

THE ROLE OF SINGLE LAYERS IN THE PERFORMANCE OF CDTE/CDS THIN FILM SOLAR CELLS

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ABSTRACT: The CdTe/CdS thin film solar cell is composed of four layers that are deposited in sequence on a glass substrate. The first layer is a transparent and conducting oxide (TCO) that acts as a front contact. The second and the third layer are CdS and CdTe that make the active junction and the fourth layer is a material that could be both a metal or a low gap semiconductor that acts as a back contact. Each of these layers should exhibit peculiar characteristics in order for the cell to show high performance.

In this paper, each layer together with its interaction with the other layers will be analysed in order to find out the characteristics that are suitable to make high efficiency and stable solar cells.

Keywords: CdTe, CdS, Thin Films

1 INTRODUCTION

The CdTe/CdS thin film solar cell is probably the most suitable for the production of low cost modules at an industrial level. The techniques that are used to deposit the layers that compose the cell are sputtering and close-spaced sublimation, both easily scalable from 1cm² laboratory solar cell to a 0.6x1.2 m² module. This has been already demonstrated from the fact that two industries, namely First Solar in USA and Antec in Germany, produce 0.6x1.2 m² CdTe/CdS modules of 7-9% efficiency. A small area efficiency of 16.5% has been demonstrated from the NREL group [1] and a 15.8% efficiency for a completely dry process has been reported by ourselves [2].

In order to further increase both the small area and module efficiency, the role of each layer and its interaction with the other layers that compose the cell in relation to the techniques used for their deposition, has to be clarified.

In this paper we shall analyse the preparation of each layer and try to explain what is its influence on the performance of the cell.

2 STRUCTURE OF THE CELL

The CdS/CdTe thin film solar cell prepared in our laboratory is composed of four layers, namely the front contact, CdS, CdTe and the back contact. The front contact is made up of two sublayers. The first one is a high conductivity ITO layer with a sheet resistance of about 5 Ω-square and a thickness of 400nm and the second one is a seminsulating layer with a resistivity of 10³Ωcm and a thickness of 100-200nm. This last layer could be both SnO₂ or ZnO. Typical thickness of CdS and CdTe is respectively 60nm and 6μm. As a back contact a double layer, made up of 200nm of Sb₂Te₃ and 200nm of Mo, is used (Fig.1)

3 THE TCO LAYER

The most important characteristics which a TCO front contact must exhibit are a low sheet resistance and a high transparency in the visible region. Indium tin oxide with a 10% of Sn fulfils these requirements. However, due to the high temperature at which CdTe is deposited and/or treated in presence of chlorine, some In can diffuse from the ITO into the subsequent deposited layers. The use of a 100-200nm thick buffer

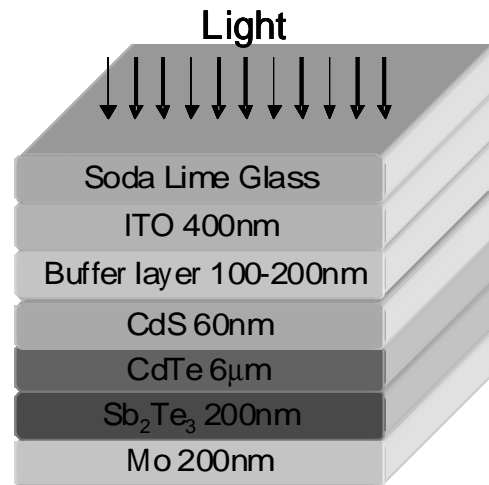


Figure 1: Structure of the CdTe/CdS thin film solar cell

layer between ITO and CdS, such as SnO₂ or ZnO can hinder the In diffusion. Recently we have demonstrated, by SIMS depth profile measurement [3], that In has a concentration of 5 · 10¹⁵cm⁻³ in CdTe when SnO₂ is used as a buffer layer while its concentration rises to values of 8 · 10¹⁶-10¹⁷cm⁻³ when the buffer layer is not used. Besides, due to its relatively high resistivity, the buffer layer reduces the effect of a shunt resistance which could come from pinholes in the very thin CdS layer.

In prevision of an industrial production, the TCO is deposited by D.C. magnetron sputtering that is less expensive than R.F. magnetron sputtering while SnO₂ and ZnO are prepared by reactive D.C. magnetron sputtering in presence of O₂ using pure Sn or Zn targets.

4 THE CdS LAYER

High performance CdTe/CdS thin film solar cell can be obtained with CdS prepared by three different techniques that are chemical bath deposition (CBD), close-spaced sublimation (CSS) and R.F. sputtering. We chose this last technique, since it is the most suitable for industrial production. However, in order for a sputtered CdS film to give high efficiency cell, it has to be made with some F in the sputtering chamber. We prepared F-doped CdS films by introducing in the sputtering chamber Ar containing ≈ 3% of CHF₃. This gas is decomposed in the sputtering chamber and

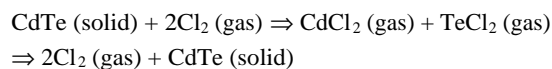
fluorine, being negative, is directed to the substrate. We expected that F decreased the resistivity of the CdS film but this did not happen. On the other hand, F-doped CdS exhibits a forbidden gap a little larger than the one of not doped CdS [4], a stronger cathodoluminescence emission [5], a stronger photoconductivity and, what is most important, gives higher efficiency solar cells [2]. Possibly, fluorine, bombarding the CdS film during the growth, eliminates any excess of Cd and S and gives a more stoichiometric film. On the other hand, it could form some CdF₂ which could passivate the grain boundaries. F-doped CdS has revealed to be more stable in respect to the CdS-CdTe mixing when the CdTe/CdS structure is treated at 400°C in presence of chlorine.

5 THE CdTe LAYER

The most suitable method to deposit CdTe is close-spaced sublimation (CSS). This technique allows high deposition rates of the order of several microns per minute and it has been used for the preparation of the highest efficiency CdTe/CdS [1],[2],[6] solar cells. In our CSS we use a compact CdTe source. The substrate temperature is typically 500°C and the distance substrate-crucible is 3-4mm. The deposition is done in an atmosphere of Ar containing 5-50% of O₂ with a total pressure of 20-100mbar. The use of O₂ is important since it improves both V_{OC} and fill factor. The macroscopic effect of O₂ is that CdTe grows more compact and with a smaller grain size. On the other hand, O₂, forming CdO, makes CdTe to grow in excess of Te and this can help in forming more Cd-vacancies that are known to behave as acceptors in CdTe.

6 TREATMENT OF THE CdTe/CdS STRUCTURE IN PRESENCE OF Cl₂

Treatment of CdTe in presence of Cl₂ is necessary in order for the solar cells to exhibit high efficiency. This treatment is generally done by depositing CdCl₂ on top of CdTe by evaporation or by dipping CdTe on a solution of CdCl₂-methanol and with a subsequent annealing at 400°C in air or in an inert gas such as Ar [2]. In view of an industrial production we found out another method to make the Cl₂-treatment that does not use any CdCl₂. The CdTe/CdS structure is put in an ampoule in which vacuum is done. A mixture of 100mbar of Ar and 20mbar of a non toxic gas containing Cl₂ such as HCF₂Cl (difluorochloromethane) is introduced in the ampoule and the temperature of ampoule is raised to 400°C. an annealing of ≈ 5-10 minutes is done at 400°C and then vacuum is made again. After the treatment the CdTe morphology is completely changed with a size increase of small grains. Since HCF₂Cl is decomposed at 400°C and CdTe starts to decompose at around 400°C, we suppose that the following reaction happens especially for the small grains that are the first-ones to decompose:



A vacuum for a few minutes keeping the temperature at 400°C is done after the treatment in order to make

CdCl₂ formed on the CdTe surface to reevaporate and to have a clean CdTe surface ready for the back contact. The Cl₂-treatment can be made with any gas of the freon family. The only need is that the gas contains Cl. This method is very effective in producing high efficiency cells. It avoids the use of CdCl₂ that could be dangerous and instead uses a gas that is stable, inert and not toxic at room temperature. Besides it eliminates the step of CdCl₂ evaporation and as a consequence it is much more suitable for an industrial production. This process has been patented [7].

7 THE BACK CONTACT

The back contact is done by sputtering in sequence 200nm of Sb₂Te₃ and 200nm of Mo on top of CdTe at a substrate temperature of 300°C. The CdTe surface is not etched since, using a semiconductor rather than a metal as a contact, a Te rich surface is not needed. Besides, with the treatment process described before, the CdTe surface is completely clean. The ohmicity of Sb₂Te₃ has been verified by making contact resistance measurements in a p-type CdTe single crystal [8].

8 THE CdTe/CdS SOLAR CELL

One cm² CdTe/CdS solar cells have been prepared using the layers described before. These cells have been tested by using an Oriel solar simulator under an AM1.5, 100mW/cm² simulated solar light. Open circuit voltages range between 840 and 870mV, short circuit currents between 24 and 26 mA/cm² and fill factors between 0.6 and 0.72. The highest efficiency has been 15.8%. The I-V characteristic of this cell is shown in Fig.2.

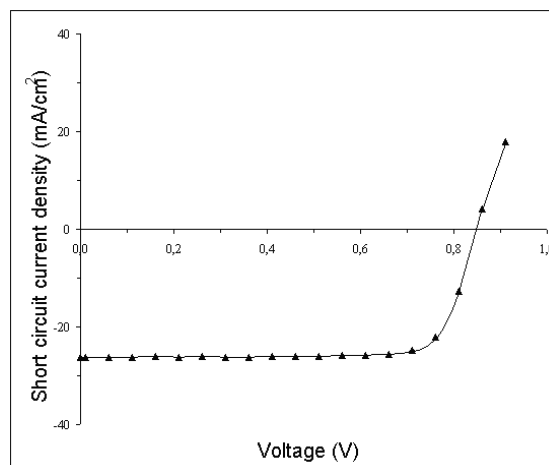


Figure 2: I-V characteristic of our best completely dry-processed cell under a 100mW/cm², AM1.5 simulated solar light. V_{OC}=0.862V, J_{SC}=25.5 mA/cm², ff=0.72, η=15.8%

9 CONCLUSIONS

We have described a completely dry process that can produce high efficiency cells. No use of CdCl₂ is made nor etching is done. Each layer has an important role. The TCO has to be stable and has to be made with a buffer layer. CdS can be made by sputtering but with

some fluorine in the sputtering chamber. CdTe works better if it is deposited with some O₂ in the sublimation chamber with a relatively high pressure of Ar. The Cl₂-treatment can be made very easily without using CdCl₂ and finally the back contact can be made without using any free metal guaranteeing a high stability. The process is made of 5 sputtering systems, one close-spaced sublimation chamber and one vacuum chamber for the Cl₂ treatment. It can be easily scaled up and, completed with three laser scribing systems, it can constitute a production line that, by using 0.6x1.2 m² glass modules, can produce more than 10MW per year.

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