PHOTOVOLTAIC MINIMODULE BASED ON CdTe

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Abstract

CdS/CdTe solar cells were fabricated without antireflection coatings by successive growth without intermediate processing from the close space sublimation of CdS and CdTe thin layers on conductive and transparent SnO_2/glass substrates. At 300 K and 100 mW/cm^2 the following best photoelectric parameters were obtained: Isc= (18-19)mA/cm2 and Voc=(0,80-0,82)V. The conversion efficiency is around 10%. The quantum efficiency (QE) in the 510 nm and 845 nm range of wavelengths is on the order of 80-85%. The minimodule fabricated on the basis of the CdTe cells shows power of 0.45 W, corresponding to a voltage of 3 V, and current of 150 mA.

1. Introduction

CdTe is an excellent choice for use as a semiconductor in solar energy. It is perfectly matched to the solar spectrum. CdTe-based PV solar cell devices have achieved (laboratory) conversion efficiencies of 16.4% [1,2] while commercial CdTe PV modules typically demonstrate efficiencies between 7-9% [3-5]. The theoretical efficiency for a CdTe PV device is >27%, higher than for Si or $CuInSe_2$ [1]. Although concerns exist regarding the potential use of Cd in large-scale PV deployment, it has been reported that the amount of Cd used in present production modules is about the same amount as in a Size-C NiCd battery (~10 g for a Size-C battery, ~7 g for a 50 W PV module) and it is expected that future CdTe thin-film modules will use even less Cd. Although Cd use remains an issue, it is noteworthy that recent closures of some CdTe PV production facilities in the U.S. and Germany were not due to problems of toxicity, but rather due to problems of cell stability. Many of these CdTe PV device stability concerns may relate to use of Cu-containing back contacts [1-5]. In contrast to Cu-containing contacts, some research groups are exploring alternative contact processes involving Te-rich surfaces using either Br-methanol or HNO_3-H_3PO_4 etch treatments. Although these studies are encouraging, some of these studies have suggested that the chemically formed Te interface layers contain oxides, and these oxides may be related to cell instability. As an alternative to using chemically formed Te contact interface layers, the MSU group has pioneered the use of a pure Te layer by thermal evaporation [6]. This Te layer may be the reason for the stability and reproducibility of the CdTe devices.

2. Fabrication of the CdTe solar cells and minimodule

The Moldova State University uses for the fabrication of thin film CdTe solar cells Close-Space-Sublimation (CSS) method. Thin film CdTe solar cells fabricated on glass plates with an area of 2x2 cm^2 covered with a SnO_2 layer with a conductivity of $10^3\Omega^{-1}cm^{-1}$ were used as substrates. SnO_2 served as the transparent front contact to CdS. Both CdS and CdTe layers were grown sequentially without intermediate processing. CdS was usually 0,46 μm thick and had the resistivity 2-3 Ω·cm and transparency above 90%. After the CdTe layer was deposited, the structures were held in either $CdCl_2$:H_2O saturated solutions and then annealed in the air at 400^0C ±5^0C for 25-30 min. To minimize the contact barrier, improve stability and fill factor of cell, an additional layer of Te was used. All devices were completed with a Ni contact, which was deposited by the thermal evaporation process in vacuum.

Within the framework of our CdTe research program, a multi-cell solar battery for small-power electric devices was developed. Minimodule, pictured in Fig.1, consists of 24 individual CdTe cells and shows a power of 0,3 W, corresponding to a voltage of 3 V, and current of 150 mA. This voltage and current are achieved by connecting a group of six solar cells in series, and then four such groups in parallel.

3. Photoelectrical characteristics of solar cells

A photovoltaic module performs better when assembled of solar cells with similar parameters. Therefore the current-voltage characteristics at room temperature at illumination with 100 mW/cm^2 were investigated (fig.2). Analysis of *J(U)* measurements as a function of temperature and intensity allowed more detailed understanding of the cells. The basic diode relation is

$$J = J_0 \exp[(\frac{qV}{AkT}) - 1] - J_L \quad , \tag{1}$$

where

$$J_0 = J_{00} \exp(\frac{\phi}{AkT}); \tag{2}$$

J_L is the light generated current ($J_L \sim J_{sc}$), where J_{sc} is the short circuit current); J_{00} is the recombination current density, A is the diode factor and $\frac{\phi}{A}$ is the barrier height or activation energy for the recombination mechanism. For Schockley-Read-Hall (SRH) recombination, $\phi = E_g$ which is the bandgap of the absorber region where the recombination is occurring, and A~2. The external voltage U is related to the actual voltage across the internal junction U_j by correcting for the series resistance losses as:

$$U = U_j + (J * R_S), \tag{3}$$

where R_s is the lumped series resistance. From equations (1) and (2), the open circuit voltage U_{oc} is when J=0 or

$$U_{oc} = \frac{AkT}{q}[\ln\frac{J_L}{J_D}] = \frac{\phi}{q} - \frac{AkT}{q}\ln\frac{J_{00}}{J_L} \quad , \tag{4}$$

which shows that ϕ can be determined from the intercept of U_{oc} *(T)* at *T=0*.

From equation 1 and 3, the derivative $\frac{dU}{dJ}$ is

$$\frac{dU}{dJ} = R_s + \frac{AkT}{q(J + J_L)} \tag{5}$$

Table 1 shows the diode factor A, series resistance R_s and recombination current J_0 for the three of the best cells.

Table 1. Diode parameters from analysis of the dark J(V) characteristics and calculated and measured U_{oc}.

Solar cell	R_s, Ω cm^2	A	J_0, mA/cm^2	U_{oc}, V (theor)	U_{oc}, V (measur)
71	3,6	2,2	5 E-6	0,78	0,81
168	5,5	2,0	1 E-6	0.80	0,78
175	5,6	1,8	2 E-6	0.82	0,80

All the parameters were obtained from analysis of the dark *J(V)* curves. U_{oc} was calculated from these parameters and is compared to the measured value in the table. Calculated U_{oc} obtained from $\frac{AkT}{q}\ln\frac{J_{sc}}{J_0}$ using dark diode parameters. Fig.3. shows U_{oc} vs. T for the cells at 100 mW/cm2 The intercepts are $\frac{\phi}{q} = 1{,}4\ \mathrm{V}$. This confirms that the CdTe cell has SRH recombination since the intercept $\phi = E_g$ CdTe. The investigation of photovoltaic properties at different temperatures can be used for the determination of the work solar cell temperature range. Uoc and Jsc temperature for thin film CdS-CdTe HJ is given in fig.2. As one can see U_{oc} linearly decreases with temperature increase up 320 K. The cell's open-circuit voltage increased at reduced temperatures at the expected rate of approximately –2 mV/°C.

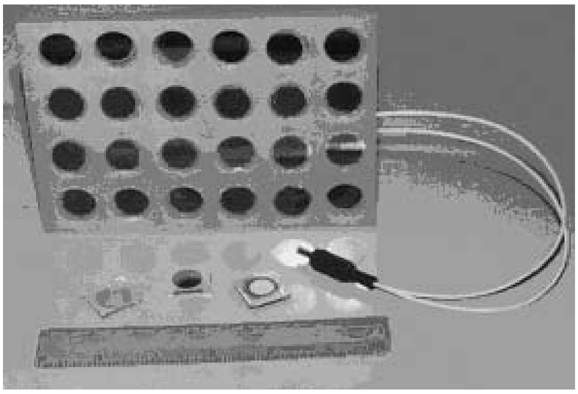

Fig.1. CdS/CdTe Minimodule

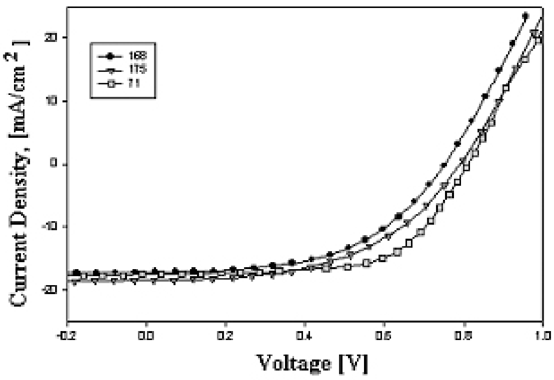

Fig.2. *J-V* characteristics of the CdS/CdTe solar cells at illumination 100 mW/cm^2 and 300 K.

The current density changes insignificantly (fig.3) which in the investigation temperature region is in good agreement with theoretical calculations for solar cell temperature characteristics.

The short-circuit current density increases proportionally to the light intensity (fig.4) and the open circuit voltage V_{oc} tends to saturation (fig.5). By taking into consideration that $J(U{=}0){=}J_{sc}{=}\ J_L$ and for the linear recombination case, the photocurrent proportional dependence on illumination, i.e. $J_L{=}BE$, where $B{=}const$, E illumination one can get

$$U_{oc} = \frac{AkT}{e}\ln\frac{BE}{J_0} \qquad (6)$$

From the U_{oc} = *(ln E)* slope the value AkT/e has been determined. From this dependence coefficient A ~2 agrees well with that obtained from the dark current-voltage characteristics. This indicates the CdTe devices are limited by Schockley-Read-Hall (SHR) type recombination.

The short-circuit current density J_{sc} and the open-circuit voltage U_{oc} statistics of 30 cells are investigated. Nearly 75% of solar cells reached open-circuit-voltage values between 0.78 and 0.80 V, 15% above 0.81 V-0.82 V. The value of short-circuit current among 25 cells was 18.6-19.8 mA/cm^2.

The quantum efficiency (QE) for all cells is reasonably good (on the order of 80-85%) for wavelengths between the band gap of the CdS window layer (510 nm) and that of the CdTe (845 nm).

The QE for the three of the best cells is illustrated in fig. 6. The QE cut-off in the blue region corresponds to the energy E_g =2,4 eV, the band gap of CdS. The infrared QE cut-off corresponds to the energy ~ 1,48 eV, band gap of the CdTe cells. The primary loss over this range is the reflection of the cell.

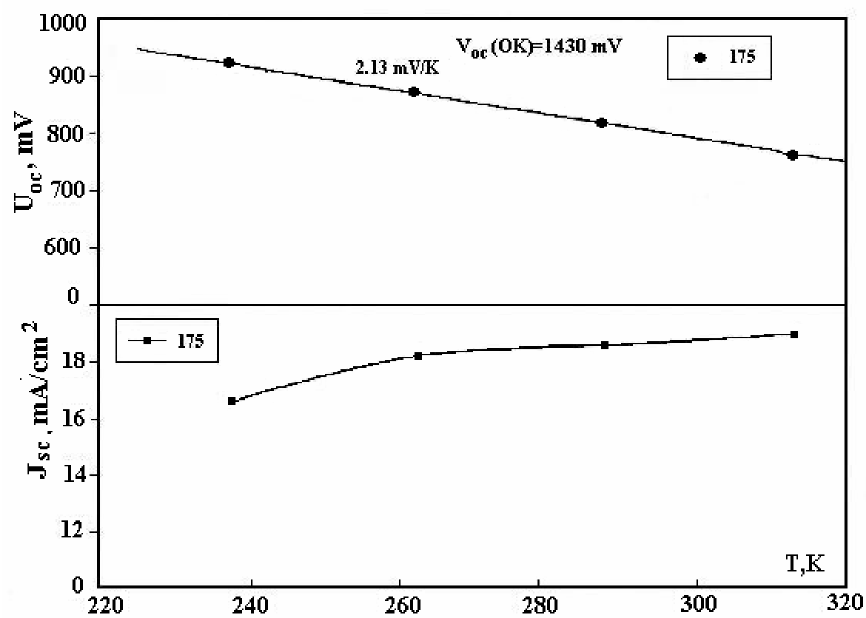

Fig.3. J_{sc} and U_{oc} parameters of CdS/CdTe solar cells as a function of temperature.

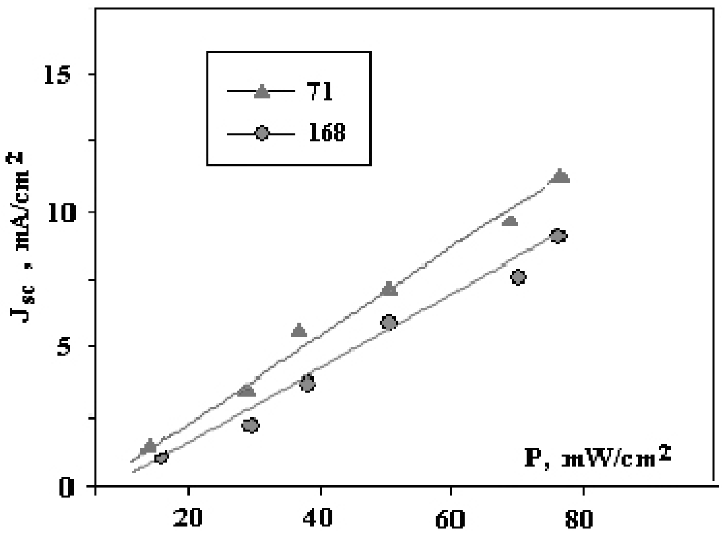

Fig.4. Dependence of J_{sc}=f (P) for the CdS/CdTe solar cells.

The highest-efficiency cell in this group has the most gradual transition between 500 and 600 nm, which is characteristic of intermixing between the CdTe and CdS layers.

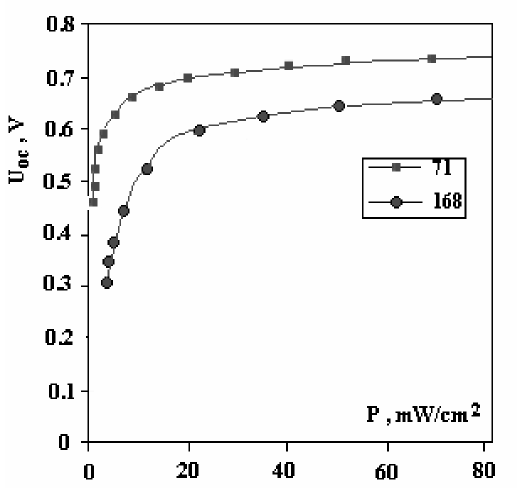

Fig.5. Dependence of $U_{oc} = f\ (P)$ for the CdS/CdTe solar cells.

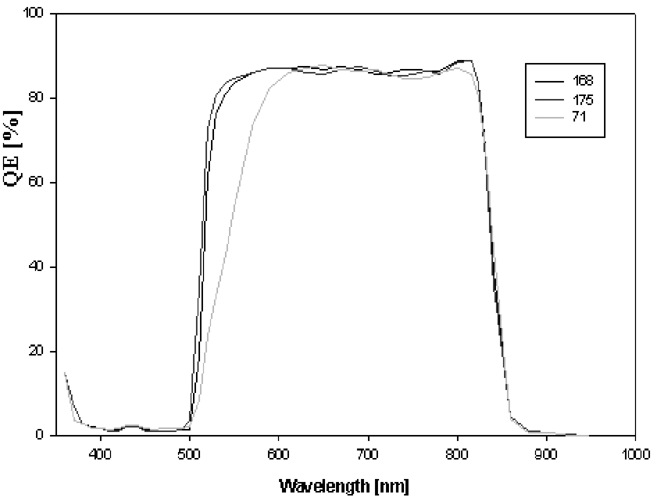

Fig.6. Quantum-efficiency for the three best CdS/CdTe solar cells.

Conclusions

CdS/CdTe solar cells made by using the $CdCl_2$ treatment had the efficiency of about 10 %. The short-circuit current density J_{sc} and the open-circuit voltage U_{oc} achieved values of (18.0 - 19.0) mA/cm^2 and (0.80 - 0.82) V for the best cells. In the condition of the laboratory multi-cell solar batteries for small-power electric devices can be fabricated.

References

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