

## The Role of Transparent Conducting Oxide and Glass Substrate in the Performance of CdTe/CdS Thin Film Solar Cells

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### ABSTRACT

A study of high temperature interaction between the glass substrate and several types of TCO and the TCO and CdS films is reported. We found out that the most suitable TCO, when a soda-lime glass is used as a substrate, are  $\text{Cd}_2\text{SnO}_4$  and fluorine doped  $\text{In}_2\text{O}_3$ . CdTe/CdS solar cells with efficiency around 14% and a high stability can be prepared on these kinds of TCO if  $\text{Sb}_2\text{Te}_3$  is used as a back contact for CdTe.

Keywords: TCO Transparent Conducting oxide - 1: CdS - 2: CdTe - 3

### INTRODUCTION

CdTe/CdS thin film solar cells can exhibit an efficiency above 16% as it is reported by the NREL group in this conference [1]. However these cells are presumably prepared on alkali-free glass substrate at very high substrate temperatures namely 600°C. Besides the back contact is made by using a paste containing copper, which is known to be a very fast diffusing element in CdTe rising some doubt about the stability of the cell. We believe that the role of copper on these high efficiency solar cells is not only that of making a good contact with CdTe but also that of doping CdTe p-type thus increasing the number of p-type carriers and as consequence the efficiency of the solar cell.

Having in mind that CdTe/CdS solar cells can be used for a large-scale production, we followed a different approach in preparing the cell. First of all, we used soda-lime glass as a substrate and developed a new type of back contact not containing copper or other first group elements. This contact, consisting of a thin layer of  $\text{Sb}_2\text{Te}_3$  covered by Mo resulted to be a good and very stable back contact [2]. Having resolved the problem of the stability of back contact we found out that an instability in the cell can rise from the front contact namely, the TCO. In this paper we report the study of several TCO, their interaction with CdS and their influence in the performance of the CdTe/CdS solar cell.

### 1. EXPERIMENTAL RESULTS

Our solar cells are prepared following the scheme depicted in fig. 1. As a substrate we use a 1-inch<sup>2</sup> soda-lime glass. The back contact on CdTe is made by depositing in sequence at a substrate temperature of 300°C, 1500 Å of  $\text{Sb}_2\text{Te}_3$  and 1500 Å of Mo. Both materials are deposited by R.F. sputtering with a deposition rate of 10 Å/sec. CdTe is deposited by a CSS as it is shown in fig. 2.

The substrate temperature is 480-520°C while the CdTe source is kept at 650°C. An Ar pressure of 1 mbar is kept in the CSS chamber during the deposition.

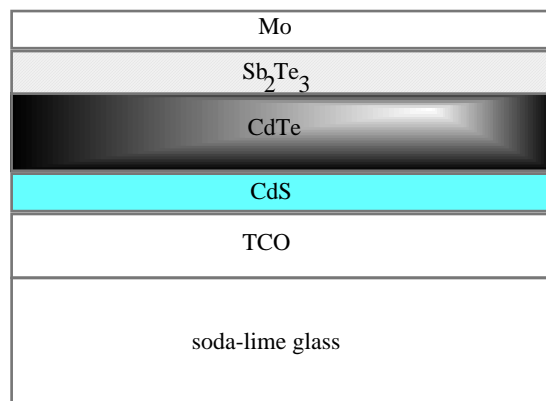


Figure 1: CdS/CdTe thin film solar cell structure

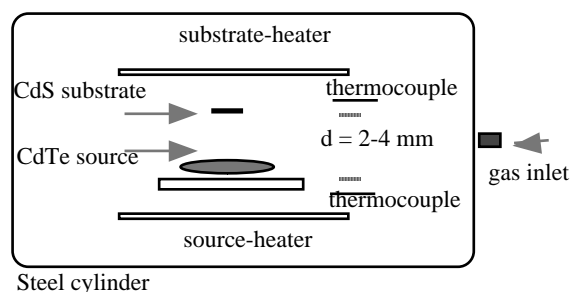


Figure 2: Schematic diagram of our CSS System

The distance between source and substrate is around 2-4 mm. A typical deposition rate is 2µm/min. The CdTe source is a compact circular block with a diameter of 3 inch and a thickness of 10 mm. This block is obtained by melting and resolidifying CdTe pellets under 50-100

atmosphere of pure N<sub>2</sub>. This compact source allowed us to not use any artifact to stop the fine powder which can be split from the source to the substrate when the source is made of CdTe pellets.

CdS was prepared both by CSS or sputtering. Since we did not observe any improvement in the cell performance by using CSS, we preferred to use sputtering because sputtering allows to get a perfect control of the film thickness.

During the CdS preparation by sputtering, the deposition rate was 10 Å/sec and the substrate temperature was 300°C. The most important part of this work concerns the preparation of TCO and the study of its interaction with the glass substrate and CdS.

Several types of TCO were investigated; all of them were prepared by R.F. sputtering:

- a) In<sub>2</sub>O<sub>3</sub> doped respectively with 1, 2, 4, and 10 % weight of Sn.  
Sn is incorporated in the sputtering target by making a hot pressed mixture of In<sub>2</sub>O<sub>3</sub> and SnO<sub>2</sub>. This TCO exhibits a resistivity of  $2.5 \cdot 10^{-4} \Omega \text{ cm}$  and is enough transparent to be used as bottom contact for CdTe/CdS solar cells. However, we found out that the efficiency of the cells, despite in some cases, by using a TCO layer thick than 1.2 µm, could be quite high (above 14%), is not much reproducible. This is because the ITO target modifies after several runs forming some In-rich nodules in the target, which can cause occasional discharges during sputtering.
- b) SnO<sub>2</sub> (F).  
This kind of TCO was prepared by using a target of SnO<sub>2</sub> and by doping the film by mixing Ar with 5% of CHF<sub>3</sub>. The minimum resistivity we were able to obtain in this case was  $8 \cdot 10^{-4} \Omega \text{ cm}$  and its transparency was not as good as that of ITO.
- c) Cd<sub>2</sub>SnO<sub>4</sub>.  
Cd<sub>2</sub>SnO<sub>4</sub> has been developed by the NREL group [3]. We prepared this material by R.F. magnetron sputtering at a substrate temperature of 500°C in Argon containing 5% of O<sub>2</sub>. It exhibits a resistivity of  $2 \cdot 10^{-4} \Omega \text{ cm}$  and a transparency larger than 90% in the wavelength range between 400 and 8500 Å. This material seems to be quite suitable to prepare high efficiency cells. However, the sputtering target, since it is made from a mixture of SnO<sub>2</sub> and CdO, being CdO hygroscopic, is difficult to be handled and the deposition rate must be kept low (< 2 Å/sec) in order for it to be not modified during sputtering.
- d) Fluorine doped In<sub>2</sub>O<sub>3</sub>.  
In<sub>2</sub>O<sub>3</sub> can be sputtered at high deposition rate (> 10 Å/sec) without modifying its target surface. When it is not doped it exhibits a minimum resistivity of  $10^{-2} \Omega \text{ cm}$  which is not suitable for application as a TCO for CdTe/CdS solar cells. However it has been found out [4] and confirmed by our experiments that 1000 Å of this material are sufficient to passivate Na when it is deposited on a soda-lime glass. On the other hand In<sub>2</sub>O<sub>3</sub> can be doped, without putting any dopant in the target, simply by introducing a gas containing fluorine in the sputtering chamber. Recently it has been reported that by using CF<sub>4</sub> a resistivity of less than  $10^{-3} \Omega \text{ cm}$  can be obtained [5]. We were able to

obtain a resistivity of  $2.5 \cdot 10^{-4} \Omega \text{ cm}$  by doping In<sub>2</sub>O<sub>3</sub> introducing Argon containing 5% of H<sub>2</sub> and 5% of CHF<sub>3</sub> in the sputtering chamber during the deposition. Evidently the presence of H<sub>2</sub> helps fluorine to enter the matrix of In<sub>2</sub>O<sub>3</sub>. The sputtering rate for preparing the fluorine doped In<sub>2</sub>O<sub>3</sub> was typically 10 Å/sec.

Combining all the characteristics namely stability of the target, reproducibility, deposition rate, resistivity and transparency fluorine doped In<sub>2</sub>O<sub>3</sub> resulted to be the most suitable material to be used for preparing stable, reproducible and efficient solar cells.

The choice of the TCO is very important for the preparation of the CdTe/CdS solar cells, especially if one considers its interaction with CdS. We found out that independently from the type of TCO and from the method used to prepare CdS, this last needs to be annealed in air at 500 - 520°C in order to get high efficiency cells. During the annealing in air, there is a reaction between the TCO and CdS which is denounced by the presence on top the CdS of a thin layer of a new material which is the reaction product.

This material is soluble in hot water and has to be removed before depositing CdTe. Its thickness depends on the annealing temperature and the annealing time. It depends also on the presence of Na and the thickness of both TCO and CdS. In fig. 3 it is shown the AFM surface morphology of this layer compared with the CdS surface morphology.

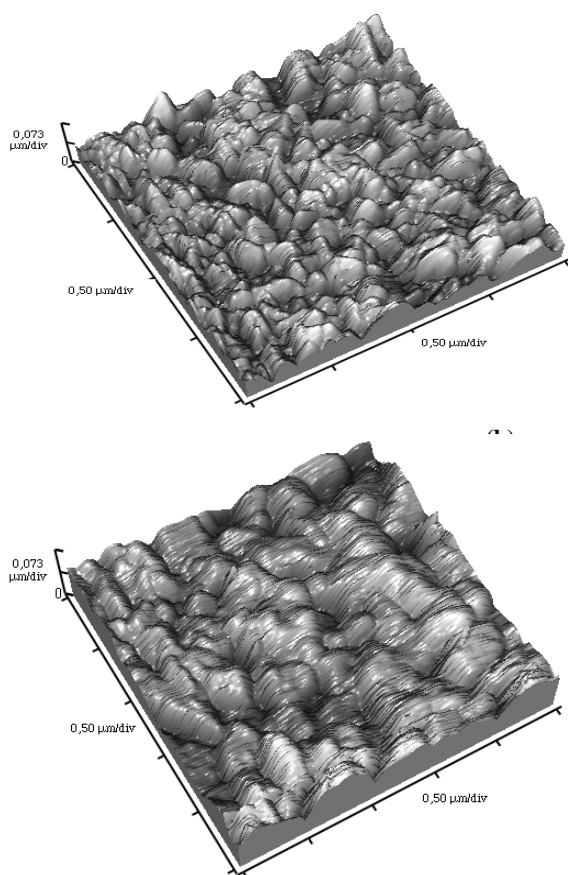
An attempt to clarify what is this material by making x-rays has failed probably because this material is amorphous. We presume that this material is CdSO<sub>4</sub> since it is soluble in hot water and it appears both when CdS is deposited on top of Cd<sub>2</sub>SnO<sub>4</sub> or on top of In<sub>2</sub>O<sub>3</sub> (F) and it forms by the reaction of CdS with the oxygen of the TCO and the air. The annealing in air made on CdS deposited directly on alkali free glass did not show the formation of this layer indicating that the TCO is needed for it to be formed. The best performance of CdTe/CdS solar cells was obtained by using soda lime glass as a substrate, on top of which 600 nm of fluorine doped In<sub>2</sub>O<sub>3</sub>, 120 nm of CdS were deposited by sputtering. An annealing in air at 520°C for 30 min has been done.

In this way a 1 cm<sup>2</sup> CdTe/CdS solar cell with the following photovoltaic parameters was obtained:

$$\begin{array}{ll} V_{oc} \sim 848 \text{ mV} & ff \sim 0.65 \\ J_{sc} \sim 25.4 \text{ mA/cm}^2 & \eta \sim 14 \% \end{array}$$

(a)

A limiting parameter in these kinds of solar cells is the fill factor since there is a roll-over in the positive part of the I-V characteristic. However, these types of solar cells are very stable since they can improve their efficiencies by making a light soaking of several hours under ten suns at 110°C. In most cases their efficiency is higher after aging. We believe that this high stability is due to both the use of Sb<sub>2</sub>Te<sub>3</sub> as a back contact and the CdS stabilization with a possible CdS grain boundary passivation after the air annealing at high temperatures.



**Figure 3:** (a) Surface morphology of the CdS film after annealing in air at 520°C; (b) Surface morphology of the CdS film after annealing in air at 520°C and washing in hot water.

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#### REFERENCES

- [1] X. Wu, J. C. Keane, C. DeHart, R.G. Dhere, D.S. Ibin, A. Duda, and T.A. Gessert, This Conference.
- [2] Romeo, A. Bosio, R. Tedeschi, A. Romeo, V. Canevari, Solar Energy Materials & Solar Cells **58** (1999) 209-218.
- [3] X. Wu, P. Sheldon, T. J. Coutts, D. H. Rose and H. R. Moutinho, 26<sup>th</sup> PVSC, 1997, Anaheim, CA.
- [4] Yang Meng, Xi-liang, Hua-xianChen, Jie Shen, Yi-ming Jiang, Zhuang-jiang, Zhong-yi Hua, Thin Solid Films **394** (2000) 219-223.
- [5] Yuzo Shigesato, Naoko Shin, Masayuki Kamei, P. K. Song and Itatu Yasui, Jpn. J. Appl. Phys. 39 (2000) 6422-6426