

ENHANCING THE PERFORMANCE OF PbS:Hg QUANTUM DOT - SENSITIZED SOLAR CELLS BY CONTROLLING THE SURFACE CHARGE OF TiO₂ ELECTRODE

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ABSTRACT

Colloidal quantum dots offer a number of advantages such as higher molar extinction coefficients, multiple exciton generation and tunable energy band gap due to the quantum confinement effect. They are providing a powerful platform for the development of several optoelectronic devices including solar cells, infrared detectors and light emitting diodes. Semiconductor quantum dot - sensitized solar cells have received more attention in recent years due to their cost - effectiveness as well as ease of fabrication. Recently, several types of quantum dots have been studied in quantum dot - sensitized solar cell applications such as CdS, CdSe, CdTe, CdSeTe, PbSe, PbS etc. In this work, TiO₂ nanoporous layer has been sensitized with Hg - doped PbS quantum dots by successive ionic layer adsorption and reaction (SILAR) method. Effect of surface charge on TiO₂ electrode has been studied by changing the amount of triethanolamine (TEA) in the cationic precursor solution during the SILAR process. A maximum efficiency of 4.25 % has been obtained with an open - circuit voltage of 626.1 mV and a short - circuit current density of 10.91 mA cm⁻² corresponding to 0.8 M TEA in the cationic precursor solution.

Key words: Exciton, quantum confinement, optoelectronic devices

1. INTRODUCTION

Recently, Quantum dots (QDs) have been at the focus of much research attention due to their distinct optical and electrochemical characteristics and the applications in solar cells, Infra-red detectors, light emitting diodes and various optoelectronic devices [1 - 4]. Quantum dots have high molar extinction coefficients, ability of multiple exciton generation and tunable energy gap due to the quantum confinement effect. Semiconductor quantum dots are being widely used in solar cell applications with different configurations such as QD sensitized solar cell, QD hetero-junction solar cell, QD Schottky junction solar cell, QD hybrid polymer solar cell and QD & Dye co-sensitized solar cell [5]. Quantum dot-sensitized solar cell (QDSSC) is a promising third generation photovoltaic system for cost-efficient solar energy conversion application. A number of semiconductor quantum dots such as CdS, CdSe, CdTe, PbS, PbSe, HgTe have been reported for applications in QDSSC [6 - 10].

QDs are formed on TiO₂ nanostructure using several methods such as Successive ionic layer adsorption and reaction (SILAR) method, chemical bath deposition (CBD) method, spin assisted SILAR method and electrostatic adsorption method [11]. SILAR method is one of the cost - efficient method for loading the quantum dots on TiO₂ nanostructure. In this method, size of quantum dots and amount of quantum dots loaded on the TiO₂ can be easily changed by changing the concentration of precursor solutions and controlling the surface charge of the TiO₂ [12 - 14]. In

this study, Hg - doped PbS quantum dot - sensitized solar cells have been fabricated using SILAR method. Effect of pH on the amount of loaded QDs and the overall performance of the solar cell has been studied.

2. EXPERIMENTAL

TiO₂ compact layer (CL) solution was spin coated on cleaned Fluorine-doped tin oxide (FTO) glass at 3000 rpm for 1 minute and the layer was sintered at 450 °C for 45 minutes. 0.25 g of TiO₂ P-90 powder was ground for 15 minutes with 1 ml of 0.1 M HNO₃. The paste was spin coated on the TiO₂ compact layer at 3000 rpm for 1 minute and sintered at 450 °C for 45 minutes. 0.25 g of TiO₂ P-25 powder was ground for 15 minutes with 10 drops of 0.1 M HNO₃, one drop of triton X-100 was added to the mixture and ground. 0.05 g of polyethylene glycol was added and the mixture was ground well. Finally, appropriate amount of 0.1 M HNO₃ was added to the mixture and ground well until the mixture became a creamy paste. TiO₂ paste was spin coated on P-90 layer at 1000 rpm for 1 minute. Then the electrode was sintered at 450 °C for 45 minutes. The electrodes were allowed to cool to room temperature. This TiO₂ - P25 paste deposition was repeated.

For SILAR method, cationic precursor solution was prepared with 0.1 M Pb(NO₃)₂, 6 mM HgCl₂ in de-ionized water. Triethanolamine (TEA) was added to this cationic precursor solution with different concentrations. 0.1 M Na₂S in de-ionized water was used as anionic precursor solution. Initially, TiO₂ electrode was dipped in to the cationic precursor solution for 1 minute followed by dipping process was done in to the anionic precursor solution for 1.5 minutes. The electrode was rinsed with de-ionized water and dried in between each dipping process. 6 SILAR cycles were done. Polysulfide electrolyte was prepared with 2 M Na₂S, 2 M S and 0.2 M KCl in a mixture of water and methanol in a ratio of 3:7 (v/v). A cleaned brass plate was immersed in conc. HCl at 80 °C for 10 minutes. A tape mask with appropriate area was applied on the surface of the treated brass plate. Few drops of poly sulfide electrolyte were applied to the unmasked area then this plate was used as a counter electrode.

Optical absorption spectra of electrodes were obtained using Shimadzu 2450 UV-Vis spectrophotometer in the wavelength interval from 350 nm to 1100 nm. current - voltage characterization of each type of PbS:Hg QDSSC were done under the illumination of 100 mW cm⁻² with AM 1.5 spectral filter using a computer controlled multi-meter (Keithley 2000 model) coupled with potentiostat/galvanostat unit (HA-301).

3. RESULTS AND DISCUSSION

Fig.1 shows the scanning electron microscope (SEM) image of the TiO₂ nanostructured electrode. The average thickness of the TiO₂ - P90 layer is around 1µm while the thickness of the TiO₂ - P90 layers are 1.286 µm and 1.571 µm respectively. Overall thickness of the TiO₂ nanostructured layers is around 3.857 µm. The TiO₂ compact layer which was spin coated on the FTO layer is not appear in This image due to its very small thickness. The TiO₂ - P90 transparent layer act as an additional compact layer and it reduces the recombination by filling the pinholes on the first CL. More light is harvested by scattering due to the TiO₂ - P25 double layer, this may increase the light absorption.

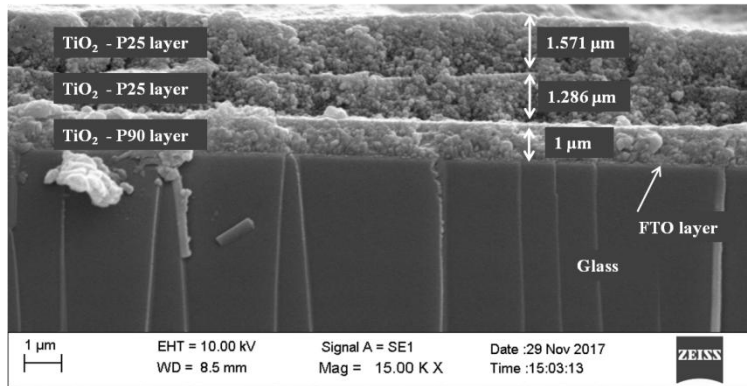


Fig.1. Cross - section view of the TiO₂ nanostructured electrode.

Fig.2 shows the absorption spectra of the photo electrodes. It displays a broad absorption in the visible region to near- infrared (NIR) region and an absorption peak at around 1050 nm. Both electrodes peaks at nearly same wavelength range. This shows that, there is no considerable change in the size of the PbS:Hg quantum dots due to the surface charge control by TEA. The absorption spectrum of the surface charge controlled photo electrode exhibits a strong absorption compared to the untreated photo electrode. Number of PbS:Hg quantum dots attached on the TiO₂ nanostructure may increase by the surface charge control [13].

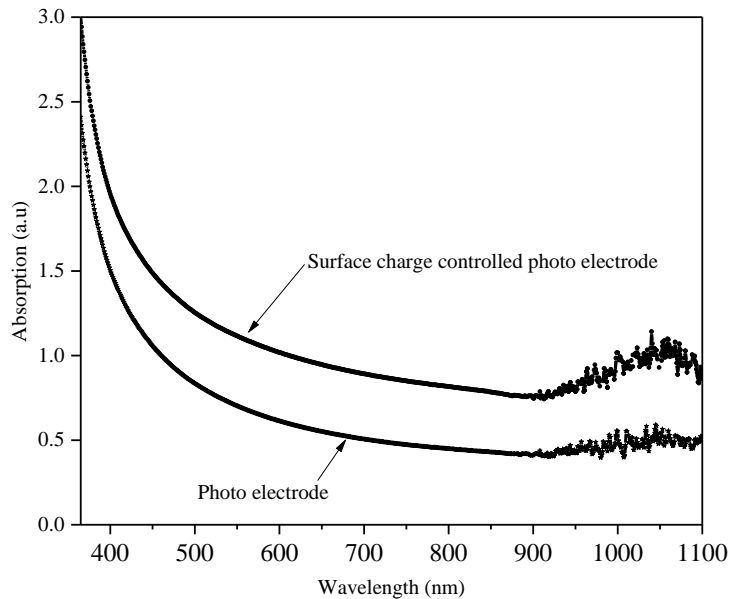


Fig.2. Absorption spectra of photo electrodes with and without surface charge control.

Fig.3 shows the variation of the overall power conversion efficiency (PCE) of PbS:Hg QDSSC with the amount of TEA in the cationic precursor solution. The efficiency of the QDSSC is increases with the amount of TEA and it shows a maximum value of 4.25 % corresponding to the 0.8 M of TEA added to the cationic precursor solution.

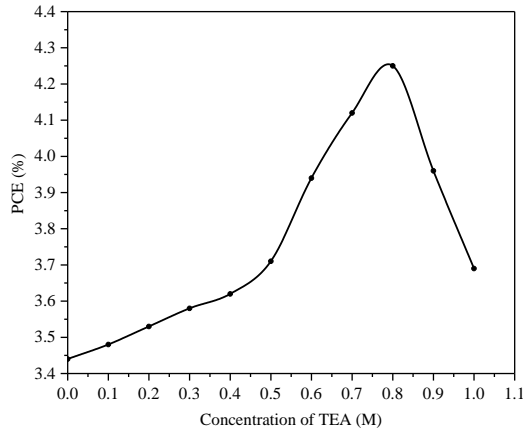


Fig.3. Variation of efficiency of the PbS:Hg QDSSC with amount of TEA.

Point of zero charge (PZC) of the TiO_2 is the pH value where TiO_2 material in solution shows zero net electrical charge on its surface. PZC of the TiO_2 is in the middle of the pH scale makes it possible to change the adsorption on positively and negatively charged surface of TiO_2 over a broad range of pH [14]. When pH of the solution is higher than the PZC, the surface of the TiO_2 in solution is negatively charged. TEA changes the cationic precursor solution as basic solution then the surface of the TiO_2 nanostructure becomes negatively charged and this surface attracts more Pb^{2+} and Hg^{2+} ions this increases the number of PbS:Hg QDs formed on the TiO_2 nanostructure [13, 14].

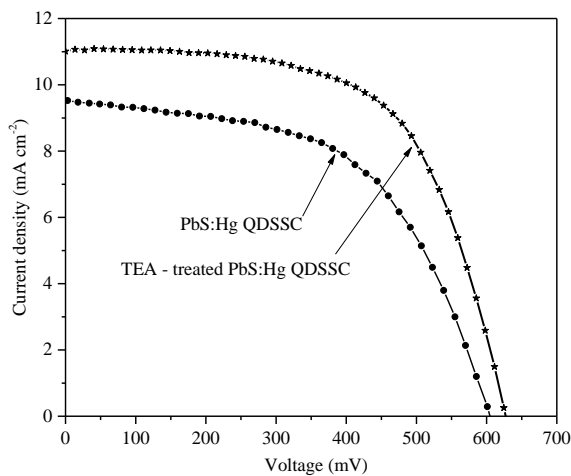


Fig.4. Current - voltage characterization of the QDSSCs under 100 mW cm^{-2} with AM 1.5 spectral filter.

TEA treated QDSSC shows the better performance than the untreated cell. The photovoltaic parameters of the QDSSCs corresponding to the Fig.4 are shown in the table 1.

Table 1. Photovoltaic parameters of PbS:Hg QDSSCs

Photoanode	J_{SC} (mA cm ⁻²)	V_{OC} (mV)	FF (%)	PCE (%)
Untreated	9.67	604.7	58.83	3.44
Treated with TEA	10.91	626.1	62.33	4.25

The current density and overall efficiency are enhanced by 12.8% and 23.55 % respectively. TEA encourages the adsorption of a large amount of Pb and Hg cations on the TiO₂ surface this leads to the enhancement of the efficiency as described in the Jin-Wook Lee et.al [13].

4. CONCLUSION

In quantum dot - sensitized solar cells, the adsorption of the quantum dots on the semiconductor nanostructures can be controlled by controlling the surface charge of the semiconductor. In SILAR method, pH of the cationic precursor solution can be easily converted as a basic solution by adding like triethanolamine, due to this large number of cations such as Pb²⁺ and Hg²⁺ can adsorb on the TiO₂ nanostructure. Therefore, efficiency of the QDSSC can be controlled by controlling the pH of the precursor solutions.

6. REFERENCES

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