Optik - International Journal for Light and Electron Optics 169 (2018) 41–47

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Short note

Luminescent down shifting CdTe colloidal quantum dots for enhancing polycrystalline silicon solar cells

A.Z. Kainarbay[a,*], T.N. Nurakhmetov[a], D.K. Daurenbekov[a], A.A. Eliseev[b], T.Y. Sachkova[b], Z.M. Salikhodzha[a], A.M. Zhunusbekov[a]

[a] Faculty of Physical-Technical Science, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
[b] Faculty of Material Science, M.V. Lomonosov Moscow State University, Moscow, Russia

ARTICLE INFO

Keywords:
Semiconductor quantum dots
Luminescent down shifting
Solar cell efficiency
Spectral transformation

ABSTRACT

In this paper, CdTe quantum dots (QDs) with emission bands at 762 nm and 812 nm were investigated for their use in luminescent down shifting (LDS) layers. Spectral location of emission bands and quantum yield of luminescence of the QDs in solution proposed that they were suitable nanoparticles for inclusion in LDS layers. QDs were dispersed in poly (methylmethacrylate) (PMMA) polymer matrix and thin films were fabricated approximately of 70 microns. Significant solar cell efficiency enhancements (approximately 5%–10%) under normal (AM1.5, 25 °C) condition were observed after QDs doped PMMA coatings. The experimental results showed increments in the V_{oc} from 478 to 541 mV, I_{sc} from 35 to 42 mA, J_{sc} from 8.96 to 10.51 mA/sm^2, FF from 69.1 to 77.3% and efficiency from 13.12 to 19.48%. PMMA thin film doped with CdTe QDs was spin-coated on the front surface of Si solar cell for enhancing the solar cell efficiency via photoluminescence (PL) conversion and antireflection effects.

1. Introduction

Current manufacturing of solar cells is almost based on polycrystalline silicon. If the first stage of development was based on monocrystalline silicon with energy efficiency ~ 25% [1], then the samples of modern solar cells have smaller energy efficiency rate and the cost of technology. Solar cells of the third generation will be based on the use of nanomaterials or nanostructures, including nanoparticles or quantum dots of semiconductors with predictable high solar energy conversion coefficient and lower cost of technology [2].

At this time nanoparticles are being studied as a promising practical application of new solar energy materials, as materials that can potentially increase the efficiency rate of solar cells. There are a number of physically grounded premises for this. *The first premise* is that an increase in the efficiency of solar energy conversion becomes possible due to the passivation of surface defects of crystalline silicon. *The second premise* is that thin films transmit long-wavelength solar radiation with a noticeable absorption of short-wavelength part. *The third premise* lies in the possibility of implementing “down shifting”, i.e. transformation of the high-energy part of solar radiation during interaction with a film, as a result of which nanoparticles will luminesce in the low-energy spectral range.

Potential LDS materials should have the following properties: as like a wide area of absorption (excitation); narrow emission spectrum etc. [3]. All these requirements are met by quantum dots of semiconductors. The use of which as light emitting centers in LDS materials show encouraging results [4]. For example, also in the work of the authors, an increase in the efficiency of conversion of the solar cell to 10% is achieved when using CdSe QDs [5]. The doped quantum dots ZnSe: Mn deposited in a thin film of polylauryl

* Corresponding author.
E-mail addresses: a.kainarbay@yandex.kz, kainarbay_azh@enu.kz (A.Z. Kainarbay).

https://doi.org/10.1016/j.ijleo.2018.05.046
Received 26 March 2018; Accepted 10 May 2018

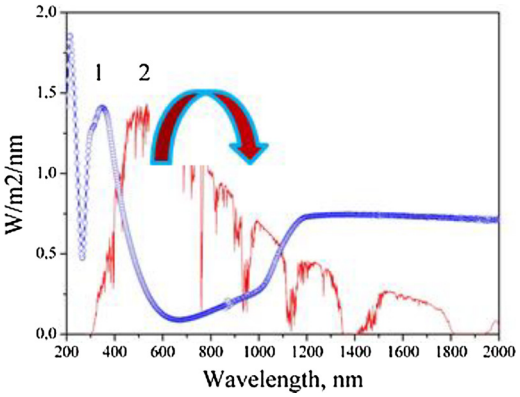

Fig. 1. The spectrum: 1) optical diffuse reflection of a polycrystalline solar cell, 2) solar emission at AM 1.5.

methacrylate on front surface of the solar cells shows an increase in the efficiency of the solar cells by 5–10% under the conditions of AM0 [6].

LDS thin films containing QDs CdTe (λ_{max} = 587 nm) and QDs C (λ_{max} = 415 nm) were used to increase the efficiency of solar cells reported in [7]. PV parameters are measured with and without LDS thin films. According to the results, reported a slight increase in V_{oc} (1.02%, 0.72%), J_{sc} (1.08%, 5.24%), FF (4.6%, 4.8%), PCE (6.43%, 4.5%) from the initial values, for case QDs CdTe and QDs C, respectively.

The use of QDs as LDS materials also suggests a relatively easy implementation not only in polymer matrices, but also in others. e.g., [8], the authors used silica as a transparent matrix for encapsulation QDs CdSe/CdS/ZnS (λ_{max} = 660 nm, QY = 25.4%). The use of nanocomposites on the surface of the solar cell (4 cm^2) showed an increase relative to the initial values of PCE (5.2%), Jsc (2.61%), FF (1.78%) when four layers of LDS were applied.

Carried out own research based on QDs CdTe, CdSe, PbS and etc., also a literature review showed that LDS layers containing various QDs can provide improved electrical parameters. However, such improvements are insignificant. One of the reasons is the low quantum yield of QD luminescence. Consequently, the synthesis of high-quality QDs is a key problem for increasing the efficiency of photovoltaic devices using the LDS layer [8].

A distinctive feature of our research is the following: 1) we set the goal of obtaining a QD CdTe with a high quantum yield of luminescence; 2) Nanoparticles should have luminescence bands occurring in the region of maximum spectral sensitivity of the solar cell; 3) The synthesized QDs should have an excitation spectrum coinciding with the spectrum of solar radiation in the range from 450 to 700 nm (AM 1.5), Fig. 1. When these conditions are fulfilled, as well as the effect of "antireflection effect", it becomes possible to significantly improve the electrical quantities of the solar cell.

In this paper we show that coating by thin films QDs on the surface of a commercial solar cell leads to an increase in efficiency from 13.1 to 19.4%, depending on the thickness of the applied film. To measure the photovoltaic parameters of solar cell of a certain size upon irradiation by a solar simulator SolAAA (Newport Corp.), the standard conditions were chosen: temperature 25 °C at AM1.5.

2. Experiment

2.1. Synthesis of CdTe quantum dots

In this paper, the CdTe QDs was synthesized by a slightly modified method of authors [9]. In general, the CdTe QDs is obtained from the pre-prepared molecular precursors of cadmium oleate and tri-*n*-octylphosphinetelluride (TOPTe). Tellurium precursor was preparation by dissolving 0.064 of tellurium powder in 1.54 mL of TOP at heating 50 °C, to produce a solution of TOPTe (this involved the formation TOPTe in the TOP). 5.0 mL of diphenyl ether, 0.564 g of oleic acid, 0.1332 g of cadmium acetate dehydrate were loaded into 250 mL quartz three-necked flask. The mixture was heated to 140 °C under argon flow for form cadmium oleate. A heating mantle and a magnetic stirrer were employed for heating up the reaction flask with simultaneous stirring. After a formation of cadmium oleate, the flask heated to 250 °C, at this temperature tellurium precursor solution was quickly injected into the reaction flask. After one hour the reaction flask removed from heating mantle and cooled rapidly to room temperature and after purification QDs dispersed in heptane and stored in a dark and cool place.

3. Results and discussion

3.1. Measurement of luminescent properties

Photoluminescence spectra of the CdTe QDs were measured using CM2203 UV–vis spectrofluorometer. CdTe QDs were dissolved in heptane and placed in a quartz cuvette. Photoluminescence spectrum at 300 K is shown in Fig. 2 (curve 2) and axcitation spectra (curve 1). CdTe samples have intense luminescence band consists a main peak at 761 nm and a long-wavelength shoulder with a