8.3.2 Essentials of Producing Thin Film Solar Cells

General Remarks

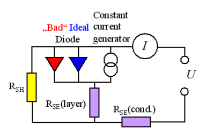
- If we look at the cross-section of the **CIGS** cell in the preceding subchapter, we see parts of what we are up to if want to mass produce this type of thin film solar cell.
  - We have to deposit various thin films on a glass substrate. In order of appearance we have

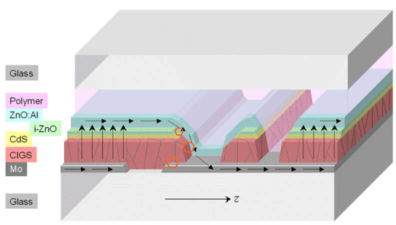
    - **Mo**
    - **CIGS**
    - **CdS**
    - Intrinsic-**ZnO**
    - **Al** doped **ZnO**
    - Some Polymer

    and then put the lid on - another glass plate.
  - Then we must "put the lid on" - another glass plate.
- The **CIGS** materials would be the "base" of the solar cell diode or the principal absorber material; it is always **p-**doped. The **CdS** and the **i-ZnO** form the **n-**doped or emitter part of the diode. They have bandgaps different from that of **CIGS**, so we actually have what is called a **hetero-junction**, something we will encounter extensively in Optoelectronics.
  - Hetero-junctions have basic properties similar to the **pn**-juntion we know, but a number of peculiarities, too, which we will not go into at present. The **CdS** layer, a rather crucial part of the **CIGS** solar cell, also serves as **"buffer" layer**, mediating the lattice mismatch between **CIGS** and **ZnO**, a necessary function to keep the interface properties in the tolerable range.
  - The heavily **p**-doped (by **Al**) top **ZnO** layer provides the transparent front side contact (and, perhaps, some anti-reflection coating).
  - The two top layers of polymer and glass are rather "trivial"; the essentially keep the rain out and just protect the whole cell for **20** years or so from the environment (including things like extremely corrosive birds shit).
- The first task thus is to deposit those layers - on a substrate typically **1 m × 1m** in size or, using some a role-to-role process, on a flexible substrate like polyimide or stainless steel that moves inside some piece of equipment at **1 m/min** or so and comes out at the other end with at least some of the relevant layers on it.
  - For layer deposition we can use some of the processes we learned about earlier, use some that have been around but that we have not encountered yet, or use the ones especially invented for exactly this task. In other words: We cannot go into this here at all.
  - Instead we look at some specialities of thin film layer solar cell production that goes beyond "merely" depositing thin films on a substrate

"In-situ" Series Connection

- As we have seen before, having very low series resistances is decisive if you want to have a solar cell with an efficiency **η > 10 %** or so.
  - Unfortunately, even heavily doped **ZnO** - a member of the important material class of "***TCO***" or **transparent conductive oxides** - has a lousy specific conductivity of at best **200 µΩcm** - two orders of magnitude above that of decent metals like **Ag** or **Cu**.
  - Worse, the intrinsic **ZnO** layer is almost an insulator, and the **CIGS** itself is also not overly conductive. We have a problem shown in the left half of the picture below; the right half shows the solution.





Courtesy of Dr. Powalla; ZWS Stuttgart,

- In some simple equivalence circuit diagram we must split the total series resistance somehow into an internal series resistance coming from the active layers and an "external" one coming from the "wiring", i.e. the conductors. The bad one is the internal one, because there is not much we can do about that for a single solar cell. This is one of the reasons why we do not use a low-resistance metal grid like for the **Si** bulk solar cell in this case: it wouldn't help much to bring the series resistance down.
- The only way to cope is to make the individual solar cells small in one direction (***z***-direction)- we have a stripe of about **1 cm** in width and up to **100 cm** long - and to switch these stripes in series. In other words, we produce little current in ***z*** direction but a lot of voltage. The voltage loss in the internal resistance is proportional to the current; if we keep the current low, we keep the internal losses down. In other words we use the same kind of reasoning that leads to high-voltage power lines in the face of finite line resistances.
- The problem, of course, is that we cannot manufacture individual stripes of thin film solar cells and then solder them together - we must do all this series connection "in-situ" while we deposit the various layers - fast and cheaply.

Sounds difficult - is difficult. We can also learn an important lesson:

- A potential disadvantage - large internal resistances - may be turned into an advantage. Just solve the problem of how to do "automatic" series connections, and you are no longer producing mediocre solar cells but large-area solar *modules* with a high-voltage output that not only alleviates the internal resistance problem but is just perfect for the power conversion electronics that must come after the module.
- As always, there are a few second-order problems with this approach too, but basically it is a sound approach that is used with practically all thin film solar cells.

The way it is done is shown in the schematic cross-section of a **CIGS** solar cell at the left-hand part of the picture above. If you follow the black arrows symbolizing current flow, you clearly see that the top of the left cell is connected to the bottom of the right cell; we have a series connection.

- If you look at the red circles, you see also that we three nominal short circuits in this structure:
  - The **ZnO:Al** layer, which is the front side "conductor" here, short circuits the junction formed by the **CIGS** and the **CdS/i-ZnO**.
  - The **ZnO:Al** layer also short circuits to the backside contact via the **CIGS** layer.
  - Both cells are short-circuited at the backside via the **Mo** layer overlap.
- This doesn't seem to make much sense. However, the short-circuits for the real thing are only nominal. In reality they have very high resistances (partially because the overlap areas are tiny) and therefore can be tolerated. If we accept this without further proof, a question still remains:
- Why? Why is this connection structure not made in a way that avoids these nominal short circuits? Even it they don't matter much, wouldn't it be better to stay on the safe side?
- The answer is: No! The way its done is the best - all things considered. One could easily draw cross-sections of smarter structures, but don't forget, you have to make them - cheaply and quickly. This leads to a little exercise:

Exercise 8_3_1
Making in-situ series connections

By now you should be utterly confused - and that is the point: What we see here (again) is that the simple issue of making solar cells, very simple devices after all, immediately blows up into your face and gets rather complicated if you look at any "detail".

- We will not go into more details here, but keep in mind that thin film solar cells *modules* are quite different from bulk **Si** solar cell modules.

Building and Running a Thin film Solar Module Factory

So your laboratory-scale process for a novel thin film solar cell has been very successful.- you can make something like **(5 × 5) cm^2** solar cells that have a decent efficiency of **η = 15 %** and can be made by what appears to be cheap processes.

- All that remains to be done is to built and equip a small (pilot) factory, capable of producing, let's say, solar cells good for **10 MW$_p$** per year. Having in mind that it takes about **8 m^2** for **1 kW$_p$**; we are talking about **8.000 m^2** solar cell area per year, or **22 m^2** per day. You want to process **1 m^2** at a time, i.e. make a whole module in one go.
- Where do you buy the layer deposition equipment and whatever else you need? The companies serving the microelectronic community can't offer anything for that kind of area. Companies making equipment for flat panel displays are more on target, but they don't know, for example, how to deposit **CdS**.
- And no company out there can help you with what ever it takes to do the in-situ series connections.

Your only choice left in the beginning it to make your own equipment, optimally in cooperation with some company that has a solid background in the general area.

- After you did that, and it works, you do what? you keep it to yourself!

- Keeping this in mind, you understand why there is so little information around about how you actually make thin film solar cells on a large scale, and why there are some many variants of any process discussed in the literature.

What we are witnessing is an evolutionary process - trial and error - where competition on any level and survival of the fittest determines the outcome - and this is not necessarily what "pure" science would have chosen.