The effect of role $TiCl_4$ on the performance efficiency of the Quantum dots Solar cells

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ABSTRACT.

In this work, we have prepared the quantum dots solar cells (QDSSCs) based on the TiO_2/CdSe photoanodes prepared by SILAR method. A TiO_2 film was deposited onto $TiCl_4$ solution to coat with TiO_2 nanocrystalline. This nanoscale coating enhances the power conversion efficiency of 0.575 % compared with power conversion efficiency of 0.02 % of TiO_2 photoanodes without $TiCl_4$ 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, we have prepared the quantum dots solar cells (QDSSCs) based on the TiO_2/CdSe photoanodes prepared by SILAR method. A TiO_2 film was deposited onto $TiCl_4$ solution to coat with TiO_2 nanocrystalline. This nanoscale coating enhances the power conversion efficiency of 0.575 % compared with power conversion efficiency of 0.02 % of TiO_2 photoanodes without $TiCl_4$ 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

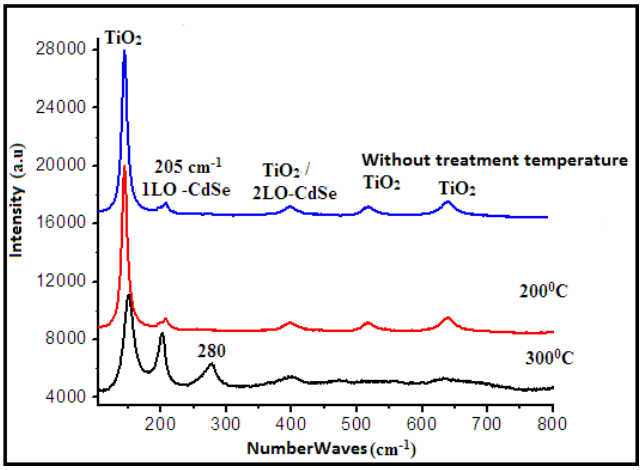

Figure 1. The Raman of the TiO_2/CdSe photoanode.

To investigate the change of the TiO_2 host material after $TiCl_4$ treatment, XRD analysis was performed. Figure 1 shows the raman of different photoanodes such as: without annealing and annealing at 200^0C and 300^0C. The peaks at 145cm^{-1}, 395cm^{-1}, 518cm^{-1}, 639cm^{-1} is the oscillation modes correspond to the TiO_2 anatase and the oscillation modes 1LO (205 cm^{-1}), and 2LO (410cm^{-1}) the CdSe cubic. In addition, The sample at 300^0C appeared a

280 cm^{-1} peak correspond to –Se-Se- oscillation mode of CdS_xSe_{1-x} ligands. So, from results of the raman, we noted that the CdSe QDs loaded on the TiO_2 film.

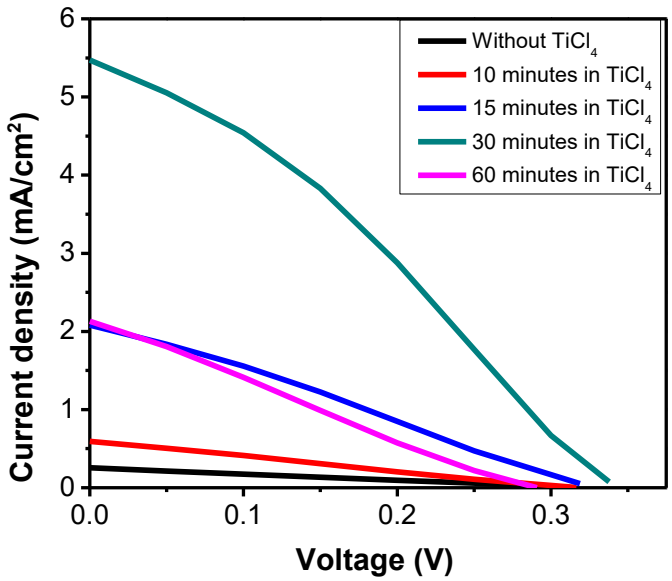

Figure 2. The I-V curves of the QDSSCs based on the photoanodes at the different temperatures.

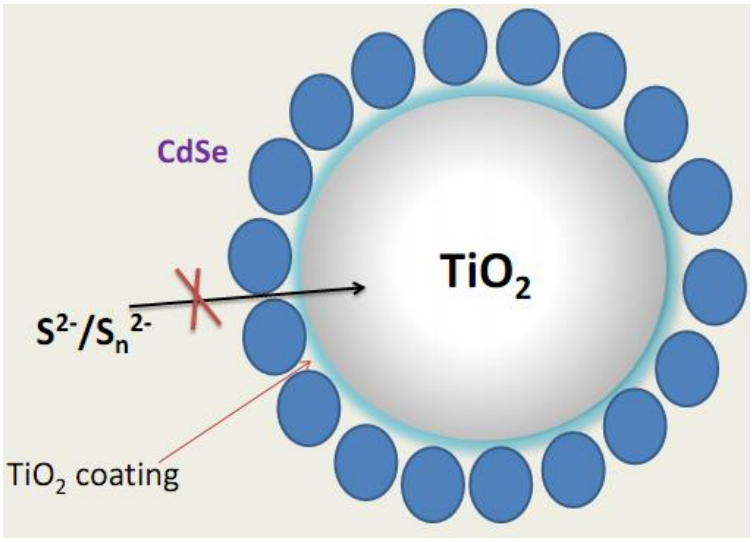

Figure 3. The schematic of $TiCl_4$ treament effects on the QDSSCs

Table 1. Photovoltaic performance parameters of the QDSSCs

Solar Cells	*J_{SC} (mA/cm^2)*	*V_{OC}(V)*	*Fill factor FF*	*Efficiency η(%)*
Without $TiCl_4$	0.256	0.31	0.25	0.02
10 minutes in $TiCl_4$	0.59	0.32	0.24	0.046
15 minutes in $TiCl_4$	2.08	0.33	0.27	0.184
30 minutes in $TiCl_4$	5.47	0.33	0.31	0.575
60 minutes in $TiCl_4$	2.13	0.29	0.24	0.15

Figure 2 shows the I-V curves of the CdSe-sensitized solar cells as a function of $TiCl_4$ treatment time. Improvements in the open-circuit voltage, short-circuit current, and power conversion efficiency are observed as the treatment time increases (Table 1). We show that all samples appeared the I-V curves (Figure 2). The obtained performance efficiency was the highest correspond to the QDSSCs based on the TiO_2/CdSe photoanode at 30 minutes is 0.575 %. The performance efficiency decreased when the treatment times decreased. On the other hand, after 60 minutes treatment, both the fill factor and performance efficiency decreased, indicating the existence of an optimum TiO_2 coating layer thickness for QDSSCs.

Figure 3 shows a schematic illustration for the effect of the TiO_2 nanocrystalline coating layers. The electrons recombination at the contacts of TiO_2/CdSe/polysulfide electrolyte were suppressed by the $TiCl_4$ treatment coating layer. After TiO_2 nanocrystalline coated, the TiO_2 nanoparticles were prevented with electrolyte. And then, the reduced electrons transfer from the TiO_2 to electrolyte. As a result, the electrons in conduction band captured by the FTO electrode increases, and the photoelectrons in the TiO_2 layer is improved by reduced recombination (increase of V_{oc}), therefore the power conversion efficiency is enhanced. On the other hand, the coating layer eventually increases both the residual strain of the TiO_2 nanoparticles and the series resistance of the electrolyte. Thus, the fill factor and cell efficiency decrease with comparatively thick coating layers.

CONCLUSIONS

The QDSSCs based on the TiO_2/CdSe photoanodes with the different $TiCl_4$ treatment times. The result shows that this nanoscale coating enhances the power conversion efficiency of 0.575 % compared with power conversion efficiency of 0.02 % of TiO_2 photoanodes without $TiCl_4$ solar cells.

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REFERENCES

1. Nozik, A, J (2005), Exciton Multiplication and Relaxation Dynamics in Quantum Dots: Applications to Ultrahigh-Efficiency Solar Photon Conversion. *Inorg. Chem. 44*, 6893-6899.
2. Wu. Jiang, Wang. Zhiming M. (2014), Quantum Dot Solar Cells. *Springer-Verlag New York*, Volume 15.
3. Guyot-Sionnest, P (2008), Colloidal Quantum Dots. *C. R. Physique*. *9*, 77-787.
4. Vogel R, Pohl K, Weller H. (1990), Sensitization of highly porous polycrystalline TiO_2 electrodes by quantum sized CdS, *Chem Phys Lett*,174,241-6.
5. Lee Y. L, Lo Y. S. (2009), Highly efficient quantum-dot-sensitized solar cell based on co-sensitization of CdS/CdSe, *Advanced Functional Materials*, 19, 604–609.
6. Zhang Q, Zhang Y, Huang S, Huang X, Luo Y, Meng Q, Li D. (2010), Application of carbon counterelectrode on CdS quantum dot-sensitized solar cells (QDSSCs), *Electrochemistry Communications*,12, 327–30.
7. Chen J, Zhao DW, Song JL, Sun XW, Deng WQ, Liu XW, Lei W. (2009), Directly assembled CdSe quantum dots on TiO_2 in aqueous solution by adjusting pH value for quantum dot sensitized solar cells, *Electrochemistry Communications*, 11, 2265–7.
8. Yu X-Y, Lei B-X, Kuang D-B, Su C-Y. (2012), High performance and reduced charge recombination of CdSe/CdS quantum dot-sensitized solar cells, *J Mater Chem*, 22, 12058–63.