline/n-PbS heterojunction at room. Moreno-García et al. (2011) reported the use of chemically synthesised p-PbS thin films in the fabrication of heterojunction solar cells with another n-type semiconductor such as Bi2S3. Szendrei et al. (2010) fabricated efficient ITO/PbS/10 nm LiF-100 nm Al solar cells with a device active area of 4 mm^2 using the spin-coating method. Hernandez-Borja et al. (2011) constructed solar cells on an indium tin oxide (ITO) substrate using cadmium sulfide (CdS) as window layer and PbS as absorber layer through chemical bath deposition (CBD).

CdS is one of the most important II–VI semiconductors with a direct band gap of 2.42 eV at room temperature (Razykov et al., 2011). CdS is widely used as a window

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layer in the fabrication of solar cells with various p-type materials such as CdTe and PbS (Romeo et al., 2004; Matsune et al., 2006). Joshi et al. (2011) developed stoichiometric and nonstoichiometric nanostructured heterojunction solar cell of CdS/$CuInS_xSe_{2-x}$ where x varies from 0 to 2 with an interval of 0.5 using cost effective and simple chemical ion exchange method at room temperature on ITO glass substrate.

CBD method is well known to be commonly used in the preparation of nanocrystalline PbS thin films because of its low temperature requirement, low cost, suitability for large-scale deposition areas, the ability to deposit thin films on different types of substrates, and facile control of thin film properties through adjustable deposition parameters (Obaid et al., 2012a,b). However, PbS thin films prepared using CBD require a long preparation time, where heat is usually transmitted from the outside to the inside of the material, which may cause uneven distribution of temperature in the solution (Obaid et al., 2012c). Microwave irradiation is widely used in the preparation of both organic and inorganic materials. In this case, heat is generated from inside the material through microwave irradiation (Wang et al., 2001). The production of internal heat reduces reaction time and energy cost, as well as allows the synthesis of new materials (Tu and Liu, 2000).

Microwave-assisted chemical bath deposition (MACBD) synthesis, which is a combination of both methods, is generally fast, simple, and energy efficient. It is important to know that highly efficient and cost-effective fabrication of solar cells remain a challenge for scientific research. Therefore, the authors focused on using MACBD in the synthesis of good-quality PbS/CdS heterojunction solar cells. To the best of authors' knowledge, no reports related to the fabrication of PbS/CdS heterojunction solar cells using MACBD are available. In the present work, structural and optical properties of CdS/PbS thin films prepared through MACBD, were investigated. This study primarily aims to fabricate PbS/CdS heterojunction solar cells.

2. Experimental details

2.1. Thin films preparation

The conducting ITO/glass commercial substrates (ITO shortened for indium titanium oxide), were washed with hot distilled water and then cleaned ultrasonically using diluted HCl solution for 10 min and then washed in acetone. After that, the substrates were cleaned ultrasonically by distilled water for 20 min and dried under nitrogen atmosphere. Nanocrystalline CdS thin film was deposited on ITO/glass substrates using microwave-assisted CBD method in an alkaline aqueous solution containing cadmium chloride [$CdCl_2$] (0.05 M), ammonia acetate (0.15 M) and thiourea [$CS(NH_2)_2$] (TU, 0.04 M), then ammonia solution was added to adjust the pH to 10; the total volume was 100 ml. The substrates were fixed vertically in a chemical bath, a beaker was then placed in a microwave oven (2.4 GHz) where the preparation temperature was fixed at 80 °C for 30 min. After that, the samples were taken out of the solution and washed ultrasonically with distilled water for 2 min to remove any contaminants. To fabricate CdS/PbS solar cells, nanocrystalline PbS thin films were prepared on CdS/ITO/glass. The samples were immersed in solution containing lead nitrate [$Pb(NO_3)_2$] and TU with various molar concentrations (0.025, 0.05, 0.075, and 0.1 M). The pH of the solutions was fixed at 12 by adding sodium hydroxide (NaOH); the total volume was 100 ml. The beakers were placed in the microwave oven (2.4 GHz) and the reaction temperature was fixed at 80 °C for a deposition time of 30 min. Beyond 10 min, the solution turned dark gray indicating that PbS was formed. The preparation of PbS thin films was returned three times sequentially to obtain thick PbS films. After the deposition process was completed, the samples were removed from the solution, cleaned ultrasonically with distilled water for 5 min, and then dried in air. Aluminium (Al) metal was deposited on the surface of PbS thin films via thermal evaporation method as Ohmic back contact. The active area of the device was 1 cm^2. Fig. 1 shows the schematic diagram of the fabricated cells. The errror bars of the data were estimated from instrumental errors of the optical properties and solar measurements, based on four replicate experiments, the displayed percentage errors and average values are shown in the manuscript and Figures.

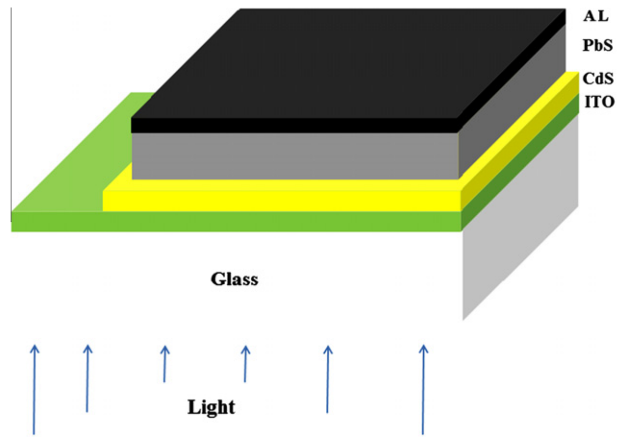

Fig. 1. Scheme for the solar cell.

2.2. Characterisations

The film thickness was determined using an optical reflectometer (Filmetrics F20). The measured thickness of CdS thin film was around 340 nm whereas that of PbS films was found to increase from 985 to 1380 nm as the molar concentration increases from 0.025 up to 0.1 M, respectively. This may be due to the increase of ions reaction with increasing molar concentration. The structure evolution of the as-prepared CdS and PbS thin films was examined by high-resolution X-ray diffraction (HR-XRD) using X'Pert