Solar Photovoltaics: Principles, Technologies and Materials

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Lecture – 30
Generation I Technologies (Poly Silicon Solar Cells)

So, welcome again to the new lecture of Solar Photovoltaics: Principles, Technologies and Materials. So, let us just do a bit of recap.

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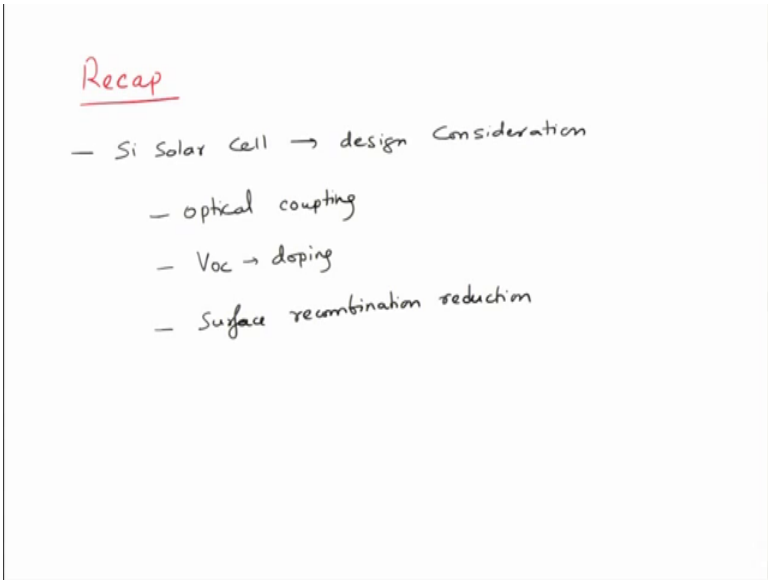

So, in the last lecture we did discussion on silicon solar cell. So, basically we looked at the design considerations as to what must make a device good. So, we will talked about improving the optical coupling of light. So, basically more light should be absorbed into the device. We looked at the strategies do that we can do that by texturing you can do that by minimizing the electrode coverage on the surface by burying the electrodes into the solar cell and then you can also put a passivity you can also look antireflection coating on top which will reduce the reflection.

And then we also look that how to improve the voc by doping, but doping cannot be indiscriminately large because it also reduces the carrier diffusion length as a result your doc current increases. So, there is optimum doping that one can do and then we also look that the surface recombination reduction strategies as to how to reduce the surface recombination to make a good solar cell. We will again dwell we will we have a few more things to talk about the silicon solar cells before we go to polycrystalline silicon solar cells.

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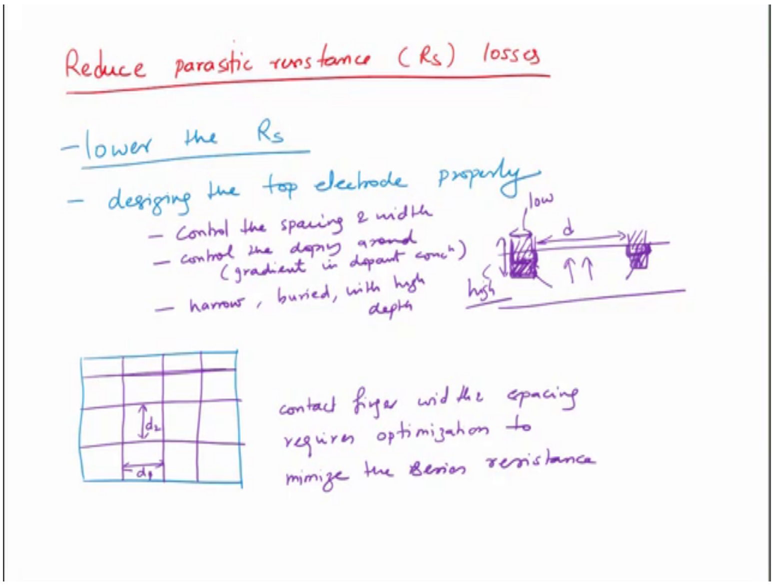

So, the next thing in improving the performance in the performance of a solar is to reduce the parasitic resistance losses and first we will talk about series resistance. So, basically the idea is to you can say the idea is to lower the lower the series resistance. This is the important thing and this is done by basically designing the this is mostly about the top electrode top electrode properly. Now what happens is that if I look at the top of the device if I look at the top view of the device top view of the device will have these contacts. So, these are the contacts ok. So, you have these lines running here.

Now, you want to design these lines in such a manner so that they do not cover top of the surface, but at the same time. So, the distance between these lines is extremely important in. So, we can say this is d 1 d 2. So, this contact finger width and spacing requires optimization to reduce to minimize the series resistance. If you are if contacts are very far from each other then again the collection is poor because you know if you can see that if you if you have this is a device and let us say one contact is here, one contact is there. Carriers are coming they are getting collected here they are collected here, but if they are too far what happens to the carriers which are in between ok, they do not get collected efficiently.

So, the distance between these contacts is extremely important and the depth up to which they are buried into silicon is also extremely important. So, one needs to control the so, what do what one needs to control is control that spacing. Spacing means both the width and the spacing, but one also needs to control the doping around it. So, the doping around the contact as I said that there is a gradient in doping the it is not a same doping all throughout. So, basically you can say there is a gradient in dopant concentration around the contact ok.

And generally these contacts are narrow they are narrow on top, but they are they are buried which means with high depth. So, they make a good contact by going deep into the end layer, but they are they are spread on the top is low. So, if you look at the top view this is low and this is high and this is extremely important to improve the charge collection. So, what we are what is important from the perspective of series resistance is to make it go as deep as possible. Of course you cannot make it very deep because end layer itself is very thin. So, you have to optimize the depth.

. So, make it make it go reasonably deep make it narrow on top and optimize the distance between these two. So, that carriers are efficiently collected there should be no carriers which are not collected if they are too far then of course, series resistance will increase they are not carriers in the middle will not get collected. So, you need to optimize this. So, you need to optimize that the width of the contact you need to optimize the spacing between the contact and you need to optimize the depth of the contact. These are essential parameters to minimize the series resistance.

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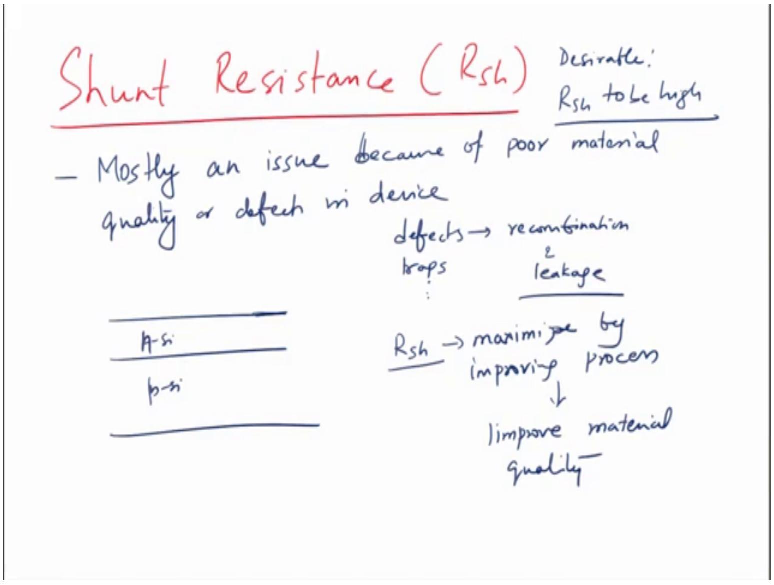

And if you look at the shunt resistance on the other hand, so, if you look at the shunt resistance is mostly a problem. So, basically we want R s h to be to be high that is the desirable whereas, R s h should be lower. So, this is mostly an issue because of poor material quality or defects in devices. So, you can see that you have a p n junction here. So, this is p silicon this is n sorry this is n silicon this is p silicon. If you do not if the vapour quality is not very good, if you have excessive amount of defects in the in the device the defects leads to defects or traps will lead to recombination defects traps etcetera will lead to recombination and leakage.

So, idea is to lower maximize R s h by improving process quality, improving the process which leads to improved material quality. So, basically your leakage current should be smaller and this is mainly to do with the control of process and material quality as instead of design. So, it is less of a concern from the design perspective but if it is more of a concern from the processing and material quality perspective ok and based on these guidelines there are few kinds of solar cells people have made.

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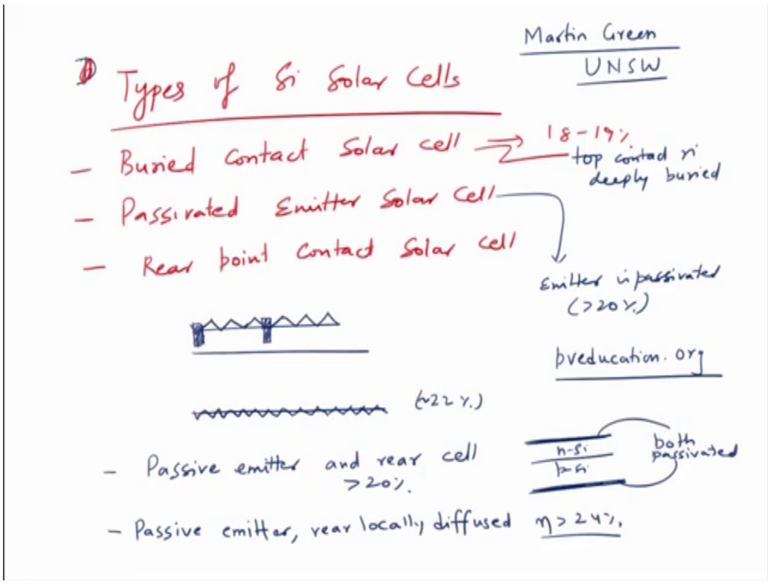

So, you can say types of silicon solar cells; there is something called as buried contact solar cell, there is something called as passive passivated emitter solar cell something called as rear point contact. So, buried contact have efficiencies of the order of 18 to 19 percent. In this what happens is that the contact is buried. So, basically the top contact is the top contact is deeply buried all right.

In case of passivated emitter the emitter is strongly passivated. So, emitter is that is the top silicon. So, you have a thin oxide layer on top which is there in most cases, but so, these have efficiencies of the order of about 20 percent and higher. Rear point contacts sometimes people also use a strategies to make the point contact on the back. So, on the back the contact is like this sorry. So, if you have this as a device, so, if this is your device even on the back. So, front surface we know is like this and the contact is buried and so on and so forth ok. In the in the in the in the rear also you can have contact in this fashion.

So, this is point contact at the rear. So, people have done this they have got efficiencies of the order of 22 percent or so ok. And this lot of work has been done in this area by University of New South Wales in Australia. The Professor Martin Green is one of the pioneers in this silicon solar cell area. If you go to his webpage and you can also go to website called as p v education dot org which gives pictures of these solar cells, you can look at them online. And then we have other variations such as passive emitter and rear cell, passive emitter and rear cell. So, passivation is done on both front and the back side. So, even the so, if this is this solar cell even the front surface is passivated and the back surface both are passivated.

So, both passivated. This again gives you efficiencies of more than 20 percent and then we have another one passive emitter. You can see that common theme is passivation of emitter, passivation of emitter is very important because the light comes from the top and end side is thinner as a results the combination there is extremely important, ca[rrier]-surface recombination and rear locally diffused this has efficiency of more than 24 percent.

So, in this case the surface is passivated, but on the backside the contact has p plus doping at the base. So, as a result the base is more heavily doped as compared to the rest of the base. So, near the near the contacts there is heavy doping in the p side and that helps to improve the performance. So, these are certain design variations in the solar cells which are again based on the similar design (Refer Time: 13:15) that we talked in the beginning. So, there are various types of you can see if you can if you can go online and you can have a look at the pictures of the solar cells all resources are available and they will tell you exactly what they look like schematically.

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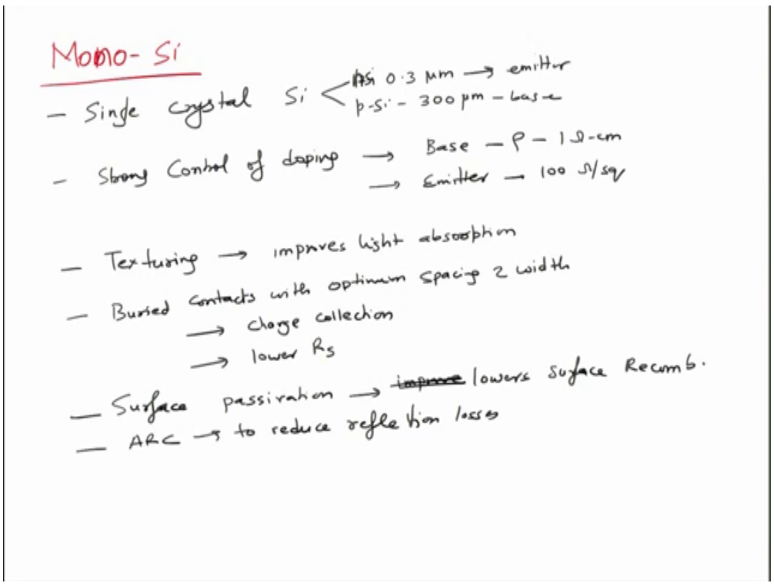

So, if we just make a summary of silicon solar cells or mono silicon solar cells, so, they use single crystal silicon right with p type being about sorry n silicon being which is on the top about 0.3 micron thick and p silicon being about 300 micron thick. So, this is called as emitter and this is called as base and there is a strong control of doping in such a fashion. So, that your base doping base resistivity is about 1 ohm centimetre whereas, the whereas, the top surface which is emitter have the sheet resistance of about 100 ohm per square its very thin that is why we talk in terms of sheet resistance. So, it is about 100 ohms per square.

And it is also improves the it is also important to dope it carefully so, that you have good surface recombination surface characteristics. And then we have surface texturing improves light absorption right. Then we have buried contacts with optimum spacing and width right. This improves the charge collection and lower series resistance ok. And then we have surface passivation we have antireflection coating to reduce reflection losses and this improves sorry lower surface recombination you can say right. So, these are certain things that we need to consider when we talk about silicon solar cells. So, this is about mono silicon.

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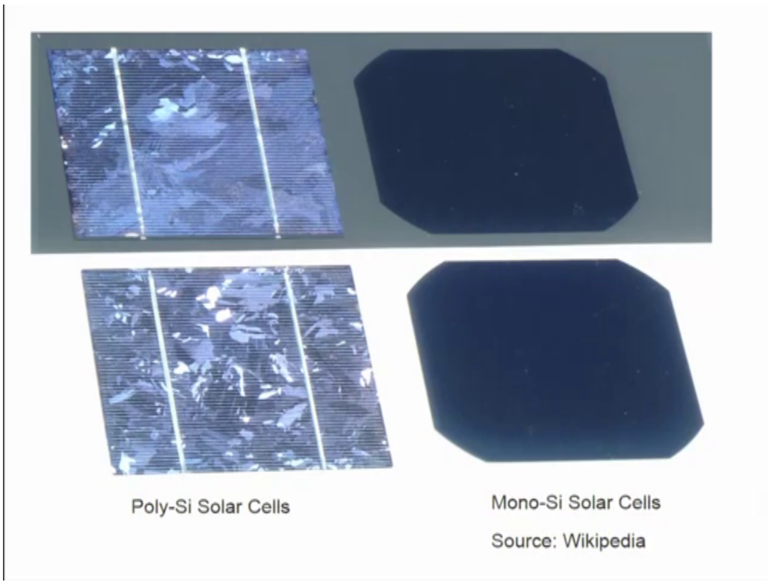

Now let us move on to poly silicon solar cells. So, these are so, when we look at poly silicon solar cells there are distinct differences between the poly silicon is mono silicon solar cell so, this is taken from Wikipedia. The mono silicon solar cell is very dark it has absolute dark thing it has does not have any grains. So, as a results surface contrast is a almost is a dark surface. If you look at the poly silicon because you have grains of different orientation on surface as a result different grains have different reflectivity there is a surface texture and you can see this blue white black kind of texture on the surface. So, this is on the left you have two images which show you the texture of a polycrystalline silicon which is very different to mono crystalline silicon.

. So, this is the distinct difference between the 2 solar cells 2 cells 2 vapors from the perspective of distinguish in them. And so, if you if you come across this you know that is this is a if you come across a textured surface you know that polycrystal poly silicon solar cell. If you come across a very dark looking solar cell you know it is a mono silicon solar cell. And you can see that you have these contact lines on the top these are the fingers and these are again fingers running in this way. So, these are sort of the contacts on the solar cells.

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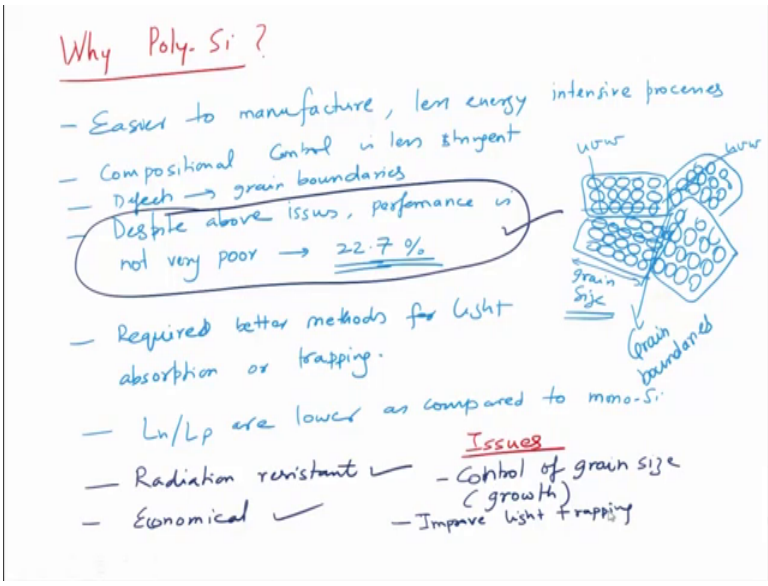

So, what are the major points about say poly silicon why do we want to use poly silicon. We use poly silicon because one easier to manufacture less because of less energy intensive manufacturing single crystals are always difficult to make because dislocations are not easy to get rid of. So, you need to do solidification extremely slowly using (Refer Time: 18:16) method of 4 zone method which are very slow processes of solidification as a result energy cost in is very high in mono silicon and these are low energy intensive processes ok.

And then the composition control is less stringent; however, all this does not lead to despite the above and of course, they have defect such as grain boundaries. So, you will have this atomic arrangement like this in one grain this is one grain in the next grain you will have atomic arrangement like this. This will be next grain and another grain may maybe something like that this is another grain and then here you may have another grain.

So, these are what we called as grain boundaries for grain is the region in which orientation of atoms is similar and a grain boundary is the one which separates two such regions with different orientations. So, in this case you can see the atoms are running in this direction, in this case atoms are running in this direction, or this direction. There is a misorientation in this case the atoms are running in this direction. In this case they are running in this direction, there is a misorientation along same cryptographic direction. So, let us save this is uvw this is uvw the uvws are at different angles with respect to each other in different grains and these regions are grain boundary. So, here what is important is the grain size.

In polycrystalline silicon solar cells generally the grain size is the order of thickness of the device or even larger. So, they have larger big grains they do not have small grains. So, grain boundary effect is minimize. So, despite above issues performance is not very bad is not very poor. So, polycrystalline solar cells as we have seen they have efficiency of nearly 22 to 23 percent as of today. So, which is comparable which is not too bad as compare to mono crystalline silicon solar cell given that you achieve much lower cost and they require they require methods to control require better methods for light absorption or trapping.

Of course, they have grain boundary is they have effects as a result the diffusion names are lower. So, Ln or Lp are lower as compared to mono silicon, but they have, but you can be you have some good things they still have despite above issues they have good performance. They are more radiation resistant. So, this is positive thing and they are economical that is the most important thing for any technology to succeed they are cheaper.

There are certain issues that we need to control. So, so, for example, one needs to control. So, control of grain size is important which means one needs to control the growth of these crystals ok. And you need to improve light trapping remember in silicon say monocrystalline silicon the top surface is all 1, 1, 1 plane and when you texture it everything becomes 1, 1, 1. So, from 1, 1, 1, 0, 0 it becomes sorry I said 1, 1, 1. So, everything is 1, 1, 0, 0 on top when you texture it becomes. So, you have these facets of 1, 1, 1 planes.

So, in single crystals it is easy in polycrystalline you have multiple grains of multiple orientations. So, you require. So, only etching will not work. So, you need to do some other things. So, chemical etching does not does not work you may also do some physical methods to improve the light texturing.

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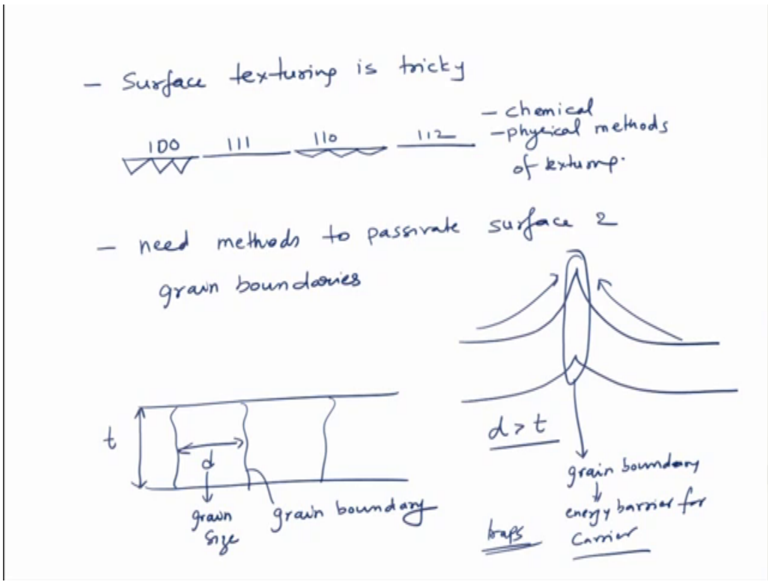

So, texturing of the surface. So, surface texturing is tricky I would say because you have different orientation. So, this is 1,1,1 this could be 1,0,0 this grain could be 1,1,1 this grain could be 1,0,0 this grain could be 1,1, 2 and so on and so forth.

Now, to create the same texturing as you created an single crystal silicon is difficult because chemical texturing works on removal of atoms from certain planes preferentially. So, in this case it might create 1, 1, 1 facet here, but it may not here 1, 1, 1 facet there it will create 1, 1, 1 facet here, but at different angles the angles will be different. So, surface texturing is tricky. So, you need to apply both chemical as well as physical methods to of texturing all right. And you also need to need methods to passivate the surface and grain boundaries and generally the physical characters.

So, the device is like this the grain size. So, if this is s o, this is the grain boundary the device thickness. So, this is device thickness t and this is d ok. So, d is the grain size. So, d is generally larger than t. So, that you do not have horizontal grain boundaries you only have vertical grain boundaries ok. That is generally the consideration that you have an this devices other thing that you often come across is since you have a grain boundary the energy grain boundary leads to formation of energy barrier at the grain boundary.

So, this is grain boundary it forms a energy barrier for carriers and one needs to because it is a internal surface without with dangling bonds as a results take carriers also get trapped. So, these so, it also have has traps. So, you need to passivate these traps grain boundary passivation is extremely important here in the solar cells. So, any carrier will find a barrier here under grain boundary. So, this is the grain boundary region.

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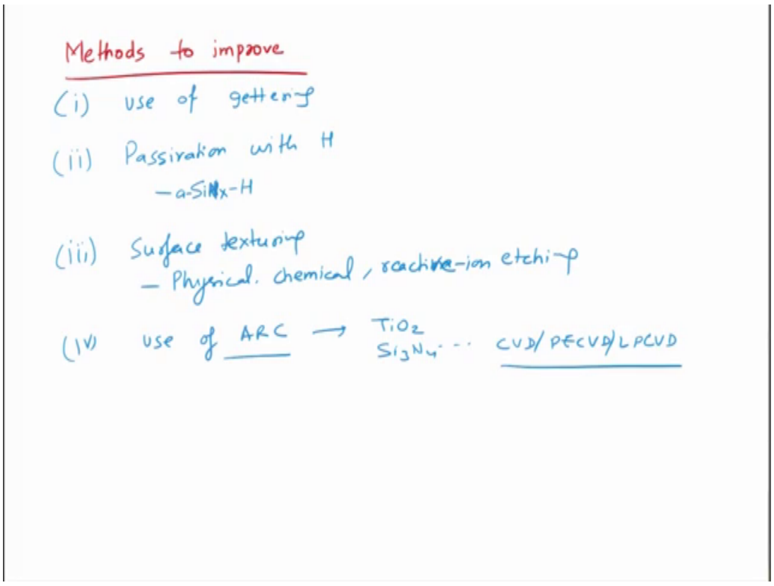

So, what do you do in case of the solar cells to improve the performance? So, methods to improve the performance so, first thing that you do is to use of the gettering gettering is to use of materials which during the processing which remove extra impurities. So, use getter as for example, titanium is a good getter because it sucks up oxygen. So, use of these materials which suck up the impurities so, that you have lower impurities and then you do passivation with hydrogen is a good passivating agent in silicon. So, use of for example, sin x amorphous sin x H for passivation of surface and grain boundaries. Then of course, we do surface texturing as we said using physical and chemical means as well as reactive iron matching etching reactive ion etching.

And then one can also of course, use the use of anti reflection coating on top such as you can have Tio 2 Si 3 and 4 etcetera which are typically CVD PCVD or chemical vapor deposition plasma enhanced CVD or LP CVD that is low pressure CVD processing. So, this is generally the about silicon solar cells polycrystalline and multi crystalline solar cells in the next lecture we will talk bit about the silicon manufacturing how the silicon is manufactured and before we move on to the next generation solar cells ok.

Thank you.