



Preparation and stability study of broadband anti-reflection coatings and application research for CdTe solar cell

Dingqin Hu, Dong Liu, Jingquan Zhang^{*}, Lili Wu, Wei Li

College of Materials Science and Engineering, Sichuan University, 610064, Chengdu, China

ARTICLE INFO

Article history:

Received 28 December 2017

Received in revised form

18 January 2018

Accepted 19 January 2018

Keywords:

Sol-gel method

Dip-coating

Anti-Reflection coatings

CdTe solar cell

ABSTRACT

Reflection loss is essential factor to limit the efficiency of all of photovoltaic devices. Glass substrate that with no trapping mechanism to reduce the reflection of light as most CdTe commercial thin film solar cells are manufactured. The absorption band gap of CdTe devices is 387–850 nm, to minimize the losses, a broadband anti-reflection coating that its transmittance must as high as possible at 390–850 nm is designed with TFCALC modeling software and deposited with sol-gel method and dip-coatings technique on both sides of the glass substrate. See from the transmittance spectrum of broadband anti-reflection coatings (BARCs) is more than 98% at the band of 390–870 nm which is the same as the band gap of CdTe photovoltaic cells and its maximum transmittance is 99.70%. In addition to matched band and high transmittance, the durability of BARCs is crucial for applying on CdTe devices. It presents that BARCs that uses trimethyl chlorosilane (TMCS) to optimize the hydrophilic of the surface of BARCs is relatively stable from the examination of Contact angle and Environmental include damp heat, ultraviolet radiation and light-tact. The BARCs can well apply on CdTe modules that the optical property of BARCs is not affected by the preparation process of CdTe solar cell with simulation.

© 2018 Elsevier B.V. All rights reserved.

1. Introduction

The highest efficiency is 22.1% and short circuit current density is 30.2 mA/cm² of CdTe thin film solar cells have been reported by First Solar Inc in the year of 2016 [1]. But theoretically, the maximum short circuit current density allowed by AM1.5 spectrum is 31.2 mA/cm² (between 350 and 850 nm) and efficiency is about 29% [2,3]. The reason for the loss of current density of CdTe solar cell is the absorption in the window layer of CdS, the second is the reflection of the glass substrate on the incident light [4,5]. Changing the thickness of CdS and add suitable buffer layer before CdS include SnO₂, CdSe [6] and so on, it can enhance the absorption of light between 350 and 515 nm. However, it is rather difficult to figure out that the complexity interface in SnO₂/CdS/CdSe/CdTe and need much time to research interface recombination and the inter-diffusion of CdSe at CdSe/CdTe interface and the formation of CdTe_{1-x}Se_x alloys [7]. It is the most direct and convenient method compared the changing of absorbing of window layer to reduce the reflection of substrate. Designing one single and multilayer

antireflective thin film on glass substrate is staple way to reduce reflective.

BARCs is not only suitable for CdTe solar cells, but also for other photovoltaic (PV) devices such as perovskite, silicon and CIGS. The reasons for applying the BARCs on CdTe thin film solar cells are performed: (I) Considering the compatibility of process and practical, the application of BARCs on devices must ensure that the optical properties of BARCs should not affect by the preparation of CdTe solar cell. Experimental results show that BARCs is conducive to apply on CdTe cells with detailed simulation that is the influence of the preparation process of CdTe solar cell for BARCs; (II) G. Womack and P. M. Kaminski is the only one to detail design and apply BARCs on CdTe solar cell as far as the current report is concerned, but the cost is expensive with vacuum evaporation deposition and also cannot achieve large area and various size deposited on substrate. It is not advantageous to use high-low and limited to prepare BARCs for applying as marketable CdTe solar cells. In this paper, the preparation of BARCs with sol-gel dip-coating and a serial of optimization are to improve propitious; (III) The transmittance of BARCs is over 98% at the band of 390–870 nm which is consistent with the CdTe absorption offset of 387–850 nm, therefore, it can maximize the effect of transparency and make full use of the light.

^{*} Corresponding author.

E-mail address: zhangjq@scu.edu.cn (J. Zhang).

Single layer anti-reflection coatings have been applied on solar cells and solar modules such as magnesium fluoride (MgF_2) which is prepared by sol gel method and deposited with evaporation coating, silicon dioxide (SiO_2) and titanium dioxide (TiO_2) which are measured through sol gel and spin-coating technique. However, these coatings can have effect on photovoltaic (PV) devices in narrow wavelength range compared the response interval (387–850 nm) for CdTe thin film solar cells. In addition to narrow wavelength, the surface of SiO_2 , TiO_2 and MgF_2 have much more -OH bonds because of the preparation of sol-gel which is hydrophilic, therefore, these coatings have poor durability application on solar modules for outside use without surface optimized. However, sol-gel method with dip-coating technology is widely used because of low cost, simple operation and adjustable chemical process parameters [8–14] compared thermionic vacuum arc, magnetron sputtering, chemical vapor deposition (CVD). Taking advantage of surface optimization of BARCs to ameliorate its adhesion, scratch-resistance, durability environmental and hardness to figure out the adverse factors for coatings, because the topography of these coatings are particles and the surface of BARCs have much -OH can make much effect on its stability.

The improvement of short circuit current density depends on that the transmittance of anti-reflection coatings enhances in short wavelengths and expand in long wavelengths, at the same time, broadband anti-reflection coatings (BARCs) for photovoltaic devices to reduce reflection is necessary. The technique of BARCs is significant for CIGS, CdTe, Perovskite and a-Si solar cell to minimize reflection and improve photovoltaic collection efficiency. The BARCs is vital for the study of specific technology of specific device, because the difference of device preparation technology, photovoltaics structure and spectral response interval. There are many multilayer thin films such as $\text{MgF}_2/\text{ZrO}_2/\text{Al}_2\text{O}_3$ [15] and $\text{ZnSe}/\text{ZnS}/\text{YbF}_3$ [16] with evaporation coating, $\text{SiN}_x/\text{SiO}_2$ via inductively coupled plasma chemical vapor deposition (ICPCVD) [17] and $\text{SiO}_2/\text{TiO}_2$ with sol-gel method [18], but G Womack and P. M. Kaminski is the only one to detail design and apply BARCs for CdTe solar cell as far as the current report is concerned [19,20]. Through their work shows results about application and make research on environmental durability tests about multilayer thin film of $\text{ZrO}_2/\text{SiO}_2$, the cost is expensive with vacuum evaporation deposition and also cannot achieve large area and various size deposited on substrate. It is not advantageous to use high-low and limited to prepare BARCs for applying as marketable CdTe solar cells.

The reasons for using SiO_2 to design broadband anti-reflection coatings (BARCs) are performed: (I) The SiO_2 silica is prepared by sol-gel is stable that can withstand high temperature over 600 °C, therefore, the optical property of BARCs is not be affected with the preparation process of CdTe thin film solar cell at high temperature; (II) The preparation of SiO_2 thin film is relatively simple and its refractive index can be control from 1.05 to 2.46 with different preparation process such as sol-gel method, oblique angle deposition, vapor deposition [21–27]. Additionally, different reaction conditions can form the different morphological structure of SiO_2 phase [28,29]; (III) The chemical property of SiO_2 is durable that it is not insoluble in water, acid (except hydrofluoric acid) and organic matter, at the same time, SiO_2 is a green material with no pollution for environment.

In order to achieve minimum reflection of broadband wavelengths with low-cost, simple operation and any size and shape of the substrate can be deposited, in this study, we attempt the preparation of BARCs on glass substrate with sol–gel dip-coating method. To achieve the best performance along the desired spectrum, the refractive index and thickness of each layer must be designed with TFCALC modeling software, acid and base catalyzed SiO_2 are used respectively for the preparation of BARCs. The

stability of BARCs is also an important factor for application on CdTe thin film solar cell with long time, therefore, the surface optimized of BARCs with trimethyl chlorosilane (TMCS) is necessary and use environmental-testing to examine its durability. Matching BARCs with the preparation process of CdTe solar cell to ensure that the optical property of BARCs have no effect on the preparation process of CdTe devices.

2. Experimental

2.1. Preparation of broadband anti-reflection coatings

Tetraethyl orthosilicate (TEOS) as precursor, ethanol (EtOH) as solvent, hydrochloric acid (HCl) and ammonia ($\text{NH}_3 \cdot \text{H}_2\text{O}$) as catalyst for preparing silica sols, deionized water (H_2O) as medium for hydrolysis reaction, polyethylene glycol (PEG2000) as pore-forming agent for $\text{SiO}_2(\text{H}^+)$ sol, trimethyl chlorosilane (TMCS) as solvent for the grafting of surface of broadband anti-reflection coatings.

Sol-gel method is used to prepare silica sol: (I) preparation of silica sol under base-catalyzed hydrolysis, the SiO_2 sol with the refractive index is 1.26 and 1.12 are prepared that the reactant are mixed in required amounts with a volume ratio of $\text{TEOS}:\text{EtOH}:\text{H}_2\text{O}:\text{NH}_3 \cdot \text{H}_2\text{O}$ to 4.7:43.3:2.7:1 and 3:30:2:1. And then, the solution is vigorously sired at 3 h and age at room temperature for 7 days; (II) preparation of silica sol under acid-catalyzed hydrolysis, firstly, measure out 2 mL HCl dilute 150 times with water and the volume ratio of $\text{TEOS}:\text{EtOH}:\text{H}_2\text{O}:\text{HCl}$ is 5:30:4:1 which is sired 2 h at room temperature. Secondly, putting PEG2000 into solution until it is completely dissolved that the mass ratio of $\text{TEOS}:\text{PEG2000}$ is 1:1 and then age at room temperature with 1 day; (III) preparation of multi-antireflection thin film under dip-coatings technique: $\text{SiO}_2(\text{H}^+)/\text{SiO}_2(\text{OH}^-)/\text{SiO}_2(\text{OH}^-)$ films are deposited on glass substrates with the withdrawal speed is 1000 $\mu\text{m/s}$, $\text{SiO}_2(\text{H}^+)$ layer is heated at a temperature of 150 °C for 5 min and $\text{SiO}_2(\text{OH}^-)$ layers are dried at a temperature of 40 °C for 10 min; (IV) the surface optimization of BARCs is achieved by placing BARCs into trimethyl chlorosilane (TMCS) with 20 min and then clean up with acetone, ethanol and deionized water.

2.2. Manufacture of master molds

The transmittance is tested by ultraviolet–visible spectrophotometer (Lambda 950). The surface morphology of multilayer thin film is examined using scan electron microscope (JSM-7500F). The IR spectra of optimized BARCs measured on Fourier infrared spectrometer (Nicolet 6700). The contact angle of coatings is tested with hanging drop method by contact instrument (JC2000C1). The film refractive index and thickness are measured on ellipsometer (SE850). The environmental-testing of broadband anti-reflection coatings is tested by light-tact (KD/LS01-2226), ultraviolet radiation (KD/UV02-2226) and high and low temperature alternating hot and humid (ETH-4005-CP-AR) test chamber. The heat treatment of thin films by annealing furnace (NBD-M1200).

3. Results and discussion

3.1. BARCs designed and measured

For the design of broadband anti-reflection coatings (BARCs), the refractive index of prepared BARCs decreases along glass substrate to air that the reflection waves can occur offset interference [25]. However, the conventional SiO_2 thin film has a refractive index of 1.46 which cannot achieve the change of the refractive index gradient, therefore, the nano-structure that is nano-particle [26–28], oblique-angle [24] and nanotip arrays [23] of surface of

Download English Version:

<https://daneshyari.com/en/article/7907237>

Download Persian Version:

<https://daneshyari.com/article/7907237>

[Daneshyari.com](https://daneshyari.com)