Solar Photovoltaics: Principles, Technologies & Materials
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Lecture - 37
Generation II Technologies: CIGS and Multijunction Solar Cells

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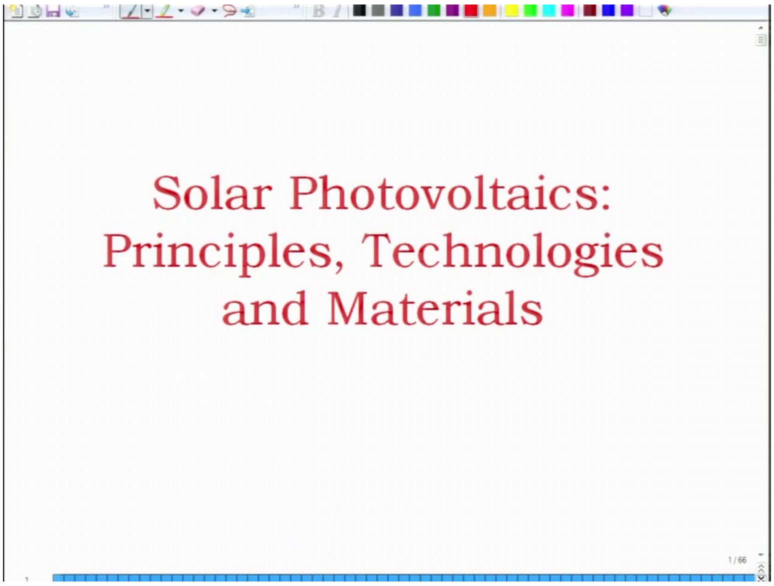

So, welcome again to the new lecture of this course solar photovoltaics principles, technologies and materials. So, we will just do a brief recap to begin with and then move on with the remaining part of the lecture.

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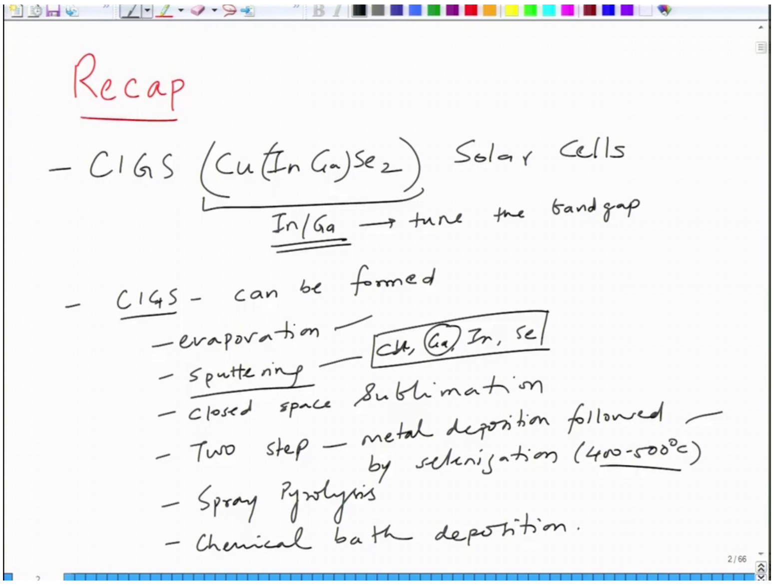

In that in the last lecture we talked about CIGS or Copper Indium Gallium Solenoid solar cells and these materials this is the interesting material. Because, by changing the ratio of indium to gallium one can tune the band gap and this material; again it has a similar structure to the to CdTe solar cells.

And, CIGS layers as we saw last in the last lecture can be formed by various processes including evaporation, sputtering, closed space sublimation. And, then also using chemical processes such as cvd sorry; I think we looked at the two step processes basically two step process where you deposit the metal layer first and then followed by the salinization.

So, metal deposition followed by salinization and in these solar cells salinization is very important aspect because, selenium vacancies deficiency of selenium can lead to poor devices. And, which is turn at about 400-500 degree centigrade which is a fairly high temperature. And so, and one can also do these by spray pyrolysis etcetera as well as a chemical bath deposition, chemical bath deposition. So, these are various processes through which you can deposit CIGS. We have looked at evaporation we looked at two step process in some detail and the remaining processes are well understandable, sputtering we have discussed in case of CdTe which is fairly similar in this case also.

So, all you are going to need to have is four targets of one of one of cadmium copper one of gallium one of indium one of selenium. So, gallium of course, is not present in its a metal which is in liquid form. So, it has to be at room temperature in liquid form. So, you have to form you have to sputter it from a compound source. So, as a result sputtering main required to be done from the compound sources and then of course, when the plasma species reach on the reach the surface of the substrate, they reacted from the compound.

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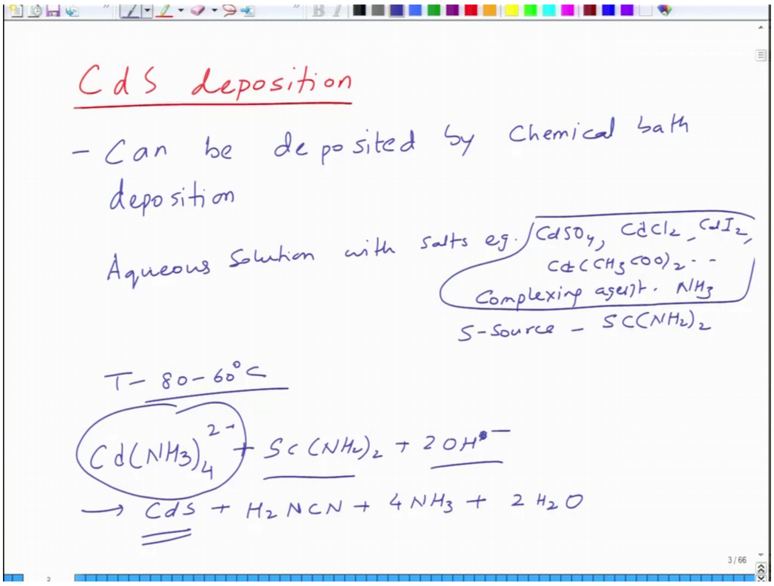

So, these are various processes by which you can synthesize CIGS. If you look at CdS deposition, CdS can be deposited by chemical bath deposition essentially what you have here is basically you have aqueous solution with salts of cadmium, such as cadmium and sulfur, such as cadmium sulfate. You can have cadmium chloride as well sorry and you can have cadmium iodide etcetera. So, these are the salts of cadmium cadmium acetate etcetera.

And in these so, this is a cadmium salt then we use a complexing agent of ammonia and then sulfur source is essentially thiourea that is SC NH 2 twice. And, these are basically deposited these are basically stirred in a chamber and then you put a substrate there and on this you can deposit at a certain temperature and the temperature is about 80 to 60 degree centigrade.

So, at this temperature the reaction occurs and the reaction rate, but can be controlled by things like temperature and concentration of the salts and that you have to optimize and this leads to the position of cadmium sulfide this is also valid for by the way cadmium telluride solar cells.

So, the reaction that takes place is Cd NH 3 4 2 minus plus SC NH 2 2 plus 2 OH minus minus they give rise to CdS plus H 2 NCN plus 4 NH 3 plus 2 H 2 O. So, essentially using these two you make the, you make complex salt of cadmium in ammonia. This is thiourea, this is from water and this gives rise to your cadmium sulfide which is the final compound. So, this is the method of growth of CdS in CIGS solar cell.

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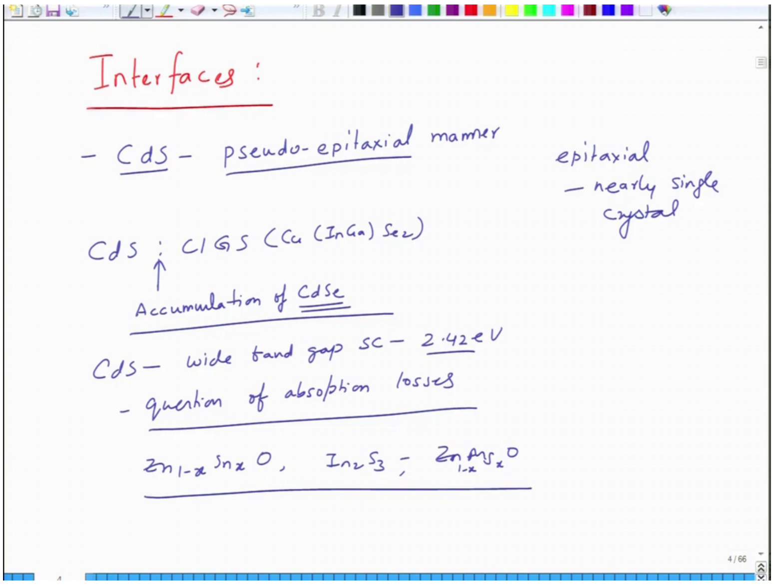

Now, the important thing in these solar cells is the role of interfaces. So, since you have first is the growth of CdS. So, CdS is something which needs to be grown in sort of pseudo epitaxial manner, pseudo epitaxial means epitaxy epitaxial would mean nearly single crystal films. So, which means all the regions in the film will be at the same orientation. Pseudo epitaxial will be sort of nearly close to being epitaxial, but not quite there.

So, it is somewhere between poly crystalline and single crystal films sort of textured films and what happens is that in these cases CdS. So, if you have CdS next to CIGS, CIGS is copper indium gallium Se 2; the problem that happens is that you tend to have at the interface accumulation of CdS e. This tends to accumulate at the interface and this also tends to reduce the performance of the solar cell.

So, this can be a issue in these solar cells and we need to avoid this by appropriate designing appropriate temperature. And CdS also has it since, it is a cadmium sulfide is wide band gap semiconductor with a band gap of 2.4 2 e V this leads to some absorption loss in the cell current. So, there is a little bit of question of absorption losses in the short wavelength range.

So, people have tried to look for alternatives of various serious things like you know things like zinc, tin oxide, indium solenoid etcetera they been researched to look for an alternative towards forming even zinc magnesium oxide ZnMgO. So, these have been tried to replace CdS; however, CdS is the most used material in case of these films.

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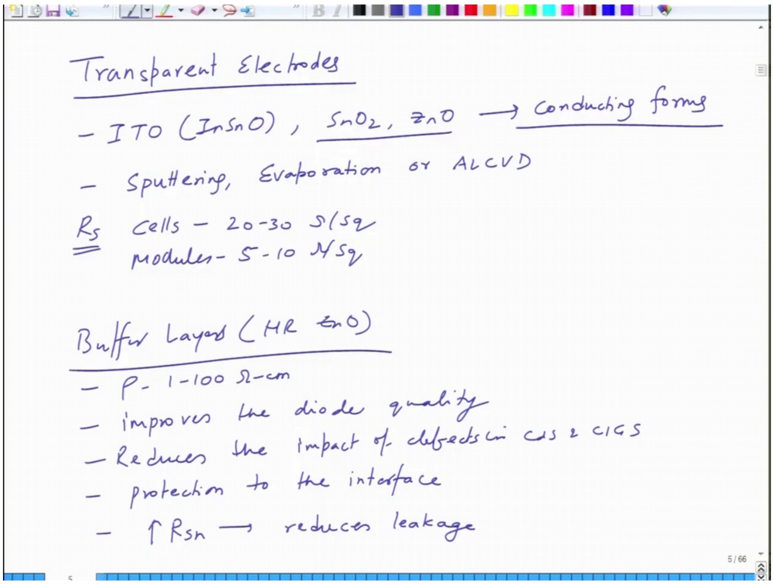

Now, other materials so, if you look for transparent electrodes in these cases. So, transparent electrodes generally we use indium tin oxide, indium tin oxide or tin oxide doped tin oxide or zinc oxide. So, these are transparent electrodes which should be conducting ok; so, these are all conducting conducting forms. So, the composition is such that they are conducting, they are generally made by either sputtering or evaporation or ALCVD that is Atomic Layer Chemical Vapor Deposition the sheet resistance of these electrodes in the cells about 20 to 30 ohms per square. So, R s of electrodes whereas, in modules modules already have parasitic losses so, resistance is lower which is 5 to 10 ohms per square.

The buffer layers are generally so, on top we use buffer layers of high resistivity ZnO. So, high resistivity ZnO has a row of about 1 to 100 ohm centimeter and this basically reduces the defect density at the interfaces and this improves the diode quality. You can say it reduces the impact of defects in CdS layer as well as in CIGS and it also provides protection to the interface. And, it leads to increases the shunt resistance and hence reduces the leakage. So, these are some attributes of high resistance zinc oxide layer that we use these devices.

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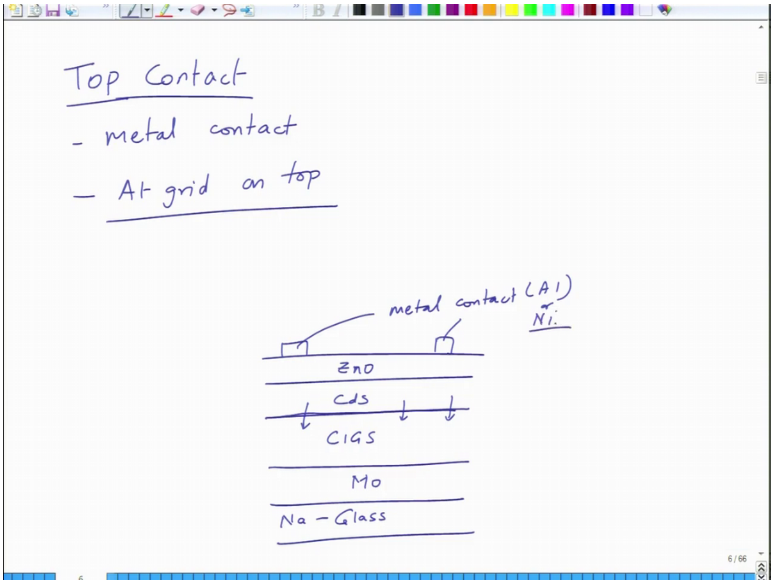

And then we have top contact so, top contact on these cells is of. So, basically I it is a metal contact and you can have a aluminum grid on top and generally it is done through a shadow mask. So, if I just draw the structure of this device again, if you recall the structure was like this so, you had soda lime glass. So, this was glass sodium containing glass, then we have moli which is the back contact, then we have CIGS, then we have CdS.

So, in this case CdS is deposited after c CIGS is deposited. So, that is why when you deposit CdS on CIGS the diffusion of the compound formation takes place at the interface and CdS diffusion into CIGS may occur. And, then we have ZnO and then on top we have these metal contacts which is let us say aluminium or it could also be nickel.

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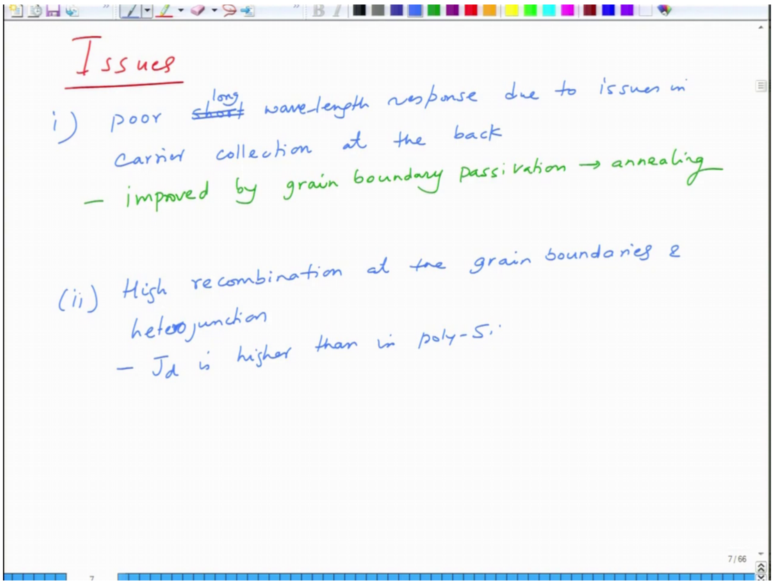

These solar cells have certain issues, the issues are number 1; there is a poor short wavelength response, sorry poor long wavelength response spectral response due to problems in due to issues in carrier collection at the back. So, on the moli side carrier collection is poor and this can be improved by grain boundary passivation. So, adopting appropriate heat treatment strategies due to by annealing ok. Then second issue that comes is high recombination in grain boundaries at the grain boundaries and heterojunction, since it is a heterojunction the recombination is more. And so, basically the J d is higher than then in polysilicon. So, this is the issue and so, these are certain issues in these solar cells.

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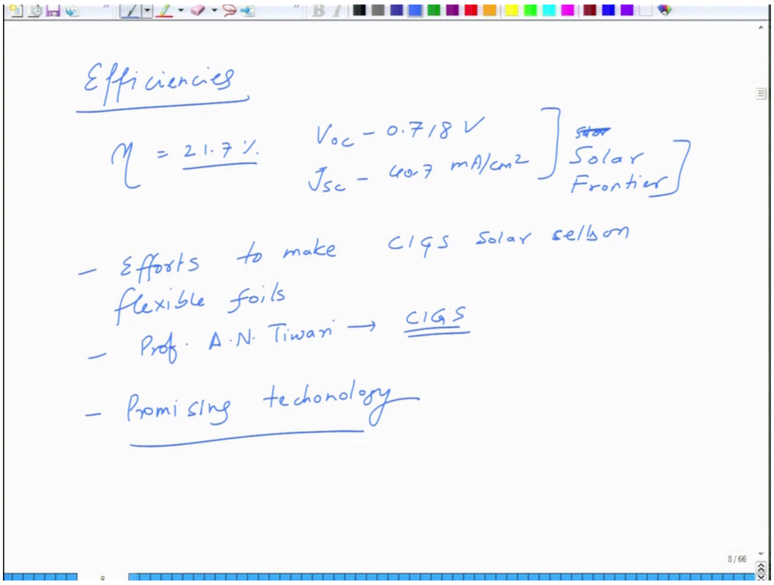

And so, I as I said the efficiency of these solar cells have increased to the efficiencies have increased to 21.7 percent approximately with the V oc of nearly 0.718 volt and J sc of nearly 40.7 milliamps per centimeter square. This is at the lab scale so, modules are lower and this is made by solar frontier solar frontier. So, but this is a and there are also efforts to make solar cells on efforts to make CIGS solar cells on flexible foils.

So, for example and in Switzerland Professor A. N. Tiwari he is leading he is a one of the world leaders in CIGS solar cells in Switzerland. So, lot of work has been done, but say it says it is a promising technology for future and could be commercialized in near future. So, this is about CIGS solar cells that we have looked over past one and a half lecture or so.

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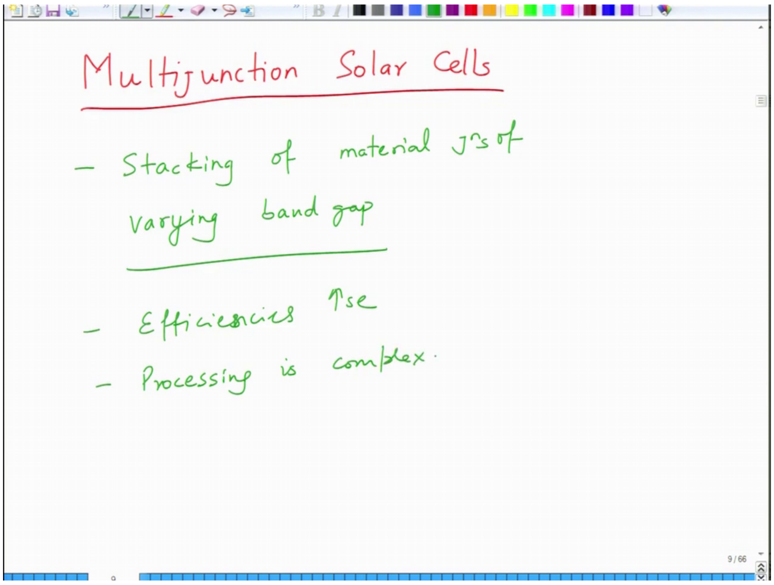

Now, what we discuss is we move on to just a quick overview of multi junction solar cell before we go to Gen III technologies ok. Multi junction is something which basically takes care of multiple band gaps within a structure. So, that you can harness from long to medium to short wavelengths all together thereby increasing the performance of the solar cell.

So, essentially the idea is to use because, in a silicon solar cell or in a CIGS solar cell, in CdTe solar cell is only one band gap. So, it means anything any energy which is lower than the band gap is not going to be harnessed.

So, if you can use multiple materials with varying band gaps in a stack that offers you promise of using promise of giving you higher efficiencies. And for example, theoretically if you can have infinite combination of band gap efficiencies can be as higher than 85 percent. So, that is where a lot of effort has been. So, basically its about stacking of material junctions of varying band gap. However, the while the so efficiency is improve increase, but processing also becomes very complex.

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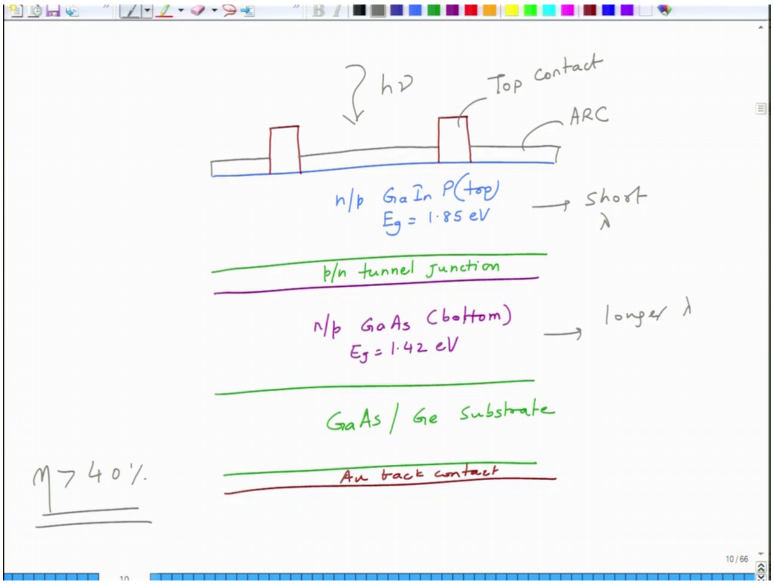

So, example of this solar cell for instance is let us say we have we have a gallium arsenide substrate. So, this is a so lot of work has been done on multi junction on gallium arsenide based substrates because, gallium arsenide is tunable; you can add you can dope with the indium or aluminium change the band gap. And as a result it is a very so, gallium arsenide or germanium substrate on the back you put a metal contact. So, this is a metal contact of gold and then we have on the top we have we can say n p gallium arsenide bottom cell at the bottom and this has a band gap of 1.42 eV.

Then we have a p n tunnel junction. So, we have a p n tunnel junction and then we have another top cell. So, we have a top cell which is of n p let us say gallium indium phosphide and this has a band gap of 1.85 eV and then we put anti-reflection coating on top and we put electrodes. So, we have these top electrodes. So, these are and we also have a these anti-reflection coatings. So, we put ARC and this is top contact. So, this is how so, basically when the light comes so, when the light comes this absorbs short lambda and this absorbs longer lambda.

So, this is just two band gap, you can have multiple band gaps and these solar cells give you efficiencies if you look at the efficiency chart, efficiency have crossed 40 percent now. So, these multi junction solar cells have efficiencies. So, various combinations have given you efficiency is higher than 40 percent, but they are very expensive because, making them is not easier you need to have precise layers in between you need to have you need to prevent the shorting of cells and so on and so forth.

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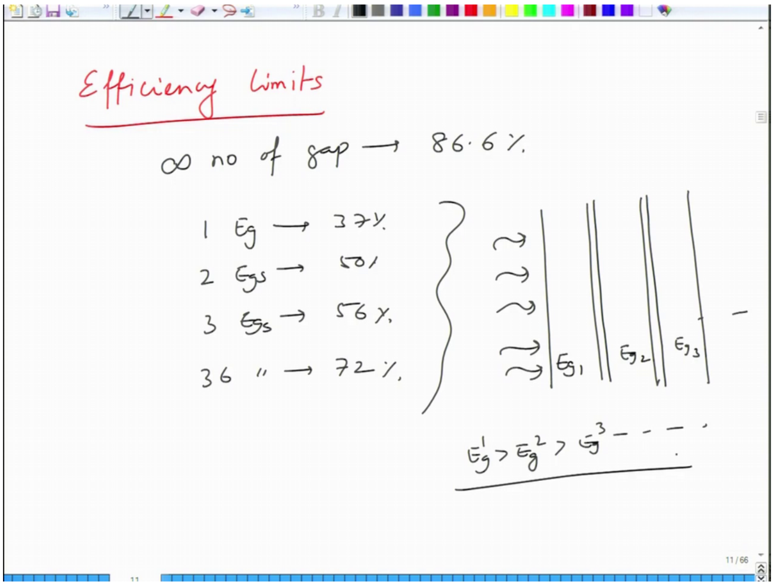

So, if you say as we as we saw earlier that efficiency limit, if you have infinite number of gaps then efficiency limit is 86.6 percent. However, if you have one band gap then we have 37 percent, nearly if you have 2 Egs then we have about 50 percent. If you have three band gaps then you have about 56 percent, if you have 36 band gaps then it is about 72 percent.

So, you can increase this number very close to and generally the way it is stacked is; so, you have the first junction and you have a separator, then you have second junction, then you have a separator and then again. So, this is how so, if your light is coming from this side. So, let us say this is Eg 1, this is Eg 2, this is Eg 3 and so on and so forth.

So, Eg 1 is greater than Eg 2 is greater than Eg 3 and so on and so forth. So, basically you are putting the highest band gap on top and lowest band gap at the bottom. So, that short wavelengths have absorbed on the top and longer wavelengths are absorbed at the bottom. So, for instance we can have a combination of indium gallium phosphide, indium gallium arsenide, indium gallium arsenide, indium gallium arsenide and indium phosphide indium arsenide; this is a very good combination three junction cell that can give you fairly good efficiencies in these solar cells.

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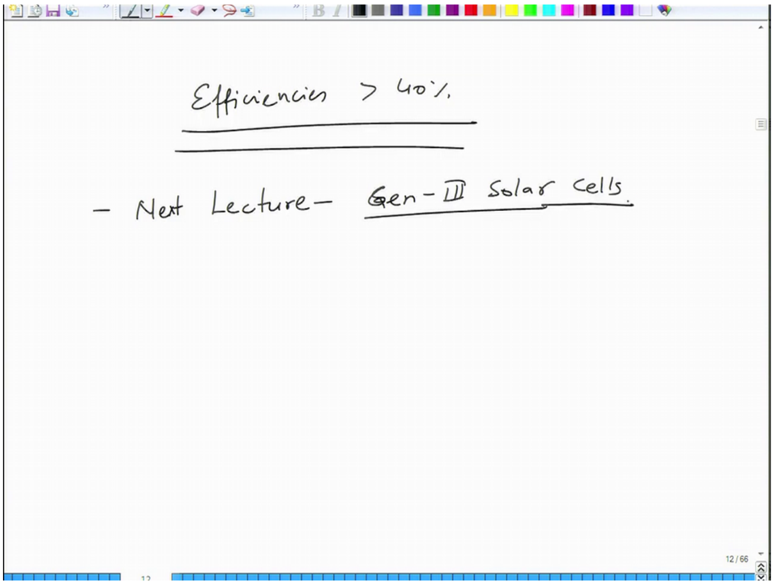

So, multi junction efficiencies as we said have exceeded have exceeded 40 percent practically speaking. So, before now the next lecture in the next lecture now we are going to start Gen III solar cells. So, before we start and Gen next lecture let me just summarize now this part.

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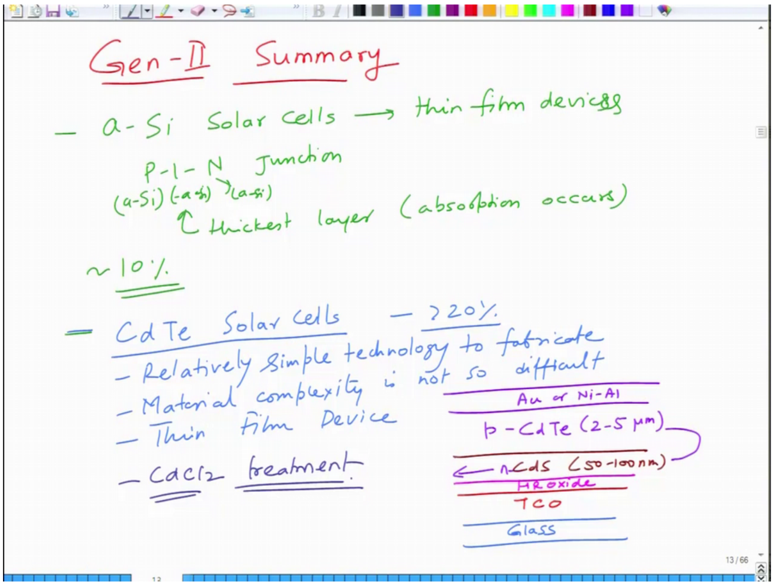

So, in Gen II so, in the Gen II we first started our discussion with amorphous silicon solar cells, amorphous silicon is a thin film solar cell which is which is based on P-I-N junction. So, you have P silicon, you have I amorphous silicon and then you have N amorphous silicon alright. P and N are very thin and a is the thickest layer where, I is the thickest layer where most of the absorption occurs right. These solar cells give you efficiency of the order of about 10 percent. Then we looked at so, this was interesting technology at a time, but now it is not so, much in favor.

Then the second thing that we looked at was CdTe solar cells, CdTe solar cell is a technology which is wonderful technology because, it gives you efficiency is more than 20 percent right now. It is a relatively simple relatively simple technology to make, to fabricate material complexity is less because it is a binary compound of cadmium tellurium. So, material complexity is not so, difficult and it is a thin film device and the structure that we saw so, in this case we had so, if you have a glass substrate. So, this was glass on top of glass we had a layer of let us say TCO, then we had a sort of high resistivity oxide layer..

On top of this we have a cadmium sulfide window layer which is 50 to 100 nanometer and then we had a layer of CdTe which is about 2 to 5 micron and on top of this we had so, this is n type n CdS, this is p CdTe this is what is p n junction. And, then on top of CdTe we had a gold contact or you know nickel aluminum contact ok.

So, in this case you can see that on top of oxide on the glass we have TCO on the TCO we have oxide, then we have CdS, then we have CdTe. So, CdTe so, deposition is done after the CdS is deposited. So, here that is the difference you have to note that (Refer Time: 26:56) is deposited after CdS, I said relatively simple structure.

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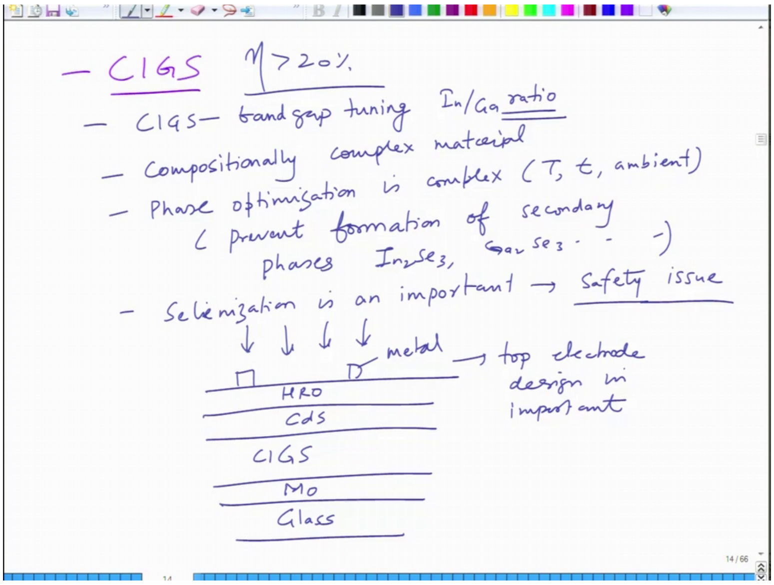

If you look at CIGS that is what other technology that we looked at, CIGS efficiency is again more than 20 percent as of now. CIGS offers you very good band gap tuning by changing indium gallium ratio ok. So, you can go from 1 electron volt nearly to slightly higher voltages, you do not go to very higher very high V oc's, but the V oc's are very high band gaps, but you stay around 1.1 or so. And, that is what gives you the optimum performance and this one more thing which I wanted to mention in CdTe, CdTe has important thing of cadmium chloride treatment.

So, this cadmium chloride treatment is very vital to improve the performance of CdTe solar cell. So, in CIGS as we are talking about in CIGS this is the however, its a compositionally complex material. So, phase optimization is complex. So, one needs to have right temperature time and ambient to synthesize the correct phase, otherwise you are you end up farming and the binary and ternary compounds which are not CIGS. So, you have to prevent formation of secondary phases and these secondary phases are basically you can have In 2 S e 3, you can have Ga 2 S e 3 and so on and so forth, variety of these compounds can form ok.

Selenium salinization is the important step which is also a safety issue because, dealing with selenium requires you to have safety protocols. So, safety is an issue here; however, nevertheless CIGS is an interesting technology. And in CIGS you have glass on top of this we deposit a moly contact and on this molly we deposit CIGS. So, you can see that the difference here is that on glass we have moly and moly is a opaque metal as a result CIGS is deposited on top, CdS is deposited on the top of CIGS. So, you can see that CdS deposition is after the CIGS deposition. So, this is a difference with respect to (Refer Time: 30:01) and then of course, you have a high resistance oxide layer and then you have metal contacts.

So, here the light comes from top so, as a result the optimization or top grid is important just like in silicon ok. Because, light cannot come from the glass slide because you have a metal electrode on top of it. So, here top electrode design is important and then we looked at multi junction solar cells which are nothing, but the combination of various band gaps.

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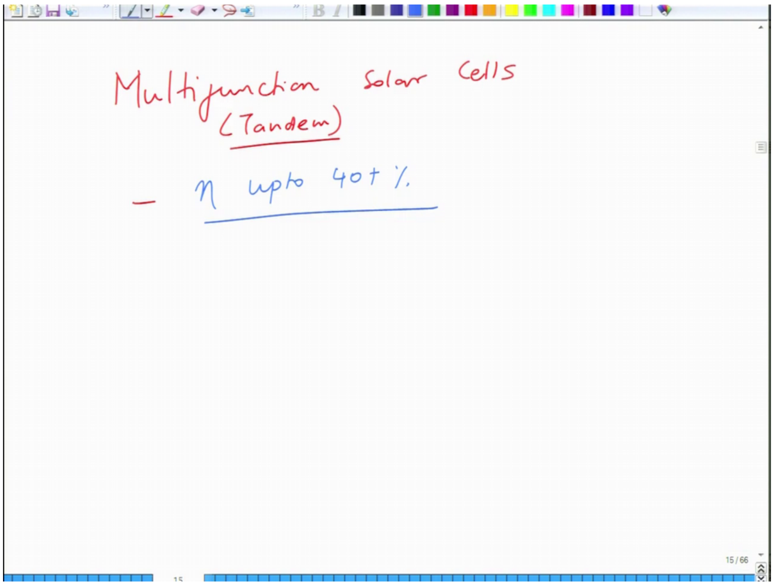

And, I can say these are tandem solar cells in you can say tandem cells in which you put in multiple band gaps in tandem and you increase the efficiency up to 40 plus percent. So, between 40 and 50 percent have been achieved by combining various materials of different so, this is what is summary of Gen II solar cells and I have already told you the books which books you have to go through. There are two good books good books that is Handbook of Photovoltaic Science and Technology and Thin-Film Solar Cells; these are two good books for learning about the solar cell technologies.

So, we finish here, in the next lecture we will talk we will start our discussion on Gen III devices.

Thank you.