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SCIENCE DIRECT
Solar Energy Materials & Solar Cells
ELSEVIER
Solar Energy Materials & Solar Cells 82 (2004) 307–314
www.elsevier.com/locate/solmat

CdTe/CdS Solar cells on flexible molybdenum substrates☆

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Abstract

Development of CdTe/CdS solar cells on flexible metallic substrates is highly interesting due to the light weight and flexible nature of the solar modules. We have deposited CdTe films onto flexible molybdenum substrates using close-spaced sublimation technique and the CdTe/CdS junction was developed by depositing a thin layer of CdS onto the CdTe substrate from a chemical bath. The devices were characterized by Current–voltage (*I–V*) and photocurrent spectroscopy techniques. Prior to the deposition of the transparent conducting layer, the devices were annealed in air at different temperatures and found that the devices annealed at 400°C have better photovoltaic parameters. The efficiency of a typical device under $60\,\mathrm{mW\,cm^{-2}}$ illumination was estimated as 3.5%.

Keywords: CdTe/CdS solar cell; Flexible substrates; CdTe; CSS

☆This work is part of the Ph.D.Thesis of J.P.Enriquez at CIE-UNAM.
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0927-0248/$ - see front matter
doi:10.1016/j.solmat.2004.02.017

1. Introduction

CdTe is one of the leading thin film photovoltaic materials due to its optimum band gap of 1.5 eV for the efficient photo conversion, high optical absorption coefficient and variety of fabrication methods. Among the various methods, close-spaced sublimation (CSS) is the popular technique due to the large grain size of the crystallites, rapid film growth technology and economical experimental set up. The present status of the thin film CdTe/CdS solar cell is more than 16.5% efficiency for devices on conducting glass substrates [1], 7.8% efficiency for devices on flexible metallic substrates [2] and 8.6% efficiency for devices on flexible polymer substrates [3].

The conventional, thin film solar cells are manufactured on glass substrates having the disadvantage of weight and fragile nature of the modules. In order to obtain larger grains as well as to improve the electronic parameters of the devices, the post-deposition annealing of the films and the devices are a routine procedure in the device fabrication process. Normally these annealing steps take the films to the melting temperature of ordinary soda lime glass, causing rupture of the glass substrate. On the other hand, solar cells on flexible metallic substrates are light weight, free of damage and are suitable for space as well as terrestrial applications. High efficiency can be achieved using photovoltaic materials having high optical absorption coefficient. For example, in CdTe, light is absorbed within 2 μm and crystalline defects are relatively less important than in single crystal cells [4]. Since an all thin film CdTe/CdS device can be as thin as 5 μm and the flexible substrate is 0.01–0.05 mm thick, weight saving is significant. It is known that among the various photovoltaic materials, CdTe has the highest stability under proton and electron irradiation, which make it suitable for space applications [5,6]. For terrestrial applications, cells mounted on flexible foil have a special advantage since they can be wrapped onto any suitably oriented structure and the cost of support can be minimized. In this article we are reporting the development of a CdTe/CdS device on flexible molybdenum (Mo) substrate and the post deposition annealing to improve the photovoltaic parameters.

2. Experimental

The CdTe thin films were developed on flexible Mo substrates; Mo is considered as the suitable substrate material from the point of view of the matching thermal expansion coefficient with CdTe. The CSS system consists of a graphite reactor enclosed in a quartz tube. The tube was evacuated and flushed with nitrogen gas and later pure nitrogen was admitted to a pressure of 10 mbar followed by 2 mbar oxygen, and the final pressure of the CSS chamber was 12 mbar. The graphite plates were heated independently using two tungsten halogen lamps of 2 kW each, and thermocouples were inserted into the graphite plates to monitor and control the temperature. The source of CdTe was a thick film of stiochiometric CdTe evaporated on a quartz glass. The films were prepared at a substrate temperature of 570°C and a source temperature of 670°C. The films were treated with a saturated solution of $CdCl_2$ and annealed at 400°C in dry air. After the annealing, the CdTe films were rinsed with 0.2 vol% Br–methanol solution for 2 s to clean the CdTe surface, followed by a thorough rinsing in de-ionized water in an ultrasonic bath.

CdTe/CdS junctions were prepared by depositing approximately 0.1 μm thick CdS layer onto the CdTe substrates from a chemical bath containing 0.033 M cadmium acetate, 1 M-ammonium acetate, 28–30% ammonium hydroxide and 0.067 M thiourea. The bath was maintained at a constant temperature of 90°C and continuously stirred during the deposition to ensure homogeneous distribution of the chemicals [7]. The CdTe/CdS device was washed with de-ionized water and dried in air and later annealed at different temperatures in air. The top contacting material is made by sputter depositing ITO on the annealed CdTe/CdS surface followed by soldering of an indium (In) grid. The current–voltage characteristics in dark and under light were measured by a computer-controlled source/measure unit (Keithley 236) and an oriel solar simulator. The photocurrent spectrum in the 350–900 nm range was obtained using a Spex monochromator (1681 Minimate-2) with a 100 W tungsten halogen lamp. The spectral response system was calibrated using a standard Si cell calibrated in NREL, Colorado.

3. Results and discussion

3.1. CdTe and CdS films

The difference in work functions of p-CdTe and Mo necessitates the need for an interlayer between CdTe and Mo substrate that can form a non-rectifying contact between CdTe and Mo. The materials used to obtain ohmic contact in superstrate CdTe devices are graphite paste, Te/Au, Sb/Au, Ni, PbTe, SnTe, HgTe and ZnTe [4,8–12]. In our devices we have used a thin layer of Au/Pd alloy as the interlayer. The schematic of a CdTe/CdS device in the substrate configuration is shown in Fig. 1. The thickness of the Au/Pd interlayer was approximately 0.05 μm, deposited by sputtering. CdTe films of approximately 8 μm thickness were deposited onto the interlayer by the CSS technique.

The XRD spectrum of the as-deposited CdTe film is shown in Fig. 2. It can be seen that the film is crystalline, but do not have any preferred orientation for the

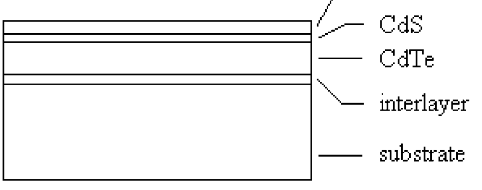

Fig. 1. Schematic of the CdTe/CdS device in the substrate configuration.

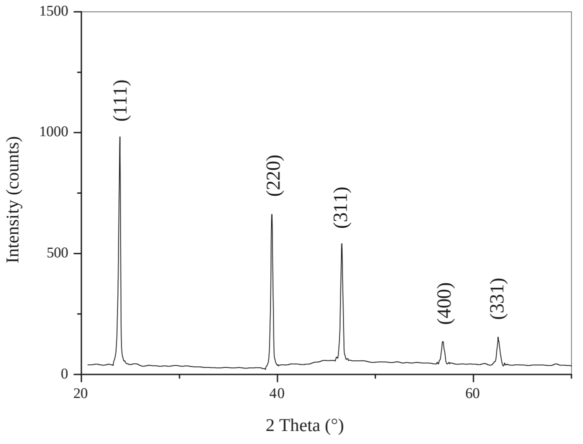

Fig. 2. XRD spectrum of the as-deposited CdTe film on Mo substrate.

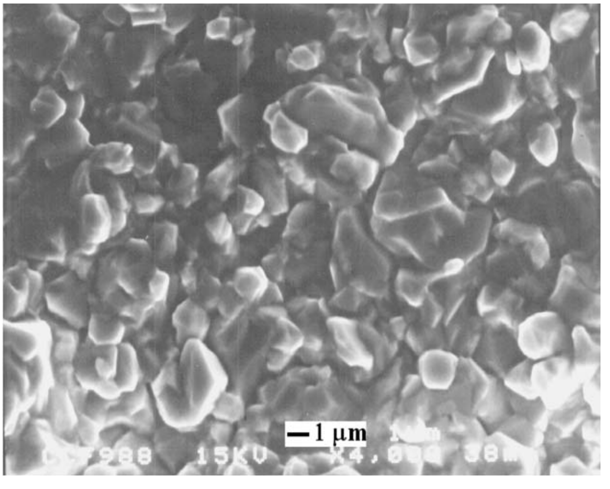

Fig. 3. SEM picture of the as-deposited CdTe thin film.

crystallites. The SEM picture (Fig. 3) shows that the film surface contains voids and the grain size is in range 1–2 μm. The AUGER depth profile analysis revealed that the composition is uniform throughout the thickness of the film and the percentage composition of the film is 50.5% Te and 49.5% Cd. The transmittance of the thin film heterojunction partner CdS was determined using an identical thin film of CdS deposited on a glass slide simultaneously with the CdTe substrate from the same chemical bath. The transmittance was estimated as 75% at 830 nm and 60% at 510 nm.

3.2. CdTe/CdS device

The CdTe/CdS junction was developed as explained above and annealed at different temperatures to study the effect of annealing temperature on the device parameters. The *I–V* characteristics under illumination of a typical device annealed at 400°C is shown in Fig. 4. The device was illuminated in an Oriel solar simulator operating at $60\,mW\,cm^{-2}$. The device parameters were estimated as $V_{oc} = 0.5\,V$, $J_{sc} = 10.6\,mA\,cm^{-2}$, $FF = 0.40$ and $\eta = 3.5\%$. Considering the fact that the device was not optimized for the ohmic contact and the heterojunction formation, this result is encouraging. We assume that during annealing there can be a decrease in the thickness of the CdS layer due to sublimation of the CdS from the surface. Annealing of the CdTe/CdS device and subsequent deposition of CdS layers to investigate the effect of different CdS layers on the photovoltaic parameters of the solar cell is under progress.

The Figs. 5 and 6 demonstrate the variation of the open circuit voltage V_{oc} and the short circuit current density J_{sc} of the devices with the annealing temperature. At each temperature the devices were annealed for 30 min. The maximum value of the V_{oc} and J_{sc} was obtained for devices annealed at 400°C indicating that the optimum temperature for the annealing process of the CdTe/CdS junction is near to 400°C.

The dependence of the spectral response of the CdTe/CdS device on annealing temperature is presented in Fig. 7. It is clear that the observation in Fig. 7 is in agreement with Figs. 5 and 6 where the maximum value of the V_{oc} and J_{sc} was for devices annealed at 400°C. It can be seen that the virgin device has only a poor response and at higher annealing temperatures the response increases and reaches a maximum at 400°C. This can be due to the fact that during annealing interdiffusion of S into the CdTe and Te into the CdS occurs and improves the quality of the junction.

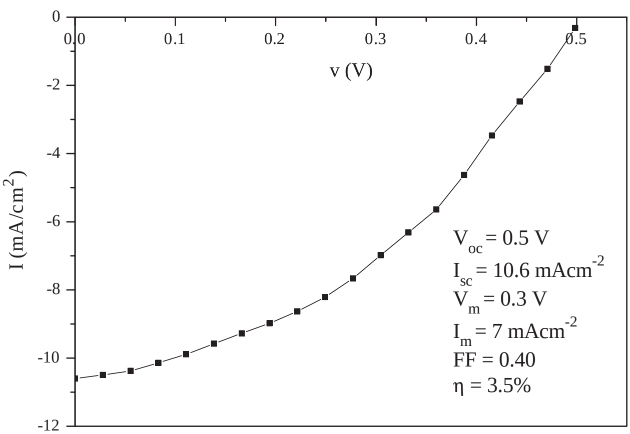

Fig. 4. *I–V* characteristic of a CdTe/CdS solar cell developed on flexible Mo substrate.

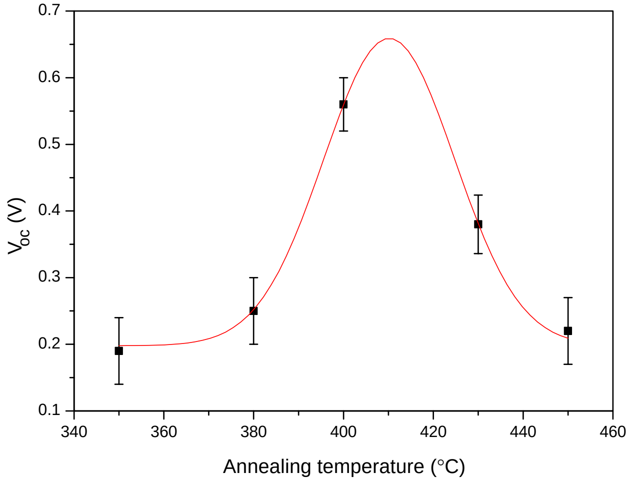

Fig. 5. Graph showing the dependence of V_{oc} on the annealing temperature of the CdTe/CdS device. The markers are experimental data and the line is a guide to the eye.

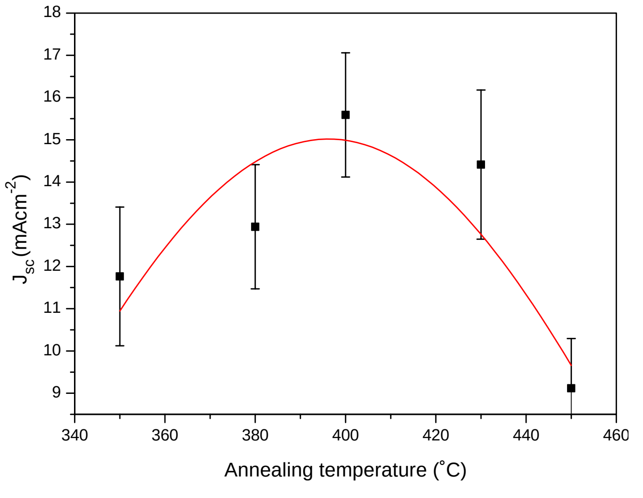

Fig. 6. Graph showing the dependence of J_{sc} on the annealing temperature of the CdTe/CdS device. The markers are experimental data and the line is a guide to the eye.

4. Conclusions

We have developed a CdTe/CdS solar cell on flexible molybdenum substrate. The dependence of the optoelectronic parameters of the cell on the annealing temperature of the CdTe/CdS device has been investigated and found that the optimum annealing temperature for obtaining better photovoltaic parameter is about 400°C. The

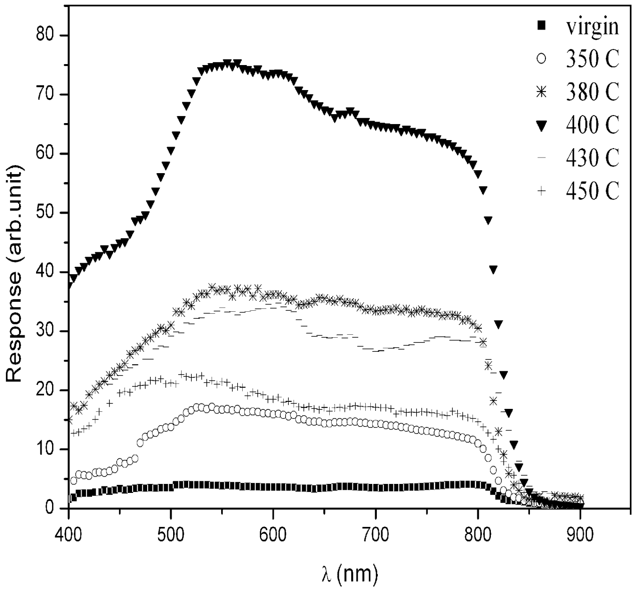

Fig. 7. Spectral response of a typical CdTe/CdS solar cell developed in the substrate configuration on flexible Mo substrates. The dependence of the spectral response on the annealing temperature of the CdTe/CdS device is clear from this figure. The maximum response is observed for device annealed at 400°C.

efficiency of a typical cell is estimated as 3.5% and the efficiency is expected to improve by optimizing the interlayer, the heterojunction and the transparent conducting contact to the CdS layer. Work is in progress to investigate the effect of annealing and subsequent deposition of multiple CdS layers on the efficiency of the CdTe/CdS solar cells.

Acknowledgements

This work was supported by CONACYT and PAPIIT-UNAM through the projects 38542-U and IN115102-3, respectively.

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