THE EFFECT OF CdS QUANTUM DOTS THICKNESS ON THE EFFICIENCY OF THE QUANTUM DOTS SOLAR CELLS

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ABSTRACT.

The quantum dots solar cells (QDSSCs) have been investigated to the researchers in over the world because the quantum dots (QDs) have more advantages than molecular dye in the dye – sensitized solar cells (DSSCs). In this work, the QDSSCs based on the TiO_2/CdS/CdSe/ZnS photoanodes were prepared by the different methods. we focus on the effect of the CdS thickness on the recombination resistance, the chemical capacitance of the performance QDSSCs. The results show that the efficiency of the QDSSCs increased (*reduced the recombination resistance*) when the CdS thickness were 3 layers.

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

INTRODUCTION

- Recently, the scientists in the world have interested in the 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 article, the QDSSCs based on the TiO_2/CdS/CdSe/ZnS photoanodes were prepared by the different methods. we focus on the effect of the CdS thickness on the recombination resistance, the chemical capacitance of the performance QDSSCs. The recombination resistance and chemical capacitance were determined from the Electrochemical impedance spectroscopy (EIS) to study the dynamic processes in the QDSSCs.

EXPERIMENT

Preparation of TiO_2 films

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 (Figure 1). 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.

Preparation of TiO_2/CdS/CdSe/ZnS photoanodes

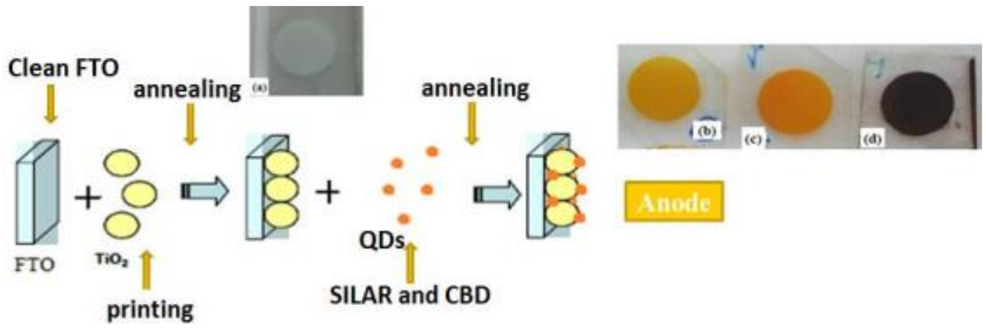

Figure 1. Schematic of photoanode structure.

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

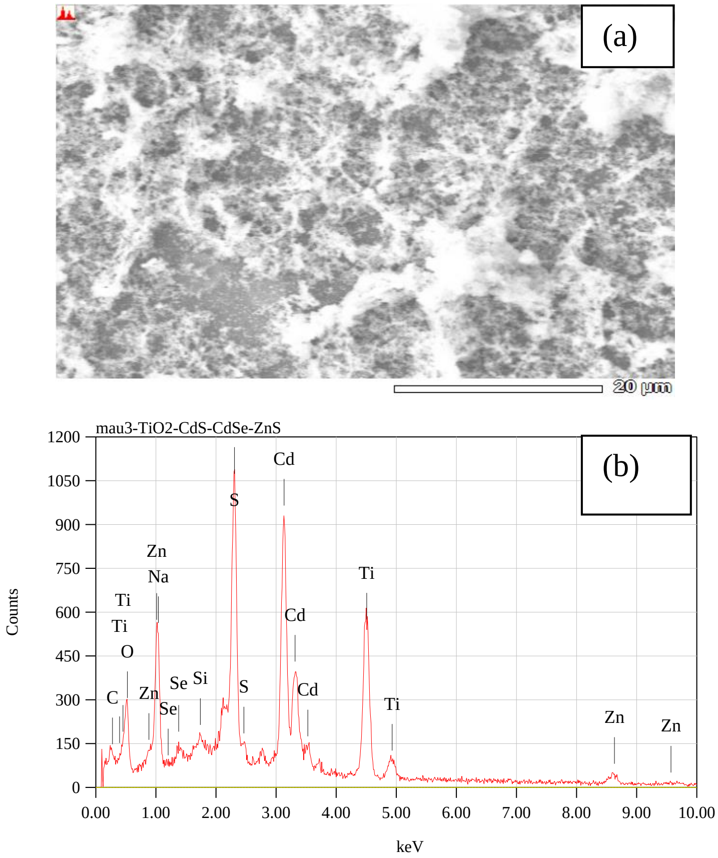

Figure 2. (a) The SEM image and (b) the EDS of the TiO_2/CdS/CdSe/ZnS photoanode.

Figure 2(a) shows the SEM image of the TiO_2/CdS/CdSe/ZnS photoanode at 300°C in vacuum. The result indicates that the morphological photoanode became high porous and were suitable for the photoanodes. In addition, we investigated to the concentration of the CdS, CdSe and ZnS deposited on the TiO_2 films by the EDS spectra (shows in the Figure 2(b)). We can show the Ti and O peaks of the TiO_2, Cd and S peaks of the CdS, Si of the FTO substrate. The result shows that the CdS, CdSe, ZnS concentrations have deposited on the TiO_2 films.

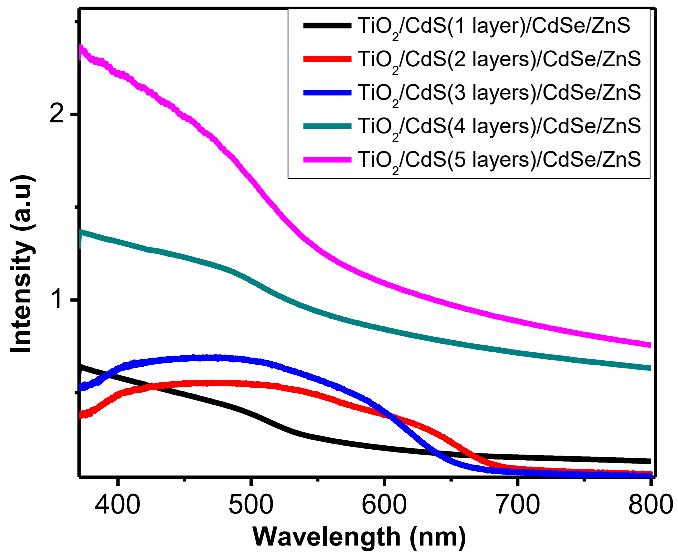

Figure 3. The UV-Vis of the TiO_2/CdS/CdSe/ZnS photoanodes.

In the QDSSCs structure, the fabricated photoanodes is very important. The photoanodes should absorb the light in the visible regions and extend to the UV-Vis peak. Therefore, we investigated the effect of the CdS thickness on the performance efficiency of the QDSSCs. The optical properties of the photoanodes were investigated to the UV-Viss in the Figure 3. However, The CdSe QDs is the difficult to deposit on the TiO_2 surfaces. For this reason, the CdS layers were deposited on between the TiO_2 films and the CdSe QDs. As expected, the peaks of the UV-Vis increased when the CdS nanocrystall were more loaded on the TiO_2 films (*shows in the Figure 3*). The photoanode with the CdS(3 layers) has the UV-Vis peak shift toward the long waves and extend to the visible regions. In the long waves from 380 nm to 550 nm, the UV-Vis peaks increased when the number SILAR of the CdS nanocrystall increased. The CdS concentration loaded on the photoanodes were the best. Moreover, the changed UV-Vis spectra also can show through the changed band gap of the photoanodes from 1.97 eV to 2.7 eV calculated by the peak of the UV-Vis.

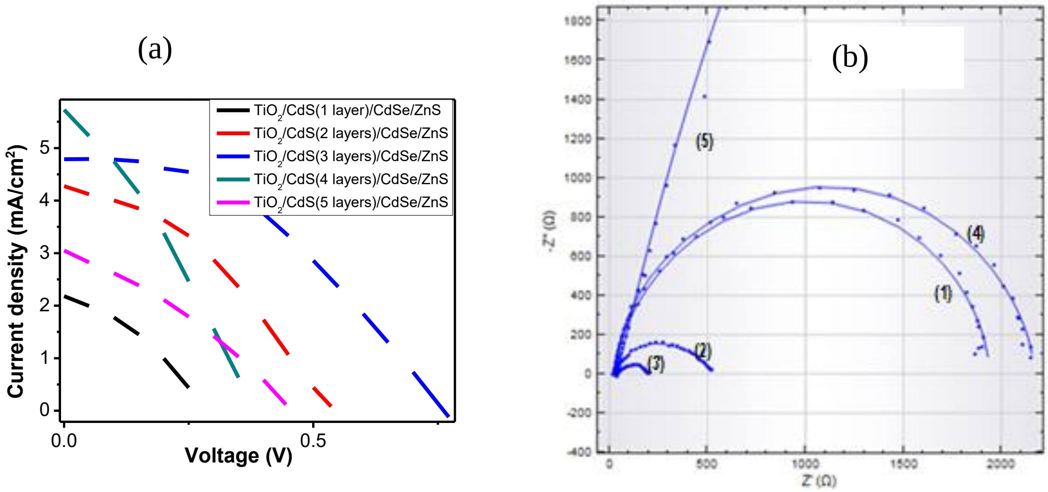

Figure 4. (a) The I-V curves and (b) the Nyquist plots of the QDSSCs with the different photoanodes.

For determined the effect of the CdS thickness on the performance efficiency, we investigated to the I-V curves of the QDSSCs based on the different photoanodes. The Figure 4(a) shows the I-V curves of the QDSSCs with CdS layers. The QDSSCs based on the TiO_2/CdS(3 layers)/CdSe/ZnS photoanode were determined to open circuit (V_{OC}) of 0.44 V, short current (J_{SC}) of 13.97 mA/cm^2, fill factor of 0.41 and efficiency (**η**) of 2.07 %. The result agree well with the UV-Viss. The obtained performance efficiency were low when the numbers SILAR were below 3 layers. To explane for the reason, we noted that the CdS nanocrystall were little loaded on the TiO_2 films. The performance efficiency decreased. Similarly, The obtained performance efficiency were low when the numbers SILAR were over 3 layers because the CdS nanocrytall interwinded.

Table 1. The parameters of the QDSSCs obtained to the EIS

QDSSCs	R_r (Ω)	C(μF)
TiO_2/CdS(1)/CdSe/ZnS	351	46.4
TiO_2/CdS(2)/CdSe/ZnS	333	44.9
TiO_2/CdS(3)/CdSe/ZnS	92.7	1040

TiO_2/CdS(4)/CdSe/ZnS	1930	600
TiO_2/CdS(5)/CdSe/ZnS	16100	35.4

R_r was noted the recombination resistance.

The EIS spectra were used to investigate the influence of the CdS thickness on the recombination resistance and chemical capacitance of the performance QDSSCs. The obtained results show in the Table 1. Figure 4(b) shows the EIS of the QDSSCs based on the photoanodes with the CdS thickness changed from 1 to 5 layers. The results indicated that the CdS thickness increased correspond to the increased recombination resistance beacause the surface states of the QDs were enhanced. However, the recombination resistance (R_r) obtained low when the SILAR number of the CdS was 3 layers. To explain this reason, we suggested that the loaded CdS particles perfected (*reduced the recombination resistance*). Beside R_r, the chemical capacitance (C_μ**)** correlates to the electrons concentration in the conduction band of TiO_2 determined by the EIS. C_μ values were increased when the CdS SILAR number were 3 layers correspond to the enhanced charge concentrations in the TiO_2 conduction band.

CONCLUSIONS

In summary, the QDSSCs based on the TiO_2/CdS/CdSe/ZnS photoanodes with the different thickness. The result shows that the performance efficiency of the QDSSCs with 3 layers of the CdS nanocrytall were 2.07 %. The result also indicates that the recombination resistance decreased when the number SILAR of the CdS concentration were 3 layers.

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