Materials Science in Semiconductor Processing 80 (2018) 179–183

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

CdS sensitized pristine and Cd doped ZnO solar cells: Effect of SILAR cycles on optical properties and efficiency

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ARTICLE INFO

Keywords:
ZnO
Cd doping
Optimization of SILAR cycles
CdS
Optical study
Solar cells

ABSTRACT

We report the CdS sensitized pristine and Cd doped ZnO using a successive ionic layer adsorption and reaction (SILAR) technique towards solar cell application. The effect of number of CdS SILAR cycles on the performance of pristine and Cd doped ZnO solar cells have been studied. A chemical synthesis technique at relatively low temperature (70 °C) was employed for the preparation of nanoparticulate powders of ZnO and Cd: ZnO. Doctor blade technique was used towards the preparation of film. The sensitization of CdS was done over ZnO and Cd: ZnO films with different SILAR cycles (4–16). The UV–Vis clearly shows the significant change in absorbance with the number of SILAR cycles for both the films. The results of J-V measurements with polysulfide as electrolyte and CuS as counter electrode were obtained by using 2420 Keithley source meter. The maximum power conversion efficiency of 0.279% and 0.604% was obtained for 12 cycles CdS sensitized ZnO and Cd: ZnO based solar cells, respectively.

1. Introduction

One of the most abundant renewable and clean energy available on the earth is solar energy. Therefore, translating the same into electricity using efficient solar cell is the crucial need of the society. Numerous materials and technologies have been proposed to meet the current demand towards the development of efficient device at lower cost and considerable progress has been made in this direction. In the beginning, dye-sensitized solar cells (DSSCs) received significant interest because of its simple fabrication procedure and high efficiency [1,2]. Semiconductor quantum dots (QDs) with a narrow band gap have recently attracted extensive interest and have been widely studied as an alternative to the expensive dyes as sensitizers [3,4]. Now a day, QDs are emerging out as a suitable and promising candidates for designing the next generation solar cells [5,6].

Usually, TiO_2 is used as a metal oxide semiconductor towards the fabrication of solar cells [7]. On the other hand; ZnO, ZrO_2, SnO_2, In_2O_3, and Nb_2O_5, can also be used as photoelectrodes towards the fabrication of solar cells. Presently, ZnO attracts more attention of researchers as an alternative to routine TiO_2 due to its wide optical band gap, high electronic mobility and similar electron affinity with that of TiO_2 along with a similar electron injection process from excited dyes [8,9]. Moreover, ZnO can be effortlessly synthesized via low cost chemical methods with assorted morphologies [10]. Variety of small band gap sensitizers have also been investigated for QDSSCs, such as CdS [11,12], CdSe [13], SnS [14], PbS [15], Bi_2S_3 [3,16], and SnS [17]. Among these, CdS has been paid much attention as it is n-type semiconductor with a direct optical band gap in the range of 2.2–2.6 eV [18], and it also absorb the light in visible part of the solar spectrum.

In order to improve the performance of the solar cell, one can use the different type of dopants in quantum dots and photoelectrode [19,20]. Wang et al. reported the performance improvement using metal salt solutions treatment over photoanode [21]. Improvement in photovoltaic performance of QDSSC was observed using ZnS [22] and ZnSe [23] passivation layer. The effect of CdS nanoparticles size over TiO_2 on the performance of device was investigated by Sankapal et al. [24]. Recently, we have reported the effect of post-annealing temperature over CdS nanowires, it is observed that the improvement in efficiency with increasing post annealing temperature [25].

In the present study, we have prepared pristine and Cd doped ZnO films using doctor blade technique as a photoelectrode sensitized with CdS towards the fabrication of solar cells. The influence of SILAR cycles on the photovoltaic performance of CdS sensitized ZnO and Cd: ZnO are studied in detailed.

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https://doi.org/10.1016/j.mssp.2018.02.033
Received 22 November 2017; Received in revised form 6 February 2018; Accepted 22 February 2018

2. Experimental

2.1. Materials and chemicals

Fluorine doped tin oxide (FTO) coated transparent conducting glass was used as substrates with dimension 1 × 1 cm^2. Zinc nitrate, cadmium nitrate and sodium sulfide flakes (99.9% Thomas Baker Chemicals Pvt. Ltd.), sodium hydroxide and ethyl cellulose AR (SDFCL, India), ethanol AR (99.9%, ChangshuYangyuan Chemical), acetyl acetone (MERCK, India) were used as received without further purification.

2.2. Preparation of photoanodes using doctor blade method

Pristine and Cd doped ZnO films have been prepared by using doctor blade technique. The respective powders were prepared by dissolving 0.1 M $Zn(NO_3)_2{\cdot}6H_2O$ in double distilled water (DDW) at constant stirring for 30 min to form homogeneous solution. After complete dissolution of zinc nitrate, equal volume of 1 M NaOH solution was added to it drop-wise. The reaction bath was maintained at 70 °C with constant stirring for 2 h followed by centrifugation. Finally, collected powder was wash with double distilled water for several times and dried at 60 °C in incubator to obtain ZnO powder. Similar route was used for the preparation of Cd: ZnO powder by doping 0.1 M Cd $(NO_3)_2{\cdot}4H_2O$ as describe earlier [26]. The paste was prepared by using synthesized powders, ethyl cellulose, ethanol, terpineol and acetyl acetone [12].

The preparation of photoelectrodes was done by doctor blade technique at room temperature. In brief, the FTO substrates were cleaned with soap solution, double distilled water and then with acetone followed by drying in incubator. Prior to the porous layer deposition, the compact layer deposition of ZnO on FTO substrate was done by chemical bath deposition method. In detail; 0.05 M solution of $Zn(NO_3)_2{\cdot}6H_2O$ was prepared in DDW with addition of 20% NH_4OH till it becomes clear. Immersed the pre cleaned FTO substrate in the solution bath maintained at 65 °C for 10 min to form compact layer. These compact ZnO coated FTO substrates were then rinsed with DDW and annealed at 450 °C for 1 h. The porous ZnO and Cd: ZnO films were deposited over these substrates using the respective pastes by doctor blade technique followed by annealing at 450 °C for 1 h to evaporate organic binders and improve the crystallinity.

For CdS sensitization, 0.05 M $Cd(NO_3)_2{\cdot}4H_2O$ solution in ethanol was used as a source of cadmium ions. For rinsing; ethanol was used to eliminate the loosely deposited species of Cd^{2+} ions. Subsequently, it was dipped in the anionic precursor solution of 0.05 M sodium sulfide flakes (Na_2S) prepared in methanol followed by rinsing in methanol in order to remove the unadsorbed species. A sulfide ions solution was exposed with the adsorbed cadmium ions and at last stage CdS nanoparticles were successfully build up on a surface of the films. The immersion time of the photoelectrode in a cationic and anionic precursor was taken as 5 min in each, with 30 s rinsing time. The ZnO and Cd: ZnO based photoelectrodes were sensitized with CdS nanoparticles for different number of such SILAR cycles.

2.3. Cell fabrication

The CdS sensitized ZnO and Cd: ZnO photoanodes were assembled into a sandwich-type open cell using CuS coated FTO as a counter electrode [27]. The photoanode and the counter electrode were separated by 3 μm thick spacer over CdS sensitized photoanodes. Polysulfide was used as a liquid electrolyte which is composed of 0.5 M Na_2S and 0.1 M sulphur powder in mixture of 22.5 ml ethanol, 5 ml methanol and 2.5 ml DDW. One drop of it was introduced between the sensitized film and the counter electrode by capillary action.

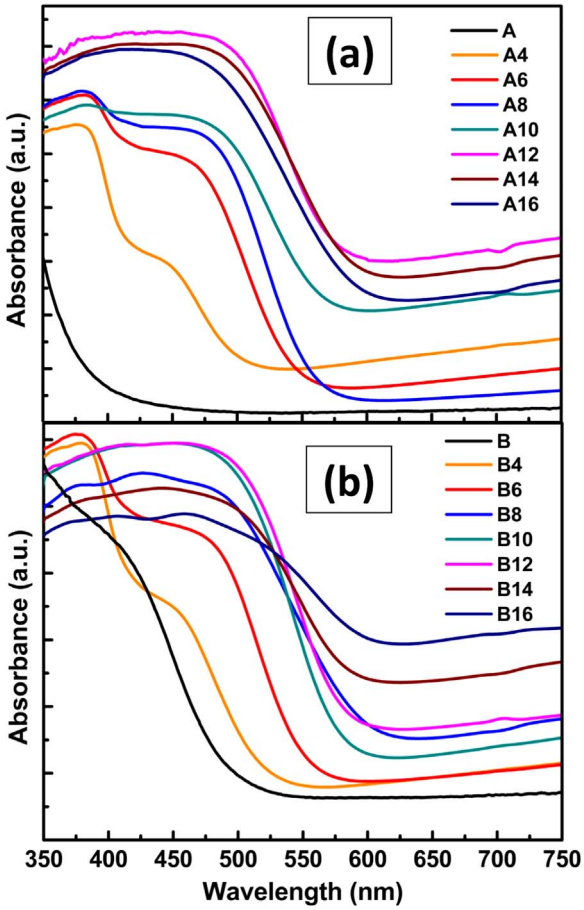

Fig. 1. Optical absorption spectra of (a) pristine ZnO and (b) Cd: ZnO with & without CdS for different SILAR cycles (4–16).

2.4. Characterizations

The pre and post CdS sensitized ZnO and Cd: ZnO films were examined with help of X-ray diffractometer (XRD) [Bruker D8 ADVANCE with CuK_α radiation having wavelength of 1.54 Å], UV–Visible spectroscopy [JASCO V-670], Scanning electron microscope (SEM) [JEOL-JSM 6360-A operating at 20 kV] and Energy dispersive X-ray spectroscopy (EDS) unit coupled with SEM. The device performance i.e. current density-voltage (J-V) curve was measured using source meter (Keithley 2420) under Xenon lamp illumination at 80 mW/cm^2 intensity supplied from solar simulator (Newport) with exposed area 0.25 cm^2 for all cells.

3. Results and discussion

3.1. Optical absorption

The optical absorbance spectra were recorded in the wavelength range from 350 to 750 nm. The absorption spectra of bare ZnO, Cd: ZnO and CdS nanoparticles-coated films with different SILAR cycles are illustrated in Fig. 1. A sharp increase in the absorption spectra at shorter wavelength (below 380 nm) can be observed for pristine ZnO, suggesting that the absorption band edge would facilitate its application as a wide band gap semiconductor material. The absorption spectra of the CdS-coated ZnO and Cd: ZnO films for the different number of SILAR cycles is shown in Fig. 1(a) and (b), respectively. It is clearly observed that, the absorption from 400 to 600 nm is increases with number of SILAR cycles; this clearly indicates a red-shift in the absorption edge. One can also observed the sharp increase in absorption spectra up to 12 cycles and then decreases for 14 and 16 cycles. This might be due to the