Solar Energy 174 (2018) 757–761

Contents lists available at ScienceDirect

Solar Energy

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

Towards CdZnTe solar cells: An evolution to post-treatment annealing atmosphere

S. Chander[a,b,*], A.K. De[a], M.S. Dhaka[b]

[a] Department of Chemical Sciences, Indian Institute of Science Education and Research Mohali, Knowledge City, Sector 81, SAS Nagar, Mohali 140306, India
[b] Department of Physics, Mohanlal Sukhadia University, Udaipur 313001, India

ARTICLE INFO

Keywords:
CdZnTe solar cells
Efficiency enhancement
Vapor proceed techniques
Atmosphere evolution
Microstructural and optical properties

ABSTRACT

The increasing energy demand and resulting decay in the conventional energy resources indicate to find viable and affordable alternative resources. The cell efficiency and properties of absorber/window layers concerned can be tailored by the different post-treatments and therefore an evolution of post-treatment atmosphere conditions is undertaken in this work to enhance the performance of vapor proceed CdZnTe solar cells. Firstly, the microstructural and optical properties of absorber CdZnTe layer were optimized where films have zinc blende cubic structure with maximum crystallinity for Ar + O_2 atmosphere while the energy band gap is influenced by the annealing in different atmospheres. Secondly, CdZnTe solar cells were fabricated using vapor proceed technique with device structure ITO/CdS/CdZnTe/Au and performance analysis is done by varying the atmosphere of post-annealing treatment. The device treated at 400 °C in the Ar + O_2 atmosphere has maximum cell efficiency of 8.49% and more trap-states crossed the Fermi level as confirmed by Mott-Schottky plots. The dopant density and built-in potential are also evaluated. The findings of this work reveal that the efficiency of CdZnTe solar cells can be enhanced by the post-annealing treatment in different atmospheres.

1. Introduction

The continuous reduction in available conventional fossil fuel energy resources for the remaining 21st century needs to find viable and economically affordable substitute energy resources. The burning of fossil fuels also releases greenhouse gases into the environment which contribute in the global warming as more than twenty-five million tons of carbon dioxide has been delivered into the environment in a single year. Therefore, non-polluting renewable energy resources are needed as an essential substitute and among all the renewable energy resources, solar energy is one of the best and freely available energy resource because it is directly obtained from the sun (Gogan et al., 2017; Chander and Dhaka, 2016a). Apart from the conventional energy resources, the photovoltaics is an enormous potential resource as the performance of photovoltaic cell is very flexible power resource and does not depend on the size of a photovoltaic plant. The most common solar cell technology is wafer-based crystalline silicon but it has limited stock which is a major barrier to reduce the cost. The thin film solar cells have emerged as a competitor to crystalline silicon in the solar photovoltaic industries and have low-cost vis-à-vis to the silicon solar cell technology and cell industry. These devices are less efficient but much cheaper to produce, rendering them a viable alternative (Amarasinghe et al., 2018; Burst et al., 2016; Hegedus, 2006).

Polycrystalline cadmium telluride (CdTe) thin films are one of the front prime candidates to develop cost-effective and reliable solar photovoltaics where these solar cells and modules have cadmium sulfide (CdS) layer as n-type window layer in typical heterojunctions (Ferekides et al., 2004). Sometimes CdTe solar cells have inherent problems viz. suitablility of metal rear contact (in superstrate structure), high-density of surface states and large recombination rate of absorber CdTe layer (Paudel and Yan, 2014; Paudel et al., 2015; Wichrowska et al., 2018). The superstrate structure is the appropriate device structure for CdTe solar cells. As per principle of detailed balance to the maximum limit, the efficiency beyond 33% of any solar cells could only be attained by a tandem-structure having top ($E_g \sim 1.7$ eV) and bottom ($E_g \sim 1$ eV) absorber layers. These layers are connected in a series combination (Yilmaz, 2012; Chander and Dhaka, 2017a) and their combination also based upon the deposition process viz. two-terminal and four-terminal devices. CdTe material does not have the band gap required for the top layer but a compact solution of cadmium telluride and zinc telluride can provide a band gap as required for top layers by forming CdZnTe semiconducting material which is very

* Corresponding author at: Department of Chemical Sciences, Indian Institute of Science Education and Research Mohali, Knowledge City, Sector 81, SAS Nagar, Mohali 140306, India.

E-mail addresses: schander@iisermohali.ac.in, sckhurdra@gmail.com (S. Chander).

https://doi.org/10.1016/j.solener.2018.09.025
Received 16 July 2018; Received in revised form 26 August 2018; Accepted 12 September 2018

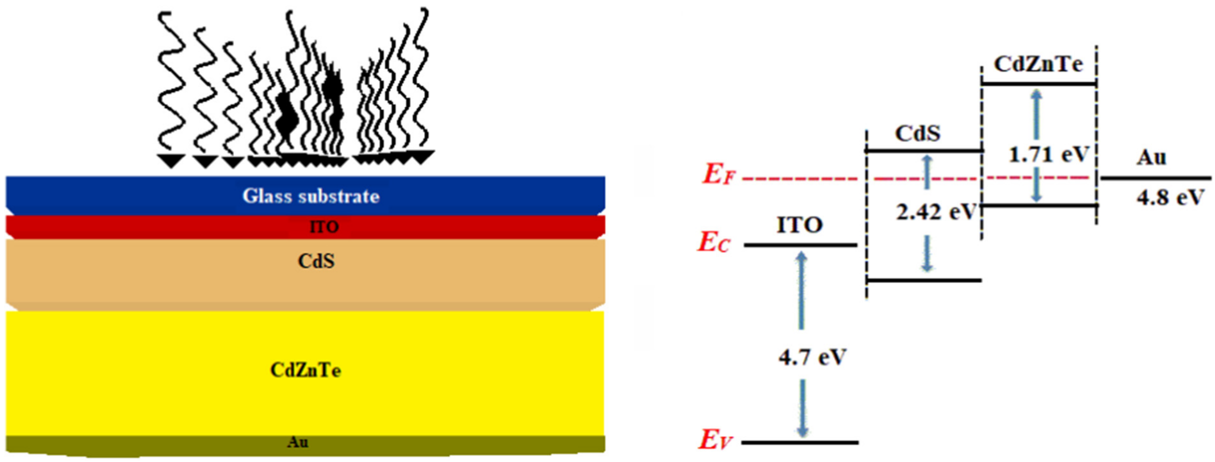

Fig. 1. (a) A schematic device structure in superstrate configuration and (b) energy band diagram of fabricated CdZnTe solar cells.

promising as its optical bandgap can be tailored in the range of 1.45–2.26 eV (CdTe-ZnTe) by monitoring the composition of thin layers (Rohatgi et al., 1988; Chander and Dhaka, 2016b). This material has demonstrated a promising and competing candidature for solar photovoltaic applications in place of conventional CdTe material to avoid and reduce the above-mentioned problems owing to its tunable bandgap energy, stability, good electron-transport properties and almost unity segregation coefficient of zinc (Rohatgi et al., 1988). Some vapor and solution process techniques are available to fabricate CdZnTe solar cells like magnetron sputtering (Banerjee and Ghosh, 2013), pulsed laser deposition (PLD) (Yang et al., 2016), evaporation (Khrypunov et al., 2006), close-spaced sublimation (CSS) (Gao et al., 2012), molecular beam epitaxy (MBE) (Zhao et al., 2014) and chemical bath deposition (CBD) (Han et al., 2011). The vapor proceed technique (electron-beam evaporation) is used herein to make CdZnTe solar cells as this technique provides some advantages like reproducibility, controllable growth-rate and lower consumption of material. To resolve the issue related to loss in open-circuit voltage in CdTe solar cells, CdZnTe-based solar cell technology is a viable and low-cost substitute solar photovoltaic technology to get highest cell-efficiency in view of the Shockley-Queisser limit to the maximum efficiency. As far literature concerned, the efficiency of solar cells has influenced by several factors viz. processed technique, layers thickness and different conditions of pre or post-treatments as well as no report is available on enhancement in performance of CdZnTe solar cells post-treated in different annealing atmospheres, so this work is carried out herein.

2. Materials & methods

2.1. Deposition

Prior the deposition process, the substrates were ultra-sonicated for 30 min at temperature 60 °C and cleaned by acetone and isopropanol and then dried by nitrogen gas and kept in box having methanol. The chamber of vacuum coating unit (BC-300, HHV) was also cleaned by both chemical agents (i.e. acetone and isopropanol) to remove any residual of earlier deposition and then substrates (microscopic glass) having area of 6.45 cm^2 (i.e. 1″ × 1″) were placed on holder inside the chamber. The source material i.e. powder $Cd_{0.90}Zn_{0.10}Te$ (99.9999% trace metal basis, Aldrich) was made into pallet shape by hydraulic pressure and placed in the pot/crucible having distance of 18 cm from the substrates and then films were prepared by electron beam evaporation within the vacuum of 4×10^{-6} mbar following the film deposition process discussed in previous work (Chander and Dhaka, 2017b). Herein the vacuum was obtained by Turbo and Rotary pumps and the evaporation rate was measured by quartz crystal monitor and kept almost constant (4–5 Å/s) while the layer thickness of 1.2 µm was verified by stylus profilometer (NanoMap 500ES, AEP Technology Inc.). To obtain uniform and homogeneous surface, the pristine absorber CdZnTe layers were subjected to thermal treatment at 400 °C for one hour in vacuum and different atmospheres like hydrogen (H_2), nitrogen (N_2) and argon plus oxygen ($Ar + O_2$) where a digital microprocessor was used to maintain the annealing conditions. The pristine and samples treated in different annealing conditions were used for structural, optical and surface morphological studies employing X-ray diffraction (XRD) (Bruker: AXS Kappa Apex-II), UV–Vis spectrophotometer (Perkin Elmer) and scanning electron microscope (SEM) (Hitachi: S3400N) coupled with energy-dispersive X-ray spectroscope (EDAX), respectively. The structural and optical properties were measured and explored as methods discussed in the previous report (Chander and Dhaka, 2016a).

2.2. Device fabrication

CdZnTe based solar cells in superstrate configuration have been fabricated with device structure glass/ITO/CdS/CdZnTe/Au. CdS material (99.9999% trace metal basis) and indium tin oxide (ITO) substrates were procured from Aldrich. Initially the thin cadmium sulfide (CdS) window layer of 100 nm was deposited on ITO coated glass substrate in high vacuum of 4×10^{-6} mbar employing electron beam vapor evaporation (BC-300, HHV) and then absorber CdZnTe layer of thickness was 1.2 µm deposited on window CdS layer followed by annealing treatment in different atmospheres at 400 °C for sixty min. Au contacts of 15–20 nm on the surface of absorber CdZnTe layer were made by an evaporator in the glove-box having nitrogen atmosphere where the active device area was 0.126 cm^2. The evaporation rates of CdZnTe and CdS were kept almost constant (5–6 Å/s). The light current-voltage measurements were taken inside a glove-box by varying voltage (within required range) and recorded the corresponding current employing a Keithley 2400 source-meter under the illumination of the class A solar simulator (Newport, AM1.5G) having one sun intensity (1000 W/m^2) as verified by a calibrated Newport reference solar cell. The solar cell devices were illuminated where light-beam was incident from the front side of device (as intimated in Fig. 1). To undertake electrical measurements, two probes were used with the help of calibrated standard crystalline silicon cell having short circuit current of 1.67 mA as reference. A Keithley source meter (Model: 4200-SCS) was used to find the capacitance-voltage characteristics having probe frequency of 20KHz to determine the width of depletion layer and dopant density. Total eight solar cell devices were made in identical fabrication conditions and all devices have almost similar performance as well as the reproducibility of these devices was also made by a sequential deposition process and was found to be excellent having $< 10\%$ deviation.