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CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

9.1 Conclusions

This thesis focuses on the optimization of parameters in QDSSC for the enhancement of solar cell performance. A typical QDSSC structure consists of two electrodes, namely working electrode (or photoanode) and counter electrode (CE) assembled in a sandwich type with an electrolyte in between. Each element has the potential to be optimized for a high efficiency solar cell. High performance CdS and CdSe QDSSCs have been produced by step-by-step parametric optimization. Optimization work was focused on QD deposition, polysulfide electrolyte, CE materials and surface treatment on QD-sensitized TiO_2 layer. The results of the optimization work were presented and discussed in five chapters (Chapter 4 to 8).

The core element of a QDSSC is the QD sensitizer. In Chapter 4, preparation parameters of SILAR method for sensitizing TiO_2 layer with CdS and CdSe QDs were studied and optimized. Best performance CdS QDSSC was achieved when CdS QDs were prepared with precursor solution having a concentration of 0.10 M and using 4 SILAR cycles with 5 min of dipping time in each solution. The precursor solutions used were $Cd(NO_3)_2$ in ethanol and Na_2S in methanol. For CdSe QDSSC, the best performance was obtained when the parameters for CdSe QDs preparation were set at precursor solution concentration of 0.03 M and using 7 SILAR cycles with 30 sec of dipping time in each solution. The precursor solutions used were $Cd(NO_3)_2$ in ethanol and Se^{2-} solution in ethanol. It was also showed that band gap energy of the QD could be tuned by varying the QD size which was produced by varying the SILAR parameters (i.e. precursor concentration, dipping cycles and dipping time).

With the optimized QD preparation, the next step was to prepare a suitable polysulfide electrolyte for the solar cell. An efficient polysulfide electrolyte for CdS QDSSC has been reported previously, where the electrolyte consists of 0.5 M Na_2S, 2 M S and 0.2 M KCl in methanol/water (7:3 by volume) solution. Thus, this work focused on the optimization of polysulfide electrolyte for the application in CdSe QDSSC. The best CdSe QDSSC performance was achieved with polysulfide electrolyte composed of 0.5 M Na_2S, 0.1 M S and 0.05 M GuSCN in a solution mixture of ethanol/water (8:2 by volume) as reported in Chapter 5.

Apart from optimized QDs preparation and polysulfide electrolyte, a good electrocatalytic material for CE is necessary for a high performing QDSSC. Few low-cost CE materials were prepared to study the CE materials effect in CdS and CdSe QDSSCs. It was found that carbon-based materials were a good candidate for the CE in

CdS QDSSC while platinum and Cu_2S performed best in CdSe QDSSC. These CE materials showed relatively lower R_{CE} and CPE values at the CE/electrolyte interface in QDSSC. However, as the carbon-based materials needed further optimization for long term stability, platinum was a better choice for the CE material in CdS QDSSC.

Co-sensitization of more than two types of QD materials on TiO_2 film is expected to produce a better solar cell performance. In Chapter 7, a better performance of QDSSC was obtained with QD sensitizers structured as CdS(4)/CdSe(6), where the number denotes the total SILAR cycles required for the QD preparation. The good performance of such cell was attributed to the effective stepwise energy band structure alignment of the QDs. However, the performance of the CdS(4)/CdSe(6) co-sensitized solar cell obtained in this work was low. The lower than expected result could be attributed to the inhomogeneous QDs distribution throughout the TiO_2 layer. To further enhance the performance of the QDSSC, back electron transfer or charge recombination at the photoanode/electrolyte interface needs to be suppressed with a passivation layer. It was showed that not all Zn chalcogenide could function as passivation layer. By applying ZnS layer on top of the QD-sensitized TiO_2 film, the efficiency of the cell improved. Thus, the role of ZnS can not be neglected when designing a QDSSC.

Chemical treatment on TiO_2 film and the film thickness also affect the overall cell performance. It was observed that a thicker TiO_2 film thickness yielded a higher QDSSC performance. With TiO_2 film thickness of 24 μm coupled with ZnS passivation layer on top of the active layer, both CdS and CdSe QDSSCs achieved best efficiency of 1.48% and 3.05%, respectively under 1000 Wm^{-2} illumination. Doping with Mn^{2+} ion in CdS QDSSC produced an even higher efficiency of 1.89% under 1000 Wm^{-2} illumination. However, such effect was not evidenced in CdSe QDSSC.

In conclusion, a step-by-step study on QDSSC parameters has been performed. A good performing CdS QDSSC is obtained when the QD is prepared via SILAR method with preparation parameters of 0.10 M precursor solution concentration and 4 SILAR cycles with 5 min dipping time in each solution. The polysulfide electrolyte should consist of 0.5 M Na_2S, 2 M S and 0.2 M KCl in methanol/water (7:3 by volume) solution. With Mn^{2+} doping and ZnS passivation layer, best efficiency of 1.89% was obtained under 1000 Wm^{-2} illumination. On the other hand, a good performing CdSe QDSSC is obtained when the QD is prepared via SILAR method with preparation parameters of 0.03 M precursor solution concentration and 7 SILAR cycles with each solution dipping lasting for 30 sec. The optimized polysulfide electrolyte for CdSe QDSSC consists of 0.5 M Na_2S, 0.1 M S and 0.05 M GuSCN in ethanol/water (8:2 by volume) solution. Best efficiency of 3.05% was obtained under 1000 Wm^{-2} illumination with photoanode having TiO_2 film thickness of 24 μm and ZnS passivation layer. In both cells, platinum was the choice of the CE material. The optimized parameters of CdS and CdSe QDSSCs are summarized as in Table 9.1.

Table 9.1. Optimized parameters of CdS and CdSe QDSSCs prepared via SILAR method.

QDSSC	Precursor solution concentration	SILAR dipping cycle	SILAR dipping time in each solution	Polysulfide electrolyte	Counter electrode	TiO_2 surface treatment
CdS	0.10 M	4	5 min	0.5 M Na_2S, 2 M S and 0.2 M KCl in methanol/water = 7:3 (v/v)	Pt	Mn^{2+} doping and ZnS passivation layer
CdSe	0.03 M	7	30 sec	0.5 M Na_2S, 0.1 M S and 0.05 M GuSCN in ethanol/water = 8:2 (v/v)	Pt	TiO_2 24 μm with ZnS passivation layer

9.2 Suggestions for future work

Although optimization of CdS and CdSe QDSSC has been completed as reported and discussed in this thesis, there are other factors that need to be perfected before a prototype of the QDSSC module can be fabricated. In this work, TiO_2 film structure used was in planar form. If the TiO_2 structure is designed as nano-tube or nano-wire, a better cell performance can be expected as more QDs will be able to attach to the enlarged surface area of the TiO_2. A new photoanode structure is proposed where co-sensitization of TiO_2 layer with QD and inorganic dye can result in better solar cell performance. It will be beneficial to optimize the parameters of such hybrid solar cell. Another possible work is the fabrication of solid state QDSSC. Solid state QDSSC is able to solve the leakage problem of the liquid electrolyte used in the current design. A gel polymer type electrolyte can be the substitute for the liquid polysulfide electrolyte. In short, the proposed future works are: nano-tube or nano-wire structure of TiO_2, co-sensitization of TiO_2 structure with semiconductor QD and dye, and solid state QDSSC.