Dependence of photovoltaic properties of CdS/Si Isotype Heterojunction Solar Cells on Deposition Temperature

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In this paper, we present the dependence of some photovoltaic characteristics (V_{OC}, I_{SC}, η_m, τ_c, FF and R_λ) on deposition temperature (300-500°C) for isotype n-CdS/n-Si heterojunction solar cell made by chemical spray pyrolysis (CSP) technique. Optimum photovoltaic results (V_{OC} = 465 mV, J_{SC} = 42 mA/cm^2, FF = 0.32, and η_m = 6.4%) at AM1 condition were obtained for T_S = 450° C without using any of post-deposition annealing and frontal grid contacts. Deterioration in parameters has been observed for T_S > 450°C. Spectral responsivity results were strongly depended on deposition temperature. Stability characteristics of theses cells have been investigated.

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Keywords: CdS/Si, Heterojunction, Solar Cell

1. Introduction

The photovoltaic heterojunction has been found to be candidate for high performance and inexpensive alternative to the homojunction photovoltaic device [1-3]. In the last three decades CdS/Si heterojunction has been proposed by many authors [4-7] as low–cost and high efficient photovoltaic devices. Many methods adopted to prepare CdS film e.g. vacuum evaporation, sputtering, spray pyrolysis, Chemical Bath Deposition(CBD), MBE, electrochemical deposition etc. [8-12]. It shown that the electrical, optical , and structural properties of grown CdS depends strongly on the preparation method. One of the promising method for producing of large areas of inexpensive CdS film for photovoltaic applications is spray pyrolysis and here we are followed this method to prepare CdS film. Chemical spray pyrolysis has advantages over other methods such as: simple, inexpensive, possibility of large area deposition does not need high vacuum apparatus, and stoichiometery preservation. Furthermore, the properties of grown film can be varied and controlled by proper optimization of spraying conditions The published results showed that the CdS film characteristics were strongly dependent on preparation conditions. One of these major importance preparation conditions is the deposition temperature (T_S). The reported results revealed that the characteristics of CdS film deposited by vacuum evaporation [13], sputtering [14], and spray pyrolysis [15] were influenced by deposition temperature. In the present work, the effect of T_S on photovoltaic parameters of CdS/Si heterojunction prepared by chemical spray pyrolysis was investigated. The electrical properties of these heterojunctions were studied previously by the authors [16-19].

2. Experiment

Cadmium sulfide thin film was deposited on clean n-type monocrystalline silicon substrate having (3 – 5) Ω.cm resistivity and (111) orientation with area of 25 mm^2 by chemical spray pyrolysis. The deposition process was achieved by spraying 0.4M of $CdCl_2$ aqueous solution. The spraying was carried out on heated substrates (300–500 ^{o}C). The substrate temperature was well monitored using K-type thermocouple, and the spraying rate was 25 cm^3/min .When the solution is sprayed the following reaction takes place

$$CdCl_2 + (NH_2)_2CS + 2H_2O \rightarrow CdS + 2NH_4Cl + CO_2$$

This yields a uniform growth of CdS film on the substrate. Each time 3cc of thiourea was sprayed on heated substrate so as to prevent excessive substrate cooling. The optical and electrical characterization of deposited CdS film is presented elsewhere [18]. The x-ray diffractometer using CuK_α source was used to study the structural properties of grown CdS films. The ohmic contacts were made on CdS and Si by deposition of In and Al films respectively using thermal evaporation technique .Fig (1) shows the schematic device structure of CdS/Si heterojunction solar cell.

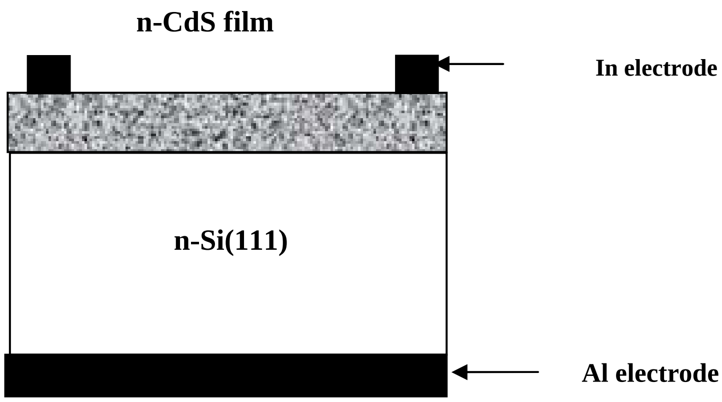

Fig.(1) cross-sectional view of CdS/Si solar cell

The conversion efficiency η_m was investigated under standard AM1.5, 100 mW/cm^2 illumination condition. The excess minority carrier lifetime τ_c was measured using open-circuit voltage decay (OCVD) technique. The experimental set-up of OCVD technique has been described elsewhere [16]. Spectral responsivity R_λ was determined with aid of monochromator in the spectral range of 400 to 1100 nm after power calibration with Sip power meter. The mentioned measurements were done for samples prepared at different deposition temperatures in the range of (300-500 °C) with a step of 50 °C and the samples denoted by S_{300}, S_{350}, S_{400}, S_{450}, S_{500} where the subscripts indicate to the deposition temperature.

3. Results and discussion

Fig.(2) shows XRD spectrum of CdS film grown on glass substrate at 450 °C, the film are found to be in the single phase and the identification of peaks indicates that the film is polycrystalline in nature. All the peaks agree with ASTM data for hexagonal CdS. The XRD spectra of CdS films grown at other temperatures revealed that these films were cubic and having some nonstoichiometric phases and lower diffracted peaks intensities.

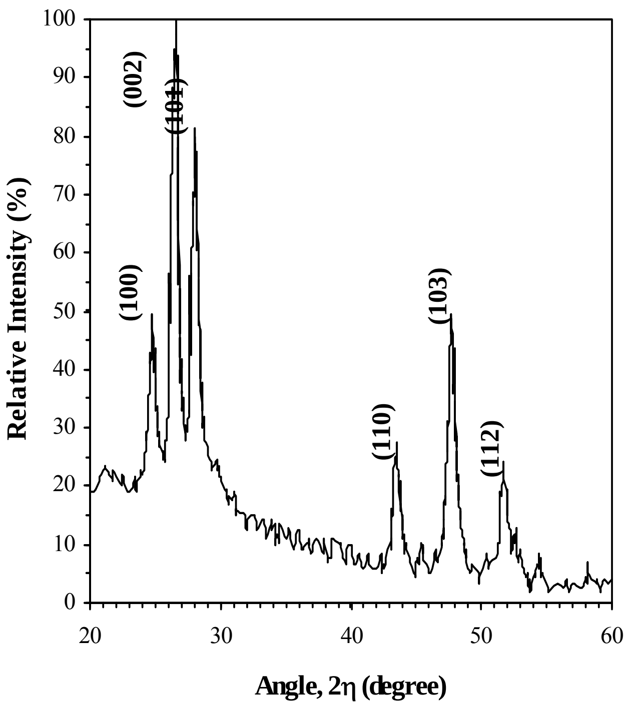

Fig.2. XRD spectrum of CdS film deposited at 450°C.

Variation of J_{SC} and V_{OC} as with deposition temperature (substrate temperature) are shown in Figs.(3) & (4), it is obvious from these plots that these parameters are highly depended on Ts. Increase in J_{SC} with Ts (up to 450 ^oC) can be related to the improvement in crystalline quality of CdS thin film [19].Increasing deposition temperature means that the cubic to hexagonal phase ratio increases and hence the lattice mismatch between CdS and Si will reduce [18]. However, no significant variation in V_{OC} with T_S (up to 450 ^oC) has observed. Further increase in T_S (500 °C) deteriorates the V_{OC} and J_{SC} values. This deterioration can be attributed to the effect of CdS interdiffusion into silicon and due to high resistivity of CdS film (due to decreasing of mobility [19]). Furthermore, the silicon oxide layer formation in the interface region may degrade the photovoltaic properties.

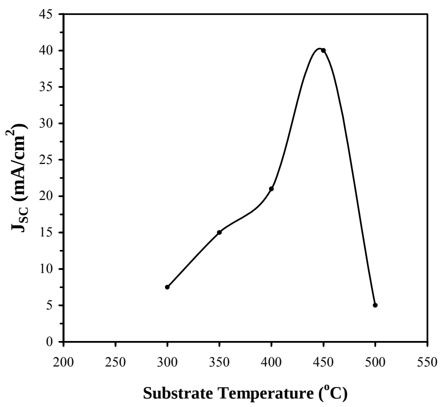

Fig. 3. Variation of Jsc with Ts at AM1.5 Condition.

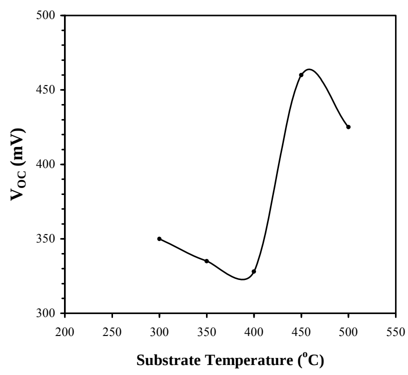

Fig.4. Variation of V_{OC} with Ts at AM1.5 Illumination Condition.

Fig. (5) demonstrates the illuminated J-V curves plotted in the fourth quadrant to represent the power extracted from the devices. This plot describes the photovoltaic performance of the heterojunction and from this figure; FF and η_m were deduced and listed in Table (I). It is apparent that the photovoltaic performance can be enhanced with increasing T_S up to 450 ^oC. The low value of FF at high $T_S \rangle 300$ °C is may be attributed to the high value of series resistence which appears as a result of decreasing the thickness of grown CdS film [21] and actually it needs deep study. No significant degradation in solar cells photovoltaic characteristics have been noticed after one year of real operation in the field.

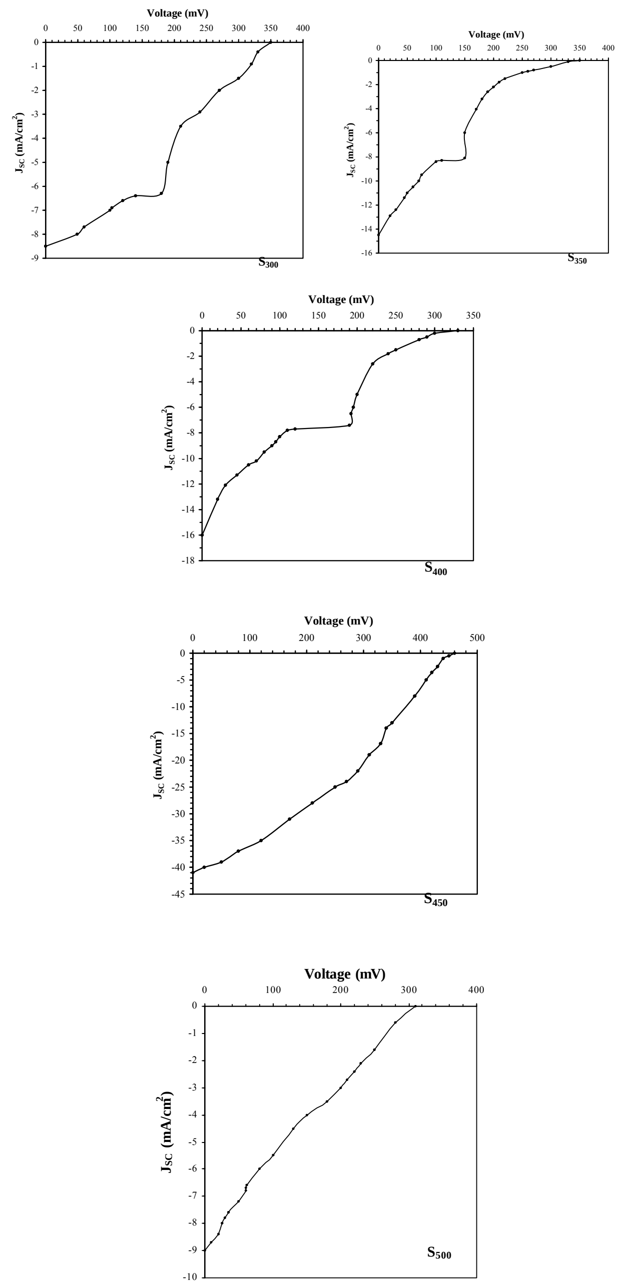

Fig.5. Photovoltaic Performance of CdS/Si Solar Cell deposited at different deposition temperatures under AM1.5

The results of OCVD measurement are shown in Fig. 6. It is noticed that τ_c increases with T_S (up to 450 °C) and then decreases at T_S (500 °C). This behavior is consistent with that of photovoltaic performance. The low values of minority carrier life time of solar cells prepared at other values of T_S can be ascribed to the recombination defects established at the interface of heterojunction as well as the structural defects of CdS film.

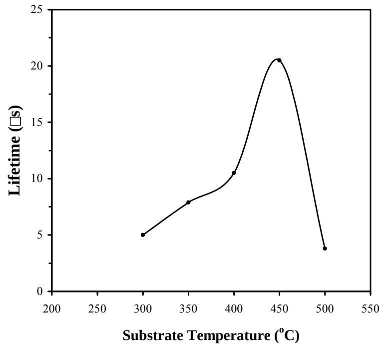

Fig.(6). Lifetime as Function of Ts.

The effect of T_S on R_λ is presented in Fig. 7. There are two distinct regions, the first one located at 550 nm (absorption edge of CdS E_g =2.4 eV), while the second one at 800 nm. At T_S = 450° C, appearance of another peak at λ = 1050 nm, this result can be useful for Nd:YAG laser detection. It is found that these results are reproduced when fabrication process is repeated .

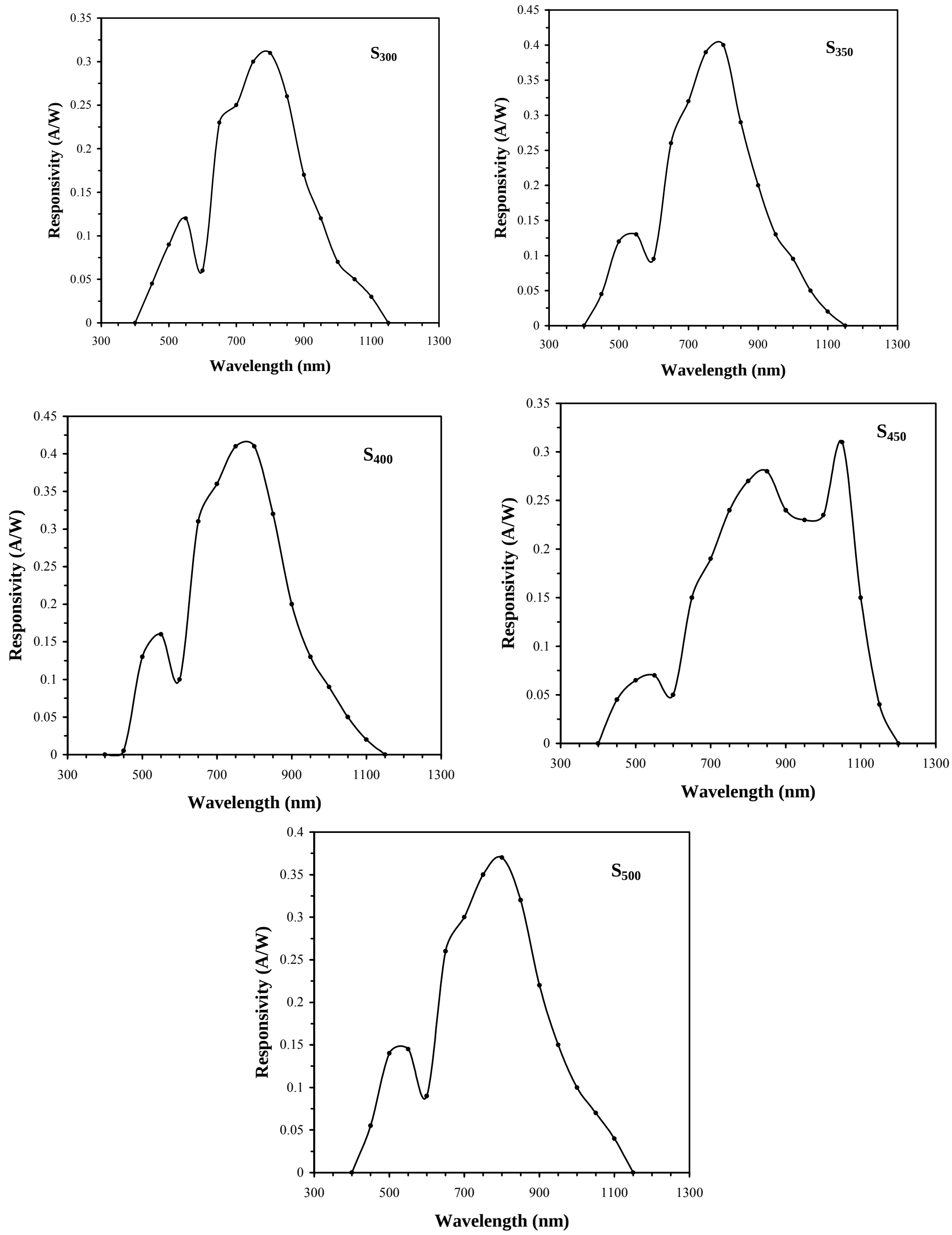

Fig.7. Spectral Responsivity for samples prepared at different Ts.

Table 1. Photovoltaic Parameters of the n-CdS/n-Si Cells Fabricated by CSP Technique under AM1.5 Illumination

T_S	Cell	Jsc (mA/cm^2)	Voc (mV)	FF	η_m(%)
300	S_{300}	8.4	345	0.38	1.18
350	S_{350}	15.0	335	0.23	1.25
400	S_{400}	21.0	430	0.22	1.6
450	S_{450}	42	465	0.32	6.45
500	S_{500}	9.0	430	0.17	0.72

4. Conclusions

High dependence of photovoltaic parameters of undoped CdS/Si heterojunction solar cells made by CSP without antireflection coating on deposition temperature has been studied and analyzed for the first time. The results of efficiency and stability of cells deposited at T_S = 450° C indicated that this temperature is candidate to be optimum for fabricating low-cost, reliable, and applicable heterojunction solar cells. The values of minority carrier lifetime found to be comparable with those of CdS/Si devices prepared by thermal evaporation technique. The profile of R_λ of these solar cells shows an enhancement towards short wavelengths (window effect) and high responsivity at wavelength of 1050 nm was noticed for samples prepared at 450 °C. Increasing the efficiency of cells using ITO electrodes and by doping CdS film is underway.

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