Materials Chemistry

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Module - 7
Lecture - 1
Solar cells

In the last few lectures, we have been looking at the importance of materials, specially inorganic and organic materials, which play a very important role in optoelectronic applications. Specially, the lectures on OLEDs have highlighted the use of simple organic molecules, and how color tuning can be made and how this can affect the display industry. In today's talk, I will be specially concentrating on solar cells, and how materials chemistry has played a important role, and the way organic materials have emerged as key players in this very coveted technology.

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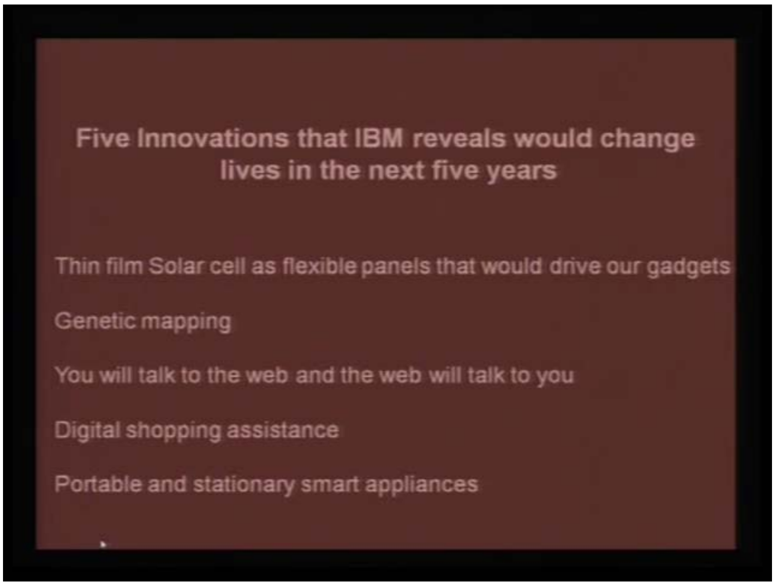

Before I go into details, I just want to give you a latest projection from IBM website which says, there are 5 innovations that would change our lives in the next five years and this has just appeared in the IBM website. They have forecasted that, thin film solar cells has flexible panels, would drive most of our gadgets in the days to come. And the next innovation that would really revolutionize is a genetic mapping which means, the moment a person is born, the genetic mapping will tell, what sort of diseases or imperfections or any health hazard that a person would face through his lifetime.

So, that is going to come in a big way and then you can talk to the web, web can talk to you digital shopping, portable and stationary smart applications. Why I am highlighting is, in all this materials chemistry is involved and if you would categorize item 3, 4 and 5, these innovations are also in one sense display materials, where materials chemistry is used or polymers are used. So, of the five innovations that are projected to revolutionize our modern living, 3 to 4 are in majority seems to deal with the inorganic and organic materials. Therefore, it is very imperative that we study the materials chemistry and understand the photonic and electronic applications in these devices.

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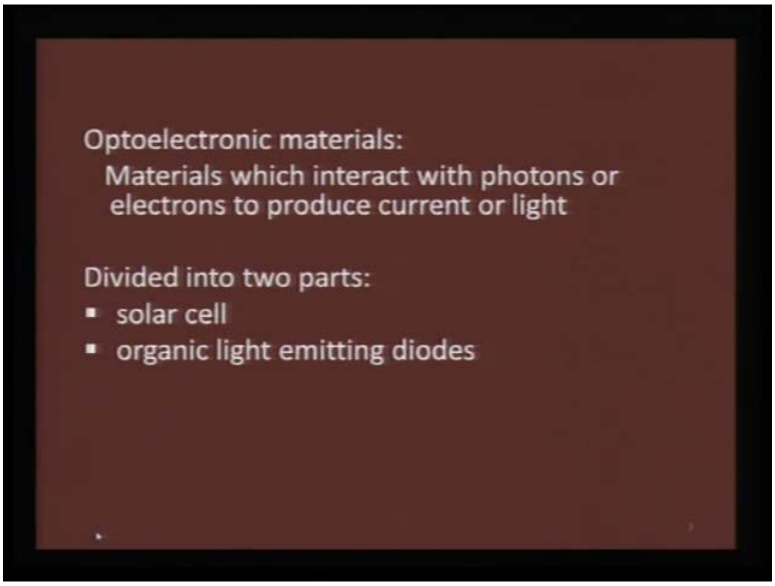

As I told you, we can broadly classify the photo luminescent materials or photonic materials into optoelectronic materials, because materials which interact with photons or electrons, they either produce current or light inversely. So, in the case of OLEDs, we are actually harvesting light and in the case of solar cells, we are actually harvesting current. So, either way, both these devices can be categorized as optoelectronic devices and there is lot of peculiarity between solar cells and the organic LEDs, because the device configurations by enlarge remain the same.

But, what do we do with the electrons and holes that are generated in these devices is the question and for solar cell, we actually would like to harvest the number of electrons and holes that are generated. And in organic light emitting diodes, we would like to generate more of this at a particular interface to harvest light, so either way they have a close resemblance, but doing two important functions.

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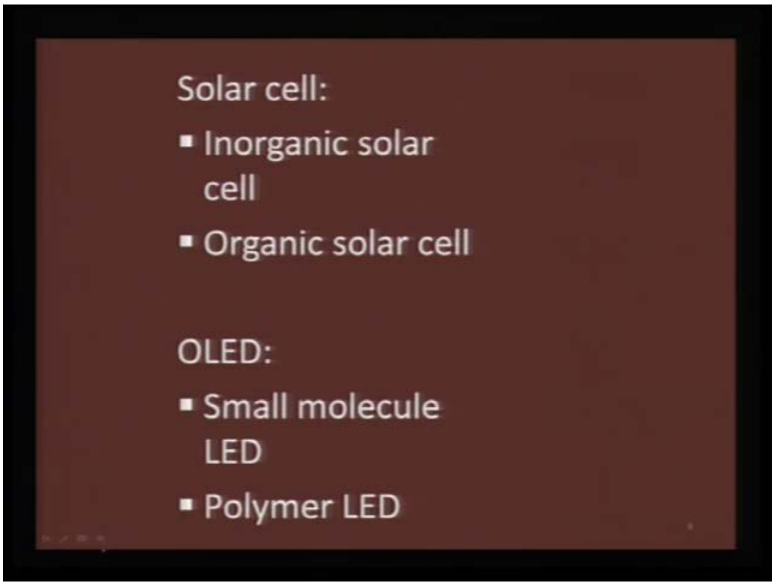

In both solar cell and organic LEDs, we see there are two categories that are emerging, one is inorganic solar cell, mostly to do with silicon devices and organic solar cell, which is the new generation ones, which are also showing lot of prospects for large area applications. In organic LED, again we have this small molecule LEDs, which are principally molecular based and then you have the polymer based compounds. So, both solar and OLED devices seemingly have a give and take on the inorganic and organic components, which we can look at it.

Just to give you a brief outlook on the solar cells and it is history, the actual concept of photovoltaic that is, generating current out of photons was a proposed by Becquerel in 1839. So, it is a very old, century old and in 1877, the first solar cell was made by Charles Fritts with the efficiency less than 1 percent. Nevertheless that was the first demonstration of a solar cell. 1930’s, lot of issues concerning solar cell, the physics of it was expounded by Einstein and Schottky and physical principles involved in the solar cells were manifested through their experiments and studies.

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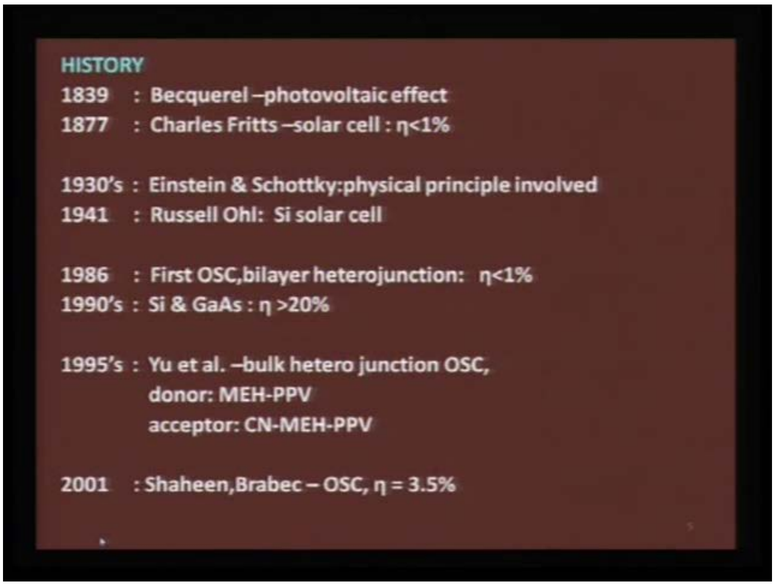

1941, the first silicon solar cell was made by Russell Ohl and in 1986, it was the first organic solar cell, a bilayer heterojunctions with the efficiency less than 1 percent was reported then on, we have seen a remarkable change in the solar cell research. In 1980s, we have almost reached the maximum, therefore we can see a lot of impact on today's life, where more solar panels are now figuring into almost every multi storey buildings.

1990s, silicon and gallium arsenide based solar cells with a efficiency of greater than 20 percent has been found and I would show you shortly that, the theoretical capability is up to 26 to 39 percent, one can achieve using silicon solar cell and this is a remarkable jump in 1990s. And in 1995, bulk heterojunctions with organic solar cell was proposed by Yu and coworkers and then there has been several combinations between MEH, PPV and carbon nanotube PPV, PPV blunts, where they act both as donor acceptor molecules.

2001, we had another report of a organic solar cell, which is actually showing the first efficiency above 3 percent. Since then in the last 10 years, many companies have tried to speed up the possibilities of organic solar cells and to bring it into variety of framework including flexible solar cells. So, lot of panels are being experimented with the large area deposition and with limited efficiency, but the efficiency as if now, is going upto 7 percent as on today with the organic solar cells. Therefore, there is a great market around organic solar cells compared to the most well established silicon solar cells.

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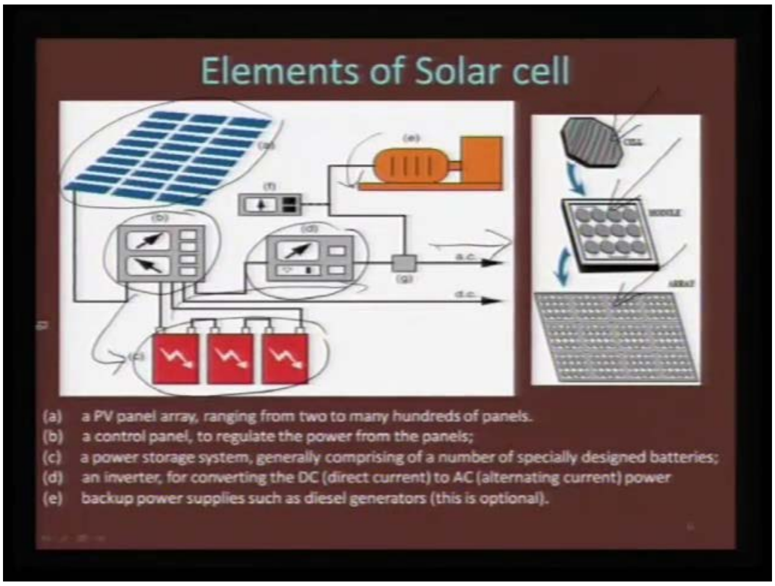

Let me just give you a brief outline about, what this solar cell is and what are the elements, which are contained in the solar cell. So, if you see any panel that is housed on the top of a building, you should understand that, there are many issues that confronts with that assembly, it is not simply mounting a panel. So, here is the viewgraph which tells, what sort of elements it takes to construct a solar panel. One is a primary cell is involved and this cell actually is a made into a module with a series of cells.

And the module is now integrated into a array or a solar panel and this is the solar panel that you see here, which is mounted on a roof top. And from the roof top panel, we can actually generate current, which is regulated to a powers control panel here and from control panel, it is actually stream line to a series of special batteries, where the energy is stored. Therefore, this is not a alternating current, this is a DC voltage that is generated, so energy is packed up and this is actually released over a period of time.

And as a backup, you can also have a generator here and this is the inverter that inverts your DC to AC and this can be used for your house applications. So, the solar energy is actually primarily harvested as a DC current and then it is converted into a AC current using a inverter. So, even in the night, whatever that has been harvested through the day can be used in the night or even in hill stations or so where you do not get sunlight much, this energy can be stored and can be released at a later time. So, this is in essence, a typical solar cell assembly is, but what we will be concerned is, what really it takes to construct a solar cell here and what are the physics and chemistry issues that are related to it.

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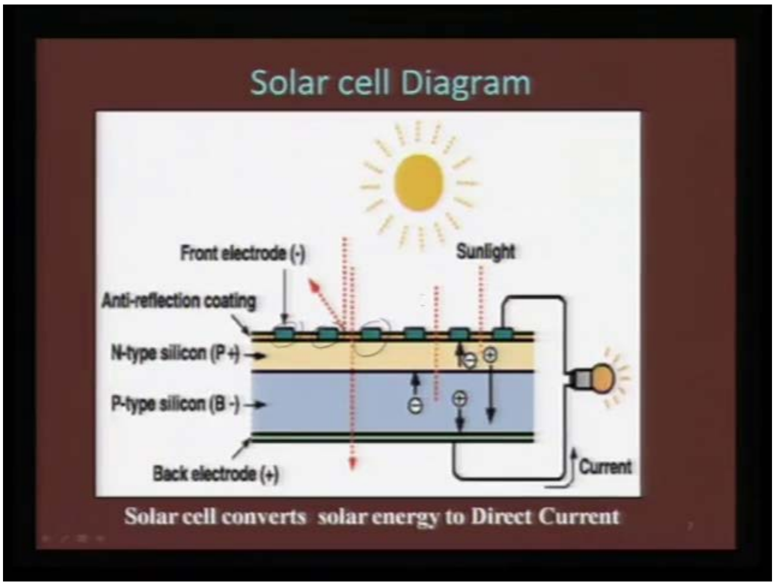

So, in a solar cell diagram, you would see something like this, a assembly of a N-type and a P-type silicon. We will come into this issue later, where the N-type gives out an electron and the P-type gives out a hole and they together at the interface will form a junction. And at the junction, you will have the charges accumulated both electron and holes and they would actually travel opposite to the corresponding electrons going towards the anode and the holes going towards the cathode, so because of this, you can actually generate a current.

So, solar cell in essentially converts solar energy directly to current and this is the assembly and in this assembly, you have lot of intricate things, which we will be looking at it. For example, you have reflective coating and then you need to have a transparent electrode so that, you can knock out electron from the N-type silicon.

When you look at the types of solar cell, there are different types, which has emerged among the silicon solar cells. All these are in reference to silicon, you have single crystal solar cell which is actually the most efficient, but also it is very expensive. Single crystal solar cells and in this single crystalline solar cells, you have limitations, where you cannot make a panel more than this, because in single crystal silicon, it is mainly due to vacuum technology.

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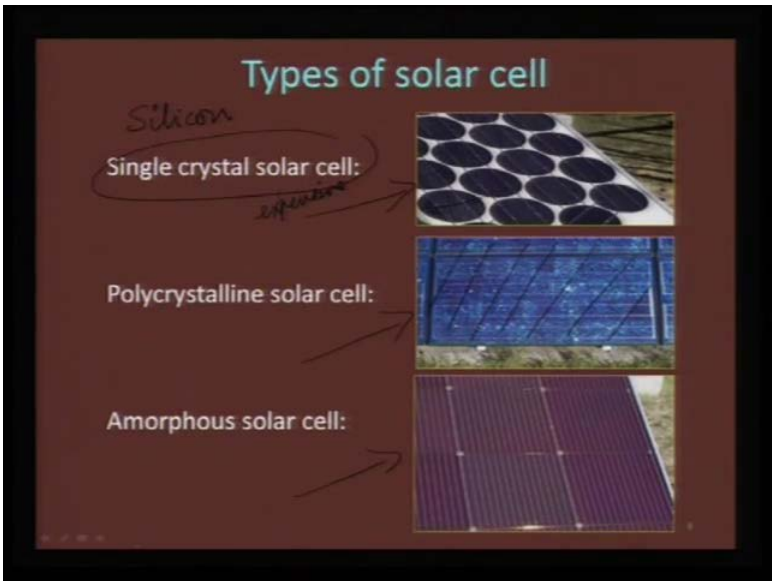

And therefore, the vacuum technology, the dimension of the cell that you can make or the wafer that you can coat is limited, because of the size of the deposition chamber. As a result, you can maximum go for a 6 inch wafer, this can be a 6 inch wafer with lot of solar cells embedded into it and this is the maximum that can be achieved using a vacuum assembly. As a result, if you try to compromise on a single crystal solar cell then you can go for larger panels, where you can try to make a polycrystalline solar cells, so the panel can be much more bigger or we can go for amorphous solar cell.

All this have unique efficiencies, the current output is proportionally large or small but then maximum efficiency has been found in single crystal solar cell, because of the physics involved in it. But, still it is one of the most costliest technology, therefore all the other versions have also been experimented.

Now, when you look at inorganic solar cells, we can either have silicon doped or we can have gallium nitride, we can have gallium arsenide, aluminum gallium nitride or indium gallium arsenide. These are some of the other candidates that can replace silicon and still do the job, because silicon is in group 4 and you have gallium aluminum indium in group 3 and then arsenic nitrogen phosphorous in group 5. In group 5 you have nitrogen phosphorous and arsenic, therefore you can make a combination of a three phase semiconductor.

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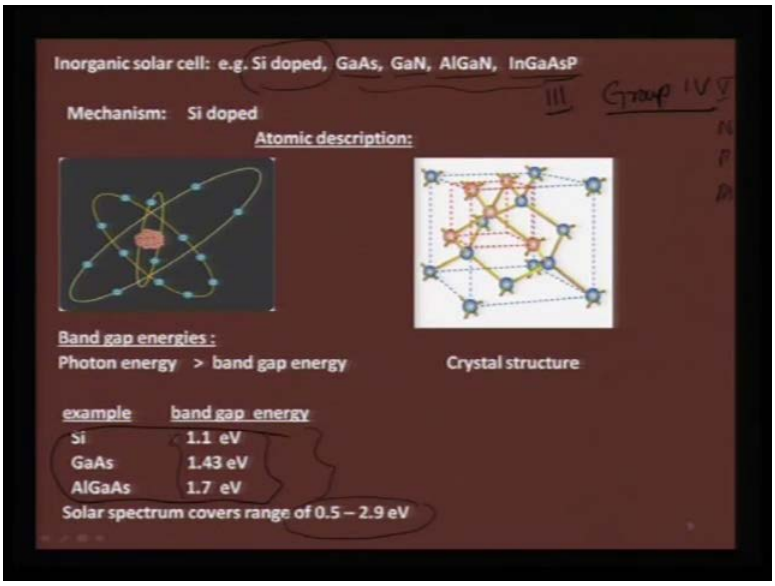

So, these are grouped as 3 5, so they can also perform the same action, mainly because if you look at the values here, the band gap that is generated by this three phase semiconductors are nearly comparable to that of silicon. So, whatever action that you expect out of silicon, you can simulate from the other ones, mainly because making pure silicon is a very involved technology, therefore the other technologies have emerged over the years.

Now, what is the advantage and why silicon technology will play a pivotive role is, mainly because the solar spectrum covers the region 0.5 to 3 electron volt and therefore, it really fits into the scheme of things as far as the silicon band gap is concerned. So, it is therefore, a very good candidate, which can really take the whole spectrum of solar spectrum for converting into current.

Now, when you look at silicon doping, we would see a animation in the next slide but then just to draw your attention to what would happen, if you substitute boron which is in group 3 in a silicon site. Then you are actually generating a hole, because it is one electron deficient or if you would substitute phosphorous, you are actually generating one extra electron. So, that way you either make a N-type or a P-type silicon by doping appropriate amount of boron and phosphorous together and that is what you see in this crystal lattice with a silicon, which is tetrahedrally coordinated. You can bring about an extra electron or you can actually create a hole here, because of boron substitution. So, silicon crystal lattice can be altered the band gap with the suitable dopant atoms.

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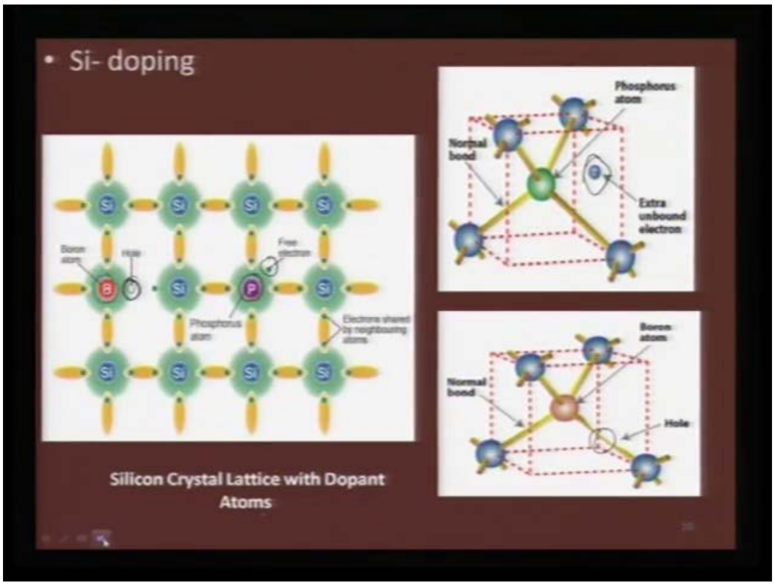

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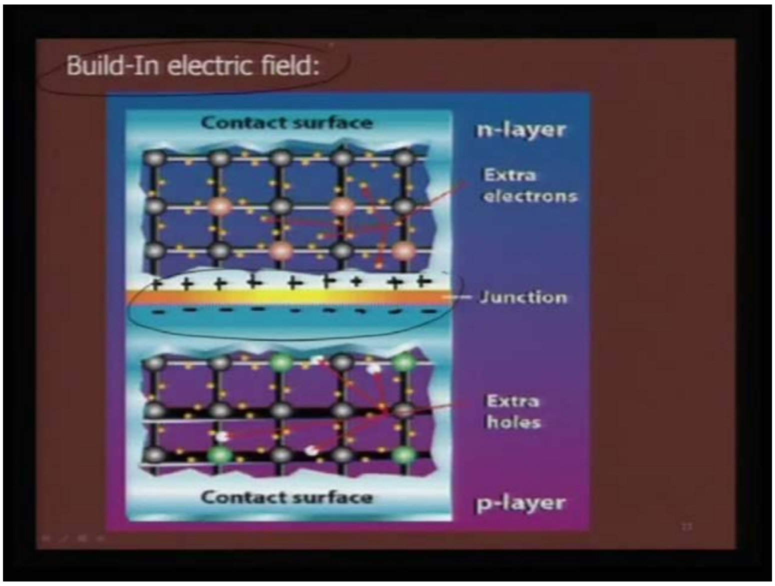

And once you create that what happens is, you create a internal feel, because you are making a array of positive holes and you are making array of extra electrons. And this can actually, if you bring a N-type and a P-type together, you can form a electric field at the p-n junction. And this can actually drive the electron and the hole pairs to the respective electrodes, as a result current can flow and you can generate flow. So, the inbuilt electrical field is, what will bring about the production of current.

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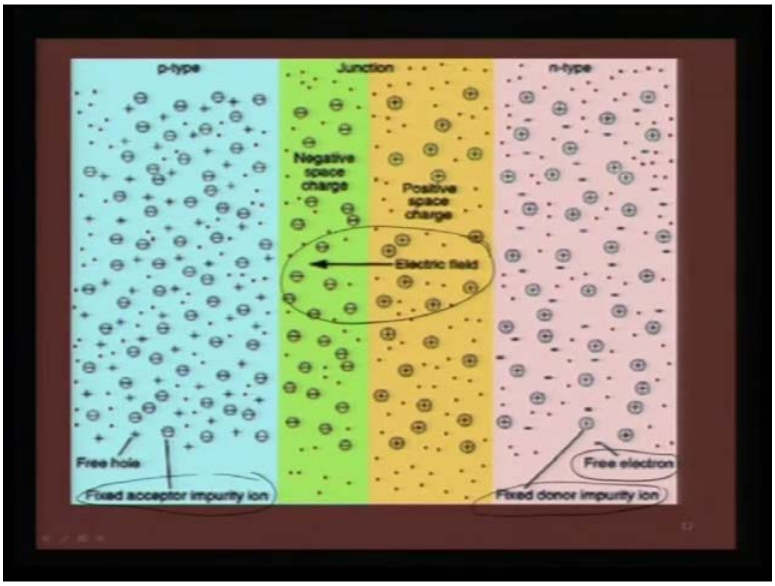

So, how this is done and what are the issues related to it, we will see and this is how the p-n junction is made. So, you have a p-type with the free hole and fixed acceptor impurities and then you have free electrons in the n-type and then fixed donor impurity ions are there. So, when you bring this junction, you actually create a electric field of this kind, where the electrons will flow to the anode and the electrons will go towards the cathode and the holes towards the anode, as a result you can generate the current.

And what really happens at that time, this could be the HOMO and the LUMO level of your p-type conductor and this is your LUMO and HOMO for the n-type. And when you bring this together as a device then you can see that the HOMO and the LUMO levels, they will adjust themselves, because of the electric field. And as a result, you will see that, there is a lowering of the band gap, because of this p-n junction, which will bring about the charge generation. As a result, your current output will also be maximized, because you are changing the band gap in the p-n junction.

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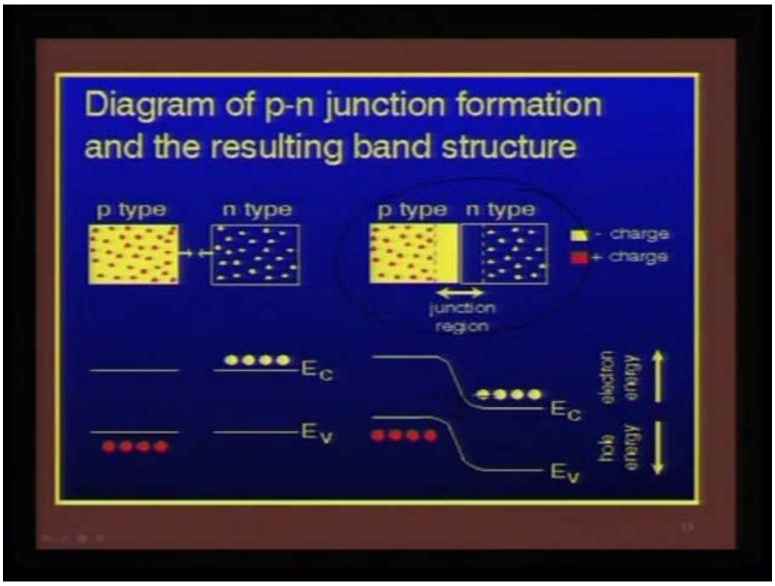

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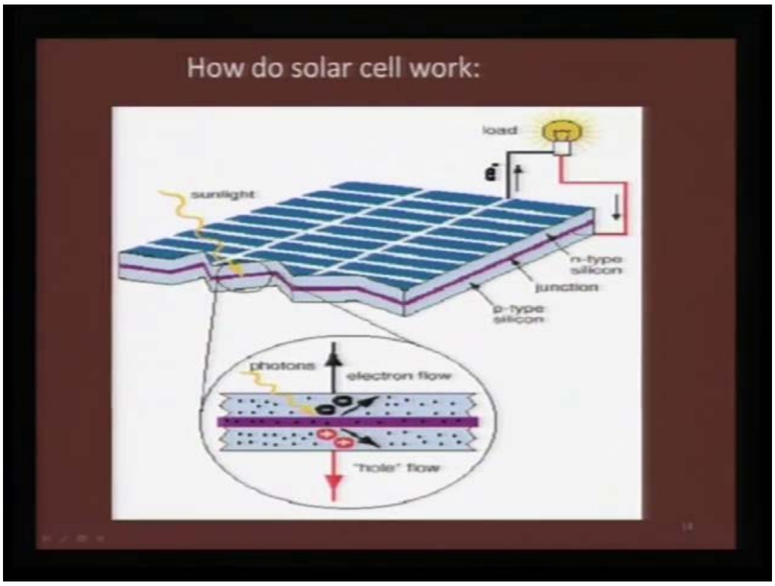

Now, what really happens here is the electrons in a p-n junction in a typical a solar panel, operates when electron hits this junction and electrons will be generated towards the cathode and the holes will move towards the anode. And then the electron will do the work and then it will return back to the electrodes, it will recombine here and again this flow will be generated continuously.

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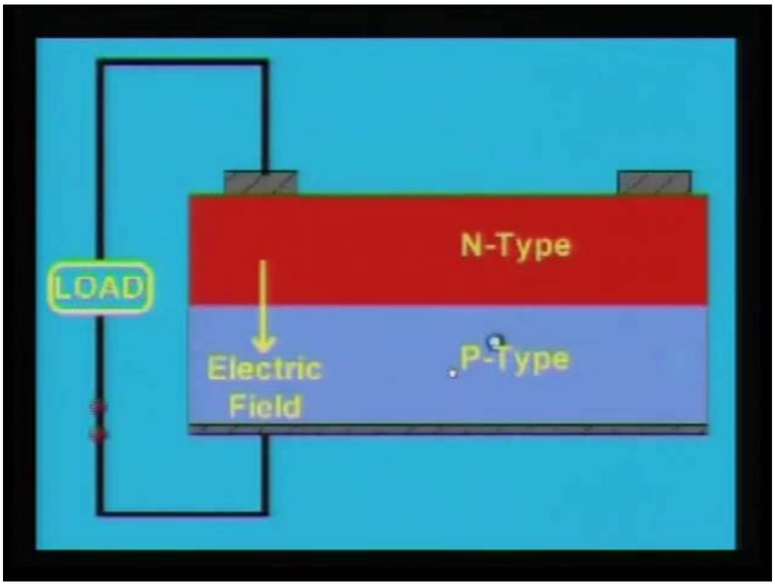

We will look at this animation which tells us, how this silicon solar cell operates, usually this silicon is made from sand and therefore, the process of generating pure silicon is a very rich technology. And what you see here is silicon that is, pure silicon is made out of a refining process and to this silicon, we dope boron and we can also dope phosphorous. As a result, we get both the N-type and the P-type semiconductors and when we bring these two N-type silicon and P-type silicon then you generate a electric field in the p-n junction. And the electrons and the holes will start moving towards the respective cathodes, so when sunlight falls essentially at the junction then electrons are pumped out. And these electrons through a connected wire, will go and recombine with the hole that is generated in the P-type conductor.

And that is how, the current is generated in a typical solar cell, now what are the issues that we need to bear in mind, when we think of a solar cell. The physics of it is also important, so we need to know, what sort of a I-V characteristics is needed. So, the current voltage graph or plot of a typical solar cell will tell, whether it is a useful one or not, right by looking at the shape of the curve.

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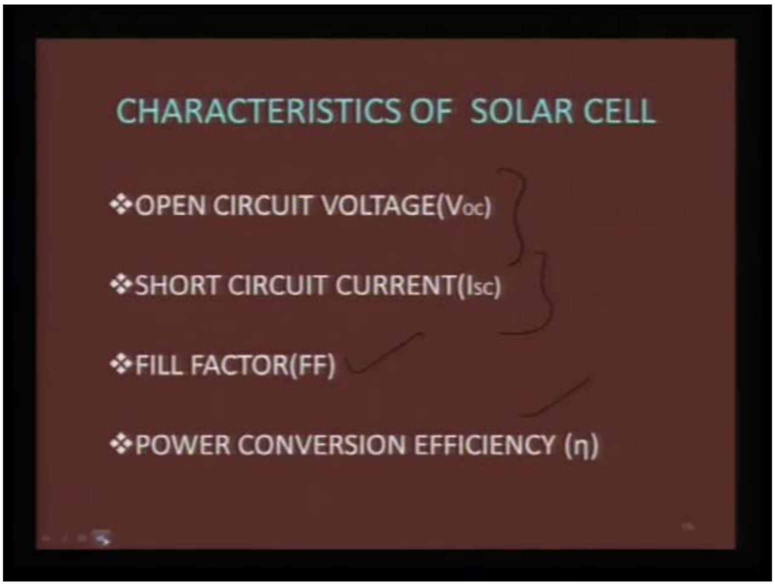

So, there are one is the open circuit voltage, which is called as V o c, open circuit voltage and the second one is short circuit current Ii suffix s c and fill factor, which is a combination of open circuit voltage and a short circuit current. So, that will give you a measure, whether you are really having a very good device or not and then the power conversion efficiency. So, if you are familiar with these four factors then you can easily evaluate, whether you have made a good solar cell or not.

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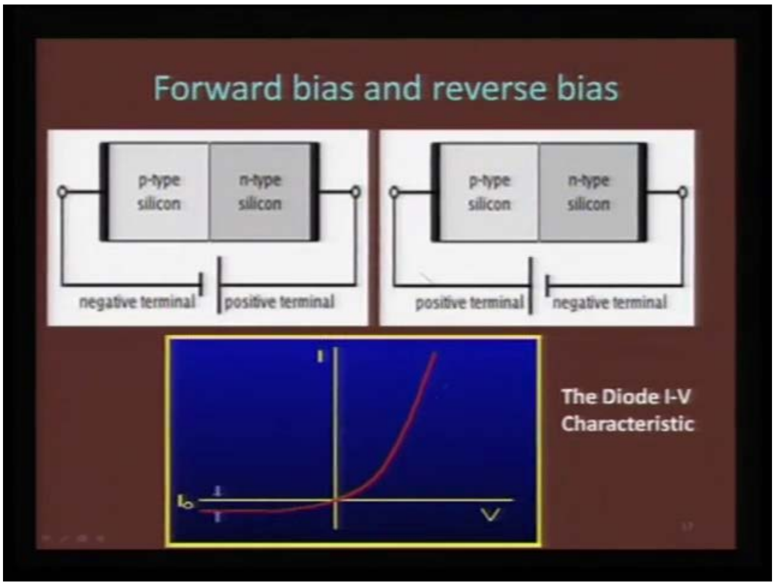

So, these are the four important parameters that we need to have in mind, so in a typical solar cell, you would see I-V graph like this. And this is in a situation when light is not shining or this is called as dark current. When light is not illuminating, you would typically see a I-V curve, which is actually in the first quadrant, it is actually increasing exponentially in the first quadrant. And if we apply a forward or a reverse bias then you would have a configuration like this. P-type silicon connected to a negative terminal in the forward bias, n-type to a positive and it would be the reverse case, when you do a reverse bias.

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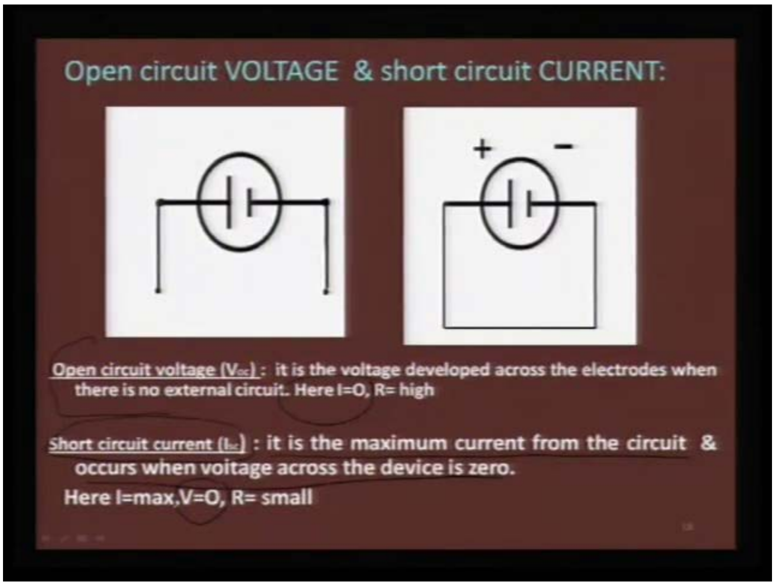

So, in this case you would actually have a diode characteristics of this order and we would also take a look at, what this open circuit voltage means and the short circuit current means. Open circuit voltage is actually defined, it is the voltage developed across the electrodes when there is no external circuit. In other words, at I is equal to 0, what is the maximum potential that is developed, which is called as V o c, open circuit voltage. And short circuit current is nothing but a current that is at it is maximum when voltage is 0.

So, when voltage is 0 you get maximum short circuit current, when current is 0 you get the maximum open circuit voltage and this is a measure of the maximum power that the solar cell can generate. So, in short circuit current, the definition it is the maximum current from the circuit that occurs when voltage across the device is 0. So, this is the representation of a open circuit voltage and the short circuit current that you see.

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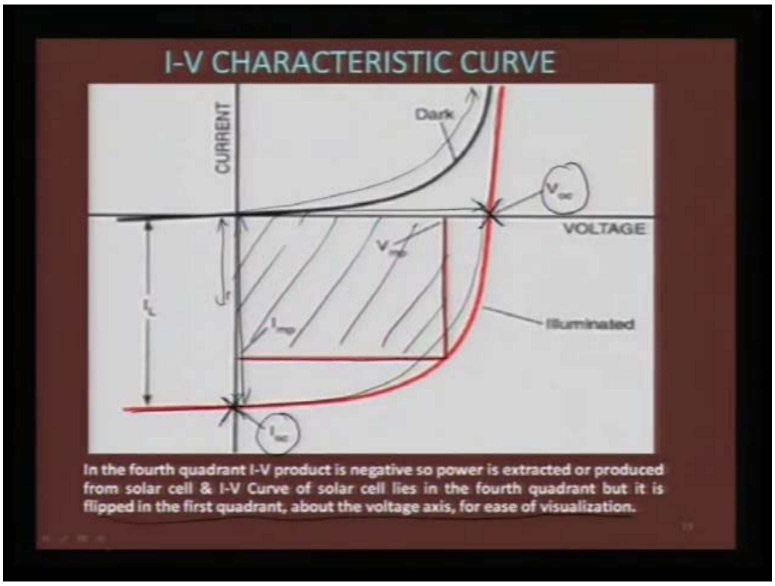

A typical viewgraph of a solar cell, which is performing under the illumination of light is this. As I told you, this is the dark current curve what you see here, this is in the absence of light. The moment light is incident on a solar cell, you would immediately see that, this I-V curve is jumping from the first quadrant to the fourth quadrant. So, when it goes from the first quadrant to fourth quadrant, the values what you see here at the x and y axis becomes critical.

And this is exactly what you call as I s c that is, your short circuit current, which is actually cutting at the y axis and the curve that is cutting at the x axis is called your open circuit voltage. So, this is important and this is important, if this is very less then it is going to carry very less current density, therefore the current density is a measure of, how lower that you can take it. So, when light is incident, immediately your solar cell will jump from the first quadrant to the fourth quadrant, so this measure is very important.

So, when you have this V o c and I c generated what is important is, to draw or to fit a rectangle within this space and the maximum area that you can generate in this rectangle, is what you call as fill factor, we will come to this in the next viewgraph. So, if I can achieve a maximum fill factor that is, maximum rectangle area then that will be the measure of the performance or efficiency of your solar cell. So, what we will do, we can just flip this fourth quadrant behavior into the first quadrant and try to take a look at it and see, what exactly those values mean.

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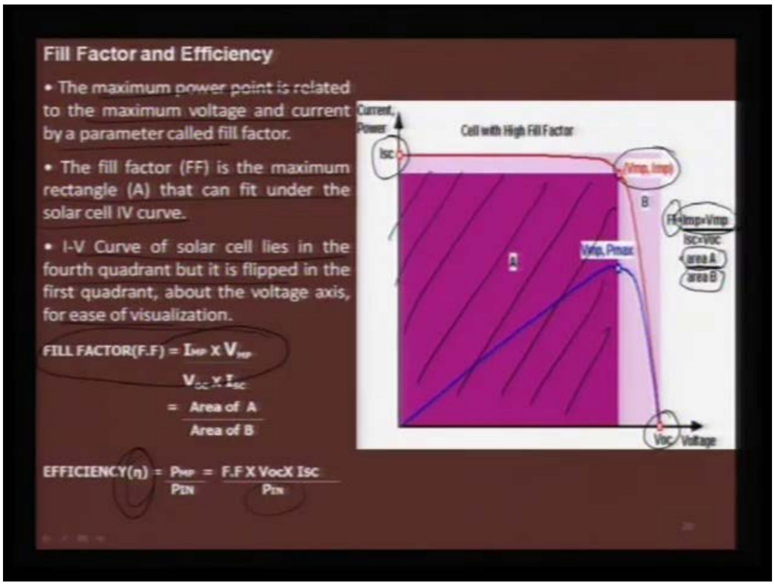

So, this is nothing but the same curve what we have flipped from the fourth quadrant, just to have an understanding and this is your I s c and this is your V o c and this point is actually called the V MP and I MP that is, the V and I at it is maximum. So, if that is the case then we can actually define, what is the fill factor and fill factor is actually given as your I m p, V MP over I s c and V o c. So, this fill factor will give you a measure of the performance of your solar cell, more the fill factor more the efficiency.

And therefore, we can also say, the area of A that is, the shaded region over the area of B will give you the measure of your fill factor. And accordingly we can also define, what is the efficiency of your solar cell by the same formula, fill factor into V o c multiplied by the short circuit current over the power input, will give you exactly what your efficiency is. So, the fill factor is the maximum rectangle that can fit under the solar cell I-V curve and the I-V curve of solar cell lies in the fourth quadrant, but it is flipped just for our understanding.

So, the maximum power point is related to the maximum voltage and current by a parameter called fill factor. So, if we have this in mind, whenever we measure a solar cell all that you would like to see is, the maximum area that you can generate under the curve by. So, visually we can guess, whether we have achieved the right efficiency or not.

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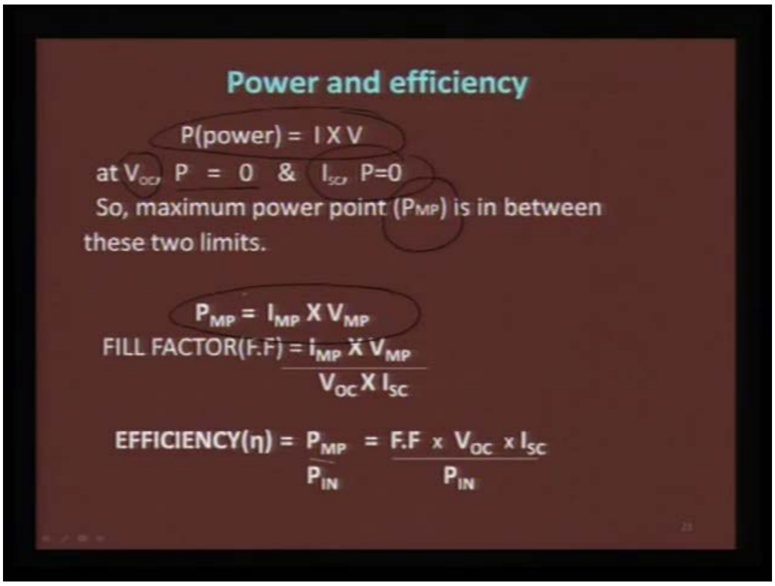

So, the power and efficiency is now defined this way, so power is I cross V, so at V o c, your power is 0 and at I s c, your power is 0. So, the maximum power point is P MP, which is at the maximum value of I and V. So, that is what is given here and we have already seen that expression in the previous viewgraph. So, maximum power point is I MP cross V MP, this we should bear in mind.

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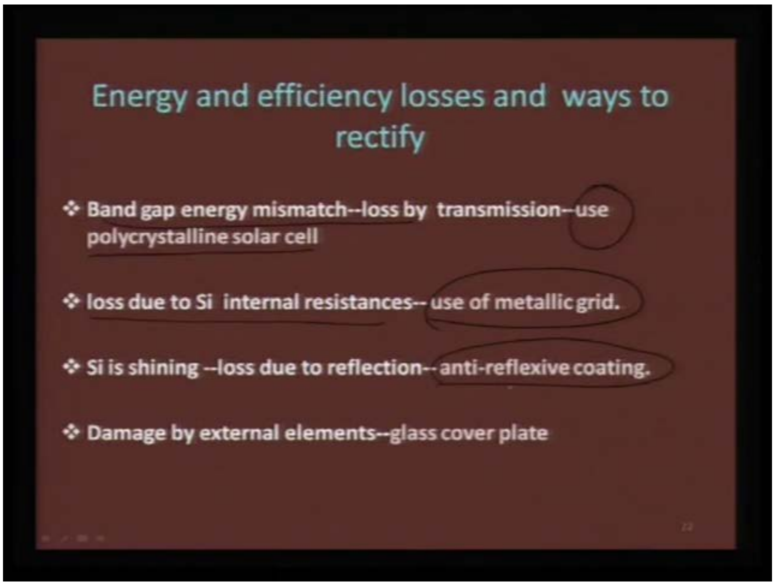

Now, there are ways that we can improve this efficiency, because when you construct a solar cell, there are easy ways to lose it, because of many factors that are imperatively causing leakage of current within this cell. For example, band gap energy mismatch can also lead to loss by transmission, therefore in silicon solar cells, one of the possible ways to avoid that is, use a polycrystalline solar cell, because in single crystalline solar cells, you have some problem with the band gap mismatch.

Another thing that we can do is, to use a metallic grid, in cases where you have loss due to silicon internal resistance. And I will show you in the next cartoon, how you can built that solar cell in order to avoid this internal loss due to internal resistance, use a metallic grid and silicon itself if you make it as a panel, whether a polycrystalline or a single crystalline is very shining, therefore it will be reflective. So, when solar light is falling, sunlight is falling, you need to avoid this reflective behavior, therefore you need to use a antireflective coating.

And again, because it is exposed to air, it can accumulate dust, it can accumulate any other gases occluding to it, therefore to preserve the cell from this sort of contaminant, you need to have a glass cover plate. So that, the amount of solar energy that is absorbed is always maintained, so for this reason lot of external things also has to be done.

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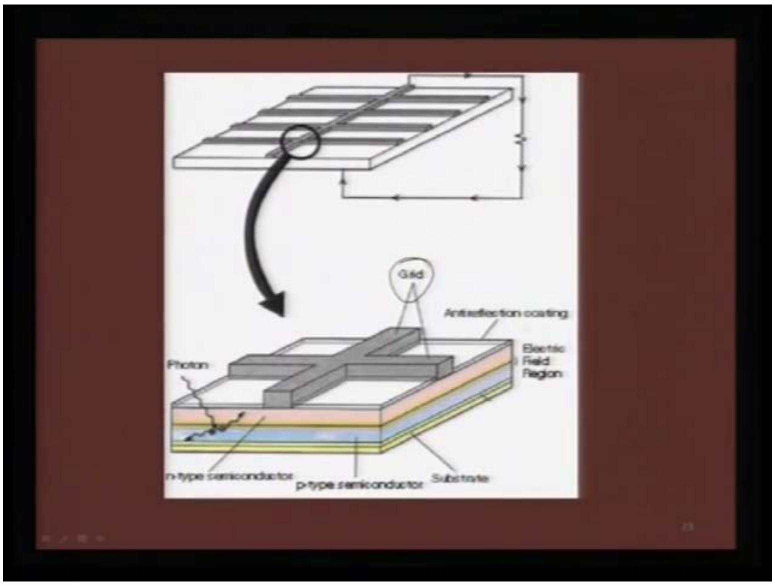

So, typically this is how you overcome for avoiding the silicon internal resistance, you use a metallic grid and then you can actually put a antireflection coating. And we can house it in a place, which is actually free and again it is also mounted in a slant way, you never see a flat one, because you do not want any dust and other stuff to deposit, therefore you always keep it on a slant position. So, the mountable issues are also to be taken into to improve the efficiency of the solar cell.

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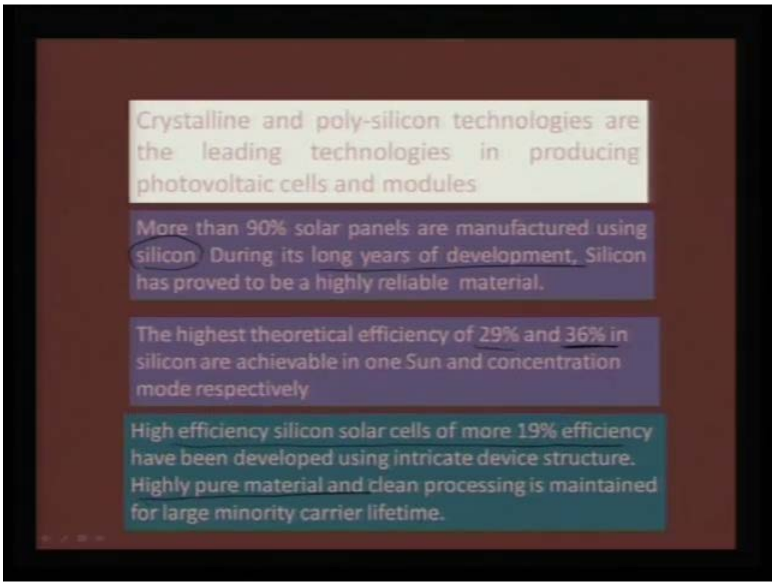

There are few things that I want to comment about the silicon solar cell, one is crystalline and polysilicon technologies are the leading technologies in producing photovoltaic cell, as of now. Because, 90 percent of the solar cell modules what you see in our household applications or even in energy sectors, those are all proven by silicon. Therefore people would not like to invest on anything other than a silicon solar cell as of now, because it is well established.

But, the amount of power that you generate per dollar or for the rupee that we give, it has to be lowered in order to go for variety of applications, therefore silicon has to be replaced and that is the reason, why organic solar cells are coming into picture. During it is long years of development, silicon has proved to be highly reliable material, the highest theoretical density is that, you can achieve for a concentration mode that is, 36 percent, but as of now what is available is, only upto 20, 23 percent.

Therefore, there is a long way to go to improve, but this technology has it is own limitation, therefore there is still lot of other combinations, which are being worked out in the silicon solar cell. High efficiency silicon solar cells of more than 19 percent efficiency have been developed with the intricate device structure and for this, you actually require highly pure material.

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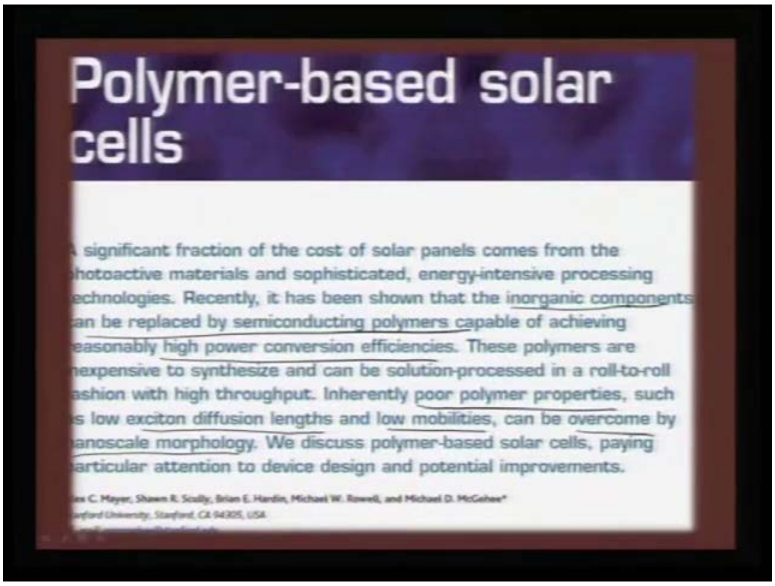

So, because of these constraints and also because of not able to make larger panels, organic solar cells have been dried. Because, in organic solar cells, you can actually go for flexible substrates, you can roll it, roll to roll you can make, therefore processing feasibility is there number 1, number 2 organics can be prepared with much more ease compared to making pure silicon. As a result, organic solar cells are taking lot of attention, but again the problem is, some of the organic molecules can degrade with exposure to sunlight over a period of time.

Therefore, you need to bring about the right combination of organic molecules, which can actually withstand a harsh environment. So, there are several possibilities are there, but from the lab based solar cells or lab fabricated solar cells, there are several issues that we can understand about the mechanism, about the chemistry that is rich in this organic solar cells. So, I would go through few details to show you what it is, there is a very good article in materials today by Alex Mayer's group from Stanford, where they have made a very good review article on polymer based solar cells.

And they have also comprehensively covered all the solar cells, which are in the market, both developed from the industries and from leading universities. Just would like to bring out few points what they have mentioned in their abstract, it has been shown that, the inorganic components can be replaced by semiconducting polymers, capable of achieving high power conversion efficiency. So, this is one of the attractive term to convert from silicon to polymer solar cells.

But inherently, the polymer properties are limited, because of low exciton diffusion lengths, low mobilities and therefore, nanoscale morphologies have been tried now. So, even among polymer solar cells, you now have nanosized based semiconductors coming as a interplay with these polymers. So, these are called as heterojunctions, where inorganic components mixed with polymers are coming out to be very good compromise for this polymer based solar cells.

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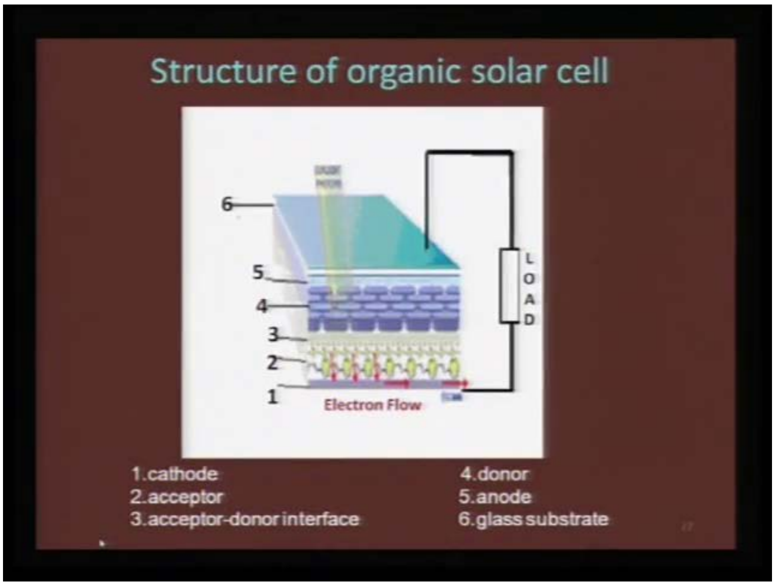

I will show you few examples of that, now in organic solar cell, it is not the band gap that would determine which is nothing but your p-type, and n-type band gap which will determine the performance of your solar cell. Here in this case, you are talking about the HOMO and LUMO gap, so if you are going to promote a electron from a homo level of your donor to the LUMO level and the electron will actually be transferred to the acceptor LUMO level and that will be generated as the current.

But, what happens here, when we try to generate this electron, a hole is formed in the HOMO level. And this binding energy of this electron hole pair is very high of the order of 1.4 electron volt compared to the binding energy of the excitons in the silicon solar cells. As a result, the diffusion lengths are going to be very less, so there are problems encountered in generating maximum efficiency in this organic solar cell. Now, this is how it happens, what you see is a glass substrate, which is on the top and sunlight falls on the glass substrate.

And then goes through anode, anode ejects out the positive hole and then it is going to come to a interface here, where there is a donor acceptor interface. And then the electron is actually accepted by the acceptor solar cell that we are seeing, because the combinations that you can work out between a donor and the acceptor is actually to do with the HOMO LUMO levels and not with the band gaps. So, you need to have a proper understanding of, what a HOMO LUMO level gap is.

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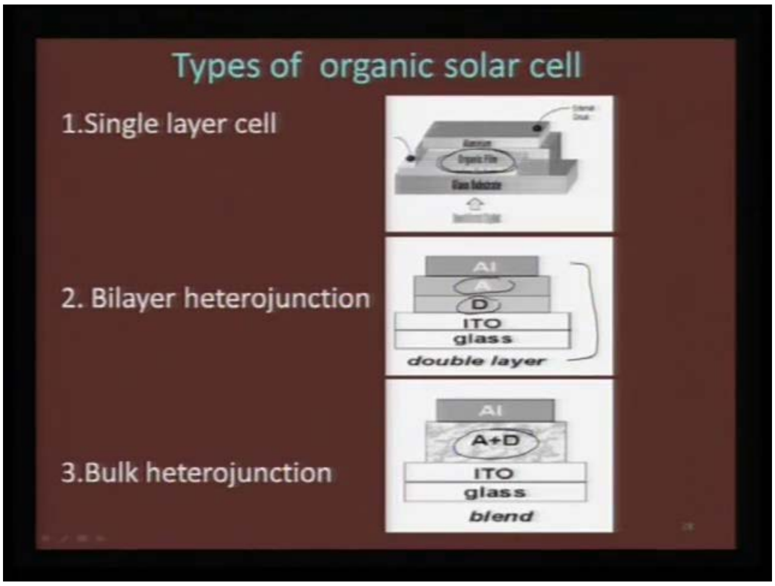

And for this, we can actually have few types of organics solar cells, one is a single layer solar cell, where you have glass substrate then indium tin oxide which is your anode and aluminum as your cathode, just a single organic film. Or we can actually go for a donor, which will donate electron and the acceptor, which will take a electron and this sort of double layer organic solar cell can be generated. Or we can have a bulk heterojunctions, where you can have both a blend of acceptor and donor mixed together, mainly making a single layer and thereby, you can make a bulk heterojunctions.

So, in this organic solar cell, we do not have the concept of a n-type and p-type, we rather talk about a donor and a acceptor layers. And the main issue there is, they should have a smaller optical band gap, for this reason most of the molecules that we have, should be conducting and also they should be having a extended conjugated pi bonds. And extensively conjugated pi structures can actually play a very important role, both as a acceptor or a donor and with a reduced optical band gap.

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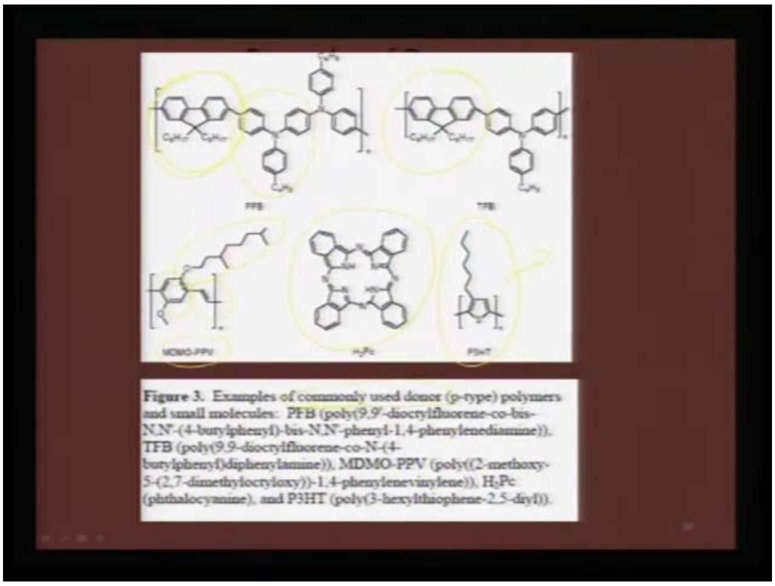

And I will show you some examples of the structures that are already used for example, in the case of donors, so we have most frequently used donors are those, which are having a fluorine moiety and the triphenyl amine moiety. So, these are very much repeated as donor molecules, they have a very low band gap and easily they can give out electrons. Also we have porphyrin unit, which can be used or P3HT, which is nothing but your hexyl thiophene which is substituted in the third position, this is of a polymeric form, so it is popularly called P3HT.

This can also play a very useful role as a donor molecule and also we have polyphenylene vinylene, this is your vinylene moiety, this is your phenylene moiety. So, if your actually substituting this to a octyl group then you get this MDMO - PPV and this PPV is nothing but phenylene one vinylene unit and this is also one of the most frequently used polymer as a donor. There are lot of integrated compositions or with new substitutions have emerged, but by enlarge, the fluorines are widely used.

One of the reasons, why flourines are used over other ones is, because of the high molecular weight. With high molecular weight, it is very easy for you to make a larger panel and it is easy to roll and you can make a good connectivity in the thin film.

Therefore, high molecular weight polymers are generally recommended, therefore fluorines do play a very important role.

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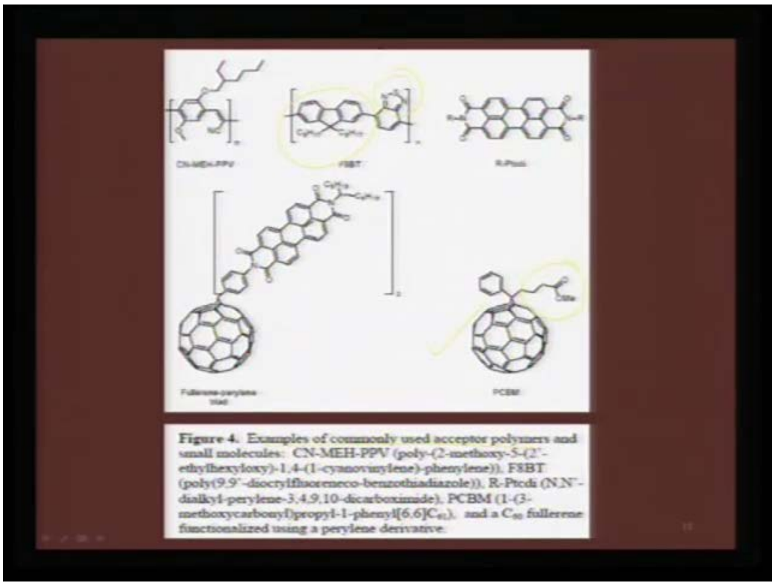

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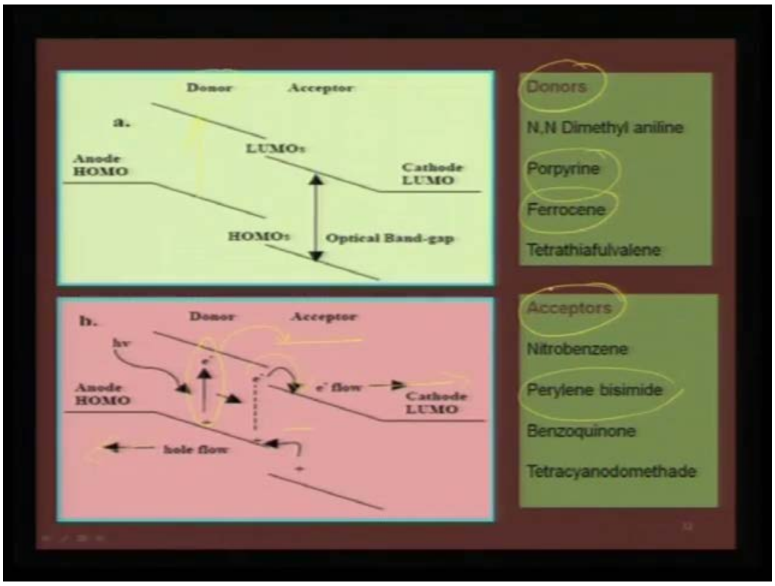

Similarly, we can have some acceptor polymers also with substitution here, you can have this sort of benzothiadiazole substitutions in fluorine, which can make this more as a acceptor. But, predominantly used acceptors are PCBM which is nothing but a esterified unit of C 61 and this C 61 is with this ester linkage is one, which is very popularly used as a blend with the donor molecules. And again we have this fluorine perylene triads are also being tried out, mainly for stability and also for extended conjugation, therefore this is also one of the good candidates for acceptor polymers.

Now, as I told you, what is more important is the match between the donor HOMO LUMO levels and the acceptor HOMO LUMO levels. And the HOMO level of your donor actually has to be higher than the HOMO level of your acceptor and also the LUMO level of your donor has to be higher than the LUMO level of your acceptor. Therefore, electron when it is actually promoted here, when it is promoted it can easily go across the interface to the acceptor and electron can flow easily and further, the hole can flow in the opposite direction.

So, the combination of your donor and acceptor depends on the HOMO LUMO levels of your donor and acceptor molecule. So, if your HOMO level of your acceptor is going to be here then the promotion of the holes will not be synchronized. Similarly, if the LUMO level is going to be here then there will be a barrier for this electron to be injected to the acceptor level. Therefore, this match has to be taken into care, there are also several other combinations of donor acceptor molecules that are verified. Porpyrine is known, ferrocene and C 60 is also a very good combination, perylene bisimide is a well-known acceptor now, which is being evaluated. So, these are other donors and acceptors, which are also emerging as good candidates.

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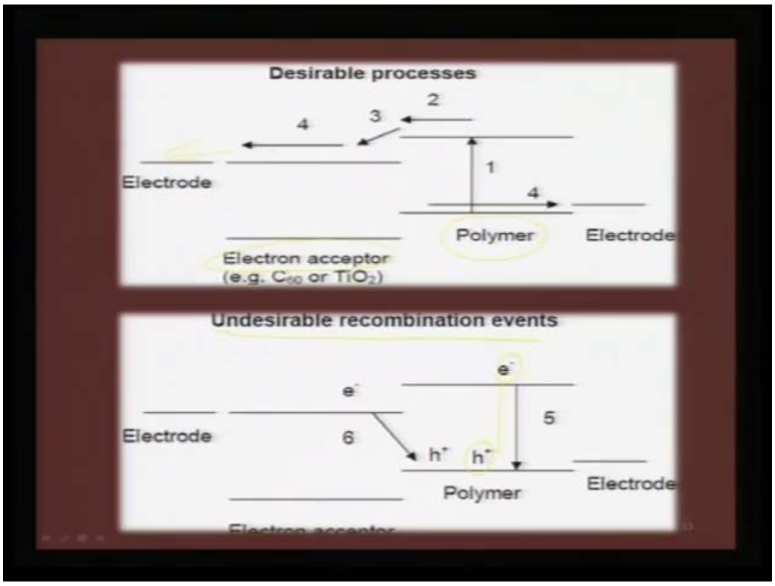

Now, when we look at this polymer solar cell, there are few things that we should make sure while we make the right match. So, that the desirable and undesirable combinations or process are taken care, when you eject an electron, we expect the electron from the a polymer surface to actually go into the electron acceptor, either a polymer or which is doped with C 60 and TiO 2. This electron should actually be channelized properly to go straight into the electrode, this is what is the desired process.

But, what can happen is the undesirable recombination effects, where electron can actually get bound to the hole as a exciton and it is not free to move. Therefore, your diffusion length has to be pretty large for the traffic to be modulated in this direction or what can happen is the electron can go to the electron acceptor level but then again can be recombining in this fashion, which is not a desirable case.

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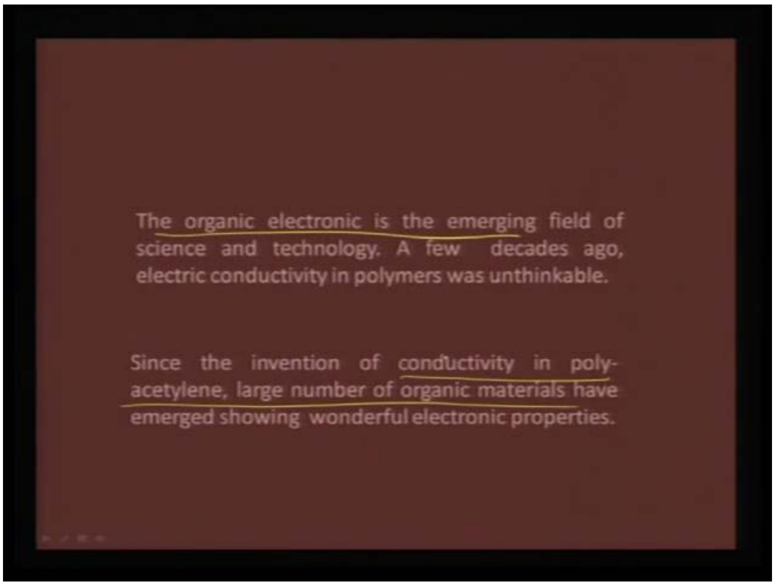

So, when we look at the organic electronics, it is a emerging field, it was not thought to be a candidate at all at least few years back. So, what is really the motivation was the conductivity in polyacetylene, which actually created more interest for exploring newer polymers or organic molecules, which can play the role of donors and acceptors.

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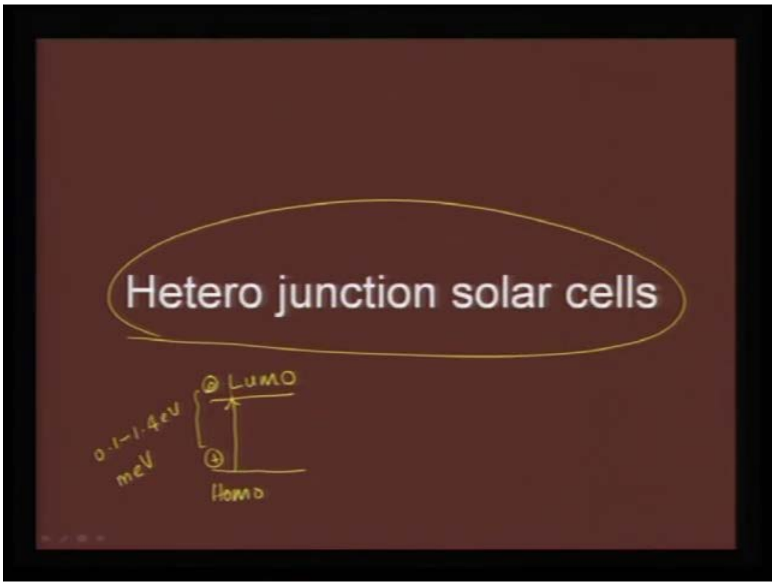

Now, because of this problem of exciton hole getting bound and they are not able to get dissociated into electron and hole separately then heterojunctions solar cells have emerged into picture. As I told you, this is your HOMO level and this is your LUMO, when electrons are ejected then you have the electron here and the hole here, and these pairs are actually bound and the excitonic binding energy is of the order of 0.1 to 1.4 electron volt, that is what is measured in the organics.

Whereas, if you take the silicon solar cells, the electron hole binding pair is of the order of millielectron volt, because they have a very less binding energy, they can easily dissociate into electron and hole, and the current can be generated easily. But, in this case, there is a problem of this overcoming the exciton diffusion length, as a result, instead of having the donor and your acceptor at a larger length scale, we can try to bring this as a heterojunctions, where you can reduce the length so as to overcome this binding energy, and that is what we can achieve. The concept of bulk heterojunction using low band gap polymers and nano particles like C 60, C 70 and it is functionalized derivatives like PCBM, this has led to about 7.9 efficiency. And these are the candidates, I have already discussed with you about the use of p c b m and these are some of the donor molecules.

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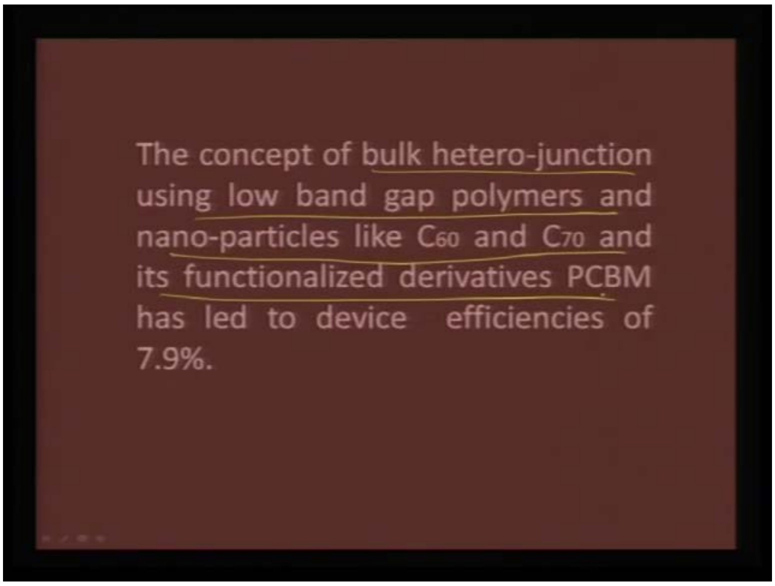

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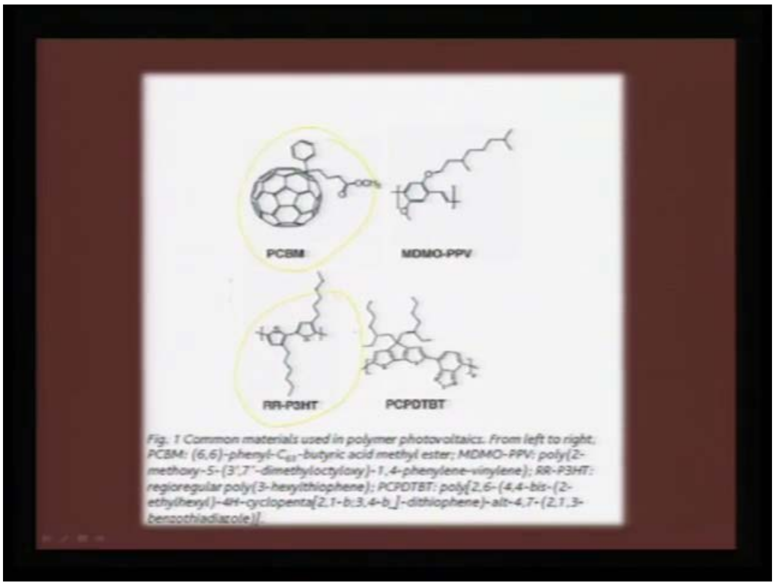

So, this is the typical configuration of your donor acceptor configuration in a organic solar cell and these are your bilayer solar cells and this is actually not giving enough efficiency. So, the heterojunctions are construed like this, where you make a physical mixture of the both this in this fashion or we can try to pattern this in this form, where you have the donor and the acceptor in a smaller length scale and it is alternatively placed. So that, the exciton binding energy, diffusion length can be overcome with this nano structures, that is the reason why this patterning is made instead of making a double layer.

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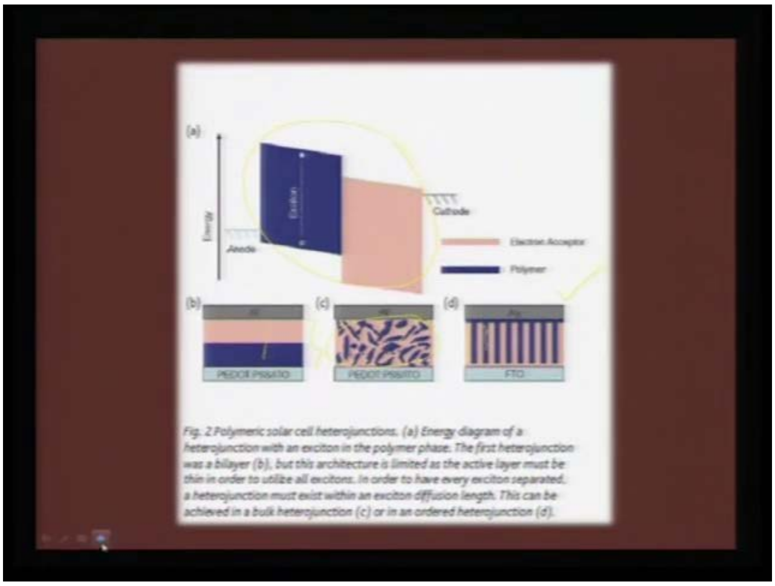

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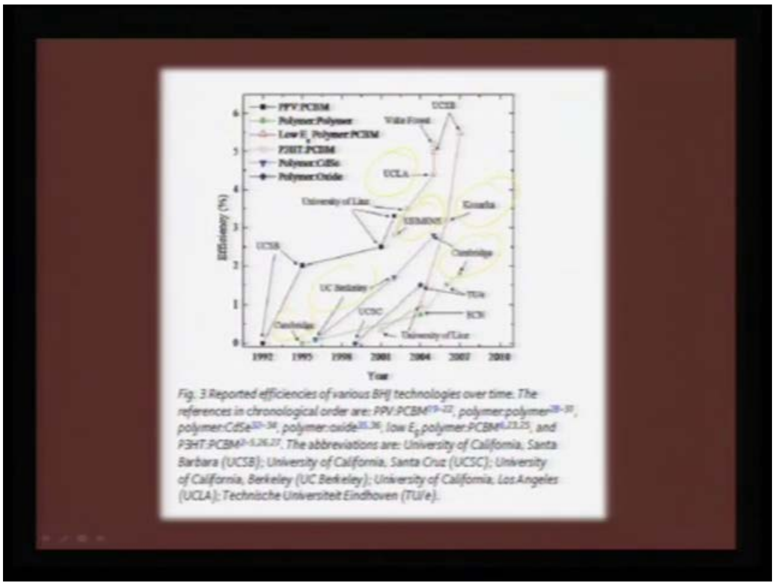

And by this way, the efficiency of your solar cell has been achieved to a greater extent and this is a viewgraph which tells that, there is a equal competition between the leading universities and also the companies, where they are trying to experiment on polymer solar cells. As you can see here, Konarka, Siemens these are all leading players companies, who are working in bringing this to market.

And equally there are several universities Berkley, Cambridge then you have Santa Barbara and UCLA, all these universities have actually brought several nano structures, which are having efficiency upto 6 percent. So, there are more prospects to harvesting higher efficiencies in these organic solar cells.

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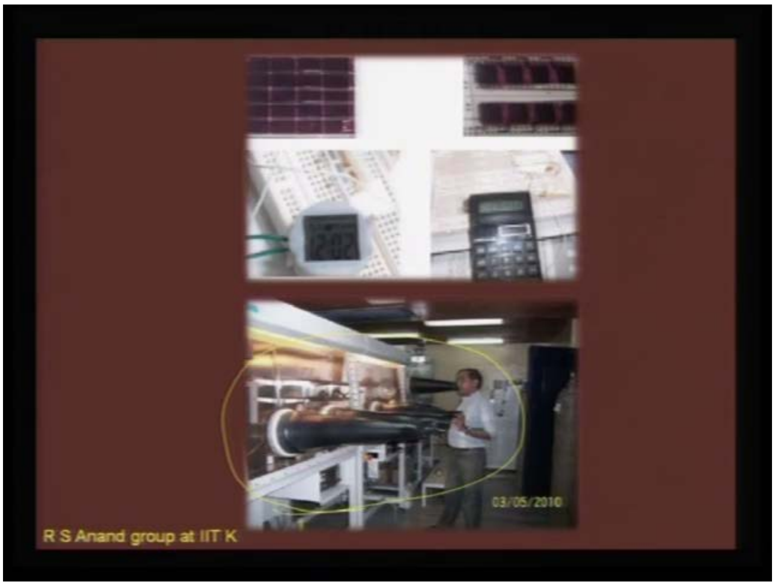

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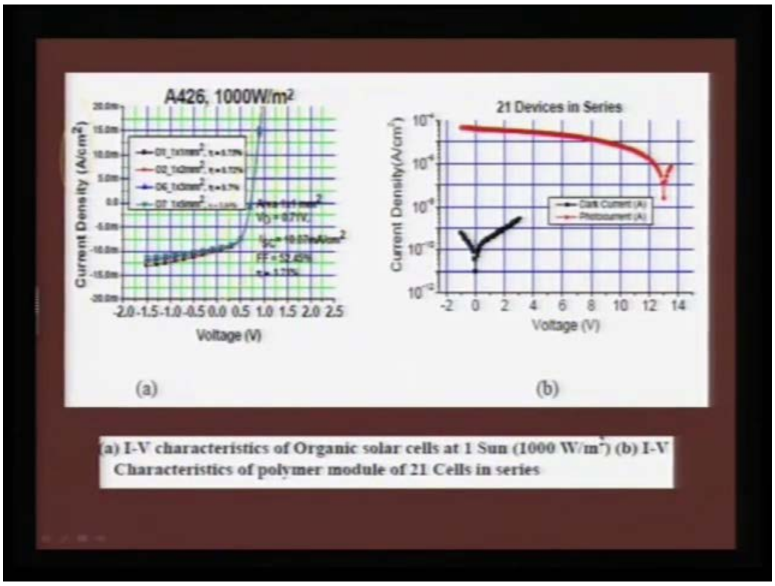

In IIT Kanpur also we have a group, which is actively working, this is a Dr. Anand's group and typically you can see, the organic solar cell requires synthesizing platform like this, where you do absolutely in a inert condition, you do not expose it. So, you can actually get a very clean heterojunctions made within one chamber, all conducted inside vacuum. And many solar panels have been made in this lab in this institute, where simple gadgets like calculators or timers, anything can be operated using the solar cells and these are demonstrations from our own groups at IIT Kanpur.

And you can see the threshold voltage for this solar panels are less than 1 volt, therefore the device performance are good. And you are able to get very good current density and 21 devices in a series can be arranged to demonstrate, how this can be made.

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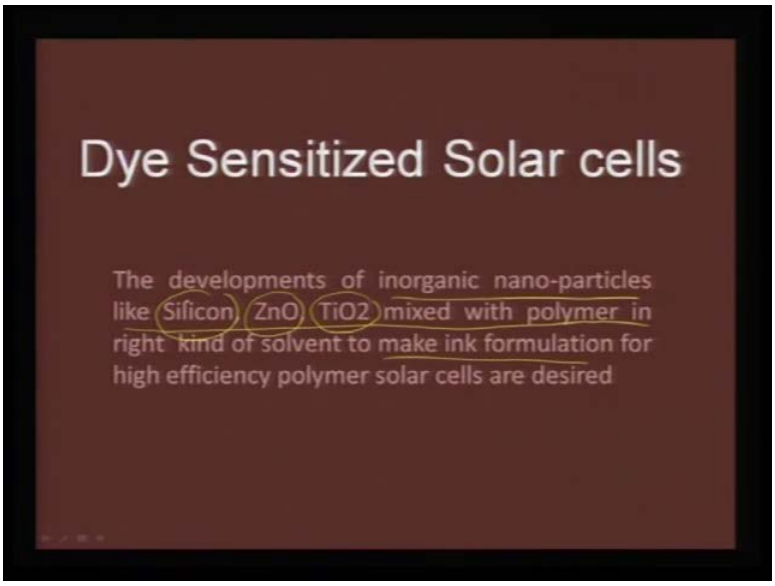

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I will touch a briefly on dye sensitized solar cells before I close, the developments of inorganic nano particles like silicon, zinc oxide, TiO 2 mixed with polymer can actually help us make ink formulation, so that we can make very big panels. At the same time, we can overcome the issue of exciton binding energy by using a dye sensitized solar cells and this is possible, because these semiconductors can do the job that is required in a organic photovoltaics.

And this is a demonstration of, how such a dye sensitized platform can work and as you see here, this is typical device out of a dye sensitized solar cell. And if you look at a block, this is how the device configuration is, where you have the glass protective electrodes and then conductive electrodes, titanium dioxide and a catalyst, which is actually forming the middle layers. Electrons can come and go from both the extremes, where the middle layer is actually packed with titania particles and on the surface of the titanium particles, you can see this red spheres, which are the dyes.

And when light falls, the red dyes actually bring out electron and it is pumped into the titania conduction band. And this electron is now transferred to the conductive layer, which actually does the work and then this electron flows to the lower conducting layer. And from this lower conducting layer, it is actually transferred to another layer through a catalyst, where it comes in contact with a electrolyte, which is a triiodide.

And once this electron goes here, this triiodide is converted into a iodide ion and then this iodide ion actually moves to the upper layer and comes in contact with your TiO 2 doped with dye and transfers the electrons back to the dye and then it returns back as triiodide. Now, these deactivated dyes can actually do the performance again, as a result this can happen hundred thousand times in a second and thereby, generating a continuous stream of electron.

So, this is one way, the organic solar cell efficiency can be improved by incorporating nano particles of semiconductors like TiO 2 and so on. Lastly, I would like to just conclude with some of the prospects of these solar cells, because of the ability to make large area displays, we can actually use it in different environment, remote light sensing, telecommunication, solar powered water supply, emergency power systems and so on. Not only that, the application of solar cell is now transcending more than that, even to satellites and space vehicles.

So, the use of solar cell cannot be limited and as you would see here, within few years, the amount of materials that can be used from the chemistry point of view, has accelerated to a larger extent. There is a great combination between organic and inorganic materials and nano materials are also now pitching into prove the efficiency of the solar cell to a greater extent and therefore, there is lot more excitement that is possible.

So, when you think of solar cell applications in perspective, we need to think about the band gap, we need to think about the donor and acceptor abilities, we need to think of the efficiency that it can bring about and the four parameters that I told you. The fill factor, the efficiency, the short circuit current and the open circuit voltage, all these are critical parameters when we try to think of solar cells. And I will also list some of the links and some more references, where you can get more comprehensive idea about the materials that we can use and how chemistry can play a very vital role in designing these solar cells.