Fundamentals of Semiconductor Devices

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Lecture - 44
Solar Cell Basics

Welcome back. So, if you recall we have finished up the compound semiconductor portion of the syllabus. In the last class, we have discussed about three nitride semiconductors, introduced the concepts of polarization, how the material is polar gallium nitride and its alloys. And, you know we can make this LED based on gallium nitride and indium gallium nitride sort of materials, continued band gap you can emit in blue and green which is very difficult to achieve in other conventional semiconductor. And, that is the white LED that has been made possible by the blue LED and you know converting it by phosphor coating.

Green LED and green laser diodes are also very active areas of research and then I finally, told you about a transistors. High electron mobility transistors based on gallium nitride. If you recall we do not have to dope this materials, the inbuilt polarization in the materials assists in generating the very high density of electron gas that can be used for lot of applications like high speed RF as well as power electronics. So, those are some basic you know familiarities or you know basic awareness we should have about tri nitride semiconductors because these are very big you know chunk of compound semiconductor industry now.

So, today we shall start with the optoelectronic devices. So, we have a few lectures lined up, today we shall start with Solar Cell and maybe in a couple of lectures we will finish solar cells and photo detectors and then another couple of lectures on LEDs. So, those will be essentially towards the end of this course now. So, we will come to the white board.

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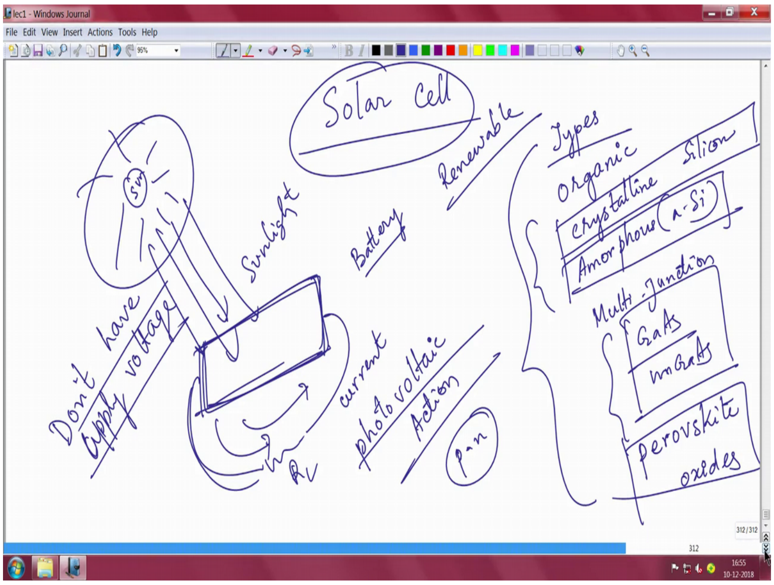

So, I will introduce with solar cell today, you already know how solar cells work an irrespective of other this optoelectronic devices are a part of your different entrance exam like NAT, GATE or other things it is important that you should be basic you know you should have the basic knowledge and awareness about the design, about the types of working of this optoelectronic devices.

So, solar cells are everywhere now, the power industry is heavily dependent on solar cell. There are many kinds of solar cell, many types of solar cell or of course, there is organic solar cells those are used for you know flexible sort of a area displays and other things.

You might use organic solar cell, you have conventional crystalline silicon solar cell right. Silicon can be used as a solar cell and crystalline silicon solar cell and then there could be amorphous silicon solar cell right. It is called a-silicon this will be cheaper, but of course, as not as high performance as crystal and silicon solar cells. There could be multi junctions; multi junction solar cell based on you know gallium arsenide, indium gallium arsenide and so on right. Hetero junctions also there solar cells, there are also solar cells on other materials you know that that are not exactly silicon or this compound semiconductor. There could be other materials that might be use an one area is perovskite solar cell which is very upcoming.

These are perovskite oxides solar cell, essentially in a solar cell you have the sun know, you have the sun. So, sun light should fall on some area some device ok, sunlight should fall and what you should get is that you should be able to get if you connect a load at load you should be able to get current. You shine light, you expose it to sun light and you should be able to get current that is called that is the basic photovoltaic action is called photo voltaic action. And, this photovoltaic action results in this solar cell behaviour, you are shining light and your getting electricity out of it, that electricity can be used to drive your you know TV or you know charge up your phones and whatever you know light bulbs and all.

So, solar cell is a source of power, it is like a battery almost you can say in that it supplies electricity except that you cannot store energy per say it is a source of energy, but the light has the sun has to be shining. If the sun does not shine then you cannot get electricity all the light, you know you have to store the energy separately in a battery that is a different thing. But, solar cell behaves like a battery in the sense it gives you electricity without any bias voltage, you do not have to apply any voltage. Of course, you do not have to apply any voltage right because, if you apply voltage and get electricity then how is it a solar cell. Then it defeats the purpose of being a battery or being a you know source of energy.

So, you can you probably know that in India the government is also investing a lot and having many of the solar plants and solar cell is becoming a very big thing now. Soon we will be moving to solar energy that will give us electricity in our houses, it is already giving by the way not at the whole scale of the country, but it will give. So, you know dominantly we get electricity from the hydroelectric power plant the coal thermal primarily coal based energy, but those are fossil fuels that lead to depletion of resources as well as those are non-renewable energy that gives you also lot of carbon dioxide emission, a lot of pollution, lot of issues. So, this solar energy is green energy, it is a renewable you know energy because in the sense that solar energy does not die out right.

It is like an infinite source of energy, it is again it does not lead to pollution like carbon dioxide you know emission and other things when you burn coal or petrol or other thing. So, it is a very awesome form energy except that that you know it was little costly, but now the costs are coming down. In many countries like Germany and European countries you can see that solar cell is a big industry, India will also become a very big solar cell user. Already there are solar cell plants in the country and they provide electricity to many areas of the country by the way, I forgot the number exactly right. So, solar cell is on another 5 or 10 years you will see that more and more houses, industries, buildings, you know classrooms everything will be lit by solar energy electricity; you get electricity out of the solar energy ok so that much you know.

So, if you have done a course on semiconductor, if you are doing this course on semiconductor devices here in NPTEL you should be aware of how solar cell basically works ok. You do not have to understand all this type of solar cell working, but basic solar cell is a p-n junction and you know a p-n junction working very well. But, there are certain aspects related to a p-n junction which are used in solar cell that you should be aware of.

And, some figures of merit how do you qualify a solar cell, how do you compare a solar cell the very basic you should know. So, that if someone ask you, you should be able to tell that is what the motto is. So, sun's energy of course, is very vast and solar cell is not only about a p-n junction, but also about the energy that the sun gives us right.

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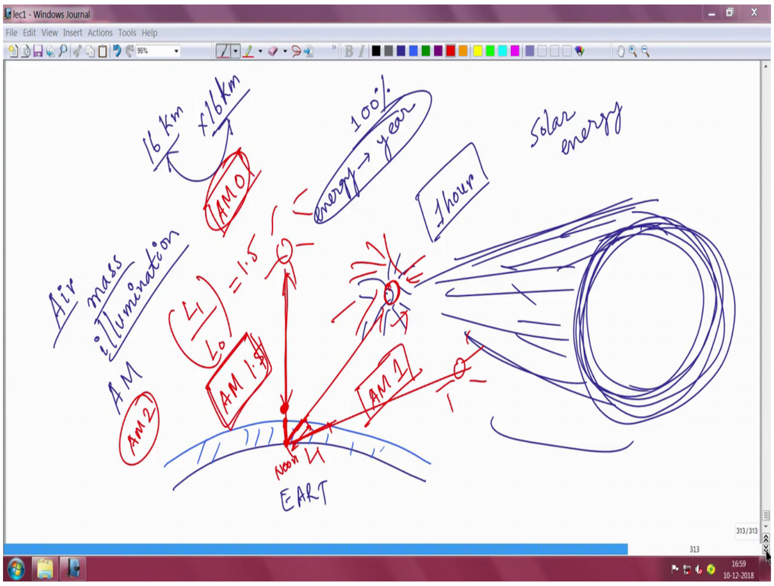

So, I not able to recall the exact number but the solar energy is so much solar energy falls on earth that you know if you have the earth here and the sun is shining here. If you are able to take all the energy it falls on the earth, all the sun light that falls on the earth. Here if you are able to take all this energy you know what ever energy is there you convert everything into electricity then not even electricity energy. Then you should be able to meet 100 percent of the energy requirement of the world in a year. The 100 percent of the energy required by the whole world in a year can be you know can be harnessed by just I think it is 1 hour of sunlight or 1 day of sunlight, 1 hour probably ok.

In 1 hour sunlight, if the whole world, if the whole world's energy you know that it falls on the world can be captured then you can generate electricity or energy that will cater to almost the whole of civilisation, but the problem is we cannot put a blanket of solar cell around the earth. So, we only capture a very small fraction in the efficiency also is very low, very very small area of the earth is covered ok, very small area of the earth is covered. And, there are calculations to show that I think 16 kilometre by 16 kilometre area if you have of solar panel on the in India you can cover probably I think yearly electricity needs of the country. Solar energy so much solar energy is so much.

So, that is great energy. So, it is a large amount of energy that we have to harness and solar cell is basically the device that converts a sunlight to your electricity ok. So, before we come to the working of how's p-n junction works as a solar cell you of course, know that when you shine like you will generate carriers and you will get electricity. But, let us have some basic ideas about you know solar energy for example, what is the solar energy that falls on the earth. So, in that context there is something call air mass illumination ok, air mass illumination. What is air mass illumination? It is sort of a spectra of sunlight that you use in different convention it is called AM.

So, I will tell you suppose this is your earth this is your earth and of course, you have an atmosphere; atmosphere is almost same thickness you assume and suppose now you have a sun here overhead in the noon time, this is a sun. So, when it comes directly like this ok, on the surface of the earth it has to cover some distance in the atmosphere know you take this distance as suppose L naught. So, this is noon and if suppose in the afternoon 3 PM or 4 PM the sun will come like this right, sun will come like that sun light will come like that. So, this path length that this travels in the atmosphere has now increased to L 1. So, this L naught by L 1 ratio that is the air mass illumination you tell.

[FL] What is the path length through the atmosphere the sun light has to travel compared to the path length at noon time because, at noon time the path length is the minimum right. So, for example, if at evening the path length is travelling is 1.5 times the path length at noon then you call the 1.5. So, the solar spectra in the evening will be called one point AM 1.5 air mass illumination 1.5. At noon at noon because it is 1 only 1 is to 1, at noon you will call it air mass 1. Of course, this exact nature of the spectra although it is very similar everywhere, there might be differences depending on the local climatic conditions cloud covers and all other things right. So, at almost very at that near to sunset you will have larger path length.

So, you will call it AM something like 2 or something and then you know your intensity will also come down and so on. Above the atmosphere if you are here, if you are now above the atmosphere like a satellite above the atmosphere the sunlight will come directly without any atmospheric interference and then you call it AM 0 air mass illumination 0. What are these actually physically mean? This air mass will actually mean the spectra I will tell you why.

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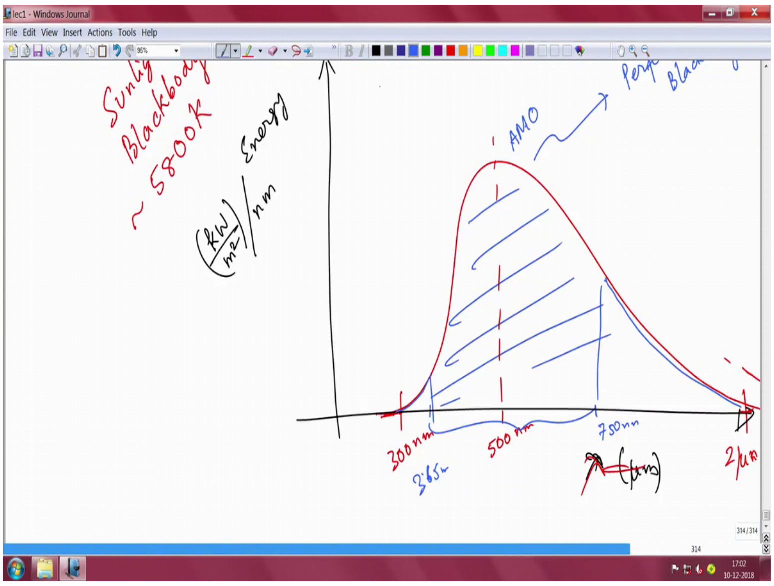

So, essentially sunlight the sunlight is a black body right, it is a black body radiation. The black body is at a temperature approximately 5800 Kelvin ok. So, you know, if you plot this is the energy of the sun that emits as you receive on the earth and this is your wavelength; you can say wavelength in micron or nanometre whatever you say ok.

So, this is energy what is the unit you know, it is actually power kilo Watt per metre square. So, every 1 metre by 1 metre area how much energy you receive per nanometre of wave length of light because, it is the density spectral density. So, you see it will basically have a plot like this you know it is a black body right. So, it will fall like this ok, it will come down very very well.

So, it will come like this ok, the spectral the power this is the energy of the sun per unit area per unit wave length. And, this will be around 500 nanometre of wave length, the peak will come this is lambda (Refer Time: 11:58) nanometre. And, I think here around you know around 300 nanometre or below the sunlight is almost nothing there is nothing ok.

At around 300 nanometre it will come up rise then of course, this will be around 2 micron or 2000 nanometre which is (Refer Time: 12:14). So, it also has some wave lengths in the (Refer Time: 12:15), your human eye is visible in this range know around 365 sorry around 365 nanometre to around 750 nanometre. Your human eye is sensitive, this is the sensitive area of the human eye, but sunlight emits slightly below the human visibility that is UV you know.

And, also sunlight has quite a large not quite a large, but there is also a important fraction of area energy beyond the in the infrared and that is the thing. So, this is sunlight's energy and this is the perfect black body for example, this is a perfect you know black body; you can Google search of course, black body radiation of sun. This is a perfect black body and this is outside the atmosphere I can call it AM. This spectra will be call AM 0; that means, air mass illumination 0 which means I do not have atmospheric interference.

So, I am measuring this outside the atmosphere, but the moment I come to atmosphere what will happen? Moment I come below come inside the atmosphere on the surface of the earth where, we live there suppose I talk about noon. So, AM 1 or AM 1.5 will be in the afternoon or evening what will happen in that case? What will happen in that case is that let me erase the excuse me, let me erase this part. So, what will happen is that when you come below the; when you come below the atmosphere when you are when you living there then of course, this intensity will fall down this intensity will fall down.

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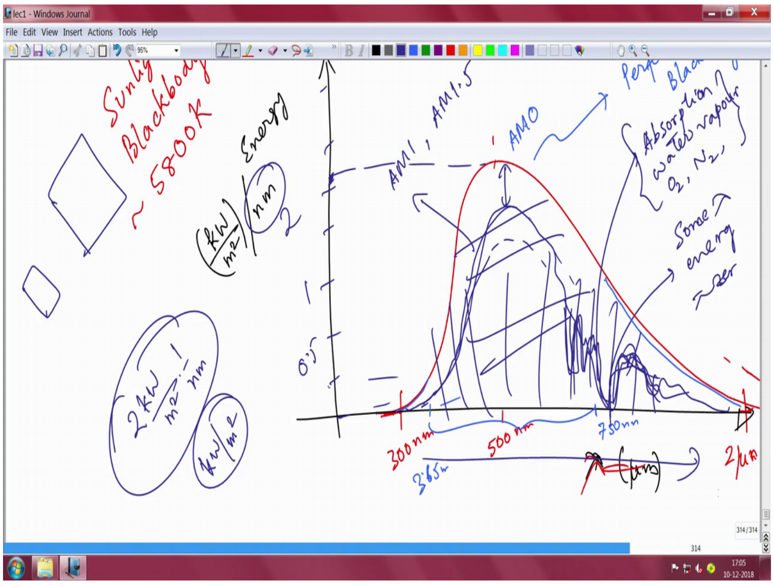

Because the atmosphere is absorbed know and also there will be some peaks that you will see like this. I am not drawing the exact location of the peaks, but you will be able to see some peaks, like the some peaks will come here ok.

Some dips will come in some wave lengths some wave lengths the sunlight will have some lambda, it will energy will be almost 0 ok. Energy will dip, you know in the black body there is no dip, but in after atmosphere there will be some dips and peaks here, those correspond to absorption. Those correspond to absorption of the sunlight by certain things like water vapour, in the atmosphere in the atmosphere water vapour will absorb something.

There might be absorptions from oxygen, absorption from nitrogen and so on and so forth right, their gases that will absorb. So, all this absorption happen in water in the atmosphere and a fixed you know at the fixed wavelength these water vapour or oxygen will absorb. And so, and those fixed wavelengths there will be some dip ok. So, black body pattern is still follow loosely, but you know the intensity has come down ok.

And, you will have some dips and peaks because those are the wavelengths at which the atmosphere will absorbs the sunlight that is why you do not reach them. So, that is for example, this will be now AM 1 or AM 1.5, AM 1.5 will be even lower probably slightly lower in magnitude. Because, your sunlight has to travel a longer distance in the evening intensity will come down, noon intensity will be high.

So, AM 1 will be higher, but AM 0 will be the highest because it is outside the atmosphere know. So, this is what is meant by air mass illumination thing [FL] and what is the y axis here, you know this is energy I told you what is the what are the typical values. So, the peak value is typically around 2. So, 2 kilo watt per metre square per nanometre, you know then 1 you know 0.5 and so on right.

So, this 2 kilowatt at the peak you probably get around 2 kilo watt metre square per nanometre. Of course, the if you can integrate the whole area, if you integrate the whole area under this you will get you know this nanometre will go away because, you are integrating with respect to this wavelength.

So, essentially you will get the energy in kilowatt per metre square of course, it depends on the area; if you have a 1 by 1 centimetre or a 1 by 1 metre area you know electricity will be energy will be more the more the area energy will be more. So, anyways the peak intensities on 2 kilo Watt per metre square per nanometre ok. This is your sunlight spectra and this is what you harness.

Now, the question is semiconductors are used for harnessing this energy, for absorbing this energy and converting it into electricity that is what we have to do. So now, a simple question is you might have to think about it maybe you can answer it in the end; I will keep drawing this now and then ok.

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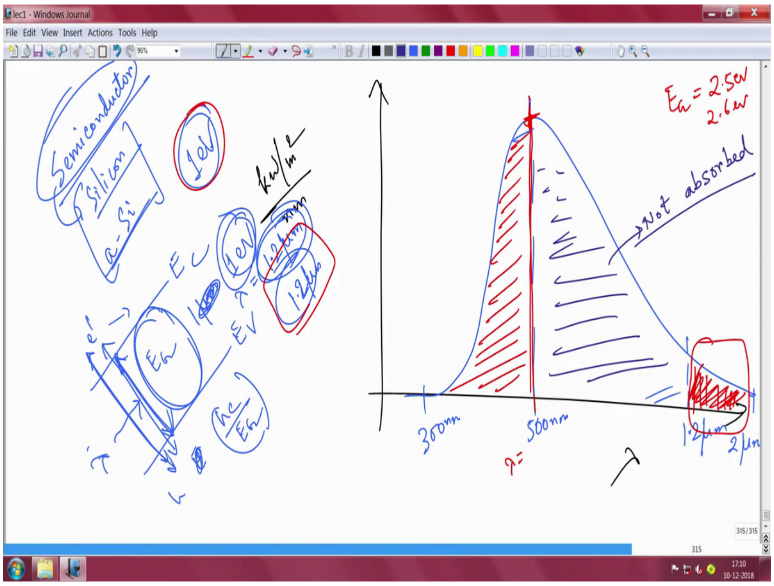

So, this is the solar mass spectra solar spectra nanometre. So, I told you that this is kilo Watt per metre square per nanometre and I told you that this will go something like this. So, here may be around 2 micron, the peak will be around 500 nanometre slightly to the right may be 510 nanometre or so.

This will be around 300 nanometre and so on. So, the thing is a semiconductor whatever semiconductor you use and of course, predominantly we use silicon because, silicon is very cheap. Silicon is integrable to all CMOS, all electronics is silicon based mostly. So, if you mix something in silicon it is easy to integrate, easy to scale up, easy to commercialize in a large scale. If you make an a very exotic perovskite solar cell and all then the large scale manufacturability integration it industry and all these things become tricky.

So, there is always a cost aspect, there is always a cost aspect and silicon always wins in the cost aspect. So, silicon if its silicon if silicon works as a solar cell we will use silicon of course, silicon works as a solar cell and the good thing is that silicon actually works as a very good solar cell. You will see that silicon's efficiency can be very high compared to you know it is it can be almost you know it is not bad actually it is very high.

We will see that I will not tell the number right now, but so silicon will be predominantly used as a solar cell. But, crystalline silicon that you know I am talking about crystalline silicon like what you have band gap where you have this you know crystalline, if a you grow with perovskite method or so.

The crystinalls crystalline solica silicon solar cells will have slightly better efficiency, but it is a little bit costly I mean it is cheap, but it is little costly compared to amorphous silicon that I call A-silicon. Amorphous silicon is that is non-crystalline silicon is amorphous is cheaper and you know wide scale you can use, although efficiency will be little low ok.

We will tell is efficiency numbers subsequently right now we are just introducing these things. So, silicon is widely used of course, different application you can also use organic solar cells and different other kinds of solar cells that are used ok. But, silicon is also very widely uses, silicon solar cells extremely you know common.

So, you will use a semiconductor eventually as a solar cell and semiconductor has a band gap if you recall, you have a conduction band, you have a valence band ok. And, suppose this energy is easy the wavelength of light that we will be absorbed is h c by E G. This is the wavelength of light that will be absorbed and a photon, a photon whose energy is more than this also will be absorbed, but may not be very efficient in giving the electricity out.

Of that the most f I you know the most sensitive photons will be the ones that are corresponding to bandage. But, photons that are observed above this also will be absorbed and they may not necessarily give you electricity by the way because this photons are absorbed to higher energies.

So, this electron whole pairs that are generated you know they might thermalize and may not give you those things will come ok. And, photons whose energy is lower that this band gap which means suppose this band gap is suppose I am telling you 1 micron and the lambda corresponding to 1 on fourth non sorry.

The band gap is suppose 1 electron volt which is close to silicon band gap, the lambda corresponding to that will be around 1.2 micron 1.2 micron. So, essentially all the energy photon energy whose energy is more than 1 electron volt will be absorbed. In other words, all the photons whose wave length is lower than 1.2 micron, lower than 1.2 micron ok; suppose this is 1.2 micron.

So, all the wave length all the photons of wavelength less than 1.2 micron will be actually absorbed in the solar cell, will be actually absorbed in a solar cell [FL]. So, it means the energy is higher than 1 electron volt, the energy is higher than 1 electron volt which is the same as saying the wavelength is lower than 1.2 micron will be absorbed.

And, most of these could contribute to electricity, may not all of them may not contribute, but most of them will contribute to electricity which means all the wavelengths all the photons of sunlight whose wavelength is more than 1.2 micron or energy is less than 1 electron volt which is this; this will not be absorbed. So, those part is wasted those part is wasted those are useless.

So, for example, if I use a material of band gap you know around 2.4 or 2.5 E V for example, or 2.6 E V which is very large then you will have a wavelength of around 500 nanometre which means it is the peak here. I understand this is the peak here, but the problem is that I can only absorb this. All the photons that have this energy will be absorbed and contribute to electricity, the rest the rest this part this part is actually wasted because, these are not even absorbed in the material, these are not even absorbed in the material so, those are wasted. So, what does it mean? It means that to harness most than more and more of sun’s energy, I need a semiconductor I need a semiconductor such that you know sorry I need a semiconductor ok.

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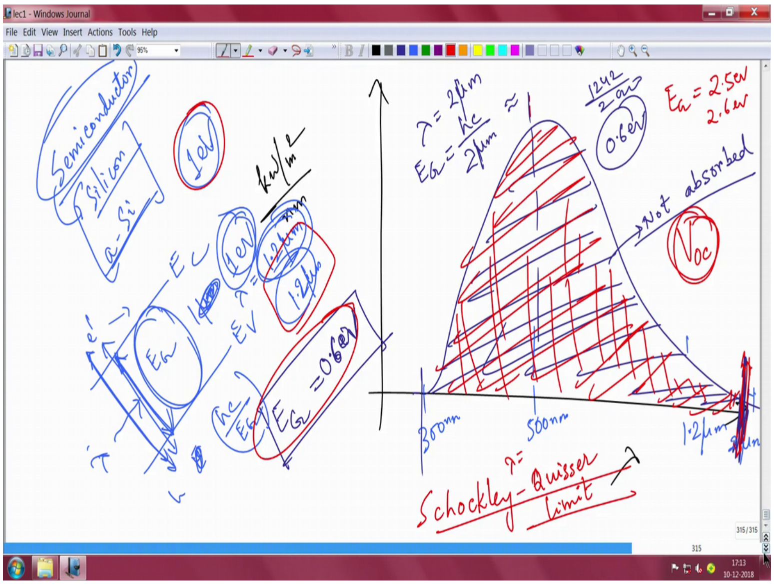

I need a semiconductor which has which can absorb everything right, I need a semiconductor which can absorb everything from 300 nanometre to right up to 2 micron. What does it mean? That means, I need a semiconductor whose wavelength the will correspond to around 2 micron or in other words the band gap has to be very small. It will be h c by 2 micron that will correspond to very small band gap, it will be like 1242 by 2000. So, around 0.6 E V which means if I use a semiconductor with a band gap of 0.6 E V which is much lower than silicon may be germanium or even lower than germanium.

If I use a semiconductor of energy band gap 0.6 E V then that will correspond to here right, that will correspond to here which means it will absorb everything; it will absorb everything here. So, that should be the best to harness the solar energy right, but actually it is wrong. It is wrong because, there are two things that will come you know subsequently in the chapter. It is not necessary only necessary that you absorb everything that is there in the solar spectra, then you can use a wide small band gap material. But, there is something called open circuit voltage we will come to that.

So, you know it is not very off it is it seems obvious that you know if I use a very narrow band gap semiconductor I will be able to get all the suns spectra will be absorbed. But, the problem is there is something called open circuit voltage and that open circuit voltage is a they say that is a measure of how much you know voltage you can drop across your load, when you are using a solar cell.

And, you want that voltage to drop is large then only you will be able to draw higher power and get better efficiency. If you use a narrow band gap semiconductor your open circuit voltage actually suffers so, your efficiency comes down. There is some very beautiful trade off ok, it is called Schockley-Quisser limit ok, Schockley Quisser limit.

And, that something we have to discuss in one of this lectures now; you cannot arbitrarily have a small band gap material it will not lead to an efficient solar cell that is what is meant ok. So, those are design things will come to their. Now, but you know the basic thing is that you want to harness the solar energy that is there you want semiconductor and semiconductors are band gap. So, band gap means that you can only absorb light of a particular wavelength or wavelength lower than that, you cannot absorb wavelength light more than that. So, this is the basic idea of a solar cell.

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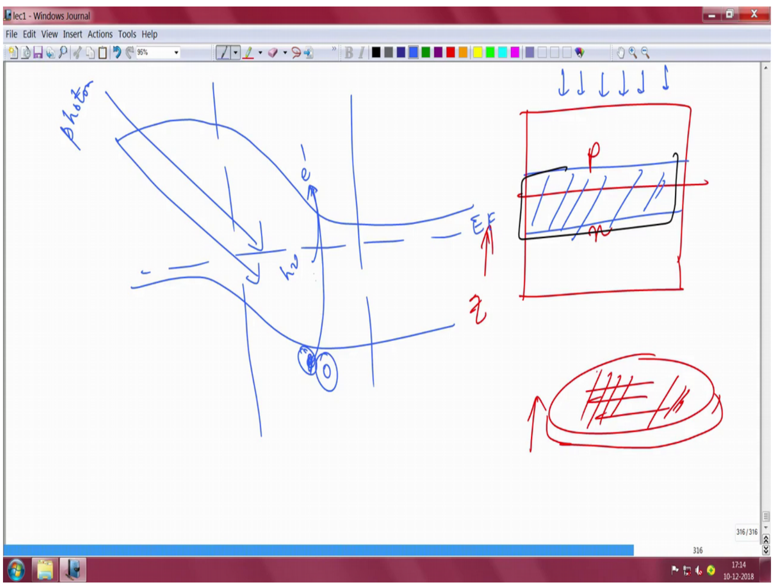

And you might now, want to take an example of a silicon p-n junction which behaves like a solar cell. So, suppose you have a p and n and this is a wafer you know practically you will have a wafer like this ok, you will have a wafer like that that you make the devices right.

You make the devices this is the z direction, sunlight will come from here. Sunlight will come from here, but silicon is you know this is sunlight will come from here, a silicon p-n junction will have a depletion region that I define as this. This is a depletion region remember, if I draw the band diagram it will look like this right. This is the depletion region, if you recall that is your depletion region and that is this depletion region.

Photons absorbed only in the depletion regional will contribute to electricity by the way ok. Please remember photons absorbed only in the depletion region will correspond will give you electricity. So, this is a Fermi level [FL]. So, any photon that falls any photon that falls in the depletion region it is absorbed here know, that will that energy will be used to excite an electron from a from the valence band an electron will be excited. Because, that energy is absorbed sunlight; if the energy corresponds to the band gap or more than an electronic will be excited from here to the conduction band what will remain here is a hole. So, electron hole pair is essentially created.

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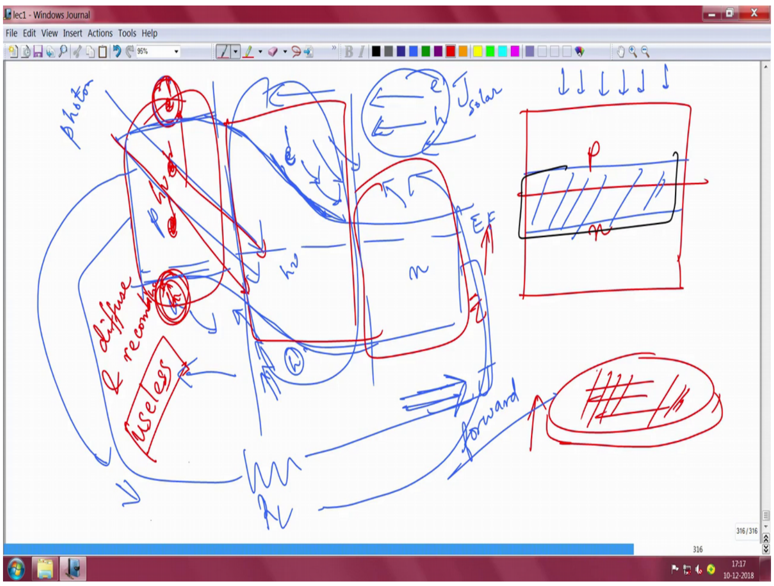

I can say that an electron hole pair is created, there is a hole here, there is an electron here. So, an electron hole pair is created for 1 photon, if it is 100 percent efficient. Now, when an electron is created when a hole is created here the default even, if you do not apply any bias there is an already a field in the depletion region you know that because, there is slope in the conduction band, there is a slope in the valence band. So, there is a field that you know, this field will push the electron in this direction because, it will slope slide downwards. I told you think of it is a floor and you think of it is like a cricket ball it will slope downward this way.

So, electron will come that way that field is sweeping the electron away without applying any voltage this is default field and this hole will be swept this way. So, electron going this way means that current is going this way and hole going this way means the correct current is going this way. [FL] both electron and hole current will be in this direction and this direction is the direction opposite to the direction of a forward bias p-n junction current.

In a forward bias remember this is n type, this is p type. So, electrons are injected from this side, holes are injected from this side. So, the net current flows in this direction in a forward bias; remember in a forward bias. But, now the solar cell when a ele when a light is shining the electron hole pairs that are generated are swept away in this direction in this direction.

So, the total current because of solar cell is in this direction which is opposite to the direction of the forward biased p-n junction. But of course, you do not intentionally forward bias a solar cell, I am just leaving it unbiased connected across a load maybe. I will connect across a load, the load may be your table fan, your light or whatever. So, when you shine light electricity will be generated in this direction ok.

So, current will flow in this direction ok, current will flow in this direction and only this depletion region has the feel. So, you have photons that are falling on the depletion region will only contribute to electricity. The photons that are falling here, I am sorry the photons that are falling here will generate anele electron here and a hole here, but there is no field. This part is quasi neutral you remember, this is neutral there is no field.

So, the electron that is generated here, the hole that is generated here there is no field to sweep that away and they will diffuse they will diffuse randomly and they will recombine. So, the electron and hole produced in this natural region is useless because, they do not contribute to they do not contribute to electricity. The electron and hole will diffuse and recombine within the p-type layer, with in the n-type layer if the photon is absorbed here. Those are useless ele photons and useless electrons and holes that do not contribute to electricity and that will contribute to reducing the efficiency of your solar cell. So, you want the photons to be only predominantly absorbed in the depletion region because, only in the depletion region you have an electric field that can sweep the carriers away ok.

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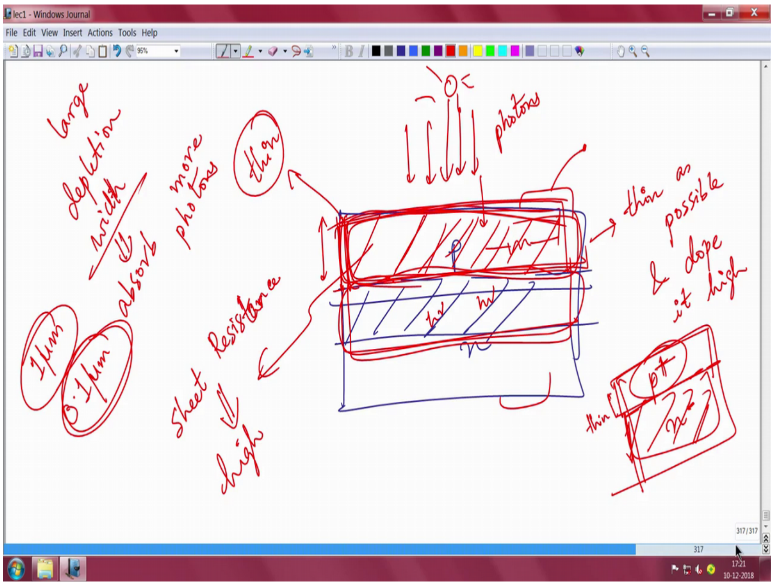

So, now if you come back to the structure; so, I will come back to this structure now, this is your p, this is your n, there is a depletion region here. Now, your sun will be here that photons are coming like this, these are photons that are coming right. The photons will be absorbed in this neutral region, those are useless and this photons that are absorbed will be so much that only very few photons will reach here.

Because the p-layer will be thick for example and it will absorb all the photons. The fraction of this sun light that is reaching the depletion will be narrow very small and your efficiency and working will be also terrible. What does it mean? It means that you do not want to waste the photons in the top p plus layer or in top p layer.

So, you have to make this layer as thin as possible, you have to make the top layer as thin as possible so that sunlight is not wasted in a getting absorbed there; thin layer will absorb less know that is the [FL]. But, if you make it very thin there is a problem, you have to make a contact also remember you have to make a p type and n type contact at top contact button contact. If your layer is very thin then your sheet resistance will be very large, your sheet resistance, your sheet resistance will be very high. And, that will be bad because whatever you know if you are trying to extract some voltage a lot of this parasitic voltage will drop here, that will not deliver good power to the load; you do not want that sheet resistance to suffer.

So, you have to dope it high, you have to dope the top layer high very high. So, it is called p plus, the bottom will be n minus. So, first thing is that this level will be thin still a this will be thin so, that sunlight is not wasted there, still there will be a lot of absorption. Now, still there will be a lot there will be very little absorption in this p plus layer so that most of the photons are absorbed in the depletion.

And secondly, it is doped high so, that the lateral resistance is not very bad. So, that you can carry decent power, decent current and other things can flow ok. If your resistance is high then current only cannot flow so, much I mean the voltage will be dropping unnecessarily. So, you want it to be highly doped and very thin.

And, when it is very highly doped and n is lightly doped then most of the depletion will be in the n and you want the depletion to be large. You want the depletion width to be large. Why? Because, a larger depletion width will absorb more photons, a larger depletion width will absorb more photons right.

Suppose your depletion width is 1 micron in a p-n junction and another p-n junction has a depletion width of 0.1 micron. Of course, there will be more photons observed in 1 micron then in 0.1 micron that it means you will be able to get more electricity out. So, you want the depletion to be large. So, you want n minus, you want lightly doped n and you want a highly doped p plus that you will see that there are many design considerations that will ensure that you cannot dope this n very light also ok. You cannot dope this p very high also, there will be the other problems that will come.

So, what will do is that we will wrap up the class here today; this is the first introduction to your solar cell. So, there are some design considerations I told you know in terms of p-n junction and all the sunlight, the air mass illumination, the amount of energy you can harness and so on. Next class we shall introduce some equations of p-n junction and solve and try to exploit the expression for solar cell current, voltage, efficiency field factor those are very important. Once we do those I will tell you about the practical considerations in designing a p plus n junction or an n plus p junction for a solar cell ok.

And, then I will talk about this efficiency and field factor which are very important, short circuit current and open circuit voltage. And, we will try to see what is the Shockley-Queisser limit, you cannot arbitrarily have a material of low band gap to absorb all the light; it will lead to terrible efficiency; all those things we will discuss [FL]. And maybe we can have a quick introduction to other kinds of solar cell and other things ok. So, those we will take up in the next class.

Thank you for your time.