Solar Photovoltaics:
Fundamental Technology and Applications
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Lecture-22
Photophysics of Bulk Heterojunction Solar Cells

Welcome everyone to our 5th week 2nd lecture, in the last lecture we introduced you the concept of the organic semiconductor. And we have seen that organic semiconductors have certain advantage over the inorganic semiconductor. For example flexibility and also tunability, compactness and sometimes the efficiency or performance. Now this organic semiconductors they can be classified either as a conducting polymer.

These are a special class of polymer which can conduct electricity and they have alternative single bond and double bond. And the another class of organic material is small molecule which usually acts like an acceptor material. Now using this organic material we can make a sandwich kind of solar cell where the acting material is placed between the 2 electrodes cathode and anode. Now depending upon the configuration of the distribution of organic materials the different varieties of the organic solar cell configuration is possible.

And we said that there are 2 important configuration of the organic solar cells are particularly interesting namely the bilayer solar cell and bulk heterojunction solar cell. Today we will learn about what is the difference between a bi-layer solar cell and a bulk heterojunction solar cell and what is the photophysics of a bulk heterojunction solar cell.

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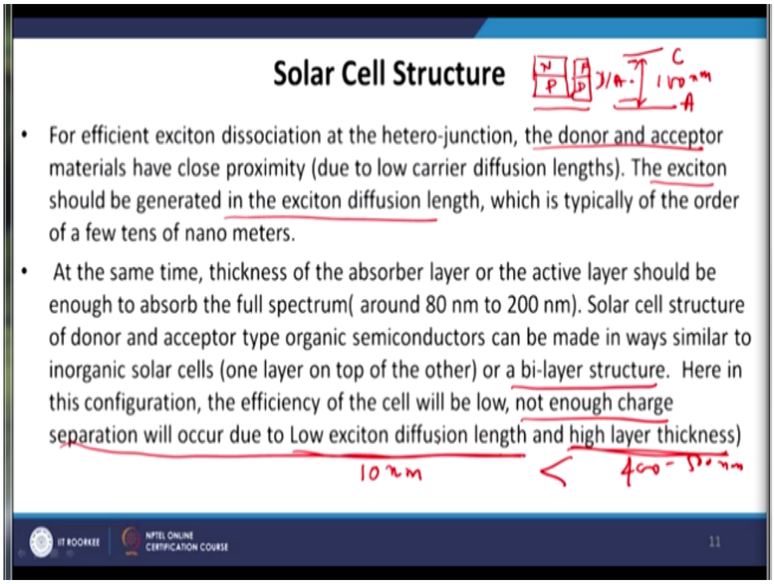

Solar Cell Structure

- For efficient exciton dissociation at the hetero-junction, the donor and acceptor materials have close proximity (due to low carrier diffusion lengths). The exciton should be generated in the exciton diffusion length, which is typically of the order of a few tens of nano meters.
- At the same time, thickness of the absorber layer or the active layer should be enough to absorb the full spectrum(around 80 nm to 200 nm). Solar cell structure of donor and acceptor type organic semiconductors can be made in ways similar to inorganic solar cells (one layer on top of the other) or a bi-layer structure. Here in this configuration, the efficiency of the cell will be low, not enough charge separation will occur due to Low exciton diffusion length and high layer thickness)

10 nm < 400 - 500 nm

Now the solar cell structure for efficient exciton dissociation at the heterojunction, the donor and acceptor materials have close proximity due to low carrier diffusion lengths. The exciton should be generated in the exciton diffusion which is typically of the order of few tens of nano meters. Now this is very important factor in organic materials for example conjugated polymer, the exciton diffusion length is very low usually like 10 nano meter.

So what do you mean by exciton diffusion length it is the distance the exciton or the electron hole pair can travel before they recombine. Now for example let us say I have these 2 electrode which is one is anode and another is cathode and the separation between these 2 electrode is 100 nano meter. So we at least need 200 to 300 nano meters or even 500 nano meters to absorb the light, we need a good amount of thickness to absorb the light.

But if the excitons or the charge carriers which is generated here if they can travel only 10 nano meters before the recombine then only those charge carriers which have been generated in the vicinity of the electrodes, they will only be collected by the electrodes. And those who are in the between or in the bulk of the semiconductor they contribute to the effective charge carrier generations in the circuit.

So that is one of the major bottle neck of the organic semiconductor and there are ways to prevent this thing and that is called the exciton diffusion length engineering. And in ideal case what we want that this donor and acceptor materials which made this heterojunction and which you can imagine like a p-n junction. For an inorganic semiconductor we have seen that we have these 2 different layer right one is the n layer another is the p layer.

Similarly in an organic solar cell we have these 2 different layer one is the donor material another is the acceptor material. Now in the p-n junction we first put a layer of p type semiconductor and top of that we diffuse the n type semiconductor. Here also like let us say I have a bi-layer device where I have a donor polymer layer on top of that I have an acceptor semiconducting layer.

Now this charge carrier of this 2 different kind of materials the donor and the acceptors they have to be in a close proximity because of the low diffusion length of the charge carrier. In an inorganic semiconductor the diffusion length of the electrons and holes are very large in an order of like micro meter. But here it is only nano meters, so that is why the electrons has to travel a larger distance before it can recombine before it can recombine to some kind of defect or trap states.

So to minimize this effect the 2 types of donor and acceptor material has to be in a close proximity and the excitons should be generated in the exciton diffusion length. At the same time the thickness absorber layer of the active layer should be enough to absorb the full spectrum around 80 nano meter to 200 nano meter. Solar cell structure of donor and acceptor type organic semiconductors can be made in ways similar to inorganic solar cells, it can be one layer on top of the other or a bi-layer structure.

So just like we get this example of this p-n junction semiconductor here you can see that first you have a p type layer on top of that we have an n-type layer. Similarly we can put a donor type of polymer on top of that we can put an acceptor type of material and that we call as a bi-layer structure. Here in the configuration the efficiency of the cell will be low why because not enough charge separations will occur due to the low exciton diffusion length and high layer thickness.

Now these are the 2 competing parameters one is the low exciton diffusion length, so when I say that low exciton diffusion length what is the relative parameters this value low. So basically in a conjugated polymer the exciton diffusion length is 10 nano meter whereas the high layer thickness. So the active layer has to be thick enough so that it can absorb the sunlight and usually the thickness of this active layer is something around like 400 to 500 nano meter.

So this number is much higher than the 10 nano meters, so exciton diffusion length is much smaller than this layer thickness. So if I make the layer thickness very very small, so that we can become in the scale of the exciton diffusion length so then our light absorptions also decrease significantly. So we cannot compromise with the layer thickness, we need a minimum amount of layer thickness to get a good amount of light absorptions.

But if we increase the layer thickness the possibility of the exciton recombination is much higher because now the exciton diffusion length is low. So these are the 2 competing parameters and once needs to optimize these 2 parameters simultaneously to get a good efficiency.

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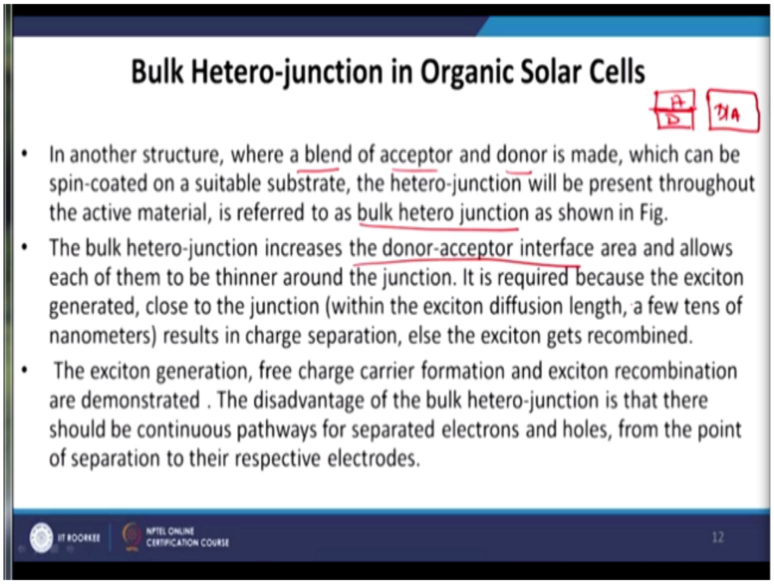

Bulk Hetero-junction in Organic Solar Cells

- In another structure, where a blend of acceptor and donor is made, which can be spin-coated on a suitable substrate, the hetero-junction will be present throughout the active material, is referred to as bulk hetero junction as shown in Fig.
- The bulk hetero-junction increases the donor-acceptor interface area and allows each of them to be thinner around the junction. It is required because the exciton generated, close to the junction (within the exciton diffusion length, a few tens of nanometers) results in charge separation, else the exciton gets recombined.
- The exciton generation, free charge carrier formation and exciton recombination are demonstrated . The disadvantage of the bulk hetero-junction is that there should be continuous pathways for separated electrons and holes, from the point of separation to their respective electrodes.

In bulk heterojunction solar cell we can remove this kind of bottle neck or we can get some advantage over the bi-layer devices. In another structure where a blend of acceptor and donor is made which can be spin coated on a suitable substrate, the heterojunction will be present throughout the active material is referred to as the bulk heterojunction as shown in the next figure.

So in a bulk heterojunction solar cell we do not put layer by layer you remember in a bi-layer devices what we have done we first make a layer of donor material on top of that we put a layer of acceptor material. But here we mix the donor and acceptor together and make a continuous film so now the probability of the donor to see acceptor interface is much higher than this kind of configuration.

Because here only at the interface the donor material is looking at the acceptor material but if we mix them together like here. So we can create many nano interface where the donor material has a possibility of looking after the acceptor material. So when and you can make this kind of structure by blending the acceptor and the donor. So blending means mixing the donor and acceptor in a suitable organic solvent.

The bulk heterojunction increase the donor acceptor interface as you just mention the interfacial area between the donor and acceptor area is much higher in a bulk heterojunction solar cell in comparison to the bi-layer devices. And allows each of them to be thinner around the junction, it is required because the exciton generated close to the junction within the exciton diffusion length a few tens of nano meters result in charge separation else the exciton get recombined.

So those of the excitons which are near the junctions in a length scale of 10 to 20 nano meter, they can only contribute to the charge carriers generation. But those excitons which have been generated in the bulk of the semiconductor they cannot contribute but on the other hand if we create of lot nano interface then the exciton has the probability of using those nano interface or using that percolating network to reach to the electrodes.

The exciton generation free charge carrier formation and exciton recombinations are the 3 important parameters in this kind of solar cells and we will demonstrate it later on. These advantage of the bulk heterojunction is that there should be continuous pathways for separated electrons and holes from the point of separation to their respective electrodes. So what do you mean that will come to the next slide.

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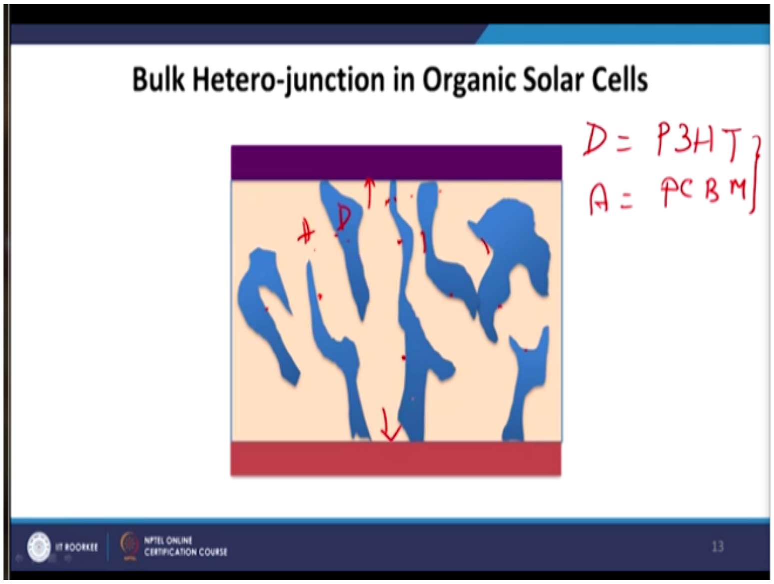

Bulk Hetero-junction in Organic Solar Cells

D= P3HT

A= PCBM

Look at a bulk heterojunction solar cells, so here like let us say this is a donor material and this is an acceptor material. Now as a donor material we use conducting polymer like poly 3 hexylthiophene which we call it as a P3HT and acceptor material we use PCBM and these are the 2 which is use in a very standard way the reason behind is that their energetics matches and people have achieved an efficiency of 6% by using this P3HT PCBM and in a module to 3 to 4%.

Now what will happen let us say this is by P3HT and this is my PCBM, so instead of layer by layer now we have mix them the P3HT and PCBM in the same solvent and spin coat it on a glass substrate. Now we have created lot of this nano interface, now these are all this nano interface, now at all of this nano interface the exciton has been dissociated why because of this nano interface now I have a potential difference.

Since there is a potential difference there will be an electric field gradient and this internal electric field gradient helps to dissociate the exciton or the bound excitons. And because of that now the exciton has been dissociated at all of these interfaces, you can see that we have created lot of the nano interface throughout this active material. And now those of the excitons which have created at the interface and within a length scale of 10 nano meters or 20 nano meters.

They have a high probability to reach to the electrodes, so now we can generate or we can reduce the loss of the recombination loss in this kind of structures. So that is why this bulk heterojunction geometry is much preferred or it gives higher efficiency in comparison to the vapor deposited bi-layer devices. But also it is true that in sometimes like you know bi-layer heterojunction devices you can also get a good efficiency depending upon the material choice or how good your morphology is that.

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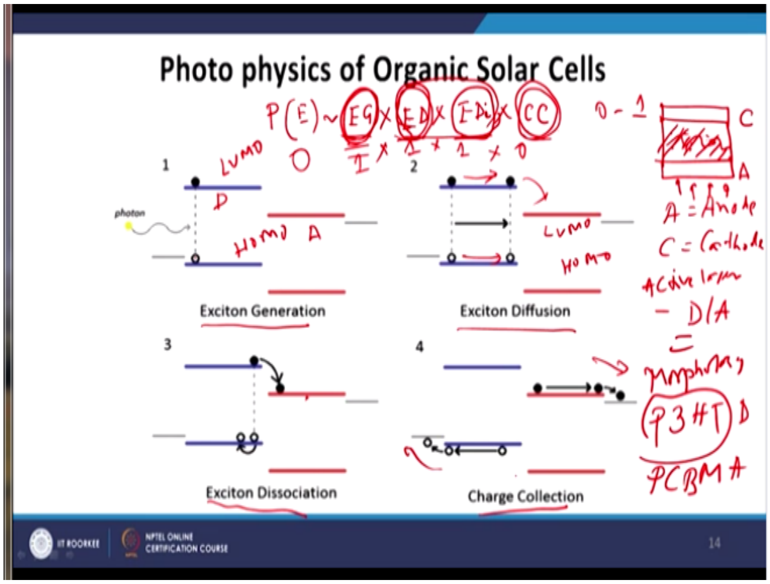

Photo physics of Organic Solar Cells

The next thing is the photophysics of an organic solar cells, now the efficiency of an organic solar cells or for that say any kind of solar cell is a product function. So what we mean if I the production function if we call the probability of efficiency as PE, so that is the product of exciton generation times, exciton diffusion times, exciton dissociation times, charge collections, so there are 4 different process which happens right from the light absorptions.

So let us say this is my bulk heterojunction solar cell, these are the 2 electrodes one is the anode A stands for anode and C stands for cathode. So A is anode and C stands for cathode right and here is my active material, this is a active layer and this active layer we made it by a donor polymer and an acceptor material by blending them and by spin coating them or by doctoral blending them to make a uniform thin films.

So that we can create lot of nano interface in the active material, so the first process in this case is the exciton generation. Now when let us say this site is transparent, so light falls on from this site what will happen, donor material will absorb the light. And it will create or it will generate the exciton, it will generate the bound electron hole pair that is my first process exciton generation EG stands for exciton generations.

The next process is that whatever the exciton has been generated they are now bound but we know that the charge carrier has to be free. So now we need to break this excitons or we need to dissociate this excitons but before that we have to keep in mind that exciton has been generated in a donor material but we have a donor acceptor interface. Now at the interface the exciton can dissociate, so exciton needs to move from the place where it has been generated to the interface area.

So that is the second stage, interface or exciton diffusion, now the 3rd phase is that once it comes to the interface now it needs to dissociated. Now why it is dissociated, now I have a donor acceptor interface at the interface there is a potential difference, potential difference means there is an electric field is there. And that electric field gradient helps to dissociate the excitons to a free charge carrier, so that is our 3rd process exciton dissociations.

So now exciton has been dissociated to the free charge carriers, so one of the materials contain now electrons another materials contains holes. Now this electrons and holes needs to be collected by the respective electrode, so that is our 4th stage charge carrier collection or CC. So charge carrier collection has to be also be good because like let us say now the exciton has been dissociated and it has generated a free charge carrier.

But the electrode potential is such that it is not able to collect the charge carrier, so although all of this things is good. So if the charge collection is not good now whole this process will be suffered. For exciton generations we need a material which has a very good absorptions what do you mean by good absorptions that means we have to design a material which can absorbs the light in a near infrared regions and whose absorption coefficient is large.

Now when I say that a material which can absorb the light in near infrared region that means the band gap of the material should be small. In ideally here it is band gap should be close to the silicon band gap or germanium band gap, that means ideally it should be very close to 1.1 electron volt or 0.7 electron volt. But most of this organic polymers they have a band gap in the regions of 2 to 2.3 or 2.4 electron volts some of them has 1.6, 1.8 electron volts.

So the challenge of the field is to reduce the band gap and design material which has low band gap and which can absorb the light in a near infrared regions and those kinds of materials are called low band gap polymer. So we need to have a low band gap polymer with a suitable absorption coefficient, so that the light can be absorbed and exciton can be generated or my first stage will be fulfilled ok.

So now I have a very good material, a low band gap material which can absorb the light and we can which can generate lot of charge carriers but this charge carriers are now bound. So to separate them to a free charge carriers what we next need to do, we need to carry those excitons to the interface, interface of the donor and acceptor. Now who will carry them that donor material, so donor material has to have a very charge carrier conduction properties.

So look at this thing, so not only the absorption is important, charge carrier mobility of this material is also very important. If the charge carrier of the exciton what have been generated in of the particular side if that is not able to diffuse to the interface then there is no point of this charge carrier generation even it is very high. So that is why the diffusion of the exciton needs to be very very optimized, we need to design a material which has a very high hole mobility or very high electron mobility.

Especially if it is a donor material we will prefer to have a material with the high hole charge carrier mobility. Now the exciton has been reach to the interface next thing is that it has to be dissociated and it will be dissociated if we have a very nice interface. So what do we mean by the nice interface in the case of the bulk heterojunction we need a phase separate bi-continuous percolating network.

Now this phase separated bi-continuous percolated network is call an morphology or optimum morphology of a solar cell. Now that is very very challenging to get an optimum morphology and there are lot of parameters which affects this exciton dissociations. So as you can see the exciton dissociation and the exciton diffusions these 2 process will be only be good or optimize if the morphology of the active layer is very good.

So that is why the morphology plays an important role in determining the photophysics of the devices. And there are lot of work is ongoing to optimize the morphology, so what do we mean by the optimum morphology we mean a bi-continuous phase separated network, bi-continuous because we need to see the donor and acceptor at each and every interface, phase separated because we have 2 different phase donor phase and acceptor phase.

In principle if you look at this active material, so throughout this active layer I want to see the donor acceptor interface. So there are bi-continuous phase separated network using which the electron charge carrier or hole charge carrier can percolate or they can move from one place to another place that will be ensured only if I have this kind of particular morphology. Now next question is that if our material is a low band gap polymer that does not always guarantee that it will always give a good morphology.

Morphology depends on lot of different parameters it will depends upon how or what is the quality of the film. Now the quality of the film will depends upon the polymer to the acceptor ratio it will depends upon the solvent. For example let us say you have an polymer P3HT which we are using it as a donor polymer. Now we can use this polymer to spin coat the film we can spin coat the film from different solvent.

We can use chloroform as a solvent, we can use chlorobenzene as a solvent, we can use 1, 2 dichlorobenzene as a solvent. Now what is the difference between all these solvent they are dielectric constant they are polarity. Now if you make the film of the same material P3HT from this 3 different solvent the morphology will be completely different. And one can examine the morphology by some microscopic techniques or electron microscopic techniques like scanning electron microscopy or atomic force microscopy.

Now if I make this material from chloroform or dichlorobenzene or 1, 2 dichlorobenzene will preferred 1, 2 dichlorobenzene because the quality or the bicontinuous percolated network which is our desired morphology that will be obtained if we use 1, 2 dichlorobenzene rather than using chloroform. Because the boiling point of the chloroform is very very low 65 degree Celsius, so it rapidly evaporates.

So before the films align or distributed in a bicontinuous way along with the acceptor material let us say PCBM the solvent will evaporate. So solvent plays a important role in determining the morphology, so here we are P3HT PCBM for example to make the material one is the donor another is the acceptor. So the first thing it depends upon which solvent we are using to make the films, second thing is depends upon the ratio of the donor to acceptor and it has been absorbed this ratio matters a lot.

If I use 1 to 1 weight ratio or if use 1 to 4 weight ratio the morphology is way different. Similarly once we mix this donor and acceptor materials and if we spin coat it on a substrate we will get a film. Now what will happen if we anneal the film, annealing mean hitting the film at a certain temperature. Let us say I heat the film at 120 degree Celsius, what will happen and I am using a solvent for example chloroform.

Now if I heat it the solvent will evaporate, now once the solvent will evaporate the way the PCBM will crystallize or the PCBM will aggregate in the presence of the P3HT that will be different. Now if it is a faster evaporation or if it is a slower evaporation it will give a completely different morphology. So based on that or based on the heating temperature if I heat the film at 70 degree Celsius or if I heat the film at 120 degree Celsius the morphology will be way different.

And we need to have a bicontinuous percolated phase separated network where the charge carrier can percolated using this bicontinuous morphology. So apart from solvent and polymer to accept a ratio the annealing temperature also plays a very very important role. So there are for several parameters which can impact this morphology for example let us say we are making the films from the chloroform solvent we can use another solvent in addition to the chloroform as an anti-solvent.

So the meaning of the anti-solvent is that this material or the donor P3HT will be not be soluble in our anti-solvent and since it is not the soluble in that particular solvent that is why this is called anti-solvent. Now for example P3HT is soluble in chloroform, so P3HT chloroform is a solvent of P3HT. But if I take something like toluene the solubility of P3HT in toluene is not good, so we can say that the toluene is an anti-solvent of P3HT.

And it is you need to optimize parameters it will be soluble but in the beginning it will not be very very good solvent. So now if I add toluene to the P3HT chloroform fabricated thin film during the spin coating process the morphology will be different. So depending upon that depending upon the experimental parameters the morphology of the films can be way different and if the morphology is different then what will be the different.

The exciton diffusion and exciton dissociation both these 2 parameters will be different. Now what this tells you it actually tells you about the photophysics the timescale over which the charge carrier translate whether there is a lot of recombination in our sites or there is a less recombinations. Now these are all the informations we get by doing the photophysics study, so that is why to get a good photophysics from the device a good morphology is required or morphology on photophysics they are correlated to each other.

Usually we call it as a structure property relationship, now as good it will be your structure or whatever it will be a structure your property, your optical properties will depend on that. Similarly depending upon your morphology your photophysical properties is be dependant, so that is why the study of the morphology and photophysics often organic solar cell or for any kind of solar cell is very very important for optimizing the efficiency of this devices.

And the last thing is the charge collection efficiency, now everything is good, we have the exciton diffusion, we have the exciton dissociation, now the exciton has been dissociated to a free charge carriers but the electrode has to collect them, anode and cathode has to grab them. Then only the electrons and hole can the electrons can conducting the outside circuit to run a load, so that is why the charge collection efficiency or at the interface has to be also be very very good.

Now if each of these parameter is bad while all the other parameters as good my efficiency will be suffered. For example if I number this parameter in a probability parameters between 0 to 1 let us say I have a ideal material whose optical absorption is very very good it is a low band gap polymer. And I number it the exciton generation efficiency as 1 and then this material is has an excellent hole conducting material.

So it is exciton diffusion properties is also I give a number of 1 and what will happen along with the acceptor material the dissociation is also very very good. So I give a number of 1 here but the charge collection along with a electrode is very very bad, so I give a number there 0. So what is my product 1 times 1 times 1 times 0 that is 0. So although you have a nice material, you have a nice morphology your interface is not good, your metal semiconductor interface is not good.

That is why your charge collection efficiency is 0, let us say instead of when you deposit the metal as a counter electrode you deposit instead of a metal and insulating metal oxide. So basically you have not formed a metal semiconductor interface, you have formed a metal oxide semiconductor interface. Now everything all this 3 parameters are ok good. But there is no charge collection at the electrode.

So then the total efficiency will be 0 because there is no short circuit current in the outside circuit. So that is why it is better to be every parameter to be 0.5 or 0.6 rather than 3 of them is 1 of them is 0. So 1 has to optimize all the parameter simultaneously while fabricating a device or while designing a ideal solar cell devices. That is what we call it as a product function not an additive function, if it is an additive function then if one of the parameter even if it is 0 then we do not care.

The other parameters I know like you know they will add up to the efficiency but it is a product function each and every parameter should be optimized or should be ideal. And that is makes the job very very challenging, so designing a material which will be low band gap or which will be absorbing the sunlight very well. Designing a material which will have a very good hole transfer properties, designing and proper acceptor material whose energetic will match with the donor.

And which will do a nano interface with the donor material, so that the exciton dissociation happens perfectly and also the same time designing an interface between the metal and semiconductor depending upon the energy level. So all of these 4 parameters has to be optimize simultaneously to get an good or optimum organic solar cell. Now in that graph you can see that there are these 4 steps has been showing here in this diagram.

The first is the exciton generations, so here the light falls on the materials and the electron goes from the HOMO level this is your HOMO level to the LUMO energy level ok electron goes from here to here, so we leaves a hole in the behind. Second process is that now this electron they have to diffuse and the hole has to diffuse, so that is our second process first was exciton generation, second method was exciton diffusion.

Now this blue color is a donor material and this red color is an acceptor material ok this is your donor material, this is your acceptor material. So the charge carrier has been generated in the donor material and it has been now diffused. Now it looks an acceptor material in it is vicinity that is your donor acceptor interface. So the energy level matching is such that it is energetically favorable for the electron to jumps to this the LUMO level of the acceptor.

So that is a step 3 exciton dissociations, now the electron jumps from the LUMO of the donor to the LUMO of the acceptor materials and holes stays back here. So now I have separated 2 different charge carriers electron is in now in the acceptor and hole is in the donor. So donor can now conduct the hole to the one side and the acceptor can conduct the electron to the other side.

So the next thing is that this electrons will be now injected to the metal electrode and the hole will be injected to the other metal electrode.

And this hole circuit will be completed and that it is charge collections, so all these 4 process has to happen simultaneously and very very rapidly and it is very very simultaneous and rapid to get a current in the outside circuit. If any of these process is not good we will see that effect in JSC, we will see that effect in VOC, we will see that effect in fill factor. That means we will see that effect in the efficiency, we will show you a very small animation of this process in an next video where you can understand like how this things is happening ok.

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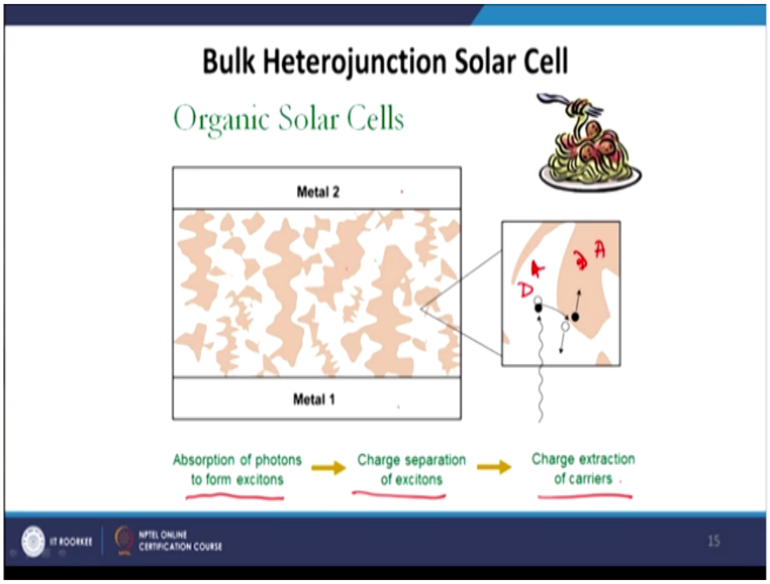

Bulk Heterojunction Solar Cell

Organic Solar Cells

Absorption of photons to form excitons → Charge separation of excitons → Charge extraction of carriers

So as we promise that this bulk heterojunction solar cells or the organic solar cells here we have this 3 or 4 different mechanism. First is the absorptions of the photons to form excitons and the next is the charge separation, but before that we have also the charge diffusions. Now you see this kind of nano morphology we have created in the active layer in the bulk heterojunction solar cell.

And here the exploded view of that this is an AFM image this is your donor layer and this is your acceptor layer or like you know you can consider the other way round also. Like you know I mean so your electron is here and your the hole is here ok or like you know I can consider like you know consider this is your donor material and let us say this is your acceptor material.

So the charge carrier the exciton has been created here, one of them when we sees the interface one of them is separated. So hole goes in one way electrons stays back it here, now if I put 2 electrode like here metal 1 and metal 2 one of them will go in one direction another one will go in the another direction, so finally this will be a charge extractions of the carriers right.

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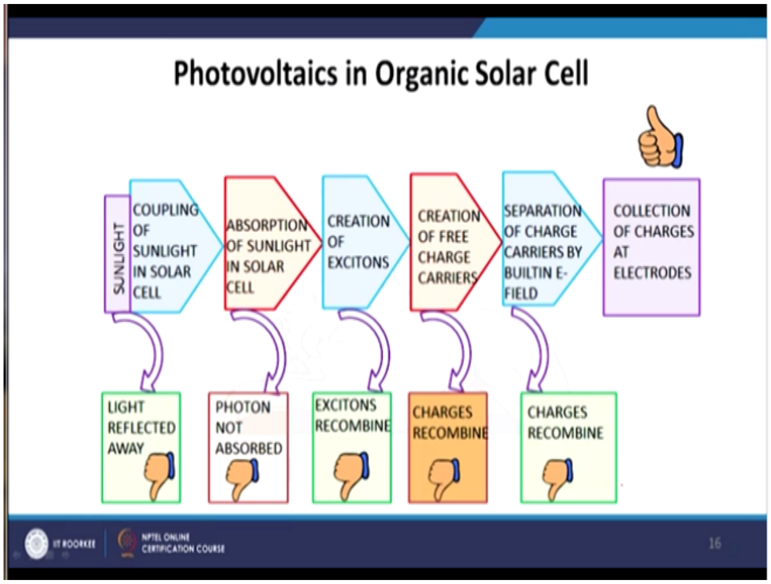

Photovoltaics in Organic Solar Cell

SUNLIGHT

COUPLING OF SUNLIGHT IN SOLAR CELL

ABSORPTION OF SUNLIGHT IN SOLAR CELL

CREATION OF EXCITONS

CREATION OF FREE CHARGE CARRIERS

SEPARATION OF CHARGE CARRIERS BY BUILTIN E-FIELD

COLLECTION OF CHARGES AT ELECTRODES

LIGHT REFLECTED AWAY

PHOTON NOT ABSORBED

EXCITONS RECOMBINE

CHARGES RECOMBINE

CHARGES RECOMBINE

So the sunlight falls on the materials and then it is a coupling of the sunlight in the solar cell then there will be an absorption of the sunlight in the solar cell. And then creation of excitons and then creation of the free charge carriers, separation of the charge carriers and then collection of the charge carriers by the electrode. Now if the coupling of the sunlight in the solar cell is not very good due to the reflection loss then we have to take care for that factor.

And that is why we put an antireflection coating on the solar cell. If the absorptions of a solar cell is not good then photons will not be absorbed. That is why we have to design a material whose absorption is very good or we have to design a low band gap polymer. Now the creation of the excitons if that is not good then excitons will be recombined, so a recombination is usually a band to band recombination.

Now we have to develop the material in such a way there is no discontinuity there is no defect or trap states, so that we can minimize the recombination. Now the creation of the free charge carriers that has to be very good other is the charge again it will be recombine. Separation of the charge carriers by the built in electric field that has to be very good otherwise again there will be charge carrier recombination.

So all of these things charge carrier recombinations that has to be optimize by doing the morphology optimizations then only we will get a better photophysics. And finally the collection of the charge carried electrodes and that is comes from the metal electrode depositions.

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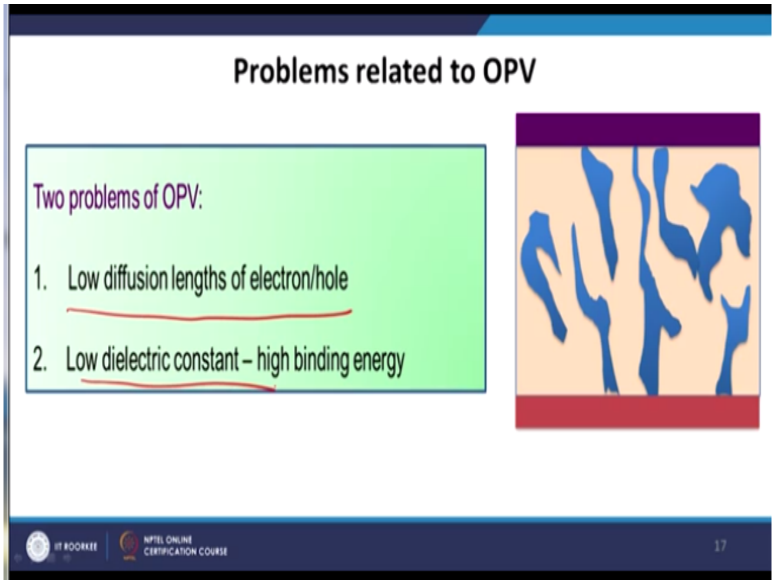

Problems related to OPV

Two problems of OPV:

1. Low diffusion lengths of electron/hole
2. Low dielectric constant – high binding energy

So although this organic photovoltaics provide us some of the excellent opportunity like flexibility and all this things they have some problems also. The one major problem is that low diffusion length of the electron and hole as I said that the electron diffusion length of a conducting polymer is only 10 nano meters some of them is like in a 15 nano meters or 20 nano meters but whereas in a silicon it is in micrometer range 100 microns.

So obviously the electrons and holes they can travel only a small distance before they recombine and the dielectric constant of this material is low. Now we know that binding energy is inversely proportional to the dielectric constant. Now if the dielectric constant is low then binding energy will also be high, how the binding energy is related to the dielectric constant we have learned it when you have done some kind of quantum mechanics.

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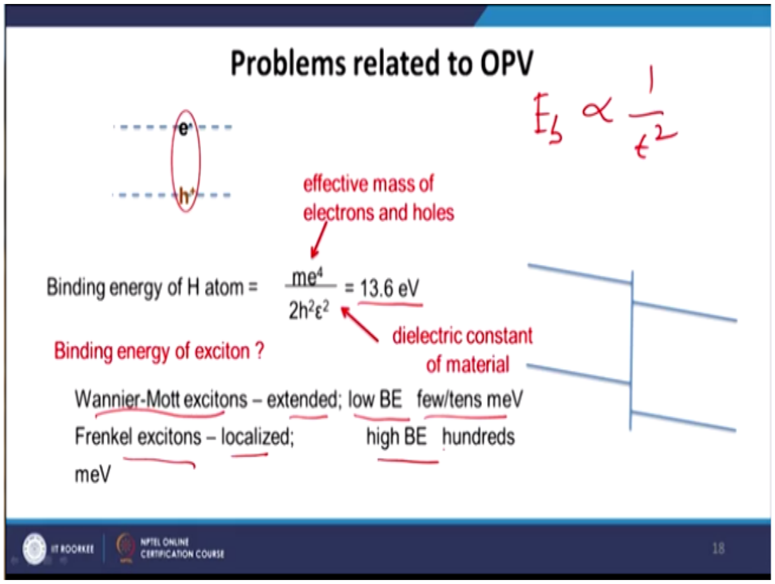

Problems related to OPV

$E_b \propto \frac{1}{\epsilon^2}$

effective mass of electrons and holes

Binding energy of H atom = $\frac{me^4}{2h^2\epsilon^2}$ = 13.6 eV

dielectric constant of material

Binding energy of exciton ?

Wannier-Mott excitons – extended; low BE few/tens meV

Frenkel excitons – localized; high BE hundreds meV

See you see that when the electrons and holes they have been generated here they are bound with each other, these are excitons. Now we know that binding energy of the hydrogen atom is me to the power 4/2h square epsilon square, m is the effective mass of the electron, e is the charge of the electron, h is the planks constant and epsilon is the dielectric constant. And if you plug all this value you know we will get this value 13.6 electron volt a very standard value for the binding energy of the hydrogen atom with a ground state.

Now what is that this binding energy Eb that is inversely proportional to the epsilon square. If the dielectric constant is low then the binding energy will be high or the dielectric constant is high then it will be low. Now in inorganic semiconductor like silicon binding energy is low that is why the dielectric constant is high or other way round the dielectric constant is high that is why the binding energy is low.

So that is why the charge carrier is free charge carriers whereas in organic semiconductor the dielectric constant is low and if the dielectric constant is low the binding energy is high. So that is why you need to apply a lot of electric field to associate to dissociate this charge carrier, that is why you get a bound charge carrier not a free charge carriers. And that is why we need to insert the acceptor material along with the donor material in this kind of solar cells.

So binding energy of an exciton we can calculate that, so the excitons if it is there can be 2 different kinds of excitons one if the wannier–mott exciton which is extended or delocalized and it has a low binding energy usually few tens of milli electron volt and the other is the frenkel excitons which is the localized excitons which has a high binding energy usually in a hundreds of meV. Now of course there are some good advantage of the organic photovoltaics that is why it becomes very very popular.

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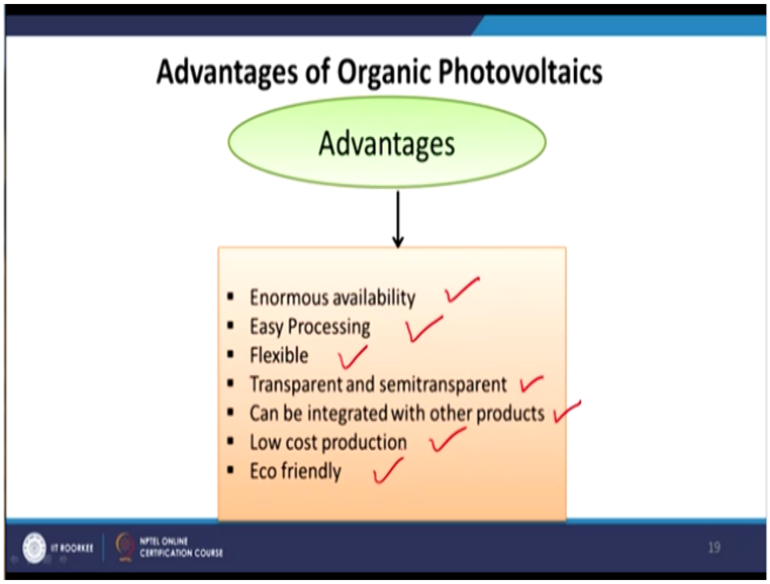

Advantages of Organic Photovoltaics

Advantages

- Enormous availability ✓
- Easy Processing ✓
- Flexible ✓
- Transparent and semitransparent ✓
- Can be integrated with other products ✓
- Low cost production ✓
- Eco friendly ✓

Like first of them these they have enormous availability, they have the easy process ability, they are flexible you can make it on any substrate, they are transparent and semitransparent. So for designing like green house building for transferring window which can be useful for indoor lighting, this kind of solar cells are very very useful. They can be integrate with other products, their cost of production is low and they are also eco friendly.

So since they are made of the organic materials and many of the organic materials are biodegradable that is why this kind of materials or this kind of synthesis approach is a green synthesis approach.

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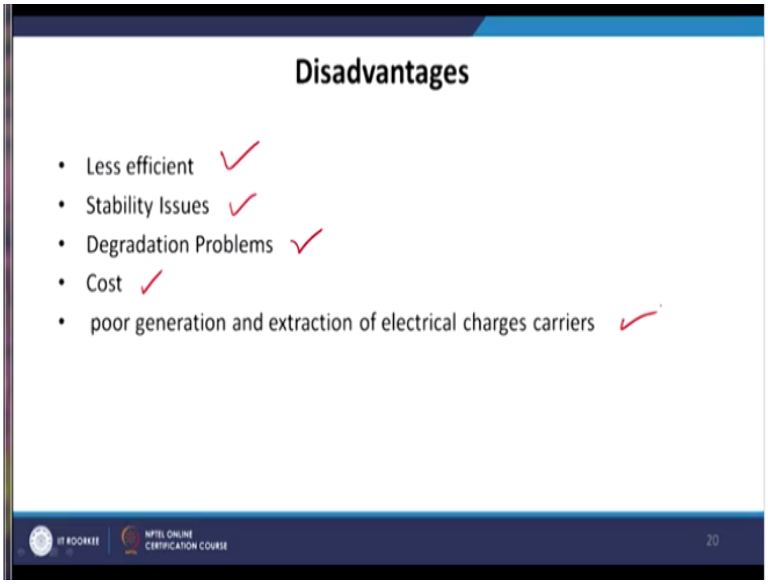

Disadvantages

- Less efficient ✓
- Stability Issues ✓
- Degradation Problems ✓
- Cost ✓
- poor generation and extraction of electrical charges carriers ✓

And some of the disadvantage of them are their efficiency is low in comparison to the first or second generation solar cell but due to the optimization this number is increasing every day. They have some issues with the stability, some of them are not very stable, now once you design a solar cell, now one has to be also make sure this solar cell is very stable to the environmental condition or even like you know difference in the moisture or humidity, temperature variations.

Now these solar cells like you know if you do not encapsulate it then like you know the stability is a problem. Then there can be photo degradations of the conducting polymer, cost of productions if we design a low band gap polymer then the cost of production increase. And because of this high binding energy the extraction of the electric charge carriers become sometimes difficult.

So these are the some of the disadvantage where people scientist are working on it and because of that the every day the efficiency number is changing.

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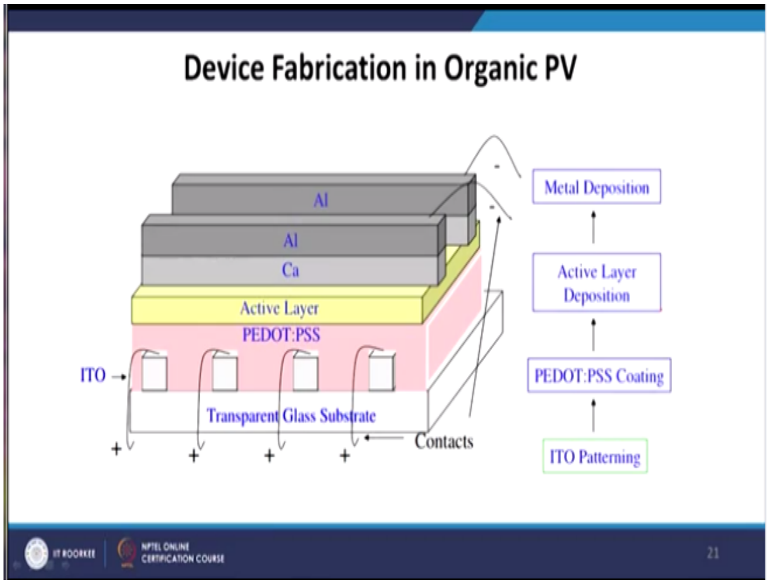

Device Fabrication in Organic PV

Metal Deposition

Active Layer Deposition

PEDOT:PSS Coating

ITO Patterning

Now let us look at the device fabrication in organic photovoltaic devices which we will discuss in our next class in details. So we will show that how to make this active layer between these 2 electrode namely the ITO and the aluminum electrode and to put an active layer there and active layer we put the ITO patterning then you put a PEDOT.PSS layer and then we deposit an active layer and finally we put a metal electrode.

This fabrication approach we will discuss in our next class in details but today we have learnt about what is the basic mechanism or what is the basic photophysics behind the working principle of an organic solar cells. And that will help us to not only for the organic solar cell but this kind of material based other devices also. In the next class we will discuss about how to fabricate this organic solar cell, thank you.