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# Comparison between Sprayed and Evaporated CdS-Si Heterojunction Solar Cells

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Abstract This paper describes work investigating the characteristics of CdS-Si heterojunction solar cells made by two techniques namely spray pyrolysis and thermal evaporation. Figure of merit for CdS film, which estimated from its optical and electrical properties, was highly dependent on film preparation methods.

## 1 Introduction

The devising of heterojunction solar cells circa 1960 has been faced by two conflicting challenges; these are the cost and the conversion efficiency. These challenges incited too-many investigators to evolve low-cost high-efficient heterojunction solar cells [1-3]. Heterojunction type CdS-Si is one of the recommended cells [4-7]. The excellence of CdS layer is to minify the reflectivity without extensively heightens the series resistance. This particularity would be greatly influenced by the method of film preparation. CdS films were formerly prepared by many techniques. The most public techniques are thermal resistive and spray pyrolysis [8, 9]. The authors are the pioneers in preparing spray deposited CdS-Si heterojunction [10-12]. The current paper is a comprehensive comparison between sprayed and evaporated undoped-CdS-Si heterojunction solar cells in the unannealing conditions. The quotient that represents the ratio between transmittance and sheet resistance (i.e., figure of merit) was also examined in this work.

## 2 Experimental Procedure

Mirror-like silicon wafers of 4.0 x $10^{15}$ $cm^{-3}$ hole concentration and 1 $cm^2$ area grown by CZ technique were used in this study. CdS films were deposited onto silicon and glass substrates by two promising spray pyrolysis and thermal evaporation methods. CdS thickness was justified to be 80 nm. Al and In were utilized as ohmic contacts at both silicon and cadmium sulfide consecutively. Experimental details can be found elsewhere [10, 13]. Optical transmission in the range of 350-900 nm was studied with aid of spectrophotometer type PV-8800. Electrical and photovoltaic characteristics of the two sprayed and evaporated cells were recognized. Spectral responsivity of solar cells in the range of 450-1000 nm was measured using monochromator after making power calibration.

## 3 Results and discussion

### 3.1 Optical Transmittance

Figure 1 shows the optical transmittance spectrum of spray pyrolyzed and thermal evaporated CdS films with the same thickness. It is obvious that the film has low transmission for all wavelengths shorter than 550 nm (i.e., the absorption edge), this is mainly due to fundamental absorption process (intrinsic absorption). On the other hand, the transmission of sprayed CdS thin films is relatively higher than that of evaporated thin films at shorter wavelengths, the sub-levels of chlorine residual content upcoming from the starting solution probably interpret this altitude. In the wavelengths greater than absorption edge, transmission exhibits evident increment for the evaporated films as compared with sprayed films and this can be explained by the good quality of the evaporated film. In addition, error that occurs from measured thickness can also produce supplementing differences.

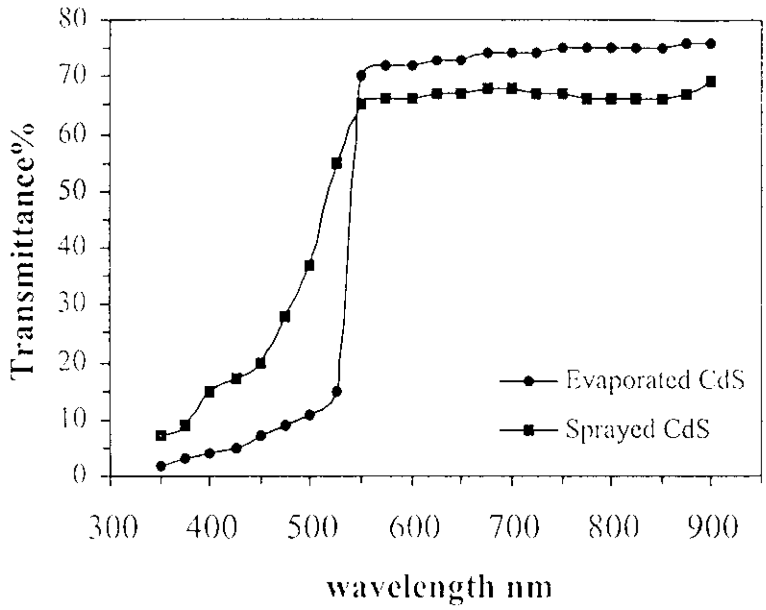


Figure 1. Spectral Transmittance for Sprayed and Evaporated CdS Thin Films.

### 3.2 Current-Voltage Characteristics

Current density (J) versus bias voltage (V) is represented in Figure 2. It is apparently shown that evaporated photodiode has a best rectification than sprayed one (e.g., rectification factor at 2 V is 7.6 and 3 for evaporated and sprayed CdS-Si heterodiodes respectively). Moreover, reverse saturation current is milder in the case of evaporated cell. On the other side, J-V profile for both cells clarifies soft breakdown in the reverse direction.

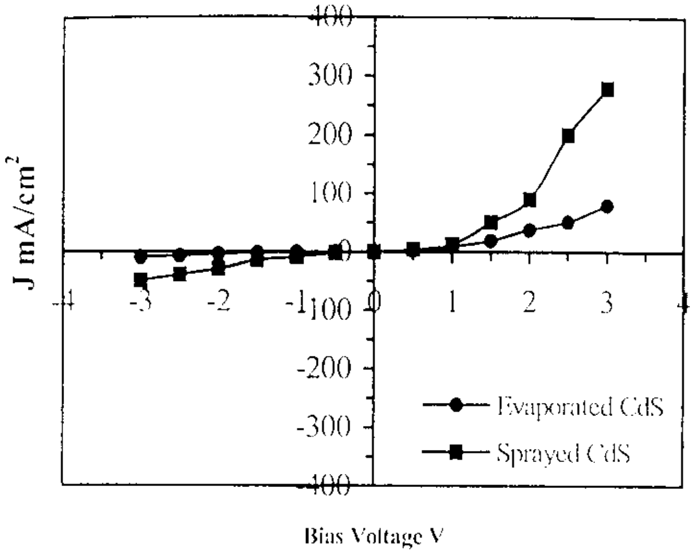


Figure 2. J-V Characteristics of CdS-Si Heterojunction Cells Prepared by Spray and Evaporation Methods.

### 3.3 Photovoltaic Performance

Photovoltaic performance of the cells is manifested in Figure 3. The fourth quadrant part of the curve (i.e., the output power plot) indicates that the rectangularity of evaporated cell is more uniform than that of sprayed cell and this outcome is undoubtedly explained by the effect of series resistance as it will be discussed later.

### 3.4 Spectral Responsivity

Spectral responsivity outline depicts two diacritic peeks as Figure 4 illustrates. The first one at 550 nm while the second at around 800 nm. This behavior is an inherent property for CdS-Si heterojunction [5]. Despite that evaporated CdS film showed better electrical characteristics, sprayed CdS-Si heterojunction cell presents higher responsivity with a factor about 1.68. The superiority of the spray method can be attributed to the formation of good junction with little dislocations perhaps due to domination of cubic phase [14] that leads to lessen the lattice mismatch effect. In the case of evaporated CdS, hexagonal phase will be dominant [13] hence; lattice mismatch will be enlarged, which in turns degrades the spectral responsivity characteristics.

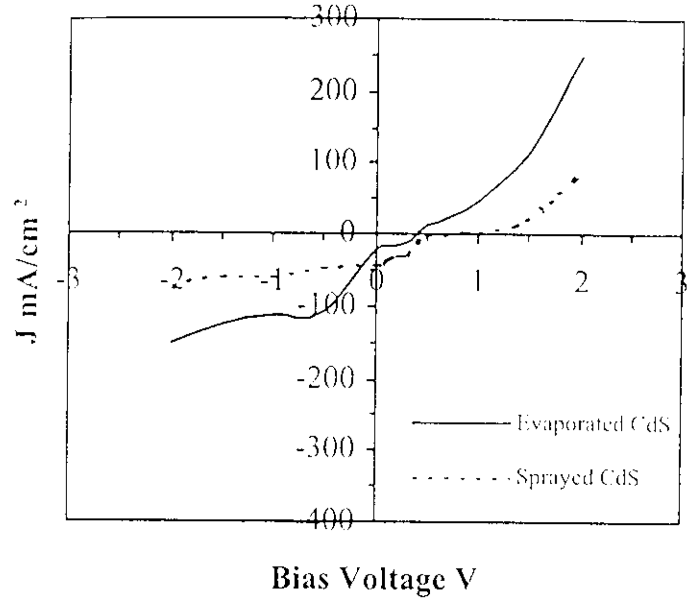


Figure 3. Photovoltaic Performance of the Evaporated and Sprayed CdS-Si heterojunction Solar Cells.

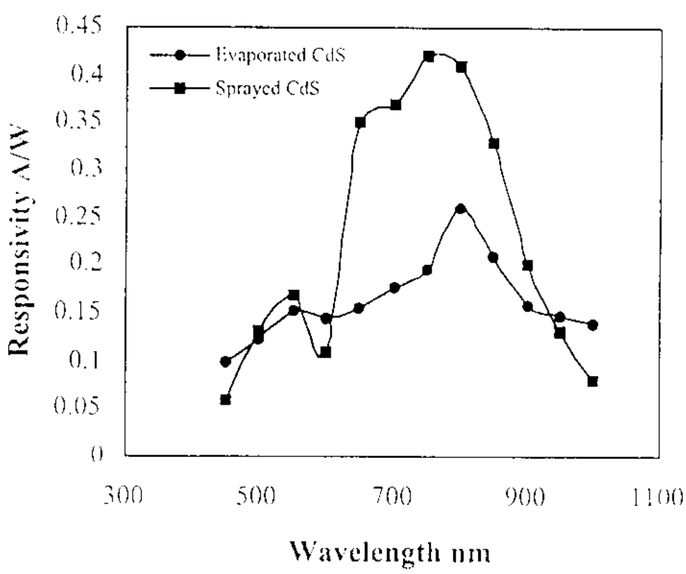


Figure 4. Responsivity against Wavelength of the Two Cells.

Table 1 demonstrates different photovoltaic parameters, it is patent that sprayed cell has a better upshots which emphasize the preeminence of sprayed CdS-Si junction characteristics. Another note can be caught from this table that is the fill factor, higher value of fill factor for the evaporated solar cell can be interpreted by the lower value of series resistance (see the sheet resistance in Table 2. This can refer to that evaporated cell may be improved to be better by post-annealing.

**Table 1. Main Photovoltaic Parameters of Sprayed and Evaporated CdS-Si Heterojunction Solar Cells.**

| Method of Preparation | $V_{OC}$ (mV) | $J_{SC}$ (mA/cm$^2$) | FF | η% |
|---|---|---|---|---|
| Spray | 465 | 40.5 | 0.32 | 6.45 |
| Evaporation | 380 | 18.5 | 0.42 | 3 |

## 3.5 Figure of Merit

Gathering high conductivity with high transparency had described by Haacke [15] by the following relation:

$$\Phi_{TC} = \frac{T^{10}}{R_S} \qquad (1)$$

where $\phi_{TC}$ is figure of merit, T is transmittance, and $R_S$ is sheet resistance. Figure of merit is a criterion that how much epitaxial window-layer transmits the light to the interface without adding substantial amount of series resistance to the total cell. Thus, figure of merit is a touchstone for the cell performance. Results of figure of merit are tabulated in Table 2. It is noticeably shown that evaporated cells have the paramount values of figure of merit, which mean that evaporated heterolayer has a better quality but poorer junction.

**Table 2. Figure of Merit Parameter at Different Transmitted Wavelengths**

| Method of Preparation | $R_S$ (Ω/□) | 550 nm | | 650 nm | | 750 nm | |
|---|---|---|---|---|---|---|---|
| | | T | $\phi_{TC}$ ($\Omega^{-1}$) | T | $\phi_{TC}$ ($\Omega^{-1}$) | T | $\phi_{TC}$ ($\Omega^{-1}$) |
| Spray | $87\times10^5$ | 0.66 | $0.02\times10^{-7}$ | 0.70 | $0.03\times10^{-7}$ | 0.67 | $0.02\times10^{-7}$ |
| Evaporation | $1.1\times10^5$ | 0.72 | $3.4\times10^{-7}$ | 0.75 | $5.1\times10^{-7}$ | 0.75 | $5.1\times10^{-7}$ |

## 4 Conclusions

A comparison between spray pyrolyzed and thermally evaporated CdS-Si heterojunction solar cells revealed that spray pyrolysis is more reliable for fabricating photovoltaic converter, while evaporation method is more credible for preparing high quality thin films but poor junction. Profound view can predict appreciable improvement in the junction characteristics after heat treatment. We think that spray method is commendable because it is efficient, inexpensive and has low technological complexity. Doping of deposited CdS and effect of annealing are under process.

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