Processing of Semiconducting Materials
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Lecture - 31
Applications of Metal - Semiconductor Contact

Some of the applications of metal semiconductor junction, and we shall discuss today. You know that in my last class, we have taken into account the different types of contacts metal semiconductor contacts particularly, what happens, when the metal work function is higher than the semiconductor work function, if the semiconductor is n type or what happens, if the metal work function is less than the semiconductor when the semiconductor is n type. So, there are different kinds of situations and we have come across at least 4 types of situations, where we have seen that in two cases Schottky contacts are made and in the two cases Ohmic contacts are made.

So now we shall see what are the applications, because why we will go for this type of contact. So, far as the Ohmic contact is concerned, it is very straight forward that that you have to send current to a device. So, all devices say diode or transistors or fet or mosfet you need some Ohmic contact otherwise, how you will send the current to the device or some output you will get. So, there must be some means some contact must be there so, these are the Ohmic contacts. But so far as the Schottky contact is concerned, why we shall make Schottky contact, what are the applications of Schottky contacts.

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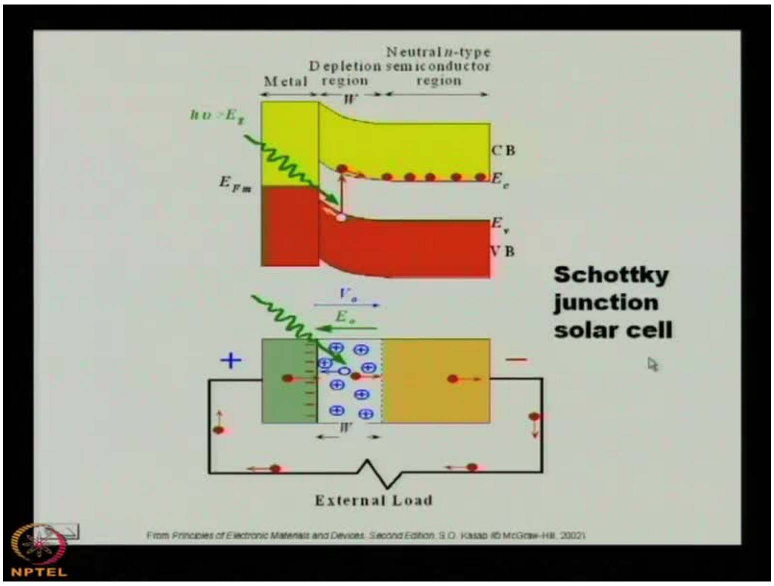

So far as the Schottky contact is concerned, you see that Schottky contact is used for Schottky junction solar cell. So, that is very important application, it is Schottky junction solar cell. And what is the solar cell you know that solar cell converts photonic energy into electrical energy that means, it converts light into electricity, light means photons. So, it converts photons into electricity and you know that in some materials, we are unable to make p type doping or n type doping that we have discussed during doping, that silicon it is very easy to make p and n both type of doping, but in some cases we cannot make doping.

So, in that case also suppose you have a material which is p type or which is n type and you cannot make the p n junction, then you can fabricate the Schottky junction to make some device. So, Schottky junction is basically a device Schottky junction is basically a device and you can use this Schottky junction in many applications. Today we shall discuss two applications one is the solar cell.

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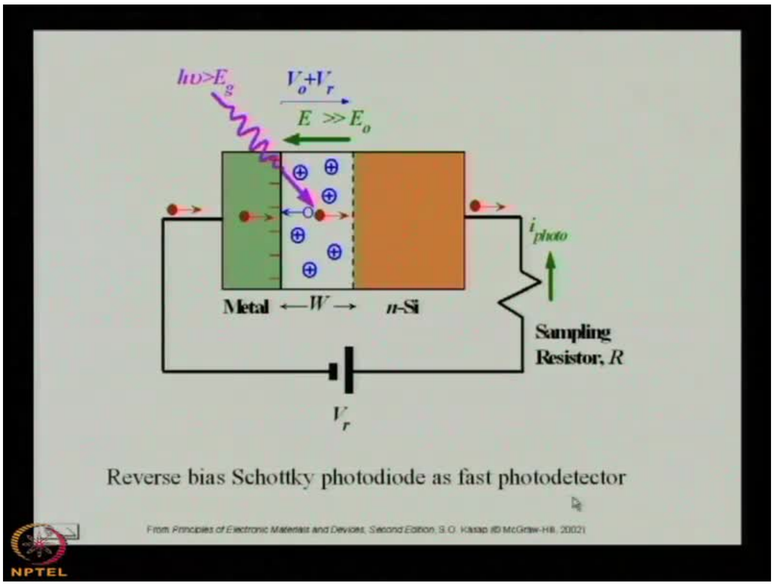

And another is the photodiode or photo detector, the same thing. So far as the Schottky junction is concerned, you see that it is basically a metal semiconductor contact. The left side is metal and the right side is semiconductor, and it is the band diagram of the metal semiconductor contact, which we have discussed and explained in the previous classes. Now, there is a depletion region, see it is the depletion region, this white region is the depletion region between the metal, and the semiconductor.

Now, when light falls on it where light falls on the depletion layer, when light falls on the metal semiconductor contact, then this light generates electron hole pairs. These electron hole pairs are driven by the electric field generated in the depletion region, and the electrons will move towards the bulk semiconductor direction, and the holes will move towards the metal direction. So there will be separation of charges, who will separate the charges, the electric field will separate the charges. What is the origin of the electric field?

Student: (( ))

Depletion region, depletion region. So, this is the physics behind the operation of a solar cell. First, you have to make use of a light, which will incident on the metal semiconductor junction, and that light will give rise to electron hole pair. Now, what is the energy required? Whether any photon having any energy can be used for the electron hole pair generation. More than more generation.

So, if it is say silicon Schottky then the semiconductor is silicon, and is band and is e g is how much, what is the E g?

Student: 1.1.

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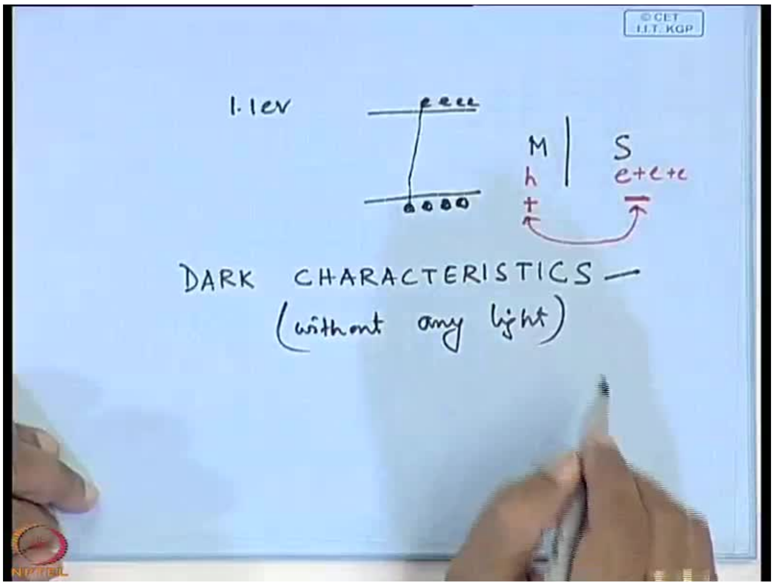

1.1, so if it is 1.1 E g say it is 1.1 electron volt and this is the silicon. So, this is 1.1 electron volt if 1.1 electron volt or more energized photons is incident on the semiconductor then these electrons will move to the conduction band, conduction band. So, that means holes will be generated here and there will be electrons and holes, which will be generated in the material. Now, we want that this electrons and holes must be generated at the depletion layer because you see that there may be other region, where the electron and hole pairs can be created, apart from the depletion layer, but problem is that if the electrons and hole pairs are generated outside the depletion layer, there is no mechanism using which you can collect the electrons and the holes.

So, not only the focus is on the generation of electron hole pairs electron and hole pairs you can generate by generated, you can generate by many ways, but you have to separate the electron and holes. So, that you get some current or voltage, without separation you cannot make the solar cell. So, now in this diagram you see that there are electrons and hole pairs, which are produced and the production mechanism is like this and the electrons will move towards the semiconductor side. Why? Because of the direction of the field, what is the direction of the field.

Student: From n side to p side.

Yes, so the electrons will move towards the semiconductor side and holes will move towards the metal side. Now, when the electrons will move towards the semiconductor side, it will reach the semiconductor bulk. So, what will happen, it will increase the number of electrons there because in the bulk say there was n number of electrons. Now, there will be n plus 1 number of electron, because of the propagation of 1 electron from the depletion layer towards the semiconductor side.

And similarly, when the hole will move towards the metal side what will happen, it will recombine with one electron in the metal. So, there by one electron will be lost from the metal side. So, on the metal side you can consider that one electron is being lost and on the semiconductor side, one electron is added. So, that means compared to the dark case, what is the dark case?

Dark case means, when there is no light on it dark characteristics DARK dark characteristics that means, without any light you can consider that it is a laboratory characterization that means, inside the room your characterizing the metal semiconductor junction or the p n junction that is the dark characteristics. And when a light is incident on it whatever be the light, the light can be from the sun the light can be from laser L E D or any other type of light, it can be from the incandescent lamp right then it is not known as the dark characteristic, it is characteristics under illumination, it is characteristics under illumination. That means your illuminating the surface.

So there can be two types of characteristics, one is dark when there is no light fall on it and another is when in presence of light it is the illumination characteristics. So, what you find that when the electron will reach say, this is metal side and this is semiconductor side, let us take the block diagram. So, there was an equilibrium thermal equilibrium as you join it there was a thermal equilibrium, and the band diagram we have seen that it will look like this type of a band diagram, this is the band diagram.

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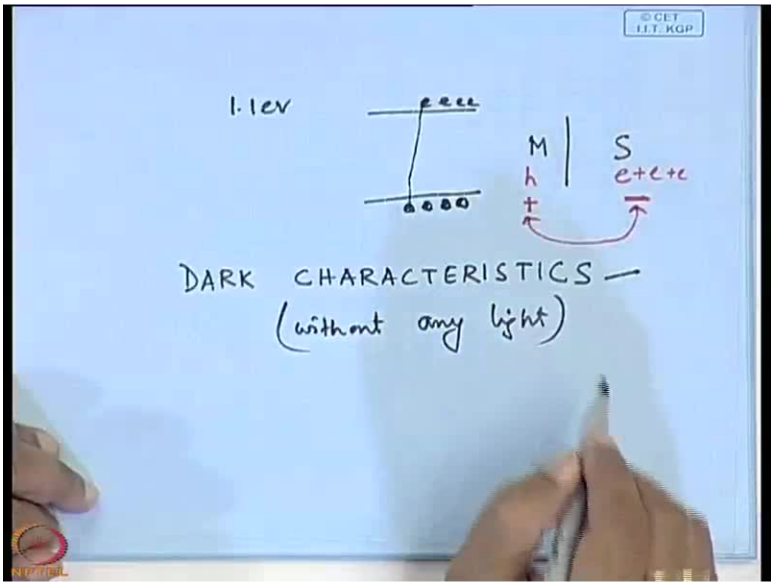

Now, when one electron will move towards the semiconductor and one hole will move towards the metal. So, that means there will be non equilibrium situation. Now, the equilibrium will be lost equilibrium means, when there was diffusion etcetera and it was stopped by the potential barrier and everthing was in equilibrium. Now, when you add some electron on the semiconductor side. So, that means, the number of elctron increases. So, that means you are…

Student: (( ))

Yes, that means you are loosing the equilibrium there is no equilibrium in the device. So, electron will increase one more electron it will be added then there will be one more electron it will be added. So, as long as there will be a sunlight on it say or any illumination on the metal semiconductor Schottky junction, the semiconductor region will have more and more electrons compared to the dark situation. Similarly, the metal side there will be loss of electrons. So, it will be more positive so, metal end will be more positive, semiconductor end will be more negative compared to more means more than what?

Student: Dark condition (( )).

In the dark, yes it is equilibrium that means in the dark condition. So, metal will be more positive and semiconductor will be more negative. So, you will get a electrodes type of arrangement and if you connect that positive and negative terminal, you will get a current. So, that is the orgin of current in a Schottky junction solar cell. In p n junction also the same thing happens, in p n junction also the same thing happens, but in p n junction fabrication is a little bit diffcult, it is more complex than schookty junction because in Schottky junction you take a material, you go to a thermal evaporation system which is available in all the labs, and you deposit a metal under vacuum. So, it becomes a metal semiconductor junction then you test with the illumination condition.

Now, if you connect this thing with a wire then what will happen, this electron will move towards the metal side, the electron will move towards the metal side, what it will do because you know that in the metal side one electron was lost. So, that will replenish that electron in the metal side. So, there will be replenishment as long as there will be photon on the metal semiconductor junction.

So, that is the continuous process, the photon will be generated, electron hole pairs will be separated electron will move towards the semiconductor bulk region, holes will move towards the metal region and if you connect by some conductor somewhere, then that elctron you can consider will come towards the metal side to replenish the electron, which were lost due to the recombination with the holes. So, there will be a current because the flow of electron means, you will get a current in the opposite direction of the electron flow. So, you will get a current in the circuit.

So, that has been demonstrated in this view graph, and the quality is not good I think that there is some problem with them. So, this is the load, this load is the external load that means, what you want todrive say this load can be a motor, it can be an LED, it can be an calculator, the load can be a calculator, it can be any motor that means, what you want to drive by the solar cell voltage, you will get a voltage basically and you want to drive the solar the some load with that voltage. You see that this is the electron that electron will be coming to the metal side to replenish, the electrons in the metal side. So, if there is a flow of electrons from this side so that means, there will be a current from theopposite direction. So, this is all about the Schottky junction solar cell.

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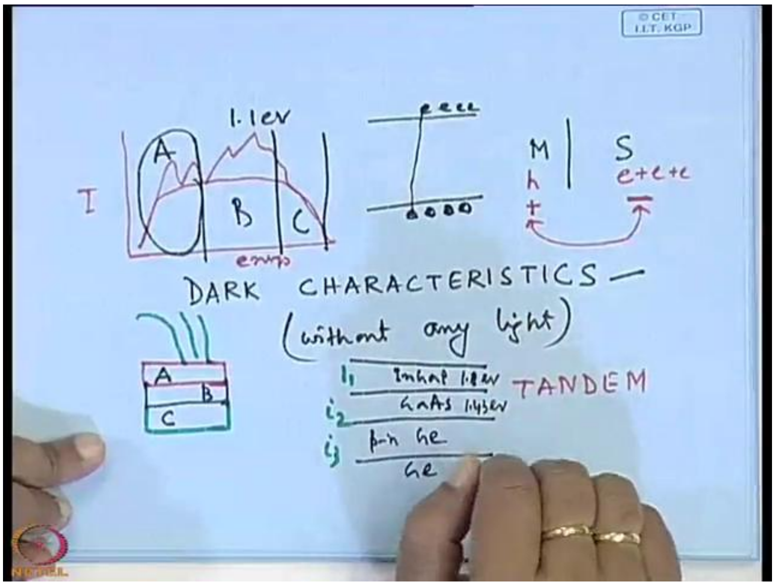

Now, a solar cell you know that we have considered here 1.1 electron volt because of the silicon. Now, if you consider the whole solar spectrum, the spectrum is like this what is that that is the inensity versus energy, it is like this. So, that means in the solar spectrum you will get any energy photon that means, the photon coming out of the solar radiation consists of photons.

The photons are having various energies, it can be ultravoilet it can be infraded and also there will be visible region. So, that means if you harness the whole solar spectrum then one single material is not sufficient because the material, the limitation of the material is its band gap. So, if you take silicon so only 1.1 elctron volt or above energy it will absorb, what will be the energy which is below 1.1 electron volt.It will transfer.

Yes! it is of no use basically, it will it will be of no use basically right. Similarly, suppose you are considering some tandem structure T A N D E M, what is the tandem structure? Tandem structure is the structure, which can harness the whole spectrum of the solar radiation. That means, it consits of 2, 3 structures say this is 1 p n junction, this is 1 p n junction then this is second p n junction, then this is third p n junction. So, 3 p n junctions we have fabricated say, and the light will fall on the surface.

So, what will happen. In the first p n junction the material will absorb the lower part of the solar energy spectrum lower part means, where the energy is less. So, if you can consider the energy to be subdivded into three parts A, B, C say if you consider this examle say. Say this is A, this is region B and this is region C. So, you choose one material, which will absorb energy in the a region. Say this is A region then you use another material, which will be absorbing the B region, and in the C region the third material. So, that means you cannot play around a single material atleast three different types of materials are required, for its absorption if you want to harness the whole solar spectrum. So, let us take one example suppose we start from germanium substrate, what is the band gap of germanium.

Student: 4.4.

0.67, 0.67 electron volt it is germanium then make 1 grmanium p n junction. That means, here the band gap is 0.67 absolutely there is no problem in it, then you use gallium arsenide, what is the band gap.

Student: 1.43

1.43 electron volt then 1 junction you make indium gallium phosphide, what is the band gap? 1.8 electron volt, 1.8 electron volt. So, what is the advantage of this structure? The advantage of this structure is that from 1.8 electron volt to 0.67 electron volt, the whole solar radiation can be made to absorb on this structure, first 1.8 electron volt will be absorbed then 1.43 electron volt will be absorbed and finally, 0.67 electron volt will be absorbed then why, I have choosen these materials because gallium arsenide is lattice constant, it is lattice matched with germanium and indium gallium phosphide is lattice matched to gallium arsenide for some percentage of indium, and gallium it is probably 0.49 and 0.51 or you can consider 50 percent indium, 50 percent gallium.

You cannot use silicon here, why you cannot use silicon here because there will be no matching. So, if there is no matching so, what will happen you cannot add the current you see that in all the junctions, the current will be produced and you have to add the current. So, that the current must tunnel through the second region, say this is i 1 current here the current is i 2 and this i 1 must be added to i 2, then the current here is i 3. So, finally, the current will be i 1 plus i 2 plus i 3. Otherwise, what will happen if you cannot design the material in a proper manner current will be produced, but you will not be able to collect it it it will not be added then, what is the purpose of fabricating the solar cell in such a complex manner.

So, that is very important thing that you have to add the current. That means, the current must tunnel through the second junction, and the third junction for that the carrier concentration. The tunnel junction that must be designed so that is a complicated process, but I am giving the example because it is though it is not a Schottky junction solar cell, but this type of a solar cell has the potential to increase the efficiency upto 40 percent, 50 percent.

And you know that in satellite communication or in the pace vechile only the solar cell is used as a power source, no other battery or any other thing is used it is the solar cell because there is abundance of solar radiation in the atmosphere, in the outer space. So, it receives solar radiation and then it is converted to the elctricity for different kinds of applicationin in the pace vehicle.

There this type of a tandem cell is used there silicon is not used, though silicon is very potential material for solar cell fabrication, in pace vechile it is not used. Why? Because of this low efficiency, the silcon solar cell has the efficiency of only just say 10, 12 percent and its efficiency, this tandem solar cell has the efficiency of 40 percent. So, obviously here the cost is very high because it is a 3, 5 semiconductor the cost of 3, 5 is higher than the cost of silicon, but even for a pace vechile this cost is nothing.

If you consider the total cost of the pace vechile. So, this is nothing and also this is very important becauseof the fact that without power, you cannot run the show. So, remember that this kind of a tandem cell is used for the space or sattellite applications, not in the domestic applications. In domestic it is the silicon p n junction solar cell still now, with 10 to 12 percent efficiency. And in Kharagpur IIT we are planning to install one 2 mega watt solar cell photo solar photovoltaic plant that will be, that will connect this new complex and this triple m hall, some of the places we shall try to connect with that greed and that is basically, an ambitious project of Kharagpur IIT for 2 mega watt solar cell photovoltaic plant.

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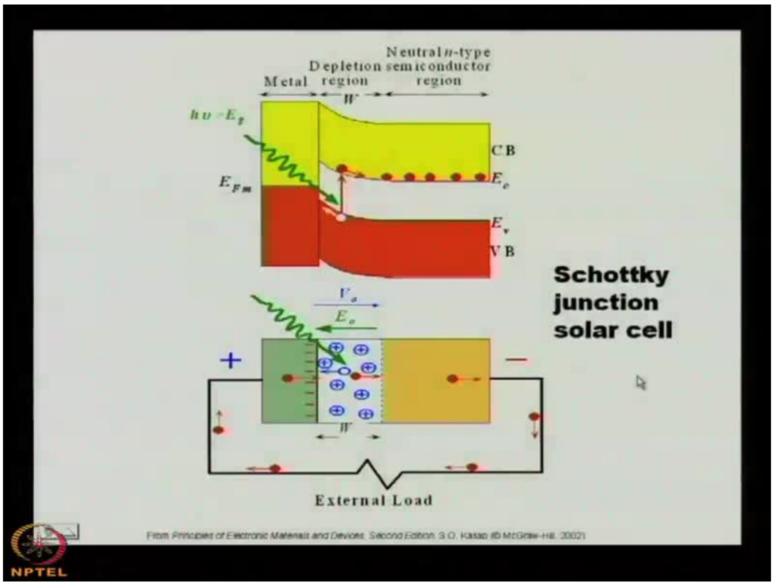

So, now if you consider this solar cell it is very simple in fabrication, you need not to bother about any junction only one condition is that, the metal must be such that it is transparent to solar radiation. Otherwise, what will happen it will absorb radiation. So, if the metal absorbs the radiation then it will not reach to the junction, metal semiconductor junction. So, generally gold or that type of a metal is used because it is transparent almost transparent of a very thin layer can be made. So, aluminum or iron or that calcium that is not used in this case mostly, gold is used. Now, what will happen if energy less than the band gap is incident on it, what will happen, what will happen if the energy less than the band gap energy falls on it then what you can expect. Then light upon light will simply transmit transfer to the materials. It is just like transparent. Yeah, no. Thermal energy is used.

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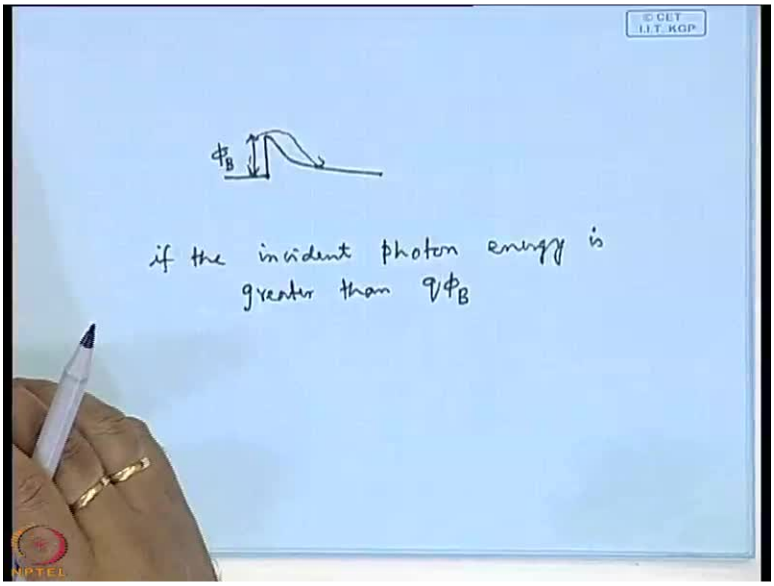

Yes, Then what will happen, see this is the metal semiconductor junction, what is this? This is barrier height we have discussed. So, if the incident energy is greater than 5 v, if the incident energy if the incident photon energy is greater than q phi B then what will happen.

Student: (( ))

Electrons from the metal.

Student: Will penetrate.

Will move towards the...

Student: Semiconductor(( )).

Semiconductor then also you will get some output, though the mechanism is not electron hole pair creation by the energy, that photon is not here creating the electron hole pairs, but since the electron will move towards the semiconductor side. So, that means on the semiconductor side, the number of electrons is increasing and similarly, on the metal side the number of electron is decreasing.

So, same thing will happen there will be a positive charge on the metal side, and negative charge accumulated on the semiconductor side compared to the dark condition, but the condition is that it must be greater than q phi B, if it is less than q phi B then nothing will happen you will not get any response. So, it is another advantage of the metal semiconductor junction. What was the first advantage? First advantage was it is very simple to fabricate, what was the second advantage.

Student: Time delay (( ))

No, no that p n junction is not required junction fabrication that is very important thing, junction fabrication is not required. Number 3 many metals many semiconductor, which cannot be doped either p type or n type can be used for such kind of application right. And number fourth is even the photon energy is less than the band gap, but greater than the barrier height that can be used for the generation of electricity from the photon, that advantage is not there for p n junction because in p n junction, you must supply energy greater than the band gap energy because there is no barrier height concept in p n junction.

So, you cannot exploit that barrier height theory here, you can exploit that barrier height concept. So, there are many advantages of Schottky junction solar cell and and those points I can ask you in the exam also. What are the advantages of Schottky junction in solar cell? So, if you have any question otherwise, I shall switch over to yes.

Student: Sir the depletion layer is always in the semiconductor side.

Yes.

Student: If the normal mode of that comes out coming from metals to semiconductor.

Yes.

Student: Then some positive ions are (( )).

There is some.

Positive ions in the metal side. How?

Student: (( )).

Actually, if you consider a metal having 10 to the power 20, 10 to the power 22 number of electrons per c c in metal. So, metal is not a semiconductor like thing, it is not the doping case in doping that kind of ionization or immobile ion type of thing is available, is seen in metal that concept is not there, there is no question of ionization it is the free electrons in the outer most cell, which will come basically and you see that huge number of electrons must be there otherwise, you will not get the sufficient amount of current.

Student: Sir no (( )) are coming from metal position.

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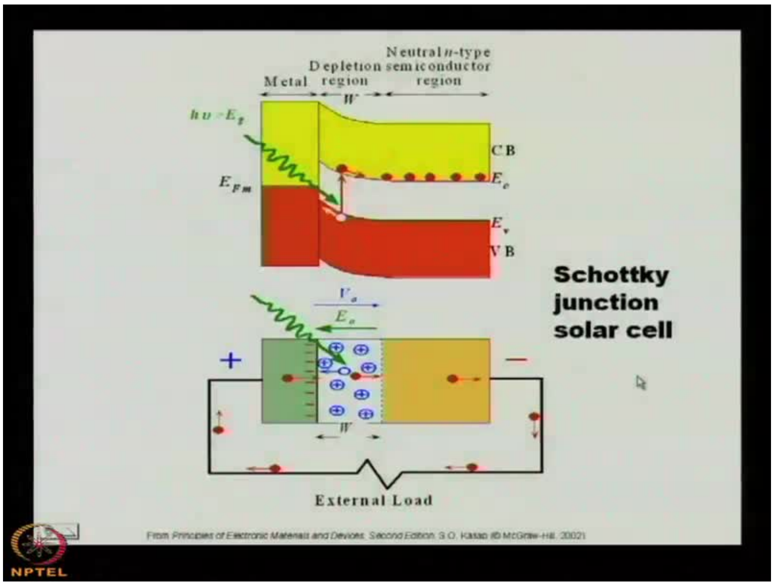

No immediately, what happens as soon as a as soon as large number electrons are coming out similarly, the electrons are moving towards the metal side also by application of this load. At that point no biasing is there. No, biasing is required you why you will bias it, it is the generation of current. They automatically come from semiconductor. They automatically come from.

Student: Semiconductor (( )).

Yes by application of this load that means, some wire must be there some wire must be there, there must be connecting wire the conductor must be there, which will conduct the electricity. In fact, you can consider this is bulk that yellowish region is bulk, this greenish region is also bulk. That means, it is metal so where the number of electrons is very, very high compared to semiconductor in all the types. In this case if this is the bulk so, you can consider that except this depletion region the whole region is covered by the conductor. That means, this electron is coming to this conductor and replenishing the electron loss in the metal side, forget about that there is a semiconductor here.

For the explanation of the Schottky junction solar cell even you can forget that, there is a semiconductor except that you need the depletion region that is all, no more thing is required. In the depletion region the internally generated electric field will drive the electrons and the holes that will separate the electrons and the holes. Now, how it is done say this is a potential energy.

So, it is like a ball if the if you let the ball go away slope. So, what will happen it will roll down basically, why? Because of the it will go to the lowest gravitational potential energy, lowest potential energy so that is the region that say the electrons is here. So, automatically it will come to the lowest position to reduce its energy because its energy is higher.

Similarly, for holes the exactly opposite thing happens that the whole energy increases when is when it is electron energy increases, when it go up hole energy increases when it goes down. So, when it roll down the potential energy slope it is energy will actually, when it will go upward its energy will decrease because it is opposite to the electron nature. Here it is when it is coming down it is decreases, when it is going up it is decreases.

So, idea is that when the energized electron and hole pairs are created the whole idea is that it must roll down the potential energy slope, for its collection in the bulk material and you must connect the wire, if you supply some bias then what is the use of solar cell you need not to make any bias, bias means you are providing the energy you are supplying the energy here you are not supplying the energy, the solar cell you are taking the energy, it is the harness thing of the solar energy by semiconductor Schottky junction.

Student: Sir whatever the depletion width it will remain constant on.

No it will depend on the semiconductor doping concentration, semiconductor doping concentration. That is that is the. That is the only characteristics.

Only the general that will be there because with solar radiation, it has solar radiation nothing to do with the width of the depletion region. So, that depletion region you have to play around, why? Your energy must be in the in the depletion region that field must be sufficiently high. So, that it can separate the electron hole pairs so, that is very important thing that means, the only consideration is the doping concentration of the semiconductor.

Student: Sir sir when light will fall on the interface.

Yes.

Student: And electrons go semiconductor side in that case it will be not applied in any load.

Yeah.

Student: Then that potential that potential difference will be there.

Yes.

In that case the depletion region will be as a light falling on.

No, no see, see when.

Then that will be change in (( )) constant.

No, no actually if you if you give sufficient time to build up then there must be some change, but that is not your idea no your idea is to connect to get the voltage out of the solar cell. So, there must be connection, connecting wire there must be conductor you must drive a load. Why you will make the solar cell. To generate the energy.

Then generate the energy means, you will you must make use of that energy suppose a bulb will be connected. So, as soon as the bulb starts glowing so, the energy will be lost basically. What was, what was stored in the electrode that is lost. So, similarly, the same thing will happen again the fixed depletion width right, but the depletion width must be you have to calculate because field you have to calculate because if the field is very low then sufficient electron and hole pairs even it is able to generate, it will not be separated. So, you will not get any voltage so that is very important thing how much field is required to separate the electron hole pair that is basically, the device simulation type of thing you have to consider. What should be the optimum depletion width.

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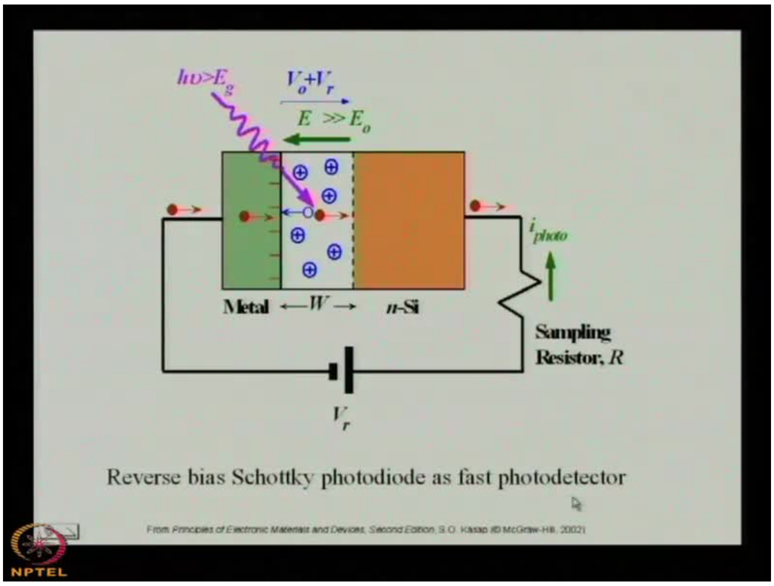

Another example is the photo detector or a photodiode basically, what is the role of a photodiode? The role of a photodiode is it absorbs photon, and gives the proportional. Current. Current or voltage now, what is the difference between a solar cell and a photodiode.

Student: Sir reverse bias.

Yes. Here you have to make use of a bias that means, the metal semiconductor photo metal semiconductor Schottky diode, if you operate that Schottky diode in the reverse bias condition you will get the photodiode. Say from the very first class I have given you the example of fiber optic communication. In fiber optic communication, we have seen that light travels in the by the means of total internal reflection, inside the fiber to propagate the information.

Actually, we tell something suppose some audio or video signal is there that signal is converted to the electrical signal by means of transducer, then that electrical signal modulates the light of a light emitting diode or a laser. So, that means at the output of the light emitting diode or laser basically, it is the modulation of the signal, which we want to send.

Student: Intensity modulation.

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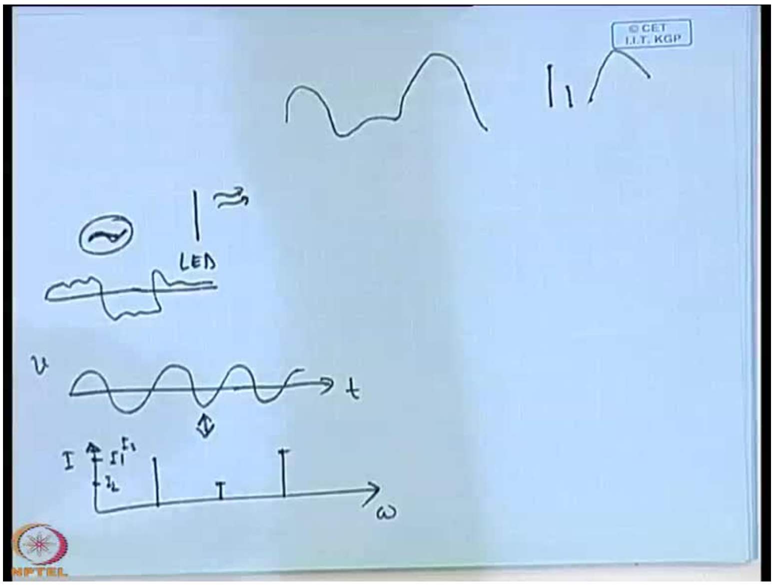

Yes, suppose this is LED light is coming out from it, if you modulate a signal say, this is the signal say this signal is there. This is the signal because you know that any information content signal must be a time domain signal with time, it must vary otherwise it is not use with time if it is fixed then that means, it has no information content in it with time it must vary.

So, that is why this is a time varying signal that means, this signal is a AC signal basically, because many frequencies are involved otherwise you cannot separate between the information's I am talking something. So, basically different kinds of intense different kinds of frequencies are involved. So, if you plot that thing in the time domain because the it can be plotted in frequency domain also, and what is the Fourier transform does the Fourier transform actually, change the time domain signal into frequency domain, frequency domain signal.

So, if it is the time domain signal say it is v versus t, in frequency domain what you will get, in frequency domain what you will get. Say it is it is intensity versus frequency omega. That means, Fourier transform of this signal in the time domain gives you the signal in the frequency domain. That means, Fourier transform this signals contains 3 frequency, this is frequency 1 having intensity i 1, this is frequency 2 having intensity i 2 and this is frequency 3 having intensity i 2. So, basically that is the frequency domain signal, which is coming out from the time domain signal by means of a Fourier transform, but that is not the issue here.

So, this led light is modulated by this time varying signal that it is nothing but a voltage. So, if you connect a voltage which is low or high that means, the light output will be low and high that is the modulation of light, that is the modulation of light. If you apply a constant D C bias the light will be a constant output, if on that D C bias you super impose one A C then the light will be modulated with the intensity of the signal, if the signal is like this. So, light will be say high then the signal is like this the light will be low then if the signal is so high, the light be very high that means the peak intensity of the light will also change, depending on the signal which you are superimposing on the light emitting diode.

So, thereby you are sending some light through the fiber optic cable then the light is fed to the fiber optic cable, and it transmits say now. So, let say it is going to Jamshedpur so, what will happen there will be a detector that detector will detect, this light output and proportional current it will get at its output so that is the role of the photo detector. So, without photo detector the fiber optic communication, which is the main network system these days is not possible.

So, that is the photo detector that means it covert it detects the light, and the major application of the photo detector is in the fiber optic communication, that circuit is known as the receiver circuit LED will be in the transmitter circuit, there will be a transmitter and a receiver in Kharagpur, if you want to send something Kharagpur must have a transmitter, and Jamshedpur must have a receiver to receive that signal and the vice versa. So, photo detector basically detects light.

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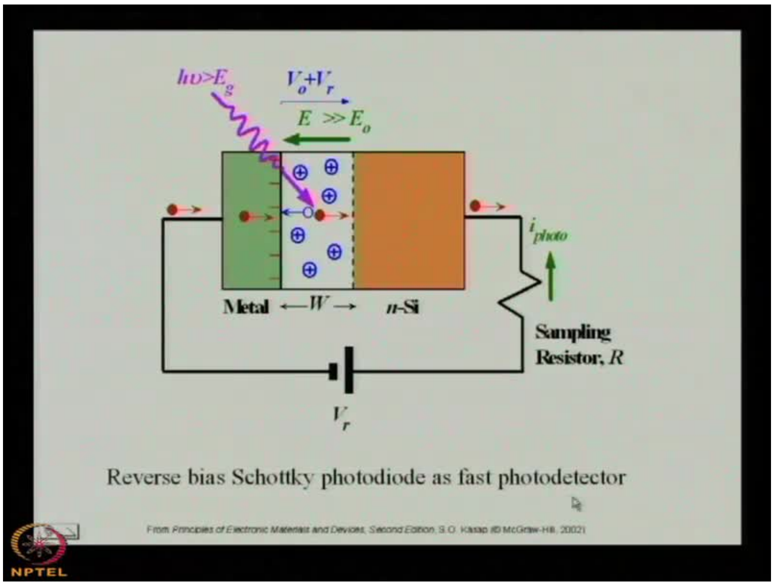

Now, this photo detector you see that it is nothing but a metal semiconductor Schottky junction with reversed bias applied on it, why reverse bias is applied, why there is a reverse bias applied on it

Student: (( ))

Yes. Actually, the field must be made very, very high. You know that with the application of the forward bias, the depletion layer width decreases. And the intensity of the electric field decreases if you make the reverse bias then the width will be high, or in other sense the electric field in the depletion layer will be high. So, if the electric field is high then what is the advantage. More advantages.

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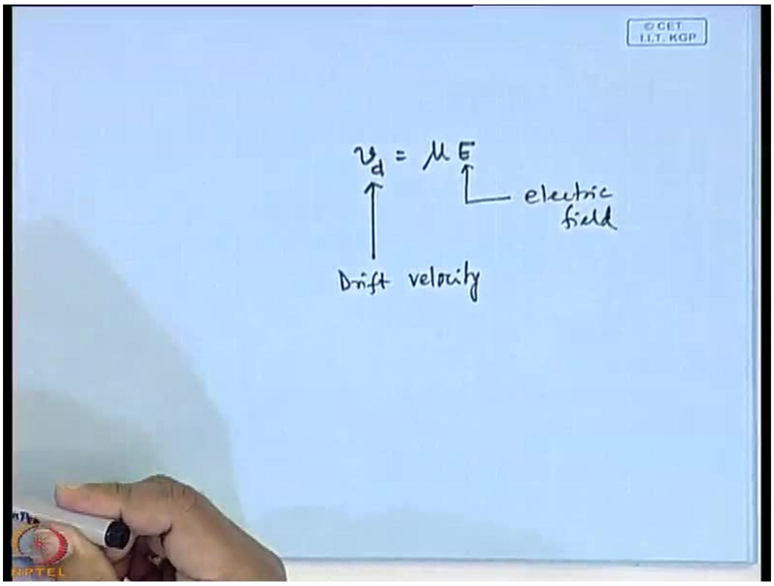

No, if the depletion if the electric field is high then v d, the drift velocity will also be high this is drift velocity, drift velocity of electrons not the number of electrons not the velocity of the electrons because this e is the electric field. Means generated whole (( )) electrons will get the high energy. Yes, not it will get the high energy it its drift velocity will be very high, it drift velocity will be very high let me let me explain.

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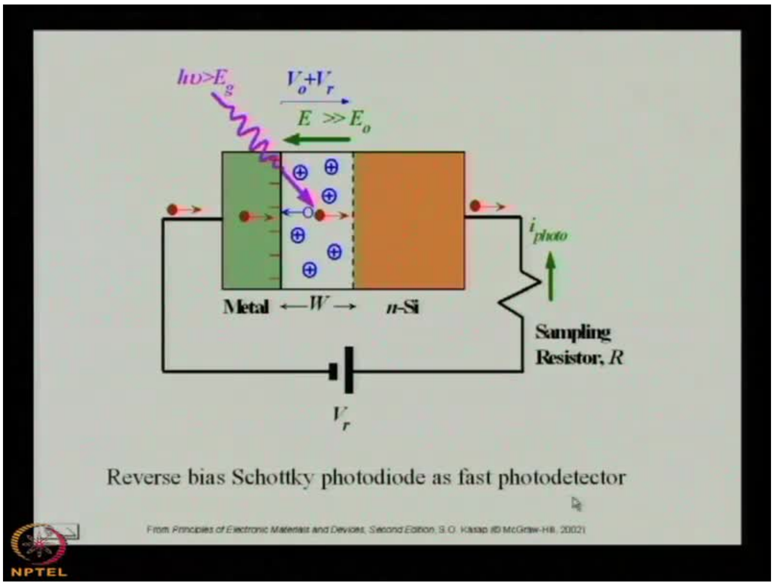

Say this is the reverse bias, you see that reverse bias is made when the positive terminal of the battery is connected to the inside. In a metal semiconductor junction remember that always we choose the polarity of the semiconductor for biasing, always if your semiconductor is n type and you want to make it forward bias. That means, the negative terminal of the battery must be connected to the n side whatever be the metal right.

If it is p material then to make it reverse bias it must be connected to the negative terminal of the battery, whatever be the condition of the metal, whatever be the characteristics of the metal. Always we choose the type of conductivity of the semiconductor in determining the biasing, forward bias reverse bias, forward bias reverse bias when it will be forward bias, when it will be reverse bias it depends on the polarity on the semiconductor, not the metal or any other thing.

If it is a junction between a p and n material, then it is very straight forward one is p connect positive one is n connect negative terminal of the battery, it is forward bias. What will happen when it is a p type material with metal, then p type material must be connected to the positive terminal of the battery, if you make it forward bias. So, it will be determined by the conductivity of the material, semiconducting material not the metal. Now, as soon as you connect a reverse bias the internal field becomes very, very high say earlier it was e 0, e 0 means the built in potential was v 0. Now, the built in potential becomes v 0 plus v r because v r is the reverse bias.

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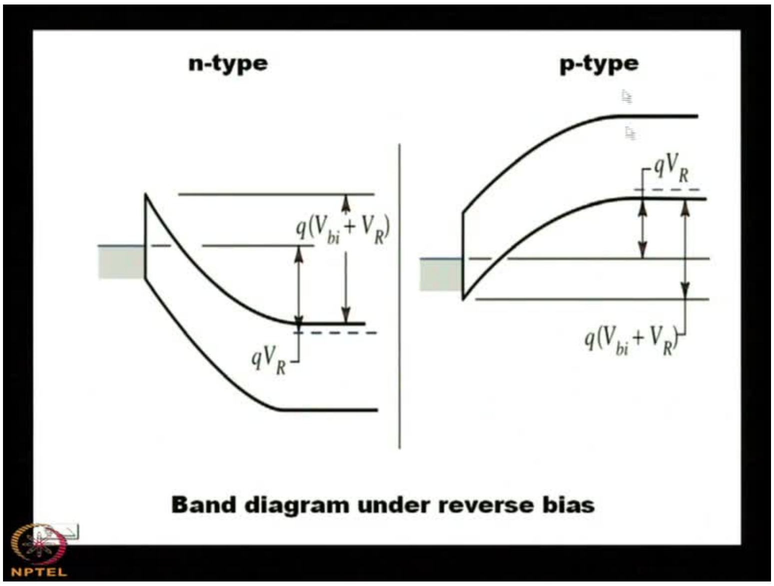

See I can show you that in this diagram, you see yes you see that earlier it was V b i. Now, it is V b i plus V r the reverse bias so that means, this increases, this increases band diagram under reverse bias this is for p type here also it increases, it is p type, n type it is also increases. So, as it increases so, you can consider that the internal field will be very, very high.

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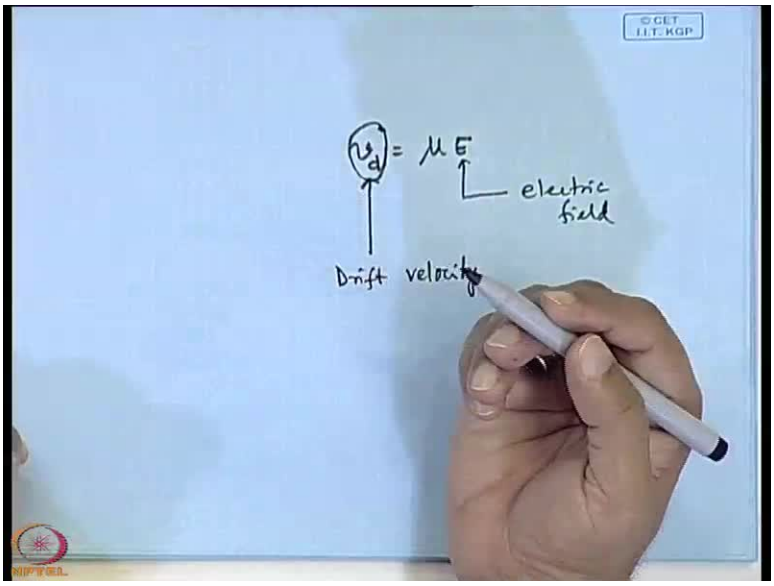

If the internal field is very, very high. So, drift velocity of the electrons will be very, very high from where the electrons are coming as usual it is basically, the light is incident on the depletion layer on the material itself.

Student: Depletion layer materials.

Yes, but depletion layer is very, very small it is of the order of nano. So, you cannot think that the it is only falling on the depletion layer, it is falling on the device basically, from all direction it is falling on the device, and electron hole pairs created in the depletion region they will be separated as usual like your solar cell, but here the drift velocity of the electrons will be very, very high because of the applied reverse bias. Drift velocity high means, the electron will reach the semiconductor side very quickly if velocity is high then what is the time taken, the transit time will be very, very less.

So, that means as soon as the light falls, the electron will be immediately on the. That means, you are getting the current immediately, if electrons take a sufficient time say light falls on it and the electron it is taking 1 minute, 2 minute or say milli second then the current will be delayed. So, that means the information which you are sending and which you are receiving there will be a delay in it. So, there may be some noise or unwanted signal.

So, that is the reason that detector must be very, very fast as if immediately, you will get the current as soon as the light falls on the material. So, that is the reason that fast response must be there, and for fast response the drift velocity of the electrons can be made very, very high. And that is possible only if the electric field is very, very high because if e is high v d is high. So, you will get the fast response.

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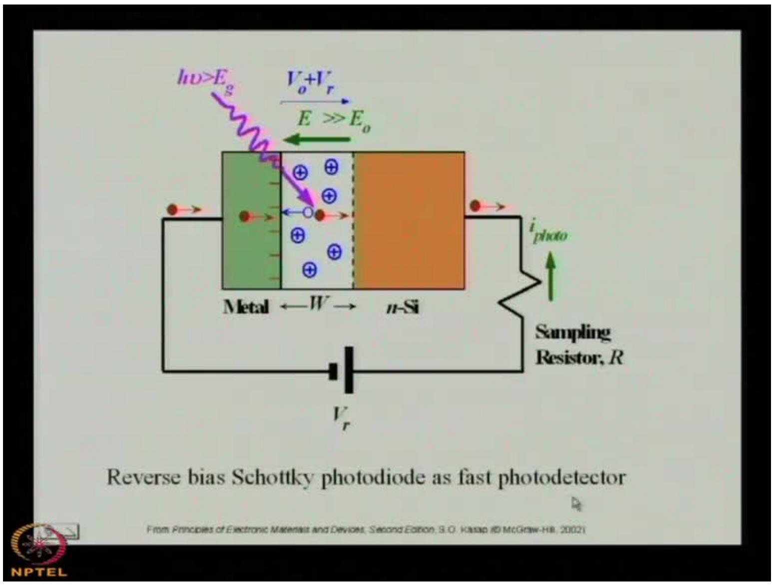

So, that is another example and you see that there is a resistance through which, the photo current is calculated or the photo current is determined because V equals to I R. So, there must be some R. So, that the current when it will be v equals to I R. So, I equals to V by R and this R must be chosen very precisely to receive that current, which is known as the photo current. That means, the photo current will be proportional to the light falling on it, and the light is proportional to the signal coming out from the transmitter.

So, that means in a sense the photo current is nothing but the signature of the information, which you have sent through the transmitter by fiber optic communication channel. So, that is very important application of a Schottky photodiode, it can be made very, very fast because of this reverse bias this is very important application of your metal semiconductor Schottky junction.

So, we have considered two examples metal semiconductor Schottky junction, one example is the solar cell another example is the photodiode. And remember that for photodiode fast response is required and fastness depends on the internally, generated electric field. So, there is a lot of work which can be done for the design of those devices, one thing is the carrier concentration of the material.

Number second is the say phi B which is the barrier height, if the barrier height can be if the barrier height can be small. So, what you can expect that even energy less than the band gap energy will be able to deliver the current through the load. Another example is the internally field for this photodiode, what must be the field so that the response is very fast.

So, that much depletion width and V r that means, the reverse bias can be applied. So, these are the things which one can be, can consider for the design of this junction. Remember that for Ohmic contact, it is true that the Ohmic contact main application is in the device current or voltage determination to receive, or to send the current through a device or from a device you must have Ohmic contact, but remember that another important application of Ohmic contact is the peltier device, that is in the thermoelectric device. In a peltier device what happens that say there is a metal semiconductor junction.

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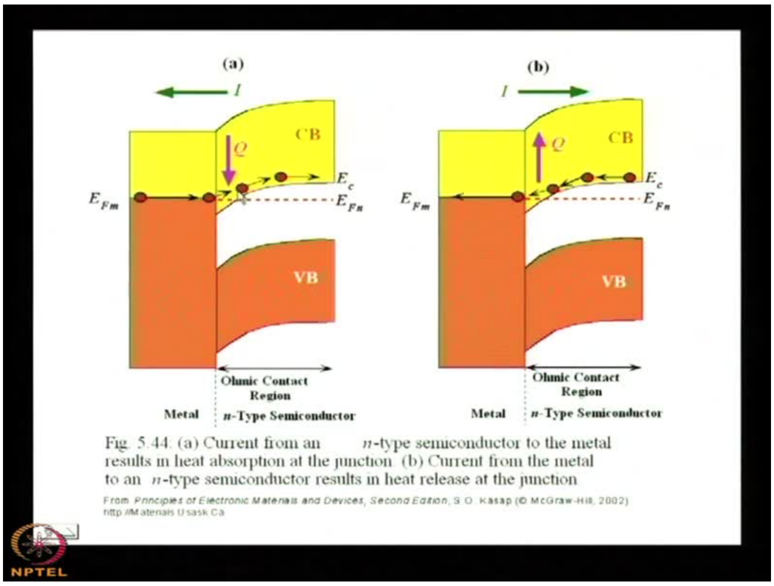

Say this example, yes say this is a metal semiconductor junction, this is metal, this is semiconductor. So, when electrons move from metal to semiconductor on the semiconductor near the junction its energy increases, why? Because you know that in the conduction band the average energy of the particles is 3 by 2 k t. So, that means it is E c plus 3 by 2 K t sorry it is E f m plus 3 by 2 K t, E f m plus 3 by 2 K t. Now, this energy is coming from what, from where this energy is coming 3 by 2 K t it must absorb heat from the junction, it must absorb energy from the junction, what is the source of energy it is a lattice vibration.

So, it must absorb energy from the lattice vibration. So, if it absorbs energy that means, that junction will be cool. That means, heat is absorbed when heat is absorbed means, that junction will be a cold junction similarly, if the reverse thing happens. That means, say electrons are coming from the conduction band of the semiconductor to the metal just reverse case then that means, here the energy was E f m plus 3 by 2 K t, but here the energy required is E f m.

So, where that 3 by 2 K t will go, it will be absorbed in the junction, heat absorption means it will be heated. So, either heat will be absorbed or heat will be released for a Ohmic contact. So, this is used for cooling a small volume of material. Since, here you see that there is a cooling at the metal semiconductor junction. So, that means something can be cooled any material of a small volume can be cooled, if you keep that material at the junction.

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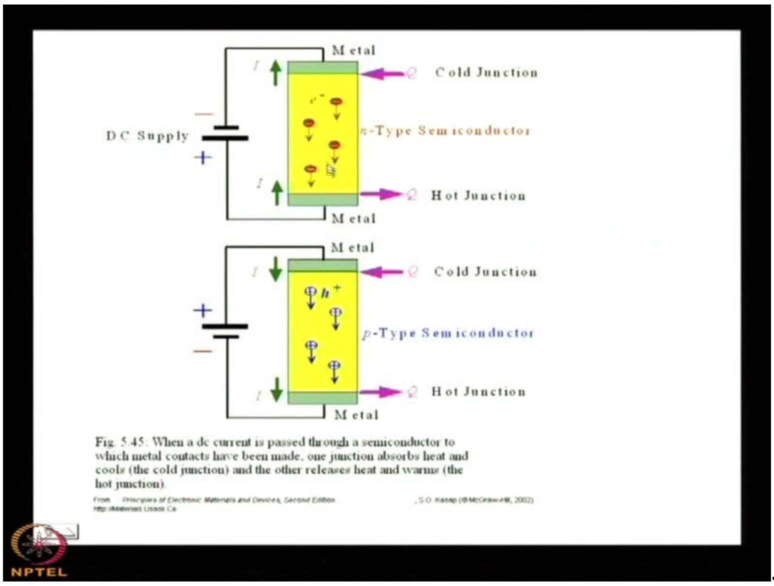

So, that means it depends on the direction of current flow here you see the it depends on the direction of current flow here, you see it is a metal semiconductor junction and it is n type semiconductor, when electrons are moving from this junction to that junction it is a cold junction. Similarly, when electrons are coming to that junction that is a hot junction. So, any metal semiconductor junction can be one junction will be hot, another junction will be cold depending on the direction of the electron flow. Yes, current flow depending on the direction of the electron flow, it will be one junction will be hot, one junction will be cold.

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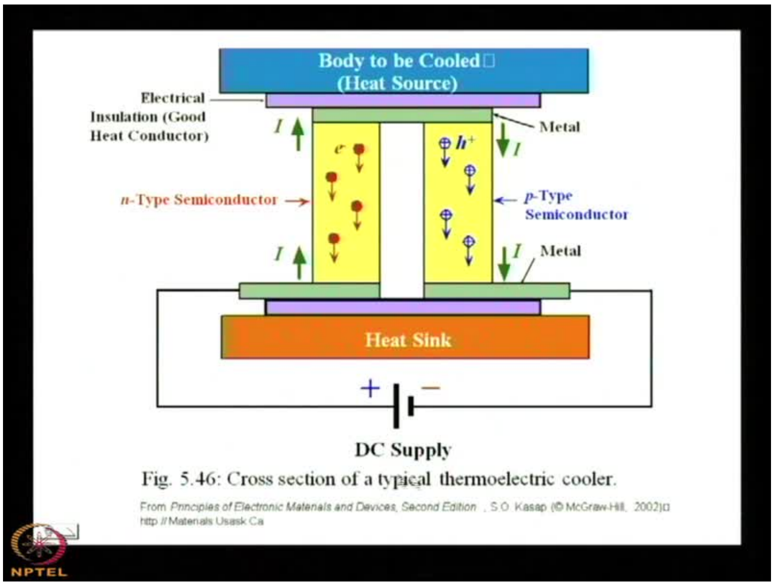

Fig. 5.46: Cross section of a typical thermoelectric cooler.

And with this arrangement you see that this is a thermoelectric cooler, where the body to be cooled is placed on the cold junction, this junctions are cold this is an n type semiconductor this is a p type semiconductor. And in a n type semiconductor this junction is cold for a p type semiconductor, this junction is cold so this has been connected to some copper wire say it is a metal means, it is copper then electrical insulation is there.

So, that it good heat conductor, but no electricity is conduct and then the material is placed on this which will be cooled and similarly, the other junction will be heated. So, this is placed on a heat sink here also it is a metal type of casing, which can receive the heat for its dissipation from the material because when it will be cooled. So, the other junction will be must be hot for the conservation of energy. So, it is a heat sink on which it is placed.

Obviously, so this can be used for a good electrical thermoelectric cooler, which is known as the peltier device. And remember that a peltier device or thermoelectric device is not a metal semiconductor Ohmic contact, it can be any two dissimilar material it can be any two dissimilar material, it is the generalized thing though we have considered this metal semiconductor Ohmic contact because we are discussing this contact, as an application, but it can be possible for any two different materials if you join one junction will be hot another junction will be cold so, that is the peltier effect. So, with this I conclude my lecture.

Thank you all.