Industrial Upscaling of CdTe/CdS Thin Film Solar Cells

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ABSTRACT: CdTe/CdS thin film solar cells, since they are made with easily scalable techniques such as sputtering and closed space sublimation, can be considered particularly suitable to be produced on a large scale. Besides, we developed a new process which is simplified in respect to the normally used processes, since it is dry and it does not make use of any acid. Furthermore, $CdCl_2$, used for CdTe treatment, has been substituted with a non toxic gas, namely HCF_2Cl. Back contact is done by a procedure that allows to make stable cells. An efficiency close to 16% is obtained on 1 cm^2 area with this process. In order to scale up this new process to an industrial production, a new company, named ARENDI, with the participation of the Marcegaglia industrial group, IFIS Bank of Venice, the contribution of Ministry of Environmental and the scientific support of the thin film group of the University of Parma, has been constituted. The line is starting to be constructed near Milan and will be ready within two years. The size of the module will be 60x120 cm^2 and the production capacity of the line should be around 15 MW/year.
Keywords: CdTe – Thin Film – Module Manufacturing

1 INTRODUCTION

CdTe with its energy gap of 1.45 eV is an ideal material to be used as an absorber in solar cells. Besides, its gap is "direct" which means that only a few microns of the material are needed to absorb 90% of photons with energy greater than 1,45 eV. Its phase diagram is quite simple and only the stoichiometric compound can be formed at temperatures higher than 400°C. At high temperature, namely 500°C, which is used when it is deposited by Closed-Space Sublimation (CSS), it grows *p*-type with a number of carrier greater than 10^{14} cm^{-3} which are sufficient to form a good junction with a *n*-type partner. This is quite important since doping of polycrystalline thin films has to be avoided due to the fact that foreign elements tend generally to segregate into the grain boundaries. CdTe thin films can be prepared by several methods, such as single evaporation, electro-deposition and CSS. Among these, CSS has demonstrated to be most effective in giving high efficiency solar cells since it allows to grow the film at high substrate temperature (500-600°C) at which CdTe grows polycrystalline with a large grain size (2-10 μm). High efficiency thin film solar cells are obtained by using as an n-partner a thin layer (less than 100 nm) of CdS in the configuration of "superstrate" that means that the light enters trough the glass substrate. The highest efficiency so far reported for CdTe/CdS thin film solar cells is 16.5% [1]. Here, both CdTe and CdS are deposited by CSS, the front contact is a layer of Cd_2SnO_4 covered by a buffer of Zn_2SnO_4 and the back contact is done with a layer containing a small amount of Cu. Due to the good photovoltaic properties of CdTe and the good scalability of the techniques used to produce CdTe/CdS thin film solar cells, these devices are already produced in modules of 60x120 cm^2 by two companies, namely Antec Solar in Germany and First Solar in the United States. Recently, First Solar announced the construction of a plant capable of producing 100 MW/year.

So far, CdTe/CdS modules exhibit efficiency between 7 and 10%. An increase in the module efficiency can be obtained if the fabrication process is simplified in order to decrease the gap between the laboratory and the industrial scale. Here, we will describe a process which is notably simplified in respect to the ones which are currently used. This process is being industrialized and a new company, named ARENDI with the participation of an industrial partner (Marcegaglia group) and the contribution of Ministry of Environment, has been constituted for this purpose. The plant will be installed near Milan, should produce 15 MW/year and will be ready within the next two years.

2 STRUCTURE OF THE CELL

The CdTe/CdS thin film solar cell is composed of four layers:

- The TCO (Transparent Conducting Oxide) layer that acts as the front contact.
- The CdS layer that is the *n*-type partner.
- The CdTe layer that is the *p*-type absorber.
- The back contact (see Figure 1)

The configuration is of the "superstrate" type that means that the light enters from the glass substrate. Both front and back contact are composed of two sub-layers as it will be explained later on.

3 THE IN-LINE PROCESS

The overall in-line process together with the temperature profile is shown in Figure 2. The in-line system is divided in three sections, namely the TCO section, the CdS and CdTe deposition comprehending the CdTe treatment in a Cl containing atmosphere, and the

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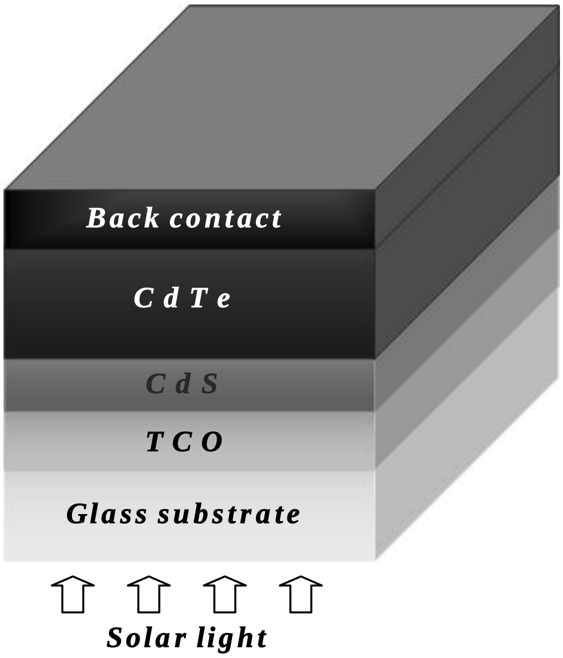

Figure 1: Structure of the CdTe/CdS thin film solar cell.

back contact. At the end of each section, there is a laser scribing apparatus that is able to make 120 parallel lines, 1 cm distant one from each other in 90 sec. All the process is fully automated and it is projected to produce a module each 90 sec. With three shifts, the in-line system can produce more than 15 MW/year. The process is completely dry and no use of acid is done. Despite, no $CdCl_2$ is used. Instead a non toxic gas containing Cl, inert at room-temperature, is used.

4 DESCRIPTION OF THE PROCESS

A soda-lime glass, whose size is 0.6x1.2 m^2, after being washed and dried, enters in a first sputtering system where is sequence 400nm of ITO and 150 nm of ZnO are deposited at a substrate temperature of 400°C. Both materials are deposited by DC sputtering with a deposition rate greater than 40 Å/sec. ZnO is done by reactive sputtering in an $Ar+O_2$ atmosphere that contains 20% of O_2. Sheet resistance of ITO is about 5 Ω/square: The ZnO buffer layer is quite important. It is intended from one hand to hinder the diffusion of In into the subsequent layers and from the other hand to avoid to put CdS in direct contact with ITO.

Since CdS is very thin (80-100 nm) a few pinholes could put in short-circuit CdTe with ITO. ZnO, exhibiting a resistivity on the order of 10^3 Ωcm, can avoid this shortening, increasing the open circuit voltage.

After the TCO deposition the temperature is lowered down to room temperature and a first laser scribing is done in parallel line distant 1cm one from each other.

Then the glass enters into the second section and the substrate temperature is raised again up to 250°C at which 80 nm of CdS are deposited by sputtering in an $Ar+CHF_3$ atmosphere containing 5% of CHF_3 with a deposition rate grater than 20 Å/sec. The presence of F in the sputtering chamber allows CdS to grow stoichiometric since any excess of Cd or S is eliminated by the substrate bombardment from F^- ions [2]. CdS could be made also by closed-space sublimation, but we prefer to use sputtering since the thickness of the layer can be much better controlled.

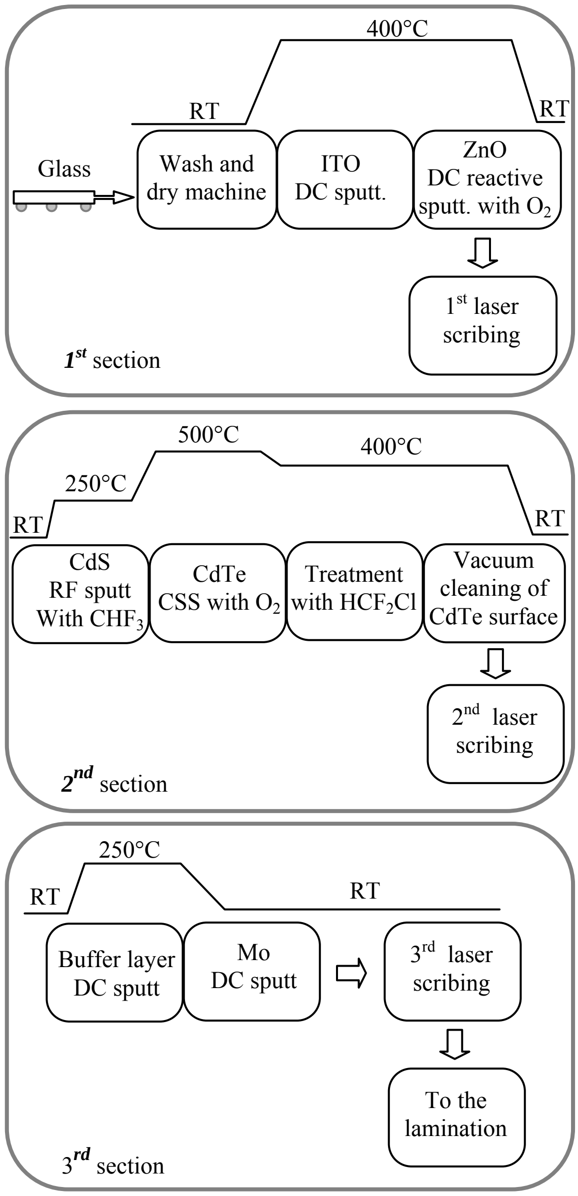

Figure 2: The overall in-line process together with the temperature profile.

After CdS deposition, the substrate temperature is increased up to 500°C at which 8 μm of CdTe is deposited by CSS in an $Ar+O_2$ atmosphere with a deposition rate of a few microns/min . The presence of O_2 in the CSS chamber allows CdTe to grow with smaller and more compacted grains with grain boundary probably passivated by the formation of an insulating layer of $CdTeO_3$ [3].

The substrate temperature is then decreased down to 400°C at which the glass enters into a chamber where a mixture of 90% Ar and 10% of HCF_2Cl with a total pressure of 400 mbar is contained.

HCF_2Cl is a gas of the Freon family. It is inert and non toxic at room temperature. At 400°C it is decomposed and it frees Cl that can react with CdTe. We believe that the following reaction happens:

$$CdTe\,(s) + 2Cl_2\,(g) \Rightarrow CdCl_2\,(g) + TeCl_2\,(g) \Rightarrow 2Cl_2\,(g) + CdTe\,(s)$$

In this way the small CdTe grains go into vapour phase and re-solidify only if they are more strongly bounded and more ordered. An increase of the grain size is clearly seen after the treatment as it is shown in Figure 3(a) and 3(b).

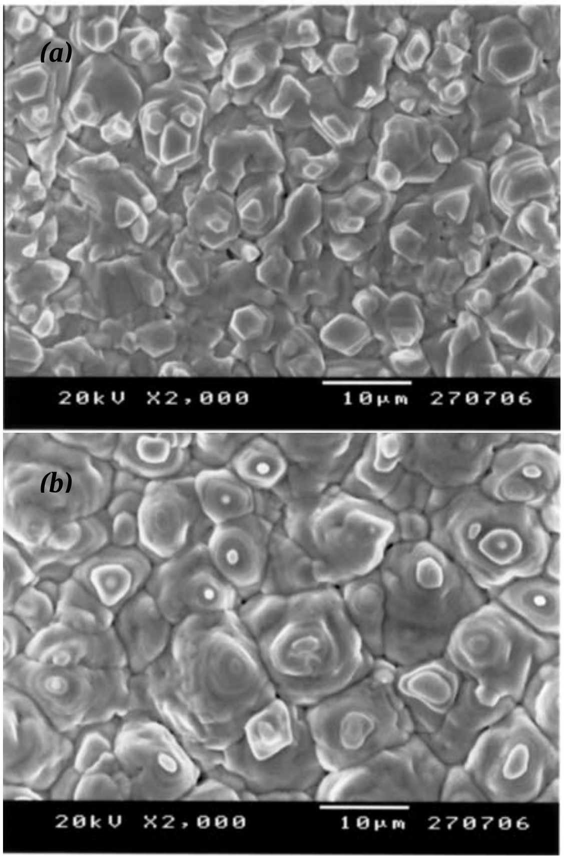

Figure 3: ***(a)*** surface morphology of an untreated CdTe film deposited by CSS method; ***(b)*** morphology of the same film after thermal treatment in Ar+HCF_2Cl atmosphere.

The treatment of CdTe with a Freon gas is reported more in details in a paper presented in this conference [4]. One can argue that the Freon gas is dangerous for the ozone belt and should not be used. However, in a production plant, this gas can be easily recovered and the recovering machines are already supplied by the gas producers. On the other hand, this big advantage of using this gas is that $CdCl_2$ is not used any more and the step of the deposition of $CdCl_2$ on top of CdTe is eliminated.

Other approaches, such as that of using HCl, are always much more risky in a production plant. After the HCF_2Cl treatment, that lasts a few minutes, the glass enters in another chamber, keeping the temperature at 400°C, where vacuum is done. Since the temperature is quite high, any residual $CdCl_2$ is evaporated and the CdTe surface is cleaned up. At this point the substrate temperature is lowered down to room temperature and a second laser scribing is done along lines very close to those made by the first laser scribing in order to expose the TCO to the material that is used for the back contact. In this way the top is put in contact with the bottom in order to have stripes 1 cm wide and as long as the glass dimension (60 cm), all put in electrical series.

Without any etching of the CdTe surface the glass enters in the back contact section where it is heated up to 250°C and a buffer layer of about 100 nm is deposited with a deposition rate higher than 50 Å/sec. Finally, while the substrate temperature is decreasing to room temperature, 150 nm of Mo are deposited with a deposition rate larger than 100 Å/sec. Both buffer layer and Mo are deposited by DC sputtering. Last step is the third laser scribing that is made in order to remove the shortening between top and bottom caused by the back contact deposition. This can be seen in Figure 4 where the three laser scribing are shown.

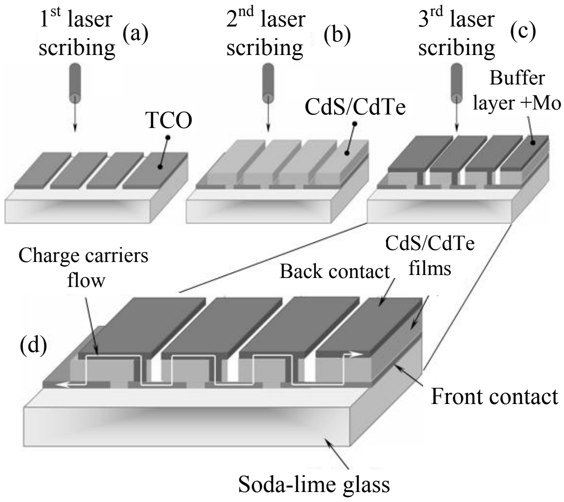

Figure 4: Typical interconnects scheme for a CdTe/CdS based solar cell module. (***a***) Laser scribing of the TCO film. (***b***) Laser scribing of the active layers (CdS/CdTe). (***c***) Laser scribing of the back contact/active layers.
(***d***) Enlargement of a schematic PV module in which the series electrical connections between all the stripes constituting the module and the charge carriers path through the cell interconnections are put in evidence.

5 CONCLUSION

The process above described has been repetitively proved in a laboratory scale by using a 1 $inch^2$ soda-lime glass substrate. One cm^2 cells with an efficiency larger than 14% are routinely obtained. By optimizing all the parameters, principally the thickness of CdTe layer and pressure and time of the Freon treatment, an efficiency of 15.8% was obtained with a V_{oc} of 0.862 mV, a J_{sc} of 25.5 mA/cm^2 and a fill factor of 0.72%. A peculiar characteristic of these cells is that they are very stable. They have been tested by making a light soaking with more than 10 suns at a temperature of 90-100°C for several hours in the open circuit conditions. In most cases an improvement of the open circuit voltage was observed while the other parameters remained approximately constant.

The process which we use to produce CdTe/CdS thin film solar cells is quite simplified in many aspects such as:

1. CdS is done by RF sputtering and a much better control of its thickness is obtained.

2. Treatment of CdTe is done by using a gas that is inert and non toxic at room temperature. The step of $CdCl_2$ deposition has been removed.
3. CdTe is not etched before back contact deposition.
4. The buffer layer in the back contact renders the cells much more stable without affecting their efficiency.

Due to this simplification of the process we believe that no much problems can rise in scaling it up to a production scale.

At this purpose a new company, with the aim of building a production line with a capacity of 15 MW/year, has been constituted. The name of the company is ARENDI and the production line will be set near Milan.

Participants of the company are:

1. The industrial group of Marcegaglia
2. The IFIS bank of Venice
3. The Ministry of the Environmental together with the Lombardia region
4. The Solar System and Equipments (SSE) that will give, trough the University of Parma, the technical and scientific support.

The building of the line is now going to start and will be ready within two years.

Acknowledgments

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