Processing of Semiconducting Materials
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Lecture - 25
Carrier Transport in P - N Junction

In my last lecture, we have discussed about the fabrication of a p-n junction, and mostly I have shown you the steps, which are required for the fabrication of a p-n junction starting from the oxidation, then photolithography, masking, diffusion or ion implantation. So, those steps were involve for the fabrication of p-n junction.

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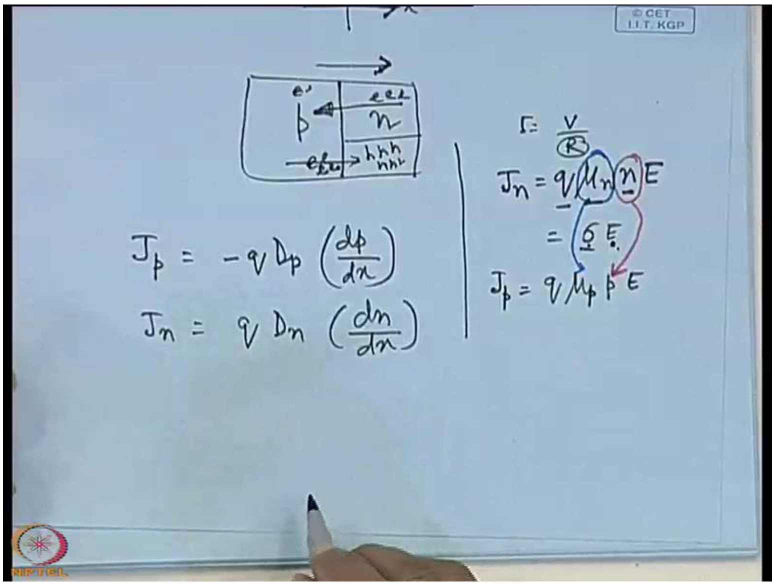

Now after the semiconductor junction is formed, then what are the carrier transport mechanisms in the p-n junction? Because you know that a p-n junction basically is the core of all the electronic devices, and current transport in this type of a semiconductor junction governs various properties of the device. Now the basic difference, if you compare with the metal is that, in metal it is only the electrons which take part in the current conduction mechanism. Here both the electrons and holes, so the transport mechanism is a little bit complicated manner in this thing.

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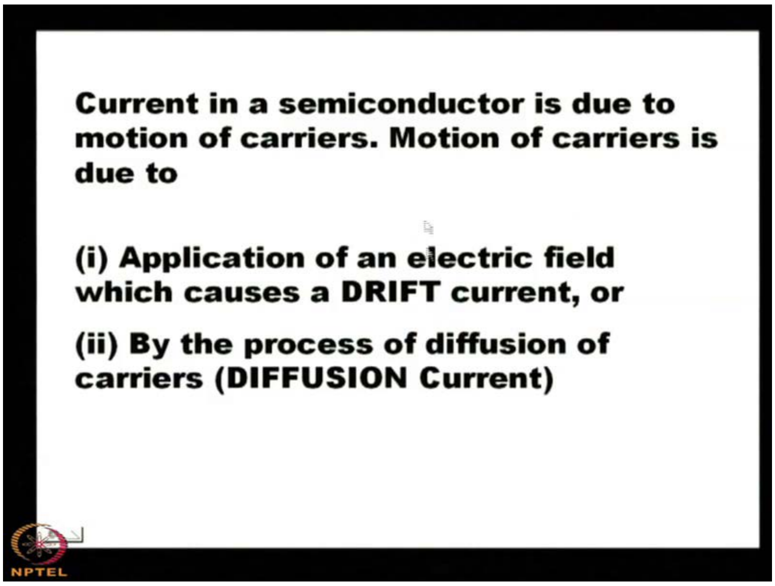

And you can find that current in a semiconductor is due to the motion of carriers. When we talk about the carriers, it is both p and n; that means the electrons and holes and motion of carriers is due to application of an electric field, which causes a DRIFT current or by the process of diffusion of carriers which is known as the DIFFUSION current. So that means in a semiconductor, we find two types of current; one is the DRIFT current, another is the DIFFUSION current. And in both the cases it is the motion of carriers, which is the cause of flow of current in the device. When we talk about the DRIFT current, it is the, it is due to the electric field and when we talk DIFFUSION current, it is because of the diffusion of carriers from the higher concentration to the lower concentration.

And we shall we will find that, in a P-N junction, the current is mostly due to the DIFFUSION, not due to the DRIFT; Because, when we talk about the DRIFT, it is basically due to the minority carriers. Minority carrier means, suppose it is a p-n junction and in this P-N junction, the electrons are the minority carriers and here the holes are the minority carriers that means, in the n region apart from the electrons, which are the majority carriers.

You will find innumerable number of holes as well, though their number is less than the number of electrons because the holes are the majority carriers in n side. So due to diffusion the electrons will move from n region to p region. That means, when the electron motion will be there from say negative x direction; if we consider that it is the negative x direction it is y, it is x. Then you can say that, the current will flow in the positive x direction because it is the convention that the current flows in opposite direction to the flow of the electron. That means, actual particle flow direction will be in the negative x direction and the current will be in the positive x direction.

So, the flow of electron will constitute a diffusion current, but what about the DRIFT current. DRIFT current is due to the application of electric field as I have shown you and this application of electric field will give rise to DRIFT current; it is because of the minority carriers that means, electrons are the minority carriers in p side. That flow of electrons will be from left to right because minority carriers are in the p side. So the electrons will move from left to right that means, from the in the positive x direction; so the current will be in the negative x direction, under thermal equilibrium these DIFFUSION current and DRIFT current will be equal and opposite. So the total current at equilibrium will be 0 and that is applicable for holes also, the same theory is applicable.

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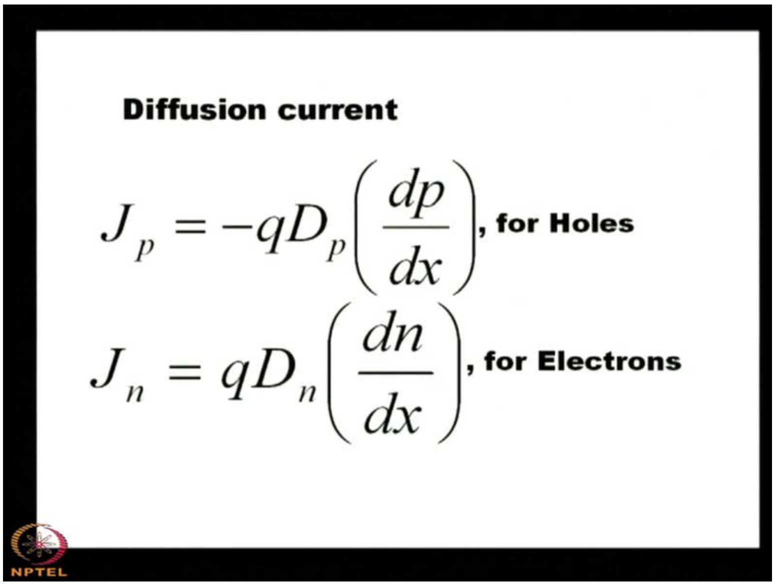

Now you see that, the diffusion current it is given by, it is given by it is basically current density. It is basically the current density is it is given by minus q D p d p by d x; this is for holes because p stands for the holes and due to electrons the current density is given by q D n d n by d x. Now what are those? This J is basically the current density that means, current per unit area; q is the electronic charge D p or D n are the diffusion constants.

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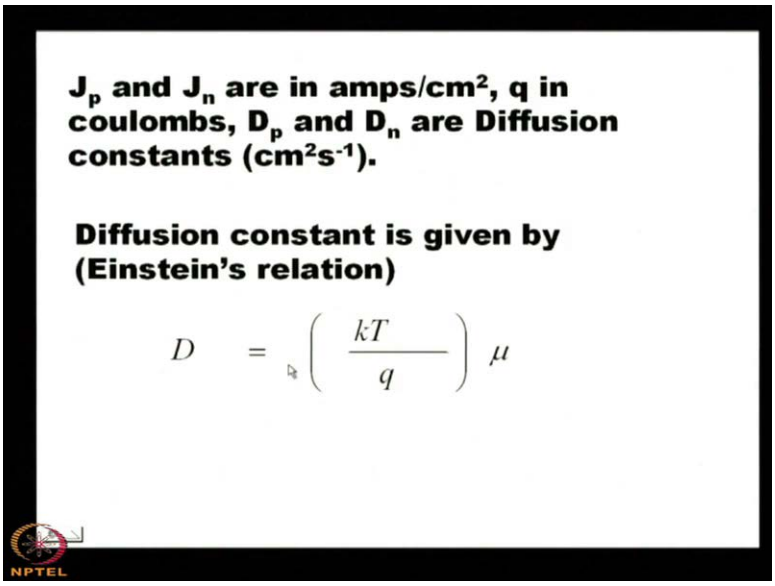

And we shall show that, this diffusion constant is given by k T by q into mu. That is known as the Einstein's relation; that means the diffusion constant and mobility are interrelated and if you know mobility, you can calculate diffusion constant or if you know the diffusion constant mobility can be calculated because you know that, what is the value of k T by q? k T by q is (( )) 26 milli electron volt at room temperature. At any temperature you can calculate so, if you know the mobility at that temperature, then you can calculate the diffusion constant for electrons and holes, which is given by the Einstein's relation.

Student: So, now this is the diffusion constant and what is d p d x? d p by d x is,

Concentration gradient

Student: Concentration gradient

It is basically the concentration

Student: Gradient

Gradient now when you talk about the concentration is it is per centimetre

Student: Q

Q and when it is divided by the length x that means.

Student: Per centimetre to the power 4.

Yes, per centimetre to the power 4; so remember that, this d p d x is decreasing. Why? Because, with diffusion the concentration gradient will decrease, always it is it is in reality also; you can find that as more and more diffusion will take place the gradient will decrease and eventually there will be no gradient so, there will be no diffusion. So this d p d x or d n d x, it is a negative quantity. It is negative because of the fact that, the carrier gradient or gradient concentration gradient, decreasing as diffusion takes place. So it is negative that is why, a minus sign is there; for electron q is negative. So that is why minus q multiplied by minus of this thing becomes positive here so, this negative sign is due to the decreasing concentration gradient with diffusion.

Now J p and J n are in amperes per centimetre square you know because it is the current per area; q in coulombs; D p and D n are diffusion constant, which is given by centimetre square per second, centimetre square per second because if you put the value here you can easily calculate because it is centimetre square per volt second and k T by q is in volt. So you will get it is centimetre square per second.

Remember that; k t by q is in volt, but k t in... Electron volt. Electron volt so, here it is electron it is milli electron volt and here it is electron volt. Electron. Electron. So basically the charge of electron will not be there so, if it is multiplied by q then it becomes electron volt; otherwise it is volt, the same amount.

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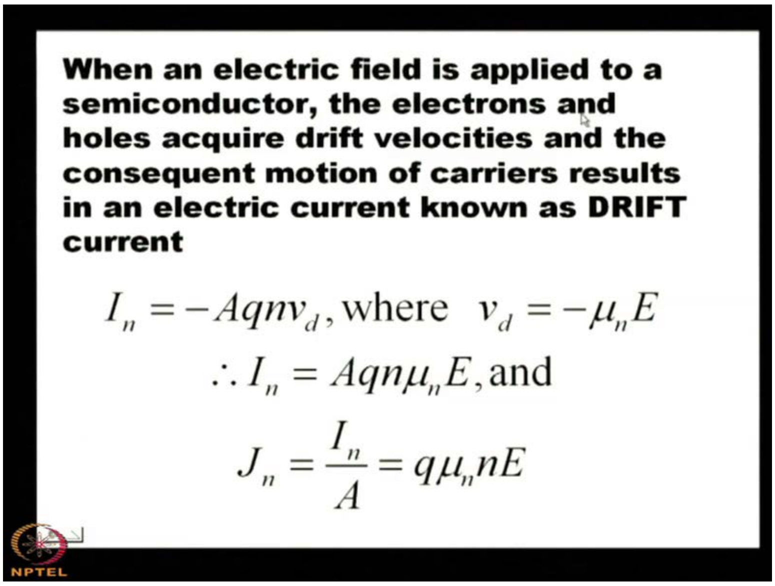

Now, when an electric field is applied so, we can say that this current you see that, J p we can write is equals to minus q D p d p by d x for holes and J n equals to q D n d n by d x. Now this is the diffusion current for electrons and holes.

Sir.

Yes.

(( )) d p upon d x is per centimetre of hole.

Yeah

What is the meaning of per centimetre hole?

No, basically n is n is the carrier concentration; n is the carrier concentration. So, basically why we are using those time of those types of units because you see that on both sides of the equality sign the units will be

Equal.

Same. So that is the relevance, otherwise it has no relevance. Per centimetre to the power 4 means, p is in centimetre cube and you are taking the gradient that means, you are dividing it by x. So it will be per centimetre to the power 4 the absolute unit, but it has no other physical significance; except to balance the units on both the sides.

Student: (( )) four times in a space

4, no no no no no no no no no no no no no no no no.

When an electric field is applied to a semiconductor the electrons and holes acquire drift velocities and the consequent motion of carrier’s results in an electric current known as DRIFT current. So remember that, this DRIFT current is due to the application of a voltage or an electric field. Here we have derived the current for the drift situation, I n equals to minus A q n v d. What is A? A is the area, q is the electronic charge, n is the total carrier concentration in the material and v d is the DRIFT velocity which is given by minus mu n into E. That means mobility multiplied by the electric field we have deduced this in our earlier lectures.

So if you put this v d equals to minus mu n into E, you will find that I n will become A q n mu n into E. Just I have replaced v d by minus mu n E in this equation and J n which is given by I n by A that means the area will be given by q mu n n into E. So finally we arrive at the situation, that J n equals to q mu n n into E; n q mu what is this?

Sigma.

Yes, it is sigma. So that means, the current density is given by sigma into E and this we have also deduced; we have started from the Ohm’s law v equals to I r. So I equals to v by

r.

r r is resistance, you see here the current density is given by sigma into E. E comes from...

Voltage.

Voltage or the voltage comes from the electric filed so, that is another form of Ohm’s law; J equals to sigma E. If you compare this J is equals to sigma E with I equals to v by r. r is resistance.

1 by...

So 1 by r is conductance so, here sigma is the conductivity what we have mentioned earlier. So that is another forms of form of Ohm law, remember that J equals to sigma E and this is the DRIFT current; this is finally the DRIFT current. Similarly for holes, you will find that J p equals to q mu p p into E. Just change this n with p n with p and this mu n with mu p.

Student: (( )) Minus 1 will be there.

Exactly 1 minus sign will be there exactly because here you see because if you, if you look at this equation, then here I n equals to minus A q was due to the negative sign of the... Charge, Charge, Charge.

For, for holes there will be...

Student: Positive (( ))

Sure it will be v d equals to in that case...

Student: (( ))

Mu n into E. So there will be...

Student: Both will be positive.

Both will be positive.

Sure Yes, I shall show you that both will be positive, it is because of the direction I, I shall show you. Yes, it is direction.

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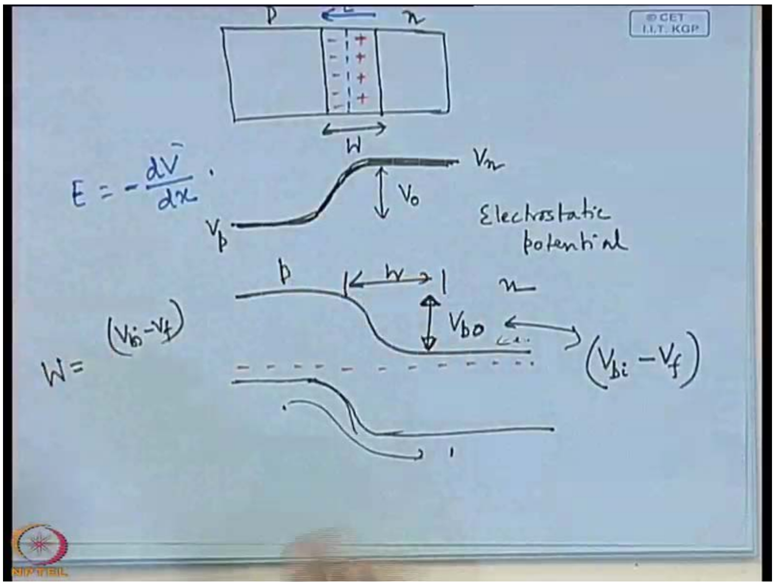

So, let us now talk about the direction, it is very important thing. That say this is your P-N junction, this is the depletion with w, here this is say the metallurgical junction, on both sides of the metallurgical junction there will be your positive and negative immobile uncompensated ions; which give rise to electric field etcetera, etcetera. Now if you draw the electrostatic potential diagram, then you can write in this manner that, this is the electrical electrostatic potential diagram that means V, it is say V p, it is V n. It is the electro electrostatic potential diagram and this is equals to V b i or V 0; that means built in potential, it is the electrostatic potential. Now what will be the electron energy? That is potential so, what will be the electronic energy? e V. So that means, you have to multiply these by minus q because it is the potential V so, you have to multiply by minus 2 for electrons, then it will look like how it will look like?

Student: (( ))

Why? Because you are multiplying by a negative quantity on throughout, throughout you are multiplying with a negative quantity; so that will be a mirror image basically, remember why it has happened? It is because of the multiplication by minus q, because of the multiplication of minus q. The actual value of the potential is V, but if you multiply with q, then it becomes minus q into v. So that is the difference between the electrostatic potential energy and the electronic energy. So when we draw the band diagram, it is the energy diagram; that is not the potential diagram, potential diagram will be exactly Reverse.

The yes, the mirror image of the...

Student: Electronic.

Electronic energy diagram. So this, this is the v b 0 so, if I draw the Fermi level this is p, this is n.

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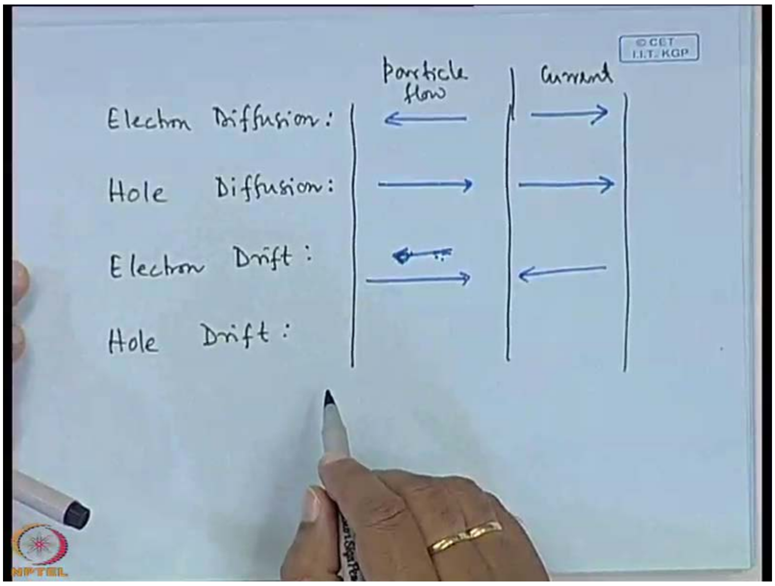

Now electron will move from left to right electron diffusion will be electron diffusion. Then there will be hole diffusion, there will be four situations; electron drift, hole drift because four types of probability can be there; particle flow and the resultant current. Now particle flow, so far as the particle flow is concerned, so far as the particle flow is concerned; you see that, electron diffusion will take place from left to right if I, if I consider this diagram. So electron diffusion will take place from...

Student: Right to left.

Right to left, right to left.

Student: (( ))

So actual particle flow will be from right to left.

Student: (( )) diffusion (( )).

Sorry, sorry, sorry.

Electron diffusion from right to left and the current will be from...

Student: (( ))

So current direction will be this. If I consider this diagram, then hole diffusion. Is also available (( )). Just opposite that means, it will be from... Left to right. Left to right the particle flow will be left to right.

Student: Current (( )).

In the left to right; then electron drift, electron drift will be from... Left to right. Left to right, electron current will be from... Right to left. Because, for electron it is reverse only, that is the combination for hole. It is same. It is the same and hole drift will be from... Right to left. Right to left and the hole current will be right to left. So what we see, that the current due to the electron drift and electron. Hole. Hole drift and electron drift are in the... Same direction.

Same direction. So there will be no change of sign in the earlier expression. Clear? So there can four situations and in all the four situations, there will be the particle flow and the resultant current direction only for electrons it will be different; otherwise, it will be same. An another important and thing that we should discuss this case is that, this electrostatic potential and energy how they are related?

Student: b is equal to w point two (( )).

What is the general relation between the empirical relation between potential and field?

Student: Field (( )).

Yes.

Student: (( )) negative or potential.

Yes negative grad of potentials, field is negative grad of...

Student: Potential d v by d x.

So this is the electrostatic, this is the electric field with the...

Student: Potential.

Potential.

Student: Gradient.

Gradient.

It is always true remember, it is always true. So that is why you can see that, here the electric field has develop from left to right and the potential is from...

Student: (( ))

Right field is from right to left and it is since there is a negative sign so, it will be just the opposite thing. So these are fundamental relations, which you can consider for the explanation of different diagrams related to a semiconductor because ultimately in for any device you have to calculate the current in the device; for any electronic device, that you have already tested for your lab classes. That whatever be the experiments be it the four probe, be it the vender paw, then the hall effect; every time you have measured either current or the voltage. So that is the main thing which we must consider, that means you must be able to calculate the current in a device, this is the primitive device; this is the core of all the devices the P-N junction, that is why we are giving much time to it.

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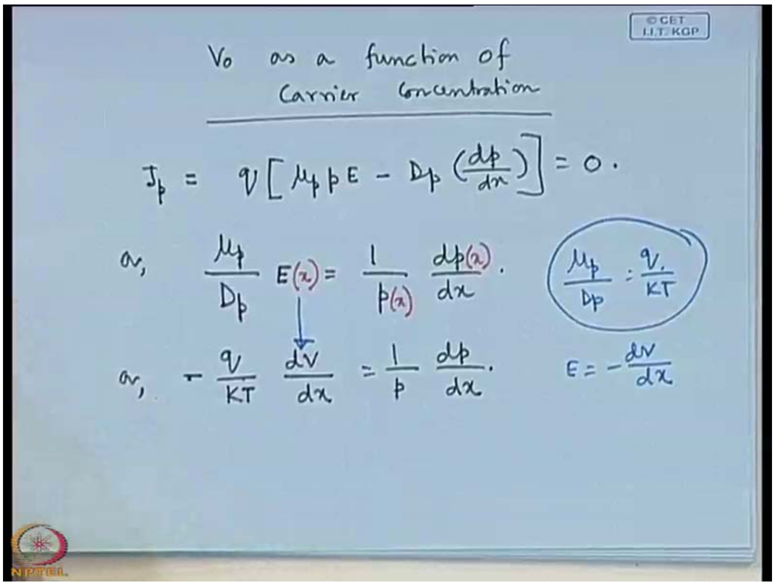

Then the important thing is that, how to calculate the V 0 as a function of carrier concentration. V 0 as a function of carrier concentration or the doping concentration of each site, because you see that in this energy band diagram, it is the V b 0 or in some text book you will find that it is V b i; which is known as the contact potential or built in potential, there are many names. This is very important thing and for current to flow you have to reduce this thing, you have to reduce this thing. What happens if we put a forward bias?

Student: Reduced.

It will be...

Student: Reduced.

This gap reduced. So if this gap reduced, then there will be many electrons which will be able to defuse again from the n region to the...

Student: p region.

p region there by you will get some current. So the applicate and what is forward bias? What do you mean by forward biasing?

Student: e plus and in negative sign

Actually the positive terminal of the battery or the line voltage, that must be connected to the p region. p region of the p-n junction and the negative terminal of the battery must be connected to the End. Other end, that means in this case the n region. Then there will be a flow of current from p site to n site through the battery and you will find that, because of that application of the positive bias this will diminish. The built in potential will be, will be reduced why? Why it will be reduced? We have discussed in the last class also because so far as the resistance is concerned in a P-N junction, where the resistance is very high.

Student: In the depletion region.

In the depletion region because in the bulk region there is sufficient number of... Carrier.

Carrier concentration. So resistance will not be very high, it is semiconducting in nature; where the resistance is not very high, but in the depletion region, since it is depleted of free carriers there is practically no free carriers in that region. So the resistance will be very high so, that means if you apply 5 volt from the battery, most of the voltage will be dropped in the

Depletion region.

Depletion region because in the other regions it is almost conducting in nature. So that means, if you put V voltage so, this means that, this will be V b i or b 0 or what b let us write b I built in potential minus V forward bias because most of the drop will be in the depletion region; that is why it is V b i minus V f. If it is V b i minus V f that means, this will be reduced. As it is reduced, many electrons will be able to surround the warier, because you know that all the electron do not have the same energy. There are many electrons having higher energy so, they are all almost ready to cross the warier. Even if minor change in the potential warier by 0.2 volt; 0.5 volt; 1volt many electrons will pass through the warrior. So that is true for the holes also, holes will come from this region. Hole diffusion will be from this region to that region.

Student: Sir.

Yes.

Student: There are two wariers one is this V b (( )) and another is the width of the (( )) region.

No no no no no no that is one warier width of the depletion region it is the result of the width of the depletion region. It is basically the width, it is a result.

Student: Means this is a depletion width and this is a (( )) potential (( )).

Problem is not with the depletion width.

Student: Sir, if we applied the forward bias.

Yes.

Student: Whether only V b decreases or depletion width also is increased.

No, here only the warier height will decrease 28; 21.

Student: Depletion width not seen.

Depletion width will decrease also, but not directly by this relation.

How it will be different. That is the different expression that I will show you later, but there also if you, if you see that depletion. Both are related to each other no.

Yes, if you see that in W, that means width of the depletion region here it is the width of the depletion region W. So W here there is an expression and in that expression also there is V b i in the numerator.

Student: Sir, meaning to say...

That means, when V f will be applied so it will applied here also. So that means W will.

Student: Decrease.

Decree reduced W will reduce, but not by the same amount. Why? Because, here it is straight forward V b i minus V f; here there are other terms also, it depends on the doping concentration 1 by n a plus 1 by n d.

Student: Sir, but another sense if you see the p-n junction (( )) depletion which incorporated with the immobile ions?

Yes.

Student: When we applied the positive potential?

Yes.

Student: Where the immobile ion will go?

Immobile ion will not go.

Student: (( )) they will not go anywhere then...

No.

Student: Depletion (( )).

Because the immobile ions are already in the crystal lattice.

Student: (( ))

For our discussion we have considered that, they are here just both the sides of the metallurgical junction, but not that they are not anywhere else. They are also any other parts of the crystal as well, because we are taking the finite structure of the crystal, but if we talk about the single crystal it is basically infinite in nature. So that is for our physical explanation and discussion we are looking at this type of a picture, but the actual picture is not that. So for when we apply a forward bias, both the thing will happen; your built in potential will be reduced as well as the depletion width will also be reduced, but depletion the reduction in depletion width is not straight forward since it depends on also the, by the it depends on the carrier concentration as well.

So now if we consider the that, the built in potential as a function of the carrier concentration. Let us start form this relation that, what is the total hole current in the material? What is the total hole current?

Student: J p plus (( )).

Hole, hole current.

Student: J p is hole potential.

J p that is equals to how much?

Student: Minus (( )) q d p by d x (( )) q d p by d x. q. d p. mu p p. p. e.Plus.Minus. Minus. d p. d p d x.d p d x, whether it is true or false.

Student: Sir it will be...

It you look at your, because I have, I have written from this thing. You see that, p here it is positive and here it is negative. Where I have taken q as a common factor and under equilibrium it is equals to....

Student: 0.

0 or mu p by d p, this is into E this is equals to 1 by p into d p d x; mu p by d p into E equals to 1 by p d p d x. Remember that, E is a function of, this E is s function of x; p is a function of x also. Then the next line that I can write, minus q by k T d v d x, this is equals to 1 by p d p d x from where it comes?

Student: (( ))

One is Einstein relation that means, mu p by d p equals to q by k T that is Einstein relation I have used; another thing is that, E equals to minus d v d x. So E equals to d v d x minus and mu p by d p equals to q by k T clear? If you have enquiry please, feel free to ask me.

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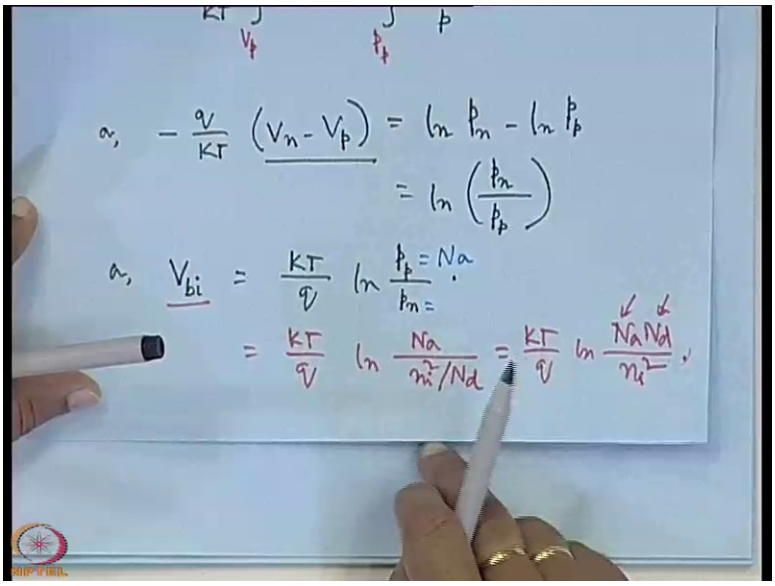

Then the next step is or minus q by k T integration of d v equals to d p by p clear? I have integrated both the sites. Now what should be the limit of my integration? What should be the limit of my integration? So let us come to this point that, here you see for voltage or potential it is V p to V n we have assumed, we have assumed. Then what about the carrier concentration because on the right hand side of the expression you will find that, it is the carrier concentration; it is the hole carrier concentration because we have started with the hole carrier density.

Now suppose, just outside the transition region the hole carrier concentration is say p p. What is p suffix p? It is the...

Student: Majority carriers.

Majority carriers.

Student: In the p site.

In the p site exactly and and here I can write it is.

Student: p n.

p n, because we are concentrating the holes only...

Student: Minority.

Minority here what is the carrier concentration majority carrier concentration it is n n? Here it is... n p, n p.

So that is the convention we use different terms. The carrier concentration has four types of situation; one is the majority carrier concentration hole, that is p p in the p region; one is the n n, it is in the n region. Then in the n region, the minority carrier concentration is hole it is p suffix n and in the p region the minority carrier is electron so, it is n suffix p. Since we are considering holes so, we are considering V p to V n as the potential and carrier concentration as p p to p n right?

So with this limit I can write that it is V p to V n and it is p p to p n or minus q by k T V n minus V p, this is equals to l n p n minus l n p p; that is equals to l n p n by p p or what is this V n minus V p? It is the...

Student: (( )) v b i.

Yes, built in potential it is equals to k T by q, since negative is there. So let us change the numerator and denominator of the l n so, that means it becomes p p by p n. So that means, if you know the carrier concentration in both sites or of the both sites of the semiconductor, you can calculate the built in potential. See k T by q is as usual 26 milli electron volt at a room temperature so, only you must know the hole concentration in this case.

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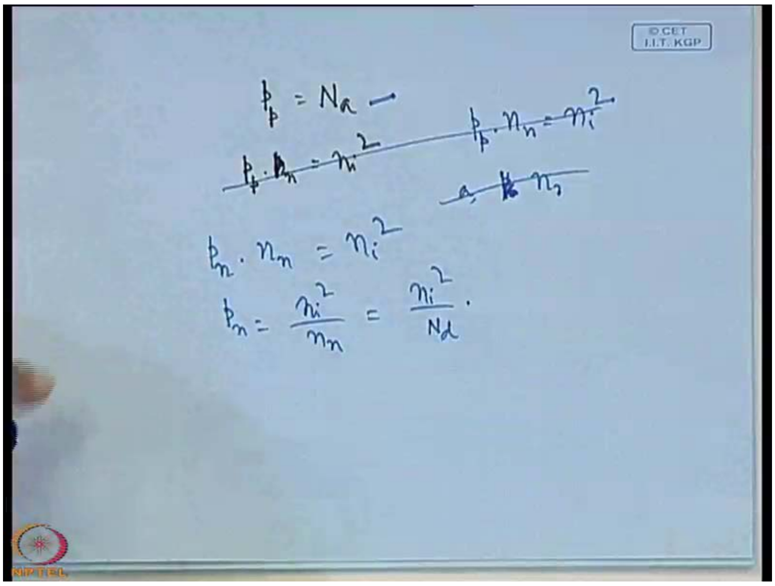

Now I can change this relation to the electron concentration as well. How? You know that, what is p p? What is this p p?

Student: n a millimetre (( )).

p p is almost equals to...

Student: n a.

n a acceptor concentration; if I consider that, all the acceptors are ionized. If you consider that, all the acceptors are ionized, then p p equals to almost equals to n a and what is this p n? Also you know that p p multiplied by p n.

Student: n square.

Sorry p p into n n equals to n i square. Let me again write p p multiplied by n n is equals to n i square or p p equals to...

Student: (( )) p p into n p and (( )) p p into n p, sir.

p p equals to...

Student: (( ))

No no no no this is, this is not the relation, I need p n into n n equals to n i square. Let us start from this relation.

Student: Sir, similarly p p into n p (( )).

Yes, so since I have p p equals to n a, since p p equals to n a I have; I, I need to know this p n this p p equals to n a, I need to know p n in terms of n d.

Student: n i square by n d.

Yes, n i square by n d. So p n equals to n i square by n n equals to n i square by...n d.n d. n d is the donor concentration. So that means here I can write this is equals to k T by q l n n a by n i square by n d. This is equals to k T by q l n n a n d by n i square. So this is very useful relation if you know the doping concentration generally in, in semiconductor problems you will find that, the doping concentration is given or in other sense, suppose you want to make a p-n junction device. You want to make some calculations before fabricating the device. If you note that, your v b i will be x milli volt; then you can calculate different carrier concentrations in such a manner because n i is constant; what is n for silicon?

Student: 1.5 into 10 to the power 10.

Yes 1.5 into 10 to the power 10. So n i is known n i is constant, it is constant for all materials; for germanium, for gallium arsenide it has separate values, but it is constant for that material. So if you know only the doping concentration, you can tune V b i. So that means, for a specific V b i n a and n d can be calculated. Suppose, you want your V b i to be 0.2 so, then it is 0.2 k T by q is 26 milli electron volt, n i square is 1.5 into 10 to the power 10 square say for it is silicon; then you can calculate n a and n d. So that is the reason that, this type of expressions are very useful for our device fabrication which actually our final aim for the processing of the semiconductor materials.

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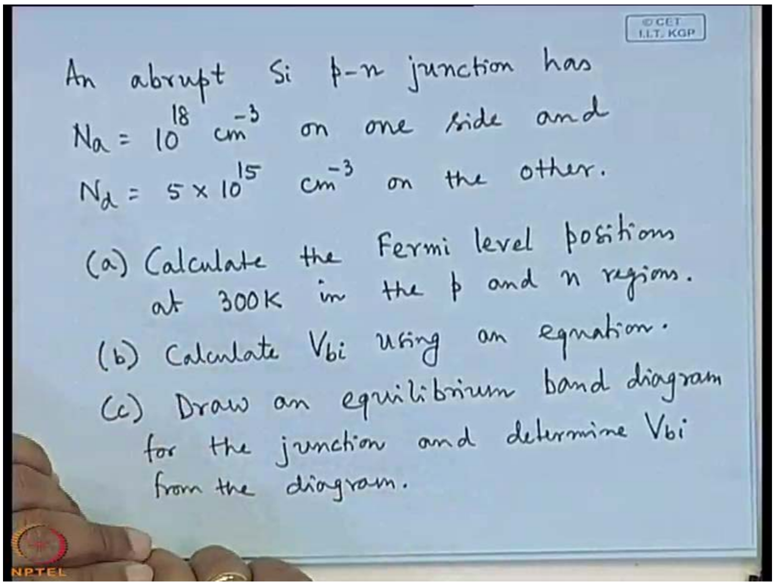

Now let us quickly have a numerical problem an abrupt silicon p-n junction has N a equals to 10 to the power 18 centimetre cube inverse on one side and N d equals to 5 into 10 to the power 15 centimetre cube inverse on the other. a) Calculate the Fermi level positions at 300 Kelvin in the p and n regions; b) Calculate V b i using an equation and c) Draw an equilibrium band diagram, draw an equilibrium band diagram for the junction and determine V b i from the diagram.

An abrupt silicon p-n junction has N a equals to 10 to the power 18 per centimetre cube inverse on one side and n d equals to 5 into 10 to the power 15 per centimetre cube inverse on the other. Calculate the Fermi level positions at 300 K in the p and n regions; calculate V b i using an equation that means, V b i equals to k t by q l n N a by N a N d by n i square because n a and n d are given an n i is equals to 1.5 into 10 to the power 10 centimetre cube inverse for silicon. Then number (c) is very important a very interesting also, draw an equilibrium band diagram for the junction and determine V b i from the diagram. So that means you can calculate V b i by two methods; one is...

Student: Equation.

Equation, which is very easy and number two from band diagram. Then you can compare their values whether they are equivalent or not because V b i will be the same for both the cases it is the characteristics of the junction. So can you solve the problem? First you calculate the Fermi level positions at 300 K; how to calculate the Fermi level positions?

Student: (( )) minus v F k t by q l n and n d (( )).

How to calculate the Fermi level positions? What are the relations?

Student: e F I minus E F (( )) k t by (( )) minus (( )).

Right .

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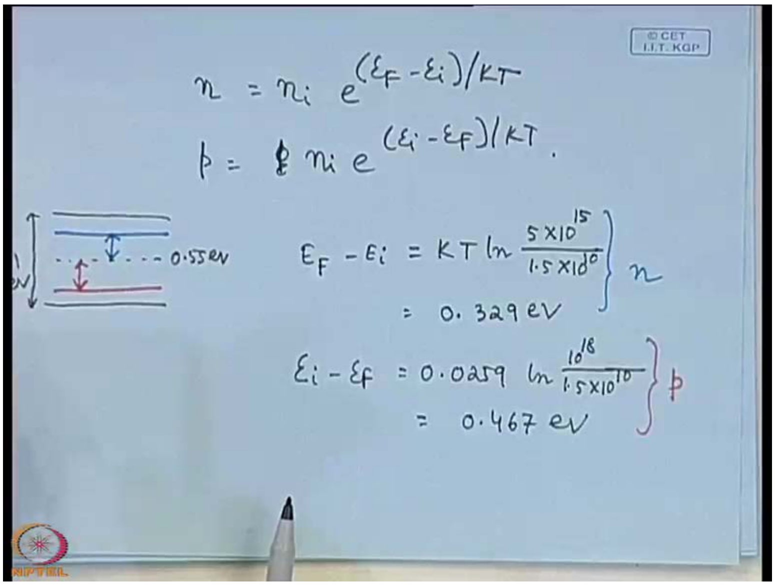

Actually the relations are you see, n equals to n i e to the power E F minus E I by k T and p equals to p, p equals to n i e to the power E I minus E F by k T. So these are the two relations using which you can calculate E F minus E I because the Fermi level position is nothing but this thing. Position of the Fermi level is E F minus E I, E I you know the intrinsic level; it is for silicon you see that, this is silicon, so it is 1.1 electron volt is the band gap; so E I will be 0.55 electron volt that is fixed, E I is fixed it is 0.55 electron volt. So for n region Fermi level will be this thing, you have to calculate this thing for n region and for p region you have to calculate this thing, the red one for p region and blue one for n region, that we have to calculate. First we can write that E F minus E I, E F minus E I this is equals to... k T. k T. l n. l n. n upon n i. n by... n i. n i , so in our case n is how much? n d n d it is how much? It is given. 5 into 10 to the power 5. 5 into... 10 to the power 15. 5 into 10 to the power 15 by...1.5 into (( )). 1.5 into 10 to the power... 10. 10 so if you multiply this with 0.0259 k T equals to... K T upon.

It is 0.329 electron volt. You can calculate using a calculator and will find that it is 0.329 electron volt. So that means E F minus E I is basically this thing, the blue one it is 0.329 electron volt and what is the value of E I minus E F? In place of...

It is 0.0259 l n 10 to the power 18 because it is the acceptor concentration multiplied by 1.5 into 10 to the power 10 and it comes out to be 0.467 electron volt. So that means, this is for n region and that is for p region. Now instead of going to c, instead of going to b that means calculation of V b i using the...

Student: Diagram.

Using the equation or any relation, let us start calculation of V b i from the diagram because from the using a relation it is very easy and you can...

Student: Putting the diagram

Yes, so from the diagram how it is possible you see that. Here this diagram will be very useful to us. Yes this diagram. You see this diagram. We find that in the n site, E F minus E I is 0.329 electron.

Student: Volt.

Volt it is n site because this E I is nothing but the mid gap energy; this is E I, this is E F so, it is the mid gap energy. Then for here the E I is this thing, it is 0 .467 electron volt. Now if you add these two thing, if you add this two thing you will find V b i, if you add this two thing you will find V b i; why? Because, Fermi level is changed, but E I is not changed. So alignment of Fermi level with respect to E I on both the sides will give you the value of the V b i, you just add these two thing.

Student: (( ))

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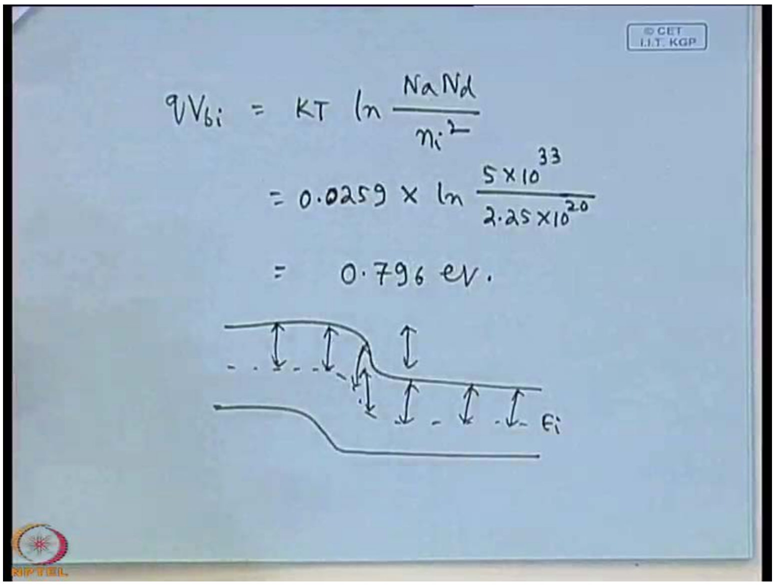

You just add these two thing you will find that it will be 0.796 electron volt and if you try to calculate from the equation you will find that, q V b i this is equals to k T l n N a N d by n i square; this is equals to 0.0259 multiplied by l n 5 into 10 to the power 33, why it is 5 into 10 to the power 33?

Student: (( )) 15 into 10 to the power 8.

Right.

Student: an n i square is...

2.5.

Student: 2.25.

10 to the power 20.

20 so, if you calculate it will be 0.796 electron volt. So, we find that, from the value of the diagram as well as from the relation V b i is same it must be, it must be. Now this diagram which I have used, what should be the E I? If I want to draw E I, then how the E I will change? E I will change in this manner.

Student: (( ))

E I throughout the material will same. So that means, V b i and here this V b i will be same; it is changing in the same manner, because of the bending of the bands E I throughout the material will also change because E I is nothing but the mid gap energy. So that means if you can calculate Fermi level and the Fermi level you can calculate V b i as well from the diagram because the fact that the E I also changes the, E I level is also changes like the bending of the bands, because the corresponding E I will be 0.55 in all the time, it will be 0.55, it will be 0.55, it will be 0.55, because it is silicon.

If it was gallium germanium, then this value will be 0.33, 0.33, 0.33 between two corresponding points it will be 0.33 as usual. So that is the thing you will find that your V b i can be calculated from the band diagram, as well as from the equation. So that means, we have seen that it is the volts and the electrons which take part in the current conduction and remember that, the number of electrons here is more because it is the majority carrier in the, in the site. Here the holes are more so, the current is due to the diffusion; most of the current is due to diffusion not due to drift. So with this thing I conclude today’s lecture.

Thank you.