ET3034TUx - 5.4 - CdTe PV Technology

A third thin-film technology we will discuss is the cadmium telluride.

This thin-film technology which has currently demonstrated the lowest cost price per Wp among all PV technologies.

Let's start with the physical properties of CdTe.

This semiconductor material consists of the II-valence electron element cadmium and the VI-valence element tellurium.

Its network is a cubic tetrahedrally lattice structure, where every Cd atom is bonded to a Te atom.

A lot of the research activities on CdTe have taken place on industrial level and First Solar is the leading company in the CdTe technology.

The band gap of CdTe is 1.44 eV, a value which lies within the optimal range of band gaps for a single junction solar cell.

CdTe has a direct band gap, consequently only a few microns of CdTe is required to absorb all the photons with an energy higher than the band gap.

It means that the diffusion length for the charge carriers has to be in the same order to have the light-excited charge carriers collected at the contact.

N-doping of CdTe can be achieved by replacing the II-valence atom Cd with a III-valence electron atom like aluminum, gallium and indium.

These elements act as shallow donors.

N-doping is achieved as well by replacing the VI-valence tellurium atom with a VII-valence electron element like fluorine, chlorine, bromine and iodine atoms.

They act as shallow acceptors.

A tellurium vacancy acts like a donor as well.

P-doping of CdTe can be achieved by replacing the II-valence atom Cd with a I-valence electron atom like copper, silver or gold.

These elements act as a shallow acceptor.

P-doping is achieved as well by replacing a VI-valence tellurium atom with a V-valence electron element like nitrogen, phosporous, arsenicum.

They act as shallow acceptors.

A cadmium vacancy acts like an acceptor as well.

In solar cells p-doped CdTe is used, however, it is difficult to give CdTe a very high doping level.

The structure of a typical CdTe solar cell looks like this.

On a glass the transparent front contact is deposited.

This can be tin oxide or cadmium stannate, which are CdSnO alloys.

On top of that, the n-layer is deposited which is a cadmium sulfide layer, similar to the n-buffer layer in CIGS solar cells.

On top of that, a p-type CdTe absorber layer is deposited with typical thickness of a few microns.

Making a good back contact on CdTe is rather challenging, the material properties of CdTe do not allow a large choice of acceptable metals.

Heavily doping the contact area with a semiconductor material improves the contact, however, achieving high doping levels in CdTe is problematic.

Copper containing contacts have been used as back contacts, however, in long time scales they may face instability problems due to the diffusion of copper through the CdTe layer up to the CdS buffer layer.

Nowadays a stable antimony telluride layer in combination with molybdenum is used.

Here you see the band diagram of a CdTe solar cell.

The p-type semiconductor CdTe has a band gap of 1.45 eV, whereas the n-type CdS has a bandgap of 2.4 eV.

Consequently, the junction is a heterojunction, similar to the CIGS PV device.

The light-excited minority electrons in the p-layer are separated at the heterojunction and collected at the TCO-based front contact.

The holes are collected at the back contact.

An important concept I did not discuss for thin-film solar cells is the two types of solar cell configurations: the superstrate and the substrate configuration.

A superstrate configuration is a cell concept in which the substrate on which the solar cell is processed acts as the front window at which the light enters the solar cell.

A substrate configuration is that either the substrate acts like a back contact or the back contact is deposited on the substrate.

Consequently, no light will pass through the substrate.

The light enters through a TCO layer deposited on top of the n-type CdS layer.

Compare this to, for instance the thin-film silicon we discussed earlier.

A p-i-n junction is considered as a superstrate configuration, whereas a n-i-p junction is a substrate configuration.

The CdS/CdTe layers are in general processed using the closed space sublimation method.

In a closed space sublimation method, the source and the substrate are placed at a short distance from each other, like a few mms up to cms under vacuum conditions.

Both, the source and the substrate are heated.

The source can be granulates or powders of CdTe.

An inert carrier gas like argon or nitrogen can be used.

The source is at a higher temperature as the substrate, and induces driven force on the precursors, which are deposited on the substrate.

The bulk p-type CdTe is formed.

First Solar and Antec are companies producing the CdTe solar modules using the closed space sublimation method.

Among new start-ups moving into the CdTe PV technology are Calyxo, Prime Star Solar from General Electric, and Abound Solar.

However, First Solar is by far the largest CdTe manufacturer in the world nowadays.

From 2008, First Solar has an annual production rate of 500 MW and more and was in 2006 and 2007 one of the biggest solar module manufacturers in the world.

The record conversion efficiency of lab-scale solar cells is 18.7% as obtained by First Solar in 2013.

The open-circuit voltage of the record cell is 852 mV, the short-circuit current density is 28.6 mA/cm^2 with a FF of 76.7%.

General Electric achieved in the same year an efficiency of 18.3%.

NREL has confirmed a new record conversion efficiency for a CdTe solar module of First Solar of 16.1%.

The current cost price per Wp of the First Solar products is in the order of 68 to 70 dollar cents per Wp and is expected to drop to 40 dollar cent per Wp in the future, keeping the cost price per Wp lower than the solar modules based on crystalline wafers.

An important aspect to be addressed is that the CdTe solar cells contain the toxic material Cd, however, the insoluble Cd compounds like CdTe and CdS are much less toxic.

It is important to prevent cadmium entering into the ecosystem.

The question is whether the CdTe modules would be a main source of Cd pollution.

A 2 GW/year production capacity, as installed by First Solar at the moment, would take up around 2% of the total Cd consumption by the industry and would not yet be a dominant contributor.

Nevertheless, recycling schemes have been set up for installed CdTe solar modules.

For instance, First Solar has a recycling scheme in which a deposit of 5 dollar cents per Wp is included, which covers the cost for the recycling at the end of the modules lifetime.

Maybe the biggest challenge for the CdTe will be the supply of Te.

Here we see again the illustration that shows the abundance of the various elements in the Earth's crust.

As you can see, tellurium is not a very abundant element, so tellurium supply might be the limiting step to upscale the CdTe PV technology to future terawatt scales.

On the other hand, tellurium as source material has only had a few users, and therefore a dedicated mining of tellurium has not been explored.

In addition, new supplies of tellurium-rich ores have been found in Xinju in China.

So at this moment it is not clear to which extent the CdTe PV technology might be limited by the tellurium supply.

So far we have discussed the inorganic thin-film semiconductor materials like amorphous and nanocrystalline silicon, CIGS and CdTe solar cells.

In the next block we are going to look at organic and dye-sensitized solar cells.

See you in the next block.