Fundamentals of Semiconductor Devices

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Lecture – 22
Breakdown of Junction and C-V Profiling

So, welcome back. So, today we shall start a new topic and that is metal semiconductor junction. So, we have covered many things till now more recently we have learned about P-N junction and there are many properties the current flow, the depletion and so on and so forth. We also had discussed about capacitance voltage profiling of a P-N junction, how it breaks down breakdown mechanism and so on. We had also touched very briefly on the working of devices like LED or photo detector using a P-N junction as the basis right. So, P-N junction forms the basis for most of the things.

You will see that in metals semiconductors junction the analysis is surprisingly similar to P-N junction, except that instead of p for example, you will have a metal. So, the analysis and many of the things are surprisingly similar, although the implications and the applications might be very different. And now before that we have to also understand why you actually need to understand a metal semiconductor junction.

So, we have to start with that. And you will always try to recall the similarities at P-N junction, so that will help you understand it faster. And in metal semiconductor junction will eventually do the same thing, the depletion, the built in voltage, the field and or maybe the current, you know the P-N junction we had current equation the this diffusion current. Similarly, in metal semiconductor junction also will have some current. So, because only then we can understand how the devices based on these junctions will work right. So, we will come to that today.

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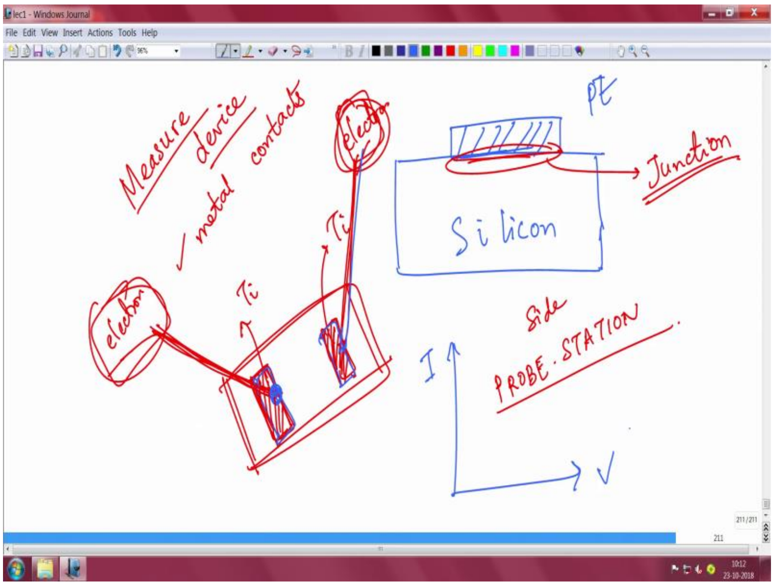

So, let us come to the whiteboard and gets into you know get started with metal semiconductor junction. So, in general when I say metal semiconductor junction, suppose this is silicon you know it can be p-type, n-type anything , maybe intrinsic also. Suppose, this is silicon. When I put a metal on top of it suppose I put any metal say titanium, I can put titanium, or I can put maybe you know I can put gold maybe any metal or maybe I can put a composite metal like a stack for example, I might put platinum and then gold right a stack of that. Initially, I will put platinum and on top of that I will put gold right. So, and thickness also could be anything right. So, this is a metal semiconductor junction.

So, I will talk about only one metal here; let us not talk about two metals. So, suppose I I put a metal down here suppose, I put platinum or something else. So, this, this interface this is called the metal semiconductor junction right that is a metal semiconductor junction. And a metal semiconductor junction is very important. Now, of course, the first question is why is a metal semiconductors function important, because whenever you have to measure any device , whenever you want to measure any device, any device, it can be an electrical device like transistor, power amplifier, it can be you know LED solar cell, it can be anything. Whenever you want to measure device, you need to put metal contacts, you need to put metal contacts.

Suppose, you know if, this is a side view, from the top view, it might lo like you know this is silicon this is one metal stack from the top. This is one metal say Ti – titanium, and there is metal say titanium, from the top view . When you measure a device, suppose these are two paths for a solar cell maybe transistor wherever; so a P-N junction whatever right. So, if you put too metal contacts like this , then only you can measure the current.

So, how do we measure current you know, you measure the current in a wafer on this, this is a wafer, this is a semiconductor sample or a wafer. You measure something using a system or a tool called probe station, there will be probe tips the probe tips will actually come like this. These are the tips at which you probe ; these are probe tips and they will be connected to some electronics some circuits and all to measure apply voltage, apply current and so on.

This will be connected to some electronic circuits and all, but there will be two probe tips that will be connected to arm and those arms are connected to some electronics and other circuits and all . So, you have to put down the probe tips. These probe tips are very tiny. This, this, this, this diameter could be few microns. So, when you put down the probe tips on these metal pads, then only you measure IV. When I say you know you are measuring IV for example, if you remember silicon in a P-N junction we set in the forward bias, the IV lo something like that, and the reverse bias IV los like that if you remember.

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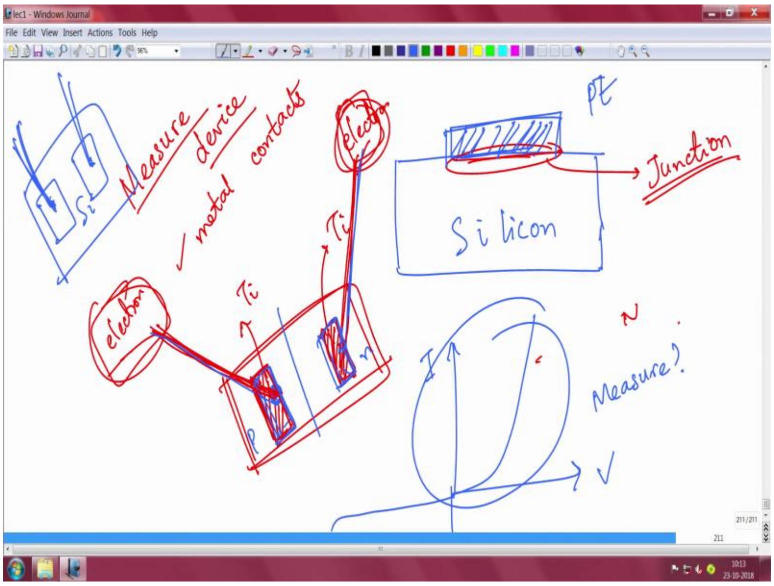

How do you actually measure this, how do you measure this? You measure this by you know if you have a P-N junction for example, suppose this is P-side, this is n-side, you have put a contact in the P-side, you put a contact on N-side, you have to bring down probe tips like this, and only then you measure. You apply voltage maybe you measure current and so on. So, you need to put metal pads, you need to put metal pads on semiconductor and measure.

You do not just take a piece of silicon like this, and just put down the probe tips like this , sometimes you do, but most of the cases you do not do like that because this probe tips do not make a good contact with silicon, you have to have a metal pad only a metal pad or a metal contact will make a good contact like this you know and then you put down the probe tips.

There are mainly two reasons even more reasons, but primarily they are two reasons why you have to put a metal contact like that , and that is why that is the importance of metal semiconductor junction. We will come to what are the two reasons here, but there are actually many things when we talk about metal semiconductor junction we also have to you know, understand how we measure and stuff like that.

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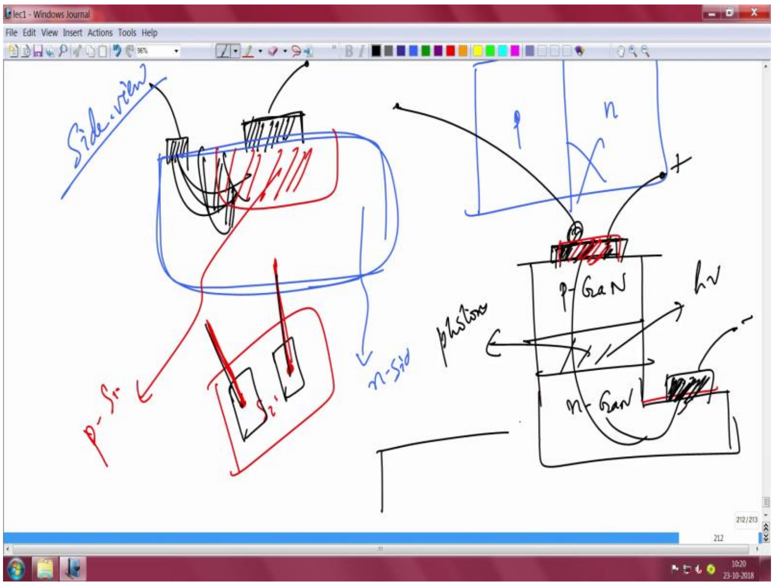

For example, P-N junction is not like that, you measure p, you measure n, the top views are not like that, this is wrong. Actually a P-N junction los in a side view , a side view P-N junction, if you take a silicon wafer for example; this is a silicon wafer the side view silicon wafer the side view. So, there could be a p pocket here which is p-type doped this red color is p-doped silicon; and the n-type is the blue the blue is the n-type silicon. So, you might want to put this is black is the metal . So, I am putting a metal contact on the p-type and perhaps I put a metal contact on n-type and then I measure. So, it is a P-N junction here right there is a depletion here, this is the depletion and on.

In reality it los like that. You need to put a metal contact to measure. For example, in an LED, in an LED, you have a p-type gallium nitride. So, gallium nitride is the material that is used to make blue LED by the way . The blue LED actually use the white led eventually that you buy from Philips or any other company right. So, it will be P-N, and then there will be some layer in between GaN and then there is an n-type GaN here right.

So, you essentially put a contact to the p-type GaN, and you have to make a contact to n-type can also. So, what you do is that you etch it down like you come it come to down. So, this is your n-type GaN, this is your p-type GaN, n-type GaN, you put another contact here. This is your contact to n-type GaN this is a contact to p-type GaN. So, when you forward bias, this is plus, this is minus that is forward bias, then the current will flow and the light will come out here, hν light will come out photons will come out. In reality, it los like they are actually .

So, what I am trying to say is that metal contacts are very important, they are quintessential, and extremely essential to make a device you know to measuring a device to actually understand to make any device you need to put metal contact . Even for wire bonding, this is one wafer when you package the device, and you put it in a you know chip or you want to package module or something that you can buy off the shelf, then you have to wire bond the device. Even for wire bonding you need to put the metal pads on which you will put like a ball and then you would wire bond out to make a package. So, metal contacts are very important . And hence we are going to study metal semiconductor contact.

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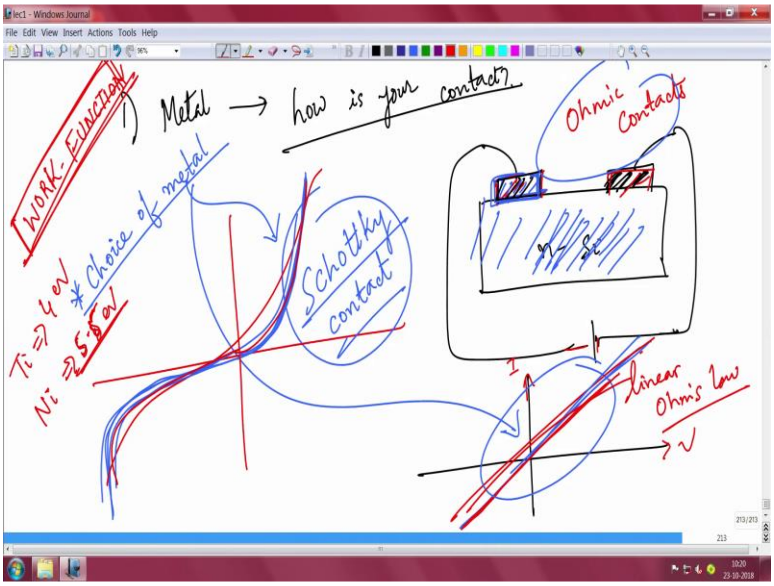

Now, what are the two reasons that are metal semiconductor in contact is very important. Because number one reason is that the metals semi the metal that you put will dictate whether your contact how is your contact, it will determine actually how your contact is. When I say how is your contact, I mean to say how is the contact between the metal in the semiconductor what is the nature of the behavior of the current that you will measure across the junction .

For example, if I put for example, n-type silicon and I put two metals here of some metal say maybe titanium or maybe aluminum . And I measure and I measured you know current voltage characteristics between them, then I might get a curve this is IV by the way this is IV current-voltage, I am measuring. I might get a curve like that which is linear which is linear which follows Ohm’s law right. Ohm’s law as in like the voltage is increasing the current is increasing linearly, it is a linear contact, it is Ohms law .

And this type of contact that will make sure that you get this kind of a linear behavior. This kind of a contact here that makes sure that you get this kind of behavior are called Ohmic contacts Ohmic contacts, because when you put those metal titanium and n-type silicon, you measured a current you get this linear kind of it IV for example . I am just giving an example that could be variety of metals and variety of semiconductor combinations that you might have.

But if you put some other metal maybe platinum for example, or maybe gold example , then you may not be able to get that kind of a linear IV. What do you might get, you might you might get something like that . It is a non-linear IV actually, it will very much lo like a P-N junction sort of a behavior only it will have it turn on here and then after some voltage will break down here. It will lo like a P-N junction, but there is no p-type silicon here it is only n-type silicon, but the choice of metal will dictate this and this kind of behavior is called Schottky behavior .

Schottky behavior which is non-linear and the contacts formed is called Schottky contact. So, primarily there are two types of contact Ohmic contact that gives you a linear IV; Schottky contact that gives you this kind of P-N junction like a non-linear diode like IV. Both on the same material which is n-type silicon same dope, it is the choice of metal please remember that it is the choice of metal it is the choice of metal that will dictate whether you get this or whether you get that.

I mean this semiconductor has to be slightly doped to something if it is completely insulating you will not get a very good Ohmic contact right. Before making a Ohmic contact, you need to have charge. So, it has to be mildly doped for example or even highly doped. So, a choice of metal will dictate whether you get this kind of behavior or you get this kind of behavior. In some devices you actually intentionally want this kind of Schottky behavior in some many of the devices you actually want this kind of linear behavior .

So, the most the one of the most important reasons why metal semiconductor junction is important is because the choice of the metal will dictate what kind of contact you make, what kind of IV you get and that will dictate your device performance dramatically. So, it is important that we understand how these metals semiconductors junction is formed and what choice of metals will dictate what kind of contact .

And the reason why the choice of metals will either form this kind of a non-linear contact , or this kind of a linear contact is because of the property of metal called work function, because different metals have different work function. If you recall from your 10 plus 2 or high school physics and chemistry, work function is the energy required to knock of an electron from a metal.

So, different metals have different work function. For example, titanium has a work function of around 4 electron volts. So, which means if you are applying energy of 4 electron volts, you are able to knock of an electron from the titanium. For example, nickel has a work function of approximately 5.5, it is a large work function metal you need to apply much larger energy or larger voltage to actually nickel to knock off an electron. So, the work function of different metal is different. And because of this work function of different metal being different, you will actually end up getting different kind of IV, we will see that .

So, the choice of metal is very important and metal semiconductor junction is very important, so that is why you need to you know put metal to actually measure the device. You cannot just bring you cannot just have a piece of silicon and you put to probe tips like that. Because this probe tips are mostly made of tungsten so you will have only one kind of work function of tungsten. So, the contact you form will basically cannot change the nature of the contact whether it is Ohmic or Schottky right. So, you need to put a pad down, right you need to put a pad on the top of pad you bring the probe tips down.

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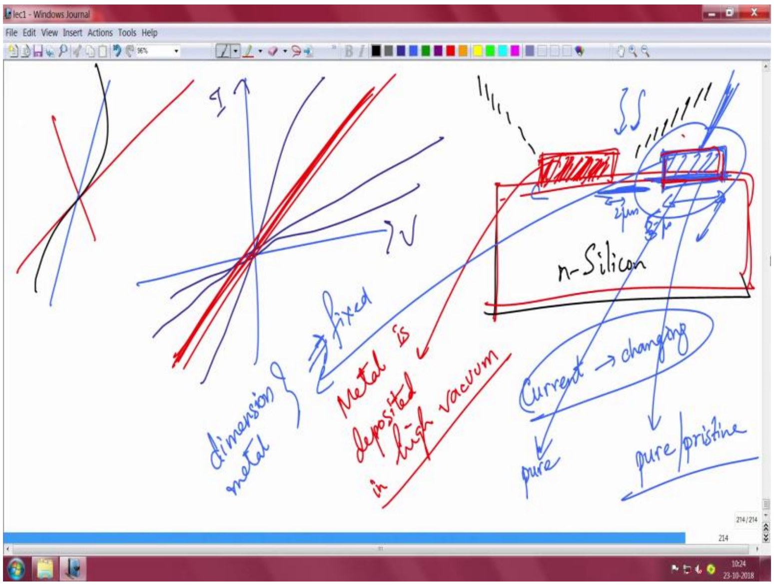

And secondly, whenever you have semiconductor for example, suppose I take a piece of silicon suppose that and am taking the side view of silicon wafer. So, this is a side view of say n-type doped silicon . When I bring down the probe tips to measure, I told you probe tips actually lo like this is tiny, this is one probe tip and this is one probe tip. If I do not put metal pad, I just bring the probe tips down then of course, when you measure the probe tip here it accumulates dust and other junk and atmospheric moisture and all the things . So, the size of this actually keep changing, it might gather some dust, it might just have some dust and so the size of this keep changing.

When the size of this keeps changing, your current also will keep changing, every time you measure right. Because how much current you are measuring depends on the contact area, the size that you are making. So, because of dirt going on off and here and there, there is no control on the size that you are having it might be 2 micron suddenly damaged by big this particle it might be 5 micron right. So, the current will keep changing.

Every time you measure IV, suppose I take a contact and I want to measure the first time I gets an IV like this. The second time the dirt has become more, maybe you know when you measure these are microscopic I mean this is a few micron you cannot see with your eyes the tips. So, you have to lo a micros cope. You saw that there is a junk here or some residues have come here.

So, next time you measure the you know the IV is lo something like this maybe, next time we measured IVs lo something like this, then you measured and the IVs los something like this. So, the IV will keep changing the current voltage characteristics will keep changing as you measure again and again, because the area here is not fixed . And besides there are moister there is all kinds of atmospheric stuff that at the surface you will contaminate. And this surface will keep modifying as the atmospheric condition keeps changing the humidity, the dirt, the flow of the air, everything will keep, these are very sensitive devices, the transistor device is very sensitive.

So, all these will modify the surface here, all this will modify the contact area. It will modify the area at which the probe tip is contacting your surface and that will keep making the IV lo keep changing, there is no consistency.

Hence what you do is that you put a metal pad, and this metal pad is put this metal pad is deposited; this metal is deposited in reality . This metal is deposited in ultra high vacuum or you can say high vacuum is deposited in high vacuum. So, you put in a chamber call E beam evaporator or sputtering or something you pump down, so that the pressure the pressure becomes low in the chamber where you where you have put the wafer, and the background impurity reduces when the pressure becomes lower it becomes vacuum.

And once it becomes vacuum, you put the metal; you evaporate the metal or sputter the metal then metals to do that. Once you put the metal down, what happens is that, in vacuum, in vacuum when you deposit this you know this interface is very pure. I mean relatively much pure and pristine, there is no atmospheric moisture and junk and other things because you are pumping down, you are ensuring there is a vacuum in a particular closed chamber.

So, when you put that then the surface becomes very pure to metal also is very pure. So, when you put the metal there the first thing is that this interface becomes very pure and control right. There is no junk and impurity. So, there is no reason of changing. And when you put a probe tip down here, the area of the dimension of this width and the length in the lateral direction you know this is very fixed. The dimension of the metal pad is fixed . The dimension of the metal pad the dimension of the metal pad is fixed because you have deposited the fixed metal so your IVs will not change, your IV will always be consistent , your IVs be consistent right. So, these are very important reasons.

And of course, when you want to package the device or wire bond the device, then you have to also need a metal pad because you need to indium where you put an indium wire something else to package it out. So, metal semiconductor contacts are very important , very, very important and you might be you know still wondering that depending on the metal I might as well get an IV like this or I might as well get an IV like this . It is very it is very possible, it is very, routinely achieved by research people in labs .

So, let us come to the semiconductor theory of why this happens. So, I told you the most important thing is metal semiconductor, it is a work function of metal is the work function of semiconductor the difference of the two is actually the reason why it is there.

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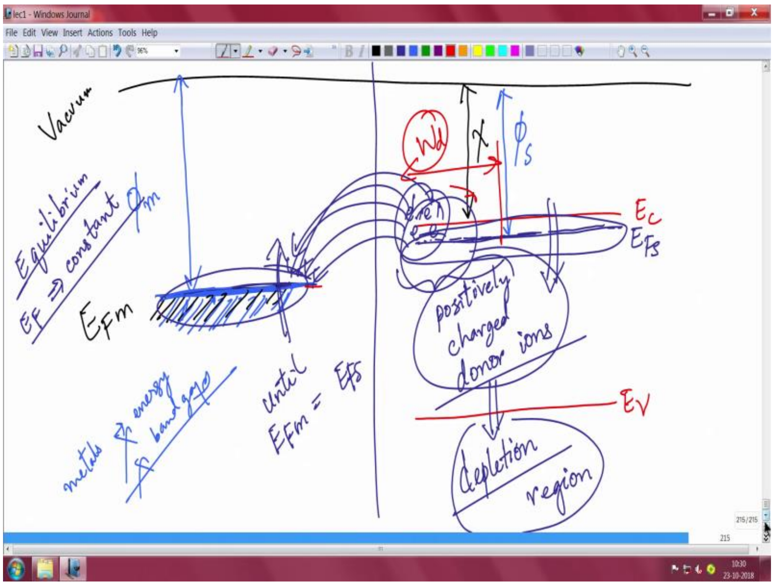

So, suppose there is a vacuum level, you know the energy of the vacuum level and that is constant everywhere. So, I take metal when I take metal there is a Fermi level of the metal. This is called metal Fermi level E_{Fm}. And the vacuum level then when I say vacuum level, it is the energy needed to knock off an electron from the metal to the vacuum is that is the energy or it is the energy required . So, I am calling that as the energy there is the vacuum is constant.

So, this sorry this energy difference between the vacuum level and Fermi level of the metal is called the work function of metal φ_m I am calling it. For example, titanium has φ_m equal to 4 you know electron volts; nickel has a φ_m as 5.5 eV and so on. So, different metals will have different φ .

Now, in metals if you remember in metals, there are no energy gaps, there are no energy band gaps . There are no energy band gaps; there are no energy band gaps. The highest field, the highest field level is the Fermi level and that is it , there is no gap here. And actually the metal conducts electricity because the electrons that are there had a Fermi level is very high density of electron like an infinite reservoir of electron right.

They can move because this whole thing actually it is like a partially field. So, they have a lot of empty states here where electron can move . There is a lot of empty states, there is no band gap here , there is no band gap here. So, please keep that in mind . This is the metal. The highest energy level is the Fermi level only here.

Now, I take a semiconductor. Now, I take a semiconductor. So, suppose I take suppose silicon, I am just giving an example . This is suppose, this is silicon some semiconductor. This is a conduction band; this is your valence band. And suppose the Fermi level is here, it is mildly n-type doped here. So, the Fermi level is here, it is mildly n-type doped not very heavily n-type doped. You see the Fermi level of the semiconductor is actually at a high energy level than the Fermi level of the metal .

So, let me do some nomenclatures here. So, this from the vacuum level vacuum level is constant throughout my drawing may not be very correct. The vacuum level is constant so vacuum level to the conduction band this is called electron affinity, this is called φ_m . This is the electron affinity of the semiconductor. And your this vacuum level to the Fermi level of the semiconductor is called the work function of the semiconductor φ_s. Remember the semiconductor work function can be dramatically different if your doping is p-type. If your doping is p-type, then a Fermi level will be here. And then your work function will be huge. So, anyways I am not talking about from p-type now, but what is saying is that depending on the doping, your Fermi level will change and that will change the work function also .

So, now this is the Fermi level of semiconductor. This is a Fermi level of semiconductor get straight here, it is equilibrium. And this is Fermi level of metal. Now, the moment you join them. And in equilibrium, you remember in equilibrium there cannot be any current flowing eventually. And in equilibrium what will happen is that the Fermi level needs to be constant throughout; the in equilibrium the Fermi level has to be constant throughout. So, eventually the Fermi level has to be constant throughout which means this metal Fermi level , this metal Fermi level and the semiconductor Fermi level have to balance have to become at the same level.

So, semiconductor bands have to come down slightly or in other words metal will slightly go up so that they will balance. Physically what is happening is that electrons from this side because this is a high energy will actually be donated or given away to metal, metal is like an infinite reservoir of receiving or accepting electron . So, electrons from this side will come to this side because that have high energy, they will keep coming until the Fermi levels equal until Fermi level on the metal side, becomes equal to Fermi level on the semiconductor side. This is Fermi level on the semiconductor side. So, both have to equalize until that point electrons will keep coming here.

Now, when electrons keep coming from this side to that side, what leaves behind here is positively charged when the electrons move from there to there what it does it leave behind. It leaves behind positively charged donor ions . It leaves behind positively charged donor ions, because electrons have come there right from some area here. And that when you have only positively charged donor ions and mobile electrons have no longer been there, then we call that as a depletion region. Much like in a silicon or some I mean any P-N junction here also you will have a depletion region because metals because the electrons from the semiconductor have gone to the metal. They have left behind positively charged ions and they without in the in the absence of any electron there that is a depletion region.

But of course, there will be a particular width in a up to which the depletion will exist I am calling it W d for example. So, particular with because then it will because only to directs them, the electrons will keep coming and it will depleted. After that the Fermi level on both sides will be equal. So, how will it lo like right?

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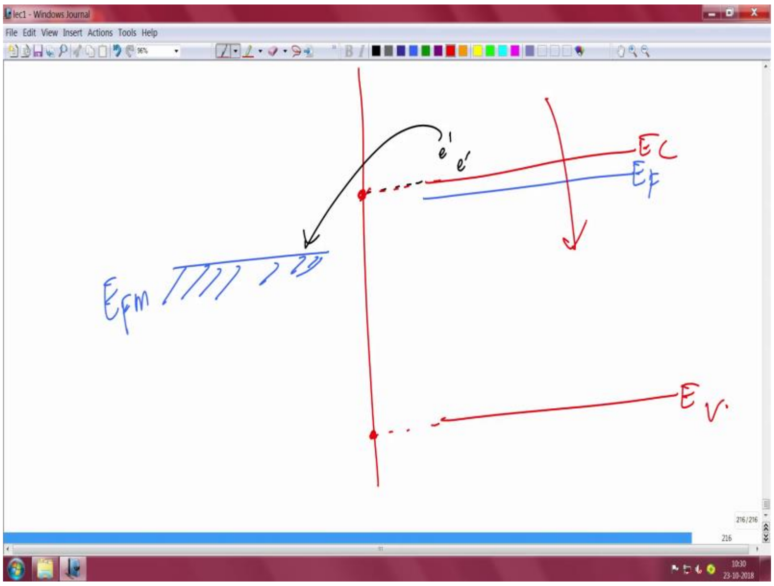

So, let me draw it again. So, suppose I have a Fermi level of the metal here . I am just I am not drawing a vacuum level; I am just drawing the Fermi level of the metal here. And there is the Fermi level of the semiconductor here. Of course, there is a conduction band here; there is a valence band here ; I am saying that joining right. So, the electrons from here will come here and create depletion. So, how it will eventually lo is that. So, you know the way to draw it is that you imagine this point to be fixed, this point to conduction band point here imagine that. You imagine that this point we fixed here, and now you move the whole thing down . So, by keeping that fixed point and keeping the Fermi level down, so what will happen is that eventually the Fermi level which is the blue color Fermi level will have to be equal everywhere.

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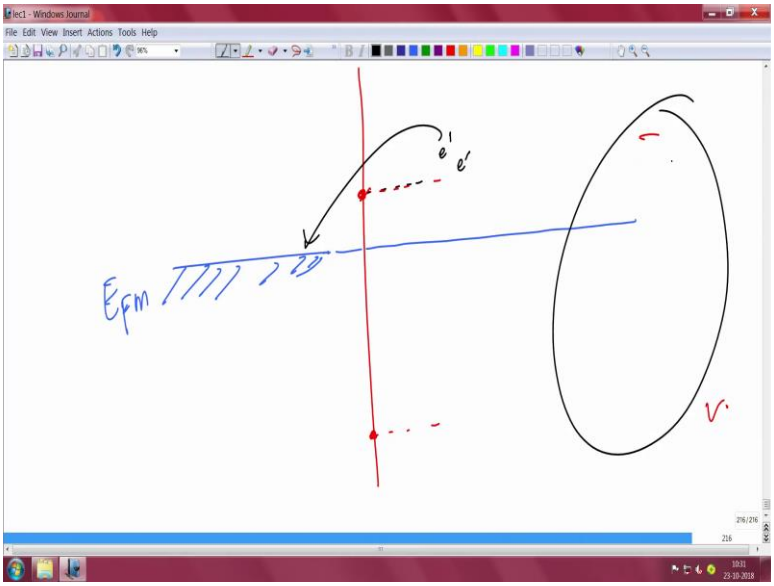

So, this Fermi level has come down here , the Fermi level has come down here, but away from the junction far away from the junction like this side, no far away from the junction, what will happen is that your semiconductor is not changing.

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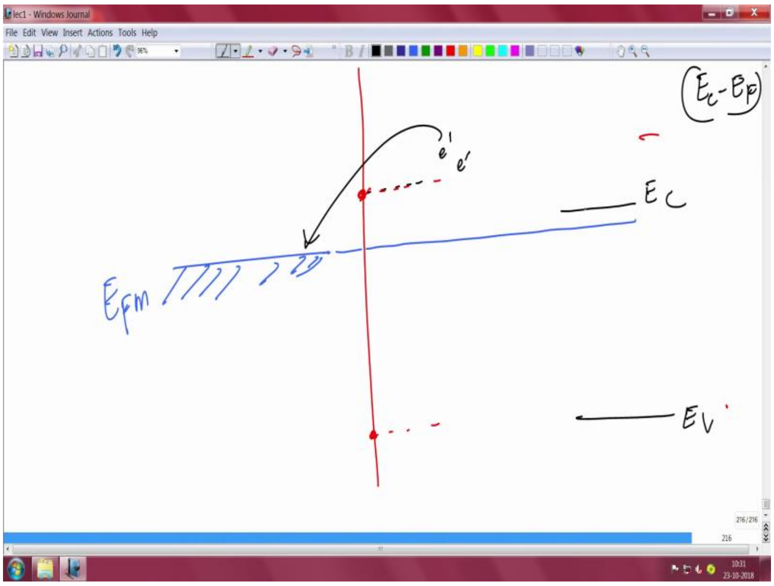

So, conduction band and Fermi level difference has to remain constant because the doping is uniform in the semiconductor eventually. So, the conduction band and Fermi level with the difference of like this know E_C E_V, the band gap is also same I mean this is just like this.

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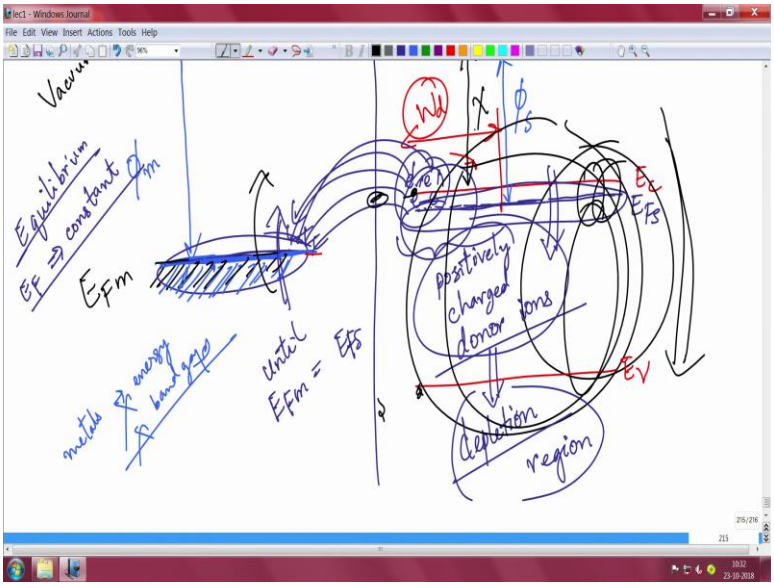

You see this I mean that the E_C and E_V difference, this, this difference, this difference cannot change away from the junction only near the junction things will change. So, this los like that right. This is actually . So, we come down little bit. So, this will lo like that right E_V.

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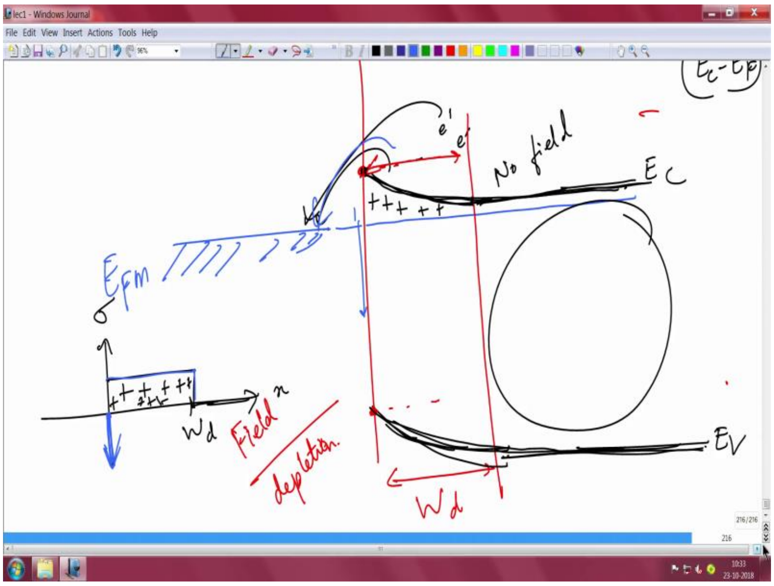

Now, you remember this point is fixed from the conduction band in a position eventually initially. So, you basically the conduction band will bend up like this, it will come like that, it will come like that . So, you see the conduction band has bent up because essentially what has happened from here you can see is that the whole thing is basically brought down we can say or you can you can think this is coming up.

So, the whole thing is brought down by fixing this point and this point. The conduction band and the valence band point you fix here, and then you move the whole thing down until the Fermi levels align both sides , until the Fermi levels align both sides. So, the Fermi level is aligned. So, you see there is some depletion region here. There is a depletion region here which I call W_d, this is depletion region that is devoid of electron.

And in the depletion region of course, there is a electric field also. Why, because you can see that there is a slope, there is a slope in the conduction band, there is a slope in the valence band, [FL] there is a field here. And after this depletion region, the bands are flap bands of flap. So, there is no field here, there is no field here no voltage is dropping, no depletion. So, the depletion only exists here, the depletion only exists here. The fields also exists in this region only, beyond that there is no depletion, there is no field, everything is equilibrium, everything is nice and very nice, because there is no field in this region. And this is a neutral region.

So, depletion has formed here. And this depletion region will have positively charged ions. Why, because mobile electrons are not there why because mobile electrons have gone to the side know that's why they are not there. So, this is depletion region. If you draw the charge diagram, then basically what has happened is that this is charge diagram say this is x. So, this is depletion W_d. So, up till depletion you will have positively charged ions. And beyond that you not have anything because this is this part is neutral; number of electrons, number of donors is same. Here it is positive.

And this is balanced by a delta like a sheet of negative charges that because excess electrons have come here know. So, at the interface, a very thin density of electrons will basically be there which will make sure that these charge is balanced, which will make sure that this charge is balanced . So, this is how the junction los.

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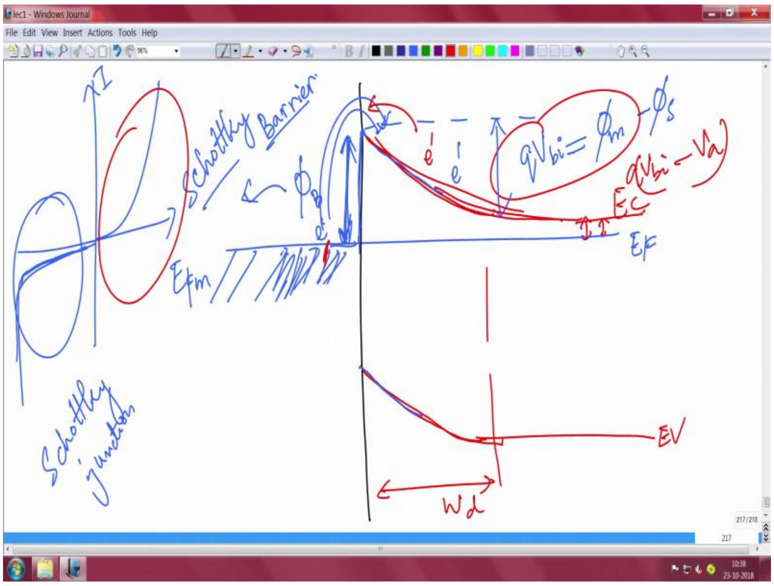

Now, let me come to a new figure here. So, how does junction lo eventually I have metal Fermi level which is the same as the semiconductor Fermi level? Far away from the junction the conduction band, the valence band, they are the same. I mean the connection band valence band will have the same spacing with respect to Fermi level right, this spacing will remain same there. Only at the junction only at the junction, this is metal Fermi level by the way , only at the junction, what will happen is that you have things like this .

It will go like that, will go like that . So, the depletion is formed here the W_d. And you see how much has the band banned do you know how much has the band bent actually. So, let me draw it again you see the band has bent. The band has bent by exactly this amount that is called a built in potential just like a P-N junction, this also has a built in potential. And that built in potential that band bending that has happened if you recall again carefully I will draw another picture here, initially before joining how was it loing like.

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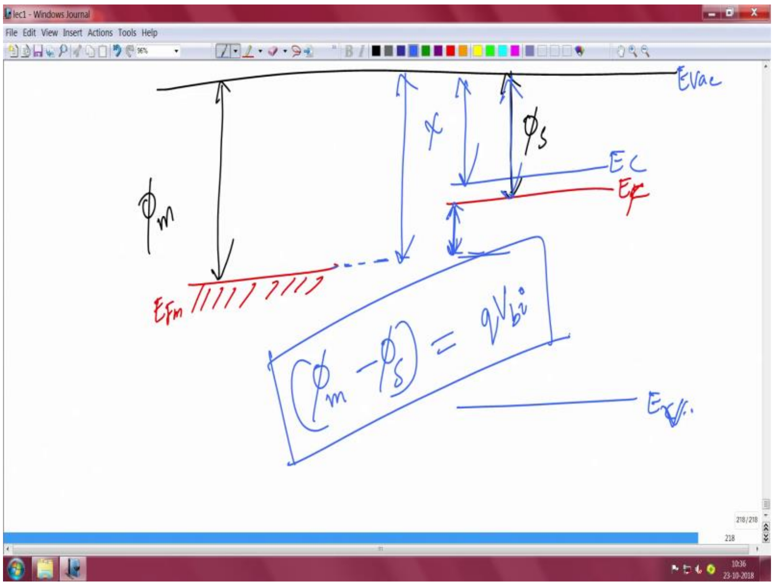

It was loing like this is metal Fermi level E_{Fm}; this is semiconductor Fermi level, semiconductor Fermi level . Let me actually draw it again better. So, let me draw the metal Fermi level here. This is your metal Fermi level . This is a semiconductor Fermi level . And then you have conduction band, you have valence band valence band.

Now, if you recall I told you there is a vacuum level here; and this if you recall is the metal work function. This if you recall it is the same again the vacuum level is the same this is the semiconductor of function and of course, this is your electron affinity. The difference between the vacuum levels E_{Vac} minus E_C is electron affinity. The Fermi level is I know the work function of the metal semi semiconductor.

So, essentially the Fermi levels will align. So, the distance, the energy distance that the Fermi level has come down is this much. And let that that basically has bent here that is basically this , that is the bend that has happened. Because once the Fermi level comes down by that amount Fermi level will be aligned in both side. And so you can carefully see that this amount actually is nothing but this whole thing minus this thing. So, essentially φ_m metal work function minus the semiconductor work function that gives you how much the band bending has happened that gives you the built in potential. So, that is the first equation of the first formula you will remember in this.

So, this built in potential is nothing but equal to metal work function minus semiconductor work function right. And then this barrier that has formed over here between the metal Fermi level and the tip of the conduction band of the semiconductor here, this is conduction band of the semiconductor right, this is the valence band of the semiconductor. So, this barrier that has formed is called φ_b it can capital B or small b either way, φ_b and that is called a Schottky barrier a Schottky barrier. It is called a Schottky barrier and that is the barrier between the metal Fermi level and the tip of the conduction band here. So, it is like a barrier.

So, you see in this across a junction this is a Schottky junction now. This whole junction that has formed is called Schottky junction. But reason and you will get an IV like this we will come to that . If you draw the IV, you will get a like IV like this. And the reason is electrons from the metal will have this barrier to go know. So, it is very difficult when you apply reverse bias on the metal which is this regime, the electrons will have a very high difficulty of going from metal to this side. So, the current is very low. Eventually it has to break down and then it will increase, it will be very low like a P-N junction. So, it is very difficult to overcome this ; it is a good barrier.

Similarly, the electrons that are when you positive bias when you positive bias the junction we are talking about this area, then you positive bias this, then electrons will try to come from here to there. And this depletion width also reduces and the built in voltage also reduces by qV_{bi}-V_a whatever voltage you are applying know that will reduce the barrier just like in a P-N junction. So, if this was the original barrier, if this was the original barrier, then at the application of qV_a your barrier will reduce like this , your barrier will reduce. So, this barrier will reduce.

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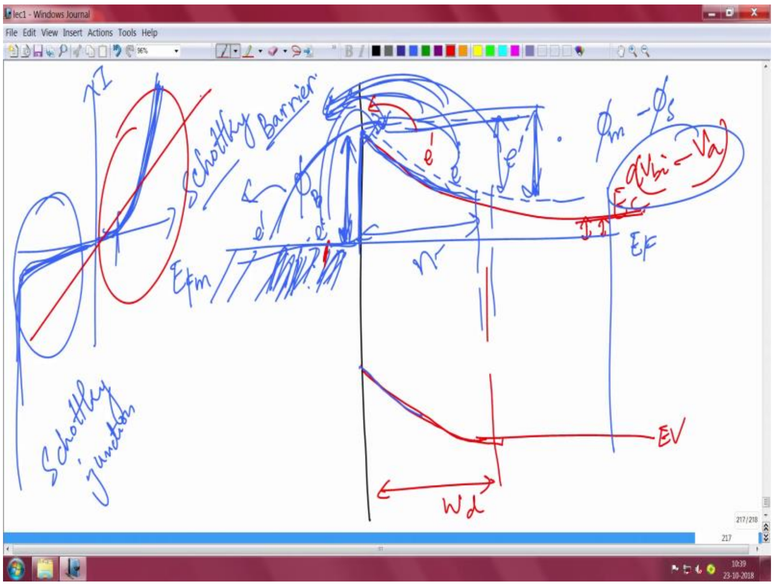

And the depletion width also will reduce ; the depletion width also will reduce just like an P-N junction, because you are applying a positive bias here which means you can say you are applying a negative bias. If you pushing the electrons away pushing the electrons away or you can say this positive bias is basically attracting the electrons. So, electrons will come, but because there is a slight barrier here, but this barrier keeps reducing as you are applying more and more positive bias.

So, initially they will be small current, then there will be a turn on like a P-N junction turn on when the electrons will now will come largely and eventually it will increase a lot. So, that is the turn on voltage of a Schottky diode. And this is the forward turn on current, this is the current in the in on current of a Schottky diode on the reverse side, there will be very little current, because from here metals from metal to the electrons from metals to semiconductor will have a lot of difficulty going. So, it will be very low reverse leakage, and it will break down.

On the forward side, electrons from the semiconductor will come to metal, and it will gradually increase like this after a turn on because as you keep increasing positive bias, your disk built is this is the potential drop that is happening will reduce. In the reverse bias, this potential drop will increase like in a reverse bias P-N junction. So, even less electron will come. So, basically this is just like a P-N junction accept that ends up p-side you have a metal here. This is a metal of n-type semiconductor, but if you can have similar metal in a p-type semiconductor also.

Now, if you might ask that if this is the barrier and this is kind of a junction that has formed, and this is the IV that am getting, then how do I get the linear IV like this, oh, for that you need a different kind of junction will come to that. So, let us wrap up the class here, and we will take up the next in the next class.

So, what did we learn here, we introduced what is the necessity of a metal semiconductor junction the very, very, very important practical you know from a practical point of view how to measure device and why metals come to contacts are needed. Then we introduce the semiconductor band diagram for metal and semiconductor , the band diagrams and equilibrium. We tried to equalize them at Fermi level on both side and we saw that you know you can form a Schottky junction, a Schottky barrier across which electrons find it difficult to travel. And hence the Schottky behavior is a non-linear kind of contact here that you form.

There are many things associated with a Schottky junction, we will come to that slowly in the next class. And then we will go to how do you form an Ohmic contact or how do you form a contact to p-type semiconductor, this is only n-type right. So, all these things will take up subsequently in the next classes .

Thank you for your time.