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Nanocrystalline TiO_2 solar cells sensitized with chlorophyll and ZnSe quantum dots

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The present paper reports on the fabrication of nanocrystalline TiO_2 solar cells sensitized with chlorophyll and ZnSe quantum dots (QDs). The performance of solar cells was observed by changing the amount of ZnSe QDs. TiO_2 solar cells with 5 wt% ZnSe QDs exhibited optimum results. The measured parameters were the short-circuit current density (J_{sc}), the open-circuit voltage (V_{oc}), the maximum output power density (P_m), the fill factor (FF), and the power conversion efficiencies (η), which had values of were 5.88 mA/cm^2, 0.475 V, 1.17 mW/cm^2, 0.419, and 1.17 %, respectively, under AM 1.5 illumination. TiO_2 solar cells sensitized with ZnSe QDs have higher conversion efficiency than TiO_2 solar cells sensitized with PbS or InAs QDs.

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1. Introduction

Dye-sensitized solar cells (DSSCs) have attracted a lot of attention due to their potential application as photovoltaic cells. The DSSC is formed by a combination of organic and inorganic components that could be produced at a low cost. The DSSC offers the prospect of a cheap and versatile technology for large scale production of solar cells. The DSSCs are based on the photosensitization of nanocrystalline TiO_2 semiconductor electrodes by dyes. [1-5] QDs have several potentially properties that are attractive for applications in solar cells. Owing to the quantum size effect, the band gap of QDs can be tuned by changing the size of QDs, it can used the optical properties to adjust the range of solar photon absorption. QDs have been shown recently to produce highly efficient multiple exciton generation (MEG), cause a single absorbed photon can generate more than one electron-hole pair. [6-8] This property can promote solar cells efficiency. Günes et. al. [9] reported hybrid solar cells using size-quantized PbS nanoparticles, and found that the cell exhibited an J_{sc} of 0.3 mA/cm^2 and a V_{oc} of 350 mV with a fill factor of 0.35 corresponding to 0.04% power conversion efficiency. Yu et. al. [10] reported nanocrystalline TiO_2 solar cells sensitized with InAs quantum dots, and found that the power conversion efficiency of 1.7% at illumination of 5 mW/cm^2 and 0.3% at illumination of 100 mW/cm^2, respectively. Lin et. al. [11] reported CdS-quantum-dots-sensitized solar cells, and found that the cell exhibited an J_{sc} of 3.44 mA/cm^2 and a V_{oc} of 657 mV with a fill factor of 0.60 corresponding to 1.35% power conversion efficiency.

In this study, since chlorophyll is the dye which easiest to obtain, and the cost very is also low, the fabrication of nanocrystalline TiO_2 solar cells sensitized with chlorophyll and ZnSe QDs were reported. Besides, we investigated the effect of ZnSe QDs to the photovoltaic performance of the solar cells.

2. Experiment

The solution consisting of 1 g TiO_2 nanocrystalline powder (diameter about 25 nm), 1 ml tritonX-100, acetic acid, and deionized water were mixture with 0.05 ml ZnSe QDs (diameter about 2 nm) solution (Evident Technologies) as colloidal solution, and the colloidal solution were daubed uniformly onto fluorine-doped tin oxide (FTO) conductive glass to form a thick film. The films were annealed at 120 ^oC for 10 min. The chlorophyll was extracted from spinach leaves as dye molecules. Heat treatment was carried out at 80 ^oC for 2 hr to extract chlorophyll. Alcohol solution with chlorophyll 0.05 ml was dropped onto the film. The films were also annealed at 120 ^oC for 10 minutes such that the chlorophyll diffusing into the film. The electrolyte was formed by mixing uniformly 20 ml propylene carbonate, 0.254 g iodine (I_2), and 1.66 g KI. The electrolyte (~ 0.03 ml) was dropped into the film and combining with another FTO conductive glass with carbon coating to complete TiO_2 solar cell. Fig. 1 shows the cross section of the completed structure. The current-voltage (*I-V*) characteristics were measured using a Keithley 2420 programmable source. A sun lamp (ULTRA-VITALUX) was used as the light source.

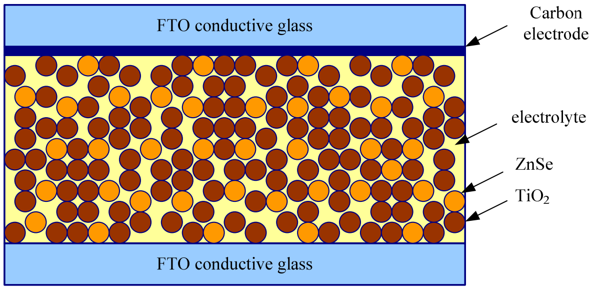
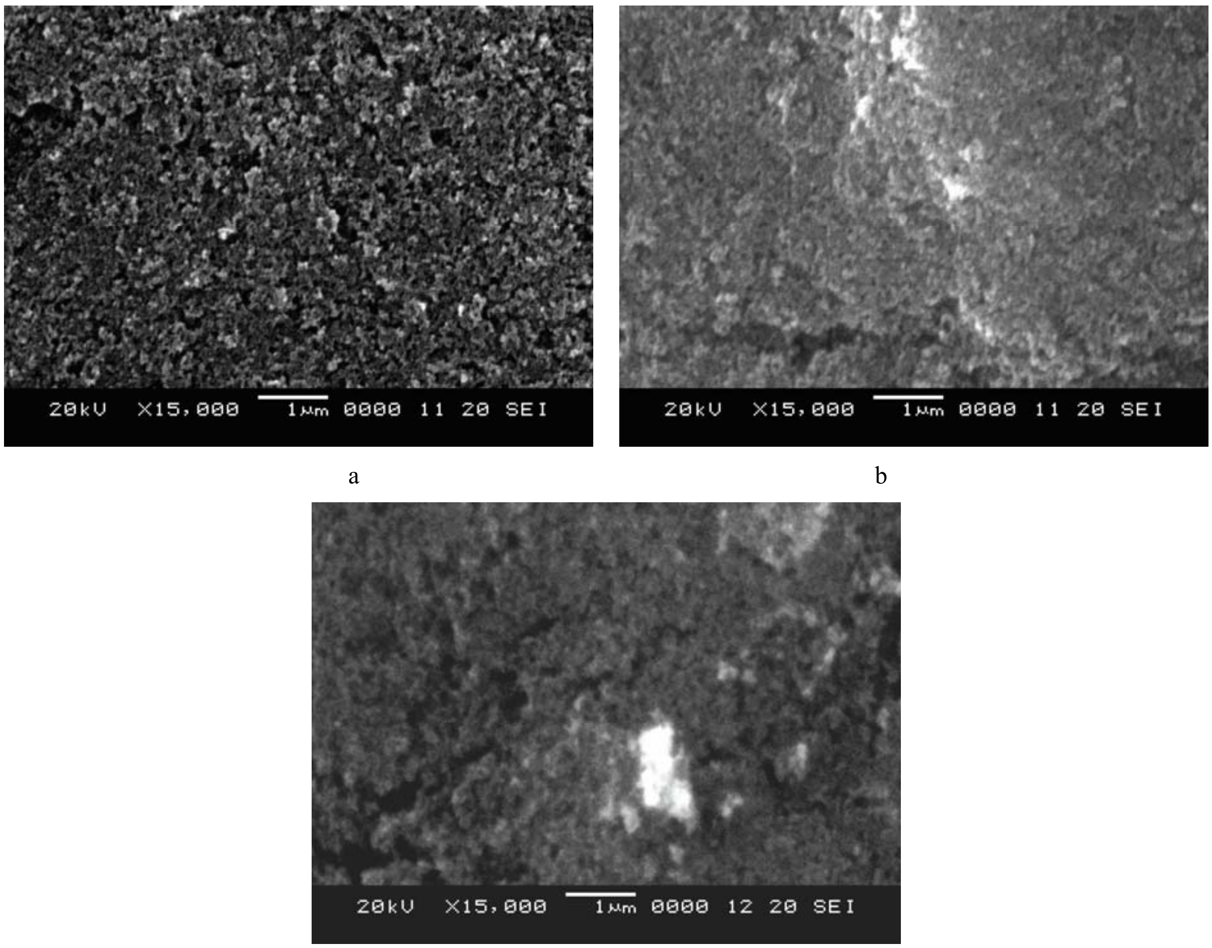


Fig. 1. Schematic cross section of the completed structure.

3. Results and discussion

Fig. 2(a)-2(c) shows the SEM images of chlorophyll-coated TiO_2 film without and with 5 wt% ZnSe QDs and 15 wt% ZnSe QDs doped, respectively. The images clearly indicate that the chlorophyll-coated TiO_2 nanoparticles are distinguishable. The ZnSe QDs penetrates into the pores of the film to fill a void between the TiO_2 nanoparticles, to result in a concentrated chlorophyll-coated TiO_2 film.



a b

c

Fig. 2. SEM images of a dye-coated TiO_2 film.

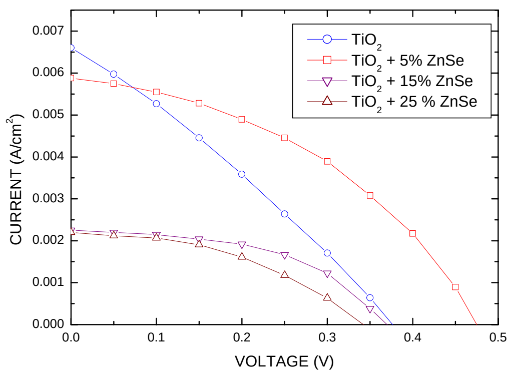


Fig. 3. I-V characteristics of solar cells.

Fig. 3 shows the *I-V* characteristics of the nanocrystalline TiO_2 solar cells sensitized with chlorophyll and ZnSe QDs. The cell performance was measured under AM 1.5 illumination with a solar intensity of 100 mW/cm^2 at 25 ^{o}C. The cell has an active area of 1.5 × 2 cm^2 and no antireflective coating. As shown in figure 3, the cells with 5 wt% ZnSe QDs exhibited the following static parameters: J_{sc} of 5.88 mA/cm^2 and V_{oc} of 475 mV. The cells sensitized with 5 wt% ZnSe QDs have a higher open-circuit voltage (by about 100 mV) than the cells sensitized without ZnSe QDs. As is well known, the fill factor (*FF*) can be described by [12]

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}} \quad (1)$$

where I_m is the maximum output current, and V_m is the maximum output voltage. Therefore, using the values of I_m and V_m deduce from Fig. 4, the value of *FF* results equal to 0.419. Similarly, the conversion efficiency (η) defined by [12]

$$\eta = \frac{I_m V_m}{P_{inc}} \quad (2)$$

with P_{inc} the incident power, results to be 1.17 %. This value is better than that of reported elsewhere. [9,10] Table 1 presents the main characteristics of this work. Evidently, the incorporation of ZnSe QDs can improve remarkably *FF* owing to the better conductivity than TiO_2. For example, the series resistance was decreased from around 54 for solar cell sensitized without ZnSe QD to around 37 Ω for solar cell sensitized with ZnSe QDs of 5 wt%. However, the conversion efficiency was decreased as the amount of ZnSe QDs more than 15 wt%.

Table 1. Parameters of solar cells.

The cell	J_{sc} (mA/cm^2)	V_{oc} (V)	J_m (mA/cm^2)	V_m (V)	FF	η(%)
TiO_2	6.60	0.375	3.59	0.20	0.290	0.718
TiO_2 + 5% ZnSe	5.88	0.475	3.89	0.30	0.419	1.17
TiO_2 + 15% ZnSe	2.25	0.370	1.67	0.25	0.591	0.418
TiO_2 + 25% ZnSe	2.20	0.340	1.61	0.20	0.431	0.322

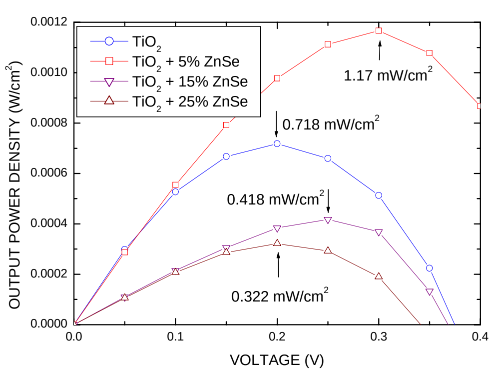


Fig. 4. Output power of solar cells.

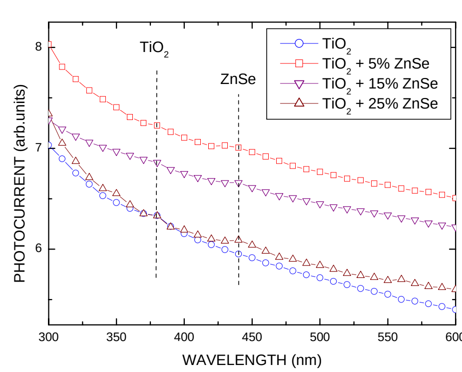


Fig. 5. Photocurrent spectra of the cells sensitized with and without ZnSe QDs.

Fig. 5 shows the photocurrent spectra of the cells sensitized with and without ZnSe QDs. The absorption peak around 380 nm and 440 nm correspond to nanocrystalline TiO_2 and ZnSe QDs, respectively. It is clear that addition of ZnSe QDs to the nanocrystalline TiO_2 solar cells increase the photocurrent. However, the photocurrent decreased when the amount of ZnSe QDs was more than 15 wt% owing to the colloidal solution hardens such that hard to produce a homogeneous mixture. The conversion efficiency was decreased due to a nonhomogeneous mixture.

4. Conclusion

In this work, we develop nanocrystalline TiO_2 solar cells sensitized with chlorophyll and ZnSe QDs. The solar cells sensitized with 5 wt% ZnSe QDs exhibited optimum photovoltatic properties under AM 1.5 illumination condition. The measured parameters were the short-circuit current density (J_{sc}), the open-circuit voltage (V_{oc}), the maximum output power density (P_m), the fill factor (FF), and the power conversion efficiencies (η), which had values of were 5.88 mA/cm^2, 0.475 V, 1.17 mW/cm^2, 0.419, and 1.17 %, respectively. The incorporation of ZnSe QDs can improve remarkably FF owing to the better conductivity than TiO_2. Therefore, the result is better than others, so it is worthy of going deep into study.

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