INFLUENCE OF SUBSTRATE TEMPERATURE ON PHOTOVOLTAIC PARAMETERS OF CdS/CdTe/Te SOLAR CELLS FABRICATED BY CLOSE SPACE SUBLIMATION

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Abstract**–***Thin Film CdS/CdTe solar cells were fabricated by Close Space Sublimation at the substrate temperature ranging from 300 ºC± 5ºC to 340 ± 5ºC ºC. The best photovoltaic parameters were achieved at substrate temperature 320^{o}C and source temperature 610^{o}C. The open circuit voltage and current density changes significantly with the substrate temperature and depends on the substrate temperature. The open circuit voltage and current density* achieves 0, 81 V and 22, 75 mA/cm^2, respectively. *CdS/CdTe solar cells with an efficiency of 9, 56 % were obtained.*

1. INTRODUCTION

The photovoltaic conversion of the solar energy, which is a direct conversion of radiation energy into electricity, is one of the principal ways to resolve the exhausting our existing natural resources of oil, gas, coil, nuclear fuel and environmental problems. The CdS/CdTe thin film solar cells is a leading candidate for low cost high-performance applications because as is well known the nature of the band-to band transitions has an important bearing on the cell thickness. The latter should be of the order of the absorption length 1/α, which is much smaller (2 μm or 5 μm for CdTe) for direct non phonon transitions than for the case of indirect phonon-assisted transitions (50 to 100 μm for Si). The large number of techniques for fabrication of CdS/CdTe solar cells have been elaborated for obtaining conversion efficiency up to 16,5 % [1]. Close space sublimation (CSS) growth technique usually gives good electronic properties and high growth rates, and may be amenable to continuous production. The CdTe CSS films deposited above 550^{o}C substrates temperatures has been investigated by researchers from Antec [2], Kodak [3], Matsushita [4], USF [5] and NREL [1].

In this paper has been applied CSS technique to growth CdTe layers onto substrates at temperatures less 400^{o}C. The effect of the substrates temperatures on the photoelectrical properties of the CdS/CdTe solar cells is discussed here.

2. SAMPLE PREPARATION

The performance of the devices depends critically on the quality of the semiconducting absorber layer. Therefore the first strategy for fabrication high-performance solar cells was the elaboration of the technological regime (substrate temperature, evaporation speed, thickness of layers, cleanliness of the substrate, impurities from precipitates and initial material etc...) for high quality thin CdTe layers. The CdTe source was formed by the direct reaction of Cd (99.999%) and Te (99.996%), taken in stoichiometric proportions. In order to determine the optimal technological conditions a set of CdTe layers deposited on SnO_2/CdS at differences substrate temperatures were obtained. The structure of CdTe layers deposited at temperatures ranging from 300 ºC± 5ºC to 340 ± 5ºC ºC with a metallographic MMR-2P microscope was studied. The microstructure CdTe films are determined by the substrate temperature and source-substrate temperature gradient. The evaporator temperature and the time of the CdTe-layer deposition were kept constant at (610 ± 5)ºC and four minutes, respectively. The source temperature 610^{o}C was chosen from point of view of granule sizes and a reasonable degree of contamination with impurities from the source. When the substrate temperature increases up to 310^{o}C± 5ºC, the grain sizes increases. With a further increase of the substrate temperature (320^{o}C-340^{o}C) the density of the growth crystallites increases, and it becomes difficult to evaluate. At substrate temperatures near 330 ºC± 5ºC the crystallite size are approximately 3 μm (Table 1). The decrease of the grain sizes with the increasing of the substrate temperature is explained by the decreasing of the degree of satiation and by the increasing of the migration velocity of Cd and Te atoms on the surface. The atoms can't become active germs of crystallization for forming the necessary compound. In this case, the speed of the layer's growth is small and micro-granular structured layers were formed. With decrease of substrate temperature alike with increases of the degree of satiation the diffusion surface velocity of the atoms decreases leading thus to the increasing in the number of the active crystallization centers.

These deposition conditions were used in the standard glass-SnO_2/CdS/CdTe cells. Before depositions of CdTe, the SnO_2-covered substrates with resistivity ~16 Ω/□, thickness of 0.36 μm and transparency 90% were degreased in a 6-g solution of $K_2Cr_2O_7$ + 10-ml H_2O + 100-ml H_2SO_4 at room temperature, then rinsed in double-distilled water, and dried. Then the CdS was deposited by CSS. For the CdS source, CdS powder with a purity of 99.995% was used. CdS was 0.29 μm thick and had the resistivity 2-3 Ω·cm and transparency above 90 %. A set of cells were fabricated with CdTe layers fabricated at substrate temperatures at a fixed source temperature mentioned above in order to find the regime that would lead to the best solar cell performance. After the CdTe layers were deposited, the structures were held in $CdCl_2$:H_2O saturated solutions for 3-4 hours. After structures were annealed in the air at 380±5^{o}C for 30 min and etched in $K_2Cr_2O_7$:H_2SO_4:H_2O. To minimize the back contact barrier [6], an additional layer of Te was deposited by thermal evaporation. Ni was used, and to increase the adherence of the ohmic contact to the CdTe, a post thermal treatment with temperatures of 200 ºC for 30-40 min was made.

3. PHOTOVOLTAIC PARAMETERS OF CdS/CdTe SOLAR CELLS

In order to see if there is any effect due to the variation of substrate temperature of CdTe layer on photovoltaic parameters we have investigated current-voltage characteristic for solar cells where the substrate temperature was changed as mentioned above. The photoelectrical properties of CdS/CdTe/Te solar cells were investigated at the room temperature under illumination 100 mW/cm^2 through the wide gap component CdS. The influence of CdTe layer structure on photoelectrical characteristics of CdS/CdTe/Te solar cells at different substrates temperature are illustrated in figure 1. The best photovoltaic parameters were achieved at substrate temperature 320^{o}C and source temperature 610^{o}C. As one can see from the Table 1 the value of the open circuit voltage (U_{oc}) and current density (J_{sc}) achieves 0,81 V and 22,75 mA/cm^2, respectively.

CdS/CdTe/Te solar cells with efficiency (η) of 9.56 % were obtained. Fill factor (*FF*) is low in general. According to the theory the fill factor is determined by the series resistance, saturated dark current density (J_o) and diode quality factor (A).

Table 1. Photovoltaic parameters of CdS/CdTe/Te solar cells

T_s (^oC)	J_{sc} (mA/cm^2)	U_{oc} (V)	FF (%)	Efficiency (%)
300	12.27	0.7595	33.27	3.1
310	1.18	0.1924	25.77	0.06
320	22,75	0,81	51,87	9.56
330	20.82	0.6025	35.91	4.5
340	20.98	0.6572	36.43	5.02

The J_o and A of the CdS/CdTe/Te cells are in the range of 10^{-9} – 10^{-7} A/cm^2 and 2.4-3.6 respectively. As one can see from table the low value of *FF* is mainly determined by high value of series resistance (Table 2) which is due probably with the fact that the cells used wet $CdCl_2$ treatment may contain oxide on the surface of CdTe.

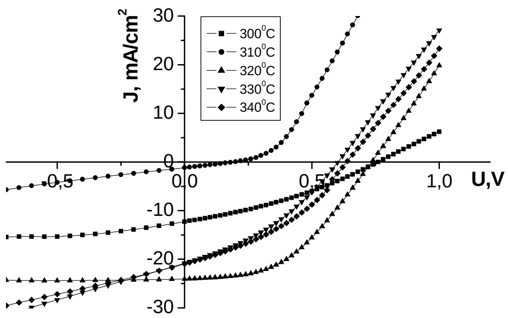

Fig. 1. Current-voltage characteristics of the CdS/CdTe/Te solar cells for different substrate temperatures.

Table 2. R_s and R_{sh} of CdS/CdTe/Te solar cells

R_{sh} (Ohm cm^2)	R_s (Ohm cm^2)
758.2	13.68
1480.6	10.96
2917.4	10.68
640.5	10.66
860.9	11.23

External quantum efficiency (EQE) data for front illumination of cells with different substrate temperatures are shown in figure 3. The thickness of the deposited CdS in all cases was 0, 29 µm. The analysis of the Q (λ) curves showed that the substrate temperature of the CdTe layer has not a strong influence on the form of quantum efficiency spectra, but has the most influence on the carrier generation and collection. The quantum efficiency (QE) for all solar cells is reasonably good for wavelengths between 520 nm and 845 nm. The high collection in the visible region of the spectra has the device obtained at substrate temperature 320^{o}C. The primary loss is the reflection of the cell.

The non-encapsulated CdS/CdTe/Te solar cells were light soaked under one-sun simulated illumination at 85^{o}C. The device was kept under constant and continuous irradiation in air. The results for this "light soaking" test for the best cell are shown in figure 4. After soaking 30 min the load I-U characteristics is improved due to the fact that the series resistance of the device decreases. A little decrease in open circuit voltage and current density is observed. But after soaking after two hours the modest rapid initial degradation of the open circuit voltage is stabilized.

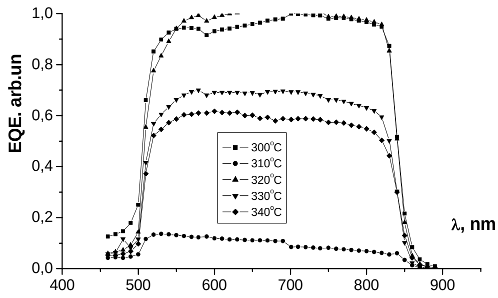

Fig. 2. External Quantum Efficiency of the CdS/CdTe/Te solar cells with different substrate temperatures as indicated in Table 1.

By choosing the right buffer-metal combination stable CdS/CdTe/Te solar cells were obtained. Cells with a thin layer of Te at the back contact show excellent stability and stress test suggest that these cells will not degrade when properly encapsulated.

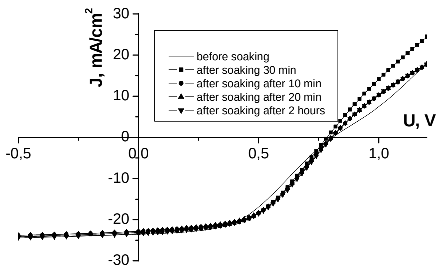

Fig. 3. Light J-V characteristics of the CdS/CdTe/Te solar cells before and after light soaked under one-sun simulated illumination at 85°C.

4. CONCLUSIONS

Processing options relating to processing of thin-film CdTe/CdS/Te solar cells have been discussed. For the best cells at 300 K and 100 mW/cm^2 the following photovoltaic parameters were obtained: U_{oc} = 0.81 V, J_{sc} = 22.75 mA/cm^2, η = 9.56 %. It must be noted that these results are obtained for unoptimised structures without antireflection coatings and can be improved by reducing both current and voltage losses and by the appropriate choice of component cell thickness.

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