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CdSe/ZnS Core/Shell for Luminescent Solar Concentrator

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Abstract

Fabrication and investigation of the properties of CdSe/ZnS core/shell for the luminescent solar concentrates (LSC) application is presented. An increase of the efficiency of a silicon solar cell was obtained by applying the LSC. The increase was a result of the optical properties of the semiconductor nanoparticles CdSe/ZnS core/shell that were deposited over the top surface of the silicon solar cell facing the illumination source (Halogen lamp). The gravity force was invested for the film deposition process.

The optical properties of these nanoparticles were studied. The absorption spectra for the CdSe/ZnS core-shell were 270-600nm, i.e., located within the spectral response area of the examined solar cell.

The energy gap values for CdSe were 2.5 eV and 3.3eV for ZnS. X-Ray Diffraction (XRD) analysis was adopted and showed that the particle dimensions are within the nanometer scale.

The efficiency value of the bare solar cell was 7.3%, whereas the value was increased to 8.0 % by applying the CdSe/ZnS core/shell LSC, indicating an efficiency gain percentage of 9.59%.

Keywords: Luminescent solar concentrators (LSC), CdSe/ZnS core/shell nanoparticles, solar cell efficiency.

CdSe/ZnS لب/ قشرة للمركزات الشمسية الوميضية

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الخلاصة

تم تقديم صناعة ودراسة الخواص CdSe/ZnS لب/ قشرة لتطبيقات المركزات الشمسية الوميضية.تم الحصول على زيادة في كفاءة الخلية الشمسية السيليكونية بواسطة المركزات الشمسية الوميضية LSC.الزيادة كانت نتيجة استخدام جسيمات نانوية شبه موصلة CdSe/ZnS لب/ قشرة التي تم ترسيبها على السطح العلوي للخلية الشمسية التي تواجه المصدر المضيء(مصباح هالوجيني).للحصول على طبقة المركز الشمسي على سطح الخلايا الشمسية تم استخدام الترسيب بتاثير الجاذبية الارضية.

تم دراسة الخواص البصرية لهذه الجسيمات النانوية ,أطياف الامتصاص ل CdSe/ZnS لب/ قشرة تبين(270–600 نانومتر). فجوة الطاقة هي 2,5 الكترون_ فولت لجزيئات CdSeو3,3الكترون_ فولت لجزيئات ZnS.استعنا بدراسة أطياف حيود الاشعة السينية حيث تم حساب حجم الجسيمات واظهرت ان ابعاد الجسيمات هي نانوية. قيمة كفاءة الخلية الشمسية العارية هي 7.3 ٪ ،هذه القيمة ازدادت إلى 8.0 ٪ عند استخدام المركز الشمسي الوميضي CdSe/ ZnS core / shell LSC.اي ان مقدار الربح المئوي =9,5%

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Introduction

Solar cells are devices that convert the solar radiation into electrical energy. Luminescent solar concentrators (LSCs) operate on the principle of enhancing the absorption spectral range of a solar cell. Incident sunlight is absorbed, re-emitted in a specific spectral range, and transferred by total internal reflection to photovoltaic (PV) cells at the edges of the LSC for electricity production.

Researches, design and development of LSCs began in the 1970s [1,2]. The active material of LSCs can be any fluorescent substance, either inorganic (such as semiconductors) or organic (e.g., dyes). However, early work used organic dyes as the active material. Inorganic semiconductor nanoparticles quantum dots (QDs) were proposed as luminescent centers for the LSC because they have several advantages over organic dye LSCs [3,4]; QDs are more stable against photo degradation and absorb over a wider spectral range, especially in the UV- region. Also, the emission wavelength can be readily tuned to a favorable wavelength by changing the QD diameter as a result of quantum confinement effects [5,6]. In spite of high quantum yield (QY), there are drawbacks, as part of the photon is reflected at the front surface of the LSC and part of the light is lost due to re-absorption (caused by the overlap between the absorption and emission spectra of the QDs) [7]. All these challenges can be addressed by using core/shell QDs, such as PbSe/ CdSe or PbS/CdSQDs, due to their higher QY and chemical and photo stability as compared to bare QDs [8].

In this research, we explore the possibility of manufacturing luminescent solar concentrators by utilizing CdSe/ZnS core/shell nanoparticles

Experimental

CdSe/ZnS core-shell nanoparticles were prepared by a chemical method. The first solution, Cadmium Selenide (CdSe), was prepared from the reaction of Sodium Selenosulfide (Na_2SeSO_3) and Cadmium Chloride ($CdCl_2$) solutions at 1:2 mole ratio, according to the following equation.

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

The second solution, Zinc Sulfide (ZnS), was prepared by the chemical reaction of Zinc Chloride ($ZnCl_2$) and Sodium Sulfide (Na_2S) at 1:1 mole ratio, as shown below>

$$ZnCl_2 + H_2O + Na_2S + 2NH_4OH \xrightarrow{\Delta} \underset{precepitat}{ZnS} \downarrow + 2NaCl + 2NH_4OH$$

The dimensions and shapes of the nano dots may be controlled by the chemical reaction time. CdSe/ZnS core-shell was prepared from the reaction of CdSe with ZnS at 25ºC with continuous flowing of argon gas for 20 minutes. All chemicals were imported from Sigma-Aldrich Company, with high degrees of purity (Se 99%, $CdCl_2$ 99%, $ZnCl_2$ 99%, and Na_2S 98%).

A Silicon solar cell was used for evaluating the performance of the LSC. A solar module analyzer device was used for testing the parameters of the solar cell before and after applying the LSC.

Results and Discussion

The spectral response of the amorphous silicon ranged from 400 nm to 800 nm, as shown in Figure-1. The absorption at 500nm is weak and, therefore, LSCs are used to enhance the absorption in this spectral region [9].

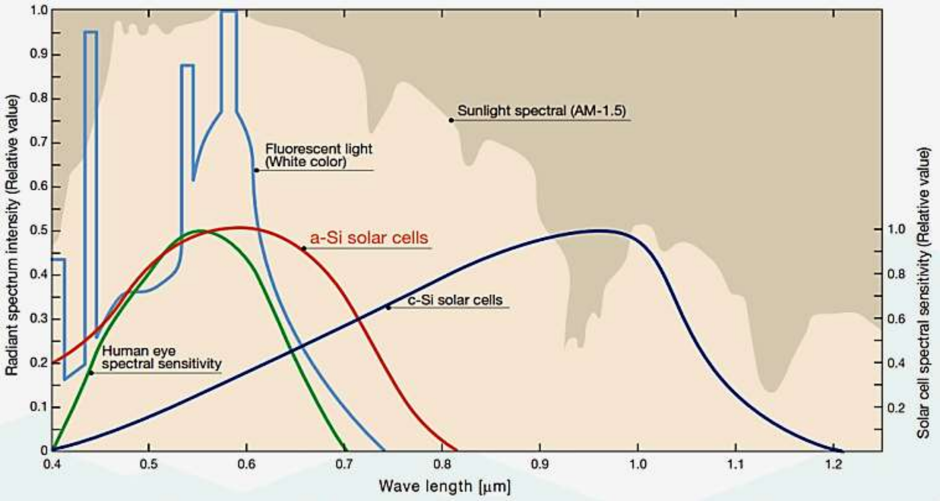


Figure 1-The spectral response of different types of solar cells.

The results of the optical test of UV-VIS absorption spectrum of the colloidal CdSe/ZnS core-shell nanoparticles are shown in Figure-2. The spectrum shows an absorption range of about 270- 600 nm. It was also noticed that there are two inflection peaks at 363 nm and at 425 nm due to forbidden gaps of ZnS, where the shallow band is usually observed within the ZnS spectrum. The absorption peaks are positioned in the UV region, while they have low absorption in the visible region. This permits the passing of the visible radiation directly towards the silicon solar cell, to be absorbed and to generate electron –hole pairs. While the UV part will be absorbed by the LSC molecules, red shifted via the fluorescence process, and emitted at 552nm (Figure-3). The emission in this region coincides with the response of the solar cell, as demonstrated in Figure-1.

Figure-3 shows high intensity peaks centered around 552nm, which can refer to the direct band transition of the ZnS and the CdSe materials. The low intensity peak observed around 377 nm may be related to the surface states formation in CdSe/ZnS core-shell system. The bands at 377 nm and 552 nm are due to the shell (ZnS) and core (CdSe), respectively [10].

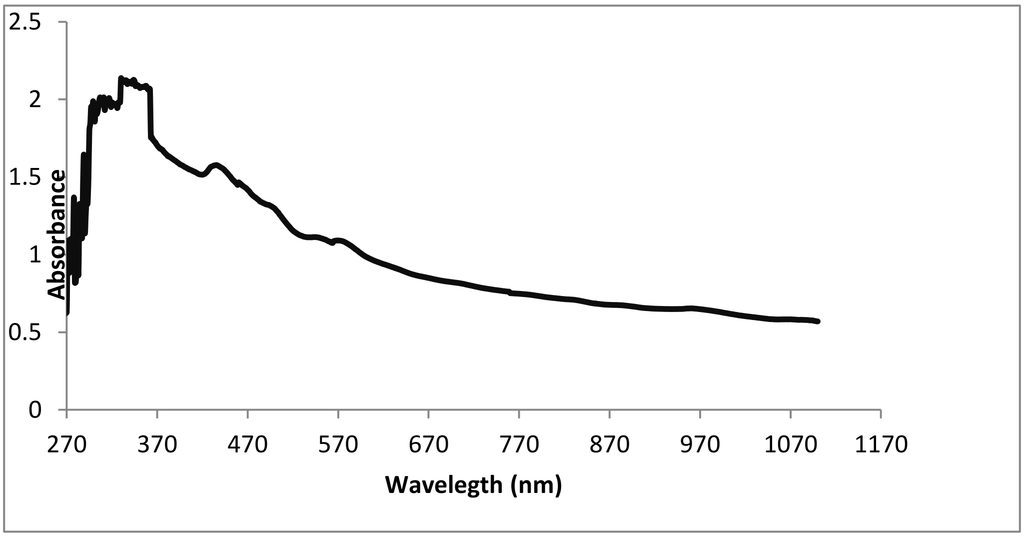


Figure 2-UV-VIS absorption spectrum of CdSe/ZnS core-shell colloidal.

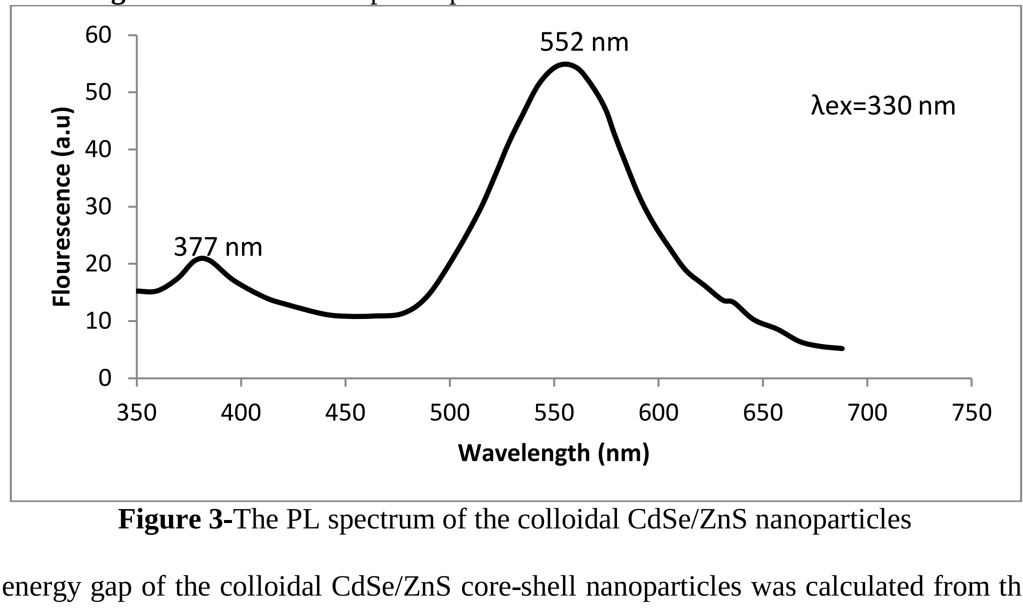


Figure 3-The PL spectrum of the colloidal CdSe/ZnS nanoparticles

The energy gap of the colloidal CdSe/ZnS core-shell nanoparticles was calculated from the photoluminescence spectrum. The optical wavelength corresponding to a given band gap energy E_g was calculated to be $E_g = 1240/\lambda$. The energy gap obtained from the CdSe/ZnS core-shell was 2.5eV for CdSe, whereas that for ZnS was 3.2eV.

X-Ray Diffraction Results of CdSe/ZnS Core-Shell nanoparticles

X- ray diffraction patterns of the prepared CdSe/ZnS core-shell nanoparticles are illustrated in Figure-4. The pattern shows three peaks; the first is centered around (28.3°) for (111) plane and around

(47.25º) and (58.3º) for (220) and (311 planes, respectively. The narrow full width at half maximum of the diffraction peaks indicates that the CdSe/ZnS core-shells are in nano scale dimensions. By applying Scherer relation [6] for the peak (111), the size of the formed core-shell nanoparticles was found to be about 3.14 nm, as shown in Table-1 [11,12].

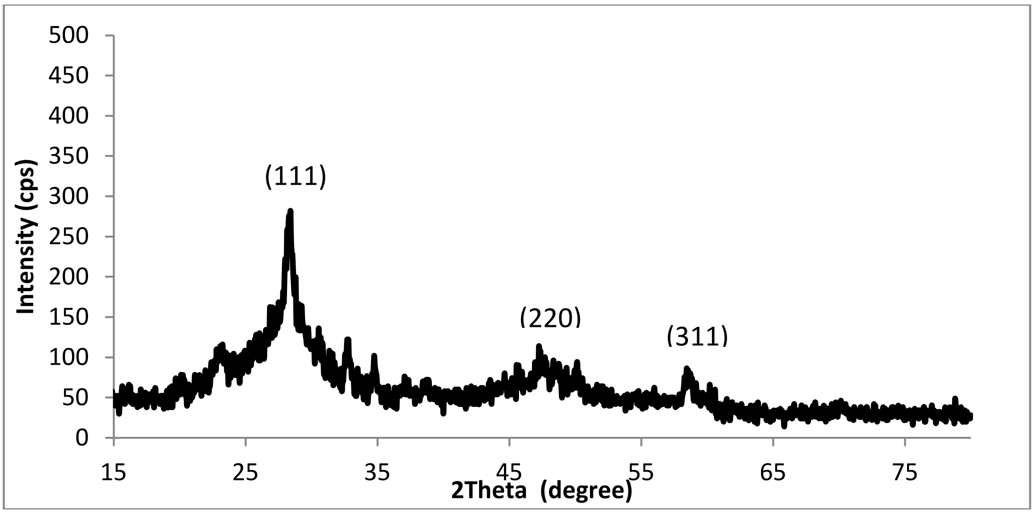


Figure 4-The XRD pattern of the CdSe/ZnS core-shell nanoparticles.

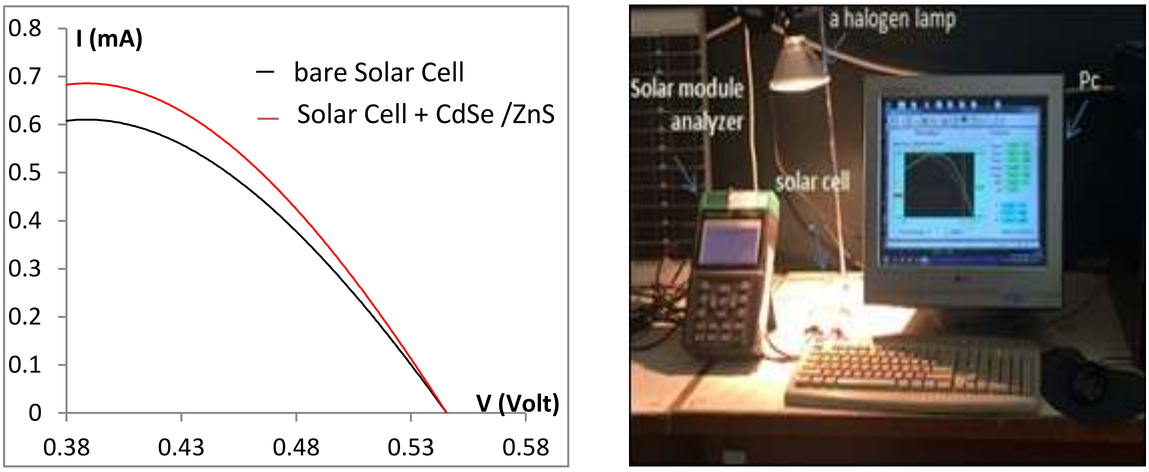
Table 1-illustrates the grain size of the CdSe/ZnS core-shell nanoparticles, as obtained from the Scherer equation diffraction angle, Miller indices, and FWHM of the diffraction peak.

2Theta(degree)	Cos(θ)	β(degree)	Calculated dimension(D) nm	(hkl)
28.320	0.969	0.950	3.148	(111)
47.466	0.915	0.975	1.913	(220)
58.555	0.872	0.617	1.575	(311)

Conversion efficiency of solar cells before and after using LSC

I-V characteristics curve of the prepared silicon solar cell was drawn with the amount of incident radiation intensity using a halogen lamp of maximum intensity (500 W /m^2). In general, the distinct behavior of the cell treated with CdSe/ZnS shows that the conversion efficiency is improved as compared to that of the bare solar cell, as shown in Figure- 5.a and Table-2.

Table-2 illustrates the results of the parameters related to the study, such as I_{sc},V_{oc}, and η for the solar cell and the solar cell +CdSe/ZnS LSC.



(a) **(b)**

Figure 5 a)-I-V characteristic curves for bare solar cell and solar cell covered with LSC+ CdSe/ZnS core-shell .b) image of the solar analyzer for efficiency measurement.

Table 2-Values of the short Circuit Current I_{sc}, Open Circuit Voltage V_{oc}, and Efficiency η for the solar cell and solar cell +CdSe/ZnS

Type	Isc (mA)	Voc (volt)	FF	η%
solar cell	624.0	0.556	0.724	7.3
solar cell+CdSe/ZnS core/shell	701.0	0.512	0.741	8.0

Conclusions

The chemical preparation is a suitable method for preparing nano-sized particles for solar applications. The use of CdSe / ZnS core shells for preparing luminescent solar concentrators is considered a successful method, since it improves the conversion efficiency of silicon solar cells. The efficiency value of the bare cell was 7.3%, which was increased to 8.0 % by applying the CdSe/ZnS core/shell LSC. In addition, we obtained values of Short Circuit Current (I_{sc}), Open Circuit Voltage (V_{oc}), and Fill Factor for the CdSe/ZnScore/shell LSC of 701.0, 0.512, and 0.741, respectively. The efficiency gain was 9.59%.

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