Introduction to Semiconductor Devices
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Lecture – 5.7
Nanohub Demo - PN Junction with Applied Bias

(Video Starts: 00:11) Hello, everyone, welcome back. So, in this video, I wanted to give you a brief demonstration of Nanohub, the PN junction tool in the Nanohub, analyze PN junction and applied bias. So, we have already seen this last week. So, to use this resource, you will have to go to Nanohub and then go to tools. And then you will find the PN junction lab**.**

We are using the older version; we are not using the new interactive front end; we are using the older PN junction lab so, launch the tool. And let us run the default parameters just like what we have done in the last week. So, one of the reasons I like this tool is that, you know, I believe the best way to learn any material, any subject is by asking questions. So, you do not learn just by listening to lectures, but you are actually asking questions and analyzing what is happening.

So, this tool is sort of a very convenient method to ask some questions and see what the answers are. And whether there is a consistent with our understanding. So, that is what we will try to do now. So, let us take the default settings, I will not go into what the settings are. We did the last week you know so, simulate. So, we have seen the equilibrium conditions in the last week.

So, now let us look at IV characteristics. So, it gives you the IV characteristics that we predict you know, exponential dependence. So, here if you extrapolate, the V T is around, 0.42 or so 0.42 0.43. And then you can also look at energy band diagram how it changes. So, here, this simulation, default is actually running from 0 to 6 volts 0.6 volts other. So, this was the equilibrium at 0 applied bias. This is the equilibrium band diagram.

But as you apply the voltage forward bias voltage, you will see that there is this built-in potential or energy barrier, which is reducing and also you are seeing that the Quasi-Fermi levels are separating out. This was the equilibrium Fermi level. So, it will be the EFN this will be EFP, Quasi Fermi levels are holes. So, these are nicely separating out. You can compute actually.

And here, you see some discrepancy because the length of the P type material is only 3 microns. So, in the end, there is some numerical issue. So, even in this other end, you will see that there is a sudden jump. This is because we are using finite number of grid points. In the end, there will be some small issue because of numerical the way to set up.

So rerun the simulation. Instead of this pick up 6 micron length, and increase the P type region and also increase the number of nodes. So, essentially, I am taking this and setting up the grid symmetrically in this case and let me simulate it one more. So, by the way, so the environment is where you specify, this is applied voltage, this is the maximum applied voltage.

So, right now, we are setting it from 0 to 0.6. So, now if we go back and look at the let us see energy band diagram, we have already seen, so we could look at excess carrier density. So, as you apply voltage, we are injecting excess minority carriers and that is what you see. So here, the total is 12 microns, 6 microns is the junction.

This is the holes and this is the electrons. You can also look at the total doping plus electron hole. This is the regular doping density. As you apply voltage, you are injecting electrons from N side into the P side. That is why you see this exponent this decay; this is the logarithmic scale, so exponential decay. So, these are the minority carriers which are getting injected.

And here, the minority carriers are again getting injected. Look at various situations, there is a lot of material here. So, net charge density. This was kind of what we have seen already.

So, this is the actual solution, not with the depletion approximation. So, if you looked at the charge density at equilibrium, this red curve was a depletion approximation we have seen, but the actual density was slightly different. Now, we will look at it as we apply voltage. The depletion region width will reduce as you apply voltage.

We could also check out you know what happens in the reverse bias. So, for that, I will take till –1 and run a simulation. So now, let us look at electric field.

So, we saw the peak electric field was this profile at 0 applied voltage. What happens as you increase the reverse pass? What happens to the peak electric field? So, let us say the peak electric field was roughly about $10^1 * 10^4$ .But as you apply voltage, you will see that the electric field increases.

So, the apply voltage of let us say 1V, – 1 V, it might actually become something close to 1.5. So, there is an increase in the applied electric field, as you apply more and more negative bias. This is because the depletion charge if you look at net charge density, so this is a net charge at 0. And as you go to more and more negative voltages, the depletion charges increasing. So, that is why the electric field is larger.

So, electric field is simply found by integrating this charge, as you go from 0 electrification to the centre. As we integrate, you will see that there is more and more charge and that is why this is stronger electric field. And because of course the same we know it is related to the electrostatic potential, we will see that as you increase your right voltage in the reverse bias, the barrier increases, potential barrier increases. All of this is consistent.

We studied what happens to reverse bias rather what happens to V-T as you change the temperature. You could run a simulation with the temperature, take 300 degrees and then 350 degrees.

As you increase temperature, we have seen that reverse saturation current increases.

Let us explore whether that happens. So, let us see if you can also plot a IV characteristics. So, that essentially is telling you from 0 to – 1. There is a kind of a constant current. Of course, this is not taking into account the impact ionization or Zener breakdown that is different. We have not included that. We have not included that in the model that is why we do not capture the breakdown we do not capture. So, this is some you know, minus the saturation current is 0.18 amps per centimetre square.

I do not know what the area was here assumed that would depend on the area as well, per unit area, so but this is what seems to be reasonably large actually. Compare this with the at 300 degrees IV characteristics, 0.003. I think you should not take the absolute numbers here. It is quite large. And I am not sure if the reason is the numerical accuracy.

So, but at least relatively you see that this is 0.3 milli amps. And at 350 degrees was expected to be larger and it is actually 0.05 so, 0.066 milli amps. So, you see that there is a strong increase in the reverse bias current. And well, I mean, there is a whole lot of things you can check, I mean, almost lot of everything that you can think of is here, CV the characteristics.

As you increase the reverse bias, the depletion width increases, because of this capacitance reduces. So, you see that the capacitance is reducing; this is the depletion capacitance, you could also download this data into your desktop and check $\frac{1}{c^2}$ versus V whether that gives you a straight line. But of course, this is not a real you know, one sided junction, if you want to do that, the analysis that we have shown that $\frac{1}{c^2}$ versus V.

If you want to verify that you will have to make 10^{18} or so, so it becomes one sided junction, then you get accurate results. So, I will go back to temperature and simulate in the forward bias, at high temperature. And then run it at room temperature 300K.

So, you could actually compare bands slightly, you know, there is a small change in the band gap, you see, this is at 350 degrees. And this is at 300 degrees. So, when I do that and both the things are displayed, so right now, it is 300 degrees. If I click all, there is a small change here in the barrier.

And let us look at the current IV characteristics. So, this was at 300. At 300 degrees, you have pressure voltage, close to 4.42. And then the moment you include it, the higher temperature, the pressure has shifted to the left, as we were discussing in the last video. So, the threshold voltage changes and that is why you get larger amount of current.

So, I mean, just, you know, all I can say is, this is a really a goldmine. I mean, you can analyze a lot of things, you know, a lot of interesting things. What is this recombination rate? If you are curious, you could explore and then you can try to think of answers. **(Video Ends: 13:08)**

So, I would just wish you good luck and let me know if there are any questions. Have a great day. Bye.