ENHANCED ABSORPTION OF THE QUANTUM DOTS SOLAR CELLS BASED ON CO-SENSITIZED CdS/CdSe QUANTUM DOTS

Ha Thanh Tung

Faculty of Physics, DongThap University, Dong Thap Province, Vietnam.
Corresponding author: tunghtvlcrdt@gmail.com

ABSTRACT.

In this work, the CdS and CdSe quantum dots were prepared on TiO_2 mesoporous film through a successive ion layer absorption and reaction (SILAR) method and a chemical bath deposition (CBD) method, respectively. As a result, simply increasing film thickness did make significant contribution to improving solar cell efficiency. The results show the enhances the power conversion efficiency of 1.21 % in the quantum dots solar cells.

***Keyword**: passivation, solar cells, quantum dots.*

INTRODUCTION

Recently, the scientists in the world have interested in the quantum dots solar cells (QDSSCs) based on the TiO_2 subtrate. The QDSSCs based on the QDs have more advantages than the Dye sensitized solar cells (DSSCs) based on the molecules for some reasons: (1) the molecules only absorb the light in visible, (2) and are unstable in the air enviromental. Beside the disadvantages of the moleccules, the QDs has some advantages such as quantum confinement effect, the higher coefficients than the dyes, the generation of multiple electron – hole pairs by a single incident photon [1-2]. Moreover, the tunable adsorption band of the QDs can be perform by the changed their size for the light harvesters in QDSSCs [3].

For those reasons, the QDSSCs were promised to become the candidate for the high efficiency. Firstly, Vogel and colleagues prepared the QDSSCs based on CdS QDs and obtained the low efficiency [4]. In 2008, many scientists only studied the single QDs as CdS, CdSe, PbS… for the application in the QDSSCs. Therefore, the results obtained the low efficiency. For the next years, the series articles focus on the improving efficiency of the QDSSCs with the subject such as: to improve the adsorption of the photoanodes [5], [6]; to use the different methods such as chemical bath deposition (CBD), successive ionic layer adsorption and reaction (SILAR)... [7]; to apply the core – shell QDs to reduce the surface states in the QDs [8]. However, the efficiency of the QDSSCs was still lower than the efficiency of the DSSCs at the present due to the high surface states at the TiO_2/QDs contact and the large diffusion resistance in the TiO_2 film.

In this work, the CdS and CdSe quantum dots were prepared on TiO_2 mesoporous film through a successive ion layer absorption and reaction (SILAR) method and a chemical bath deposition (CBD) method, respectively. As a result, simply increasing film thickness did make significant contribution to improving solar cell efficiency. The results show the enhances the power conversion efficiency of 1.21 % in the quantum dots solar cells.

EXPERIMENT

The films were coated with TiO_2 layers by silk-screen printing, and were then annealed at 500°C for 30 minutes. Their sizes ranged from 10 nm to 30 nm. The thickness of the TiO_2 films was approximately 4 µm, as measured by a stylus. Then,

the films were dipped in 40 mmol $TiCl_4$ solution for 30 minutes at 70°C and sintered at 500°C for 30 minutes.

TiO_2/CdS/CdSe/ZnS films were synthesized using the SILAR and colloidal synthesis methods. First, the TiO_2 film was dipped in 0.5 M Cd^{2+}-ethanol solution for 1 minute and rinsed with ethanol. Then, the film was dipped for 1 minute in 0.5 M S^{2-}-methanol solution and rinsed with methanol after being dried in air (a SILAR cycle). The number of CdS QDs increased by repeating the assembly cycles with three cycles. Second, the TiO_2/CdS assembly was immersed in CdSe solution (size ~3 nm) for 20 hours before being dried at room temperature. For the ZnS passivation layers, TiO_2/CdS/CdSe photoanodes were dipped into 0.1 M Zn^{2+} and 0.1 M S^{2-}-solutions for 1 minute and rinsed with pure water between the two dips (a total of two cycles). Finally, the films were annealed in a vacuum environment at 300°C to prevent oxidation. The TiO_2/CdS/CdSe/ZnS thickness was measured using a stylus. The average thickness of CdS (3 cycles), CdSe (20 hours), and ZnS (2 cycles) were 351.9 nm, 80 nm and 257.8 nm respectively.

Fabrication of QDSSCs

The structure of the QDSSCs was designed using a Surlyn between the photoanodes and counter electrodes at 170°C. The electrolyte was filled from a hole made on the counter electrode. The active area of the QDSSCs was 0.38 cm^2. The polysulfide electrolyte consisted of 0.5 M Na_2S, 0.2 M S and 0.2 M KCl in Milli-Q ultrapure water/methanol (7:3 by volume).

Characterization

The morphologies of the samples were investigated using transmission electron microscopy (TEM). The crystal structure was analyzed using an X-ray diffractometer (Philips, PANalytical X'Pert, CuKα radiation). The absorption properties of the samples were investigated using a diffuse reflectance UV–vis spectrometer (JASCO V-670). Photocurrent – voltage measurements were performed on a Keithley 2400 source meter using a simulated AM 1.5 sunlight with an output power of 100 mW/cm^2 produced by a solar simulator (Solarena, Sweden).

RESULTS AND DISCUSSIONS

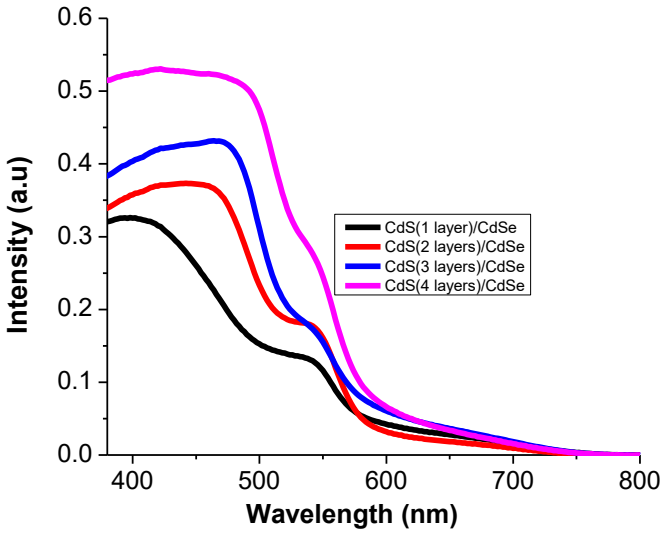

Figure 1. The UV-Vis of the TiO_2/CdS/CdSe photoanode with different CdS layers.

Figure 1 shows the UV−vis absorption spectra of CdS/CdSe/TiO_2 films with different thickness of CdS QDs. In order to remove the light scattering effect of TiO_2 films, the spectra curves were obtained by deducting the absorbance of TiO_2 films with different thickness. It is found that the absorption of the films increases with the increasing film thickness, indicating that the amount of CdS QDs increases accordingly. The shift of absorption edges from the short to long wavelength with the increase of the film thickness suggests that CdS QDs get larger with an increasing film thickness. The size of CdS QD can be estimated using the UV−visible absorption spectrum. It is not the intention of this paper to discuss the size of CdS, because the CdS layer serves as the seed layer to enhance the CdSe growth rate and is surrounded by CdSe.

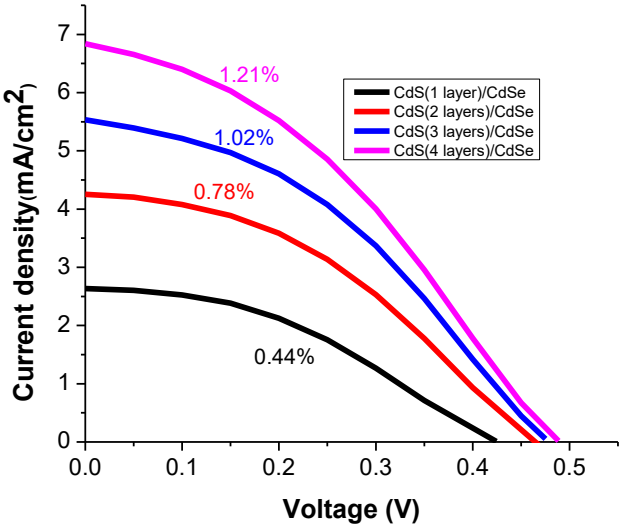

Figure 2. The I-V curves of the QDSSCs based on the different photoanodes.

Table 1. Photovoltaic performance parameters of the QDSSCs

Solar Cells	J_{SC} *(mA/cm²)*	V_{OC}*(V)*	*Efficiency η(%)*
TiO_2/CdS(1 layer)/CdSe	2.63	0.42	0.44
TiO_2/CdS(2 layers)/CdSe	4.25	0.469	0.78
TiO_2/CdS(3 layers)/CdSe	5.53	0.47	1.02
TiO_2/CdS(4 layers)/CdSe	5.47	0.489	1.21

The TiO_2/CdS/CdSe photoelectrode films were as a function of CdS thickness in the quantum dots solar cells. Figure 2 shows the photocurrent

voltage (I−V) curves for the solar cells measured under the illumination of 1 sun (AM 1.5, 100 mW/cm^2). The performance parameters of the solar cells, including open circuit potential (V_{oc}), short circuit current (J_{sc}) and power conversion efficiency (η), are listed in Table 1. It can be seen that J_{sc} increases with the increasing of CdS thickness from 1 to 4 layers. The increasing of J_{sc} is mainly caused by the increasing of CdSe amount for more optical absorption. From the results shown in Table 1, we can also see that V_{oc} also increases light continuously as increasing film thickness. This further evidences the existence of charge recombination, which is related to the electrons diffusion. A thicker film results in longer electron diffusion distance and therefore higher recombination rate. This eventually results in lower open circuit voltage. In our study, the highest efficiency, ~1.21 %, was obtained when the layers were 4 in thickness. This can be explained by the inhomogeneous distribution of QDs in the TiO_2 nanocrystalline film, which mainly concentrates at the top layer in the region of 4 layers.

CONCLUSIONS

The work reveals that it is difficult to achieve homogeneous distribution of QDs in nanocrystalline film from the surface to interior. The main portion of QDs concentrates at the upper layer of the film, resulting in the direct exposure of TiO_2 film in electrolyte and therefore serious recombination between the electrons in TiO_2 films and the holes in electrolyte. Simply increasing film thickness did make significant contribution to improving solar cell efficiency. The results show the enhances the power conversion efficiency of 1.21 % in the quantum dots solar cells.

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