Selection of Nanomaterials for Energy Harvesting and Storage Applications
Prof. Kaushik Pal
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture – 02
Solar Energy Harvesting

Hello, my friends today we are going to discuss about our 2nd chapter on Solar Energy Harvesting. So, before going to start just let us know the what is solar energy. So, basically like water and air, the sun is one of the earths life support systems providing the heat and light as we know; because if there is no sun then our life maybe will become miserable or maybe after certain time we cannot sustain on this earth. So, solar energy basically is the form of energy relies on the nuclear fusion power from the core of the sun. So; that means, actually the solar energy we are getting from the sunlight itself.

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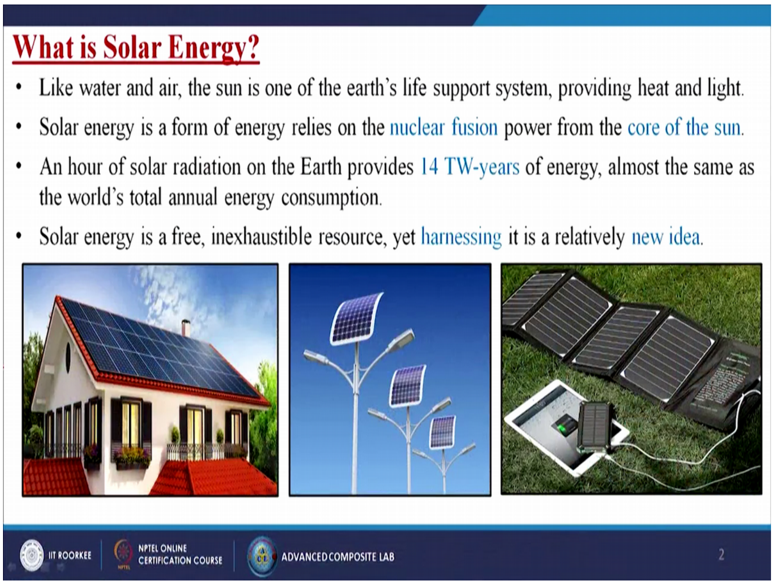

An hour of solar radiations on earth provides the 14 terawatt years of energy almost the same as the world's total annual energy consumption. So, from this particular statement you can understand that how much energy basically we are getting from the sun. Solar energy is a free inexhaustible source, yet harnessing it is relatively new idea. Harnessing means just capturing the solar energy and from capturing the solar energy just convert it into some other energy so, that we can utilize this solar energy.

Because, as we know that when the suns comes; it is comes to our whole earth surface. So, some portions basically we are using, but some we are wasting also. If we able to capture that particular energy and if we are able to convert that particular energy into some energy. So, of course, that is come on to the renewable energy without less cost maybe we can produce some kind of electricity. And, also it is a very good for the near future because when our fossil fuels are really going down.

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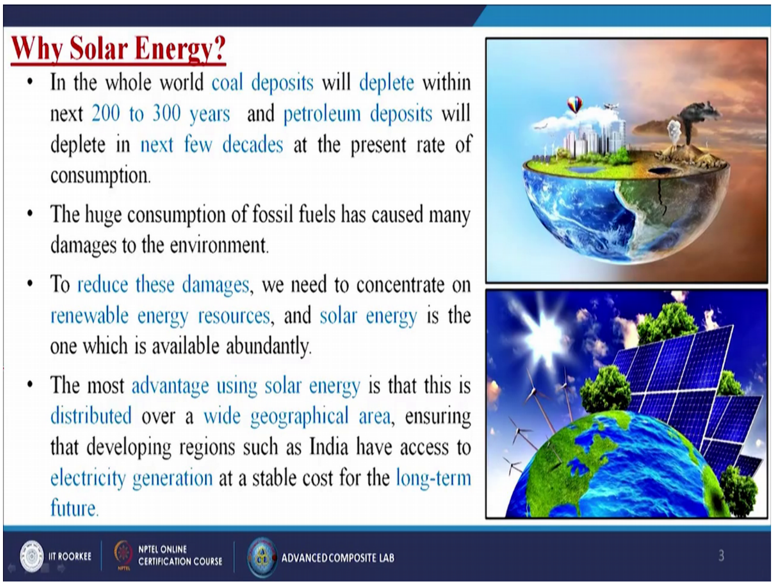

So, why solar energy? In the whole world coal deposits will deplete within next 200 to 300 years and petroleum deposits will deplete in next few decades at the present rate of consumption. So, of course, because whatever the coals we are having under the soil everyday we are extracting through mines. So, of course, after certain time that will be finished and whatever the petroleum’s we are getting from the soil or maybe some extractions from the fossil fuels.

So, basically that petroleum or may be the coal is having some time that after that we are unable to extract it or maybe it be gone down or may be finished. So, basically that time we have to depend up to on maybe some other technology or maybe other inventions from where we can generate the electricity or maybe the thermal power or maybe some kind of other minds. So, the huge consumption of the fossil fuels has caused many damages to the environment. Yes of course, because when we are cutting down the trees of course, it is creating a lots of problems towards the pollutions.

As we know that nowadays every years our pollution level is increasing tremendously all over the world. And, then automatically when we are cutting those trees automatically the land sliding and maybe the season changing is quite obvious which is affecting our day to day life. And, not only that sometimes it may happen that when we are cutting those trees and then burning so, it is creating so, many toxic gases into the environment which is also one of the causes for increase into the pollutions. So, to reduce this damage we need to concentrate on renewable energy sources and solar energy is the one which is available abundantly.

Yes of course, because we can get this kind of energy unless and until up to the life of the whole sun. So, automatically if we were able to explode this kind of energy from the solar light. So, automatically at least for next few decades or maybe the next few years at least we can think that we can get the constant energy from preserving this sunlight or may be from this particular sun. So, the most advantage using solar energy is that this is distributed over a wide geographical area because all over the world the sunlight is coming, ensuring the developing region such as India have access to electricity generation at a stable cost for the long term future whatever I have already explained.

So, now what is the importance of the solar energy? Why nowadays every people are talking about the renewable energy, solar energy or maybe the solar power systems?

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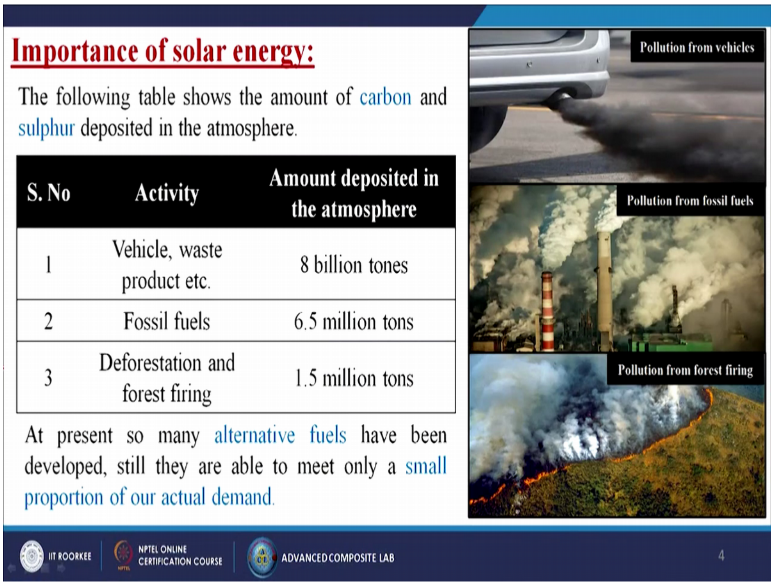

Because, from this particular table we can understand that how important it is; in this particular case it is showing the amount of the carbon and the sulphur deposited in the atmosphere. See, if I talk about the vehicle or maybe the waste products means like a exhaust gas what is coming from the vehicle itself, the amount deposit in the atmosphere is 8 billion tons. If we talk about the fossil fuels its about the 6.5 million tons. If we talk about the deforestation and the forest firing its cost around 1.5 million tones. So now, at present so, many alternative fuels have been developed still they are able to meet a small proportion of our actual demand.

Yes of course, because the solar energy or maybe the sunlight is the means the quantity what we are getting is a huge. So, if we are able to develop certain technology where we can absorb the maximum solar energy. So, that will be the very good for our near future because other this alternative fuels or may be the fossil fuels what happened, because they are having certain limitations. If I having this much of quantity I can generate this much of only the electricity, but the solar light it is countless almost. So, if I am able to construct certain kind of devices all over the world so, I can capture the whole sunlight and I can do use that particular sunlight for generating the electricity; that means, it is almost countless and the any number of productions we can do it.

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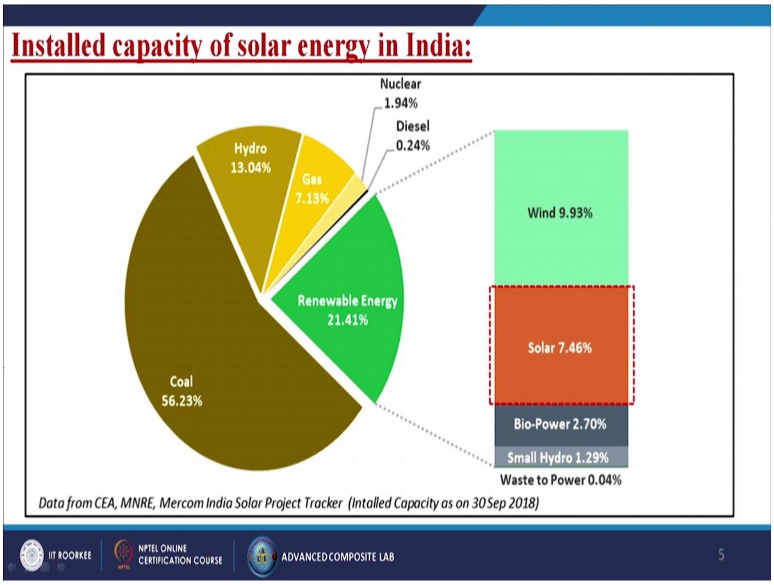

So, now in this particular image the data has been taken from the CEA MNRE that is the Ministry of Renewable Energy, Mercom India Solar Project Tracker. So, they are telling that instant capacity of the solar energy in India till today. So, till 56.23 percentage basically we are depending upon the coal. If we talked about the hydro then it is 13.04 percentage, gas is 7.13 and nuclear is 1.94 percentage because the availability of the nuclear materials is very less, if we talk about the diesel its only 0.24 percent.

Now, you can see that if we talk about the renewable energy it is coming almost 21.41 percent which is the second largest one just after the coal. So, now you can think that if in future the coal will be finished; so, that time that area can be taken care by the renewable energy. So, in future maybe the renewable energy will be the 100 percent. So now, if we talk about the renewable energy that is also divided into several parts so, basically if we talk about the wind energy. So, just simple we can use certain kind of turbine and then wind power on with the speed we rotate the turbine. So, then the turbine is rotating the generator and then it is generating the 9.93 percentage.

If we talk about the solar it is taking 7.46 percentage, if we use the biopower or maybe the biomaterials or maybe the biofuels so, that time it is 2.70 percentage. If we having the small hydro turbine plant then we can generate up to 1.29 percentage and of course, there is certain waste to power that is called as 0.04 percentage. So now, you can see that how tremendously the solar is coming up. So, maybe the solar energy can replace all other non-conventional renewable energy in later future. Now, let us talk about the history of the solar energy.

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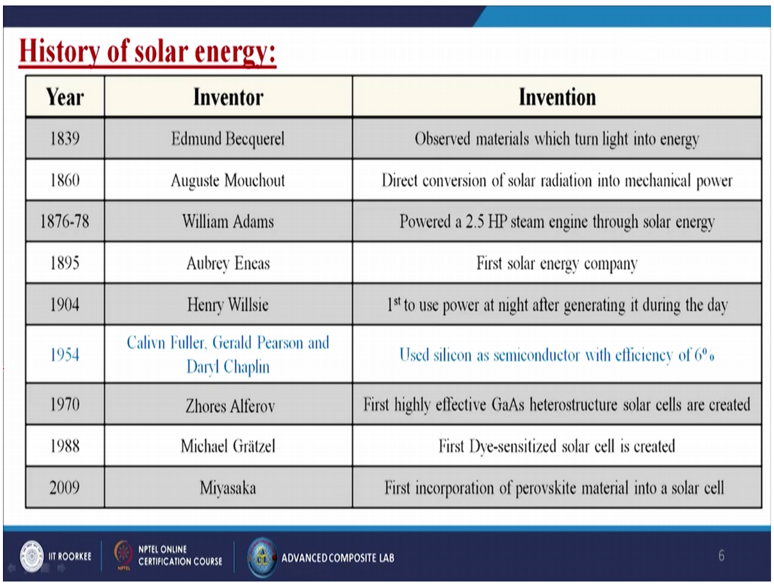
History of solar energy:

Year	Inventor	Invention
1839	Edmund Becquerel	Observed materials which turn light into energy
1860	Auguste Mouchout	Direct conversion of solar radiation into mechanical power
1876-78	William Adams	Powered a 2.5 HP steam engine through solar energy
1895	Aubrey Eneas	First solar energy company
1904	Henry Willsie	1^{st} to use power at night after generating it during the day
1954	Calivn Fuller, Gerald Pearson and Daryl Chaplin	Used silicon as semiconductor with efficiency of 6%
1970	Zhores Alferov	First highly effective GaAs heterostructure solar cells are created
1988	Michael Grätzel	First Dye-sensitized solar cell is created
2009	Miyasaka	First incorporation of perovskite material into a solar cell

So, basically you can see in the year of 1839 by Edmund Becquerel he has observed that materials which turn light into the energy. So, basically you can see; that he has seen, that the material which can turn light to energy; that means, if I am having certain materials if I put the light over there then automatically it will generate the electricity or maybe the energy.

So, basically he has started this one in the year of 1839, then followed by 1860 by Auguste Mouchout who has seen that direct conversion of solar radiations into the mechanical power. So, basically like this way slowly slowly we have come down to up to 1954 when the Fuller, Pearson and the Chaplin they discovered that silicon as a semiconductor with efficiency of 6 percent.

Then later in 2009 that Miyasaka who has developed the perovskite materials into the solar cells. So, from this particular chat you can understand that first initially we have identified the materials where we can put the light and it can generate certain kind of energy. Then slowly slowly we have come to the silicon solar systems, then from silica solar systems we have moved to the dye synthesized solar systems and nowadays people are trying to work on to the perovskite solar system.

So, basically the materials we are changing just to achieve the more efficiency from the solar light. So, automatically still today the research is going on and hopefully maybe within certain years we can achieve near about 50 percent of the efficiency from the solar light.

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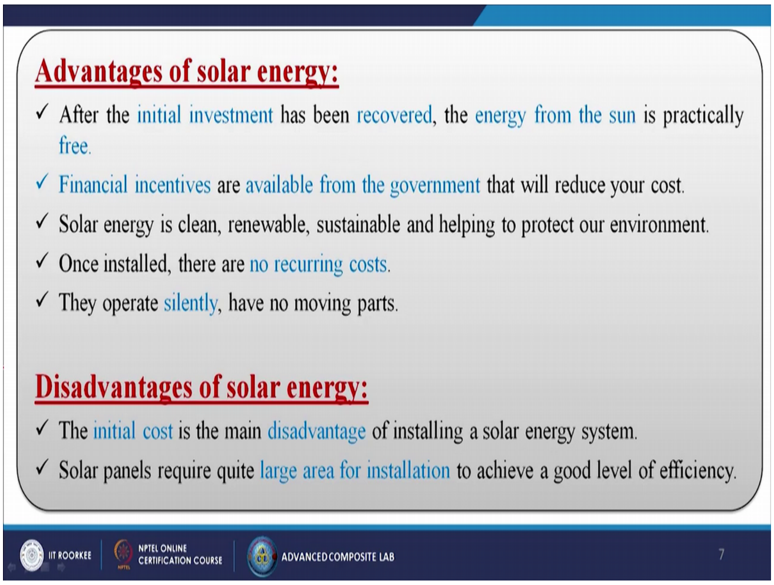

Now, what are the advantages of the solar energy? After the initial investment has been recovered the energy from the sun is practically free. Of course, because first initial stage we have to set up the device and then that device can works for a longer time. So, a very less maintenance cost is required, only the initial start up cost is little bit higher. Then we talk about the financial incentives are available from the government that will reduce your cost. Yes of course, now in everywhere the from the government like MNRE or maybe some other source they are putting the solar water heater or maybe some kind of solar panel with all the government institutions or maybe the government offices.

So, that at the roof whatever the solar energy, solar light basically we are wasting. So, by capturing those solar light and convert to it is into the electricity. So, at the time of our normal electricity of maybe we can use that particular energy to solve the problems or maybe the to continue our experimentations or may be running of the machines or may be the running of the office buildings in the night time.

Solar energy is also very clean, renewable, sustainable and helping to protect our environment because this is almost the pollution free. Once installed there are no recurring costs, they operate saliently have no moving parts. So, only you are having the collector where the sunlight is coming and then through that collector it is converting into the from solar light to the electricity. And, then just that electricity we are storing into some device and then at the time of requirement just we are using that particular energy.

Of course, there are certain disadvantages of the solar energy also; the initial cost is the main disadvantage of installing a solar energy systems as I told already. So, that is why the government is giving so, many types of incentives in terms of the loans or maybe the helping to the other peoples for opening their own business or maybe the startups. So, that they can install the solar energy and then after that slowly slowly when they are going to get certain profit and they are going to return it to the government or maybe the nationalized bank.

Solar panels required quite large area for installations to achieve a good level up efficiency. Yes of course, because as I told already the efficiency is too less maybe that time one solar panel or maybe the two solar panels will not be good enough to generate the high amount of electricity. So, that time you need a larger area so, that you can put so, many solar panels and you can generate a quite reasonable amount of the electricity at that particular time.

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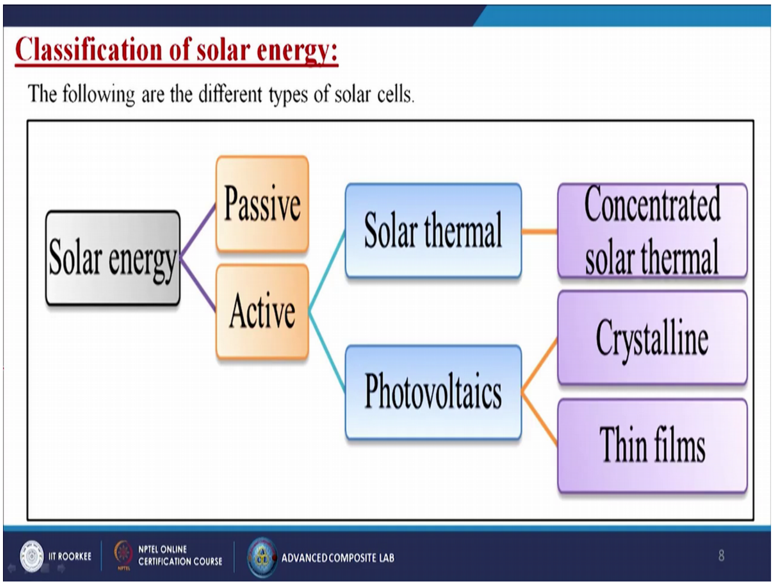

Now, what are the classifications of the solar energy? So, basically the solar energy is divided into two parts: one is called the passive and one is called the active. So, if we talk about the active, active is also divided into two parts one is called the solar thermal, another one is called the photovoltaics. And, then solar thermal is like the concentrated solar thermal and photovoltaics is also divided into two parts: one is called the crystalline another one is called the thin films. Now, we are going to discuss one by one into the next subsequent slides.

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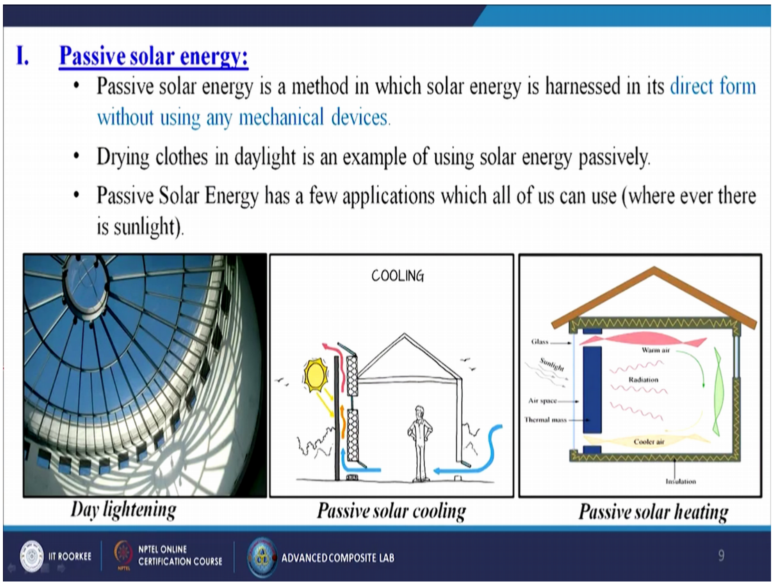

So, what is passive solar energy? So, basically from the name itself we can understand that this is passive, this is not directly active. So, basically passive solar is a energy is method in which solar energy is harnessed in its direct form without using any mechanical devices. Say suppose you can understand in our childhood our mother use to put one bucket of water into the sunlight into winter time. Why? Because, the thing is that after getting certain kind of sunlight that water can get little bit warm so, that we can use it for our bath purpose.

So, that is called the passive solar energy because here I am not going to use any kind of mechanical means directly I am using that particular solar energy into our systems. So, say suppose in the home or maybe the house or maybe the big building we are putting certain kind of glass opening kind of things where the direction light it can come and heated that particular room. We are having the passive solar cooling also, say suppose direct sunlight is coming and we are passing the water through it and then the water is getting little bit heated up and then it is releasing certain kind of moisture.

So, that we can get it cool down, we are having some kind of passive solar heating kind of things where we can use directly the sunlight to heat inside the room. So, anyway we are not using any kind of mechanical device. So, directly we are using the solar light or maybe the sunlight into our system.

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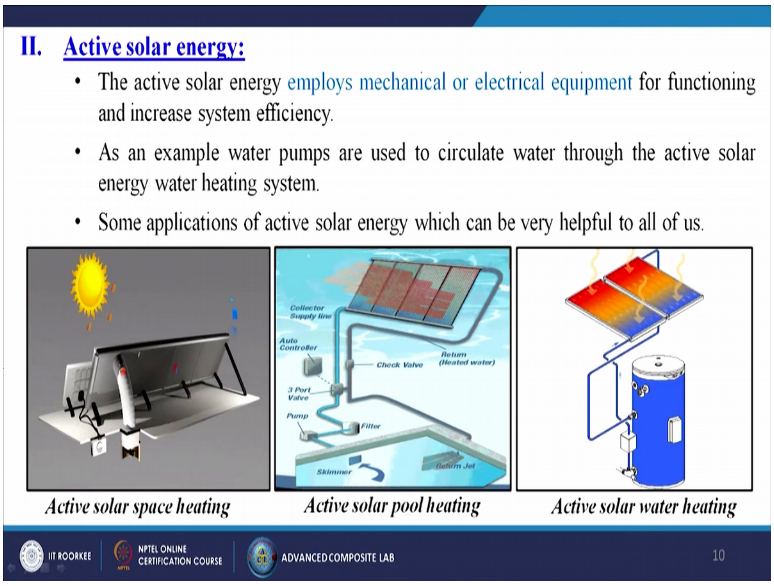

Now, when you are talking about the active solar energy that means, as I told already we are using certain kind of mechanisms, we are using certain kind of machines to store that particular solar energy so, that it can convert into certain energy. How? So, the active solar energy employs mechanical or electrical equipment for functioning and increase system efficiency. As an example water pumps are used to circulate water through the active solar energy water heating systems. Some application of active solar energy which can be very helpful to all of us is like this. What are those? First in this particular case we are having the active solar space heating.

So, in this particular case what you are seeing? The sunlight is coming on top of this panel and through this we are having the we are passing the air through this particular channel. So, the air is getting inside in this through this channel and then it is coming out. So, when air is coming through due to that sunlight the air is heated up and then that heat air we are using inside the room in winter time. So, like this way we are capturing the solar energy. In this particular case also we are nowadays we are using the active solar pool heating. So, in the winter times we that we can use that particular swimming pool because the water will getting warm over there.

So, here is the another example where is the active solar water heating systems. So, it is also like that same instead of air just we are circulating the water through that particular panel. So, that water is getting heated up by the sunlight directly and then we are using that hot warm water for our daily purpose.

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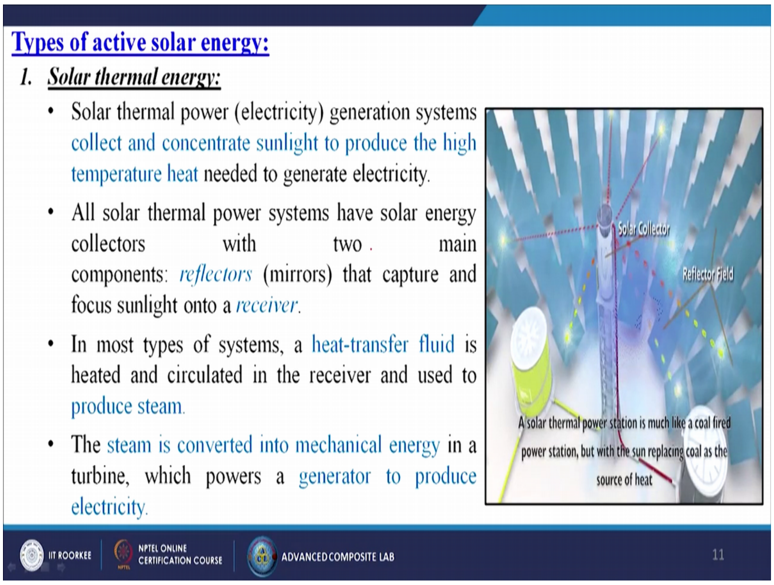

Next there are several types of active solar energy like that solar thermal energy; so, solar thermal power generation systems collect and concentrate sunlight to produce the high temperature heat needed to generate the electricity. All solar thermal power systems have solar energy collectors with two main components, one is called reflectors that is nothing, but the mirrors and that capture and focus sunlight onto a receiver. So, basically in most cases of system a heat transfer fluid is heated and circulated in the receiver and use to produce the steam. The steam is converted into mechanical energy in a turbine which powers a generated to produce electricity.

So, from this particular image we are trying to so, that how basically we are generating the electricity. We are having that solar collector; we are having the reflector field. So, simple what is happening? When the sunlight is coming, the sunlight is reflecting on to the mirror. Then I am having the receiver over there so, just I am rotating this one. So, that the full concentration of the sunlight will fall upon this one and inside it we are having that water or maybe some other means which will be heated up. And, then through that it will generate into the vapor and through that vapor it will rotate the turbine and then turbine is coupled with the generator.

So, automatically the generator will generates the electricity and that electricity we are sending to our day to day life. So, this is the basically the concept over here for the solar thermal energy.

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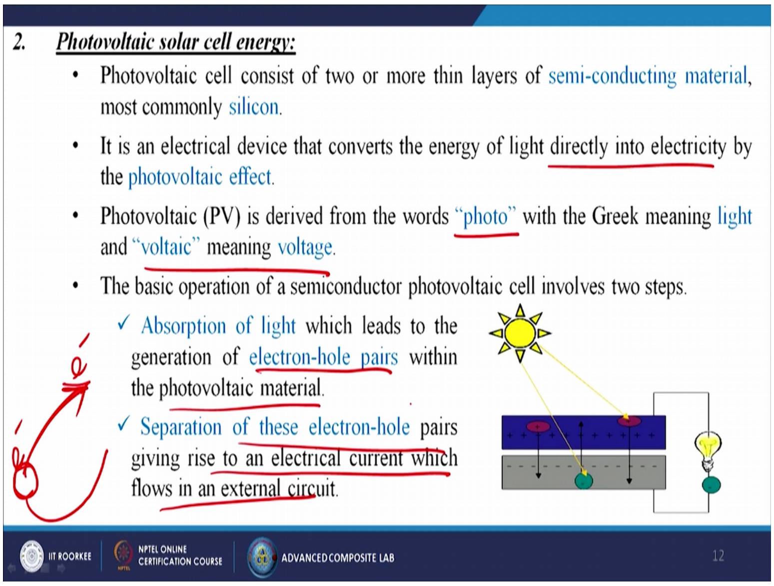

Next is called the photovoltaics solar cell energy. So, it is a one kind of battery kind of mechanism. So, photovoltaics cell consist of two or more thin layers of semiconducting materials most commonly the silicon, it is widely used. It is an electrical device that converts the energy of light directly into the electricity by the photovoltaic effect. So, the effect is called the photovoltaics so, that is why it is called the photovoltaics solar cell energy basically the mechanism is known as the photovoltaics. So, photovoltaics is derived from the words photo, photo is the Greek meaning is having the light and the voltaic meaning is called the voltage. So; that means, it is basically the light voltage. So, light is generating the potential difference over here.

So, the basic operation of a semiconductor photovoltaics cell involves two steps: one is called the absorption of light which leads to the generation of electron hole pairs within the photovoltaic materials. The separation of this electron hole pairs giving rise to an electrical current which flows a in an external circuit. So, simple in this particular case you can see that in other words we can say that when the electron is moving from one place to another. So, what is happening? Here it was the electron so now, here the electron is going into this place. So, automatically some vacant positions is creating at that particular point.

So, if the electron will go automatically the vacant will flow into the opposite directions so, that is nothing, but known as the electron hole pairs over there. So, that is creating the some kind of holes when the electron is leaving one place to another.

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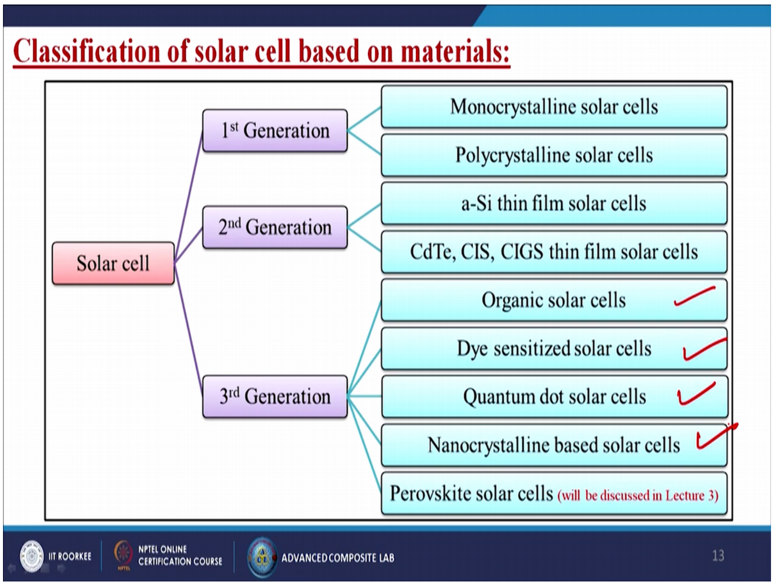

So, now basically the classification of solar cell based on materials there are several classifications. One is called the first generations, then second generations and the third generations. If we talk about the first generation solar cells; so, basically it is divided into two parts: one is called the monocrystalline solar cells another one is called the polycrystalline solar cells.

If we talk about the second generations we are having that amorphous silicon thin film solar cells, we are having that CdTe, CIS, CIGS thin film solar cells what are those I will tell you in brief. So, if you talk about the third generation solar cells so, first is called the organic solar cells, dye sensitized solar cells, quantum dot solar cells, nanocrystalline based solar cells and last one the perovskite solar cells which you are going to discuss into our next lecture.

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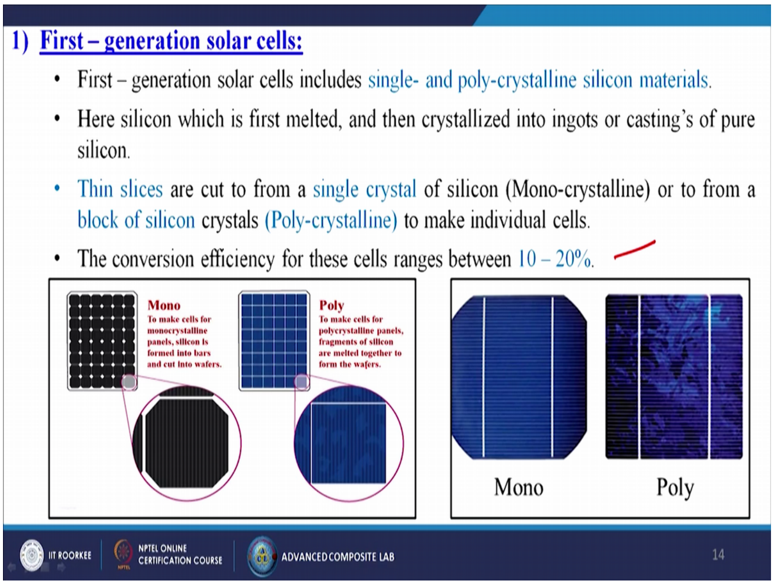

So, first is called the first generation solar cells. So, first generation solar cells includes single and the polycrystalline silicon materials. Here silicon which is first melted then crystallizes ingots or castings of pure silicon. Thin slices are cut to form a single crystals of silicon which is known as the mono crystalline or to form a block of silicon crystals which is nothing, but that polycrystalline to make the individual cells. So, the conversion efficiency for these cells range from 10 to 20 percent.

So, in this particular case when you are talking about the mono. So, basically mono case you see to make cells for mono crystal and panel silicon is formed into bars and cut into wafers. And, when you are talking about the poly to make cells from poly crystalline panels fragments of silicon are melted together to form the wafers. So, in this case it is the one and poly means many; so, many silicon crystals basically we are using. So, here is a more prominent image of the mono and the poly.

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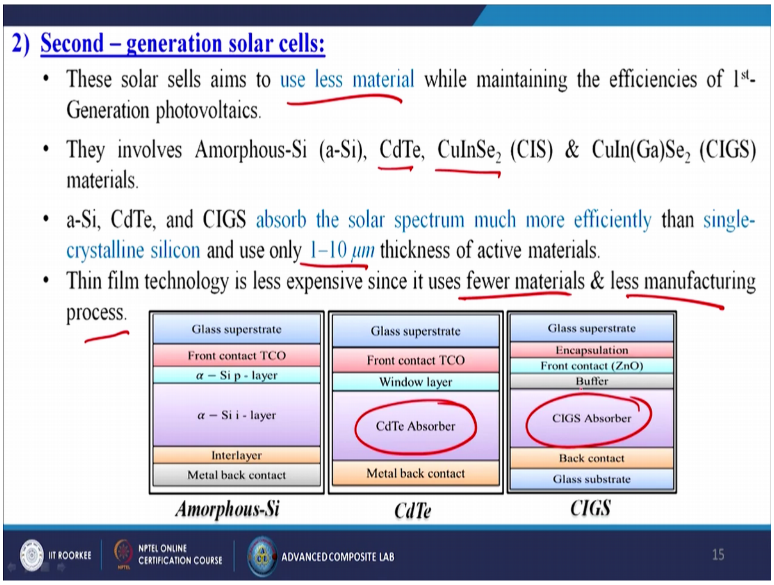

Next we are going to talk about the second generation solar cells. So, basically this solar cells aims to use less material while maintaining the efficiencies of first generation photovoltaics. So, basically they involves the amorphous silicon that cadmium telluride, copper indium disaccharide, copper indium gallium disaccharide. So, basically a-Si, CdTe and CIGS absorb the solar spectrum much more efficiently than single crystalline silicon and use only 1 to 10 micrometer thickness of active materials.

So, here from this particular line you can understand that we need a less amount of material. Thin film technology is less expensive since, it uses fewer materials and less manufacturing process. So, if we talk about the amorphous silicon where basically we are putting that particular materials. So, in this particular case you can see that we are having that metal back contact then top of that we are putting one interlayer. And, in this particular case basically we are using the amorphous silicon and then we are having that front contact TCO and the glass superstrate.

So, like this way basically in this particular case we are using the CdTe absorber, in this particular case basically you are using the CIGS absorber. So, from this you can understand that almost the manufacturing process is almost same only basically we are changing the materials just to increase the efficiency.

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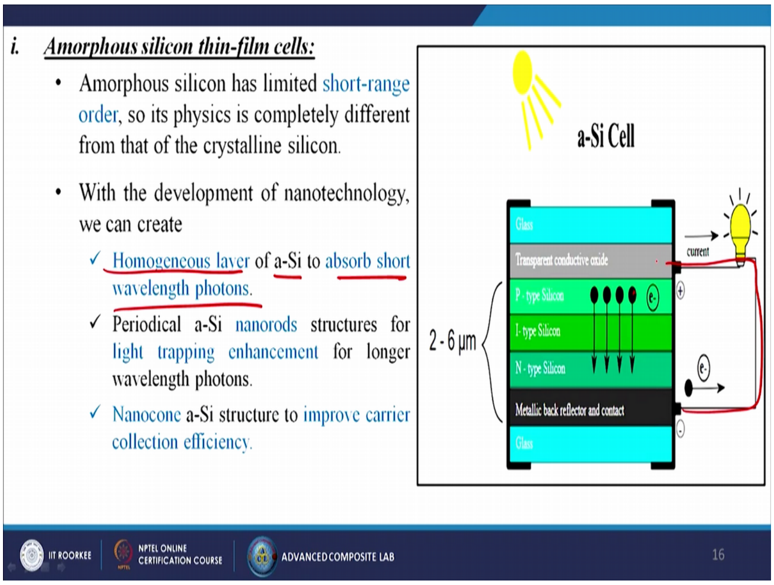

Next we are going to discuss about the amorphous silicon thin films. What is that? Amorphous silicon has limited short range order so, its physics is completely different from that of the crystalline silicon. With the development of nanotechnology we can create homogeneous layer of amorphous silicon to absorb the short wavelength photons. Periodical amorphous silicon nanorods structures for light trapping enhancement for longer wavelength photons, nanocone amorphous silicon structure to improve carrier collection efficiency.

So, basically you can see that we are having that glass substrate on top of that we are putting some metallic back reflector and the contact and then we are having that N type silicon, I type silicon and the P type silicon. And. next we are having the transparent conductive oxide and again we are having that glass. So, basically the solar cell is coming. So, in this particular case the electron is jumping from here to here; P type to the N type one. When the electron is jumping automatically you can see the whole pair is creating in this particular case.

So, now when the electron is coming hole pair. So, automatically now the electron in other way when it is going to that it will make the balance. So, that is why the current is flowing from here to here.

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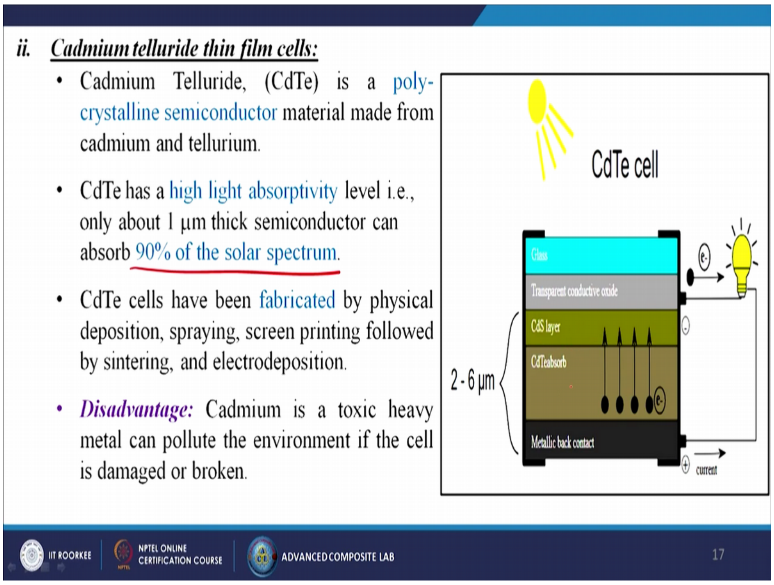

Next we are having that cadmium telluride thin film cells. So, in short generally we are calling it as a CdTe. So, is a polycrystalline semiconductor material made from cadmium and tellurium. CdTe has a high light absorptivity level that is only about 1 micrometer thick semiconductor can absorb 90 percent of the solar spectrum. Now, we can understand in our last lecture if you see properly; so, you can see that we are having 1 to 10 micrometer. But, in this particular case you can see that only we are using the 1 micrometer thick systems and it can absorb the 90 percent of the solar spectrum.

So, CdTe cells have been fabricated by physical deposition, spraying, screen printing followed by sintering and electrodepositions. Of course, there is certain disadvantages, what is that? Cadmium is a toxic heavy metal can pollute the environment if the cell is damaged or maybe the broken; that means, if the cadmium can come into the contact with the air. So, that time it creates certain kind of pollutions to the environment. So, the same like it is the amorphous silicon, in this case only we are replacing the amorphous silicon by the CdTe material.

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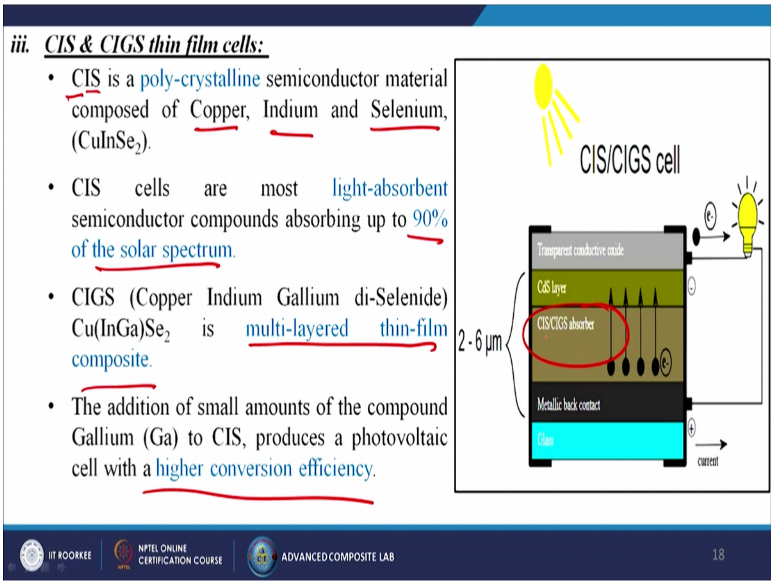

Next we are having that CIS and CIGS thin film solar cells. So, CIS is a polycrystalline semiconductor material composed of C stands for Copper, I stands for Indium and S stands for Selenium. So, basically it is the copper indium di selenide. So, CIS cells are most light absorbing semiconductor compounds, absorbing up to 90 percent of the solar spectrum. CIGS: Copper Indium Gallium di-Selenide is multilayer thin film composite materials.

The addition of small amounts of the compound gallium to CIS produce a photovoltaic cell with higher conversion efficiency. That means, the people everyday they are researching on it that which type of materials, if I add into the system so, that it can increase the efficiency of that particular systems. So, n number of researchers are working on nowadays on this particular solar photovoltaic system. So, in this particular case in this here basically we are using the CIS or maybe the CIGS absorbing materials.

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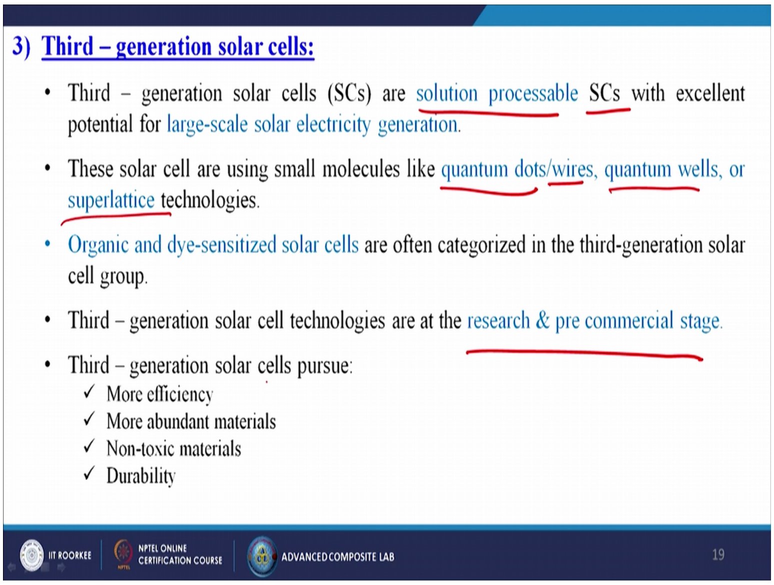

Next come to the last one which is called the third generation solar cells, it is also divided into several parts. So, basically the third generation solar cells are solution processable solar cells with excellent potential for large scale solar electricity generation. This solar cells are using small molecules like quantum dots or maybe the wires, quantum wells or maybe the superlattice technologies. Organic and dye sensitized solar cells are often categorized in the third generation solar cell group.

Third generation solar cell technologies are at the research and pre-commercial stage because, yes I will show you some literature into the next lecture that now how the people are working and how they are trying to improve the efficiency of those kind of materials. Basically, third generation solar cells pursue more efficiency, more abundant materials, non-toxic materials and the durability of that particular systems.

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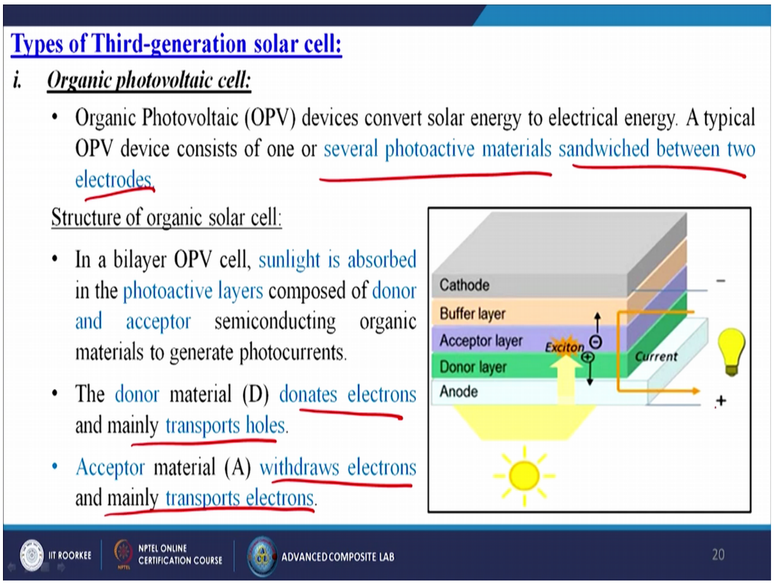

So, types of third generation solar cells number 1 is called the organic photovoltaic cell. So, basically organic photovoltaic cell in short basically we are calling it as a OPV devices converts solar energy to electrical energy. A typical OPV device consists of one or several photoactive materials sandwiched between two electrodes. So, basically it is a sandwiched structure; structure of organic solar cells is like this. In a bilayer OPV cells, sunlight is absorbed in into the photovoltaic layers composed of donor and acceptor semiconducting organic materials to generate the photocurrents. So, in this particular image just you see we are having that sunlight and then top of that we are having that anode. We are having that donor layer, acceptor layer, buffer layer and cathode.

So, in this particular case what happened? The donor material donates electrons and mainly the transport wholes, acceptor material withdraws electrons and mainly transport electrons. So, like this way basically we are getting the electricity. So, in this particular case donor layer is giving the protons which is coming to the anode. And, then in this particular case acceptor level is gives the electrons and it is going to the buffer layer and to the cathode itself. And, then automatically one is minus full of electron, one is the positive one that is the full of proton and then automatically the current is passing from the minus to the plus.

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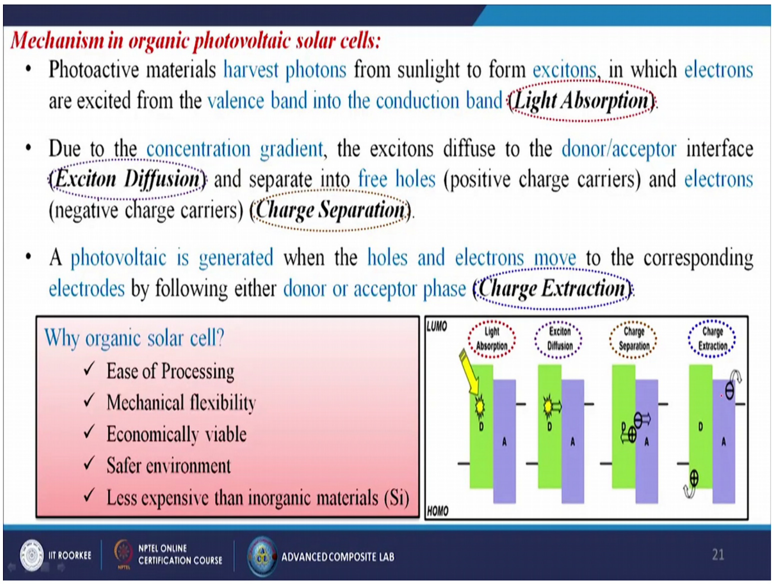

Next mechanism in organic photovoltaic solar cells. So, basically photoactive materials harvest protons from sunlight to form the exciton in which electrons are excited from the valence band into the conduction band which is nothing, but the known as the light absorption. Due to the concentration gradient, the exciton defused to the donor or maybe the acceptor interface like exciton diffusion and separate into free holes positive charge carriers and electrons like negative charge carriers; basically this mechanism is known as called the charge separation.

So, if photovoltaic is generated when the holes and electrons move to the corresponding electrodes by following either donor or acceptor phase which is nothing, but known as the charge extraction. So, why basically we are using the organic solar cell? So, it is very easy to processing, it is having the very good mechanical flexibility, it is economically viable, it is very safe to the environment. So that means, it is does not create any kind of pollutions to the in environment, less expensive than the inorganic materials like silicon.

So, in this particular case we can see that we have given the examples that how we are doing light absorptions then exciton diffusion then charge separation and the charge extraction how it is taking place. So, simple it is creating the electron hole pair the when the electron is moving, then we are having two collectors, one is collecting the protons, one is collecting the electrons. And, then the automatically the current is moving from one side and then in the loop also the electron is coming back to its original positions.

So, like this way they are making the balance inside the systems and we are getting the continuous electricity. And, here basically what the sunlight is doing? It is agitating that materials to leave the electron.

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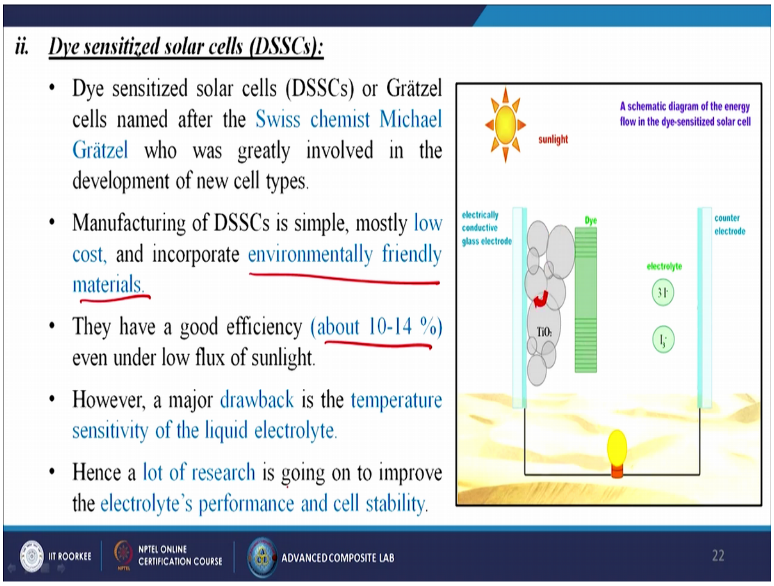

Next we are having the dye sensitized solar cells; till today maximum cases we are using this means maximum applications basically we are using the dye sensitized solar cells. So, basically the dye sensitized solar cells in short DSSC or maybe the Gratzel cells named after the Swiss chemist Michael Gratzel, who was greatly involved in the development of new cell types.

Manufacturing of DSSC's is simple, mostly low cost and incorporate environmentally friendly materials. They have a good efficiency about 10 to 15 percent even under low flux of sunlight. So that means, if you are having that little bit cloudy weather also so, by using that materials you can generate the sunlight. However, a major drawback is the temperature sensitivity of the liquid electrolyte. Hence, a lot of research is going on to improve the electrolytes performance and the cell stability.

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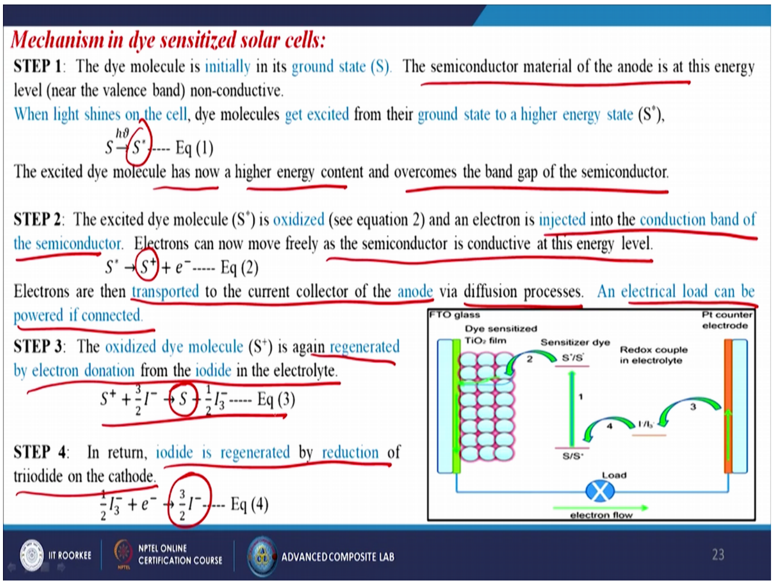

So, what is the mechanism in the dye sensitized solar cells? So, the step 1 is that the dye molecule is initially in its ground state. The semiconductor material of the anode is at this energy level near the valence band non-conductive. So, when light shines on the cell dye molecules get excited from their ground state to a higher energy state. So, simple it is coming from here to here so that means, S after getting the sunlight it is moving into the S star. So, basically the S star is nothing, but the excited dye molecules having the higher energy content and overcomes the band gap of the semiconductor.

The next step the excited dye molecules is oxidized and an electron is injected into the conduction band of the semiconductor. Electrons can now move freely as the semiconductor is conductive at this energy level. So, S star is converting into the S plus and it is releasing one electron to the systems. Now, electrons are then transported to the current collector of the anode via the diffusion process and electrical load can be powered if connected. What is the step 3? The oxidized dye molecules S plus which is generating from here is again re-generated by electron donation from the iodide in the electrolyte.

So; that means, S plus 3 by 2 I minus then again it is become stable so; that means, it is ready to again become S plus for next time. In return iodide is regenerated by reduction of try iodide on the cathode itself. So, half I 3 minus plus when it is taking the electron it is becoming this materials which is helping to form the again sulphur over there. So, its form the again S S stable S atom over there. So, in this particular case you can see that we are having the FTO glass and we are having that platinum counter electrode over there.

So, here it has been clearly shown that how the electron flow is taking place over there. If I put the load over there so, I can simply collect the electricity from this particular point. So, in this particular case I am having the dye synthesized titanium dioxide film. So, here in this particular case S is nothing but the titanium so, basically. So, what is happening over there? So, sensitizer die so, S plus or maybe the S minus like this way it is coming from here to here.

So, you see actually this green; so, when the green is going into this and then it is coming I minus and maybe the I 3 minus and then it is moving to this. So, actually it is starting from here, it is going into this and in this particular case it is coming over here, it is coming and just to stabilize this particular things over there. So, like this way from both the sides it is coming the material stabilizing into the between, but the electron is flowing from my FTO flow glass to the Pt counter or maybe the platinum counter electrode.

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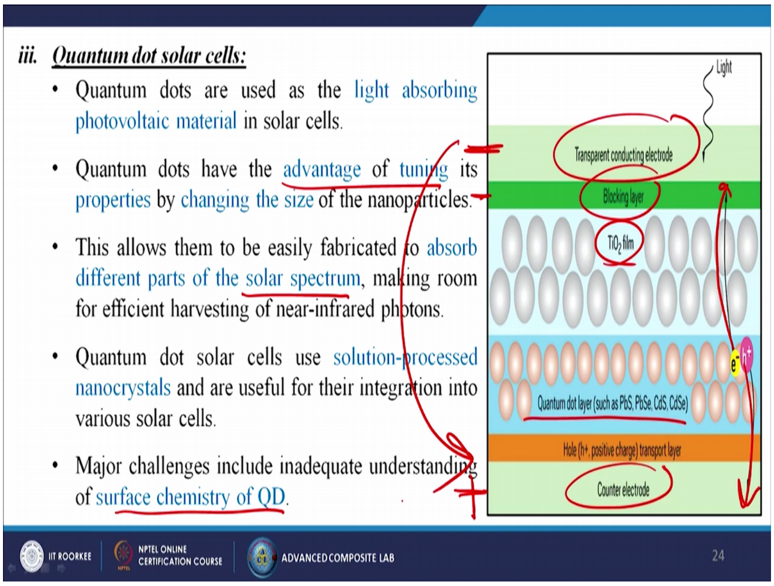

Next is called the quantum dot solar cells; so, quantum dots are used as the light absorbing photovoltaic material in solar cells. Quantum dots have the advantage of tuning its properties by changing the size of the nanoparticle. Yes, because this size you can see dots, dots means what nothing it is a ball kind of shapes. So, we while doing the synthesis basically we can control the shape of that particular ball; we can make it smaller, we can make it bigger also. This allows them to be easily fabricated to absorb the different parts of the solar spectrum making room for efficient harvesting of near infrared photons.

Quantum dot solar cells use solution process nanocrystals and useful for the integration into various solar cells. So, simple we are having that materials slowly slowly we are taking out layer by layer and then after that the smallest part physical you are getting as a quantum dots. So, major challenges include inadequate understanding of surface chemistry of the quantum dots. So, basically you can see we are having the titanium dye oxide flow over there and below that we are using the quantum dot layer such as the lead sulphate or maybe the lead selenide or maybe the cadmium sulphide or maybe the cadmium selenide.

So, these all are the materials where we are using the contents of this kind of materials and basically we are using the below of the TiO 2 film. We are having the transparent conducting electrode, then we are having that blocking layer. We are having that counter electrode in this particular case. So, what is happening? The electron is moving from here to here and the proton is moving from here to here. It is the conducting electrode will became the minus and then the counter electrode became the plus. So, automatically the current will flow in this particular case.

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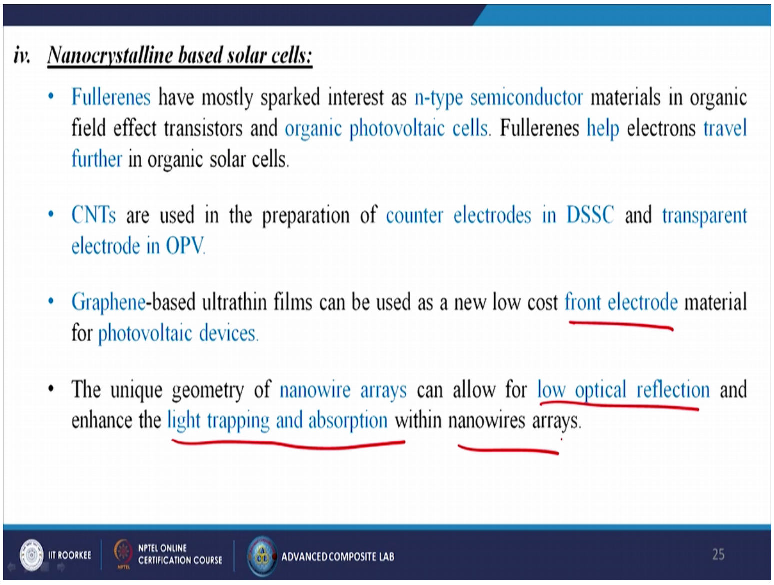

Next is known as the nanocrystalline based solar cells. So, basically the fullerenes it is a one form of the carbon right. So, have mostly sparked interest as n type semiconductor materials in organic field effect transistors; FET, organic photovoltaic cells. Fullerenes help electrons travel further in organic solar cells. So, basically the carbon nano tubes are used in the preparation of counter electrodes in DSSC, Dye Sensitized Solar Cell and transparent electrode in OPV organic photovoltaics.

So, basically graphene based ultra thin films can be used as a new low cost front electrode material for photovoltaic devices. The unique geometry of nanowires arrays can allow for low optical reflection and enhance the light lapping and absorption within nanowire arrays.

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Comparison of 1st, 2nd, and 3rd generation solar cells:

	1st Generation	2nd Generation	3rd Generation
Technology	Wafer based	Thin film based	Thin film based
Advantages	High quality, Low defect, High efficiency	Low material utilization, lower cost	Non-toxic, abundant, low cost, transparent, short payback
Disadvantages	High consumption of active silicon	Scarcity or toxicity of some materials	Optimizing lifetime efficiency-cost trade off

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So that means, the people are working, these all are the latest materials. Now, people working on these materials just to increase efficiency, decrease the cost and automatically the increase the life of those particular solar cells so, that we can use it for a longer time. Now, come to the comparison of 1st, 2nd and 3rd generation of the solar cells. So, technology wise 1st generation is the wafer based, 2nd generation is the thin film based and 3rd generation is also the thin film based. If I talk about the advantages; so, first generation we are having that high quality, low defect, high efficiency.

If we talk about the 2nd generations, low material utilizations and the lower cost; that means, cost has been reduced. 3rd generations it is non-toxic, it is abundant materials using, low cost, transparent short pay back. And, if we talk about the disadvantages; 1st generations we are having that high consumption of active silicon. If we talk about the 2nd generations scarcity of toxicity of some materials and if we talk about the 3rd generations it is optimizing the lifetime efficiency and cost rate off. So, automatically now in the 3rd generations basically we are standing. So, in this particular case basically you are trying to increase the efficiency as well as it will be the low cost.

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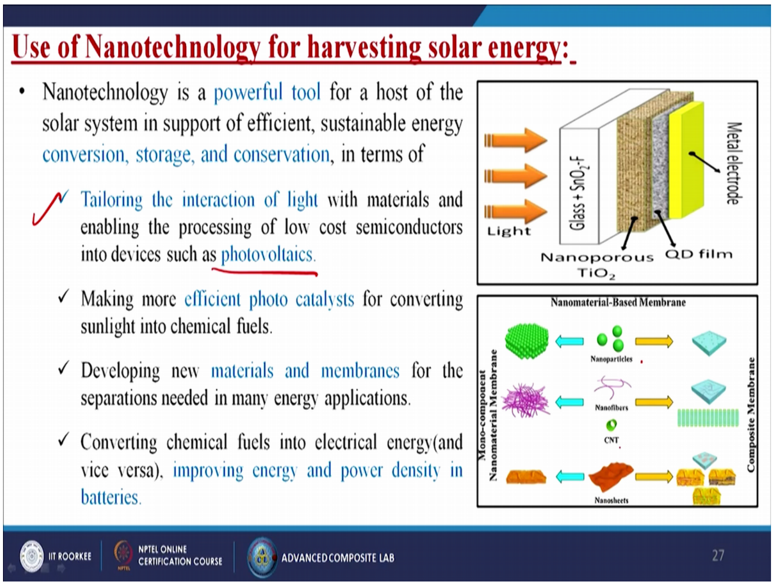

Next use of the nanotechnology for harvesting the solar energy. So, basically in the nanotechnology is a powerful tool for the host of solar system in support of efficient, sustainable energy conversion, storage and conservation in terms of tailoring the interaction of light with materials and enabling the processing of low cost semiconductors into device such as photovoltaics. Making more efficient photocatalyst for converting sunlight into chemical fuels. Developing new materials and membranes for the separation needed in many energy applications. Converting chemical fuels into electrical energy and of course, the vice versa one improving the energy and power density in batteries.

So, simple nanotechnology what does it mean? That means, we are dealing the technology with some nanomaterials. What is nanomaterials? It is nothing, but the 10 to the power minus 9 meter. So, automatically when I am using certain kind of light absorbing materials or maybe like any kind of electrode or maybe any kind of whole transport layer or maybe the electron transport layer that material basically we are making like a composites. So, in that composites we are using certain kind of filler materials which sizes into the nanometer range or maybe the nano scale.

So, basically nowadays the people are tending on to this because due to that high surface to volume ratio. So, nanomaterials is very good, it is having some outstanding properties. Basically, if we are able to nurture those materials into the nano levels and people are using like nanoparticles, nanofibers, carbon nanotubes, nanosheets, graphene, quantum dots. So, these all are the different types of examples from the nanotechnology point of view.

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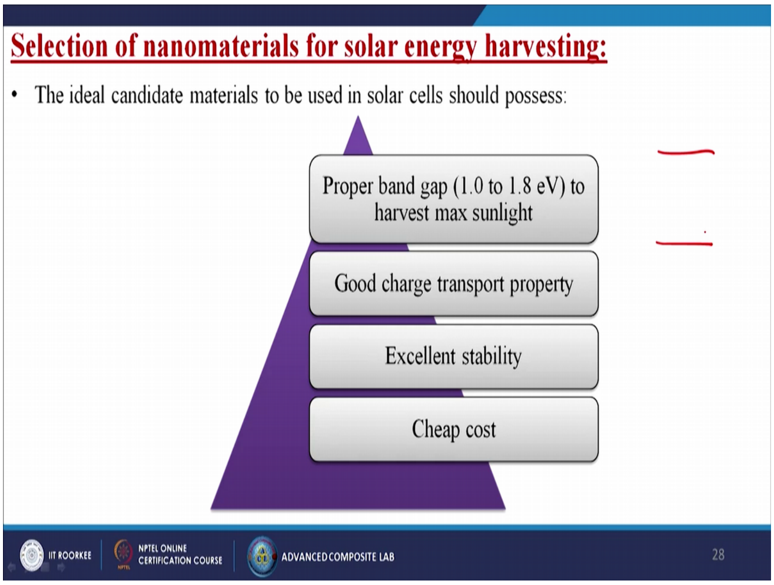

Next on which basis basically we are going to choose that whether this nanomaterials is good for the solar energy harvesting systems or not. So, the ideal candidate materials to be used in solar cell should possess proper band gap. So, basically 1.0 to 1.8 electron Volt to harvest the maximum sunlight. So, the gap should be like this so, that the electron can easily jump from one layer to another layer. So, valence band to conduction band, good charge transport property, excellence stability and the of course the cheap cost.

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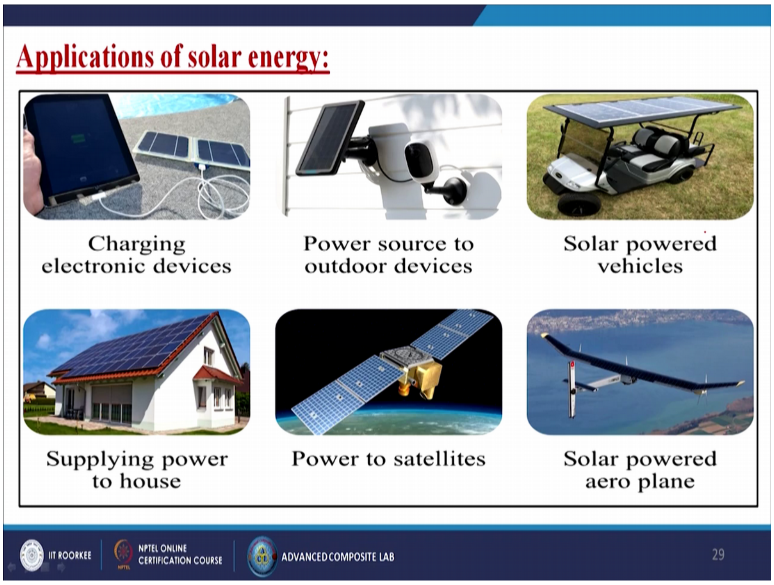

Now, there are several types of applications where nowadays we are using the solar energy directly or maybe the indirectly. So, charging of the electronic devices; now we can see that we are having the charger which is powered by the solar panel. So, directly the sunlight is coming, it is generating electricity through that we can charge our gadgets. We are having that supplying the power to the house. So, top roof basically we are putting the solar panels over there, we are having that power source to the outdoor devices, power to the satellites that is the best examples nowadays we are using.

Solar powered vehicles, solar powered aeroplane, but just think one that I have given only the six examples. But there are n number of examples are there by which basically we are using the solar energy, not only that we are using the solar energy to the automobiles to the ships, to the marines. Everyone nowadays we are using the solar energy directly so, that we can get the electricity at the time of scarcity. Now, we have come to the last slide of this particular lecture.

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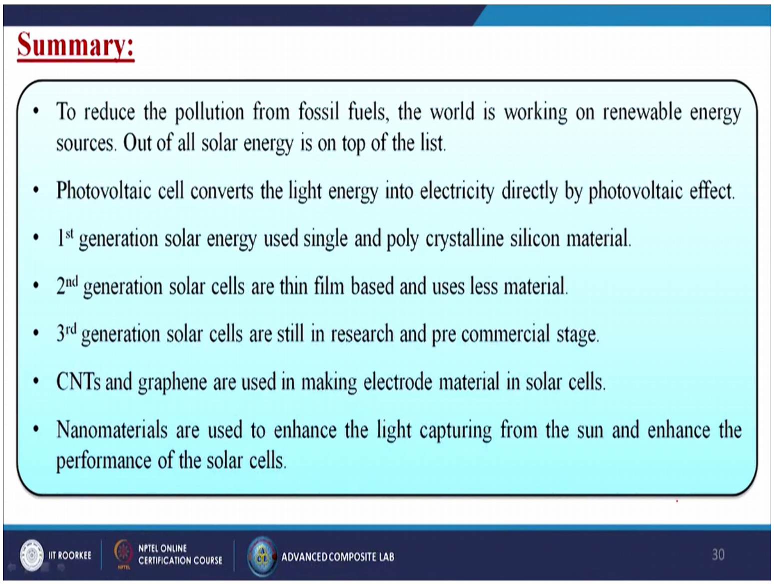

So, in summary we can say that to reduce the pollution from fossil fuels the world is working on renewable energy sources, out of all solar energy is on top of the list. So, basically what is happening? We are moving from fossil fuels and petroleum fuels to the renewable solar energy. Photovoltaic cell converts the light energy into electricity directly by the photoelectric effect. 1st generation solar cell energy used single and polycrystalline silicon material.

2nd generation solar cells are thin film based and uses less materials, means consumption of materials is less. 3rd generation solar cells are still in research and pre-commercial stage. Carbon nanotubes and graphene used in making electrodes in solar cells, also we are using the graphene quantum dots or maybe different types of quantum dots. Nanomaterials are used to enhance the light capturing from the sun and enhance the performance of the solar cells.

Thank you.