High Speed Devices and Circuits

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Lecture - 13

Metal Semiconductor contacts (contd.)

We discussed some of the preliminary aspects of metal semiconductor contacts in a general way without referring to silicon, gallium arsenide and indium phosphide because the basic theory holds good for all of them. So wWe were trying to see also what will form Ohmic contact and rectifying contact, I just quickly go through some of them because I want to build from there today.

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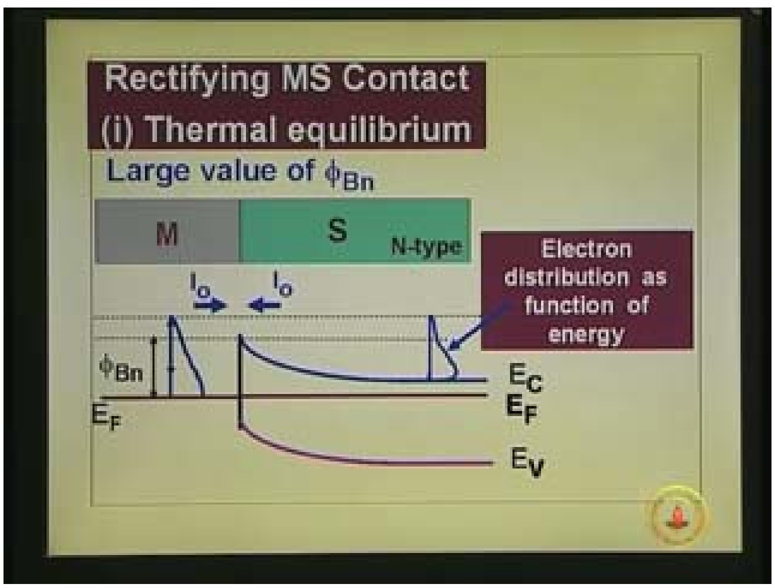

So, what we will do is, take case by case. We will take the N-type material already I have discussed yesterday but a few things I want to point out there by drawing this diagram.

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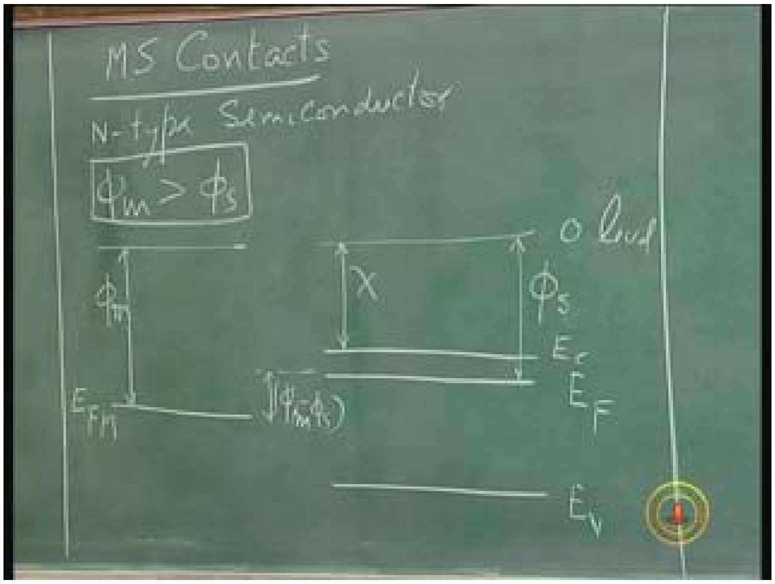

So, wWhat we try to do is metal semiconductor contacts with that general heading we take N-type semiconductor which we have done for some aspects I want that phi_m greater than phi_s. So, I will just once again draw this diagram in 0 level which is 0 level. Now, a metal is there in this portion that is E_{FM}. You will already have some of the things in the previous slides. If you take a look at that it will make things much clear. So, this is the E_{FM} and we have defined all the terms that is phi_m is greater than phi_s. So, the Fermi level is above this in the semiconductor that is phi_m and this is phi_s.

Now, if you are talking of N-type semiconductor, the conduction band is here E_c and the valence band somewhere is E_v and this is actually electron affinity that we defined yesterday or in the previous lecture. Energy between the conduction band and neutral is 0 levels.

Now the point that we had mentioned yesterday is notice the difference is phi_m. Let make the symbol consistent phi_m minus phi_s. If above this Fermi level the electrons are occupying at higher energy when compared to this. So, the electrons from semiconductor will get transported on to this metal till these are equalized. So that happens you have negative charge build up on the metal leaving positive charge behind this semiconductor. When I have this negative charge in metal, there will not be any space charge layer because what you are dumping into metal is very small compared to what we have in the electrons.

So, yYou will have on the surface hr sheet will be there which is more than usually n plus delta n that sort of thing. On this side so there is no potential drop appearing across this. So, when a charge is removed from here, there will be a potential drop appear concerned portion of this diagram. There will not be any change whatever happening on this side that is what I want to point out this.

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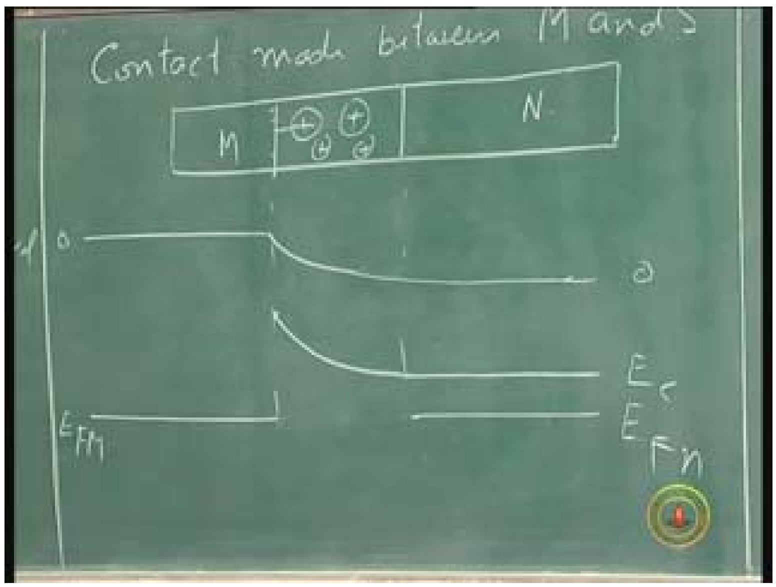

So, contact made between metal and the semiconductor. This is a metal and the semiconductor you make in the contact. So, t The electrons will get transferred on to this on the left hand side I will draw this position corresponding to same 0 level and I will not change anything on left hand side but nothing happens there because the electrons that you put are small numbers

So that is the 0 level and this position also is the same thing E_{FM} becomes equal to E_F. So, d Draw this continuously what has happened in the Fermi level as gone down because electrons have got transferred from that semiconductor to metal leaving plus charges. Why the energy levels do goes down now?. Whenever you removed electrons from there it is positively charged and it becomes easy for transporting electrons from infinity to that point. Plus charges are there. We can easily move if a point is negatively charged it becomes difficult to take the electrons because it still repel it for you expect more energy

So the very fact, you are removed electrons from here and pushed on to the other side then your left side will be positively charged. It becomes easy to take electrons to all that levels in that region have gone down energy. That is the whole key thing which I did not mention to you in the previous lecture. Because today I let kept it up for a detailed discussion and yesterday I gave you an overall picture. So that is why Fermi level has come down with all the levels of neutral region.

So, I will draw this diagram. That is the metal whose work function is greater than phi_s and this is the N-type semiconductor and let it be silicon gallium arsenide whatever it is and I have made the contact and this side electrons have moved on to that side leaving positive charges uncovering the dopants. Negative charges are here. So, t There is field from here a true static potential has gone up and energy levels have gone down because electrons are being removed. It becomes easy to take electrons and then you have a potential variation from here to here.

See this energy which all the levels have gone down and there is a potential variation from here to which would mean the energy level will bend like that depending upon the potential up to the point. We have the variation up to that point; from that point onwards it is a flat with the 0 level energy itself has gone down because electrons have been removed from there. It becomes easy to take electrons from infinity to that point which is compared to that. Here to here it had spent more energy to go there. What is about the Fermi level? You draw it only up to that point in this portion because it is a conduction band. Conduction band is draw all the way up to this point flat from that point onwards like this. So, that is the conduction band edge and the Fermi level, now if you do not draw here and you stop there. Because you talk now of the cozy Fermi level it does not Fermi level is neutral region. If you use that it will be very electron concentration on that side. Now, you can use the Fermi Dirac statistics to find the carry concentration.

Then over here the valence band that it works out better to see that diagram is drawn rather than see it in slide at one flash and that will move parallel to that so you have the situation like this. Of course, you draw it like this to show that it is the boundary of the energy band diagram surface.

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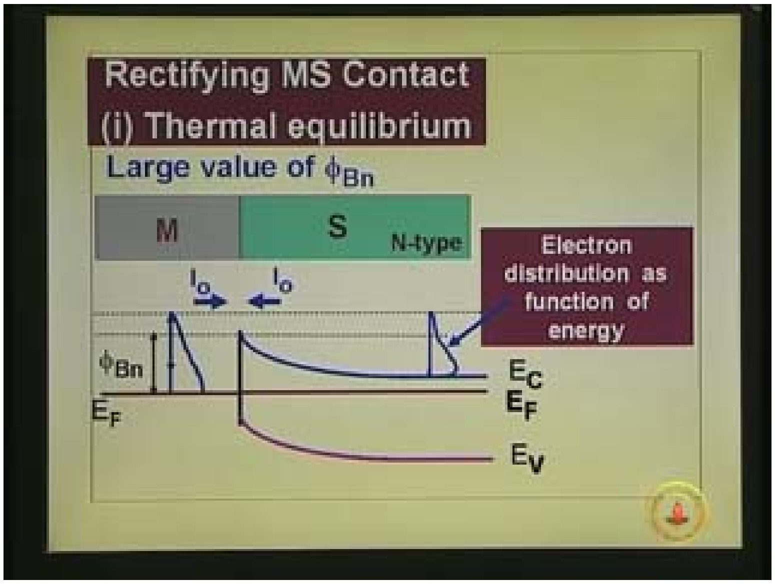

So tThis diagram what we see here is at that situation. Now I will just remove this because there is no space there the top portion is removed now.

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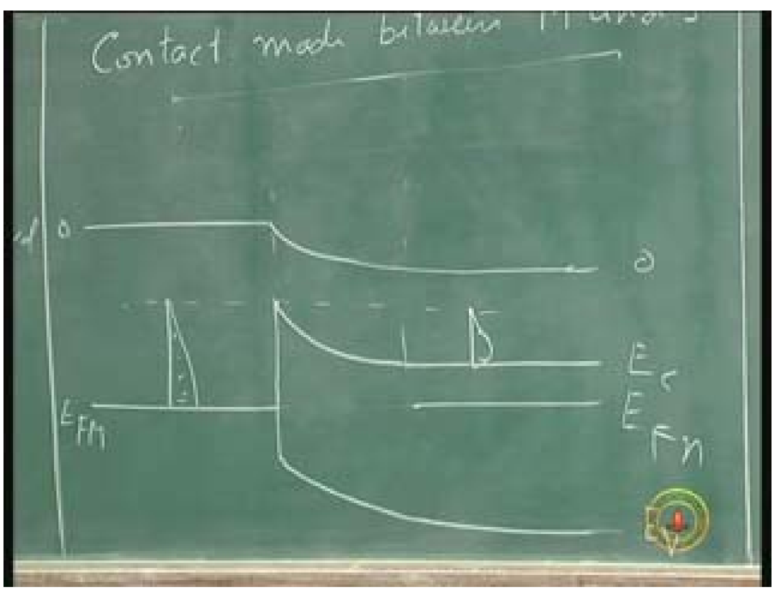

Because of now, you will understand this diagram has been obtained under thermal equilibrium condition is nothing applied. So, I will just remove that to show whatever is put there from here to here (Refer Slide Time: 11:34) the energy distribution is present here that is energy distribution. Fermi Dirac statistics levels are present all through in this metal in large numbers. So, I just draw the Fermi Dirac function itself that is given that. So, does not go to 0 there and this will be the distribution (Refer Slide Time: 11:59) all that has happened is these levels have equalized said that the tip of this matches that is what shown here.

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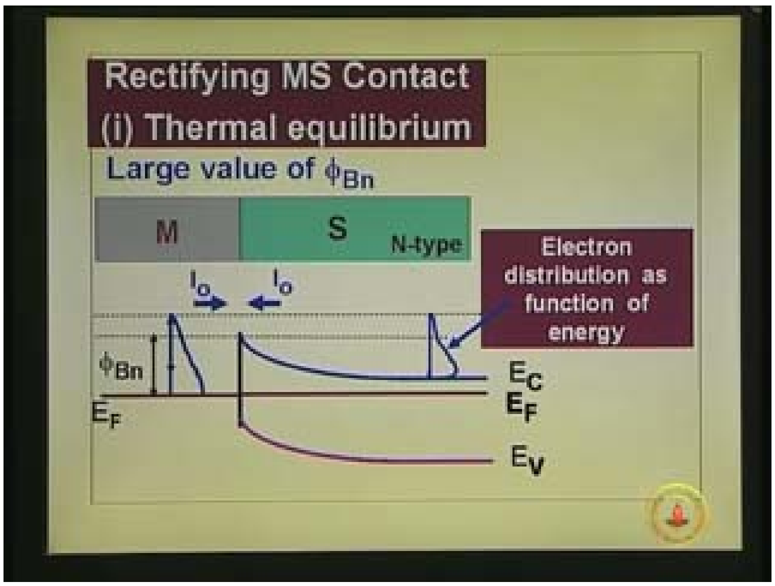

The tip is matching there and you can see the barrier here. In fact, I can refer to whole thing to this diagram itself. You can see this is the barrier which you call it as phi_{Bn} barrier for electrons. So, the electrons which are above this can cross that. So, wWhat has happened is the Fermi level when this edges number of electrons which are there above the barrier on left hand side is equal to number of electrons on the right hand side that matches that is why the current is 0. Now, the main point that I wanted to point out was this I have not shifted anything here I have shifted whole thing down with the variation there. Let go to the case where you reverse bias it.

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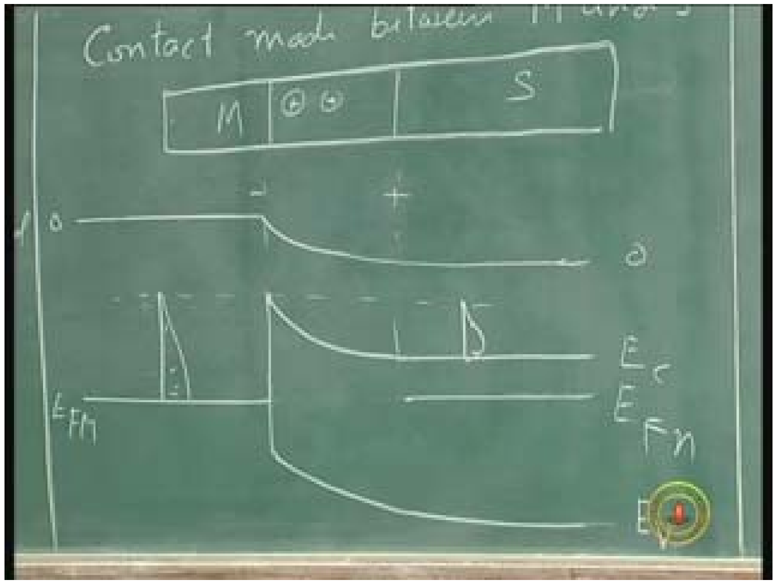

Notice also this potential is like plus and minus. Now, when I apply a reverse bias to this junction I think I could have retained this diagram. So, lLet me redraw that keep it (Refer Slide Time: 13:26). So, tThe metal and the semiconductor of this diagram come from here. So nNow, if I apply a reverse bias this is thermal equilibrium conditions the voltage can appear only at this point across this. Because in the metal, if there is a voltage that is large current flow well electron concentration is very large

So iIt is not going to appear across that going to appear across this portion. It is like two resistors in series or one resistor one insulator in series, if you apply the voltage it will not appear across the conductor it will go into the insulator. This is the insulator it goes but holds extra voltage then extra charges must come up. So tThe depletion layers widen uncovering extra charges and that widens. What happen to potential energy level at this point goes down further because you removed more electrons from the energy of those levels will go down. So tThat is why you get the entire thing shifted down there.

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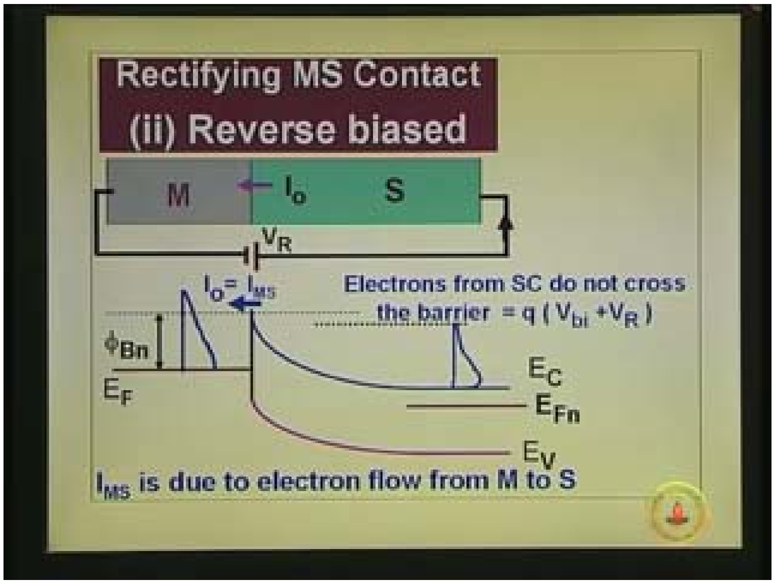

So, yYou have got just now watch it carefully that was up there going down.

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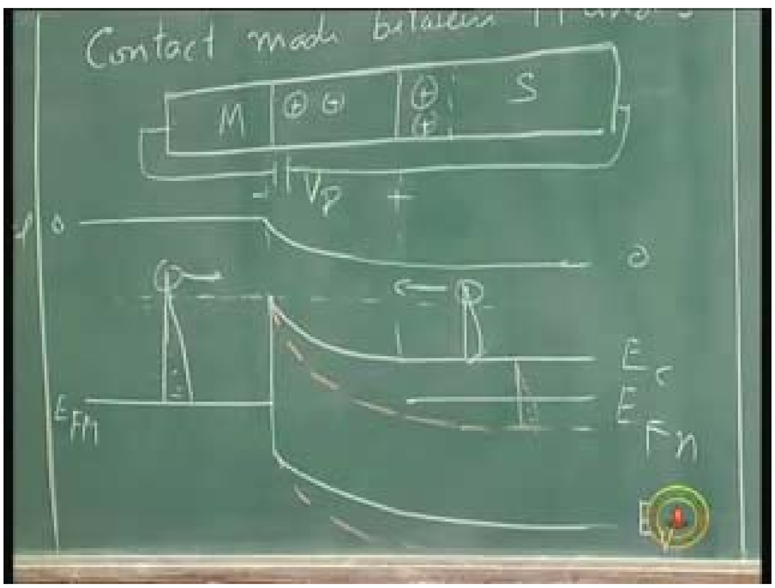

So, tThis whole curve comes down with another colour; if it is visible. So, t That is the way it goes to the main focus is on. Here now, this has shifted down with the same distribution coming like that is what is drawn there in the same distribution as there it has shifted down

But you notice what has happened in this case I just made a mistake there just redraw that the tip is actually a slightly above that I think that is why there is crossing here in this diagram it must be relook here distribution is slightly above that but it matched by the electron flow from that side.

In fact in the previous diagram it is there in slide it is already there. Just put it here wrongly. So, t That is the thing. Now, when this level goes down with reverse bias that is made it more positive V_R this will go down by an amount equal to V_R. So, tThis entire E_c will go down by V_R so whatever tip was there above this that has moved down below that.

So, yYou can see here, now going back to this point (Refer Slide Time: 16:21) if this is the thought of the barrier. On the left hand side that whatever was above that originally that has not changed and on the right hand side originally it was coming right up to this point above this just gone below. So, the electrons from the right hand side are not able to cross.

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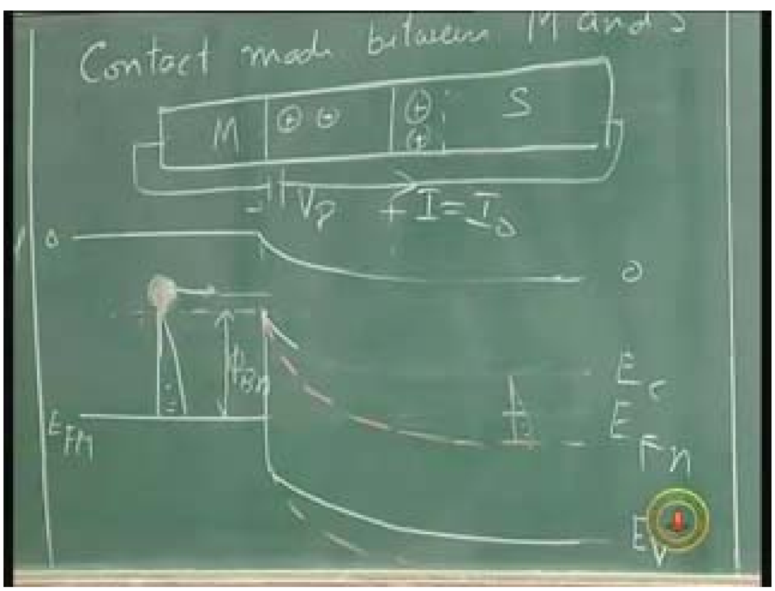

So, wWhen you reverse bias the current is due to whatever was above that. Because this is gone now and it is the picture so only these are giving rise to current flow. But again to point out what has happened is under reverse bias condition thermal equilibrium and forward bias this barrier is not changing. So, nNumber of electrons which can cross from the metal to the semiconductor that is never changing and that is I_0 current due to that is I that is I_0 changing. What has changed is this has moved down the number which is crossing from right to left is changed gone down to 0 because they are not able to cross that is what I want to point out. So, hHow many can cross that reverse bias current. Now it will be in this direction due to transport of electrons from left to right that is from right to left actual current

Actual current flow is from right to left transport of electrons is from left to right. So, h How many electrons are able to cross depends upon how much is energy above is that portion; whatever is above that will tell you how much the electrons are flowing. How much is above that depends upon how much is that minus of that. If this barrier is smaller you have more electrons. So, iIf the barrier is smaller, I_0 will be more, this I is equal to I_0. In this case that will be more. If the barrier is less that means the reverse leakage current will be large. Smaller is the barrier and larger the reverse leakage of the current. Larger the reverse leakage current but closer it will be to the ohmic contact. So, the key is that happens.

Now, here one more point that I want to point out is. What is the phi_m minus phi of S in the thermal equilibrium situation that quantity will be built in potential to see built in potential will be the energy band diagram has come down that much means that will be the potential that will be present originally there.

So, tThis quantity when you apply reverse bias, this also will come down by the same amount originally it was there. So, tThat is V_R and all that because that 0 level I have not shown here that is why just put that also down. So nNow, the key thing is the barrier height we should be able to control and barrier height by adjusting more the difference more will be barrier height more will be built in potential. Let quickly sum through that forward bias case I do not have to redraw that when you forward bias the entire thing has shifted up from thermal equilibrium situation.

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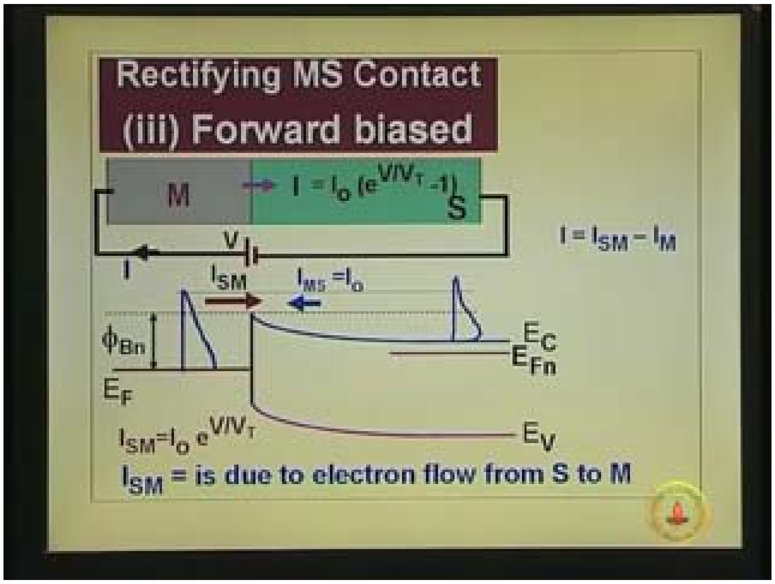

Notice here, because when you forward biased. So, tThis conduction band goes up Fermi level has gone up from the thermal equilibrium situation by an amount equal to built in potential applied voltage. Is that clear enough? So that, I just show the original Fermi level just parallel to this thermal equilibrium because you applied voltage which should be V and which is positive in this direction opposing the built in potential you already increasing the energy levels in this portion the whole thing goes up

So, tThe difference between these levels is built in applied voltage now. Once that goes up the distribution remains the same thing. Originally when thermal equilibrium condition was there, that was the limit. The tip was actually matching with that tip has gone above that level. I will just draw that for clarity

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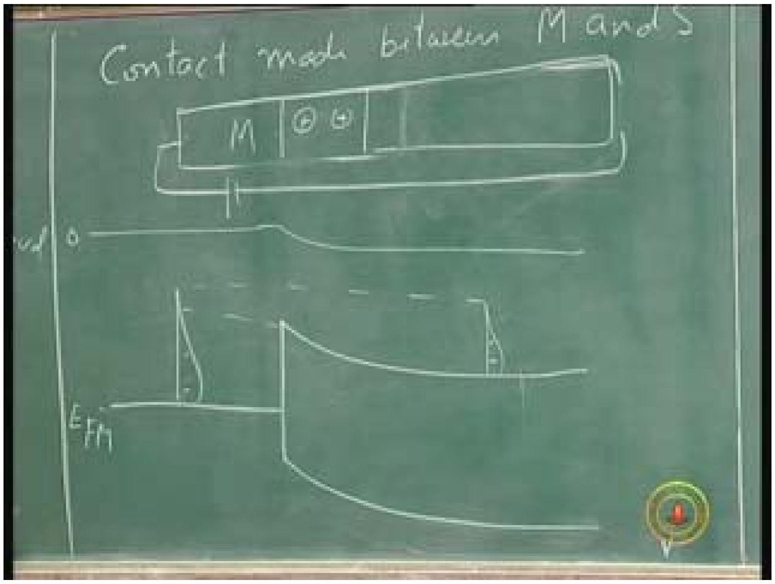

When I draw forward biased because once we go through this diagram then it becomes very simple now. What we did from thermal equilibrium situation which was like that. We have reduced the voltage by applying a forward biased.

So iIn this situation this has not changed that level is remaining same thing because nothing is happening at that level. In fact, the barrier height does not change it remains the same thing because it depend upon this conduction band edge and the Fermi level. So, in the thermal equilibrium situation if you had this thing like this those were the ones which were letting the electrons for flow and on this side redrawing the thermal equilibrium it was like that originally.

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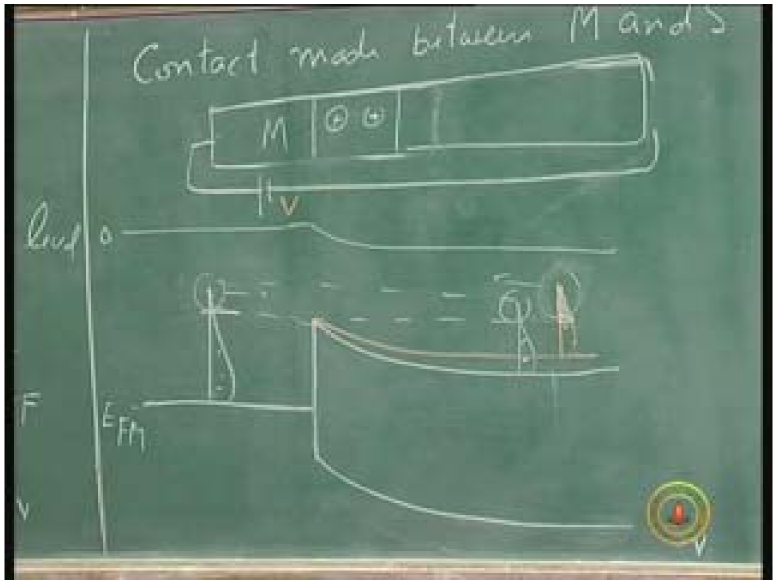

Now, when I apply forward biased V here this shifts up. So, this is I can draw with that colour just slightly drawing and corresponding to that you will have this distribution like that. Originally, you had these electrons which are capable of crossing that side and correspondingly you had these electrons which are capable of crossing now. You have this extra electrons total number of electrons here. In fact, the integral when you go from here to here those electrons are more than this number. So, they can give rise to extra current in that direction.

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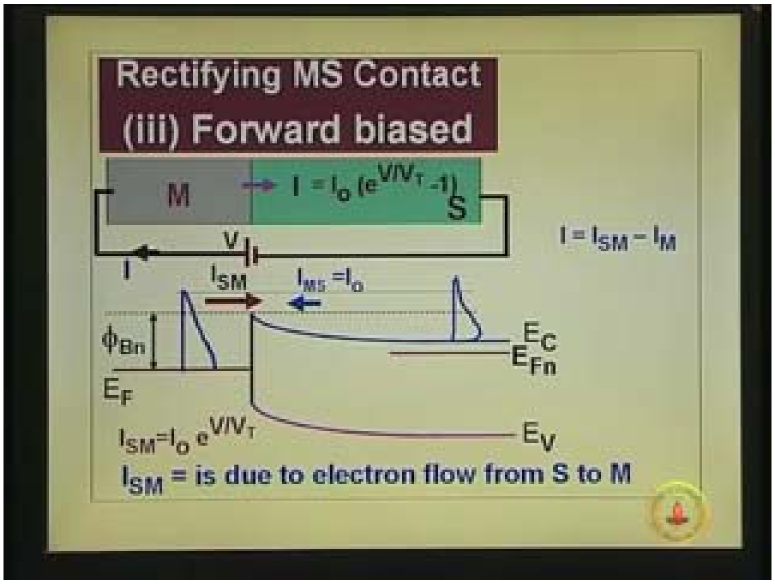

So that is the thing which we have marked as I_{SM} and I_{MS}. I_{MS} is actually current due to electrons injected from metal to semiconductor it is in the direction that is I_0. The I_{SM} is the current due to electron injection from semiconductor to the metal. That is current is from metal to semiconductor. So, tThat is the one which gives rise to this extra electron to current in this direction

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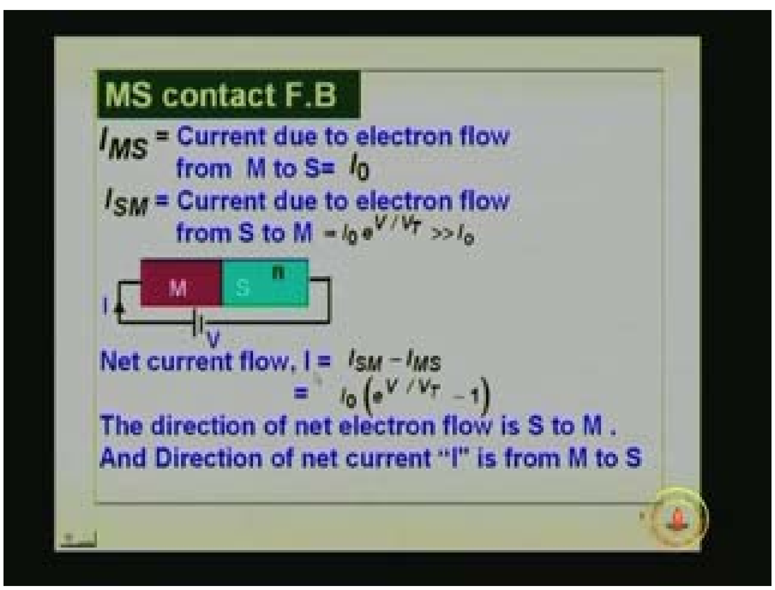

So that is why we have got now actually the current equal to I_{SM} minus I_{MS}. This I have gone through detail in last time but some of these things which you have may not been very clear. Now, with this diagram I think it is much better why those energy band diagram move up and down those things and also this extra electrons which are present giving rise to current in that direction.

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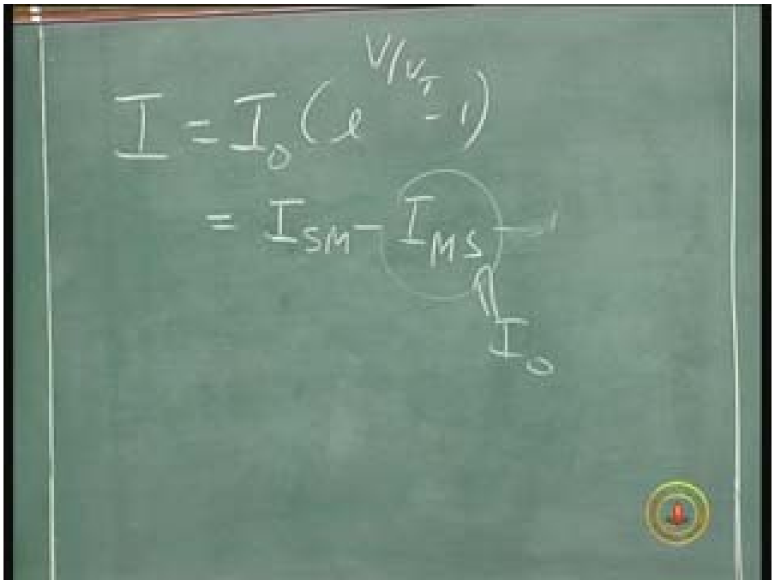

So uUltimately, you have got that current I is equal to I_0 into e to the power of V by V_T minus 1, first term is due to electrons from the semiconductor to the metal and second term minus sign is due to the electrons from metal to semiconductor. So, tThis is actually current due to the semiconductor to the metal minus current due to the metal to the semiconductor and this is the first term that is I_0 that does not change this term all the time.

So uUltimately, I explained to point out this. You can use the same equation if you drop this down 0, how do you drop this down to 0 by making V as minus 1 V_R reverse biased. So that becomes minus I_0 telling you that if I reverse this polarity whatever current was there, it will be in opposite direction with only this second term metal to semiconductor.

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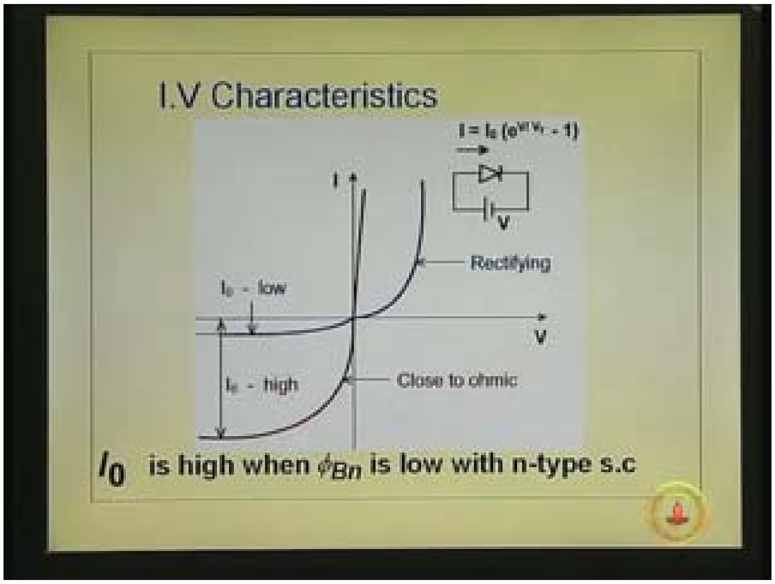

So, tThese are some of the aspects which make it clearer and now again I re showing for once more that the diode characteristics, it is after all it is a diode a good diode and a bad diode. A good diode is rectifying diode and a bad diode glows at through ohmic contact. That is all we are trying to tell a bad diode and a leaky diode.

So, wWe can see you have got a good diode. I_0 small that mean the barrier height, in the case of N-type material phi_{Bn} large which actually means phi_m minus phi_s is large. Because the bending is more and this bad one large leakage current large reverse current I_0 phi_{Bn} is small which can be phi_m minus phi_s. The difference between the phi_m and phi_s is very small or it can be even phi_m may be lower than phi_s. In fact, people are most of time will see literature N-type semiconductor with metal forms rectifying contact. If phi_m is greater than phi_s, that is what we saw. But notice if the difference becomes smaller and smaller phi_{Bn} become smaller and smaller, it can become ohmic contact. That is what I want to say because it is stretching it beyond a certain point and telling you that phi_m less than phi_s becomes Ohmic. It did not become less than phi_s till if this barrier keeps on reducing. That is if this difference is reduced this difference is reduced to phi_s that becomes smaller and smaller, so it becomes leaky. That is why I just deliberately brought this out.

Now, let us just take a look at the other case I can remove all this now quickly go through the second case N-type semiconductor with it is interesting to see what happens in a N-type semiconductor with.

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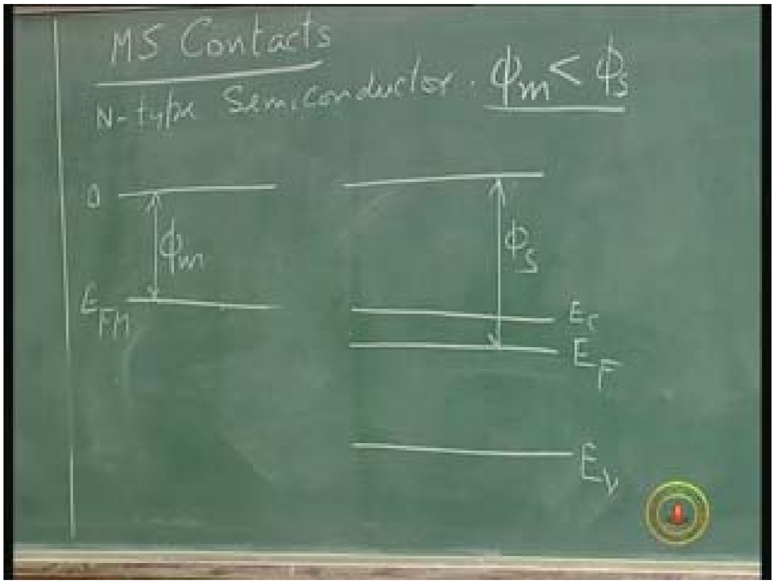

So, tThe second case now what we are going to see is phi_m less than phi of s. You should be able to clearly draw this portion somewhere here, because now the phi_m is smaller that means it is closer to this 0 level. That is the meaning of telling that E_{FM}. That is the Fermi level, now it is N-type material. We are talking of phi_m less than phi of s, this is extreme case of phi_m minus phi_s become less and less ultimately and it is less than phi of s itself.

So wWhere will the Fermi level will be in the semiconductor that is 0 levels no contact. Before contact is made 0 levels phi_s is larger than phi_m that means, Fermi level there is much below. So, lLet me put it some where here E and it is N-type material. It just draws it slightly closer. So, tThis shows small difference and that is the conduction band. What matters is how much is that. That is N-type material then I have this E_v, now what will happen?

When you join them together thermal equilibrium situation for this what will happen? Thermal equilibrium situation will be you will have electron transfer from here to here Fermi level is above. The electron transfer from here to here means you are charging this portion negatively. It will become more N-type near surface and if it becomes more N-type it becomes difficult to transport these electrons into that portion. So, tThe neutral portion here the energy band diagram will actually go up difficult to remove. If, it negatively charged when you take an electron near that it gets repelled. That means you have to spend more energy to take the electrons to that point. So oOnce it is negatively charged the band diagram will move up. That is the key thing to understand. So nNow, when you form the contact here and let me draw it bit up there, so that there is space.

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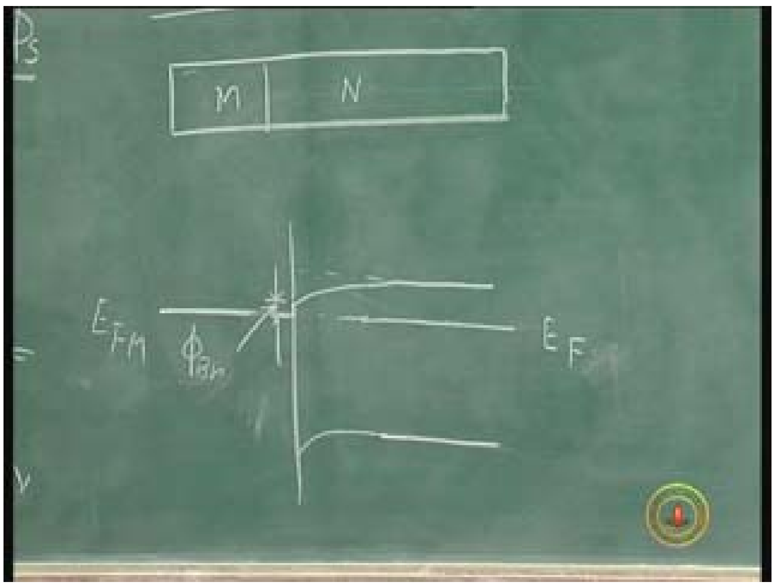

So, tThat is thermal equilibrium metal-N-type. For this case, phi$_s$ is larger than that so on the left-hand side that is not going to change I will keep it as it is and on the right-hand side Fermi level actually will go up the energy levels will go up.

So over here it will be till that is the match is there E_F and this is E_{FM} is same as E_F. Both match what happens to the energy band diagram here. I will draw that parallel there this entire thing has got shifted up. So that this two are matched and the difference will be phi$_m$ minus phi$_s$. So, wWhen this goes up what will happen the surface is actually more N-type. Because electrons have moved from here to here near the surface negative charge is there remaining. It is more number of electrons is there. So, tThat will be slightly bent down.

How much it bends down? Of course, depends upon the potential difference there. So, like this correspondingly you will have a bend here and this difference is actually equal to that difference than bending. In Previous case, it also that difference bending was phi_m minus phi of s, which was built in potential here. There is a small built in potential because this difference we are showing is small

Now, under this situation what is phi_{Bn}? See phi_{Bn} is very bad and small. If the difference is more here it can even become negative there it can this can bend below that we can have a diagram, which has a notch there. This does not have notch. The one example is that I am showing here there is no notch. So, wWhat is the phi_{Bn} that is the phi_{Bn} and of course that is phi_{Bn} and this is phi, let us not talk about that right now. That is sum of phi_{Bn} and phi is equal to band gap. If you look into this is a hole that is the barrier for holes because the energy of holes is higher when you go down

Now, what is the distribution of electrons from by transport and how does it take place? Thermal equilibrium let us plot like this (Refer Slide Time: 33:44) and this is the barrier, so many of them are above that barrier? We can immediately say that it is a very poor rectifier will be an ohmic contact.

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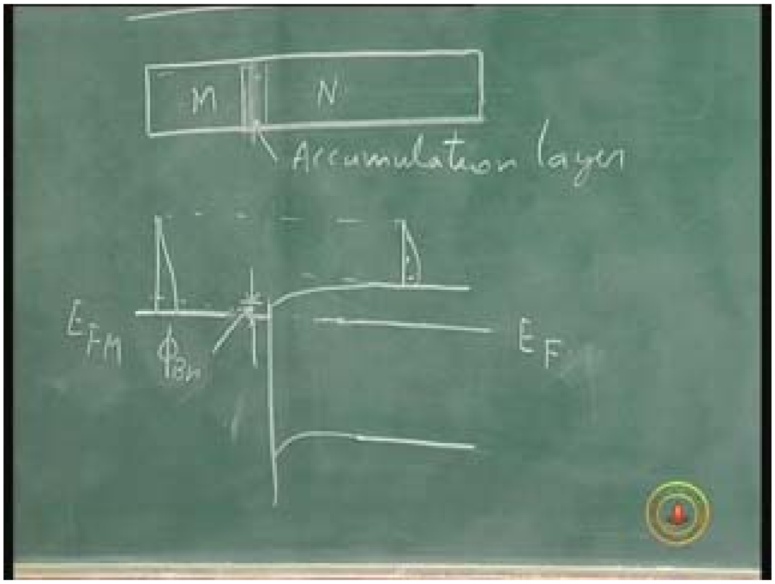

So that is why this is the stretching whatever we have been telling earlier that is phi_{Bn} smaller and smaller it becomes ohmic. So, iIt did not necessarily be phi_m less than phi of s it can still become ohmic but when it is less than that, it is definitely ohmic. So nNote here, let me remove that portion now because that is the barrier and from here you have the electrons which have the energy. You can see total number of electrons here will be more that.

So that is the thing, now what will have to say I do not have to draw any more diagram. It is very clear from here; so many electrons have their energy greater than that here which can above cross the barrier. That number is matching with that here all the electrons should be above that the level has adjusted such that number crossing from left to right is matching.

Now, if I apply a potential to this. So, wWhat you have here is a slight accumulation layer. You can draw actually the diagram, if that the difference is too much. In fact, you should be able to draw that, this will come down below that and you will have virtually a diagram which will go like that. You can I leave it to you as exercise to see. How the energy band diagram will be if this difference is even more that we can do.

Now, let us see what happens when I apply accumulation layer here. In fact, a small potential change will accumulate lot of electrons there, because it is proportional to majority carrier into e to power of V by Vt. Majority carriers are large. So, wWe can with this small change in voltage there is lot of difference here. That V is whatever comes there now if I forward bias what happens? Which is forward bias, make this plus that minus what will happen?

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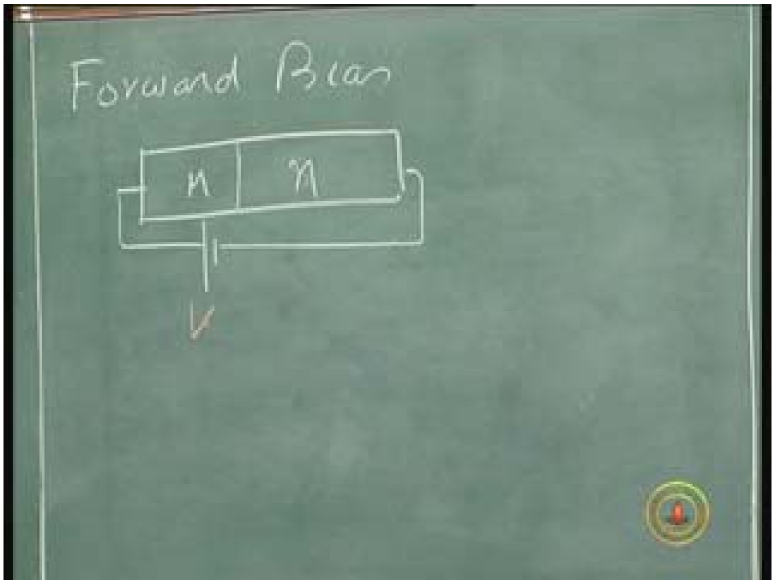

If I make this plus that minus forward bias (Refer Slide Time: 36:45) N-type, what will happen? This will go up or down, you are having a potential which is minus plus. When I am forward biasing actually I am reducing that you are changing the barrier one of them you are moving out. In fact what happens is now the electrons are moved from here to here charging is negatively. If I make that plus on that side, so polarity is like that because electrons have gone from metal to semiconductor that is the polarity and because of that polarity I have got this barrier like this.

If I make a voltage like this forward bias what will happen to this? You are increasing that it will go up. So, iIf you take a look at this whole diagram (Refer Slide Time: 38:07) of forward bias. So, tThat is the forward bias V.

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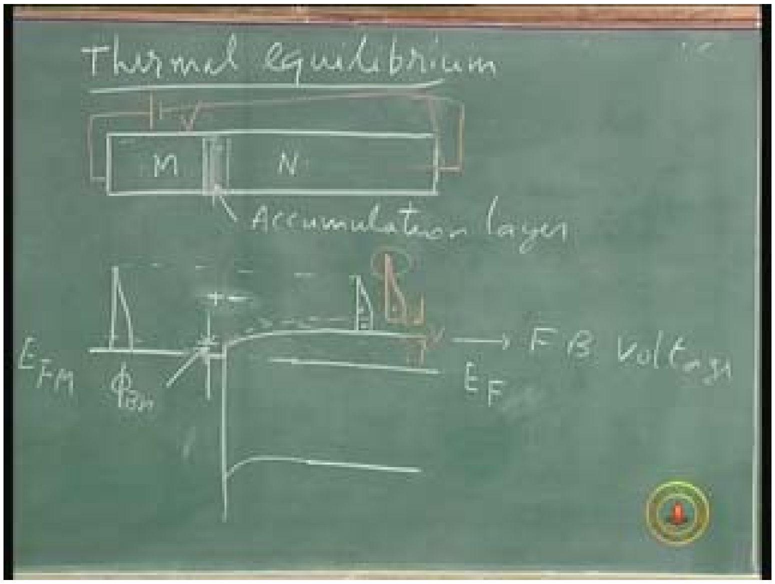

Now, if that is the case what will be the distribution now? Let me just put it down slightly bit away that is the forward bias voltage V by which it has gone up. Let me put it here itself. Distribution here does not change, what was above this was matching with that originally now this has gone up. So, tThe extra electrons the electron energy has gone up there the extra electrons now have energy to cross the barrier. They will give rise to electron flow in that direction which gives a current flow metal to semiconductor. So, battery has to raise current only in that direction.

So, tThis lifting up has enabled addition electrons large number of electrons are there they can cross. If it was downward what happens if we push down here there is so much is there thing goes down. See right now, thermal equilibrium only these are crossing. If when I reverse bias it this entire curve come down and the number that goes down I do not know whether we can draw it on same diagram. If you just supposing I reverse bias I think I will not draw it I will just show that to you this level will come down that means this whole thing will come down depending upon how much reverse bias. The moment this level comes down originally, only this much was there that was compensated by that. When this comes down the number compensating was disappear slowly, so huge number of electrons can flow.

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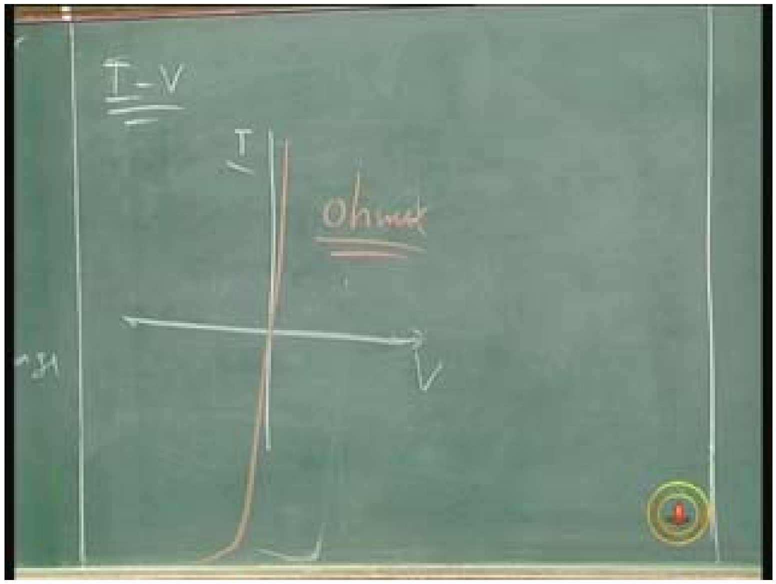

So, tThat is why this I_0 is large and you get the I-V characteristics like that going down. Let me just draw it separately here so the characteristics I-V is current versus voltage. You can write still I is equal to I_0 into V by V_t minus 1 that is like this. You may have to go down there to get right up to that point very leaky diode. Almost all of them will be able to cross from separating this down is very small voltage large current to flow through. So, tThis is a close to ohmic contact.

So, tThere is no trick if you want to make the ohmic contact, choose a material whose phi_m is smaller. It need not be less than phi of s, So long as it is closer and closer to that phi of s, you will have closer and closer to ohmic contact otherwise rectifying.

Now, go back to a p-type substrate. We can quickly draw those diagrams p-type, so this where you can see literature saying if phi_m is greater than phi of s in N-type substrate will become rectifying phi_m less than phi of s in N-type substrate metal semiconductor contact plus Ohmic. But in between situation also it can become ohmic because so long as the difference is small it can be Ohmic, if the difference is large that is rectifying that is the point I wanted to say in stress. So, tThat is missed out in many places

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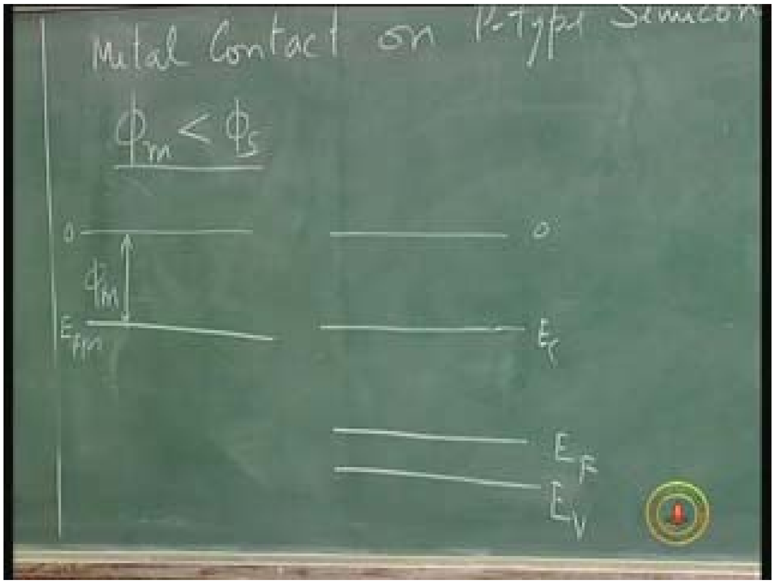

Now, metal contact on p-type semiconductor. Let us take the case, where phi$_m$ is less than phi of s. When phi$_m$ is less than that will draw that 0 level corresponding to the semiconductor and the metal that is 0 level, phi$_m$ is less than phi of s very easy because Fermi level in p-type semiconductor is way down

If you see N-type and P-type; in a P-type, E_{FM} is below so for same metal. If you put, we will have conditions different, so this is the E_{FM} that is phi$_m$ and this is smaller than phi of s and a P-type substrate. So, yYou will have this way down here and P-type semiconductor. E_F is here close to valence band and E_c is here close to conduction band

Notice here, if it were N-type could be that this is closer to that phi$_m$ and phi$_s$ may be matching. In fact it turns out to be so if you take aluminums of metal, aluminum work of function is about 4.1 phi$_m$ chi electron affinity in silicon is 4.05 and gallium arsenide also about that, so phi$_m$ is practically 0 phi$_m$ minus chi is very small. So, iIf you take N-type substrate with conduction E_F is close to conduction band phi$_m$ minus chi has to be very small you should get ohmic ideally. If you take P-type substrate that extra difference is there. This almost matching there if its aluminum and semiconductor that extra difference is there. Now let us see, what would happen so this is the semiconductor and this is the metal I bring it them together thermal equilibrium.

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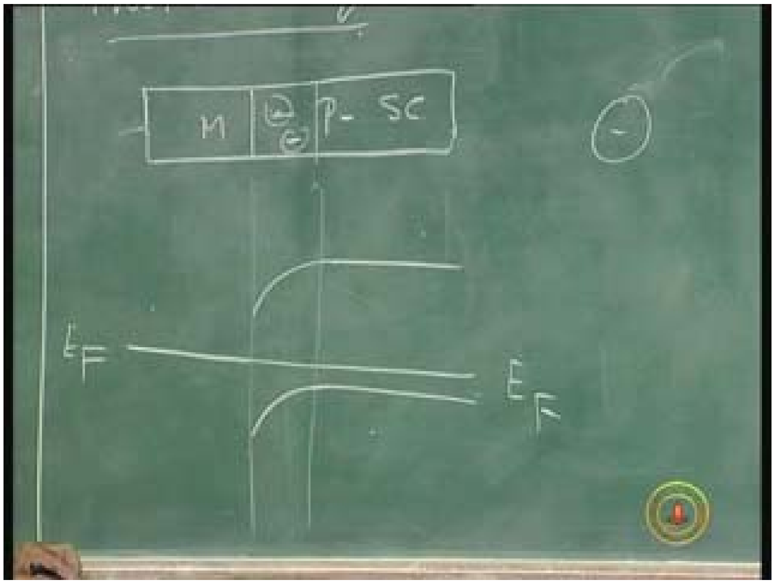

I will write down here, so we have got this specification metal p-type semiconductor. So, yYou have got nothing is going to happen here. Because no potential changes will take place in the metal. So, I will retain here. Since, Fermi level is below the electrons which have higher energy can cross over to that till they are equalized. So, tThe same thing happens here. When you have this E_F becomes same both cases electrons transfer takes place from metal to the semiconductor till the Fermi levels are equalized. Because electrons are at higher energy compared to this semiconductor E_F higher means higher energies are there. So, nNow what will you do for this portion electrons have got transferred from here to here that means this has become negatively charged

It has become negatively charged means a p-type semiconductor if you push electrons into that will neutralize the holes. So, wWhatever holes are there are removed the portion becomes negatively charge you get a depletion layer. So, when because transfer of this you will have depletion layers which are negative charges it charges negatively. Otherwise, you have that transport electron on to that is removed negatively charged. So, nNow here what is the energy band diagram how will you draw now?

Once, you draw the Fermi level it is very easy, you know that this portion is actually this is flat and that it is the valence band comes flat like this and this is negatively charged which means there is a electric field in that direction electrons have moved over there so there is electric field from left to right.

We can see it very easily; you have got the electrons transferred on to that more negatively charged. So, tThe entire energy level has gone up till the Fermi level matches with that repeat again electrons have got transferred there difficult to the bring electrons closer to that point the energy of those portions goes up energy level. So, tThis has gone up and now here that will bend down like this because electrons have gone in there it is a depleted layer or less p-type conduction band and valence band gap increases.

It is a depleted and p-type there are mobile electron holes are there that becomes smaller and smaller as you move away it may not be 0 that means some hole will be there. It is very small so it become less p-type and here conduction band like this.

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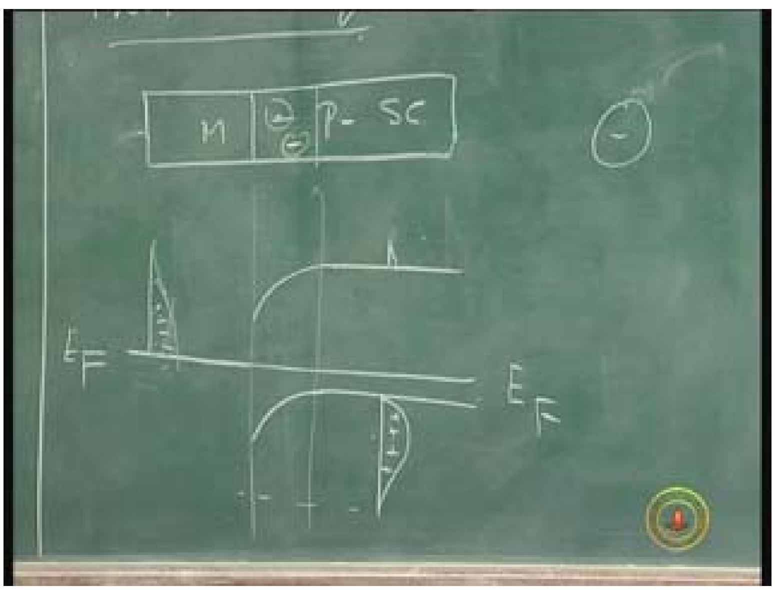

Now, you talk about these electrons may be very small numbers here and the one charge carriers in the semiconductor are not the minority electrons the holes that will come like this. Where mobile holes which have energies above that and in the metal also you can talk of holes in the sense.

See, you have got the electrons here which are coming like this you have got the electrons there. What is this due to? wWhere has it come from here?, 0,; if you go down at a very low temperature denote most of electrons will be below that. Now as at room temperature the electrons have gained energy and gone up and they have to come from here. So, tThere are actually vacancies which are present maximum here. If, you go down you will have similar distribution for the holes. What is hole after all it is absence of electrons which have gone up from there.

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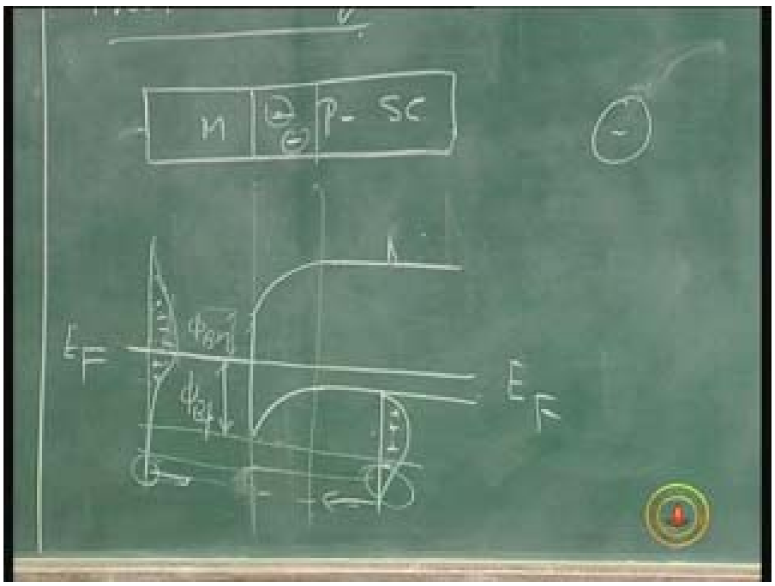

So, tThese are vacancies which can interact with these, so instead of talking of electron transport there we can talk about transport here. They are actually matched with the energy from bottom this levels are tip at thermal equilibrium. So, tThe holes which are having that can cross this barrier. This is the barrier. What is this actually? phi$_{Bp}$ and this is actually phi$_{Bn}$. We do not have to worry about phi$_{Bn}$ now, because this is small and this is the breadth point. Now, we have to see what happens to this energy band diagram. So, yYou have got those holes just crossing the barrier diagram here. I have not shown that but you have got some of the descriptions which come up later. So, yYou have got some of these holes which are the barrier. We will redraw that all these holes have energy greater than that barrier. I will start it and redraw that here.

And all these holes above that can cross that are I_0. How many holes can cross from here to here depends upon this barrier, more it is that becomes low that is exactly what we are talking for electrons holes only instead of taking the barrier up there you take of the barrier down here. Now, when you forward bias or reverse bias this, what happens?. This number here is not going to change all the number that will be changing will be this.

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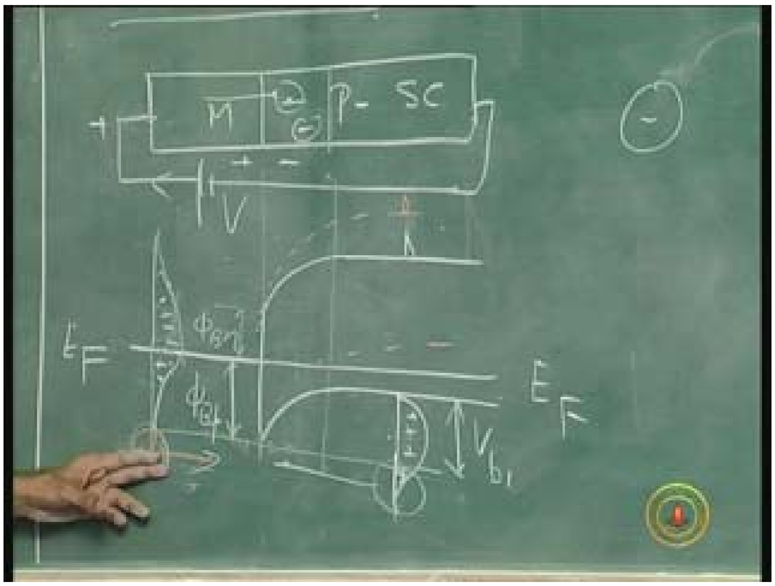

So, iIf I actually apply a plus voltage here, what would happen? I make the metal positive with respect to the p-type substrate what would happen to the barrier? You have to just see this is the built in potential here. Whatever bending was there is the built in potential and the polarity is plus minus built in potential.

When I put a polarity here V here I am not telling whether V or V. I am just telling you V now, which polarity is aiding on to the built in potential is plus here minus here. When the energy band diagram goes down that is positive and negative here. If I apply V that is adding on to that if it adds on to that what happens to the energy band diagram this whole thing actually go up like that. So, you have the energy band diagram gone up. When it goes up, this will go up there, this will go up there like a minority carrier and this actually is not changing.

So, current due to electrons will be there small current because of this minority carrier which will be very small like the pn junction minority carrier current that will be there rolling down because you have taken it up and this distribution goes up here.

I think we are running out of time today. So, I just go back to this particular I-V characteristic of this p-type substrate tomorrow or next lecture. So, the idea here is, electron is not contributing when it goes up. Because the electron concentration is small but when this goes up what happens to the whole concentration which you are passing from here to here that is going up now.

So, nNone of these holes have enough energy this is a barrier for holes, we have more barrier there not able to cross but this number crossing from here to here remains the same thing. So, you will have now current due to these holes which are crossing from here to here. We will have that is from here to here holes crossing from metal to semiconductor. So, yYou will have current to do them like that and that number will be small, if this quantity is small and that quantity will be small if this is large.

So, hHere again this will be forward bias or reverse bias. Reverse bias, if you are blocking you are not letting these holes to cross, you are discouraging them from opposing the current flow here. So you are removing them out of competition with this elect hole. So, o Once, this is removed out of competition only this is there and that is constant. If we keep on increasing that reverse voltage from this goes out this goes on increasing and at the end you will have I_0 which is decided again phi.

I will get back to this tomorrow. Then some of that may take me for 10 minutes or so. Then we will see whether what we are talking in real practical structures may be slightly different that we will take up tomorrow in next lecture. Thank you.