Semiconductor Devices and Circuits
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Lecture - 28
PN Junctions : Non-Idealities

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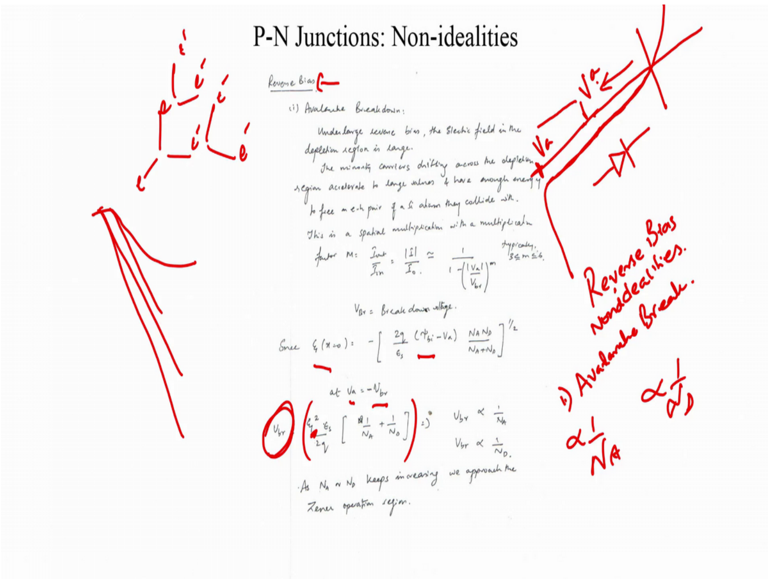

So, before we close to Schottky P-N junction diodes let us just look at some of the non-idealities ok. So, it is not, if you look at a perfectly ideal P-N junction diode, it would be the way we defined it to be but there are some non-idealities ok. First we look at the non-idealities in reverse bias ok. I am not sure if that is all very clear, but I will write it out so, reverse bias non-idealities.

So, the first one is something called as the avalanche break, which is to say that it is not that the P-N junction can keep operating with the same current voltage characteristics for an infinitely large negative voltage. There is a large enough there is a voltage, which is so this is my, this is when I apply an increasing reverse bias V a keeps getting more and more negative. So, far what our equations tell us is that the P-N junction would continue having a current that is exponentially dependent and continue increasing in magnitude in a very small manner based on our function but that is not really true.

You will reach a point where the electric field due to the band bending. See, the electric field the bending keeps increasing as you apply the reverse bias right, it gets that band bending gets steeper and steeper. And there will be a point where the electric field is so large, that the electron drift becomes so large that the electrons can now start colliding with the other silicon atoms and pull free electrons out from those silicon atoms ok. So, this is and this leads to a multiplication effect. You have 1 electron you know getting another electron out and then these would these were in turn, start generate pulling out more and more electrons because this very high electric field. And therefore, you have this avalanche of electrons that start adding to the current and you will find that there is a massive surge in the current in the device simply cannot take that surge and it simply breaks down ok.

So, this is a purely drift based mechanism, but you have a large your electron population increases dramatically because of this breakdown phenomena. And therefore, the breakdown voltage, the voltage at which this happens, what is the V a at which this happens? The V a at which that happens is defined in terms of the electric field that is needed to break the semiconductor term.

So, at V a equal to V br you find that you know using your regular expression of electric field in, if you write your electric field in terms the built in potential you have this expression. And therefore, your breakdown voltage is simply given by this term where the electric field is now large enough to create a breakdown. And therefore, if you write these expressions in this manner you find that the breakdown voltage is inversely proportional to the dopant concentrations. So, if I dope it very large the breakdown voltage decreases.

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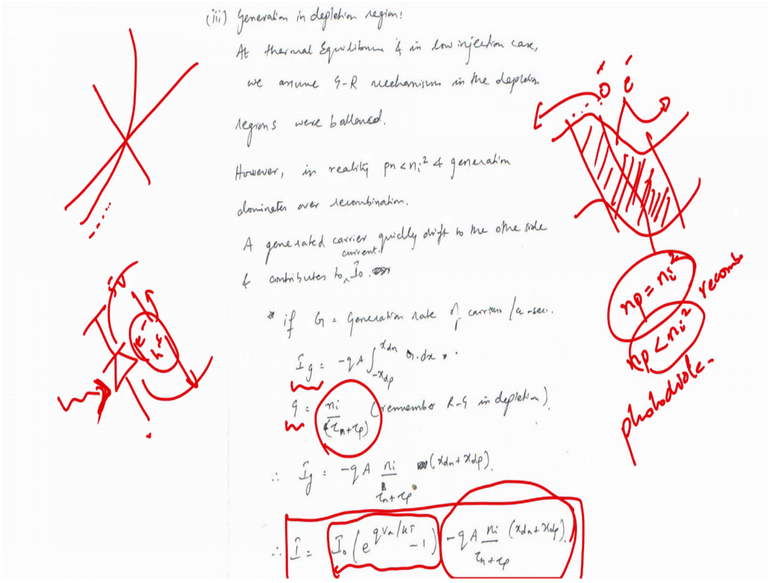

The 3rd point is something called as is a third non-ideality is defined is related to the generation of carriers in the depletion region ok. So, in a reverse biased P-N junction your depletion region is quite large and it is quite strongly depleted, with the there being no diffusion current and there being a drift current due to the electrons and holes. And in the in this depletion region your if you look at the equilibrium condition in a semiconductor your np is always a ni square so, that is your mass action law.

But since this region is not depleted, your np is less than ni square, which means that if you go back to the recombination generation mechanisms we looked at. If we look at the rate of recombination and generation this implies that this implies that, it this implies that it is going to prefer generating carriers as compared to recombining carriers.

In some sense you have altered by depleting this a P-N junction you have altered this balance of generation and recombination of carriers and you have encouraged generation a bit more than recombination. That is the carriers will effectively you will be generating carriers in the heavily depleted P-N, heavily reverse biased P-N junction diode. And whatever carriers are generated here, so let us say you generate an electron and an hole, this electron would quickly run downhill to the other side and the hole will quickly run uphill to the other side.

And this mechanism is the key between the is key to the operation of something called as a photodiode ok. So, if you want to sense light, particularly low levels of light what we do is be reverse bias the P-N junction diode ok. So, you apply a very huge reverse bias voltage and when light falls on this junction you create electron hole pairs and this electron hole pair creation is encouraged and the recombination is now going to be quite low. And these electron hole pairs now quickly drift to the other side because of this large electric field and therefore, you can collect these electrons and holes and you have a current that depends upon the amount of light you throw in ok.

So, if you were to actually throw in light the curve would actually shift you will offset the P-N junction curve a little by adding more by but because the generation of carriers. And therefore, this generation of carriers, if it has a certain generation rate G, it would create an effective current and that effective current is simply G dx integrated from minus x dn to minus x dp to x dn which is basically telling you that it is the total generated carriers in this region times the area, times q which is basically a drift component to the excess carriers generated.

So, that is the excess current that you would create by because of generation. And in a heavily depleted region we already know what the generation rate is. If you look at the if you go back to the topic on recombinational generation you will find that we look at one special case which is recombination generation mechanisms in a heavily depleted region and we find that the generation rate is given by this particular term.

And therefore, the total current in a P-N junction diode after taking into account you know your generation recombination the generation of carriers in the depletion region. In reverse bias if you include this non-ideality the total current is not only the current due to you know due to the exponential dependence of the voltage, but it is also due to the generated carriers and this current adds on to the current due to the diffusive component of the current ok.

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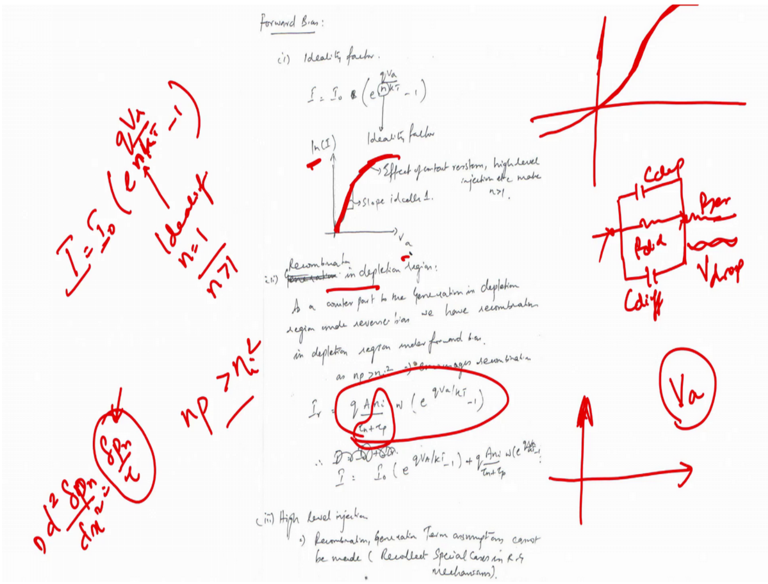

So, now what are the non-idealities in forward bias? In forward bias the first thing to notice is so the currents are going to be quite large, the currents are quite large. And because the currents are large you do have an exponential climb initially but, then because of the series resistance or because of any voltage drops in the P-N junction diode ok. If you remember the equivalent circuit or the P-N junction it had a diffusion capacitance, a depletion capacitance and a diode resistance as well as a series resistance due to the bulk regions and the contacts they make with the metal etcetera.

And if the currents are quite large it can lead to a voltage drop across the series resistance which will effectively implied the diode is seeing a much smaller voltage and that phenomena has to be taken into account and it will lead to lead to a saturation in the diode characteristics. So, the diode current would look a bit like this, this is a logarithm of the current versus the voltage.

So, initially you would see a slope of one and then slowly the slope will start tailoring down because of these effects and this is all taken care of by adding something called as an ideality factor to the equation. So, ideally your P-N junction relation had a term like this it was q V a by k t minus 1.

But then in order to account for all this we sort of tune down this exponential by adding a factor here ok. So, this is a real number that you just earned the denominator and if this n is something called as an ideality factor. It can be used to empirically model any such behavior in the P-N junction. So, if n is equal to 1 then its behaving like a perfectly ideal diode if n is greater than one then there are other effects that are sort of damping the current in the diode.

Now, the second non-ideality in forward bias is clearly the opposite of what happens in the depletion region as in reverse bias ok. So, it is the opposite of that which is in reverse bias the depletion region saw an encouraging of generation mechanisms as compared to recombination. But in forward bias the np product in the depletion region is much greater than ni square and therefore, recombination is encouraged as compared to carrier generation ok.

And therefore, if you take into account the recombination this will contribute to a current and the recombination current is essentially given by this term here ok. You have a recombination rate and then you have your continued diffusive component. And since you have excess recombination a diode and forward bias is something that is used to build your light emitting diodes for example, because you have excess recombination and therefore, you have emission of light if you choose the materials carefully.

The final non-ideality which we have not treated at all in this course is as to what happens under very large forward bias. When V a is extremely large you have a large number of carriers diffusing through and the continuity equation we used is not sufficient to handle that ok. So, the continuity equation we used was delta pn by dx square is equal to delta pn by tau ok.

So, this equation is valid only under something called as a low level injection approximation. We have a very large V a, we have a high level of injection and therefore, these equations need to be modified or you need to have a more thorough analysis of the situation. And therefore, you cannot assume any things that we assumed in this case.

So, particularly this particular term for recombination cannot hold true if you have very high level injection. So, these are some non-idealities that you must be aware of on over all the P-N junction theory we have looked at in this class. With that we will conclude our analysis of P-N junction.