Solar Photovoltaics:
Fundamental Technology and Applications

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Lecture-23
Photophysics of Organic Solar Cells

Welcome everyone to our course, in the last lecture we have started discussing about organic solar cell. Today we will discuss about the different components in an organic solar cell and especially how to fabricate an organic solar cell. Now in the context of the organic solar cell we have seen that the photophysics and the charge carrier dynamics is way different in an organic solar cell in comparison to an inorganic semiconductor like silicon.

For example we have found that when light absorbs in an organic material electron hole pair or bound exciton is generated in an organic material. And we need apply some kind of external field or force to separate those bound electrons whereas on the other side if you take an example of an inorganic semiconductor for example silicon. The charge carriers are not strongly bound as in the case of these organic materials like conducting polymers.

So their charge carriers are quite free to move around the material but in organic material we need to provide some external field or bias to separate the charge carrier. Now this external field very often is done by a combination of material with 2 different dielectric constant. Now we have seen that there are 2 different geometry is possible which is commonly used or popularly used in fabricating this kind of solar cell one was layer by layer device and the second was bulk heterojunction solar cell device.

Now in layer by layer hetero structure what we do we put a single layer of donor material and on the top of that we put another layer of acceptor material. The problem with this thing what we have discussed I mean if you have understood that this most of these organic material they have a small excite on diffusion length, so by excite on diffusion length we mean the distance the electron and hole can travel to the electrode before they recombined with each other.

Now we have learn that in organic materials like conducting polymer or conjugated polymer the excite on diffusion length is very small something in the order of 10 nanometers. Now very often to make an active layer which will be optimum for light absorptions, let us say we make an active layer of 200 to 300 nanometer. So then only those excitons which are near the electrodes they will be collected by the electrode.

Now if I make a layer by layer assembly, so only those excitons which is near the donor acceptor interface they only can be able to say for it. But those insert the bulk of the material they will be steal tract, now this kind of problem was formed by fabricating bulk hetero junction solar cell. So what we do in bulk heterojunction solar cell we mix the donor and acceptor polymer in the same solvent or in the same matrix they may fabricate the thin films out of it.

So what we get out of it basically we get a bicontinuous percolated network through which the electrons and hole can separate. So they face a lot of nano interface throughout the bulk assembly and using that percolated networks the electrons and hole can travel towards the electrode. So the bulk heterojunction geometry is more favorable in terms of solution base device approach.

Now we have also learnt that although the efficiency of this organic solar cell is less than their inorganic counterpart, it is still used in many of the application because it provides some of the advantage which the inorganic solar cell cannot do.

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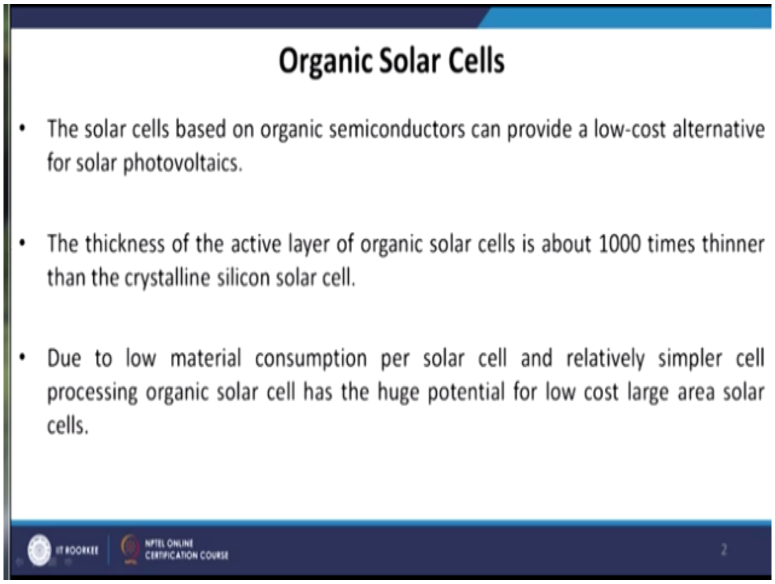

Organic Solar Cells

- The solar cells based on organic semiconductors can provide a low-cost alternative for solar photovoltaics.
- The thickness of the active layer of organic solar cells is about 1000 times thinner than the crystalline silicon solar cell.
- Due to low material consumption per solar cell and relatively simpler cell processing organic solar cell has the huge potential for low cost large area solar cells.

For example the solar cell based on organic semiconductors can provide a low-cost alternative for solar photovoltaics. Second thing the thickness of the active layer of organic solar cells is about 1000 times thinner than the crystalline silicon solar cell. So let us say as I said that in an organic solar cell we can 200 to 300 nanometer thickness of active layer while in silicon solar cell we make it in almost in a micron level.

So it is almost like 100 to 1000 times the ratio between the active layer in the active layer thickness between an organic material and an inorganic counterpart. So in a using less amount of material we can achieve the same amount of light absorptions in an organic material provided this material has a very high absorption coefficient. Now due to the low material consumption per solar cell and relatively simpler cell processing organic solar cell has huge potential for low cost large area solar cells.

Now if we specially want to make a roll to roll flexible low cost solar cells then organic solar cells will be a suitable choice. Now a geometry or the structure of the solar cells of the organic solar cells is shown in this figure.

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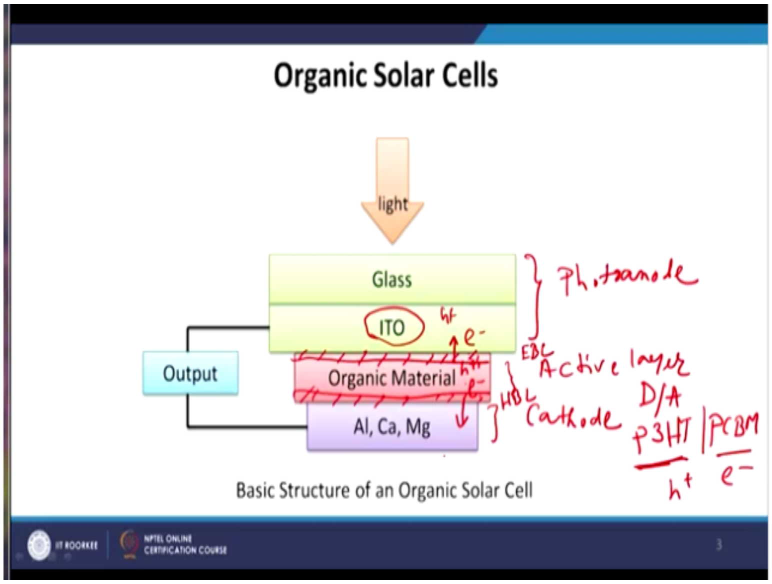

Organic Solar Cells

Basic Structure of an Organic Solar Cell

Where you can see that it still follows the basic structure of a solar cell where we have an photoanode, this is our photoanode. And what is this anode is made of there is a glass substrate which is insulating and top of that we put a conductive layer of ITO indium tin oxide glass substrate. And as a cathode we use the metal layer, so this is our cathode, so we can use either aluminum, calcium or magnesium as a cathode.

Now between these 2 electrode anode and cathode we have the active layer, so this is our active layer. An active layer here is made of the organic materials, for organic materials usually we have a donor polymer and we have a acceptor interface and these 2 connection has been taken one from the anode and the cathode and if we add any load here the load can be run by the electron flow from the through the circuit, now this is the basic structure of an organic solar cell.

Now there are like several modification one can do to make this structure more feasible for high efficient device. For example like there are some of the practical problems which we face while fabricating this device is that the interfacing. Now you see that like you know this organic material is made of the donor and acceptor, now who is the donor, the donor is a material which donates the electron for example conjugated polymer.

A commonly used conjugated polymer as a donor is P3HT, now who is the acceptor a material which absorbs the electron or which accepts the electron. Now who is an ideal candidate of an acceptor material, For example any small molecule. And we have said that earlier that PCBM is a commonly used acceptor material. So for example let us say we have fabricated the active layer with P3HT and PCBM where this is the donor molecule and this is the acceptor molecule.

Now donor will now when the light will absorb here as it is been shown in this diagram, so the electron hole pair or the excitons will be generated in the P3HT molecule. Now wherever there is a P3HT, PCBM interface is there at this nano interface there is a electric field gradient and that gradient will create a potential and that will help to separate the excitons to free charge carriers. So one of them will conduct hole another of them will conduct electrons, so the electrons goes in one way and the hole in other way.

Now let us say so there are 2 different charge carrier one is electron and then another is a hole. Now they have to travel towards the electrode, let us see electron travel to this direction actually the electrons and a hole will be created in the active materials. So the electrons will be travelling at this distance and a hole is travelling along that direction. Now in this process you also create like when the electrons travels towards this direction it is possibility that some of the holes can also travel.

And if there are holes are there, there is every possibility that electrons and hole will recombine and that will get lost. So my sole purpose should be to put a layer which will selectively allows the electrons to go in this side but blocks the hole to flex in this side. So this will act as a filter layer which will block the hole but will allow the electron to flow. So this is a example of a blocking layer and since in this particular case it is blocking the hole, so I call it as a hole blocking layer or HBL.

Similarly on the other side on the other interface here I meant the hole to pass through but I want to block the electron to minimize the recombinations. So then I can put a layer of the material which will allow the hole to pass through but block the electron, so this will be an electron blocking layer. So PDOTPSS for example is a polymer which has a very high hole conductivity and which is used as an interfacing layer between the ITO and the P3HT material.

Now on top of the ITO if I put a thin layer of PDOT:PSS then what it will do that first of all it will block the electron or it will facilate the flow of the holes not only that it will wait the interface between the organic material and the ITO for a smooth passage of the charge carriers. So basically it will reduce the interfacial resistance. Similarly when I use PCBM I can use another layer which will acts like a hole blocking layer but which will allow the electron to pass through.

Then it is possible that filter materials only selectively allow the electrons and increase the electron flow in this materials. So like this one can do lot of modification in this basic structure to fabricate a high efficiency solar cell device. Now we will see today what are the different components and what is the purpose of this components in an organic solar cell.

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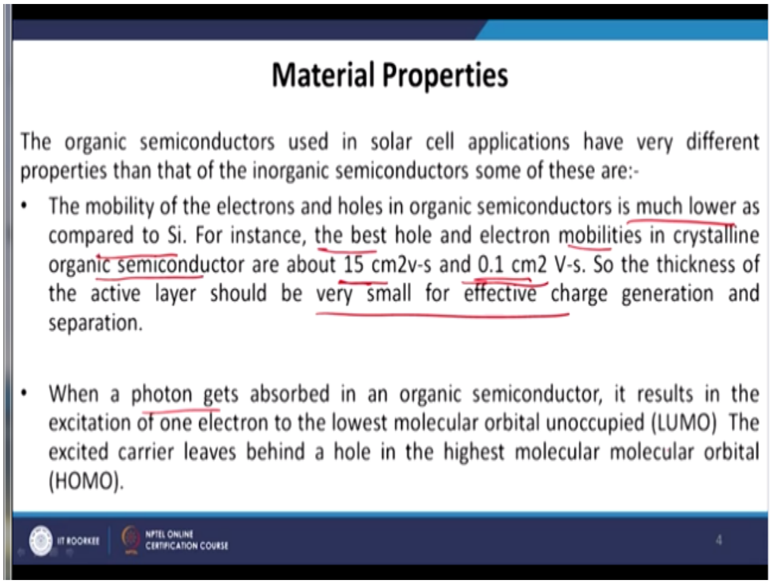

Material Properties

The organic semiconductors used in solar cell applications have very different properties than that of the inorganic semiconductors some of these are:-

- The mobility of the electrons and holes in organic semiconductors is much lower as compared to Si. For instance, the best hole and electron mobilities in crystalline organic semiconductor are about 15 cm2v-s and 0.1 cm2 V-s. So the thickness of the active layer should be very small for effective charge generation and separation.
- When a photon gets absorbed in an organic semiconductor, it results in the excitation of one electron to the lowest molecular orbital unoccupied (LUMO) The excited carrier leaves behind a hole in the highest molecular molecular orbital (HOMO).

So the material properties that includes the organic semiconductor used in solar cell application have very different properties than that of the inorganic semiconductors some that is we already mentioned. And some of these properties are the mobility of the electrons and holes in organic semiconductors is much lower as compare to silicon. So the mobility of the charge carrier electron mobility and hole mobility is in the organic material is much lower in comparison to the inorganic semiconductors.

For instance the best hole and the electron mobilities in crystalline organic semiconductor are about 15 centimeter square/volt-second and 0.1 square centimeter/volt-second, so this is the hole mobility and this is the electron mobility. So we know that 15cm/volt-second that is very very less in comparison to the silicon mobility, silicon has a much higher mobility. So thickness of the active layer should be very small for effective charge generations and separations.

So since the charge carrier have a very small mobility so they cannot travel a long distance, so if I make the light absorbing active layer very very thick, so what will happen. The electrons and hole will not be able to travel towards the electron before that they will become when it get lost. So that is why we need to make a very thin or smaller active layer for effective charge generations and separations.

Now when a photon gets absorbed in an organic semiconductor it results in the exciton of an electron to the lowest molecular orbital or LUMO. The excited state carrier leaves behind a hole in the highest molecular orbital or HOMO. So basically you create an electron in the LUMO energy level and a hole in the HOMO energy level and they are bound with each other and that bound physics we call it as a exciton.

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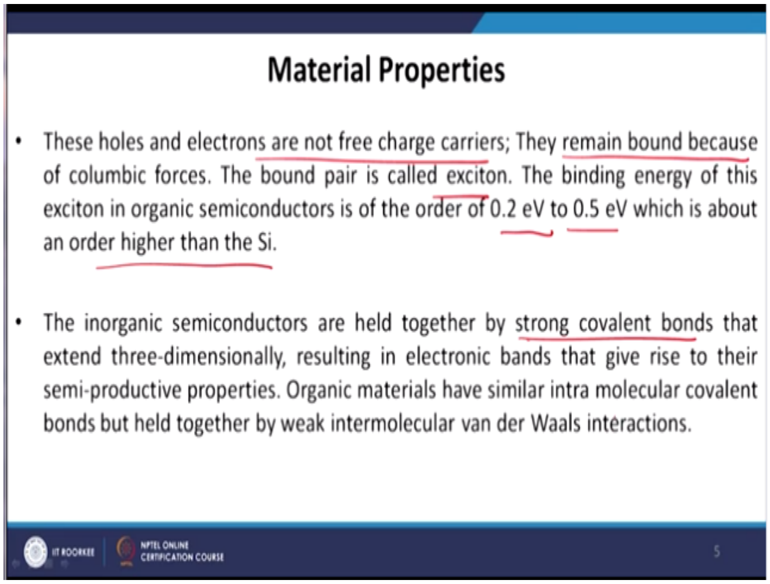

Material Properties

- These holes and electrons are not free charge carriers; They remain bound because of columbic forces. The bound pair is called exciton. The binding energy of this exciton in organic semiconductors is of the order of 0.2 eV to 0.5 eV which is about an order higher than the Si.
- The inorganic semiconductors are held together by strong covalent bonds that extend three-dimensionally, resulting in electronic bands that give rise to their semi-productive properties. Organic materials have similar intra molecular covalent bonds but held together by weak intermolecular van der Waals interactions.

These holes and electrons are not free charge carriers, they remain bound because of the electrostatic force because of the columbic force. The bound pair is called exciton, so the binding energy of the exciton in organic semiconductor is the order of 0.2 electron volt to 0.5 electron volt which is about an order of higher than the silicon. So you mention it previously then this organic semiconductors has bound excitons and the binding energy is 0.2 electron volt to 0.5 electron volt.

Now it is important to note that this value of binding energy is higher than the thermal excitation energies. So even the room temperature thermal fluctuation cannot break this excitons and this energy is also higher than the silicon. In silicon that is why we see a free charge carriers, but here we see a bound charge carriers. The inorganic semiconductors are held together by strong covalent bonds that extend 3-dimensionally resulting in electronic bands that give rise to their semi-productive properties.

Organic materials have similar intra molecular covalent bonds but held together by weak intermolecular Van der Waal interactions. So the kind of bonding in the organic materials and the inorganic materials are also different.

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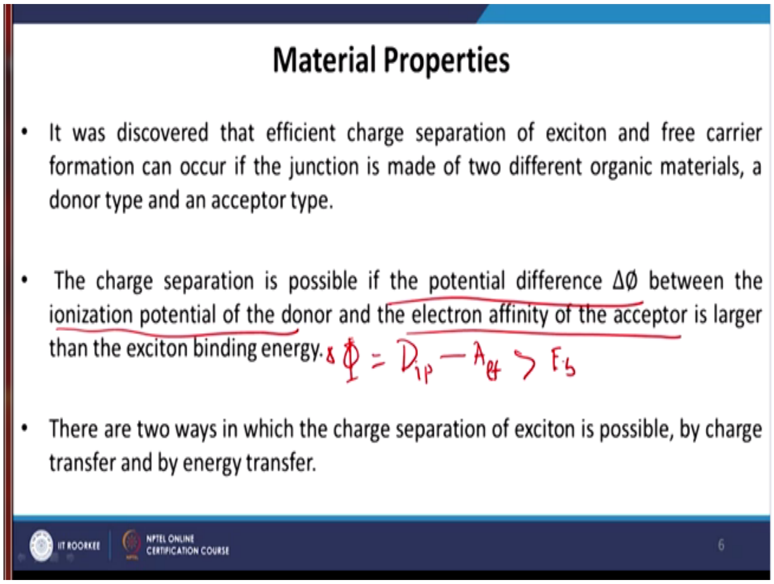

Material Properties

- It was discovered that efficient charge separation of exciton and free carrier formation can occur if the junction is made of two different organic materials, a donor type and an acceptor type.
- The charge separation is possible if the potential difference $\Delta \emptyset$ between the ionization potential of the donor and the electron affinity of the acceptor is larger than the exciton binding energy. $\delta \Phi = D_{IP} - A_{ef} > E_b$
- There are two ways in which the charge separation of exciton is possible, by charge transfer and by energy transfer.

It was discovered that efficient charge separation of exciton and free carrier formation can occur if the junction is made of 2 different organic materials, a donor type and an acceptor type. The charge separation is possible if the potential difference delta pi between the ionization potential of the donor and electron affinity of the acceptor is larger than the exciton binding energy ok. So the potential difference between the ionization potential of the donor and the electron affinity of the acceptor.

So let us say the donor has an ionization potential of ip and the acceptor has an electron affinity ef, so the value of phi or delta phi which is the difference between the ionization potential of the donor and electron affinity of the acceptor. That should be larger these value of delta phi should be larger than the exciton binding energy. Then only it is possible for the exciton to break as a free charge carrier. There are 2 ways in which the charge separation of exciton is possible by charge transfer and by energy transfer.

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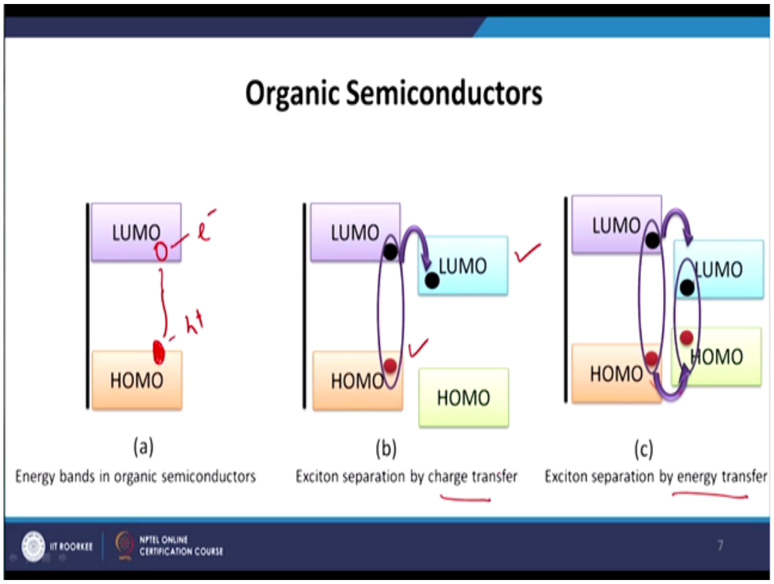

Organic Semiconductors

(a)
Energy bands in organic semiconductors

(b)
Exciton separation by charge transfer

(c)
Exciton separation by energy transfer

Now you look at here these 2 different mechanisms, so here energy band gaps in organic semiconductor and we know that there is an electron which is created here and there is an hole which is created here. And these 2 things they are bind with each other by a strong columbic force and we call them together as a exciton. Now this electrons and holes which are here the electron can jumps to the LUMO energy level of the acceptors, this is a exciton separation by charge transfer.

Whereas it is also possible that this electron and hole is here, so this hole goes from here to here and this electron jumps from here to here. So then there is an exciton separation is happening, so basically you see that hole of the now in this case electrons stays in this material and holes stays in this material. But in this case electron has transferred and hole has also transferred, so that is an example of a energy transfer, what is a difference between these charge transfer and energy transfer.

If you look very closely you see the positions of the HOMO level in the donor and acceptor here, the acceptor has a lower value of HOMO level than the HOMO level of the donor whereas here the HOMO level of the acceptor is almost in the same position or little bit higher than the HOMO level of the donor where the LUMO position is a same. So basically the difference of the HOMO level between the donor and acceptor that determines whether it will be a charge transfer or whether it will be an energy transfer.

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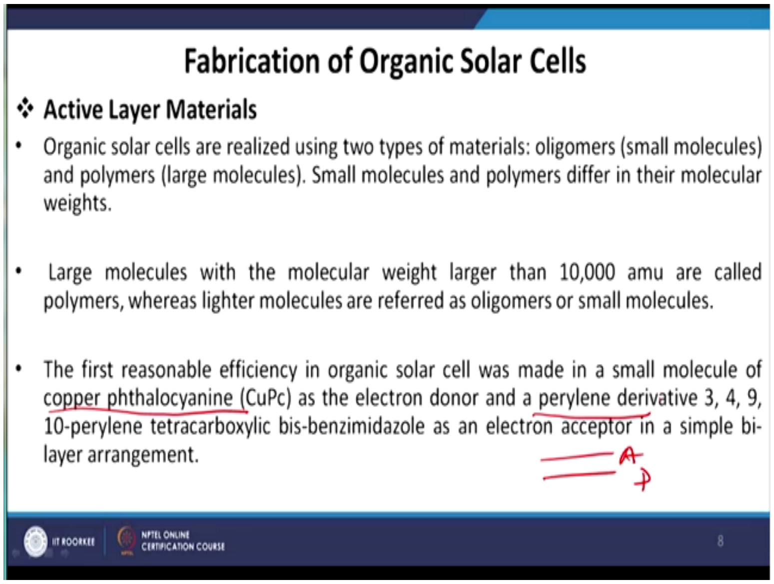

Fabrication of Organic Solar Cells

❖ **Active Layer Materials**

- Organic solar cells are realized using two types of materials: oligomers (small molecules) and polymers (large molecules). Small molecules and polymers differ in their molecular weights.
- Large molecules with the molecular weight larger than 10,000 amu are called polymers, whereas lighter molecules are referred as oligomers or small molecules.
- The first reasonable efficiency in organic solar cell was made in a small molecule of copper phthalocyanine (CuPc) as the electron donor and a perylene derivative 3, 4, 9, 10-perylene tetracarboxylic bis-benzimidazole as an electron acceptor in a simple bi-layer arrangement.

Now let us come to the fabrication of organic solar cells, now the first part is the active layer materials. Organic solar cells are realized using 2 types of materials oligomers which are small molecules and polymers which are the large molecules. Small molecules and polymers differ in their molecular weight obviously as the name suggest oligomer as a smaller molecular weight in comparison to the polymer.

Large molecules with the molecular weight larger than 10,000 amu, amu stands for atomic mass unit they are called polymers, whereas lighter molecules are referred to as oligomers are small molecule. So any molecules which has a molecular weight larger than 10,000 atomic mass unit or amu that usually we call it as a polymer and the others molecule we call it as a small oligomers or small molecule.

The first reasonable efficiency in organic solar cell was made in a small molecule of copper phthalocyanine CuPc as the electron donor and a perylene derivative 3, 4, 9,10-perylene tetracarboxylic bis-benzimidazole as an electron acceptor in a simple bi-layer arrangement. So the first organic solar cell was made by layer by layer structures. So you have a layer of donor and then in top you have a layer of acceptor.

Now as a donor material they use a small molecules called copper phthalocyanine CuPc and as an acceptor material they used a perylene base derivatives. Now this 2 molecules their solubility is very very low, so we need to deposit them in a gaseous state, this is called the vapor depositions of this molecule.

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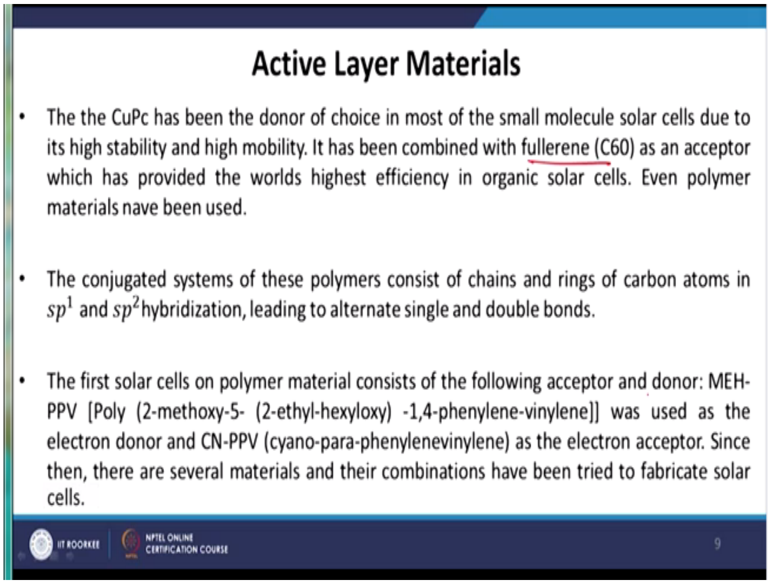

Active Layer Materials

- The the CuPc has been the donor of choice in most of the small molecule solar cells due to its high stability and high mobility. It has been combined with fullerene (C60) as an acceptor which has provided the worlds highest efficiency in organic solar cells. Even polymer materials nave been used.
- The conjugated systems of these polymers consist of chains and rings of carbon atoms in sp^1 and sp^2hybridization, leading to alternate single and double bonds.
- The first solar cells on polymer material consists of the following acceptor and donor: MEH-PPV [Poly (2-methoxy-5- (2-ethyl-hexyloxy) -1,4-phenylene-vinylene]] was used as the electron donor and CN-PPV (cyano-para-phenylenevinylene) as the electron acceptor. Since then, there are several materials and their combinations have been tried to fabricate solar cells.

The CuPc has been the donor of choice is most of the small molecule solar cell due it is high stability and high mobility. Now copper phthalocyanine and also although several other phthalocyanine has been later on tried but copper phthalocyanine is usually used in this bi-layer geometry. Because it has a very high mobility and also the high stability, it has been combined with fullerene C60 as an acceptor which has provided the world’s highest efficiency inorganic solar cell.

Even polymer materials have also been used in place of this small molecule later on. The conjugated system of this polymer consist of chains and rings of carbon atoms in sp1 and sp2 hybridizations, leading to alternate single bond and double bond. And earlier we have seen that those polymers which has an alternative single bond and double bond they can conduct the electricity and they are called conducting polymer.

Only the conducting polymer are useful for fabricating up to electronic devices. The solar cells on polymer material consist of the following acceptor and donor MEH-PPV poly 2-methoxy 5-(2-ethyl-hexyloxy) 1, 4-phenylene-vinylene. So that is the MEH-PPV full name it is a polymer which is very very light unstable and it was used as the electron donor and as an acceptor it was used CN-PPV which is a cyano para phenylvinylene as the electron acceptor. Since then there are several materials and their combinations have been tried to fabricate solar cells.

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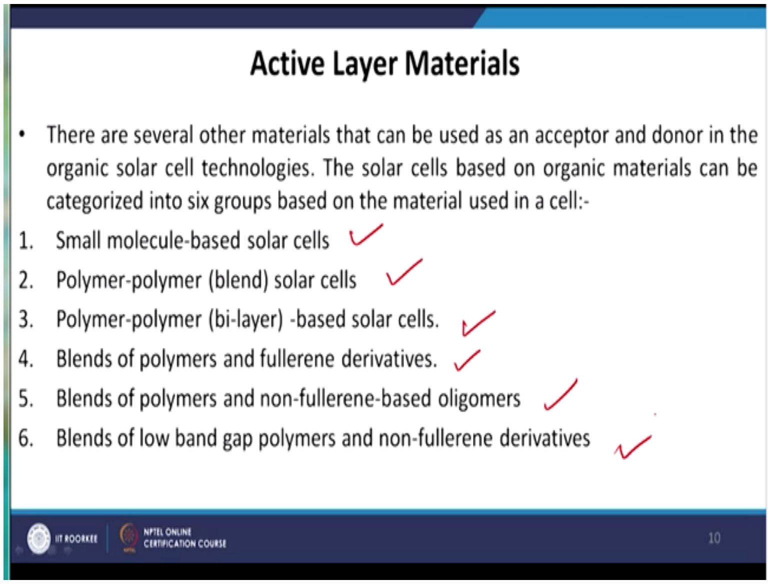

Active Layer Materials

- There are several other materials that can be used as an acceptor and donor in the organic solar cell technologies. The solar cells based on organic materials can be categorized into six groups based on the material used in a cell:-

1. Small molecule-based solar cells ✓
2. Polymer-polymer (blend) solar cells ✓
3. Polymer-polymer (bi-layer) -based solar cells. ✓
4. Blends of polymers and fullerene derivatives. ✓
5. Blends of polymers and non-fullerene-based oligomers ✓
6. Blends of low band gap polymers and non-fullerene derivatives ✓

So there are several other materials that can be used as an acceptor and donor in the organic solar cell technologies. The solar cell based on organic materials can be categorized into 6 groups based on the materials used in the cell. Small molecule base solar cells where we use the small molecules to fabricate the active layer, polymer-polymer blend solar cell where both the donor and acceptor were made of polymer.

Polymer-polymer bi-layer based solar cells you put 1 layer of polymer on top of that you put another layer of polymer one as a donor another as an acceptor. Blends of polymers and fullerene derivatives, so we can mix the conjugate polymers with different kinds of C60 derivatives like PCBM PC70BM PC71BM these are all fullerene derivatives. Blends of polymers and non-fullerene based oligomers.

Like instead of fullerene based compounds we can also use non-fullerene based compounds like NDI naphthalene diamide or perylene diamide. So you can use the molecule and non-fullerene based oligomers or blends of low band gap polymers and non-fullerene derivatives this is a right now an imaging area of research. So as you mentioned in the last class that efficiency in a solar cell is a product function, so it depends upon so many parameters to work simultaneously.

The first is was the excite on generation and in that context we have seen that if the material has a lower band gap ideally it should be as close to silicon or germanium then it is good for us. Because then the absorptions will be rate shifted, we will get an absorption in the near IR part which is more useful part of the solar spectrum. Now if you can utilize most of the solar spectrum then we can generate most of the photo carriers out of this process.

So that was the purpose or motivation behind design the low band gap polymer, so nowadays lot of people are working on designing new low band gap polymer and also replace the PCBM all the PCBM works very fine. But it is also the processing of PCBM is very very costly, so for making any commercially viable technology people are now moving from fullerene to the non-fullerene derivatives like NDI or there are so many different kinds of non-fullertive derivatives people are working on. So these are the like in a 5 to 6 different class based on their materials and their configurations.

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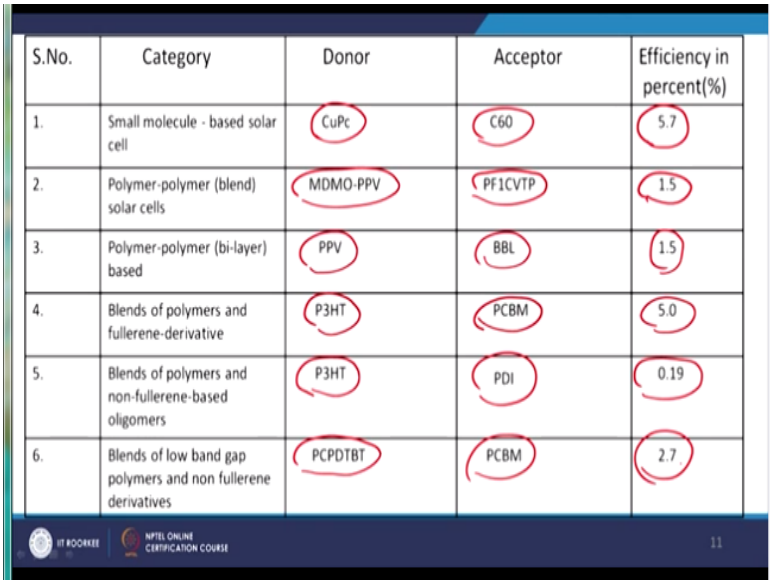

S.No.	Category	Donor	Acceptor	Efficiency in percent(%)
1.	Small molecule - based solar cell	CuPc	C60	5.7
2.	Polymer-polymer (blend) solar cells	MDMO-PPV	PF1CVTP	1.5
3.	Polymer-polymer (bi-layer) based	PPV	BBL	1.5
4.	Blends of polymers and fullerene-derivative	P3HT	PCBM	5.0
5.	Blends of polymers and non-fullerene-based oligomers	P3HT	PDI	0.19
6.	Blends of low band gap polymers and non fullerene derivatives	PCPDTBT	PCBM	2.7

Now in this table we are giving you a some example of the active materials which have been used in all the 6 different categories. For example if I talk about small molecule base solar cell as a donor we use copper phthalocyanine and as an acceptor we use C60 (()) (23:05) fullerene and the efficiency obtained was 5.7%. polymer-polymer blend solar cell, here as a donor molecule we use MDMO-PPV it is a PPV derivative and as an acceptor we use a fullerene base derivative PF1CVTP.

And the efficiency was 1.5%, polymer-polymer bi-layer devices for example again PPV and as acceptor we use in BBL and the efficiency is 1.5%. the most commonly used polymer which have been commercialized use P3HT as a donor and PCBM as an acceptor and you routinely get an efficiency of 5% even some of the solar cell company which makes the organic solar cell, they also use this P3HT and PCBM.

Because all the experimental condition for this particular materials are optimized and we can make roll to roll module even on a flexible substrate with an efficiency of 4 to 5% using these 2 materials. Now blends of polymers and the non-fullerene active so P3HT as a polymer and PDI as a non-fullerene additives and you got a very less efficiency like 0.19. Similarly one can use a low band gap polymer PCPDTBT which have been currently used along with a PCBM and efficiency is 2.7% also there are lot of low band gap polymers now a days has been worked on.

And who have the efficiency it is process like PTF7 and the lot of low band gap polymers are there and it is possible to rise the efficiency to 8 to 10% easily.

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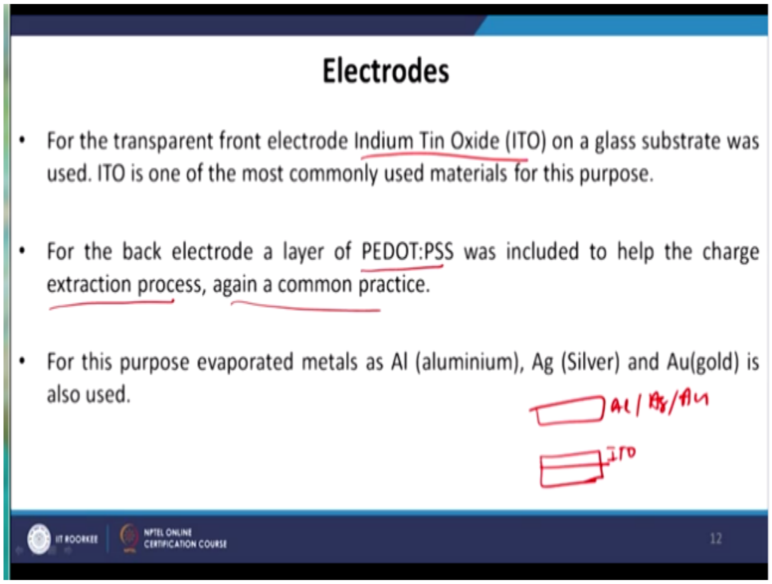

Electrodes

- For the transparent front electrode Indium Tin Oxide (ITO) on a glass substrate was used. ITO is one of the most commonly used materials for this purpose.
- For the back electrode a layer of PEDOT:PSS was included to help the charge extraction process, again a common practice.
- For this purpose evaporated metals as Al (aluminium), Ag (Silver) and Au(gold) is also used.

Now the second part in an organic solar cell is a electrodes, for electrode for the transparent front electrode indium tin oxide ITO on a glass substrate was used. ITO is one of the most commonly used materials for this purpose. For the back electrode a layer of PEDOT:PSS, now PEDOT:PSS is the polystyrene sulfonate when you and PEDOT is a conducting polymer. But when you dope that PEDOT with the PSS you get PEDOT:PSS is become more conductive soluble.

And this was included to help the charge extraction process again a common practice. As I said for the example of a filter material, for this purpose evaporated metals as aluminum, silver and gold is also used. So what happens like you know if this is your photoanode, so in the photoanode we use the glass and top of that there is an ITO substrate and as a cathode we use the metal like either aluminum or silver or gold.

And this metals they are deposited at a very high vacuum, in a vapor deposition chamber or in a vacuum deposition chamber. So usually we make 10 to the power -6 and 10 to the power -7 this amount of vacuum and so that like you know there will be no metal oxide there if the metal oxide will there, it will be acting like an insulating layer.

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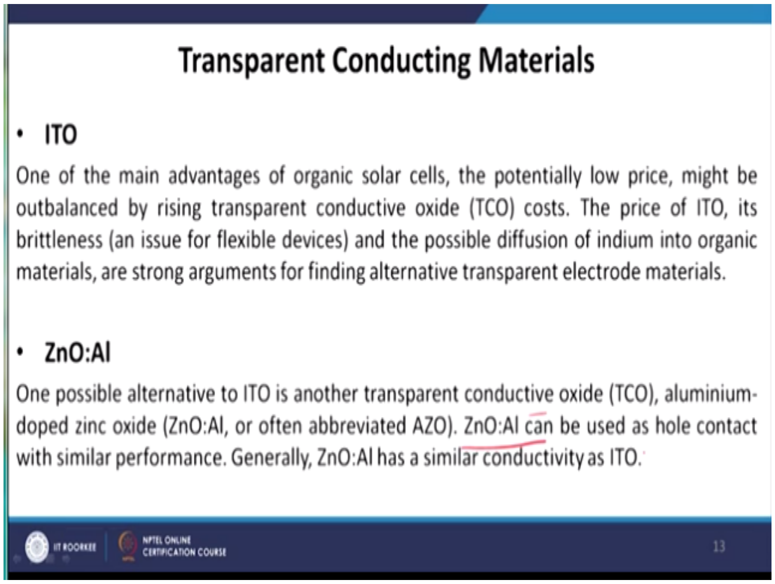

Transparent Conducting Materials

- **ITO**

One of the main advantages of organic solar cells, the potentially low price, might be outbalanced by rising transparent conductive oxide (TCO) costs. The price of ITO, its brittleness (an issue for flexible devices) and the possible diffusion of indium into organic materials, are strong arguments for finding alternative transparent electrode materials.

- **ZnO:Al**

One possible alternative to ITO is another transparent conductive oxide (TCO), aluminium-doped zinc oxide (ZnO:Al, or often abbreviated AZO). ZnO:Al can be used as hole contact with similar performance. Generally, ZnO:Al has a similar conductivity as ITO.

ITO is one of the main advantage of organic solar cell, the potentially low price might be outbalanced by rising transparent conductive oxide TCO cost. The price of ITO, it is brittleness an issue for flexible devices and the possible diffusion of indium into organic materials are strong arguments for finding alternative transparent electrode materials. Now there are lot of research is on-going to find an alternative for ITO.

Because as itself ITO is not flexible and when you put it on a glass substrate you cannot talk about a flexible substrate. But if you use a flexible polymer substrate like PET and on top of that if I put an ITO layer then still it is conducting but it is flexible. At the same time it has to be transparent, so that is why nowadays lot of work is going on for developing transparent flexible photoanodes.

Zinc oxide aluminum, one possible alternative to ITO is another transparent conductive oxide aluminum doped zinc oxide or ZnO:Al or often abbreviated as AZO. Zinc oxide aluminum can be used as hole contact with similar performance. Generally AZO or zinc oxide aluminum has a similar conductivity as a ITO.

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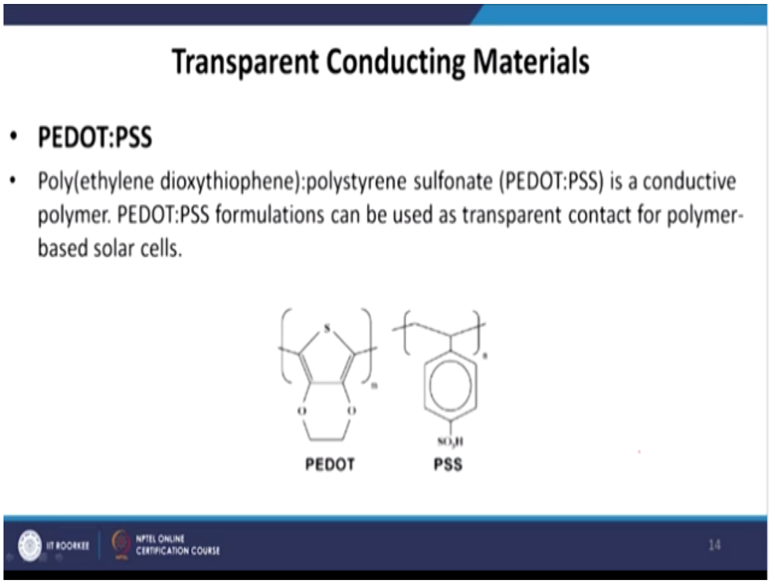

Transparent Conducting Materials

- **PEDOT:PSS**
- Poly(ethylene dioxythiophene):polystyrene sulfonate (PEDOT:PSS) is a conductive polymer. PEDOT:PSS formulations can be used as transparent contact for polymer-based solar cells.

PEDOT:PSS, poly ethylenedioxythiophene polystyrene sulfonate the full name of PEDOT:PSS it is a conductive polymer, the structure is showing here this is a structure of a PEDOT and this is a PSS. So PSS is doped in the PEDOT, PEDOT:PSS formulations can be used as transparent contact for polymer based solar cells.

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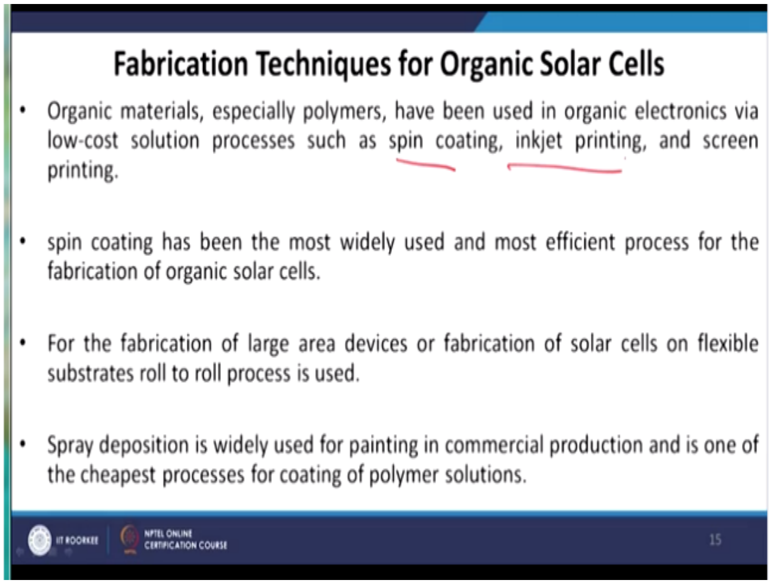

Fabrication Techniques for Organic Solar Cells

- Organic materials, especially polymers, have been used in organic electronics via low-cost solution processes such as spin coating, inkjet printing, and screen printing.
- spin coating has been the most widely used and most efficient process for the fabrication of organic solar cells.
- For the fabrication of large area devices or fabrication of solar cells on flexible substrates roll to roll process is used.
- Spray deposition is widely used for painting in commercial production and is one of the cheapest processes for coating of polymer solutions.

Now what is the fabrication technique for organic solar cells, organic materials especially polymers have been used in organic electronics via low cost solution process, such as spin coating, inkjet printing, and screen printing. So we can use either spin coating like where we have we use the centrifugal force we have a spin coated instrument on the chart we put the glass substrate then we put the material then we setup it for a desired rpm and desired time and it rotes and it gives an uniform film.

Similarly we can use inkjet printing is just like an inkjet printer, so in the (()) (28:03) you can fill out with a material which you want to print and on the flexible of transparent substrate you can print the solar cell and screen printing also. Spin coating has been the most widely used and most efficient process for the fabrication of organic solar cell. For the fabrication of large area device or fabrication of solar cells on flexible substrate roll to roll process is used.

So now there are different instrumental setup for roll to roll process, spray deposition is widely used for painting in commercial production and is one of the cheapest process for coating of polymer solutions. Now even for coating colors on the cars and everything we use spray depositions, now in a similar approach we can also coat the conducting polymer solution or we can make a coating of the polymer solution by this spray deposition method.

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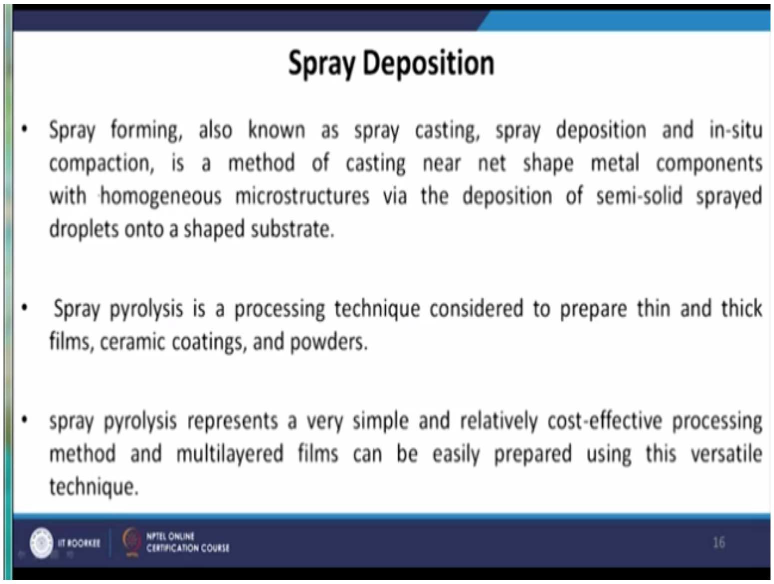

Spray Deposition

- Spray forming, also known as spray casting, spray deposition and in-situ compaction, is a method of casting near net shape metal components with homogeneous microstructures via the deposition of semi-solid sprayed droplets onto a shaped substrate.
- Spray pyrolysis is a processing technique considered to prepare thin and thick films, ceramic coatings, and powders.
- spray pyrolysis represents a very simple and relatively cost-effective processing method and multilayered films can be easily prepared using this versatile technique.

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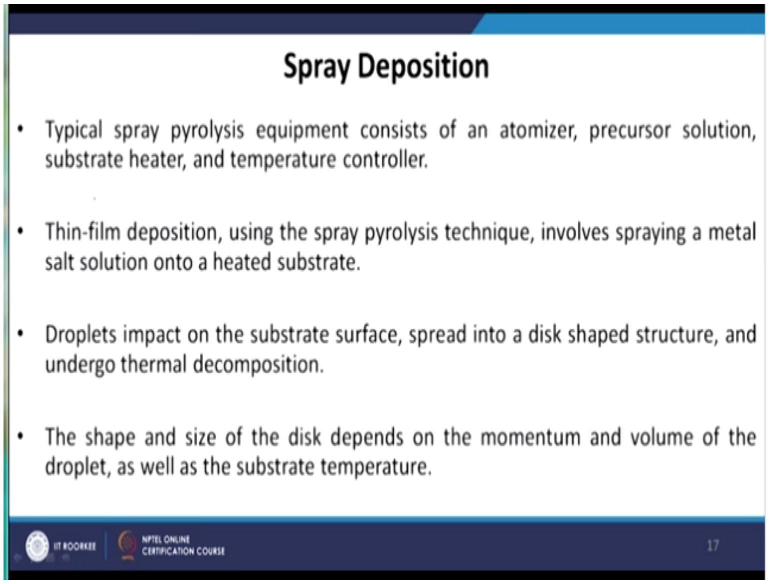

Spray Deposition

- Typical spray pyrolysis equipment consists of an atomizer, precursor solution, substrate heater, and temperature controller.
- Thin-film deposition, using the spray pyrolysis technique, involves spraying a metal salt solution onto a heated substrate.
- Droplets impact on the substrate surface, spread into a disk shaped structure, and undergo thermal decomposition.
- The shape and size of the disk depends on the momentum and volume of the droplet, as well as the substrate temperature.

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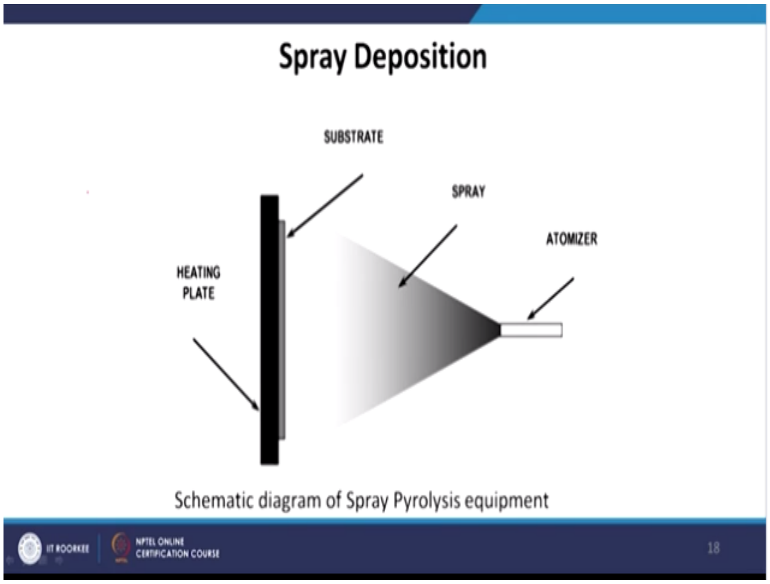

Spray Deposition

Schematic diagram of Spray Pyrolysis equipment

Here we are showing the schematic diagram of the spray deposition you can see that this is the atomizers. Here we are putting the spray and spray is uniform and isotropic on a substrate, this is a hot plate. So whatever the atom beams is coming or whatever we wanted to deposit that is falling on the substrate and depending upon the controlling the heating and temperature we can control the uniformity and thickness of this film.

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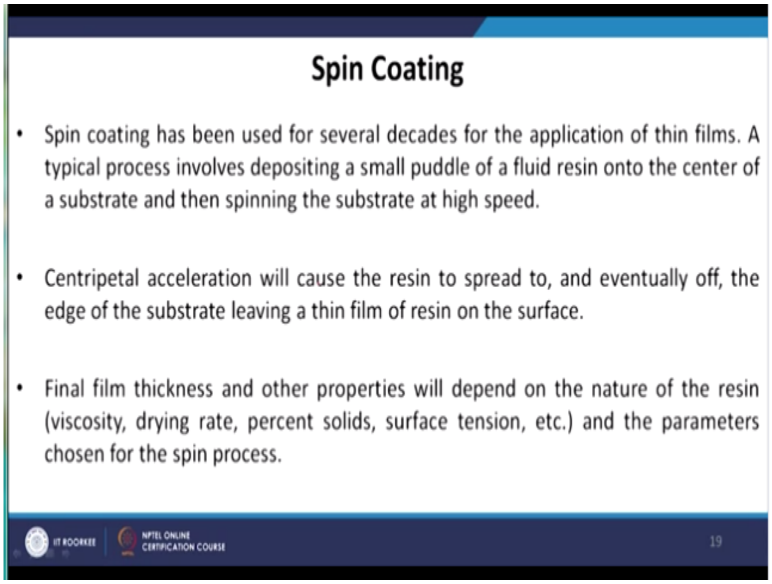

Spin Coating

- Spin coating has been used for several decades for the application of thin films. A typical process involves depositing a small puddle of a fluid resin onto the center of a substrate and then spinning the substrate at high speed.
- Centripetal acceleration will cause the resin to spread to, and eventually off, the edge of the substrate leaving a thin film of resin on the surface.
- Final film thickness and other properties will depend on the nature of the resin (viscosity, drying rate, percent solids, surface tension, etc.) and the parameters chosen for the spin process.

Second technique is spin coating, spin coating has been used for several decades for the application of thin films. A typical process involves depositing a small puddle of fluid resin onto the center of a substrate and then spinning the substrate at high speed. So basically you take your solution and then there is spin coating machine which contains a motor which rotates the chalk on the chalk you put your substrate which is held by the vacuum.

And then you pour your solution, you set up a particular rpm, you set up a particular time and we allows the solution to rotate uniformly over the film and after sometime you will get a very very uniform spread thin film. Centripetal accelerations will cause the rein to spread to and to eventually off the edge of the substrate leaving a thin film of resin on the surface.

Final film thickness and other properties will depend on the nature of the resin like viscosity, drying rate, percent solids, surface tension etc, and the parameters chosen for the spin process. Now what is the thickness ultimately we want that will depend upon lot of experimental parameters, it will depend upon the viscosity of the solution you are using, it will depend upon the your rpm speed, it will depend upon the timing of the spin coating.

It will also depend upon whether you have applied an ram that means you allow the spin coated to move at 500rpm/30 seconds and then at 1000 rpm to for another 30 second. So basically you put a step function or ram, so that is also the texture and the thickness of the film will also be changed. So depending upon like what is we need in our practical purpose we can control the parameters for the spin coating process.

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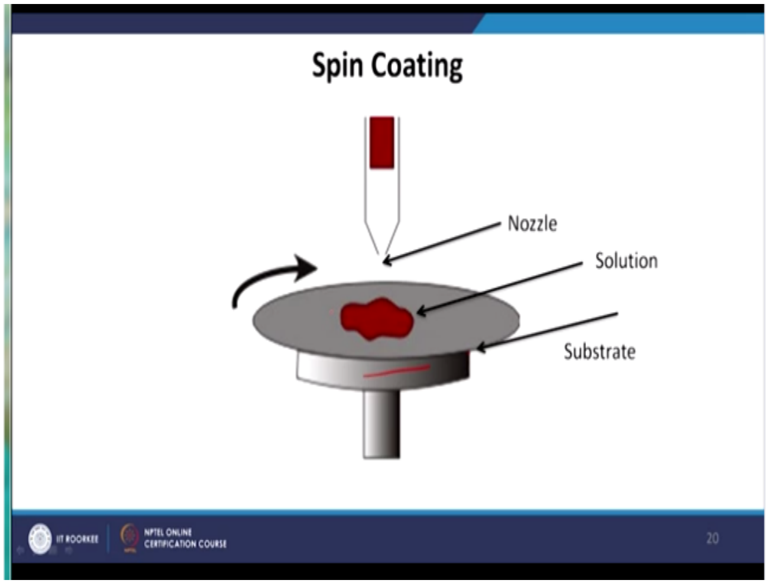
Spin Coating

For example a typical spin coater block diagram is shown here you see there is a chalk here this is the chalk and the substrate holder is there. So substrate is like you know is held on this chalk by the vacuum ok, then you pour the solutions at the center through this nostril or through this dropper. Then you switch on the machine you allow this spin coat rotate, so the centripetal accelerations will helps them to spread and this spreading should be instantaneous.

So the best way while you fabricating the film while the substrate is you just started to rotate then you add the solutions, so that you will get a very very thin uniform film. Now the another process is the inkjet printing, now when you talk about inkjet printing what did remains that is our normal day today printer. Before the discovery of the laser printer inkjet printer where you have to change the ink very often that was very very commonly used.

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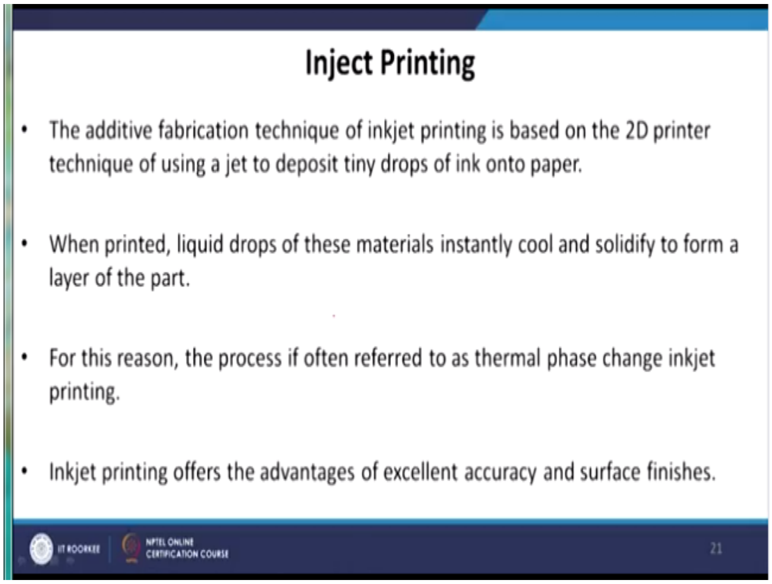

Inject Printing

- The additive fabrication technique of inkjet printing is based on the 2D printer technique of using a jet to deposit tiny drops of ink onto paper.
- When printed, liquid drops of these materials instantly cool and solidify to form a layer of the part.
- For this reason, the process if often referred to as thermal phase change inkjet printing.
- Inkjet printing offers the advantages of excellent accuracy and surface finishes.

The additive fabrication technique of inkjet printing is based on the 2D printer technique of using a jet to deposit thin drops of ink into paper. When printed, liquid drops of these materials instantly cool and solidify to form a layer of the part. For this reason the process if often referred to as a thermal phase changing inkjet printing. Inkjet printing offers the advantages of excellent accuracy and surface finishes and also you can make it on a roll to roll basis.

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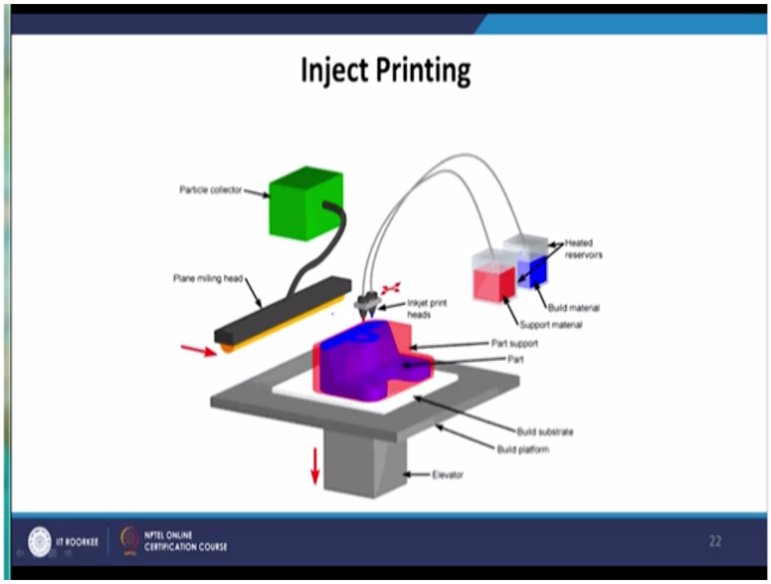

Inject Printing

The typical diagram of a inkjet printer is shown here you can see that here there are 2 or 3 different parts is there. The main part is this one which contains on inkjet print heads these are the 2 heads, so through the 1 head or the 1 channel that is a red ink and another is the blue ink. Now you can use these 2 different materials for example you can use donor material and you can use acceptor materials as this 2 inks ok and these are the heated reservoirs.

So you have to make sure the viscosity of this solution is such that it can easily or smoothly flow through this channel. Now whatever the solution which is passing through this channel that is injected on this printer ok. And then there is a build substrate and the which is rested on the build platform which is also rested on elevator and then there is a plane milling head comes from here and the particle collector which have been exploit view shows like that.

So now if I give the comment, so whatever the patterns we have generated the ink will follow that patterns and when this paper will come out or when this flexible (()) (34:34) come out you will get a uniform thin films of this P3HT or donor acceptor material. So that is the working principle of a inkjet printer.

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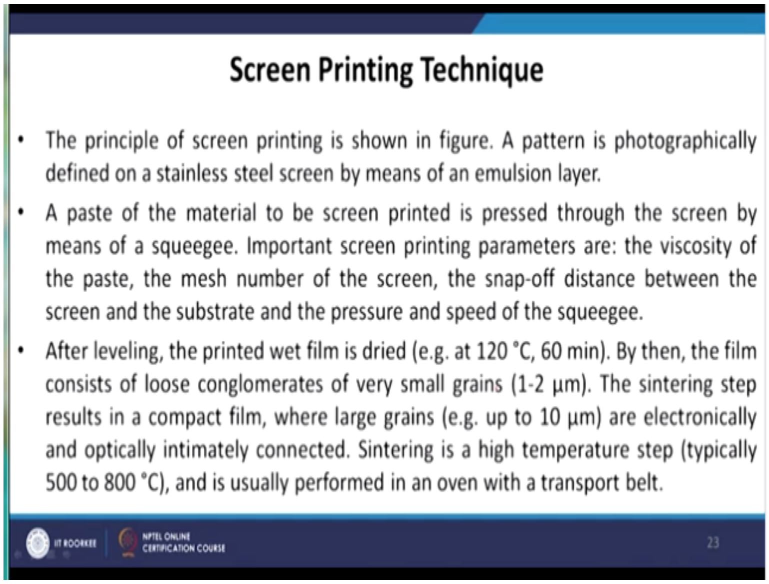

Screen Printing Technique

- The principle of screen printing is shown in figure. A pattern is photographically defined on a stainless steel screen by means of an emulsion layer.
- A paste of the material to be screen printed is pressed through the screen by means of a squeegee. Important screen printing parameters are: the viscosity of the paste, the mesh number of the screen, the snap-off distance between the screen and the substrate and the pressure and speed of the squeegee.
- After leveling, the printed wet film is dried (e.g. at 120 °C, 60 min). By then, the film consists of loose conglomerates of very small grains (1-2 μm). The sintering step results in a compact film, where large grains (e.g. up to 10 μm) are electronically and optically intimately connected. Sintering is a high temperature step (typically 500 to 800 °C), and is usually performed in an oven with a transport belt.

Finally the screen printing technique the principle screen printing is shown in the next figure, a pattern is photographically defined on a stainless steel by means of an emulsion layer. So basically here we use the stainless steel screen as a to develop the pattern by means of an emulsion layer. A paste of the material to be screen printed is pressed through the screen by means of a squeegee.

Important screen printing parameters are the viscosity of the paste the mesh number of the screen, the snap-off distance between the screen and the substrate and the pressure and speed of the squeegee. So these are all the parameters which determines the whole process or the thickness of the active layer. After leaving the printed wet film is dried for example at 120 degree centigrade at 60 minutes by then the film consist of loosely conglomerates of very small grains 1 to 2 micron.

The sintering step results in a compact film where large grains up to 10 microns are electronically and optically intimately connected. Sintering is a high temperature step typically 500 to 800 degree Celsius and is usually performed in an oven with a transport belt.

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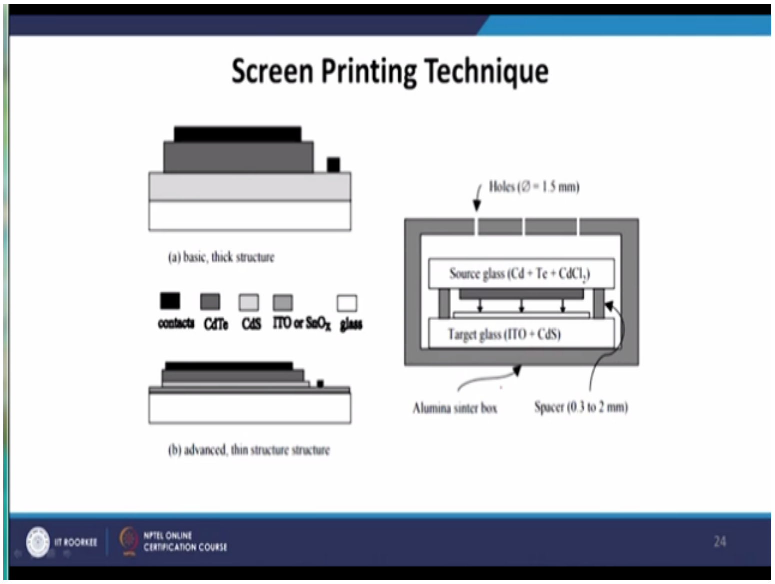

Screen Printing Technique

So here are showing the picture of a screen printing machine you can see that advance thin structure like we have a context on which we can put even CdSe CdS ITO and then glass. And this is a aluminum sinter box which have been covered through this hole which is 1.5 millimeter diameter and there is a spacer node is there, this is our source glass, this is our target glass.

So today we have discussed about what are the different components of an organic solar cells and also we have discussed how to fabricate an organic solar cells. Now for more understanding or to get details process of this fabrication process you should also look at some of the upcoming research papers which discuss about the different novel materials as a donor material and as an acceptor material. In addition to that as a standard textbook you can of course follow solar photovoltaics book by Chetan Singh Solanki.

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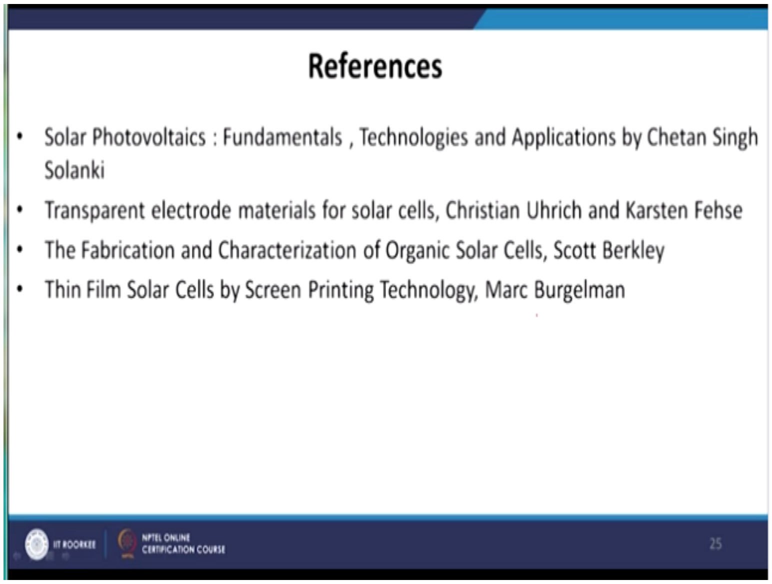

References

- Solar Photovoltaics : Fundamentals , Technologies and Applications by Chetan Singh Solanki
- Transparent electrode materials for solar cells, Christian Uhrich and Karsten Fehse
- The Fabrication and Characterization of Organic Solar Cells, Scott Berkley
- Thin Film Solar Cells by Screen Printing Technology, Marc Burgelman

And for transparent electrode materials by Christan Uhrich, the fabrication and characterization of organic solar cells by Scott Berkley and thin film solar cells screen printing technology by Marc Burgelman. So these are some excellent textbook in addition to the some research papers and some review papers which we can also refer for getting some in-depth understanding of this different constituents or different materials as every day there are new and new materials are discovered and the efficiency of the organic solar cells have been changing.