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***Physics***

***Research Article***

# OPTICAL, STRUCTURAL AND ELECTRICAL PROPERTIES OF PSi-CdSe JUNCTION

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**ABSTRACT**

Photo-electrochemical etching and spray pyrolysis methods have been used in the preparation of porous silicon (PSi) and cadmium selenide (CdSe) thin film, respectively. The first method was used in the preparation of PSi (etching time 10 min and etching current 15 $mA/cm^2$), while the second method was used to deposit CdSe thin film on porous silicon (substrate temperature 100 °C, Nozzle distance 25 cm, 20 sprays and 7.5 $kg/cm^2$ pressure). The optical properties of CdSe films showed the absorption spectrum peaks of CdSe nanoparticles at both wavelengths at 460 and 660 nm with energy gap 2.5 eV. The structural properties of the CdSe heterostructure have been also investigated. The images of scanning electron microscopy (SEM) showed that the CdSe film was crystalline with average grain size of about 49.63 nm which agrees with XRD spectrum analysis results (55.67 nm). The I–V characteristics of the heterostructure are similar to ideal diode and solar cell, with short circuit current (2.43 $mA/cm^2$), open circuit voltage (0.34 V) and fill factor (0.603).

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# ОПТИЧЕСКИЕ, СТРУКТУРНЫЕ И ЭЛЕКТРИЧЕСКИЕ СВОЙСТВА ГЕТЕРОСТРУКТУРЫ PSi-CdSe

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характеристики солнечных элементов

**А Н Н О Т А Ц И Я**

Методы фотоэлектрохимического травления и распылительного пиролиза были применены при изготовлении солнечного элемента PSi-CdSe. Первый метод был использован при изготовлении пористого кремния со временем травления 10 мин и током травления 15 мА/см$^2$, в то время как второй метод был использован для осаждения тонкой пленки CdSe на пористый кремний при температуре подложки 100 °С с расстоянием между соплами 25 см, 20 распылениями и давлением 7,5 кг/см$^2$. Оптические свойства пленок CdSe показали пики спектра поглощения наночастиц CdSe на длинах волн 460 и 660 нм с энергетической щелью 2,5 эВ. Исследована структура пленки CdSe, где изображения сканирующего электронного микроскопа SEM показали, что пленка CdSe является кристаллической со средним размером зерна около 49,63 нм, что согласуется с результатами анализа спектров рентгеновской дифракции (55,67 нм). Вольт-амперные характеристики перехода аналогичны характеристикам идеального диода и солнечного элемента с током короткого замыкания (2,43 мА/см$^2$), напряжением холостого хода (0,34 В) и коэффициентом заполнения (0,603).

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## Introduction

Single crystal silicon wafer is used in the manufacturing of solar cells of efficiency within the range 12–16 % depending on the manufacturing method [1]. The high reflectivity and high surface recombination of silicon wafers led to their replacement by porous silicon as a substrate of solar cells [2]. Porous silicon is characterized by low reflection (high absorption), low surface recombination, and high surface:volume ratio [3]. Different techniques have been used in the preparation of porous silicon including electrochemical etching [4], photochemical etching [5], photo-electrochemical etching [6] and stain etching [7]. Porous silicon can be coated by several types of semiconductors in the fabrication of solar cells. The top semiconductor layer depends on the type of porous silicon, whether *p*-type or *n*-type [8–10]. Cadmium selenide (CdSe) is one of the semiconductors that is used in the fabrication of PSi-CdSe solar cell. CdSe is an *n*-type semiconductor falling in the (II–VI) group of semiconductor compounds, which is characterized by a high absorption coefficient ($10^5$ $cm^{-1}$) within the wavelength range 380–1000 nm (IR and visible region) [11, 12], two phases: cubic (zinc blend) structure and hexagonal sulfide (wurtzite), a direct band gap of about 1.75 eV and indirect band gap of 1.23–1.25 eV, and electron mobility of 450–900 $cm^2$/V [13]. The electrical and structural properties of CdSe thin films depend strongly on the type and conditions of the preparation method. Several chemical and physical techniques are used to precipitate the CdSe thin films, such as RF magnetron sputtering [14], chemical bath deposition [15], thermal evaporation [16], spray pyrolysis technique [17], and E-Beam technique [18]. In this study, thin films of CdSe were deposited on porous silicon using the spray pyrolysis method. The optical properties of CdSe thin films, and the electrical and structural properties of PSi-CdSe solar cell were investigated.

## Experimental method

Solar cell PSi-CdSe was fabricated by the deposition of CdSe thin films on porous silicon substrate (PSi) using spray pyrolysis method (Fig. 1) [19]. P-type silicon wafers were used in the preparation of porous silicon using photo-electrochemical etching technique [20]. All variables were fixed during the etching process according to Table 1.

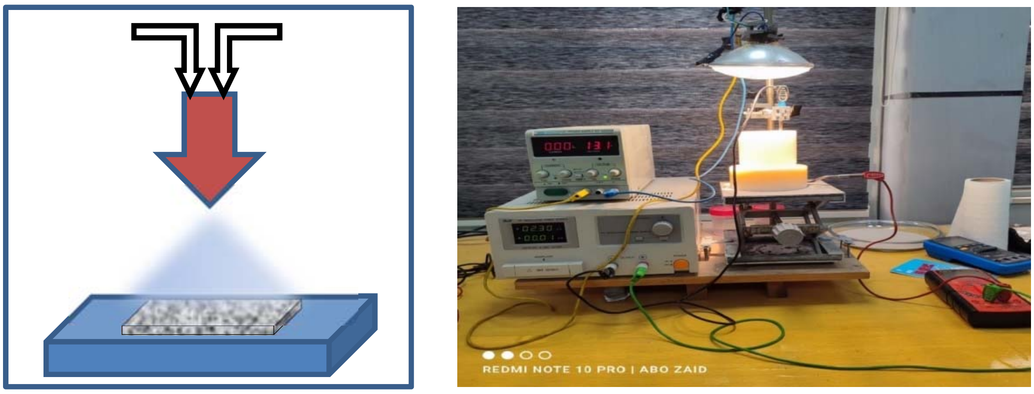
Table 1. **Parameters of photo-electrochemical etching technique**

| Etching current | Etching period | Aqueous solution |
|---|---|---|
| 15 mA/$cm^2$ | 10 min | HF (18 wt. %) and ethanol (99.9 %) (1:1) |

The Cadmium Selenium solution was prepared by mixing two solutions. The first solution was prepared by mixing 0.8 g selenium and 1.2 g sodium sulphate, each dissolved separately in 10 ml distilled water. The final solution was then heated in a Reflux system for 2–5 hours. The second solution was prepared by dissolving 1.0 g cadmium chloride in 20 ml distilled water including 1 ml ammonia. After mixing both solutions, the resulting solution was heated for 1 h at 90 °C. The spray pyrolysis method parameters are shown in Table 2.

Table 2. **Spray pyrolysis parameters**

| Deposition temperature, °C | Sprays | Nozzle distance, cm | Spray quantity, ml/5 sec | Spray rate, ml/min | Air pressure, kg/$cm^2$ |
|---|---|---|---|---|---|
| 100 | 20 | 25 | 0.4 | 4.8 | 7.5 |




*a* *b*

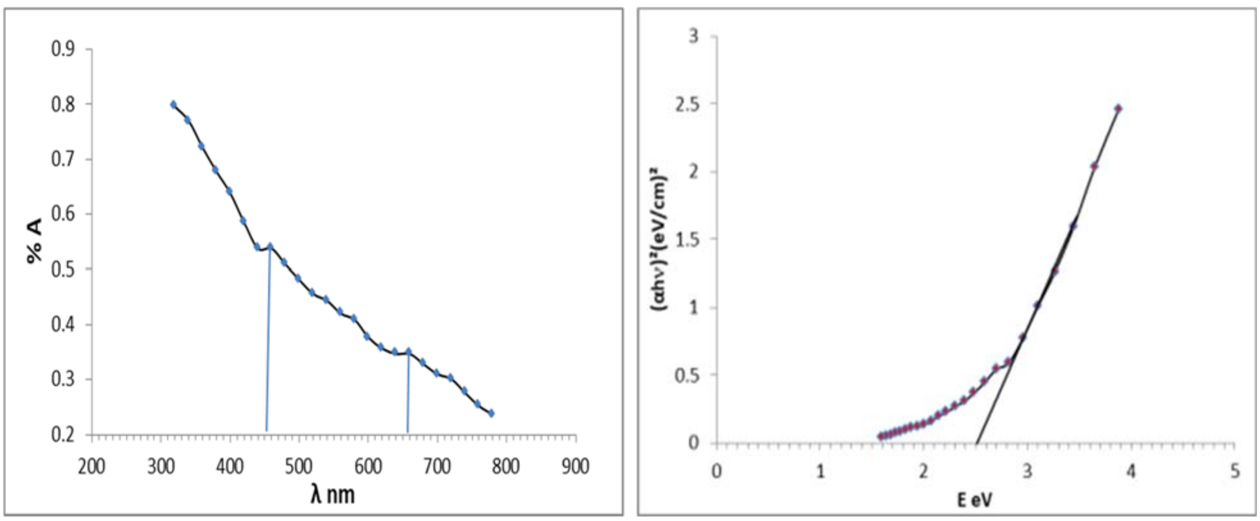
*Fig. 1. a* – Schematic representation of spray pyrolysis method; *b* – photo-electrochemical etching setup

## Results and discussion

Photo-electrochemical etching technique was used in the preparation of porous silicon, while the CdSe thin film was deposited using spray pyrolysis method. The porous silicon was used as a substrate for the PSi-CdSe junction.

The thin film of CdSe was deposited on the clean glass substrate to investigate its optical properties. The film thickness was calculated using the weight method. It depends strongly on the slide weight difference (before and after deposition process) and deposition area, which was about 1.9343 µm.

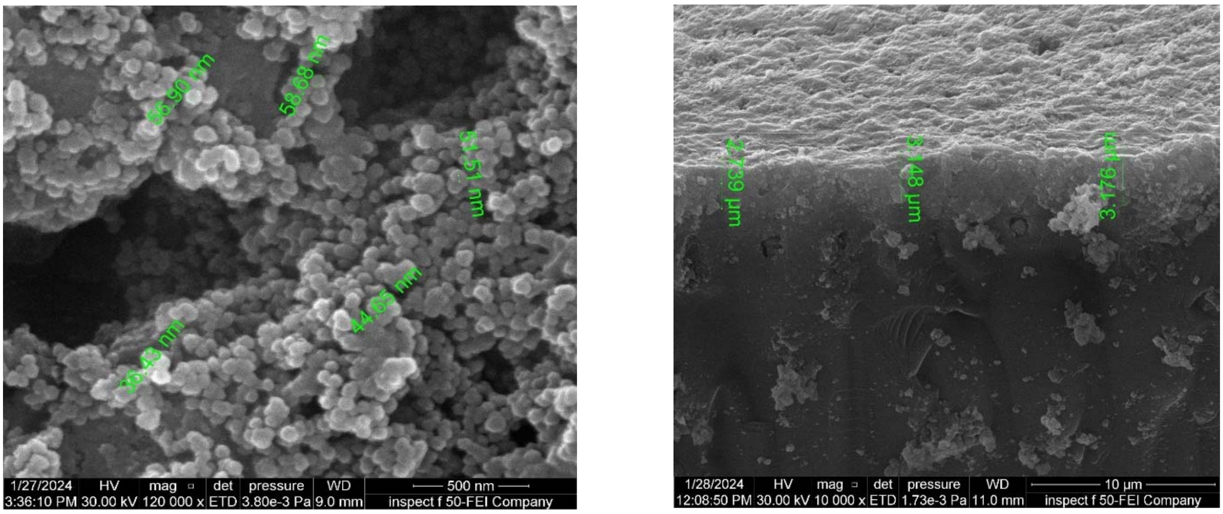
The absorption spectrum of CdSe thin film (Fig. 2) shows two peaks at 460 and 660 nm, which belong to the CdSe nanoparticles [21]. The energy gap of CdSe thin film was calculated to be about 2.5 eV.




*a* *b*

*Fig. 2. a* – Absorption spectrum of CdSe thin film; *b* – energy gap of CdSe thin film

Figure 3 shows the scanning electron images of the CdSe thin film surface and the PSi-CdSe junction. The SEM image of CdSe thin film surface (Fig. 3, *a*) shows that the average grain size is about 49.634 nm. The image also shows the homogenous distribution of CdSe grains along the gaps walls of the porous silicon. Fig. 3, *b* shows the cross section image of PSi-CdSe junction. It proves that the CdSe thin film thickness is between 2.139–3.176 µm, which is in agreement with the thickness that was calculated by weight method.




*a* *b*

*Fig. 3.* Scanning electron microscope images: *a* – surface of CdSe thin film; *b* – cross section area of PSi-CdSe junction

The XRD spectrum shows that CdSe thin film is completely crystalline, where a single peak appeared at 2θ = 28.66° (Fig. 4). Average grain size was calculated using Scherer equation. It was found that the size is about 55.67 nm, which is in agreement with SEM results (Table 3). The current – voltage of PSi-CdSe junction shows ideal characteristics of diode in both forward and reverse bias, as shown in Fig. 5.

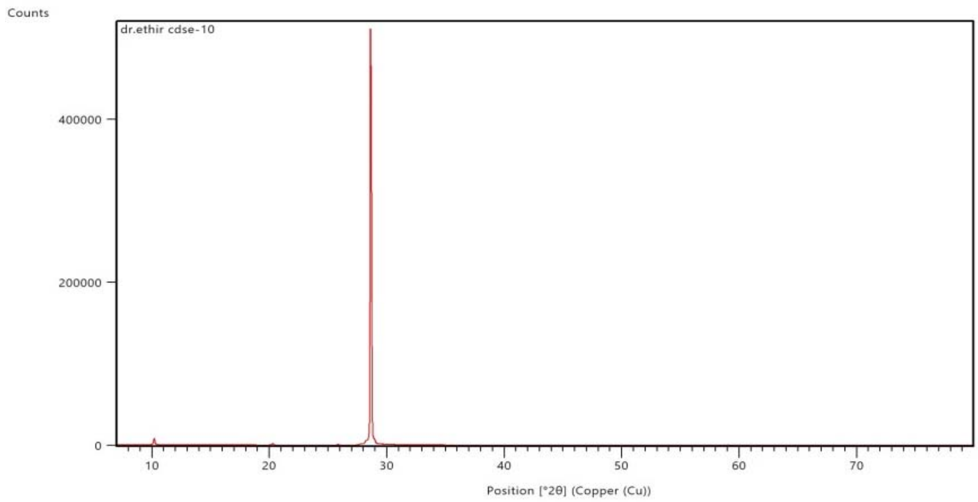



*Fig. 4.* XRD spectrum of CdSe thin films

Table 3. **Grain's dimensions of CdSe**

| 2-Theta (θ) | FWHM [°2 Th.] | D | Average grain size, nm |
|---|---|---|---|
| 10.19 | 0.11 | 71.09 | 55.67 |
| 12.89 | 3.17 | 2.52 | |
| 18.36 | 0.17 | 47.37 | |
| 27.96 | 0.50 | 16.24 | |
| 28.24 | 0.18 | 45.61 | |
| 28.61 | 0.07 | 117.30 | |
| 28.66 | 0.06 | 121.12 | |
| 28.68 | 0.44 | 18.57 | |
| 29.41 | 1.10 | 7.44 | |
| 30.82 | 1.87 | 4.39 | |
| 32.38 | 2.59 | 3.18 | |
| 34.11 | 0.65 | 12.66 | |
| 35.76 | 1.65 | 5.04 | |
| 38.20 | 1.23 | 6.78 | |
| 40.98 | 0.12 | 69.29 | |
| 47.44 | 0.02 | 394.44 | |
| 50.03 | 0.20 | 43.83 | |
| 51.85 | 0.13 | 70.32 | |
| 61.15 | 19.82 | 0.46 | |

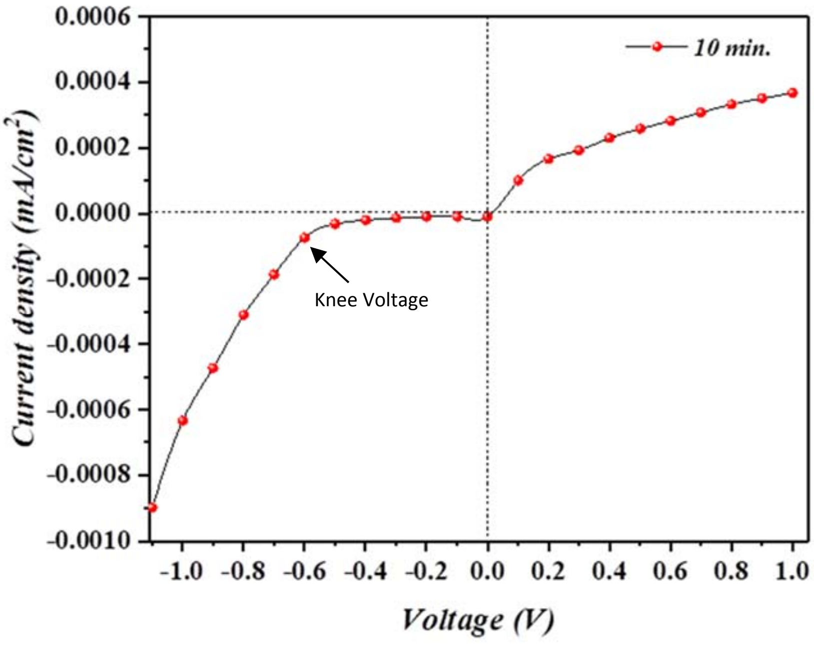



*Fig. 5.* Current-voltage curve of PSi-CdSe junction

The PSi-CdSe junction was examined as a solar cell. The junction of ideal solar cell characteristics (100 mW/cm$^2$) is shown in Fig. 6 and Table 4. The fill factor value reflects the fabrication quality of the junction.

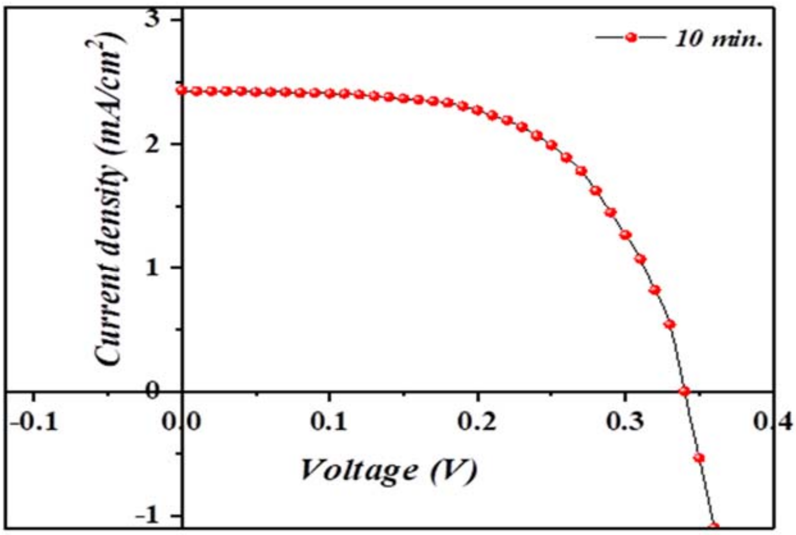



*Fig. 6.* Solar cell curve of PSi-CdSe junction

Table 4. **Fill factor, maximum current density, and voltages of PSi-CdSe junction**

| Area | cm$^2$ | *10 min* |
|---|---|---|
| | | 1 |
| $P_{in}$ | mW/cm$^2$ | 100 |
| $J_{sc}$ | mA/cm$^2$ | 2.430 |
| $V_{oc}$ | V | 0.340 |
| $J_{max}$ | mA/cm$^2$ | 1.993 |
| $V_{max}$ | V | 0.250 |
| FF | | 0.603 |
| PCE | % | 0.498 |

## Conclusions

Photo-electrochemical etching technique and spray pyrolysis method was used in the preparation of PSi-CdSe junction. Weight method was utilized to determine the thin film thickness, which was found to be about 1.93 µm. This value matches with the SEM images of the junction. The absorption spectrum of CdSe thin film shows two peaks at 460 and 660 nm. The CdSe energy gap was about 2.5 eV. According to SEM image, the average grain size of the films was about 49.63 nm, while from XRD spectrum it was estimated to be about 55.67 nm. Finally, PSi-CdSe junction shows ideal characteristics of diode in both forward and reverse bias with a knee voltage of about (–0.6 V). The junction also exhibits the following solar cell characteristics: short circuit current density (2.43 mA/cm$^2$), open circuit voltage (0.34 V), maximum current density (1.99 mA/cm$^2$), maximum voltage (0.25 V), fill factor (0.603) and PCE (0.498%).

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