Optoelectronic Materials and Devices
Prof. Dr. Monica Katiyar
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Module - 4
Optoelectronic Device Physics
Lecture - 34
Solar Cells

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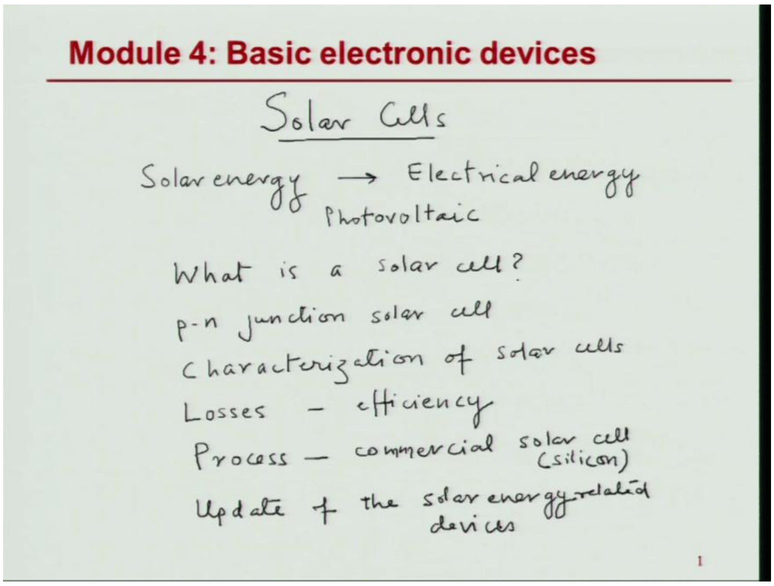

Today our discussion is going to be on Solar Cells. This is a topic which is very pertinent and relevant to today's time, the device has existed for over 50 years, but it is relevance has increased quite a lot in recent times, anything related to energy requirement for environment is related to solar cells. So, in coming years we can see much more activities in this area. Now, solar cell basically is a device, where we are talking about changing the solar energy into a electrical energy directly.

There are many other ways of harnessing solar energy, but this is a specific device, we are talking about where solar energy is converted into a electrical energy, this is also sometimes called as a photovoltaic device or a photovoltaic affect, where photons are creating a voltage inside a device. What I am going to cover in today's lecture is, what is a solar cell? What are it is basic operating principles, then I will cover since we have covered p-n junction in great detail, a simple single p-n junction solar cell and that will help in understanding the operating principle.

So, we will look at p-n junction solar cell, after that we will look at characterization of a solar cell, what are we looking for and how is it related to different material properties. Finally I will like to list all the losses, which limit the efficiency of the solar cell, look at a simple process which is used for making commercial solar cells, this is basically in silicon and give a brief update of the field on where we are right now. So, at the end of the lecture I plan to cover all these topics.

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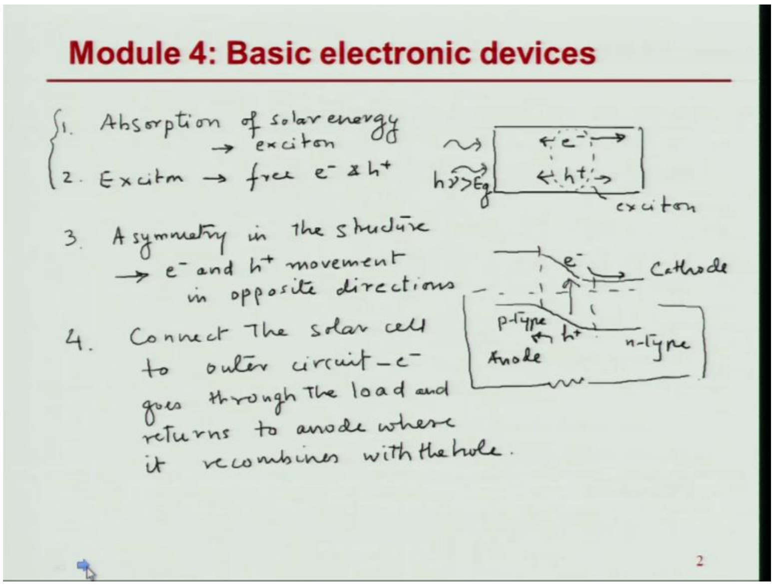

So, first we start with, what is a solar cell? So, as you can see the first step in solar cell is absorption of the solar energy and we have seen this earlier that if I have a semiconductor, by virtue of it is electronic structure, we can create a electron hole pair as long as the incoming energy that I am bringing is, is greater than the band gap of the semiconductor.

So, semiconductor by their material properties are amenable to absorb light, which is greater than their band gap and create a electron hole pair. Generally, this electron hole pair when it is generated, is bound to each other, but it is possible to free them and that is the second step is, to create the from absorption of solar energy we create, what is called as exciton, which are electron and hole celestial bound to each other and the second is from the exciton, we create free electron and holes.

So, basically this can become free, from each other and they can move away from each other, in many processes these two are simultaneous, almost as soon as they are created they can be and can become free while in some materials it is not. So, so sometimes these are combined processes. Now, comes the essential step of the photovoltaic where electronic devices are important, is we we have to have a asymmetry in the structure such that, the asymmetry in the structure it makes sure that the electrons are collected on one end and the holes on the opposite end.

Because, if they are, if there is no discrimination on how the electrons and hole move, they will eventually recombine and you will not get anything. So, there is some asymmetry has to be built in the structure and that allows the electron and hole movement in opposite directions. Other many ways of creating this asymmetry and the one which we have been discussing in this course is the p-n junction.

P-n junction allows you to build this asymmetry and that happens because if this particular material that I have made, if I make a p-n junction out of it, I have already shown you earlier that that leads to a built in field, this is p-type and in equilibrium such a junction has a built in field, which means if I have a electron here, by it is natural field it will be going towards this end, which we we have called cathode and a hole here, will be going towards the other end which will be called anode.

So, this is the the natural discriminating motion of the electron and holes is necessary to get the photovoltaic action, if you did not have that then electron holes which were free, they will recombine with other electron and holes and you will not get any generated, voltage in the device. Now, because of this action if I collect connect this device to the outer load, what is going to happen, I will have electron going to the outer circuit during the work and eventually this electron comes back to the anode and recombines with the hole that is created.

So, the energy that I had given in creating this electron, by the photon is lost is used up in the circuit and it comes back to the ground state and then I can keep the during this process as I bring more energy, I am doing the work in the circuit. So, fourth step is the, when we connect the solar cell to outer circuit, then the electron goes through the load and returns to anode where it recombines with the hole losing the energy that it got from the photon.

I could have told the same story from the hole point of view, the same thing the hole will go through the circuit and come back and recombine with the electron, but the point is that by using a solar energy, I created a current and a voltage in a circuit which I can use almost like a battery. So, solar cell is like a battery, it is used as a current source because whatever light I am putting in is generating a current. So, now let us look at the role of p-n junction in the solar cell.

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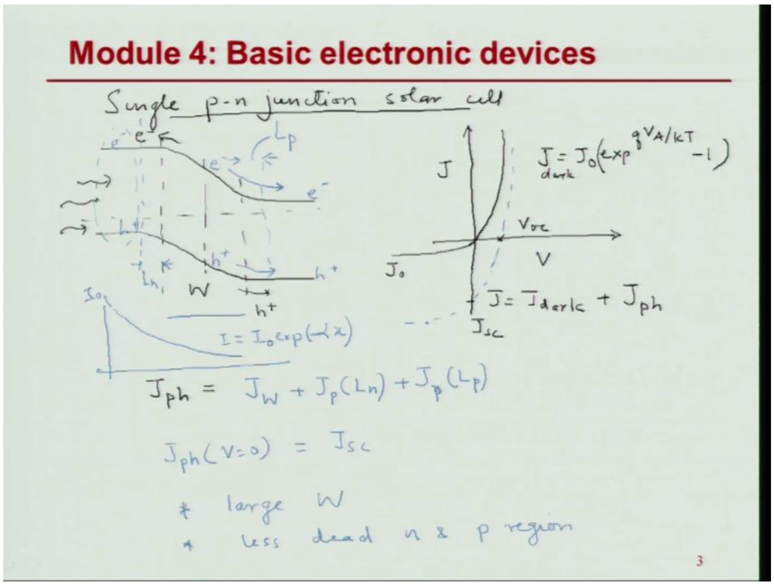

Since, we know a little bit more about the p-n junction characteristics it is a easier to understand how this is operating. So, we look at a simple p-n junction. So, you will recall that in equilibrium, this was a situation I had a depletion width, which we can calculate in terms of doping of the two sides, this is the junction and if I look at the i v characteristics when I apply a voltage and I will like to change from i v to current density because generally we talk about in solar cells, current density the current per centimeter square, to to keep the units same for different area solar cells.

Then the for a in the in dark for a ideal diode this is the i v characteristics, where the current is given by giving the exponential increase in the forward current and a saturation current in the reverse direction. This we have understood it comes mainly because electrons are diffusing in as minority carrier in the p-type and holes are diffusing as minority carrier in the n-type. Now, what has happened once, I put in photons I have generated now because of these photons, I am generating electrons and holes and the direction they are moving is, going to be opposite to the earlier forward current.

So, you can see that a forward current was going coming into the anode, while then I have put in the light the current which is generated is going out of the anode. So, this is going to be in the negative J direction using the same convention. So, due to the light I am generating a current which is, whatever was it is dark current given by this term plus a current due to light photons.

Now, immediately we can start defining some of the characteristics of a solar cell, which is when you have 0 voltage that specification is given as the short circuit current and when you have, no current that is given as the open circuit voltage of a solar cell. So, when you are using a solar cell, these are the two parameters, which define how much power you can gain from the solar cell. Let us look in more detail what is J photon or J due to the light.

J due to the light is basically all the electron hole pairs that, I have generated by the light and it can be generated anywhere, I can generate it in this area, I can generate it in this area and how how does that decide how many generated each photon will be responsible for one electron hole pair, for linear processors and from the surface, This is going to go down exponentially, because we know that the way the light gets absorbed in a material is given by, if the intensity here is I naught, given by the absorption, coefficient of the material.

So, electron holes are getting generated more here and as you go deeper in less of less of them are getting generated, but which are being collected all the ones which are in the field, in the depletion with they are feeling the field and they are going to be drifted due to the field. So, the efficiency for collection, for these electron hole pair is going to be maximum in the depletion width, what happens to the electron hole that is generated here, it is not feeling any field there is no there is minimal field in this area. So, there is no drift force on these free electron and holes.

So, they generally may recombine or drift or diffuse in either direction, but there is a region, which is close to the depletion width, which we define by the diffusion length of the minority carrier on this side. Similarly, there is a region close to the depletion width, which we define by the minority carrier diffusion length on the n side, these electron hole pairs in this region will go towards the depletion width because we are close enough to that and they will, add up to the photon the current in the light.

So, the total current that I am getting when I illuminate, can be thought of as three components, one is all the electron hole pairs which are being generated in the depletion region and they, by the virtue of the built in field will be taken to the two sides, but then you have some areas in the p-n junction, where you do not have field and if you have that area, only those electrons which are within the diffusion length of the depletion width, will be collected, on the other side those which in which are within the diffusion length of the depletion width will be collected on the other side.

So, the total J photon is going to be due to this, which means anything that is being generated in this part, is probably getting loss due to other processes and I am getting only photocurrent from this area and. so I can calculate that in some cases and generate theoretically, what is this procedure. So, the J p h is what decides my is going to be proportional to the at v is equal to be 0 is going to be proportional to the source current.

So, this is, if I calculate my (( )) current at v is equal to 0 which is basically this this is going to be the short circuited current, that is the total current I am generating which is I am able to collect, I may be generating more electron hole pairs which I am not able to collect. So, this gives me the picture, inside the depletion region and if I look at this from the, as we will go further what would I need, I would like to have in order to collect as many electron holes as I can, I need to have large W I should make my device such that there is a large built in region.

And I should have less dead n and p region and by dead I mean where you do not have the built in field and that is good because if you have that region that is also adding to the resistance of the device. So, this is the picture of a solar cell, in a p-n junction and this is the curve that you would get. So, let us not define how would we characterize the solar cell.

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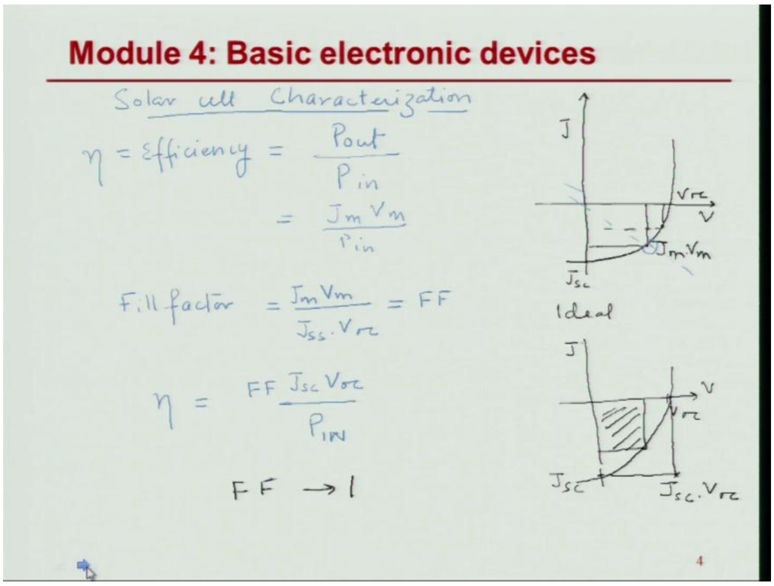

So, solar cell characterization is our next topic. Now, it is obvious solar cell is a energy conversion device. So, the main characterization for it must come from energy conversion and that is what it is, it is the efficiency of the solar cell and it comes from how much power I am collecting from my solar cell divided by how much power I am giving in the solar cell, that divides decides the efficiency of the solar cell.

Now, there are other parameters which will decide this efficiency and which will be coming from the j v characteristics. So, we we have seen in a p-n junction device or even in other devices we will have our j v characteristics which will be given like this. So, what is the power out from this solar cell, I can have any value of J corresponding to which I will have a value of v.

So, at any point that would be the power, but in order to make one definite value, what I like to do is I like to calculate a point at which I have maximum value of J multiplied by maximum value of v. So, I maximize the J v product and that point is the maximum power that I can take, basically it it means that if I put a outer circuit load which will match, the J maximum I will be able to collect the maximum power at this point. So, I end up defining my P out in terms of this maximum power, that I can get from the solar cell.

Now, there is one more parameter that one defines, with respect to efficiency and it comes from the fact that if I have an ideal solar cell, then whatever V o c I am generating and whatever J s c I am generating the maximum in ideal solar cell it should be a complete rectangle; that means, the maximum for an ideal solar cell should be J of c times V o c, but real solar cells look more like this, they are not a rectangle.

So, another term is defined in that respect and that is known as field factor and it is called basically the ratio of the maximum power point, at which I can take the power from the solar cell divided by the ideal maximum point and it is acronymed as FF. So, now with this my efficiency, given eta is nothing but field factor and I can now characterize it in terms of these two parameters short circuit current, open circuit voltage divided by the input power.

Just graphically, what is this field factor signify, this field factor is saying whatever is the the actual loop is how much is a difference is the ratio of this area, divided by the ideal area that is a field factor. So, what should be the base value of field factor, should go towards 1. So, if I have my solar cell characteristics I can figure out the output maximum power I can draw from that solar cell, if I design my circuit correctly and in order to get this information I still need to find out what is P IN. So, let us look at what is the total power that I am bringing into the solar cell.

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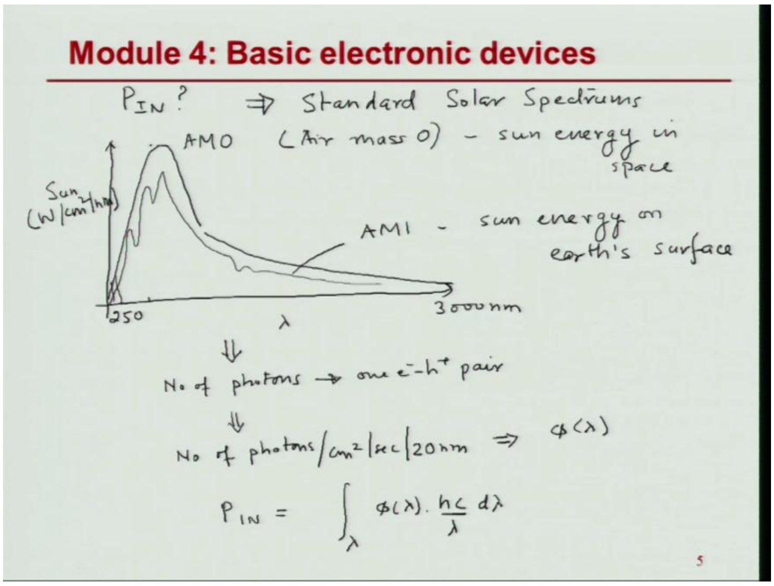

So, calculation of P IN; obviously, depends on how much power I am getting from sun on earth right. So, this is a number that I need to know and this is also a number which is varying from the space, time and and how I am putting collecting the the the sun power.

So, there are, there have to be certain standardization for the solar spectrum against which I will characterize my device and these standard solar spectrums, are generated based on the information on actual solar spectrum and general nature of this spectrum is such that if I plot the sun, power in terms of watt per centimeter square per nanometer.

As a function of lambda and this ranges almost from 250 to close to 3000 nanometer and we know the visible range is between 300 to 700 nanometer, interestingly the the solar spectrum peaks at around 500, 600 nanometer, drops very fast and then there is a huge tail going towards the larger wavelength. So, actually maximum solar spectrum is in the visible range, which is good for us that is why we are able to see things.

Now, with respect to this if I am looking at the solar spectrum and the power that it has, in the outer space it is much more, as the sun is going through the atmosphere of the earth, it is losing some power due to it is scattering, absorption of the atmosphere. So, it depends on where I am and the first standardization which is given for the spectrum is called air mass 0 and this is the sun energy that you are getting in the space.

Then as the sun travels the atmosphere of the earth, it is energy is going to be reduced and it will end up showing some absorption, coming from the atmosphere and that is called air mass 1, this is sun energy on a surface and then there are other standard spectrums defined as air mass 1.5, 1.8 which depends on if the sun is entering at an angle in the atmosphere, which will have different absorption, but whenever we report the characteristics of a solar cell, we will have to define under what solar spectrum and energy we are reporting it. So, that it can be compared with the results of other people.

So, now that we have some standard information, about solar spectrum there are equipments, who simulate the solar spectrum and against which one can measure the efficiency of the sun, further it becomes interesting to convert this chart of watts per centimeter per nanometer, what this means is the total power coming per unit area of the surface, in each nanometer it is calculating for each nanometer. So, if I need to calculate the total energy coming, I need to multiply this number and add it up basically, the area under this curve, is going to be the total energy coming onto to the point that I am observing.

It becomes easier if I change this watt into number of photons, which I can easily do because each photon is h nu or h 3 by lambda. So, I can calculate for each joule how many photons I have and the the the convenience come from the fact because we know that each photon is responsible for one electron hole pair. So, then it allows you to think in terms of number of electron hole pairs generated and that is a exercise that helps in further analysis.

So, one can change that into number of photons, coming per centimeter square per second within a wave length region and normally it is taken to be wider something like 20 nanometer. So, I know total number of photons arriving on the at the surface where I am doing the testing. So, if I need to now, calculate P IN the total energy, that I am getting in the sun spectrum I will integrate over all wavelength, I will take the flux, this I am defining as the flux at different lambda for photons and the energy at that lambda for the photons, number of photons times multiplied by energy, if I integrate this, this is my total power in.

So, what we are characterizing in solar cell is how much power I am collecting from the solar cell and how much total sun power, at that point I am able to collect per unit area and if I take that number that is the efficiency. Now, this is the number that we quote again and again when we describe our solar cell, keep in mind whenever we quote this number, we must quote also the standard spectrum we are using, for doing this measurement.

Now, what are these number generally like, it depends on which technology or which semiconductor, we are going to use that will decide this what this number is, silicon being the most common one and the one which also we have also discussed extensively, it almost constitutes 90 percent of the solar cells, even today which are fabricated and it is maximum efficiency can be something like 25 percent, which is if everything is done in a proper way but commercially what you get is somewhere between 15 to 16.

So, that is the gap on the theoretical efficiency you can get and what one manufactures and you will try to see, why that gap is there and how one can improve it. So, this is where it comes which basically means, the solar cell silicon solar cell which we buy, from the vendor today is take converting, all the energy that it can cover only 15 percent of it you are getting as power, it is not a very efficient device if you think of it, here it is only 15 percent is getting converted.

So, that is one issue than is to go to higher efficiency, but then when it comes to generating power that is probably not the only issue that one worries about, it comes out what cost you are generating that efficiency that energy and that is more driving force for technology is to reduce that cost. So, per unit of electricity generated the cost is too high by silicon, then it is not usable. So, that had been the driving force for the solar industry and we will come to that discussion also.

So, now you know how to calculate P IN you know how to calculate the P out from the J v characteristic of a solar cell and the number for a typical silicon commercial cell would be around 15, 16 percent. So, where does this, rest of the energy goes, where is the 85 percent of the energy which we are not able to collect, if I want to just take it as a academic exercise and I want to see what is it that happens to the rest of the 85 percent.

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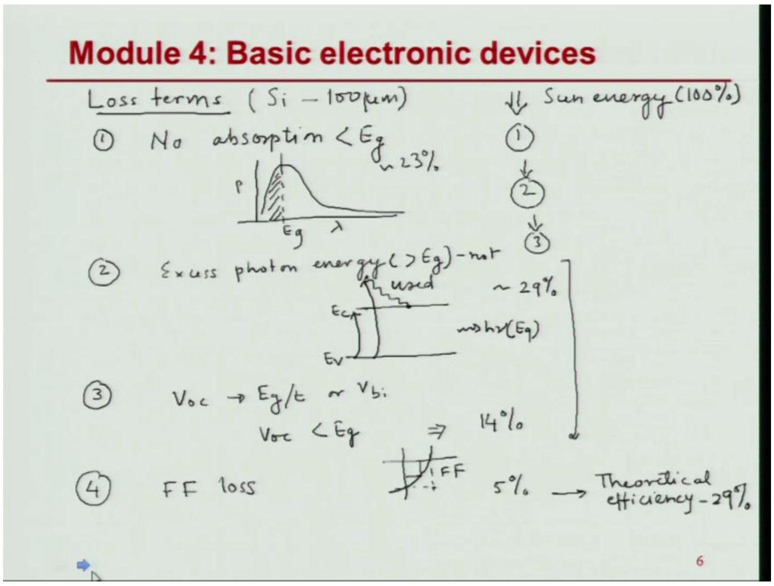

So, that is what we are going to look at. So, we are going to look at the loss terms. So, now, we will start from the sun energy that is coming assuming that is to be 100 percent as it falls on our solar cell and then we will look at each loss as we go on. Now, the first loss that comes is due to the fact, that there is no absorption, if I am using a semiconductor, there is no absorption below the band gap.

Right, what does that mean, it means that if I have the sun spectrum, given in this manner and my band gap of the semiconductor with which I have made the p-n junction and let me take silicon as an example to give you some numbers. So, we will take define these for a silicon, good silicon p-n junction which is ideally defined, which is about 100 micron thick. So, if I take a 100 micron thick, well made p-n junction, what are the losses that will be there.

So, numbers will be defined in that term because it will change depending on the material every time. So, let us look at number from the silicon point of view. So, if this is the band gap for the silicon, it basically means that I am not absorbing any of this P IN that is the first loss and if I calculate that loss, it is almost 23 percent of the total loss is coming here. So, that is the first point, is the no absorption below the band gap.

So, I have already lost 23 percent just because my material is has a certain band gap, then the second point is whatever I am absorbing above E g when I am at E g I am absorbing exactly the right amount, but if I am absorbing energy, above that amount what happens to that energy, it has to be lost non radiatively, because it will come down to the easy and then there will be a radiative recombination.

So, whatever is the excess photon energy, which is for greater than E g absorption it is not used, why is it not used, earlier we have discussed that we have conduction band and valence band, if I have exactly E g then I take it to the conduction band and I recombine and I get the energy h nu which is equivalent to the conduction band, but if I if I absorb more energy and I take the electron to a higher level, this electron will lose it is extra energy and come back to the E g and this is the loss of the energy.

So, even though I am absorbing a all along here, the any value of the energy which is higher than the E g is lost in heat. So, I am losing even that part because electrons quickly come back to the conduction band as after absorbing the light and this much part that I am losing of the rest of the spectrum although I am absorbing, almost comes out to be about 29 percent in case of silicon. So, you can see that from 1 to 2, because of the absorption and the the spectrum the way we have and we have a single material that we are using, we are almost losing 52 percent of the light.

So, you have already come down to 52 percent in absorption only, to the efficiency. Now, comes a part that I will create electron hole pair and then I will collect them and how the efficiency will go in that case. So, let us look at the third part where I lose the energy and this is where I lose the energy because my V o c, V o c the larger it will be the larger will be the efficiency and the the ideal V o c can go only as high up as band gap or the built in potential and it never goes up to that limit.

So, it is always little bit less than the band gap if I could make a device with the maximum E g then I will have the best efficiency, but there will always be a lag between V o c in in practical terms V o c would always be less than E g, when I make the device and that leads to the, in case of silicon almost loss up to 14 percent because v o c I cannot increase beyond a certain limit. Although theoretically I should be able to make it as big as the band gap of my material.

So, I was at 48 percent now, I have lost another 14 percent that gives me 34 percent, that is the power I have, but that is not enough I I have the next loss, which is coming basically from the field factor loss because this fourth loss is there because when we made our ideal device, we would have liked it to be this way, but we know that J comes in this manner and that is because there is a field factor.

So, it is not J s c V o c that we get we get less value. So, if I take certain values from that I will lose additional 5 percent from here and this is this is, just from a typical p-n junction that I have just calculated assuming ideal value this is a loss that I am going to see. So, this is my theoretical p-n junction efficiency for a silicon device and it comes to a single junction it be about 29 percent, but there are still some more loss processes which are there, which ideal p-n junction we have not considered and if I add those loss processes of which the first one that comes to mind is the sheet the series and the shunt resistance.

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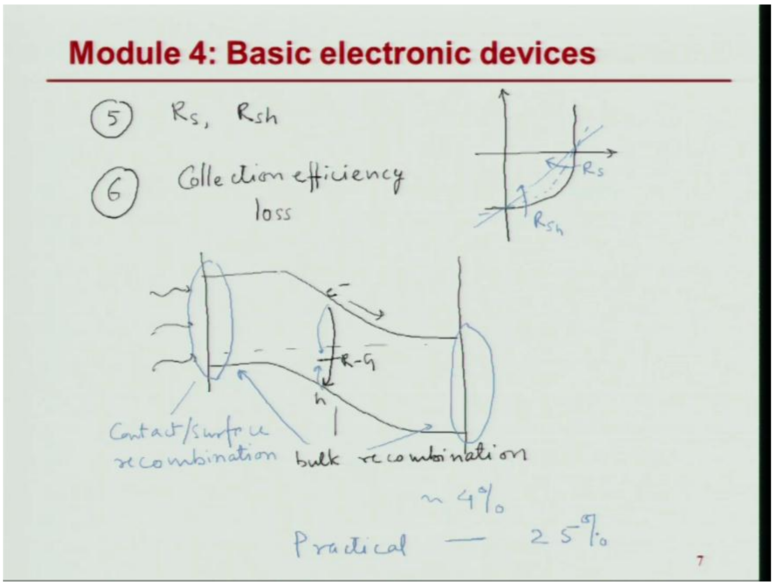

So, when we make a device because in different ways the interfaces and different layers act, the J v characteristic is not ideal. So, the ideal one with the certain field factor, would have this almost vertical and this almost horizontal, but that does not happen because there is a sheet resistance and a parallel resistance in the device and as a result, one will find the effect of the sheet resistance and the shunt resistance is going to be in the manner, that will for this series resistance it is going to move in this midway and for the shunt resistance it is going to move in this way.

So, in addition to that field factor effect, you have this series and shunt resistance effect which will reduce the field factor further. So, this is another loss that occurs. So, we can reduce that, then there is the additional loss which what we call is the collection efficiency loss. What is the collection efficiency loss I have created by one photon, one electron hole pair and I am expecting it to be collected at the two ends, as long as I am within my depletion zone plus diffusion length region.

But, that is not all it, what it can also do the electrons, while it is going to the cathode and the hole while it is going to anode you can find another electron and recombine and if it recombines you are not collecting it in the outer circuit and that is a loss to the current that you can collect. So, this is the loss that I am talking about, to to tell you pictorially what what can happen is, this is the top surface of the p-n junction from where I am collecting the light, this is a bottom contact and I can have electron hole pair rather than going in this direction it recombines with the hole.

So, this is what I call bulk recombination and this is where the minority life time of the materials, becomes important, the quality of the material become important because if it may directly recombine with the hole in the valence band or there might be traps, which are recombination centers R j centers, as we talked about R g centers and they can be the reason for recombination. So, the electron and hole may recombine at this point.

So, the quality of the materials becomes important in deciding these processes, this bulk recombination cab happen here and can also happen here, it is because of the bulk traps or bulk recombination processes and whatever the rate of recombination, you will lose that much current in the in the outer circuit. In addition to that what you have is you may have recombination, at the contacts or at the surfaces. So, you have additionally contact recombination and again this also can be altered by having a good interface. So, again electron and holes can be lost in this process.

Now, overall if I have a good p-n junction single device all these 5 and 6 end up making something like a 4 percent loss. So, I am talking about a good material, good device structure, this will be about 4 percent loss. So, a practical device is going to be something like 25 percent and that has been achieved, people have made very good devices using highly precise microelectronic processing step, which give efficiencies in the range of 25 percent but here is a problem if you use microelectronics that is we discussed in a earlier lecture, those are highly précised expensive fabrication steps and it makes the cost of photovoltaic very high.

So, ultimately the point that we want to get in solar cell is that we want to generate power in low value and hence, the kind of processing steps which are used in solar cell are of low cost and that adds to the lower, lower value of the efficiency that we get, but then it reduces the cost. So, from commercial point of view it is better to reduce efficiency as well as the cost, than to get high efficiency and having a too larger cost. So, that is what it is. So, although it is possible 25 percent, if we have good material, good processing we actually only make 15 to 16 percent.

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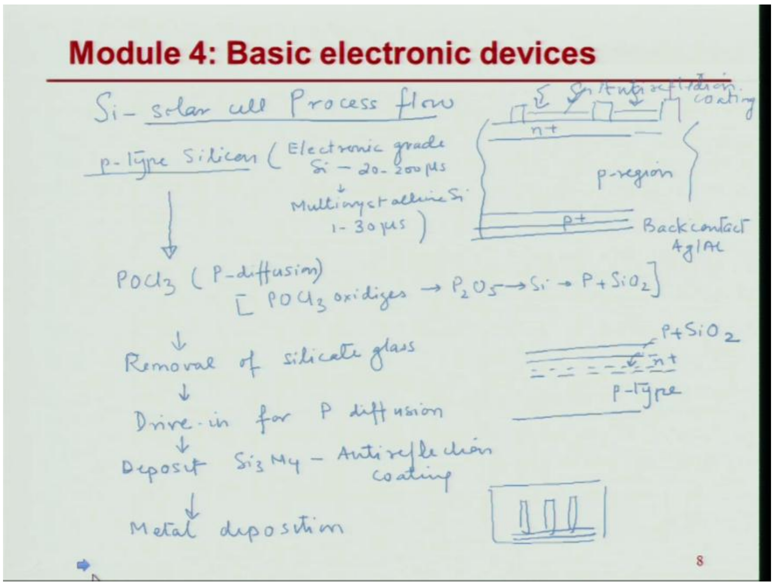

So, next I will like to since I am talking about processing of silicon solar cell, give you a process flow of making solar cell, which is which is low cost process slow. So, let us talk about silicon. So, a typical solar cell which is commercially available looks, something like this it has a p-region, then a ohmic contact region for high doping p-region, back contact which is often silver, aluminum, amalgam or some paste type of thing can also be used on top we make the p-n junction using a n plus p, if you recall our discussion we wanted very large depletion region.

So, we want to make the doping here is less and doping here very, very high. So, that the depletion region is very high, here and then you have a n region and to that n region one makes contact and in between part is also covered using a antireflection coating. This is the structure of a single cell, before I go forward I will like to emphasize that in each cell, if I am making a silicon cell the kind of open circuit voltage I am generating is only probably less than or a in the range of one volt, which is very, very small for any practical application.

So, in order to increase the voltage when when the modules that you see in the market are where lots of cells are connected in the series. And if you want to increase the current, then you can connect them in parallel to increase the current, because the currents are in the range of 10 to 100 of mille ampere. So, for any actual application one has to increase this number by putting lots of cells together and that is the module.

So, from single cell we then develop the module, which also has it is own technical issues, but that is the main point. So, let us think of only a single solar cell and how we will fabricate that. So, in this process flow we first start with the p-type silicon. Now, in terms of the cost, this is the part which is it takes almost 40 percent of the total cost of silicon manufacturing and hence, has a lot of effort in trying to reduce cost by changing the processing of this material or by compromising the quality, but you are still getting good enough efficiencies, if you can reduce the cost.

So, this is a this is almost 40 percent of the cost, if I take what we call electronic grade silicon which has of course, very high minority lifetime and other things, then that is going to be very, very expensive and the lifetime of minority carrier is in the range of 20 to 200 microsecond. So, that is for electronic grade one, one can make solar cells using that, but the cost of that material is very high.

So, one can change that to a multi crystalline, it is called multi crystalline silicon and one takes the hit on the efficiency and also on the minority carrier lifetime, which goes may be in the range of 1 to 30 microseconds and then there are other things which are coming up which reduce, further a lifetime to some extent, but the cost reduction is much more. So, that is still beneficial. So, the drive here is basically to reduce the cost, even at the cost of the efficiency, you do not necessarily want 25 percent, but if I can reduce cost quite a lot I am still in business to provide power to people.

So, that is a first step to reduce cost at p-type silicon itself, the rest of the processing is not that high end processing or high costly processing, in the next process I will go for cleaning which is normally done and then go for, the creation of the p-n junction which one process is to use P o c l 3, this is used for diffusion of the phosphorous in the silicon, P o c l 3 is a is a liquid and as I mentioned it can be one can bubble through nitrogen and oxygen through this to bring it to the surface of the silicon.

As it comes to the surface of the silicon what happens is p o c o P o c l 3 oxidizes one brings in the oxide oxygen along with it and it changes into P 2 O 5 which reacts with the silicon and gives phosphorus plus S i O 2 and this phosphorous is then doping the original p-type silicon to whatever the process is desired. So, by creating this what we have what we create is, we create a phosphosilicate on the silicon surface through this process and by annealing it.

And then we remove the top removal of silicate glass which was created in the earlier process and then the drive in process for diffusion, for phosphorous diffusion. So, by this time what I have done is I have started with the p silicon created phosphorous doped silicon oxide, the phosphorous this is p-type type not phosphorous. So, the phosphorous goes in the p-type creates the junction that I want for n plus and I remove the borosilicate that was there and drive in the junction for the to it is final position. So, I have a n plus p junction created through this process.

Then I am going to edge of the surface, I am going to deposit silicon nitride or some antireflection coating onto this particular surface, there are two ways now to after antireflection coating is deposited, which is to reduce the reflection loss, which we did not considered earlier, but that is there is going to be some reflection loss also as light comes in and then we do metal deposition for top contacts.

Now, here it one can use a expensive technique photolithography technique, but on the other hand people have shown, by using things like screen printing of a silver paste one can make these contacts and then the cost is reduced by rather than, if I put silver paste then there is no way for the light to come, in the light is coming in from this direction, then there is no way for the light to come in.

So, what is done is this metal deposition is inter digitated, fingers where you make sure that there is enough free area for the light to go in and you are able to collect the electrons which are generated. So, this is the top contact structure, then after this point I need to still make the back contact.

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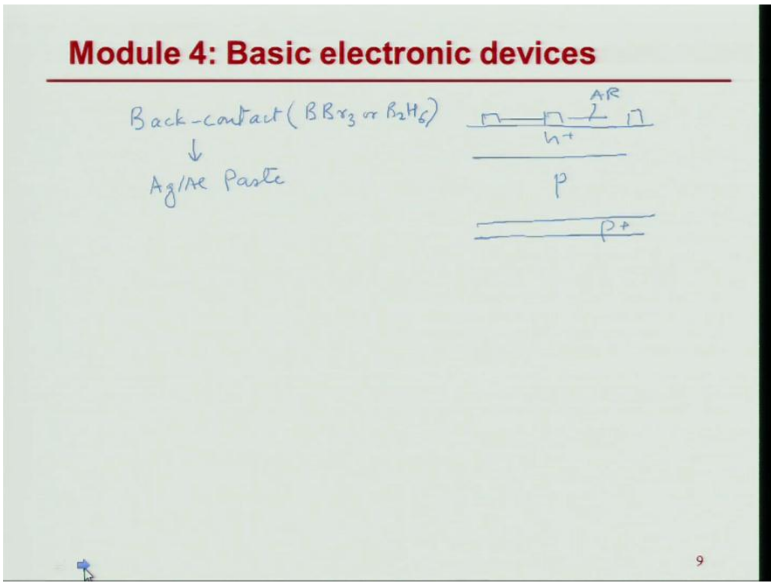

So, I go back to a process, where I make the back contact. So, I have done and plus emitter P I have made metal contacts to n plus either photolithography and I have deposited a antireflection coating, on the back side now, I repeat this process, but not for n plus, but to get the P plus and for that I can use gases like, B boron bromide or even diborane, those can be used to oxidize the surface and introduce additional p-type doping and finally, I will use silver aluminum paste for making the back contact. So, if I see this is not a very, it has avoided one can avoid using a screen printing or the photolithography step and create a solar cell and that reduces the cost although we pay, for the efficiency by compromising with the materials and the processes themselves.

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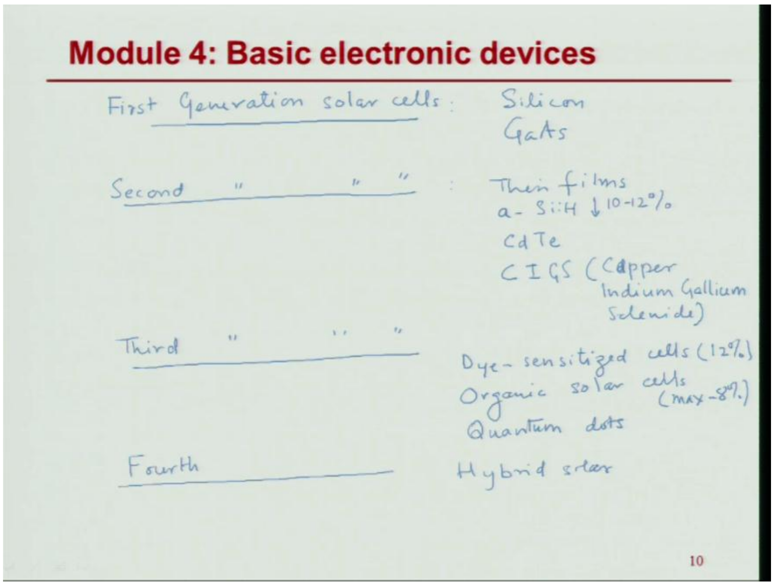

So, finally, what I want to talk about is, where are we in terms of solar cell technology I just described to you, a single p-n junction solar cell, what are the efficiencies that are, that is still the main market presence single junction solar cell, because the cost are reasonable and people are still trying to put with that cost a higher efficiency that is effort that is going on.

But, there has been tremendous effort in this area in last 40 years, the first the first generation as we call it, first generation solar cell are based on these silicon, which we have already seen or gallium arsenide, gallium arsenide by making tandem cell or by making 2 or 3 different kind of absorbers within cell structure, efficiencies can be increased quite a lot.

So, these were the first generation solar cell almost 50 years ago and they are very well deployed in space area, all the power requirement of the space shuttles are taken from the photovoltaics. So, it is a very established technologies in the in the space arena the solar cell but the problem with those solar cell was the space programs could afford, but for utility the cost is too high and hence, the driving force in development of photovoltaic has been to reduce the cost.

So, then came the second generation solar cells and here it was not to increase the efficiency, it was mainly to reduce the cost. So, the kind of materials which were used were thin films. So, as I mentioned almost 40 percent of the cost is in the silicon. So, thin films of amorphous silicon, efficiency goes down to almost 10 to 12 percent, but the amount of silicon you are using is much less. So, the cost is reduced quite a lot, amorphous silicon is one material or it can be hydrogenated also other thin films are were also there cadmium telluride CIGS cadmium sorry Copper Indium Gallium Selenide.

Individual cell efficiencies are very high for some of these cells CIGS, but when you put in the module it comes down to the to a to a lower value but these have promised much lower cost compared to silicon and that is that was the driving forces to reduce cost of power generated by the solar cell, then comes further new area region which started almost a decade ago, is the third generation solar cells and in this, once again the driving forces to reduce cost further and the example here, are dye-sensitized cells.

Now, as we we went from p-n junction solar cell to the second generation solar cell it was basically the processing technology, which was very different, but in the third generation even the mechanisms become very different, it was no more p-n junction dependent because the type of material in absorption was the very different kind. So, dye-sensitized cell, organic solar cells, they depend on the discontinuity of the materials to create a photovoltaic action, these consist of third generation solar cell.

Now, these are much lower efficiencies, dye-sensitized is in the range of 10, 12 percent, organic solar cell commercially is much a smaller, but maximum reported is approximately 8 percent. So, again efficiency is coming down, but cost is much, much lower and that is, the the driving force for this area and another fourth generation which people talk about, is basically hybrid solar cell, where they are trying to use the benefits of the regular inorganic solar cell, with the benefits of the third generation type of solar cell, quantum dots, dye-sensitized we also have quantum dots included.

So, hybrid solar cell use advantages of both inorganic, and organic solar cell or the third and previous generation solar cell to get the best efficiency. So, in summary I have covered what a solar cell device, how it works, we looked at a single junction, p-n junction solar cell and looked at the loss processes, if you have a very good p-n junction solar cell and what can be the practical efficiency that you can get and as we saw almost 50 percent is lost because we are not able to absorb it, it is lost in the absorption process itself and hence, tandem cell are increasing that absorption enhancement is one of the way of trying to get back some of that efficiency.

And then we looked at a processing of silicon solar cell, how at the cost of efficiency, we are able to do very simple processing of solar cell and reduce the cost for solar cell, with respect to that, where we are going in terms of the technology and the growth, we have looked at different generations, where it is not just the efficiency it is the cost which is driving the development with the reduced cost you want to increase some efficiency to as large as you can.