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SOLAR CELL APPLICATION OF CADMIUM-CHALCOGENIDE QUANTUM DOTS COMPOSITES

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Abstract

The cadmium (Cd)- chalcogenide thin film solar cell is the most suitable to be fabricated in the form of thin films. The quantum dot-sensitized solar cells (QDSSCs) have given an alternative way to convert solar energy into electrical energy. Among all the QDSSCs, cadmium based QDSSCs used because of their easy fabrication, less cost and high conversion efficiency. In this review, the concept and mechanism behind the QDSSCs are reviewed. Fabrication methods and possible approaches for improving the Cd chalcogenide QDSSC performance are also discussed. It should be noted that the efficiency of a QDSSC depends on the fabrication method of the quantum dots, and the choice of the counter electrode.

1 INTRODUCTION

In a sensitized solar cell, light is mainly absorbed by the sensitizer. Photo generated electrons are then rapidly injected into the conduction band of the coupled semiconductor leading to electron–hole separation. This is the most important part of sensitized solar cells [1]. Dye sensitizers of metal oxide semiconductors in combination with liquid electrolytes have offered the highest photovoltaic efficiencies. However, inorganic semiconductor sensitizers, usually referred to as quantum dot (QD) sensitizers, are recently studied with great interest. This interest stems from the several attractive features that QD sensitizers possess [1–5]

a fundamental issue is that conventional single-junction semiconductor solar cells only effectively convert photons of energy close to the bandgap (Eg) as a result of the mismatch between the incident solar spectrum and the spectral absorption properties of the material [6]. Photons with energy (Eph) smaller than the band gap are not absorbed, and their energy is not used for carrier generation. Photons with energy (Eph) larger than the band gap are absorbed, but the excess energy Eph – Eg is lost due to thermalization of the generated electrons. These fundamental spectral losses are approximately 50% [7]. Several approaches have been suggested to overcome these losses, e.g., multiple stacked cells [8], intermediate band gaps [9], multiple exciton generation [10], quantum dot concentrators [11,12], and spectral converters, the latter being down- and up converters [13,14] and downshifters [15,16]. In these so-called third- or next-generation PV concepts [17,18], nanotechnology is deemed essential in realizing most of these concepts [19].

2 BASIC PRINCIPLES OF QDSSCS

2.1 Performance Parameters

The function of a conventional photovoltaic solar cell is based on the formation of an electrical barrier between n- and p-type semiconductors. The potential difference across this barrier

Creates an electrical diode structure. Thus, the current–voltage characteristic of the solar cell follows the diode equations.

Under the dark condition, there is no current flowing. However, when sufficiently high voltage is applied i.e. higher than open circuit voltage, the contacts start to inject carriers to produce current at forward bias. Upon light illumination, additional photocurrent will be generated and flow across the junction. The maximum generated photocurrent contributes to the short-circuit current (Isc) . During open circuit when there's no current flowing, the open-circuit voltage (Voc) is defined. Power output then can be determined from the product of current and voltage. At the maximum power point (Im and Vm), the product is the largest [20]. This defines the fill factor (FF). FF=ImVm/IscVoc The maximum theoretical FF value is 1.0. However, in reality the value is limited to 0.83. The photovoltaic power conversion efficiency is defined by the electrical power density divided by the incident solar power density (P).

2.2 Working Mechanism

The working mechanism of the QDSSC is very similar to that of the DSSC. When the QDs (CdX, X¼S, Se orTe) are subjected to band gap excitation, upon illumination, electron–hole pairs are formed in the QDs. The electrons will enter into the conduction band (CB) of the QD and the hole remains in the valence band (VB). The excited QD injects the electron

from its CB into the CB of the wide band gap semiconductor (e.g.TiO2) and in doing so it itself is oxidized with the hole remaining in the valence band. The injected electron from the QD percolates through the porous TiO2 network and ultimately reaches the conducting glass. From there it travels through the external load and completes the circuit by entering back through the counter electrode. The generated voltage is perceived as an evidence of the solar energy conversion to electric energy.

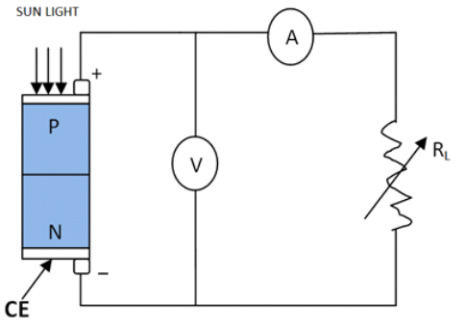

Fig. 1. Working of solar cell

2.3 Advantages Of Qds As Sensitizers

Some of the advantages of QDs are tunable energy gaps, ability of multiple exciton generation, photo stability, low cost and high absorption coefficient, which is known to reduce the dark current and increase the overall efficiency of solar cells [21]. Of all these, tunable energy gaps and multiple exciton generation features are the most desirable characteristics of the QDs [22–25].

2.4 Tunable Energy Gaps

Various research groups have studied the ability of QDs as sensitizers in QDSSCs [24-27]. The QD properties are not only limited to Cd chalcogenides but applicable to other QD materials as well. The main motivation of using QDs as sensitizers in solar cell is due to their tunable energy band gaps, which can control their absorption range [28]. There are several reports in the literature showing that CdS and CdSe with tunable band gaps property are capable of converting visible light to electric energy [29,30]. Preparation of quantum dot sensitizers Vogel et al. [28] demonstrated that efficient charge separation can be optimized by tuning the size of the QDs utilizing the quantization effect. Kongkanand et al. [29] separately reported that by varying the size of CdSe QDs assembled on TiO2 films, improvement in photo electrochemical response and photo conversion efficiency can be obtained. With the decrease of CdSe particle size, photocurrent increases. On the other hand, if the particle size is increased, the particles will have better absorption in the visible region. The disadvantage of this is lower effectiveness of electron injection intoTiO2 as compared with smaller-sized CdSe QDs.

This size dependent effect is made possible due to the quantum confinement effect exhibited by the QD itself [31, 32]. Quantum confinement effect can be manifested when QDs in colloidal solution show different color corresponding to the change of particle size which influences a different absorption band of light. When the QD particles are sufficiently small, the effective band gap energy of the QD is wider. Subsequently, the optical absorptions and emissions in relation with excitations across the band gap shift towards higher energies [24]. Quantum size effects have been demonstrated by Gorer et al. with the observed blue shift of the optical spectra of CdSe films as the crystal size decreases [34]. This phenomenon is also high- lighted in CdS QDs, as reported by Thambidurai et al. [35] where the same blue shift was observed in the optical spectra of smaller CdS QDs. Therefore, we can conclude that a combination of different quantum dot sizes in a cell will have better efficiency due to wider absorption of light by the quantum dots having a range of band gaps.

There are various methods for preparing QDs and attaching them to the wide band gap semiconductor material [59]. Generally, these methods can be categorized into two major methods: in situ fabrication and attachment of pre-synthesized colloidal QD. In situ fabrication method is the most used approach for QDs preparation. It is facile and low cost. Chemical bath deposition (CBD) and successive ionic layer adsorption and reaction (SILAR) are two well known in situ techniques. Not only the techniques are simple, but they also can be used in large scale production. However, these techniques do not allow precise control of the particle size distribution of the QDs. The other approach is to use pre-synthesized QDs (also known as ex situ fabrication). QDs are usually prepared ex situ and adsorbed on wide band gap semiconductor surface by using molecular linkers that have various functional groups. QDs can also be deposited directly without using linker molecules. This technique enables the precise control over the size and hence the spectral absorption properties of the QDs.

2.5 Preparation Of Quantum Dot Sensitizers

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2.6 Type Of Qd Sensitizers And Their Sizes

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2.6 Type of QD sensitizers and their sizes
QDs employed in QDSSCs as sensitizers include but not limited to CuInS2 [37], PbS [38], InP [39], InAs [40], Ag2S [41,42], CdS [43], CdSe [44], CdTe [45] and ZnSe [46]. Among these, Cd chalcogenide QDs have been considered as a better choice as they are more stable in QDSSCs although they may degrade upon visible illumination [47]. However, the degradation is not as severe as PbS QDs. CdS QDs are reported to be relatively more stable.

2.7 Effect Of Different Counter Electrodes

Different counter electrodes (CEs) employed in Cd chalcogenide QDSSCs can affect their overall performance [48]. In general, platinized transparent conductor layers have been used in most QDSSC assemblies. The Pt CE has been used in more than 50% of the Cd chalcogenide QDSSCs reported. However, there are other materials which have shown better performance in QDSSCs when used as CEs. Notable alternative materials for CEs include carbon, Au, Cu2S and reduced graphene oxide. In recent studies, higher efficiencies for Cd chalcogenide QDSSCs were obtained with Cu2S as CEs [49, 50]

CONCLUSION

QDSSCs have become a promising alternative for DSSCs due to the excellent properties of QD sensitizers. Among the wide variety of semiconductor materials available for QDs, Cd chalcogenide has been the preferred choice, especially CdS and CdSe, by many researchers. We have reviewed the research work reported on QDSSCs with the focus on Cd chalcogenide as sensitizers. The fabrication of QDSSCs, their working principle and performance evaluation has also been discussed. The research activities found to be focused in improving the overall efficiency of the QDSSC in recent years in order to achieve improvements and break- throughs in QDSSCs performance.

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