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CdSe/CdS core/shell in polyacrylamide polymer matrix for quantumdots luminescent solar concentrator

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Abstract

Luminescent solar concentrator (LSC) is used to enhance photoresponsivity of solar cell. The Quantum dots luminescent solar concentrator (QDLSC) consists of CdSe/CdS core/shell nanoparticles embedded a polyacrylamide polymer matrix positioned on the top surface of the silicon solar cell. This procedure improves the conversion efficiency of the bare silicon solar cell. The conversion efficiency of the solar cell has increased from 7.3% to 10.3%. This improvement is referred to the widening of the response spectral region window of the Si. Solar cell.

Key words

Luminescent solar concentrators (LSC), CdSe/CdS core/shell nanoparticles, matrix polyacrylamide polymer, solar cell efficiency.

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المركزات الشمسية الوميضية للنقاط الكمومية CdSe/CdS قشرة/ لب في مصفوفة بوليمر PAM بولي أكريلاميد

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الخلاصة

تستخدم المركزات الشمسية الوميضية (LSC) لتعزيز الاستجابة الضوئية للخلية الشمسية.تتكون المركزات الشمسية الوميضية النقاط الكمومية من CdSe/CdS قشرة/ لب جسيمات النانوية المغمورة في مصفوفة بوليمر أكريلاميد، موضوعة على سطح العلوي للخلية الشمسية السليكونية. هذا الاجراء حسنة كفاءة التحويل للخلية الشمسية المجردة. كفاءة التحويل للخلية الشمسية ازدات من 7.3% الى 10.3%. هذا التحسن هو يشار إلى توسيع نافذة الاستجابة المنطقة الطيفية للخلية الشمسية السيليكونية.

Introduction

Solar radiation can be converted into electrical energy by utilizing solar cells. These solar cells have limited conversion energy. The devices efficiency can be enhanced via many methods, among them is applying the quantum dots luminescent solar concentrators (QDLSC). LSCs consist of a transparent polymer plate matrix with refractive index≈ 1.5 doped with luminescent material, such as organic dye, inorganic semiconductor nanoparticles (quantum dots, QDs) [1, 2]. Quantum dots are nanoparticles of semiconductors materials ranging from 2 to 10 nm in diameter, like CdSe and CdS. There electronic characteristics are closely related to the size and shape of the individual crystal.

The operation principle is enhancing the absorption spectral range of a selected solar cell. Incident sunlight is absorbed, re-emitted in a specific

spectral range, and transferred by total internal reflection to the cells beneath the (QDLSC) for better electricity production. Higher efficiency can be achieved by matching the highest quantum efficiency of solar energy cells to peak emission concentrator. The design and development of LSCs began in the 1970s [3]. The active material of LSCs can be any fluorescent substance, either inorganic (such as semiconductors) or organic dyes [4]. Quantum dots or inorganic semiconductor nanoparticles are preferably used recently as an alternative to the organic dye luminescent concenters because they have many advantages such as their stability against photo degradation and absorption over a wide spectral range, especially in the UV- region, high quantum yield (QY), and, the emission wavelength can be tuned to a desired wavelength by changing the QD diameter as a reason of quantum confinement effects [5]. Also the dimensions and shapes of Nano dots are controlled by the chemical reaction time. Meanwhile, there are disadvantages such as the photon reflection at the front surface of the QDLSC, before light enters the waveguide a part of the incoming irradiation that is equal with $|(n- 1)/(n+1)^2|$ will be reflected from the top surface, where n is the refractive index [6] and part of the light is quenched due to re-absorption (caused by the overlap between the absorption and emission spectra of the QDs) [7]. Examples for using core/shell QDs, is PbSe/ CdSe or PbS/ CdS QDs due to their high QY, and chemical and photo stability with respect to bare QDs [8].

In this research the CdSe/ CdS core/shell is chemically prepared and mixed with the matrix material to fabricate QDLSC, the QDLASC is applied to a silicon solar cell to show efficiency enhancement.

Experimental

CdSe QDs are synthesized by mixing (0.36 g) of $CdCl_2$ solution with (0.25 g) of gelatin (pig skin) in (40 ml) distilled water at pH 7.2, which was achieved by adding ammonium hydroxide, and (20 ml) of sodium seleno sulfate (Na_2SeSO_3) solution Prepared by heating (0.03 g) of selenium with (0.10 g) of sodium sulfite in deionize water at 80 ^oC for three hours:

$$CdCl_2 + H_2O + Na_2SeSO_3 + NH_4OH \xrightarrow{\Delta} CdSe + 2NaCl + 2H_2O + NH_3$$

To prepare cadmium sulfide (CdS), 2-3 drops of Sulfuric acid is added to saturated sodium sulfide solution in the first flask to generate hydrogen sulfide which was carried to the second flask that contains CdSe (in presence of argon gas) and interacted with additional cadmium ions in CdSe QDs solution to form CdS.

Results and discussion

UV-visible analysis:

From Fig.1 (adopted from Manal Midhat Abdullah, et al. [9]), one can notice that the spectral response of the amorphous silicon solar cells ranges from 400 nm to 800 nm and the absorption around 500 is weak, so the QDLSCs are used to enhance the absorption in this spectral region. The idea is that the emitted radiation from the QDs via fluorescence process should match the absorption spectral region of the solar cell.

UV-VIS absorption spectrum of the nanoparticles of CdSe /CdS core-shell shown in Fig.2, the absorption range of about 350- 550 nm, the absorption peak is 495 nm i.e. the band gap is (2.5 eV), while to the band gap of bulk

CdSe/CdS (1.78 eV for 698 nm) as Mahajan, et al. [10].

The fluorescence emission peak (Fig.3) is centered around 562 nm. The low intensity peak observed around 444 nm is related to the surface states formation in CdSe/CdS core-shell system.

This result permits radiation absorption by the QDs molecules and a red shift is observed via fluorescence process to 562 nm. Meanwhile it permits passing other wavelength directly towards the silicon solar cell, to be absorbed and generates electron – hole pairs. i.e. the system of QDLSC with the a-Si solar cell will gain wider absorption spectrum.

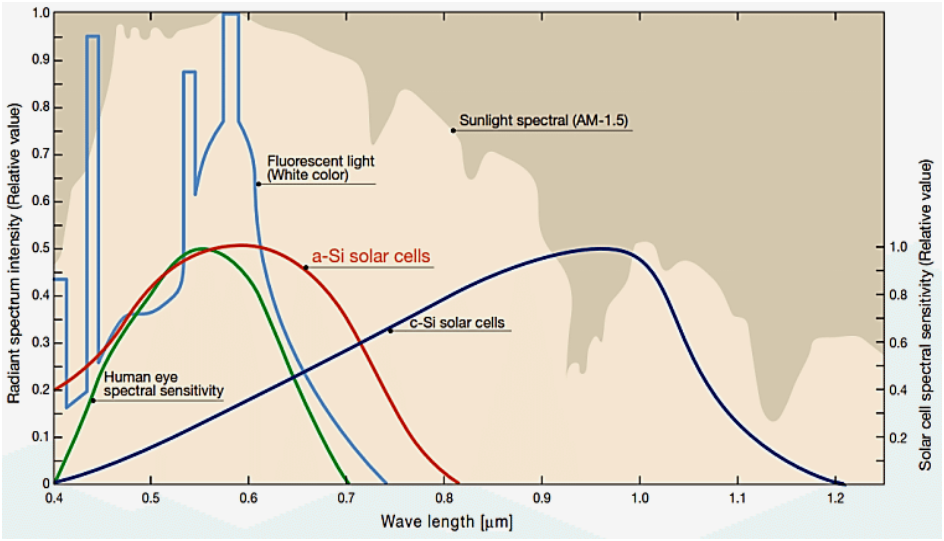

Fig.1: The spectral response of different types of solar cells, adopted from ref. [9].

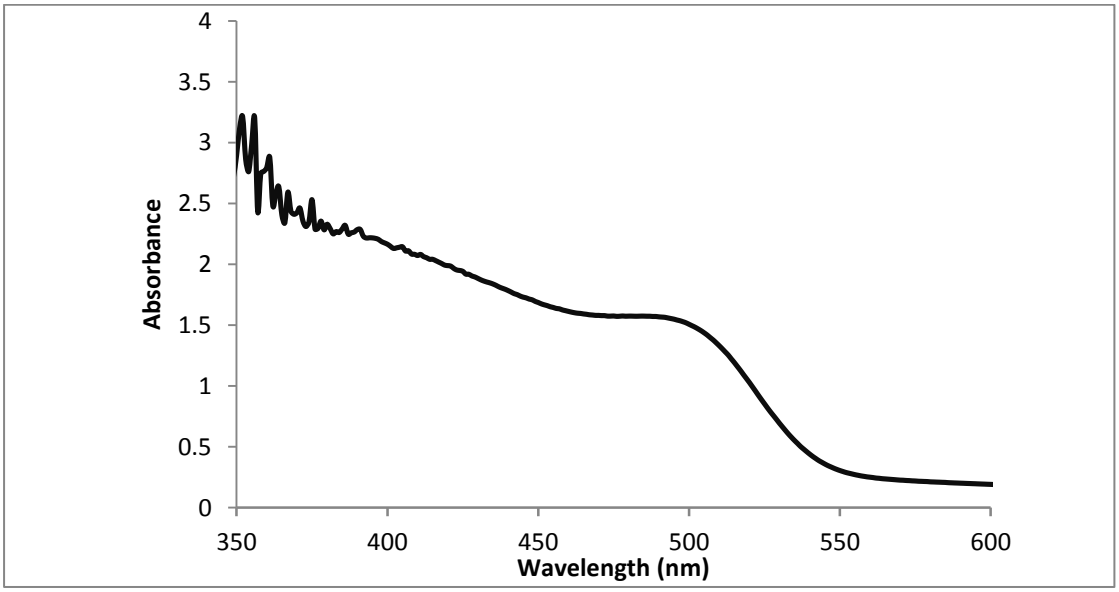

Fig.2: Absorption spectrum of CdSe/CdS core-shell aqueous solution.

For the matrix material (polyacrylamide polymer), an absorption spectrum test is shown in Fig.4. The absorption in the UV region is very low, and transparent in the visible region, this makes this polymer ideal matrix substance for hosting the active QD nanoparticles.

Fig.3 shows the fluorescence spectrum of the colloidal CdSe/CdS

nanoparticles. By exciting the sample with 495 nm, two peaks are observed (444 nm for CdS and 562 nm for CdSe).

Energy gap calculations

Generally, if the size of crystal is small, then band gap between the higher valence band and the lowest conduction band becomes high and more energy is requiring for exciting the dot and consequently, more energy is released when the crystal returns to its resting state [11, 12].

Two methods are applied to calculate the energy gap.

1- The relation E_g =1240/ λ is used to calculate the energy gap. The energy gap for CdS nanoparticles is 2.7 eV (at 444 nm), and 2.2 eV for CdSe (at 562 nm).

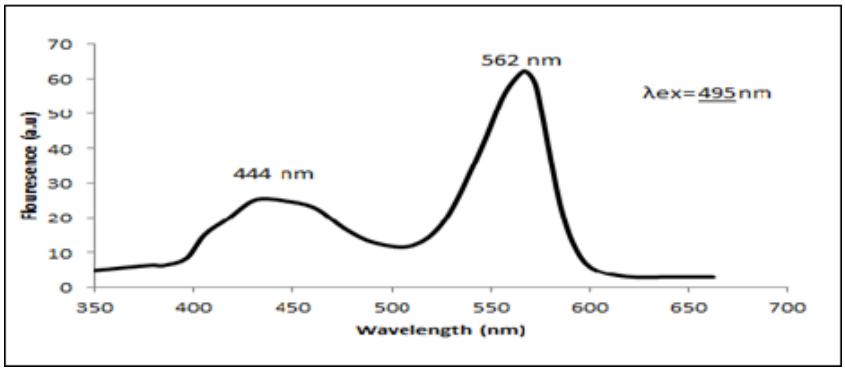

Fig.3: The FL spectrum of the colloidal CdSe/CdS nanoparticle

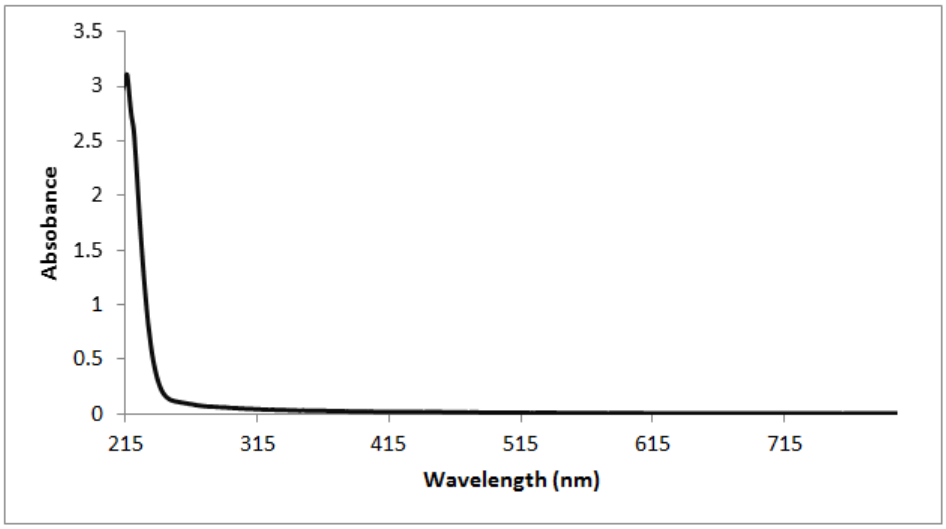

Fig.4: Absorption spectrum of polyacrylamide polymer solution.

2- The relationship between $(\alpha h\nu)^2$ and $(h\nu)$ is plotted for the incident photon as illustrated in Fig.5. The extrapolations of the linear part of the curve give two values for the energy gaps: 2.3 eV for CdSe and 2.6 eV for CdS.

The band gap of the core is smaller than the band gap of the shell, as well the band gap of the core falls within the band gap of the shell. Excited electrons and holes are completely confined in the core region, this yields higher quantum yield and long term stability [13].

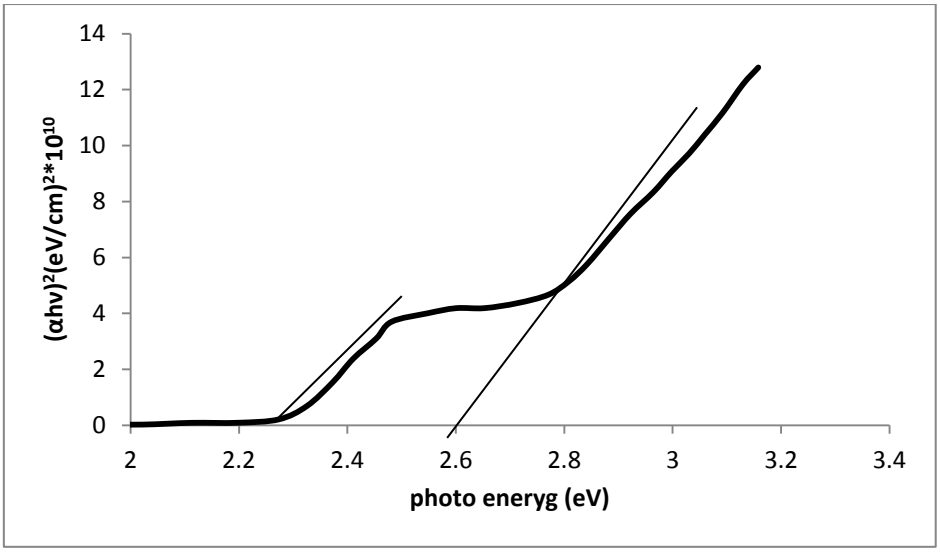

Fig.5: $(\alpha h\nu)^2$ versus Photon energy for CdSe/CdS core-shell nanoparticles.

X-ray diffraction pattern of the CdSe/CdS core–shell nanoparticles

The x-ray diffraction for CdSe/CdS nanoparticles are shown in Fig.6 from the x-ray pattern can calculate average particle size for CdSe/CdS by using Debye-Scherrer equation [14]

$$D = \frac{0.9\lambda}{\beta \cos\theta}$$

where D is the quantum dot size.

λ is the wavelength for X-ray source (X-ray source is CuKα with λ=1.5406 Å).

β is the full width at half maximum (FWHM).

θ is the diffraction angle, as well as an account interplanar spacing using Braggs Law.

$$d = \lambda / 2\sin\theta$$

Fig.6, shows three diffraction peaks at 2θ values corresponding to which peaks of CdS and CdSe (111), (220) and (311) planes, the first is centered around (25.09º) for (111) plane, and the second is centered around (42.20º) for (220) plane and the third is centered around (49.87º) for (311) plane.

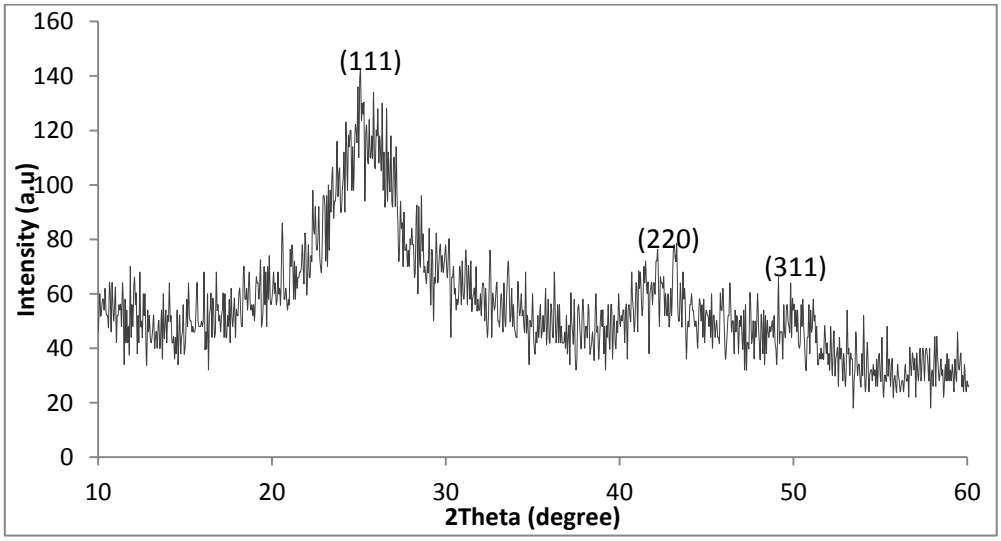

Fig.6: The XRD pattern of the CdSe/CdS core-shell nanoparticles.

Table 1: The grain size of the CdSe/CdS core-shell nanoparticles, which obtained from Scherrer equation at diffraction scattering angle, Miler indices and FWHM of the diffraction peak.

2Θ (degree)	FWHM (degree)	dhkl	Calculated dimension (D)nm	hkl
25.0934	4.0806	3.545925	1.994473	(111)
42.2026	3.1956	2.139615	2.664688	(220)
49.8722	2.1141	1.827056	4.144081	(311)

Conversion efficiency for solar cells before and after applying QD LSC

A primary I-V characteristics of a-silicon solar cell test under (500 W/m^2) is achieved by using a solar module analyzer. In general, the silicon solar cell grafted with nanoparticles CdSe/CdS in in a matrix of polyacrylamide polymer shows better conversion results comparing to the bare solar cell. The conversion efficiency (η) of the bare solar cell is 7.3 %, by applying CdSe/CdS nanoparticles to the surface of the cell this parameter is raised to 10.3 % (Fig.7).

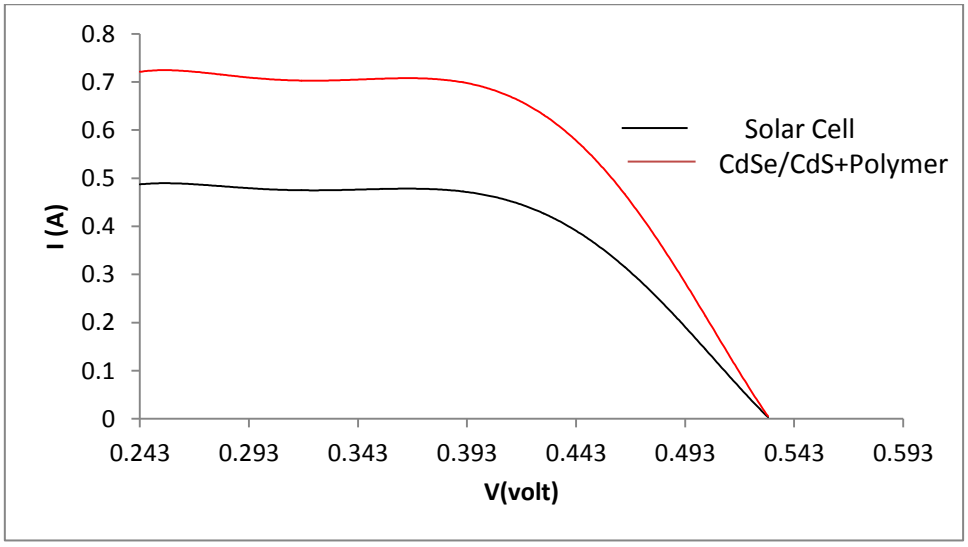

Fig.7: I-V characteristics curves for both a bare solar cell and covered with CdSe/CdS core-shell sheet.

Table 2: I_{sc},V_{oc}, and η for the solar cell and solar cell +CdSe/CdS core/shell.

Type	Isc (A)	Voc (volt)	FF	η%
Solar cell	**0.490**	**0. 540**	**0.739**	**7.3**
Solar cell +CdSe/CdS core/shell+ Polymer	**0.725**	**0.565**	**0. 667**	**10.3**

Conclusions

The work proves experimentally that the QD luminescent solar concentrators are a good method for enhancing the conversion efficiency of a bare a-Si solar cell.

Luminescent solar concentrators in this work are prepared from CdSe / CdS core shell quantum dots embedded in a polymer matrix. Results show an efficiency enhancement from 7.3 % to 10.3 % by applying the QD luminescent solar concentrator.

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