Physics of Renewable Energy Systems
Professor. Amreesh Chandra
Department of Physics
Indian Institute of Technology, Kharagpur
Lecture 4
Solar Photovoltaic Systems

Welcome again, to the course on Physics of Renewable Energy Systems. And in today's class, we will start with the topic, Solar Photovoltaic Systems.

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And in today's class, I will give you a brief introduction to the concept of photovoltaic. We will also introduce photovoltaic cells, what are the various types of solar cells and to make this technology a reality and ensure its large-scale integration, the importance of materials development will also be emphasised.

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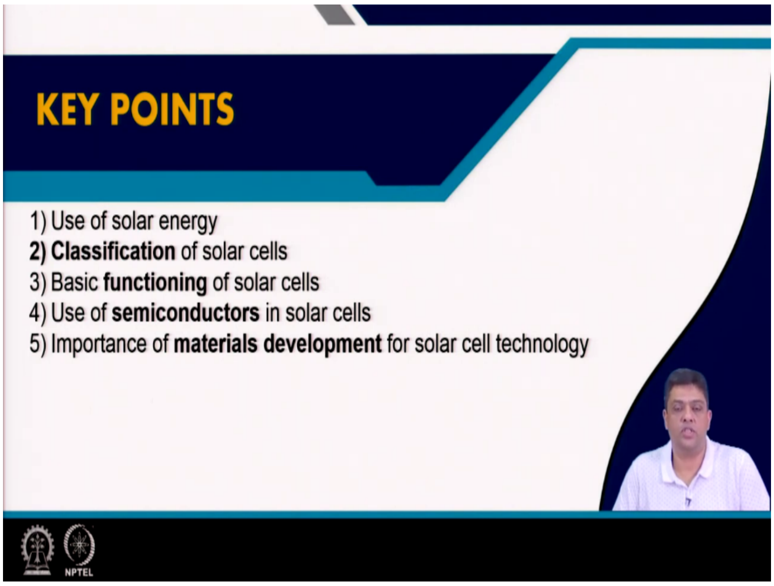

So, these are the key points, which we will cover in today's lecture. We will talk about the use of solar energy. We will start with the use of solar energy in solar cells. We will give you a classification scheme for various generation of solar cells. We will introduce the semiconductor based solar cell and also explain its functioning. And will re-emphasise the importance of materials development for next generation solar cell technology.

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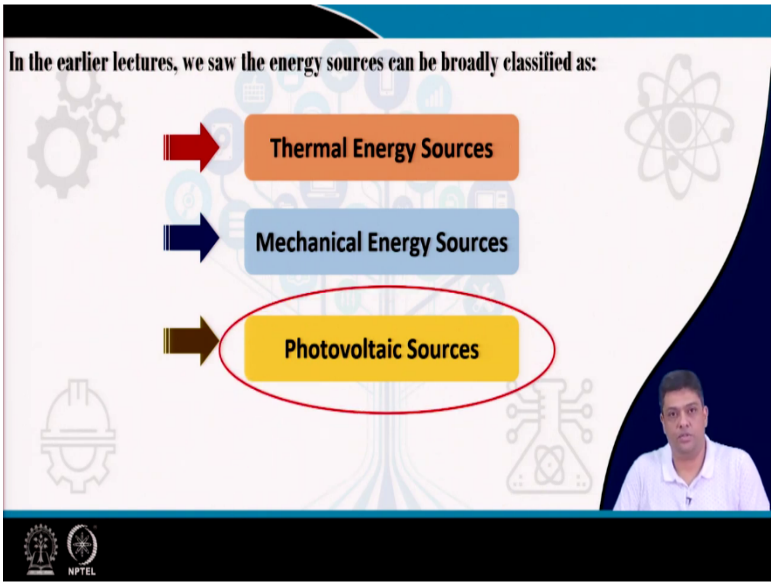

In the earlier lectures, we have seen that energy sources can be broadly classified as thermal energy sources, mechanical energy sources, or photovoltaic energy sources. But for our country, we are quite interested to talk about photovoltaic sources and therefore, let us start our discussion on photovoltaics sources.

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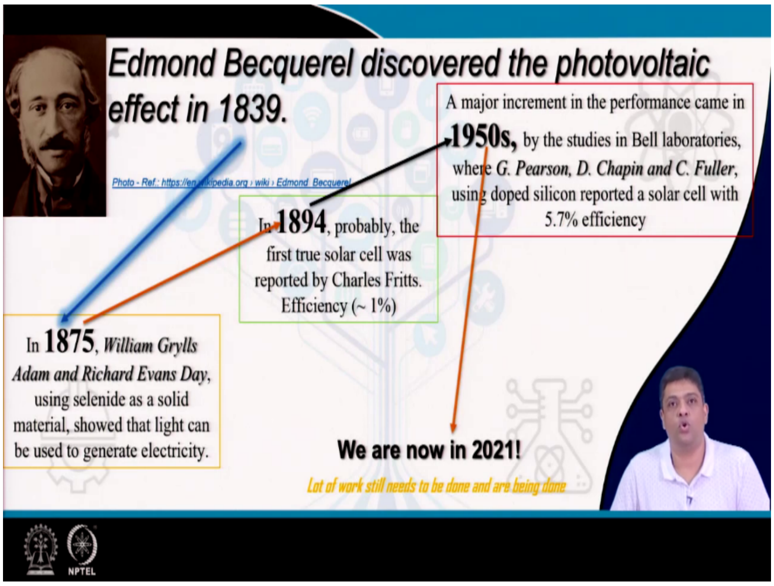

The discovery of photovoltaic effect is not new. It was actually discovered in 1839 by Edmond Becquerel. Following this discovery, it was in 1875 that Grylls and Evans using selenide as the solid active material, showed that light can be used to generate electricity. And it is believed that the first true solar cell was reported by Fritts, in 1894 which had an efficiency of approximately one percent and then people went on working.

A major increment in the performance came in 1950s by the studies that were being performed in Bell Laboratories. And in 1950s, Pearson, Chapin and Fuller using doped silicon reported a solar cell with an efficiency of approximately 5.7 percent. So, from 1894 to 1950s, there was an increment from 1 percent to 5.7 percent in terms of efficiency. So, we see in 1950s, we have reached an efficiency of 5.7 percent.

We are now in 2021. And a lot of work still needs to be done and is being done and still we have reached the values of efficiency in the range of 20 to 30 percent only. So, lot of interest still remains in the field of solar photovoltaics.

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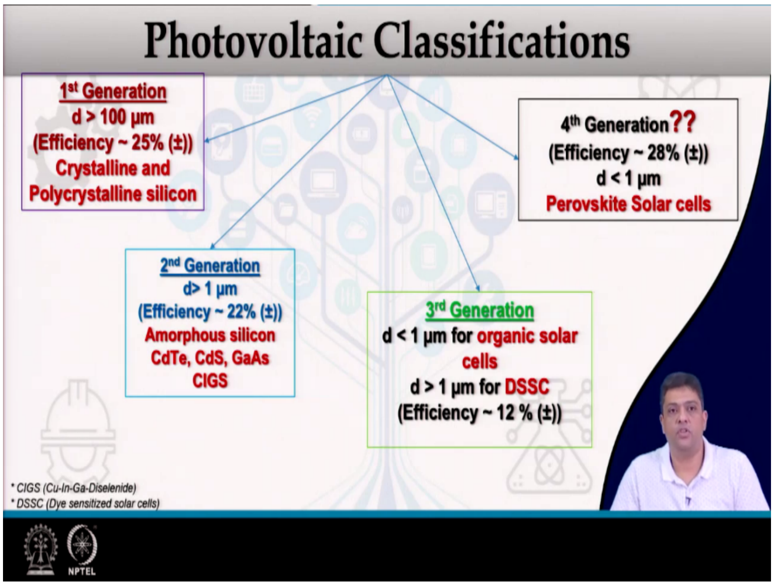

So, photovoltaic cell can actually be classified into some sub headings. The first-generation photovoltaic cells or solar cells are considered the ones which are fabricated using crystalline or polycrystalline silicon, they have a thickness of more than 100 micrometre and efficiency for such kind of solar cells are in the range of 25 percent plus minus. If you see everywhere, I am writing this value of plus minus, because it is the whole area is still evolving.

There are new results coming out and you can find literature that, which may quote slightly higher values or if you go to some other literature then it may actually quote some lower value. So, this is a rough value which I have mentioned, which is typically reported in literature. The second-generation photovoltaic cells, they are the ones which have a thickness of more than 1 micrometre, efficiencies are in the range of 22 percent and they are basically fabricated using amorphous silicon, cadmium telluride, cadmium sulphide, gallium arsenide or copper indium gallium diselenides.

The third generation were the ones which were fabricated using organic materials, they had a thickness of 1 micrometre or less and dye-sensitized solar cells are also classified under the heading of third generation solar cells and they have a thickness of more than 1 micrometre but the efficiencies on such kind of solar cells continued to be approximately 12 percent. And probably there is a new player in the market that is perovskite based solar cells.

Their efficiencies are already reaching 28 percent, some researchers don’t call them as fourth generation they club it with third generation or so, some call it at fourth generation. But, for our course, we will believe that there is another set of solar cells which are based on perovskite materials and they have an efficiency of 28 percent as of today. Let us try to understand photovoltaic effect by revisiting and phenomena which was taught to us during our bachelor's or even school days and that is photoelectric effect.

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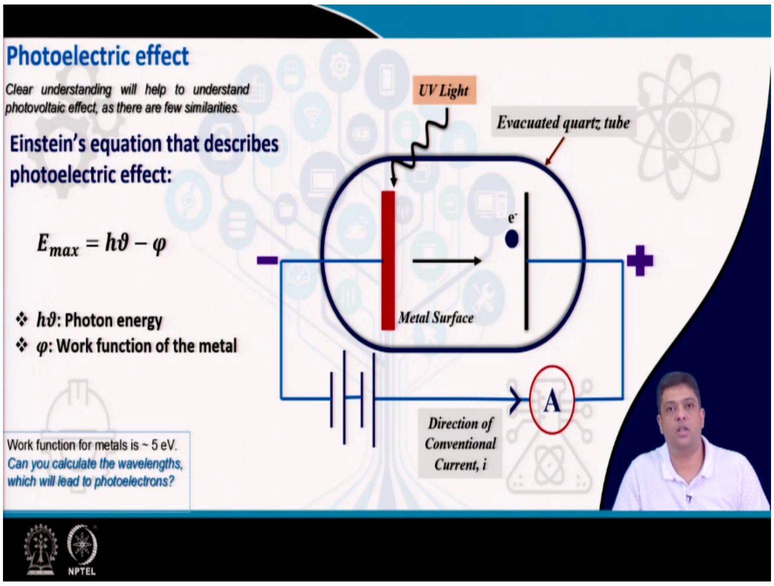

Photoelectric effect, Einstein discovered this photoelectric effect and how is it explained you have a metal surface, you have a counter electrode, which is now placed in an evacuated quartz tube which is by now these 2 electrodes are biased. And if a UV light falls on this metal surface, which is able to give photo electrons, then electrons which are called as photo electrons, that is photon induced electrons these are emitted and they move from the metal surface towards the other electrode which is suitably biased.

And the maximum energy which can be obtained is hv minus phi, where phi defines the work function of the metal. So, the energy of the UV light should be more than the work function of the metal and there are only you will see the emission of photoelectrons. And typically, the work function for metals is approximately in 5 electron volts, let us say. Can you calculate the wavelengths which will lead to photo electrons?

So, this will, this problem will make you revise your previous understanding of photoelectric effect and that will become useful while we understand the photovoltaic effects. And please remember that the direction of the conventional current is in the direction of the arrow which is given in the figure.

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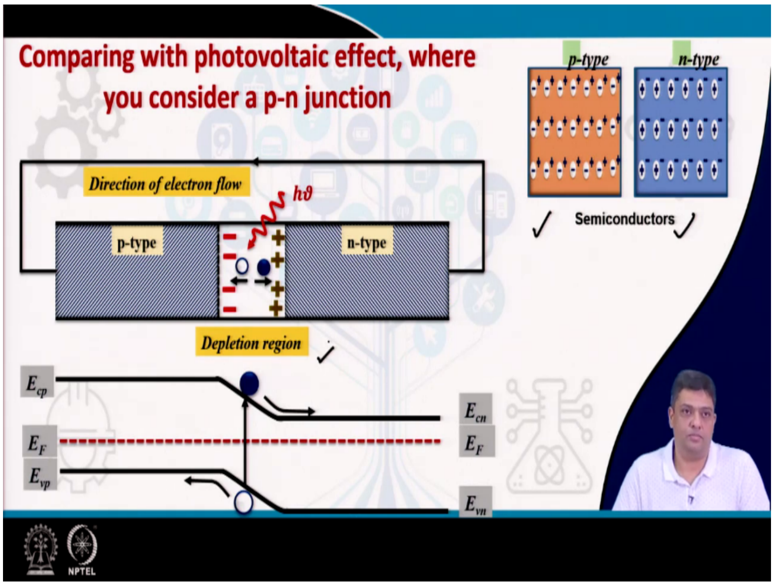

So, now, let us compare photovoltaic effect with photoelectric effect. Here in photovoltaic effect, we use p and n type semiconductors. We form a junction of p-n type. So, when you have a p type semiconductor, n type semiconductor and if there is a junction which is formed you form a depletion layer, the details will be explained bit later. Then what happens, you have the hole and electron recombination and you form a depletion layer. And if you, then ensure that the electromagnetic radiations actually fall on this depletion region, what happens? let us see.

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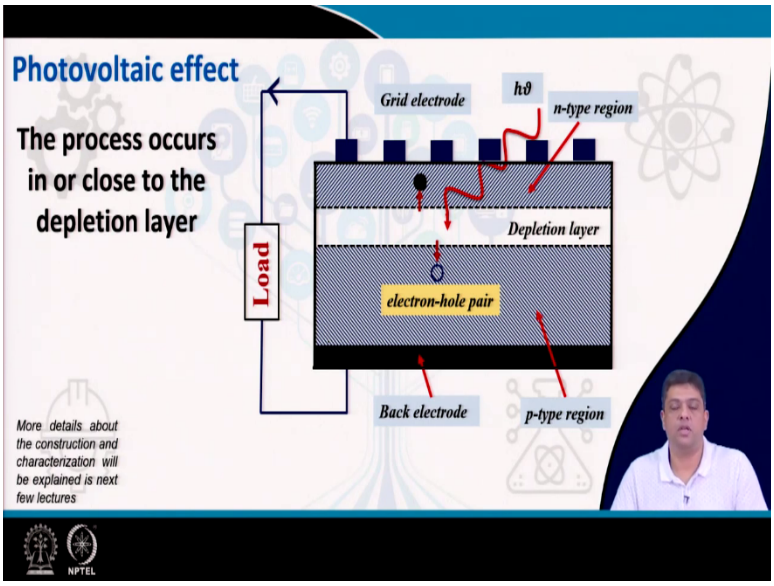

So, photovoltaic effect is a process which occurs in or close to depletion layer. So, let us see the typical solar cell the detail construction will follow. So, you have a back electrode, you have p type region, then you have the n type region, and because of this you form a depletion layer. Now, to extract the electrons which are going to become available in n type region, you coat the top surface with grid type electrode.

The details will follow. We will explain each and every term bit later. Now, if you have an external load and if the electrons are available, then there will be a flow of current from the grid electrode to the back electrode and in the p type region you will have a recombination of holes and electrons. So, let us see what happens if you have the electromagnetic radiation which is falling on depletion layer.

And if the energy is suitable enough, then you will break these charges again into electron and holes. And because of the internal field electrons will move towards the n type region, holes will move towards the p type region, and what you will get this electron which is available in the n type region is now free and if you can extract it by connecting it to an external load then you will have a current which is flowing and that leads to the generation of photo current.

So, you have the incident radiation, the breaking of electron hole pair, the electron goes into the n type, hole comes into the p type region, and then electron flows through the external load, and then recombines in the p type region.

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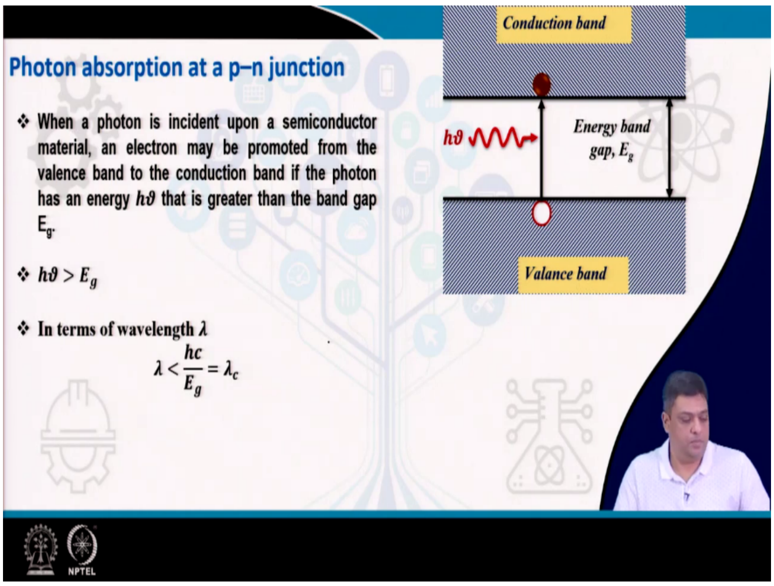

So, you can see that when there is a photon which is absorbed then what can happen, an electron may be promoted from the valence band to the conduction band if the energy hν is greater than the band gap. So, you will have electron jumping from valence band to conduction band and leaving behind an effective positive charge that is your hole. This will only happen if hν is greater than E_g. And in terms of wavelength, you will find that lambda should be less than hc/E_g and that is called as lambda c.

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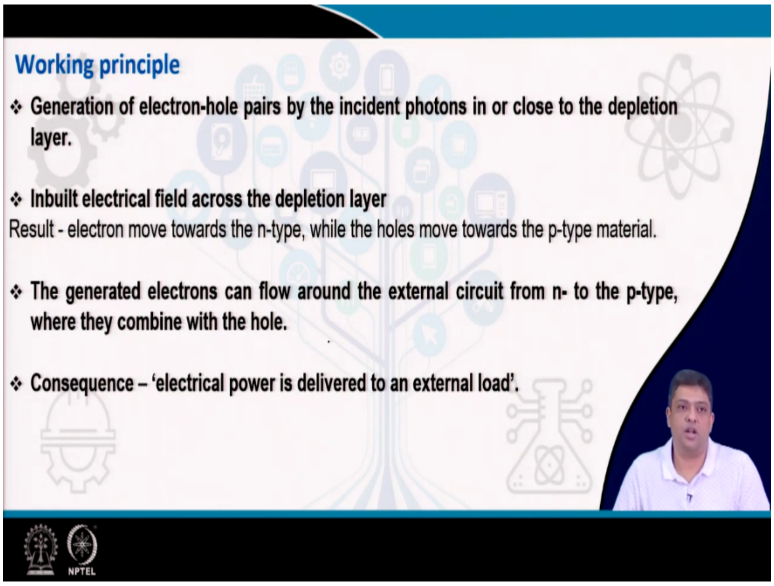

So, what is the working principle, if we repeat, you have a generation of electron hole pairs by the incident photons in or close to the depletion region. So, it is critical that to understand that you must ensure that the light falls on the depletion region. Because of the inbuilt electrical field across this depletion region, electron moves to n type, hole moves towards the p type material, for all layer.

The generated electron can now flow from the external circuit and then from the back electrode go back into p type region, where they recombine with hole and attain a charge neutral condition. And what is the consequence, electric power is delivered to an external load.

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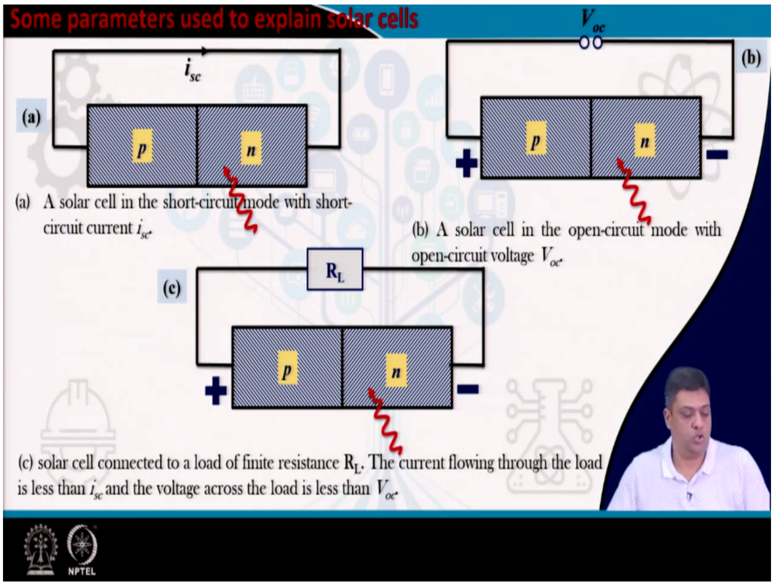

So, some of the parameters use to explain the solar cells are, the short circuit current I_{sc}, this is measured when solar cell is in the short circuit mode. The open circuit mode leads to the generation of the value of open circuit voltage V_{oc} and if I connect the solar cell to an external load, then the current which flows through this load is less than I_{sc} and you can measure the voltage across this resistance and you will find that this value will be less than V_{oc}. So, these are the terms which are routinely used in explaining solar cells.

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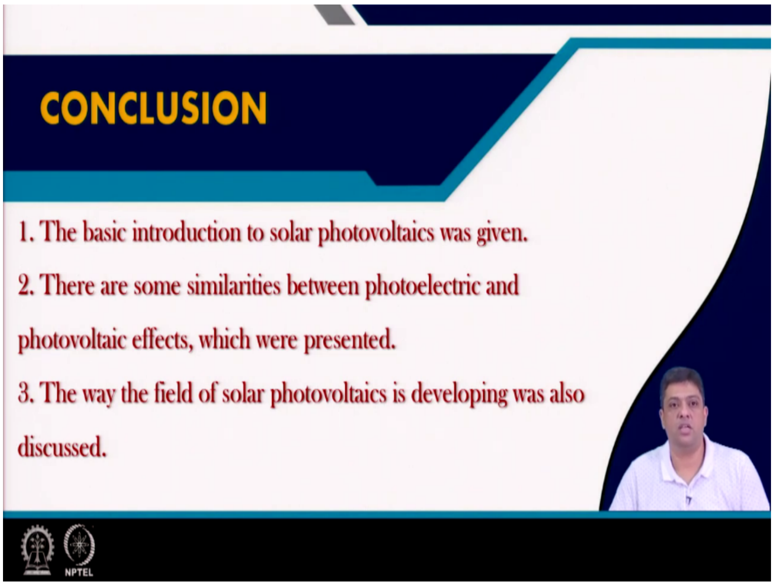

So, hopefully in today's class you have understood the basics of solar photovoltaics. There are some similarities between photoelectric and photovoltaic effects. And the way the field of solar photovoltaics is developing or the classification was also introduced. And you will understand if you go back to that slide, that the classification of solar cell is actually related directly to the materials which are being used.

So, as we move from one type of materials to the other, the performance varies significantly. The better is the quality of the material which is utilised higher is the performance and that is why materials development is absolutely essential for developing next generation, solar photovoltaic and the devices using solar as the source.

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These are the references which were followed in today's lecture. And I thank you for your attention in today's class. And in the next class we will give you the basics of semiconductors which are critical for understanding the field of photovoltaics. We will also talk about the construction of solar cells and the way we characterise these solar cells. Thank you very much.