

# Back contacts to CSS CdS/CdTe solar cells and stability of performances

N. Romeo\*, A. Bosio, R. Tedeschi, V. Canevari

INFM, Department of Physics, University of Parma, Parco Area delle Scienze 7/a, 43100 Parma, Italy

## Abstract

High efficiency CdTe/CdS thin film solar cells with a good stability can be obtained if a low gap, high conductivity p-type semiconductor, such as  $\text{Sb}_2\text{Te}_3$ , is used as a back contact for CdTe. However, even though  $\text{Sb}_2\text{Te}_3$  is used as a back contact, some cells can exhibit a low fill factor. This, at first sight, could suggest that the back contact is not the right one. Here we would like to show that a low fill factor could depend not only on the back contact but also on the front contact and on the amount of Na-diffusion from the soda lime glass substrate. © 2000 Elsevier Science S.A. All rights reserved.

**Keywords:** Films; Photovoltaic; CdTe; CdS; Contacts

## 1. Introduction

Efficiencies close to 16% have already been reported for CdTe/CdS thin film solar cells [1,2]. However, a back contact consisting in a Cu-doped graphite layer is generally used in these high efficiency cells. Since Cu is a highly diffusing element into CdTe, these cells, in the long run, are destined to degrade.

Recently, we have developed a new back contact, which does not contain any copper, or any doping element, which can diffuse into CdTe [3,4]. This contact is a stable compound, namely  $\text{Sb}_2\text{Te}_3$ , which exhibits a forbidden gap of around 0.3 eV, is highly p-type and has a very low resistivity of  $10^{-4} \Omega \text{ cm}$ .

$\text{Sb}_2\text{Te}_3$  is deposited by RF-sputtering at a substrate temperature of 300°C on top of the CdTe film, which was previously etched with Br-methanol. Solar cells, prepared by sputter depositing CdS on top of an ITO-covered soda-lime glass and by depositing CdTe by CSS, exhibit efficiencies around 15% and do not change their performance after several months under simulated 1 sun illumination in open-circuit voltage conditions. The fill factor of these high efficiency cells is around 75%, and they do not exhibit the roll over in the positive part of  $I$ - $V$  characteristic which is typical of solar cells with a rectifying back-contact. However, by studying the performance of CdTe/CdS thin film solar cells as a function of the ITO layer, we have found that the fill factor and the roll over in the  $I$ - $V$  characteristic depend on the properties of the TCO film and, in some cases cells with a low fill factor and a strong roll over can be obtained.

A systematic study of cell performance as a function of the thickness of the ITO layer has thus been undertaken, and is the subject of this paper.

## 2. Experimental results

CdTe/CdS thin film solar cells are prepared by using the following procedure (Fig. 1). As a substrate a 1-inch<sup>2</sup> soda-lime glass is used. After cleaning, the substrate is mounted in a RF-sputtering system where three targets, ITO,  $\text{SnO}_2$  and CdS, are available. ITO is deposited at 450–500°C substrate temperature with a deposition rate of 5 Å/s in an Ar + O<sub>2</sub> atmosphere where the partial pressure of O<sub>2</sub> is around  $10^{-4}$  mbar. In sequence, without interrupting the vacuum, CdS is deposited with a deposition rate of 5 Å/s at 200°C substrate temperature.

The typical thickness of the CdS layer is 2000 Å, while the thickness of the ITO film has been varied between 0.3 and 2 μm. On top of the CdS film, 1500 Å of  $\text{CdCl}_2$  are deposited by vacuum evaporation and the CdS– $\text{CdCl}_2$  layer is treated at 500°C in air for half an hour. The first important observation that we made is that the grain size of the CdS film after treatment depends on the thickness of ITO film. A large grain size of CdS, on the order of 2000–3000 Å, is obtained for a low ITO thickness, (0.5 μm; Fig. 2), while by increasing the thickness of the ITO film, the grain size of the CdS film decreases. For an ITO thickness of 1.8–2 μm the grain size of the CdS film remains as it was before  $\text{CdCl}_2$ -treatment (of about 500 Å) even though the transparency of the CdS film improves (Fig. 3).

We interpreted these results by taking into consideration the Na-diffusion from the soda-lime glass. In fact it is well

\* Corresponding author.

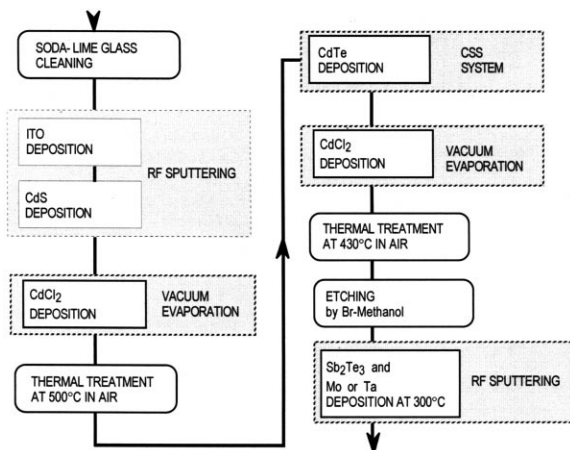


Fig. 1. Procedure for the preparation of CdTe/Cds thin film solar cell.

known that CuInSe<sub>2</sub> films grow with a larger grain size on top of soda-lime glass or in the presence of Na [5]. Similarly, a larger grain size in the CdS film may correspond to a larger amount of Na present in the CdS film.

We conclude from these results that the Na diffusion into the CdS film depends on the thickness of the ITO layer and that for an ITO thickness on the order of 1.8  $\mu\text{m}$ , the Na diffusion is quite small. How the Na presence in the CdS film influences the performance of CdTe/Cds thin film solar cells will be shown later on.

CdCl<sub>2</sub>-treated CdS films have been used as substrates for the deposition of CdTe films by close spaced sublimation (CSS). The distance between source and substrate was 0.2 cm and temperatures of substrate and source were 500 and 650°C, respectively.

The deposition was done in an Ar + O<sub>2</sub> atmosphere. Typical pressure during the deposition was 1 mbar and the content of O<sub>2</sub> was 1%. The role of O<sub>2</sub> is to slow down the CdTe growth to allow the CdTe to grow with a smaller grain size and to have a better coverage of the CdS film. The typical thickness of the CdTe film is around 6  $\mu\text{m}$  for a 5 min deposition time. On top of the CdTe film, 3000 Å of CdCl<sub>2</sub> are deposited by evaporation and the CdTe/CdCl<sub>2</sub>

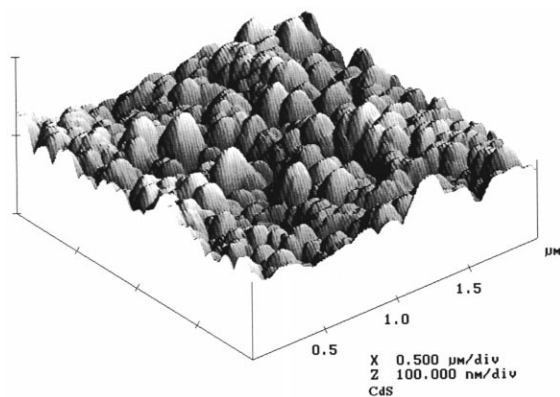


Fig. 2. Atomic force micrograph of a CdCl<sub>2</sub>-treated CdS film on top of 0.5  $\mu\text{m}$  ITO (O<sub>2</sub>).

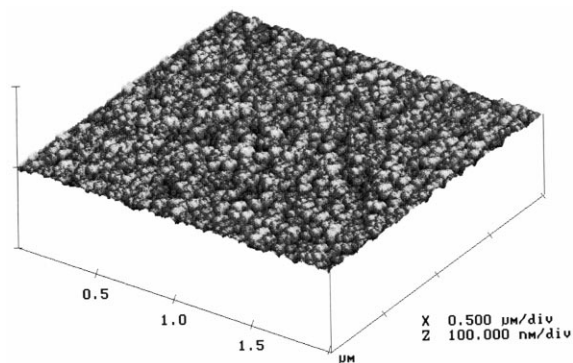


Fig. 3. Atomic force micrograph of a CdCl<sub>2</sub>-treated CdS film on top of 1.8  $\mu\text{m}$  ITO (O<sub>2</sub>).

layer is treated at 430°C in air for half an hour. Then, the CdTe film is etched with Br-methanol and the cell is mounted in a sputtering system for the contact deposition.

As an ohmic contact Sb<sub>2</sub>Te<sub>3</sub> is deposited by RF-sputtering with a deposition rate of 10 Å/s. The substrate temperature during sputtering is kept at 300°C and the typical thickness of Sb<sub>2</sub>Te<sub>3</sub> film is 1000 Å. Finally, the Sb<sub>2</sub>Te<sub>3</sub> is covered by 2000 Å of Mo or Ta deposited in the same sputtering system without interruption of vacuum.

Following the above procedure, several CdTe/Cds thin film solar cells have been prepared, in which the only parameter which has been varied was the ITO thickness.

While open-circuit voltages and short-circuit currents do not vary much, the fill factor exhibits a strong variation as a function of the ITO thickness, from about 0.5 for an ITO thickness of 0.5  $\mu\text{m}$  to 0.75 for a thickness of 1.8  $\mu\text{m}$  or more (Fig. 4).

In addition, cells prepared on thin ITO exhibit roll-over in the positive part of the *I*-*V* characteristic, while those prepared on thick ITO do not exhibit any roll-over as shown in Figs. 5 and 6.

Fig. 5 represents the *I*-*V* characteristic of a CdTe/Cds solar cell prepared on a 0.5  $\mu\text{m}$  thick ITO film, while Fig.

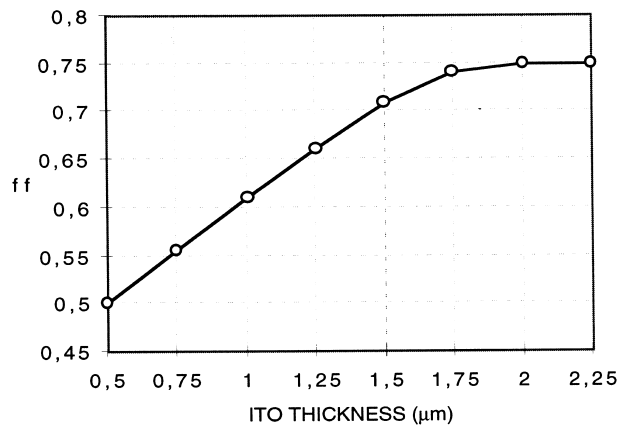


Fig. 4. Fill factor of CdTe/Cds thin film solar cells as a function of ITO film thickness.

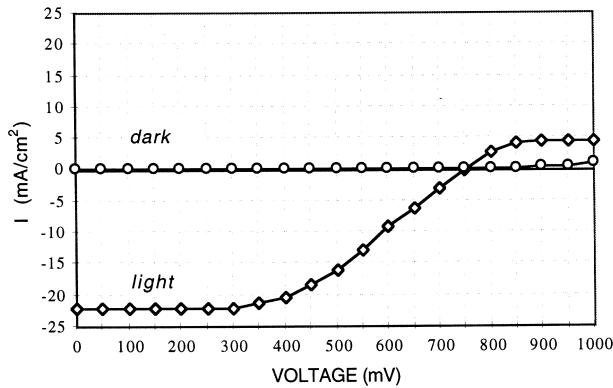


Fig. 5.  $I$ - $V$  characteristic of CdTe/CdS thin film solar cells made on a 0.5  $\mu\text{m}$  thick ITO film.

6 represents the  $I$ - $V$  characteristic of a cell made on a 1.8  $\mu\text{m}$  thick ITO film.

### 3. Interpretation of the results

We have shown that both the  $\text{CdCl}_2$ -treated CdS film morphology and the fill factor of the CdTe/CdS cells depend strongly on the thickness of the ITO film. The larger grain size of the CdS film deposited on thin ITO films leads one to suppose that a larger amount of Na diffuses through thin ITO films. If this is true, one has to explain why a larger amount of Na in the CdS film results in a lower fill factor of the CdTe/CdS solar cell.

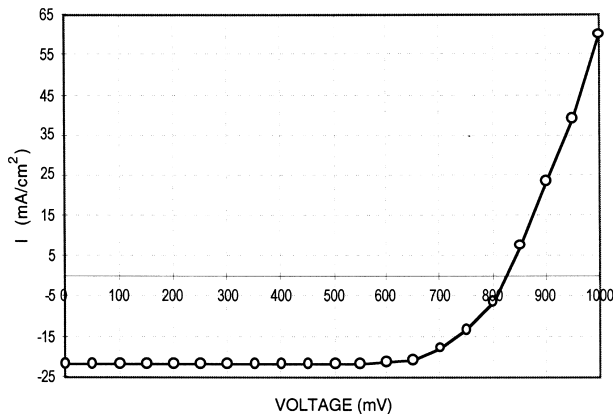


Fig. 6.  $I$ - $V$  characteristic of CdTe/CdS thin film solar cells made on a 1.8  $\mu\text{m}$  thick ITO film.

If some copper is added to the contact made on these cells, the fill factor improves although the cells are not stable, while the cells prepared on thick ITO films do not need any copper to exhibit a high fill factor and are quite stable.

One could think that a large grain size CdS film is not suitable to prepare high efficiency CdTe/CdS solar cells, since there could be a strong interdiffusion between CdS and CdTe along the CdS grain boundaries. However, this does not give a simple explanation of the low fill factor.

A possible explanation could be that Na in CdS dopes the CdTe film close to the interface, leaving the CdTe bulk undoped. At the same time  $\text{CdCl}_2$  treatment of the CdTe film may dope the CdTe film in a region close to the contact by forming  $(\text{V}_{\text{Cd}}-\text{Cl})$  complexes. In this way the doping profile in the CdTe film can give rise to a p+/p/p+ barrier inside the CdTe film. If Na is limited by a thicker ITO film, than the p+ region close to the junction does not form. When copper is present at the contact, due to its rapid diffusion, it can uniformly dope the CdTe film avoiding any barrier inside the CdTe. More experiments with a diffusion barrier for Na and chemical analysis are needed in order to clarify whether this interpretation is correct or not.

In conclusion, we have demonstrated that a low fill factor and/or the presence of a roll-over on the positive part of the CdTe/CdS thin film solar cell  $I$ - $V$  characteristic cannot be attributed only to a rectifying back contact but can depend also on the way the TCO front contact is made.

### Acknowledgements

This work has been partially supported by the European Commission under contract no. JOR3-CT98-02 18 (DGXII-WSMN)

### References

- [1] C. Ferekides, J. Britt, Y. Ma, L. Killian, Proc. 23rd IEEE PVSC, 1993 389.
- [2] J. Kester, Golden Photon, Photovoltaic Insider Report. Vol. XV, No. 12, Dec. 1996.
- [3] N. Romeo, A. Bosio, R. Tedeschi, V. Canevari, 2nd World Conf. Exhibit., Photovoltaic Sol. Energy Conv., Vienna, July 1998.
- [4] N. Romeo, A. Bosio, R. Tedeschi, V. Canevari, Sol. Energy Mater. Sol. Cells 58 (1999) 209.
- [5] J.E. Granata, J.R. Sites, 2nd World Conf. Exhibit. Photovoltaic Sol. Energy Conv., Vienna, July 1998.