IMPROVING THE PERFORMANCE EFFICIENCY OF THE QUANTUM DOTS SOLAR CELLS BY THE PASSIVATION TREATMENT

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ABSTRACT.

In this works, we have prepared the quantum dots solar cells (QDSSCs) based on the TiO_2/CdS/CdSe photoanodes coated by the ZnS layers for the reduced recombination and the increased performance efficiency in the QDSSCs. The results indicate that the highest performance efficiency obtained correspond to the photoanodes were coated with ZnS passivation. In addition, we also investigated the effect of the ZnS passivation coated on the recombination resistance, the chemical capacitance of the performance QDSSCs through the electrochemical impedence spectroscopy (EIS).

***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 works, we have prepared the quantum dots solar cells (QDSSCs) based on the TiO_2/CdS/CdSe photoanodes coated by the ZnS layers for the reduced recombination and the increased performance efficiency in the QDSSCs. The results indicate that the highest performance efficiency obtained correspond to the ZnS passivation of 2 layers. In addition, we also investigated the effect of the ZnS passivation coated on the recombination resistance, the chemical capacitance of the performance QDSSCs through the electrochemical impedence spectroscopy (EIS).

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

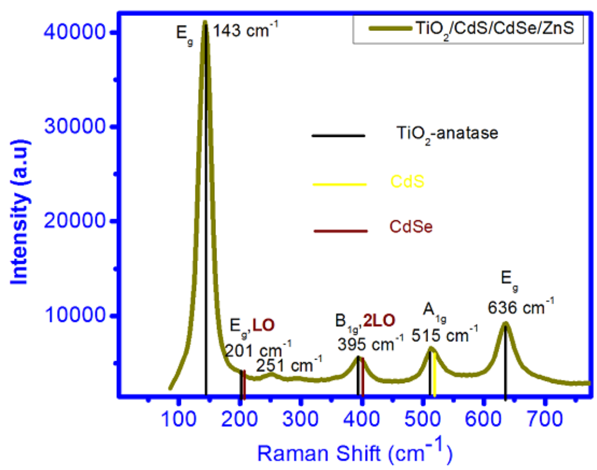

Figure 1. The Raman of the TiO_2/CdS/CdSe/ZnS photoanode.

First, the Raman of the photoanodes have been investigated by us to determine the structural materials. From the Raman (Figure 1), we noted that the TiO_2 structure is Anatase correspond to the E_g mode at 134 cm^{-1}. In addition, we also noted the three 201, 395 và 515 cm^{-1} modes correspond to the CdS, CdSe cubic. The results show that CdS, CdSe QDs deposited on the TiO_2 subtrate.

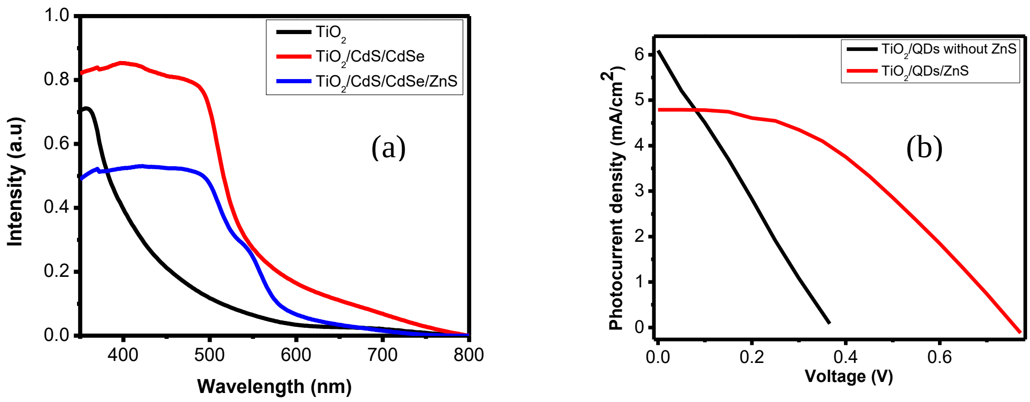

Figure 2. (a) The UV-Vis spectra of the different photoanodes and (b) I-V curves of the QDSSCs with the different photoanodes.

Table 1. The parameters of the QDSSCs obtained to the I-V curves

No	QDSSCs	R_S (Ω)	R_{ct2} (Ω)	R_{ct1} (Ω)	Efficiency η(%)
1	TiO_2/CdS/CdSe without ZnS	6.04	0.35	0.255	0.54
2	TiO_2/CdS/CdSe/ZnS	4.79	0.76	0.41	1.52

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 CdSe thickness on the performance efficiency of the QDSSCs. The optical properties of the photoanodes were investigated to the UV-Viss in the Figure 2(a). As expected, the UV – Vis of the photoanodes with ZnS passivation layers were more expanded on the visible regions than that of the TiO_2 and TiO_2/CdS/CdSe films. This results indicate that the CdSe QDs loaded on the TiO_2 films.

For determined the effect of the ZnS passivation on the performance efficiency, we investigated to the I-V curves of the QDSSCs based on the different photoanodes. The Figure 3(b) shows the I-V curves of the QDSSCs with the different photoanodes. The QDSSCs based on the TiO_2/CdS/CdSe/ZnS photoanode were determined to open circuit (V_{OC}) of 0.76 V, short current (J_{SC}) of 4.79 mA/cm^2, fill factor of 0.41 and efficiency (**η**) of 1.5 %. The result agree well with the UV-Viss. The obtained performance efficiency were low when the QDSSCs based on the photoanodes without ZnS passivation layers. To explain for the reason, we noted that the QDs with ZnS passivation reduced the recombination processes at the QDs surfaces.

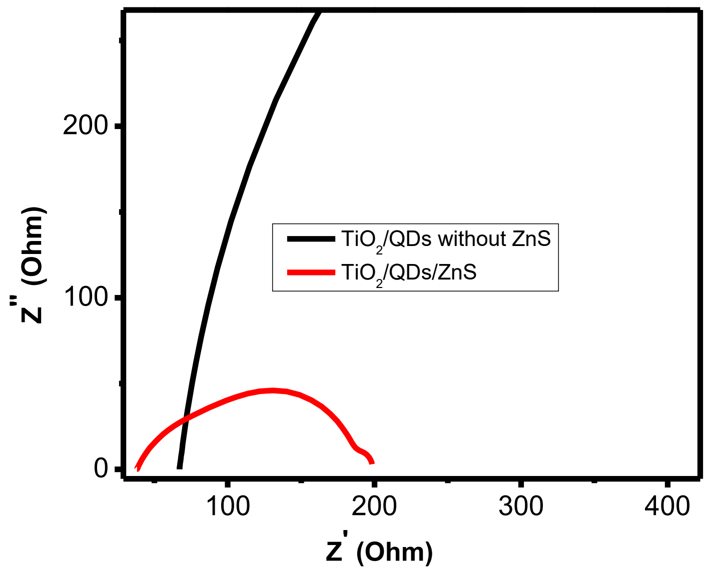

Figure 3. the Nyquist plots of the QDSSCs with the different photoanodes.

Table 2. The parameters of the QDSSCs obtained to the EIS

No	QDSSCs	R_S (Ω)	R_{ct2} (Ω)	R_{ct1} (Ω)	C_μ (μF)
1	TiO_2/CdS/CdSe without ZnS	67	1190	268	104
2	TiO_2/CdS/CdSe/ZnS	38.1	92.7	68	667

The EIS spectra were used to investigate the recombination resistance and chemical capacitance of the performance QDSSCs. The obtained results show in the Table 2. Figure 3 shows the EIS of the QDSSCs based on the different photoanodes. The results indicate that the reduced recombination resistance beacause the surface states of the QDs were passived. However, the recombination resistance (R_r) obtained large when the photoandes without ZnS layers. Beside recombination resistance, 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 decreased recombination correspond to the enhanced charge concentrations in the TiO_2 conduction band.

CONCLUSIONS

In summary, the QDSSCs based on the TiO_2/CdS/CdSe photoanodes with or without ZnS passivation layers. The result shows that the performance efficiency of the QDSSCs based on the photoanodes with ZnS passivation were 1.5 %. The result also indicates that the recombination resistance decreased when the QDs were coated with passivation.

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