Thin Solid Films 546 (2013) 326–330

Contents lists available at ScienceDirect

Thin Solid Films

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

Enhancement of the light harvesting efficiency in a dye-sensitized solar cell by a patterned reflector

Jeong-Hwa Kim, Dae-Hwan Kim, Kang-Pil Kim, Dong-Hwan Jeon, Dae-Kue Hwang *

Green Energy Research Division, Daegu Gyeongbuk Institute of Science & Technology, 50-1 Sang-Ri, Hyeonpung-Myeon, Dalseong-Gun, Daegu 711-873, Republic of Korea

ARTICLE INFO

Available online 3 April 2013

Keywords:
Dye-sensitized solar cell
Light harvesting efficiency
Reflector

ABSTRACT

Light harvesting efficiency plays an important role in improving the power conversion efficiency (PCE) of dye-sensitized solar cells (DSSCs). Many researchers have employed a scatter layer to improve the light harvesting efficiency of DSSCs. In this paper, we propose a different DSSC structure that employs a patterned reflection layer to enhance the light harvesting efficiency and improve the PCE by reusing reflected light. Optical simulation data were collected through an optical analysis according to various patterns of the reflection layer. The optical simulation results revealed that the light harvesting efficiency of a rectangular patterned reflection layer was higher than that of other patterns. We evaluated the cell efficiency with current density–voltage characteristic curves by a solar simulator. The DSSC structures with a rectangular patterned reflection layer exhibited higher current densities and higher PCE values (22% enhancement) than those of traditional DSSCs, because light that passed through the photoanode was reflected, thereby making it possible to reuse it.

1. Introduction

The development of photovoltaic technologies has attracted increasing attention due to world-wide growing energy demand as well as the need to replace environmentally critical energy resources such as fossil fuels by renewable energy [1]. DSSCs, emerging 3rd generation solar cells, are of great interest due to their many advantages, such as projected cost effectiveness and good performance under weak/diffuse light and compatibility with building window glass and flexible substrates. Therefore, DSSCs are considered a promising alternative to bulk silicon-based solar cells, which currently dominate the market [2]. However, DSSCs currently have low conversion efficiency. Many researchers have attempted to resolve this problem, by increasing the surface area of TiO_2 photo-electrodes used in the DSSC [3]. Other studies have focused on the development of different dyes. Because these studies concentrate on material characteristics, they require the development of different materials, which presents considerable challenges [4–7]. Another way of improving the efficiency is to reuse the light energy with a reflector or scatter layer. Miguez [8–10] reported remarkably improved light utilization using one-dimensional photonic crystals in a multilayer coupled inside a cell based on inorganic nano-particles. Lee et al. investigated a polymeric mirror from 1D photonic crystals exhibiting full specular reflection. The mirror is applied on the exterior of the counter electrode of a DSSC [11]. More recently, Choi et al. demonstrated improved efficiency in a solar cell by re-driving light with a reflector having a random pattern, and then reusing discarded light after it is absorbed [12].

However, these structural approaches to increase the optical absorption have several disadvantages. The inserted TiO_2 scatter layer has decreased open circuit voltage (V_{oc}) due to increased resistance with an increasing thickness of the scatter layer. The polymer mirror also has high resistance as an insulator material. It is consequently difficult to insert it inside the DSSC. Therefore, structural studies are needed to address the shortcomings of light harvesting reflectors and scatter layers.

In this study, we propose a DSSC structure that employs a regular patterned reflector in the counter electrode to enhance the light harvesting efficiency and to improve the PCE by reusing the reflected light.

2. Experimental details

2.1. Optical analysis

The effects of various shapes of a patterned Mo reflector were investigated by an optical simulation implemented by light simulation software (LightTools). LightTools, developed by Optical Research Associates (ORA), can be used to analyze various types of illumination systems (ORA, Inc., 2004). It can also be used to create virtual prototypes of optical systems for a wide range of applications [13].

Here, the optical software has been used to simulate various shapes of a Mo patterned reflector to improve the reflectance characteristics.

* Corresponding author. Tel.: +82 53 785 3710; fax: +82 53 785 3739.
E-mail address: dkhwang@dgist.ac.kr (D.-K. Hwang).

0040-6090/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tsf.2013.03.062

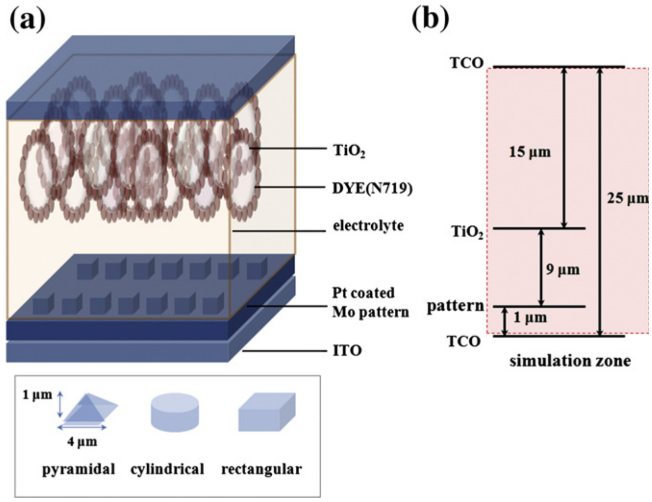

Fig. 1. (a) The DSSC structure with an applied patterned reflector, and various pattern shapes. (b) Simulation area of the DSSC with a patterned reflector.

Fig. 1(a) shows the DSSC structure with an applied patterned reflector with pyramidal, cylindrical, and rectangular Mo reflector patterns created by LightTools. The width, length, height, and spacing of each pattern are 4, 4, 1, and 4 μm, respectively. Fig. 1(b) shows the simulation zone for the optical analysis of the various shapes of the patterned reflector at the DSSC structure. As shown in Fig. 1(b), the DSSC has spacing of about 25 μm occupied by surlyn (Solranonix 25 μm) between the TiO_2 thin film layer at the working electrode, and Pt coats the transparent conducting oxide (TCO) glass at the counter electrode. The thickness of the TiO_2 thin film is about 15 μm and the height of the design patterns is 1 μm. The TCO and TiO_2 layers of the working electrode have constant optical parameters. Thus, we simulated an approximately 25 μm simulation zone from the working electrode to the counter electrode. The simulation of incident light irradiance takes into consideration the optical properties through the working electrode from one sun (100 mW/cm^2), as shown in Fig. 2(a).

2.2. Preparation of a dye-sensitized solar cell with a patterned reflector

The Mo patterned indium tin oxide (ITO) glass and non-patterned ITO glass were platinized by spin-coating an H_2PtCl_6 solution (7 mM). The anode electrode was then soaked in a $NaBH_4$ solution for 5 min. After being rinsed with deionized water (DIW) and ethanol, the Pt electrode was baked at 120 °C for 30 min. The TiO_2 paste (Solarnonix, T/SP, R/SP) was deposited on pre-cleaned fluorine tine oxide (FTO) glass by the doctor blade method. The area of the prepared TiO_2 anode was 0.24 cm^2. The TiO_2-coated FTO glass was sintered at 500 °C for 1 h and cooled to 100 °C. Before being immersed in the dye solution, the working-electrodes were soaked in a 40 mM aqueous $TiCl_4$ solution at 70 °C for 30 min. After being washed with DIW and fully rinsed with ethanol, the TiO_2 films were again sintered at 500 °C for 1 h. The TiO_2 electrode was immersed in a N719 solution (0.5 mM) for 12 h. The dye-sensitized TiO_2 electrode was rinsed with ethanol and dried under an N_2 flow. The two electrodes were sealed together with a thermal melt polymer film (25 μm, Solarnonix). AN-50 electrolyte (Solarnonix) was introduced through a drilled hole on the counter electrode.

2.3. Measurements

The UV–visible absorption spectrum was obtained on a Cary-5000 UV–visible spectrophotometer (Varian, USA). The scanning electron microscope (SEM) image was operated at 1.5 kV, 10 μA with the Hitachi S-4800 SEM (Japan). The current density–voltage (J–V) characteristics were measured with standard sandwich-type cells. The effective area of the cell was 0.24 cm^2. A 1000 W xenon light source (Newport 91192-1000, USA), which had been calibrated by a Si photodiode, was used to give an irradiance of 100 mW cm^{-2} (AM 1.5, global). The J–V characteristics of the cells were recorded by applying

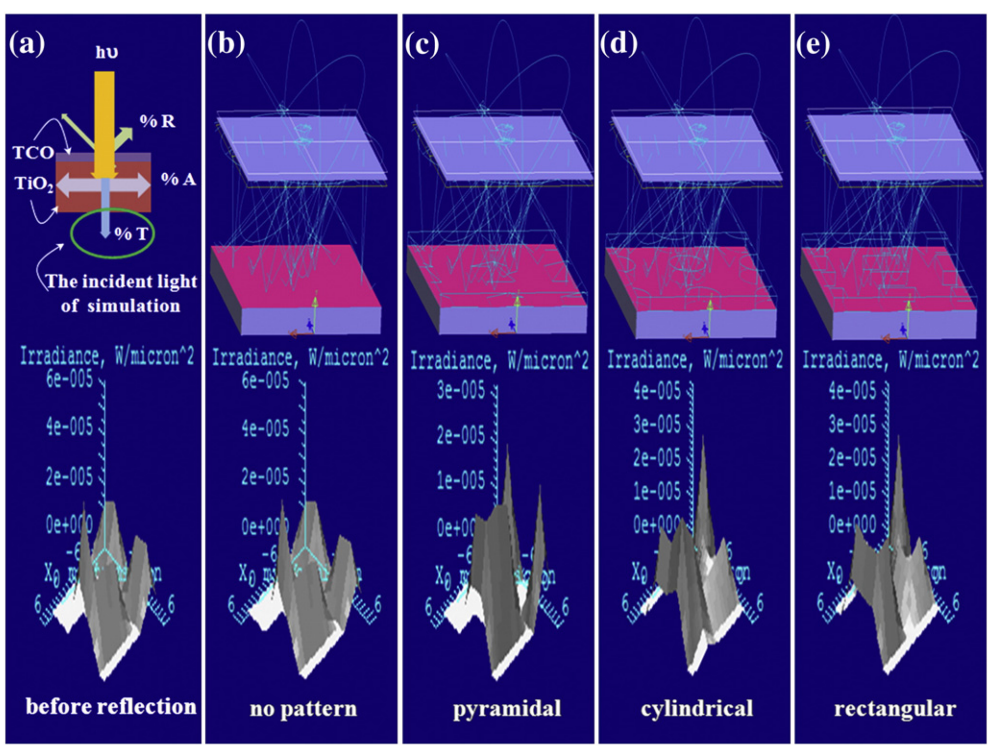

Fig. 2. Optical analysis of various reflector shapes: (a) the optical process of reflection, absorption, and transmission at the TiO_2 layer of the photo-electrode under one sun and simulation of incident light irradiance, (b) without a patterned reflector, (c) pyramidal patterned reflector, (d) cylindrical patterned reflector and (e) rectangular patterned reflector.