Solar Photovoltaics: Fundamental Technology and Applications
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Lecture – 33
Organic Nanoparticles based Solar Cells

Welcome everyone to our solar photovoltaics course, so far we are discussing about different varieties of the solar cell, if you remember we have started with silicon solar cell especially, the crystalline silicon solar cell and then we move to the amorphous silicon solar cell and finally, when you are discussing about different third generation solar cell, first we started with dye sensitised solar cell.

And we have seen that using some semiconducting materials like titanium dioxide and some absorber which can absorb the sunlight, we can make also in a very simple structure solar cell namely dye sensitized solar cell. Now, there are different varieties of the solar cells are possible but if you look all different kinds of solar cell, they have the similar kind of structure, they have a cathode, anode and in between them, there is a sandwich layer.

Now, the sandwich layer which is actually made of these which sometimes called the active layer also that actually, changes from solar cell to solar cell for example, if you take a silicon solar cell then PN junction diode like you know, so P and N type semiconductor is acting material there, if you go to organic solar cell, then the donor polymer and the acceptor small molecule, they are the active layer.

If you go to dye sensitised solar cell, then semiconductor like titanium dioxide or zinc oxide and the dye molecule like ruthenium based dye, they are the active layer, if you go to perovskite solar cell, it is the perovskite who comes the active layer. Now, in the context of the organic solar cell, we have seen that we can make an organic solar cell in 2 different ways and to make an organic solar cell, we need 2 different materials; one is the donor material where actually the exciton generation happens.

And an acceptor material which helps to dissociate the excited into free carrier, now this donor and acceptor material, we can arrange them in 2 different ways, either we can put them layer by layer like you can put a layer of donor material and then put another layer of acceptor material and then we can follow these same procedure again and again to build up multiple layers or what we can do is; we can mix that donor and acceptor together in some common organic solvent.

And from that mixture, we can make the solar cell, now the first type of solar cell was called layer by layer solar cell and the second type of solar cell was called bulk hetero junction solar cell. Now, we have also seen that this bulk hetero junction geometry is much preferred geometry in comparison to the layer by layer geometry, now in the context of the organic solar cell, when you use an organic polymer, one of the very well-known factors associated with an organic polymer is that their small exciton diffusion length.

Now, this conjugated or conducting polymer having an exciton diffusion length of 10 nanometre, so that means the electrons and holes can travel all the 10 nanometres before they recombine with each other. Now, consider the case, where we mix the polymer with a small molecule for example, you can take a very well-studied polymer; polythene hexa thiophene or P3HT as a donor polymer and a very well-studied small molecule like PCBM which is the polaring derivative.

And you mix them together to make the active layer for the organic solar cell but this organic polymer, they have a core which is electron rich and they have side which helps to solubilised them. Now, most of the time, the side chain; the diagonal outside the core and that prevents the efficient interaction between the donor and acceptor. Now, people were thinking how to circumvent this problem, how to overcome this small diffuser length problem of the organic solar cell.

See, like if the electron can travel all the 10 nanometre before they become recombine, so that means that 2 electrode has to be in a length scale of 10 nanometre because beyond that distance whatever the exciton on generated, whatever the free charge carrier generated that will not contribute to the current and that is why you always see that the thickness of the organic solar cell is much less than the silicon solar cell.

Now, scientific committee were thinking about that, how to like you solve this problem, now inspired by this inorganic self-assembly of the nano sphere, people are thinking that is it possible starting from a macro polymer, whether we can make a size tunable organic nanoparticle and self-assembled them, where only the electron rich core of the polymer will be exposed to the outside and the side chain will be dissolved or solved inside.

So that the efficient interaction between the polymer and the small molecule will be possible and also the diffusion of the electron within that certain lengths scale is possible, so that the electron can easily release to the electrode before reaching the or before recombine with each other. Now that is gives the concept of this organic solar cell, in today's lecture, we will discuss about in details what is an organic solar cell or organic nanoparticle based solar cell, how to fabricate an organic nanoparticle, what are the possible application of the organic nanoparticle.

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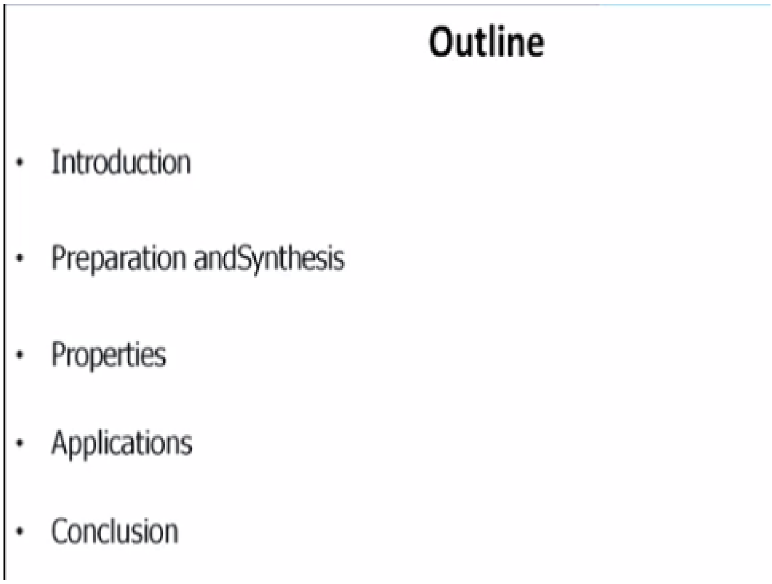

Outline

- Introduction
- Preparation andSynthesis
- Properties
- Applications
- Conclusion

And how we can characterise this kind of nanoparticle, okay, let us have a look now, the outline of the today’s talk; first we will discuss about the organic nanoparticle based solar cell especially, the essence of that solar cell and the different preparation and synthesis method, you can make it either by physical method or by chemical method, so we will discuss about that, then solve the excellent properties of this organic nanoparticle solar cell in comparison to their bulk counterpart.

Finally, what are the possible applications of this organic nanoparticles, this have been used in solar cells, this have been used for making LED, they have been used for making different kind of detectors as well as the lasers and the future outlook like you know, how we can go to high efficiency organic nanoparticle based solar cell.

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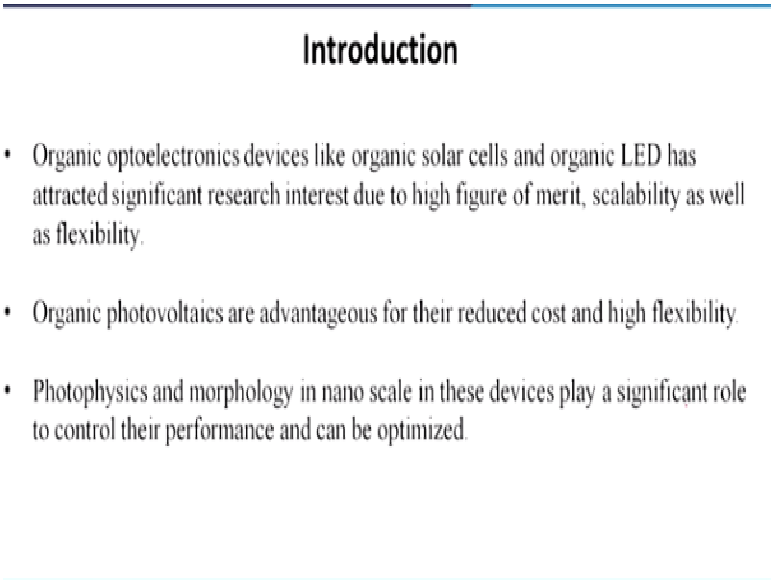

Introduction

- Organic optoelectronics devices like organic solar cells and organic LED has attracted significant research interest due to high figure of merit, scalability as well as flexibility.
- Organic photovoltaics are advantageous for their reduced cost and high flexibility.
- Photophysics and morphology in nano scale in these devices play a significant role to control their performance and can be optimized.

Now, organic optoelectronics devices like organic solar cells and organic LED has attracted significant research interest due to high figure of merit, scalability as well as flexibility now, this flexibility is one of the major issue with the inorganic optoelectronics devices, let us say, I wanted to make a solar cell which I can paint on which I can fix on my top of my college bag, so that is not possible with the silicon based solar cell.

Because the substrate is not flexible, it is rigid, so I cannot give it an arbitrary geometry but if I use a plastic substrate which can conduct the electricity then I can put it out any substrate, I can put on a close, I can put on any fabric, I can put it on a bag, so that kind of flexibility, the organic conducting polymer offers us and that revolutionise the field of the organic optoelectronics devices.

And that is scale level that means, you can make it role to role and also the figure of merit of the performance is tunable, so because of that there was a tremendous amount of research was devoted for developing new materials which can be used for organic solar cell, organic LEDs and finally, organic nanoparticle based optoelectronic devices. Organic photovoltaics are advantages for their reduce cost and high flexibility, the 2 factors you have already mentioned.

Now, many times that you know organic materials are less inexpensive in comparison to the their inorganic counterpart, one of the major reason behind is that you can make organic materials in a solution fabrication technique but you have seen that when you make a silicon solar cell, we have involved very high temperature; high temperature furnace which goes beyond 1200 degree centigrade.

Now, maintaining this high temperature is always very costly method, whereas like in this organic solar cell or organic nanoparticle solar cell, you can make it by a solution based approach in a roll to roll basis, so that reduce their cost but of course, it is true that is how the organic materials itself is most costly than the inorganic material. Photo physics and morphology in nano scale in this device plays significant role to control their performance and can be optimised.

So, this factor we have discussed earlier also, like whether we have an organic solar cell or whether we have a desensitised solar cell, the self-assembly of the assembly of the different active layers that plays a very vital role in the charge conduction and charge carrier mobility. Now, this organic polymers when you self-assembled them, what is the nano morphology or at the nano scale, how does the charge transfer dynamics changes that is play an important role in determining their efficiency and their different kind of output characteristics.

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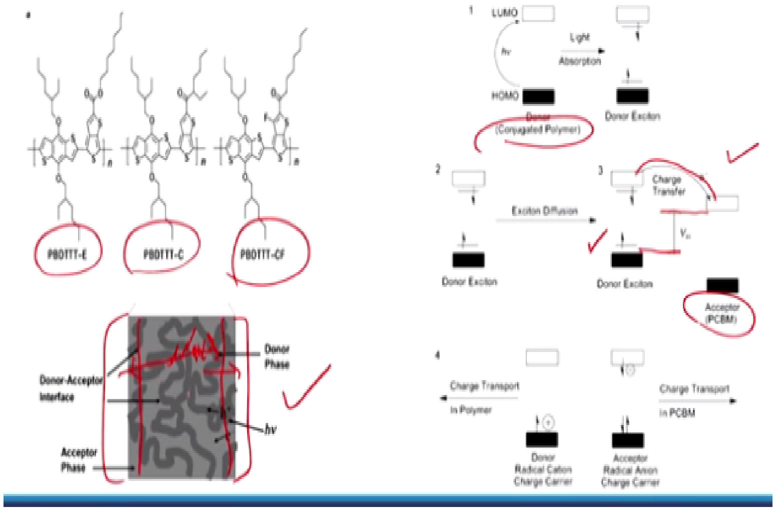
Origin of the problem



Now, what is the origin of this problem; we have already discussed little bit now, again go back to our this favourite formula of the efficiency, we know that the efficiency of any solar cell that depends upon 4 factors, right, one is the exciton generation that means, how good is my material, second is the exciton dissociation, so excitons are the bound electrons and holes but for the charge carrier, we need a 3 charge carrier, we need a 3 electrons hole which can travel to the 2 electrodes.

So, the bound exciton needs to be dissociated, so that is why the second step in this process is the exciton dissociation followed by the exciton diffusion. Now, once the exciton has been dissociated or the free charge carrier has been generated, then those electrons and holes needs to be travel or needs to be peculated to the 2 different electrodes that is called exciton diffusion.

And finally, once those electors and hole has reached to the electrode, they needs to be collected or they needs to be extracted by the electrode, so that is called charge collection. So, there are 4 process; exciton generation, exciton dissociation, exciton diffusion and charge carrier collection and we have said that this 4 process is an additive function or it is the product function.

So that means, each and every phenomenon or each and every process is dependent on each other for example, like let us say I have a very nice material which can absorb the light very well over the all spectrum and whose absorbent coefficient is very high but after generation of exciton, we do not have sufficient exciton separation, so they remains in the bound state, then what is the advantage of making this high number of excitons.

Now, the second step you know let us say, all the exciton has been separated but I have a very, very poor morphology in the devices, so what will happen; all those charge carrier although they are now separated, they are free charge carriers, they cannot travel to the electrodes, so they have get lost, so that will not contribute to any effective current, so that is also not a good scenario and finally, the interface between your active layer and electrode also play a very crucial role.

So, let us say the morphology is very good, you have a very good field factor, all the charge carrier has reach to the electrode but the energetics between the electrode and the active layer or the interface between the active layer and the electrode is such that electrode has not capable to extract those charge carrier, so that is also not a good scenario, so to get an optimal scenario, we have to optimise each and every factor equally rather than optimising one factor to the maximum and neglecting the others.

So that is why we call it as a product function not a additive function, okay now, in the context of the organic solar cell also, the same thing, the first stage is exciton generation now, if I have to have a good exciton generation that means, I need to generate more and more charge carriers, so for that what should I do; we should make materials which can absorb the light over a broad electromagnetic spectrum.

That means, we need a material with a lower band gap that is called low band gap polymer, now these are some of the example of the low band gap polymer which people have synthesised and you can see that they have a structure; chemical structure like this now, this materials like you know, they are very good to absorb the light and their absorption coefficient is also very good that was the first stage.

Now, the second step was exciton dissociation and this whole this polymer when they generated the excitons, now we bring an acceptor molecule very close vicinity to the donor material, so that there is an electric field or electric potential generated at the interface and that potential helps to dissociate the exciton into free charge carriers. So, here the donor is the conjugated polymer.

And after the light absorbance, what will happen like you know this is a homo level which is completely filled and is the lumo level which is unoccupied, after the light absorbance, what will happen; the electrons will go to the lumo level and hole will remain here. The second stage in this process is exciton diffusion, so now I have a donor exciton which will be followed by a diffusion of the exciton to the acceptor material.

We are using PCBM as an acceptor material, now the energetics or the positions of energy level such that the PCBM, homo, lumo energy level lies exactly in an ideal place and in comparison to the conducting polymer or conjugated polymer which we are using in this study, so that the electron can inject from the lumo level; to the lumo level of the PCBM and hole can inject from the homo level of the donor molecule to the homo level of the acceptor molecule.

And these difference, you see this difference; the difference between the lumo energy level of the acceptor and the homo energy level of the donor, this difference is called the open circuit voltage; VOC, so the open circuit voltage comes from the difference of the lumo energy level of the acceptor and the homo energy level of the donor. So, now exciton has been dissociated, electron is now her and hole is now here.

Now, now we do not inject here, let us consider that we although we say that we have injected the hole, so that is a possibility but when the exciton dissociation happens, electrons only inject and holes still remains here, okay. So, electron is in now in the acceptor and hole is in the donor, so the 2 electron or the 2 charge carrier has been separated, okay. Then the third process is that here this is the charge after the exciton dissociation is happen, then what it should be happen the exciton diffusion or charge transport.

So, towards the polymer, the donor of the hole will travel to this side and electrons will travel to the acceptor molecule now, for doing this process to be optimum what we need; we need an ideal morphology, we need that donor phase where this is the donor phase and the acceptor phase, which is this phase, they are separated with each other so, this is the hole which exist in the donor phase and these the electron which exist in the acceptor phase, okay.

And you can see from this the image which is a kind of block diagram, so the donor and acceptor both of them are distinctly phase separated, we can see clearly that donor phase and we can see clearly the acceptor phase and also this forms a phase separated by continuous percolated network, so that means not only the phase separation, you see that the phase separation is by continuous, I have donor phase, acceptor phase, then I have again donor phase, then acceptor donor acceptor, so it is a by continuous separation.

And the charge carrier can travel using this network, so that is why this is called a phase separated, by continuous and percolated network, so whenever we talk about an optimum morphology in an organic solar cell basically, we mean a phase separated, so donor phase and acceptor phase should be separated, by continuous; they will be repeated and percolated network, so that means the electrons and holes can travel using this percolated network.

So, by an ideal or optimum morphology we mean, a phase separated by continuous and percolated network, so that was our third step, that was our exciton transport or exciton diffusion or free charge carrier diffusion, now no longer the exciton exist because now we have let us say 80 or 90% exciton has been associated to the free charge carriers and they are now moving along the electrodes.

Now, here is the problem when the exciton diffuse or when the charge carrier diffuse, we know that the 10 nanometre is the exciton diffusion length that means electron can travel only 10 nanometre before they can recombine with the hole but let us say I put an electrode on this side and I put another electrode on this side, so what will happen? So, the electrons whatever have been or the holes which have been generated here, so they have to travel along this distance or they have to travel along this distance to reach to the electrode.

But and this distance let us say 100 nanometre but the electrons can travel at 10 nanometre, so that means, so only 10 nanometre, the electron can travel before they will recombine with hole, so then this either the thickness of the active layer is 100 nanometre, then only those electrons and holes within which is along the 10 nanometre distance scale the electrode, they will contribute to the current.

The remaining thing which is in the bulk, they will not contribute to the charge conductions, so that is not a good scenario and to prevent that thing or to circumvent that thing, we came across with this organic nanoparticle concept and we have been inspired by the inorganic nanoparticle assembly.

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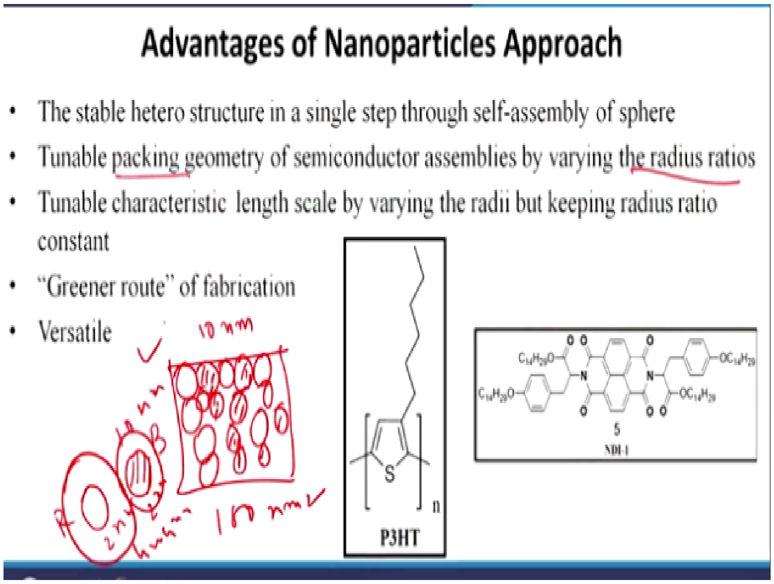

Advantages of Nanoparticles Approach

- The stable hetero structure in a single step through self-assembly of sphere
- Tunable packing geometry of semiconductor assemblies by varying the radius ratios
- Tunable characteristic length scale by varying the radii but keeping radius ratio constant
- "Greener route" of fabrication
- Versatile

So, we have seen that how the sodium chloride or how the inorganic nanoparticle system self-assembled now, the stable hetero structure can be obtain in a single step through self-assembly of sphere. Let us say like, what do you mean by self-assembly? Let us say, I have a red colour sphere and I have a blue colour sphere, okay and these 2 spheres and I have a like you know some kind of proof and I allow you to pour this red sphere and the blue sphere or red ball and the blue ball to like a pour on the floors.

Now, there are plenty n number of different ways you can place the different colours balls on the floors, I can just arbitrarily drop first the red colour ball followed by the like in a blue colour ball, so what will happen like you know, according to their potential energy, red colour ball will be like you know placed in certain location and the blue colour ball will be placed in certain location.

Now, if I do not follow any strategy or if I do everything in a very arbitrary way, so if I pour let us say in a 10 by 10 room, 1000 red colour ball and 1000 like you know blue colour ball, so they will be like you know arbitrarily oriented, so it might happen that you know one blue colour ball is sitting on a one red colour ball or a one re colour ball is like you know sitting on a blue colour ball, so we do not control their arrangement and that is and if you explain this in terms of the scientific phenomena, you calling that depending upon their potential energy or depending upon that free energy, so they assemble with each other.

Now, this kind of assembly which is not driven by any kind of external force that is called a self-assembly, now this was the example of a macro system or macromolecular system or a bulk system now, what will happen the same thing if you go to the nano scale now, this football; this red colour ball and the blue colour ball, let us say instead of a football, they are now 10 nanometre scale red colour sphere, nano sphere and 10 nanometre scale blue colour sphere or blue colour nano sphere.

Now, instead of 10 by 10 metre square room, now you consider you have been allowed to arrange those different colours balls on a 100 nano metre square area, so now the question is that how this red colour ball and how this blue colour nano ball they will distribute on this area, so again they will distribute according to their potential energy or according to a surface energy but we have learned that whatever the physics which gone, the motion of the particle in a macromolecular or bulk system that the same rule does not apply when you go to the nano system.

Because like you know, the smallness of the system prevent us to use of the very common laws of Newton's or the classical kinematics law to use there, so now even those nanoparticles or the nano sphere will self-assembled with each other, now if the nano sphere; one of the advantage in the case of the nano system in comparison to the bulk system is that here you can actually have a control over the arrangement of the systems in comparison to a bulk system.

In a 10 by 10 metre square room, if I drop like you know, 1000 red ball and 1000 blue colour ball, so I do not have a control how they are arranged each other but in 100 nanometre square floor, if I have like you know, 10 nanometre red ball and 10 nanometre like you know blue ball, then I can control the way of their arrangement and that external control actually is tuned by the internal self-organisation of this particle and that is the beauty of the nano systems.

So that; so, what is the advantage of that? First of all like you know, if you can change the diameter or the size of this nano sphere, then you can change the way they arranged, you can change either the red to blue ball diameter ratio or you can change the ratio of the all the like you know red ball keeping the blue ball same or you can change the diameter of the blue ball keeping the red ball diameter same.

So, all of these thing will contribute to define different self-assembly, so that is in each and every case, we will get a very stable structure or stable nano structure, so the stable hetero structure in a single step through the self-assembly of the sphere can be obtained in an inorganic system. Tunable packing geometry of semiconductors assemblies by varying the radius ratios, so again let us say like you know, I mean, if I draw this rectangle and let us say this rectangle has an area of 100 nanometre square, right.

So, this is 10 nanometre and this is 10 nanometre, so length is let us say 10 nanometre and width is 10 nanometre right, so this 100 nanometre square area and you have been given like you know 2 different colours ball; one is like you know red colour ball which is having like you know, 2 nanometre let us say and another is a green colour ball, this is red and this is like you know let us say green or blue colour, let us say blue colour ball which is also 2 nanometre, okay.

And now, you have been asked to fill this rectangle area by this 2 balls and you have been given the freedom, you can arrange them in an arbitrary way, when you started filling up this area with this ball like you know, I can arbitrarily put like you know 1; red ball 1, blue ball like you know blue ball and red, blue like that, now red, blue like this, I can fill like this way. Now, once I fill like this way, so I see that there is a void, which exists between these 2 balls.

Now, instead of the 2 nanometre balls, if I increase the diameter of the red ball let us say, this is now 4 nanometre and diameter of the blue ball is now 4 nanometres, so what will happen? Now, again if I fill this area with this 4 nanometres red ball and 4 nanometre blue ball, then the amount or the space of the void will now decrease so, this is called the packing of the sphere and this packing of the sphere in the case of the material science, they lead to different kind of crystallinity.

So, you can get it tunable packing geometry or tunable crystallinity by varying the radius ratio, so by changing from 2 nanometre to 4 nanometre of the red ball or by changing from 2 nanometre to 4 nanometre of the blue ball, I can change the way they pack with each other, I can change the crystallinity of the system that is one of the major advantage once you go to the nano domain.

Tunable characteristic length scale by having the radii but keeping radius ratio constant similarly, in this case like let us say, I have changed the radius of the red ball from 2 to 4 nanometres and the blue ball, 2 to 4 nanometres so, in the first example the radius of the red ball to the blue ball is 2/2 that is 1, in the second case, when I increase the radius, it is again 4/4; 1, so the radius ratio is same but you can also make radius is so different.

I can increase the red ball ratio to 2 to 10 nanometre and I can keep the blue ball ratio as 2 nanometre, so in that case, the ratio will be 5 is to 1, so if I change the relative radius ratio between the two sphere, so then also we can change the packing, we can change the characteristic length scale, so these are some of the advantage we have learned from the inorganic self-assembly of the nanoparticle.

Now, all this example translate to the organic nanoparticle self-assembly also, here also if we make a donor nanoparticle and acceptor nanoparticle, we can self-assemble them and we can change the diameter of the radius ratio of the 2 different sphere, we can change their packing geometry, we can change their characteristic length scale and also this organic nanoparticles they are fabricated in the water or ecosystem that is why it is greener root of fabrication.

Now, this organic solar cell like polymerised solar cells, they are made in the organic solvent like chloroform but in this nanoparticle, they are fabricated in water, so that is a basically, a greener root of fabrication and one can make the nanoparticle from any polymer possible which dissolves well in an organic solvent but does not dissolve in a water, so this method is also a versatile technique.

So, because of this advantage like organic nanoparticle has been used extensively in fabricating different kind of solar cell.

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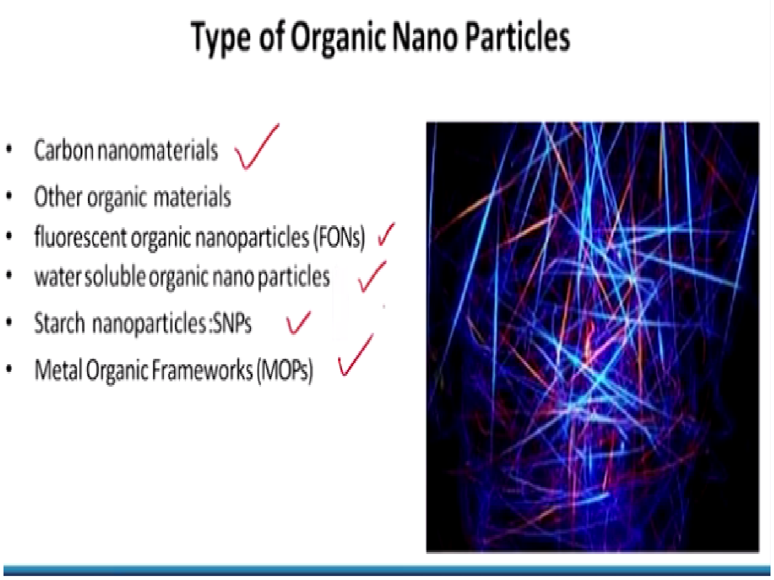

Type of Organic Nano Particles

- Carbon nanomaterials ✓
- Other organic materials
- fluorescent organic nanoparticles (FONs) ✓
- water soluble organic nano particles ✓
- Starch nanoparticles :SNPs ✓
- Metal Organic Frameworks (MOPs) ✓

Now, types of organic nanoparticles, what are the different types of organic nanoparticles are possible, one of the very common example is the engineer carbon nano materials like carbon dot, like grapheme dot, okay, other organic materials; fluorescent organic nanoparticles like organic nanoparticles can be luminous or fluorescent that means, they can emit light so, they will useful for making LED or laser.

Water soluble organic nanoparticle so, the organic nanoparticle can be water soluble, so the advantage is that like you know, you can use it for drug delivery system, you can use it for bio imaging, starch nanoparticle again, starch is carbohydrate like, so carbohydrate nanoparticle you can encapsulate any kind of drug inside the starch nanoparticle and use it as the drug delivery agent and metal organic frameworks.

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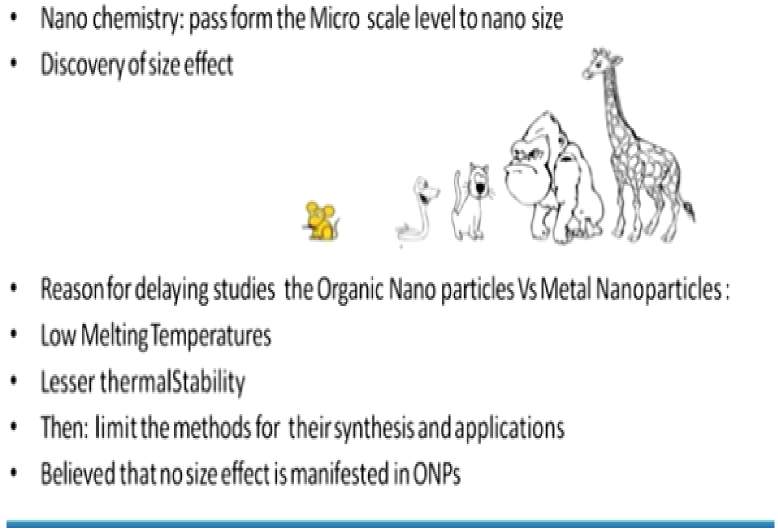

- Nano chemistry: pass form the Micro scale level to nano size
- Discovery of size effect
- Reason for delaying studies the Organic Nano particles Vs Metal Nanoparticles :
- Low Melting Temperatures
- Lesser thermalStability
- Then: limit the methods for their synthesis and applications
- Believed that no size effect is manifested in ONPs

So, these are like you know different examples of the organic nanoparticle system now, once we go from the macro level or the micro scale to the nano scale, the fabrication process or the synthesis process is also different that we call a nano chemistry now, let us say if I come from the giraffe to this creature Orangutan to this cat, to this one to this cat, so what is the difference between the these different creatures; their size.

Now, we have seen now that you know their habit, their lifestyle everything is different, so similarly if I start from an macro system and if I gradually, reduce the dimension and go to a nano system right, so than their properties will also be completely different, so that is called size effect, so it is the smallness of the size which give rise to solve the very weird properties in the nano particle system which usually we do not observe in the bulk system.

For example, like if you take an quantum dot now, for example I have this laser pointer okay, or like let us say you take any chalk which is used in writing in the board now, this chalk is a 1 centimetre chalk, if I make it a white colour chalk, if I make the chalk half, make it a half a centimetre chalk, it will still be a white colour chalk, if I again like you know make it half, like let us say, I make it like you know 0.5 centimetre or 0.25 centimetre chalk.

Again, it will be like in a white colour chalk but if I have like you know 10 nanometre scale chalk and if I make half like 5 nanometre chalk then, the colour of the chalk will be different, if I take a quantum dot like cadmium selenide; CdSe which has a diameter of like you know let us say 8 nanometre and if I reduce the diameter to 6 nanometre then the colour will change from red to blue.

If I go to 2 nanometre, then the colour will change to green, so basically we can change the colour or their optical properties by simply tuning their radius, so that is tremendous achievement actually, so that means that in a similar system without changing the compositional element just by changing the sides or the ratio or the radius, radius ratio or the radius we can change their optical properties and which is not present in the bulk system.

What is the reason behind it is that that equals size effect, you may call it as a quantum confinement or you may call it as the quantum effect, reason for delaying studies, the organic nanoparticle versus metal nanoparticles, low melting temperature, laser thermo stability, then limit the methods for their synthesis and applications and believe that no size effect is manifested in organic nanoparticles.

Now, we know that there are lot of advantage of using organic nanoparticle system but how we can make this kind of system; so let us look at their preparation and synthesis methods.

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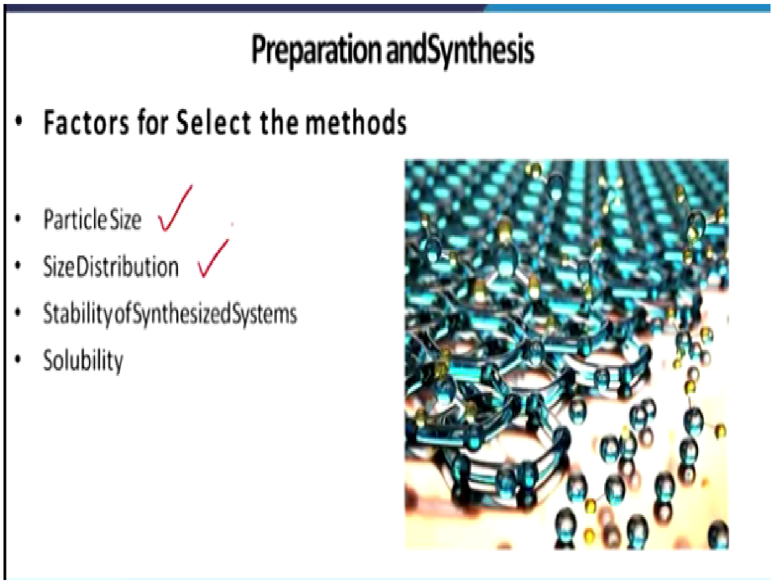

Preparation andSynthesis

- **Factors for Select the methods**

- Particle Size ✓
- Size Distribution ✓
- Stability of Synthesized Systems
- Solubility

Now, some of the factors which have to keep in mind when selecting any method is that their particle size, so that means what are the ultimate size we are looking for; size distribution, so this is also an important parameter okay, so like you know let us say I have a 10 millilitre of solution and which is filled with a nanoparticle, now out of that probably, 10 millions of them has 100 nanometre diameter, 2 millions of them has 10 nanometre diameter, 1 million of them has 1 nanometre diameter.

And like you know it say 4 million of them has 4 nanometre diameter, so there are nanoparticle in the system but they are disperse or poly disperse in their size, so that is called poly poly dispersity, on the other case let us say, I have a 10ml solution and each and every nanoparticles which exist in the solution has an exact diameter of 10 nanometre, so that is called a mono dispersed solution and this phenomena is called the size distribution.

So, whether the size is a mono dispersed or whether the size is a poly disperse, a quantitative factor to characterise the size distribution is called poly dispersity index or PDI, so if the poly dispersity index is very, very small then it is the mono dispersed solution and if it is very large then it is a poly dispersed solution. Now, depending upon our ultimate goal or the application purpose sometimes, we need a mono dispersed solution, sometimes we need a poly dispersed solution.

So, there are methods to characterise whether a solution is a mono dispersed or whether a solution is a poly dispersed things like dynamic light scattering is a method or TEM or transmission electron microscopy is a method which is used to characterise that whether a method is a mono dispersed or a poly dispersed solution or dispersion. Stability of the synthesised system that is also very important.

Let us say today, I make the nanoparticle dispersion and within 1 hour, all the system has been collapsed that you do not want, once you make it let us say, I want it to keep that solution for one month or for one year, so the stability is also very important and solubility, whether like you know, I mean this is a dispersion; colloidal dispersion or whether it is a solution that also is very important.

So that it depends upon the particle size, so whenever we prepare or wherever we synthesise the material, so all of these factors has to be kept in mind, so in today's lecture, we have discussed about like you know, different methods or whatever the factors we have to keep in mind for the synthesis or the preparations of the nanoparticles, now in the next lecture, we will discuss like what are the different physical methods and the chemical methods which is available in the literature for fabricating this organic nanoparticle system and how they can lead to some useful application. Thank you.