# Electroinic Materials, Devices And Fabrication

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## Lecture - 17
## Assignment 5 - Pn Junctions

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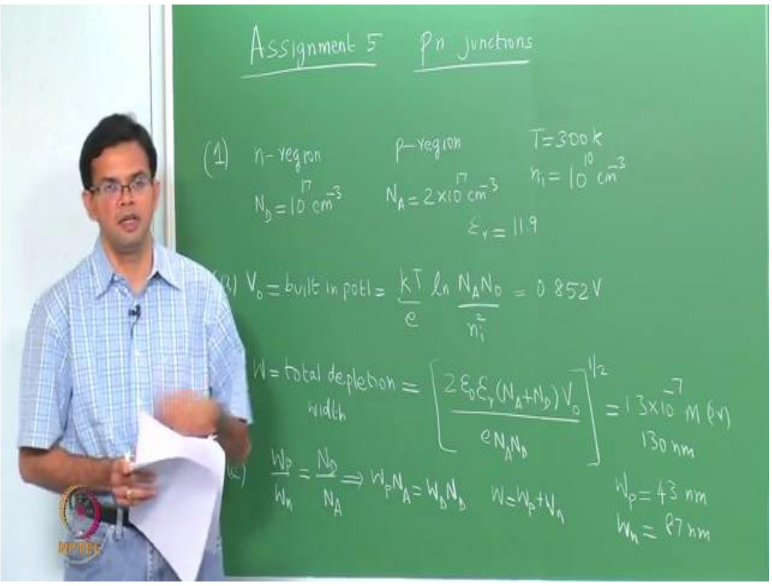

Assignment 5 pn junctions

(1) n-region p-region $T = 300\,k$

$N_D = 10^{17}\,cm^{-3}$ $N_A = 2\times10^{17}\,cm^{-3}$ $n_i = 10^{10}\,cm^{-3}$

$\varepsilon_r = 11.9$

$V_0 = \text{built in potl} = \frac{kT}{e}\ln\frac{N_A N_D}{n_i^2} = 0.852\,V$

$W = \text{total depletion width} = \left[\frac{2\varepsilon_0\varepsilon_r(N_A+N_D)V_0}{eN_AN_D}\right]^{1/2} = 1.3\times10^{-7}\,m$ (or) $130\,nm$

(c) $\frac{W_p}{W_n} = \frac{N_D}{N_A} \Rightarrow W_pN_A = W_nN_D$ $W = W_p + W_n$ $W_p = 43\,nm$ $W_n = 87\,nm$

In today‘s assignmentwe are going to look at pn junctions. This is assignment 5. In assignment 4 we looked at metal semi-conductor junctions. In assignment 5, we are going to look junctions form between p and N type. So, uaually tha p and N are of same material which it is a homo junction. We also seen hetro junctions were the junction is found between 2 different materilas. In this assignment we will focus fully on the homo junctions. We will do some calculations on built in potential when a junction is formed. The depletion width and the that is the total depletion width and also the depletion width on p and the N side. A p N junction is essentially a diode it is a rectifier.

So, that it conducts current in the forward bias and does not conduct in the reverse bias. So, we will also do some calculations of the forward bias current and reverse saturation current. So, some of this will similar to what we did in assignment 4, where we looked at a short key junction which is also a rectifier. So, later compare the properties of a p N junction in that of schottky junction. So, let me go to problem number 1.

We have a silicon p N junction which has an N region with 10 to the 17 donors per centemeter cube N region. So, N d is 10 to the 17 centemeter per qube. And there is p region with accepted concentration of 2 times 10 to the 17 centemeter per cube N a the material here silicon and it is at room temparature. So, temparature T is 300 kelwin the intrensic carrier concentration, we have seen this so many times in the past, is just 10 to the 10 centemeter per cube.

So, in part a we want to calculate the built in potential of this junction. So, v naught is the built in potential. So, it is the potential when the junction is an equalibrium. And this forms, because we have electrons from the N side moving into the p side. This is a diffusion current, we have wholes from the p side moving to the N side. These essentially meet each other and enhilate. So, that you have depletion region.

So, on one side of the depletion region you have a net possitive charge. This is the N side on the other side you have a net negative charge thats your p side. And there is a junction potetial that develops. So, this built in potential is nothing but K T over e laun of N a, N d over N i square. So, this is just direct substitution of the numbers N a and N d are given N i square is also given.

If N i is not known can always calculate N i from the gap and the effective density of states or the effective mask electrons and holes. So, we just plug in the numbers and the answer 0.852 volts. In part 2, we want to calculate the total depletion width, let me call the w that is the total depletion width. So, depletion width again forms because we have electrons and wholes moving across the junction and the recombining.

So, saying this concept of depletion width earlier when we look at a short key at a short key junction in that case the depletion width is almost entirely on the semi condutor side. So, here depletion width will be in both the p and the N side. So, total depletion width again its given by a direct fomula substitution 2 not absalon r N a plus N d times v naught were v naught is your built in potential by e N a and N d and whole to the 1 half.

So, absalon not is the permitivity of free space absalon r is the permitivity of silicon the relative permitivity and absalon r is 11.9. So, it is the known value of silicon. So, once again everything here is know we just calculated the built in potential v naught. So, that we can do the substitution and this works out to be 1.3 times 10 to the minus 7 meters or you want to write in an nanometers 130 nanometers.

In part c, we want to calculate the depletion width on the p and the N side. So, the ratio of depletion widths W p over W n is inversly proportional to the reconcentration of your dopants. So, this is equal to N d over N a another way of writing off course is a W p N a is w d N d and this comes from the charge nutrality. So, that the total positive charge due to your possitively charged donars on the N side must be equal to the total negative charge due to the negatively charged accepted ions on the p side. And those to essentially balanced. We also know the total width w is W p plus W n and total with W has been calculated to be 130 nanometers.

So, we have all the numbers, is again a case of doing the substitution and the math. So, I will just write down the final values. So, W p is 43 nanometers and W n is 87 nanometers. So, the total width comes out to be 130 nanometers, the accepted concentration on the p side is higher. So, 2 times 10 to the seventeen. So, the depletion width on the p side is smaller. So, let us to now go problem 2.

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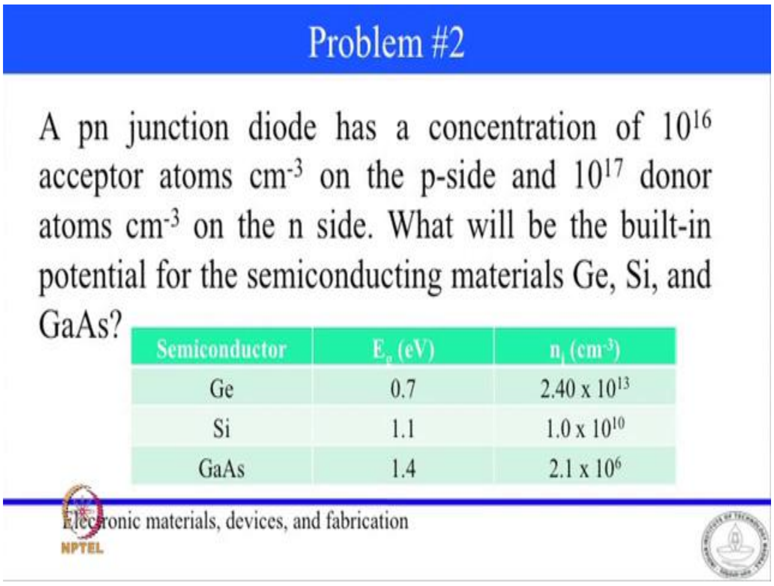

## Problem #2

A pn junction diode has a concentration of $10^{16}$ acceptor atoms cm$^{-3}$ on the p-side and $10^{17}$ donor atoms cm$^{-3}$ on the n side. What will be the built-in potential for the semiconducting materials Ge, Si, and GaAs?

| Semiconductor | $E_g$ (eV) | $n_i$ (cm$^{-3}$) |
|---|---|---|
| Ge | 0.7 | $2.40 \times 10^{13}$ |
| Si | 1.1 | $1.0 \times 10^{10}$ |
| GaAs | 1.4 | $2.1 \times 10^{6}$ |

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Problem 2, we have a p n junction diode with the concentration of 10 to the 16 accepted atoms on the p side and 10 to the 17 donar atoms on n side.

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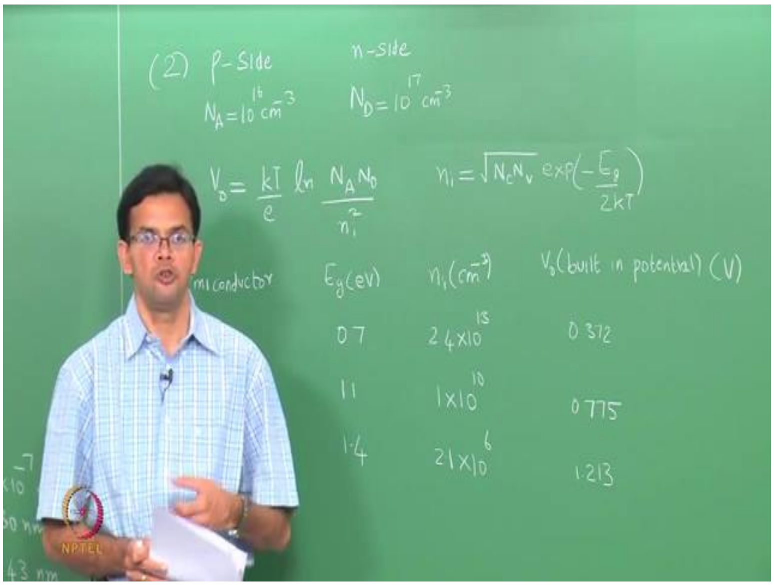

So, once again you have p side and the n side. So, N a is 10 to the 16 and N d is 10 to the 17 per centemeter cube. So, we need to know the built in potential if the material of the semi conducted is diffrent. So, in this particular case we want the built in potential for a semi conductor materials germanium, selicon and galliaum arsenite. So, if you go back to the formula for the built in potentials K T over e laun of N a N d over N i square.

So, if you change the material and if you keep dopent the concentrations the same and the temparature is also same stipically the room temparature. The only thing is changing is N i we have seen earlier that N i depends upon the bang gap square root of N c N v exponential minus e g over 2 K t. So, as the value of the bang gap increases N i essentially goes down because its an explanantial with a negative term.

If the value of N i goes down then the built in potential will essentially increase. So, in this case we have 3 materials. So, I will write down the table that is given in the problem. So, we have germaniam, silicon, galiam arsanite. The band gap values are given in eg these are mainly used for just comparison. We do not need the band gap values as far as this problem is concerned, germanian 0.7, silicon is 1.1 galiam arsanite is 1.4. What we do need is the value of ni an ni is again given for centemeter cube. So, germaniam is 2.4 times 10 to the 13, silicon is 1 time 10 to the 10 and galiam arsanide is 2.1 times 10 to the 6.

So, N i essentially decreases as the value of the band gap increases. So, we now need to calculate the built in potential for these 3 materials. We can make use of this formula just substitude N a and N d and then the values of N i for the different materials. So, we can go through and workout the math. I will just write down the final answer. So, v naught which is your built in potential is nothing but 0.372 the units is words. For germaniam, it is higher forcilican 0.775 and it is even higher for galian arsanite 1.213.

So, as the value of ni goes down because you have a higher band gap. The built in potential at the junction essentially increases. So, this information is especially useful when you try to build devices with materials apart from silican because once you know the built in potential, we will also know what kind of current that needs to be applied to the circuit for a particular kind of application.

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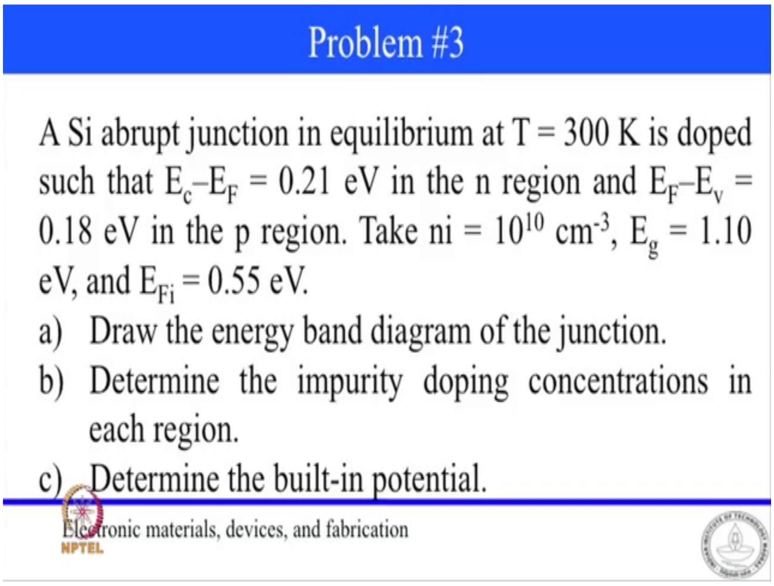

## Problem #3

A Si abrupt junction in equilibrium at T = 300 K is doped such that $E_c – E_F = 0.21$ eV in the n region and $E_F – E_v = 0.18$ eV in the p region. Take ni = $10^{10}$ cm$^{-3}$, $E_g = 1.10$ eV, and $E_{Fi} = 0.55$ eV.

a) Draw the energy band diagram of the junction.
b) Determine the impurity doping concentrations in each region.
c) Determine the built-in potential.

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Let us now go problem 3. In problem 3 we have a silican abreb junction which is internal equilibrium at room temaparature.

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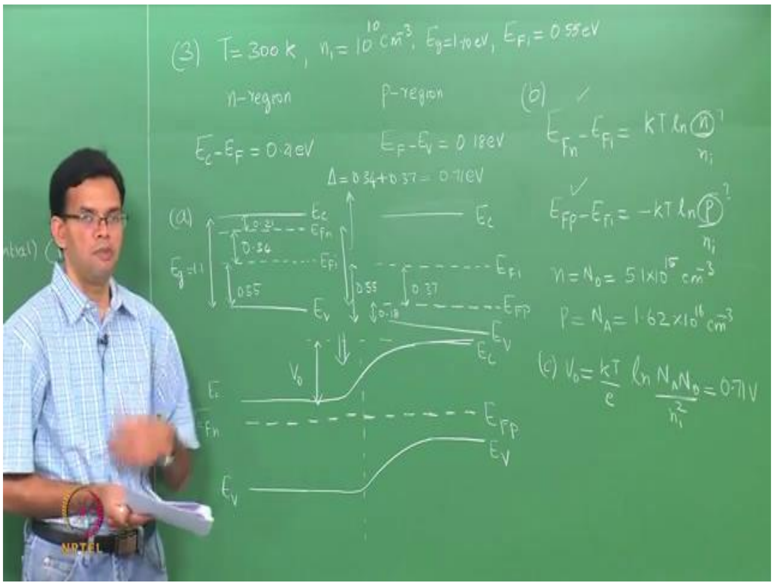

This is assignment 5 in assignment 4 we look at metal is 300 kelvin. It is doped in such a way such that E c minus E f 0.21 electron volts in the N region. So, you have an N region and you have a p region. So, in this question the doping concentrations are not given, but the position of the firm e level is. So, here E c minus E f is 0.21 electron volts and E f minus E v is 0.1 8 electron volts the material is silican. So, you have somehow with the parameters of silican n i which is 10 to the 10 for centemeter cube. The band gap of silicon E g is 1.10 electron volts.

The position of the intrinsic firmy level E f i it is not exactly at the center, but it is very close to the center. So, we can take this as 0.55 electron volts. So, these are some of the parameters of intrinsic silican that we can use. So, the first part of the questions says, draw the energy band diagram for the p n junction. So, before we do that, let we have to first draw the energy band diagram for the 2 regions separately. And then we can put them together to draw the energy ban diagram for the junction.

So, on the end side this is my cunjuction band. This is my valance band, this gap is nothing but E g which is 1.1 E f i is at the center of the gap. So, that is 0.55 and E g is 1.1. So, this question says E c minus ef is 0.21. So, the firmy level on the end side E f n is 0.2 1 electron volts. So, this height which is nothing but 0.55 minus 0.2 1 is 0.3 4. So, all the energies are in electron volts and just not writing the units, everything is in u v.

We can now do the same for the p region. So, the material is the same. So, the band gap is the same and just draw this slightly better. So, it is the same silicon. So, the E c and E v are located in the same place E f i will also be located in the center E f i in this particular problem ef minus E v is given to be 0.18 electron volts.

So, E f p this is 0.18. So, E f i to E v 0.55. So, that this hieght is nothing but 0.37. So, this is 0.55, this is 0.18 this is 0.37. So, we have the enery band diagrams of the N and p regions seperately. We can put them together and draw the fenergy banned diagrams of the pn junction, but before we do that I will like to calculate the concentration of electrons and holes on the n and the p side.

So, that we can do by basically using the formula E f n minus E f i is K T lon N over n i and E f p minus E f i is equal to minus K T lon of p over n i. So, the position of the firmy level is related to the concentration of the majority carriars on the end side it is your doners on the p side it is the acceptors. So, here this term is known and this is the unknown, same way here this is known and this is unknown.

So, E f n minus E f i is 0.34 and E f p minus E f i is minus 0.37. So, we can substitue in the values. So, that we get n equal to N d which is equal to 5.1 times 10 to the 15 centemeter cube p is nothing but N a is slightly higher 1.62 times 10 to the 16 for centemeter cube. So, even without doing the numbers we could have predicted that N a will be higher than N d simply because the firmy level on the p side is located much closer to the valance band, it is only 0.18.

Compared to the firmy level on the end side which is 0.21 electron volts below the conduction band. So, we now drawn the energy band diagram separately. We also have the concentration of the electrons and the holes. So, let me draw the energy ban diagram when the junction is found. To do that we know that the firmy levels must essentially line up at equilibrium.

So, this is E f n, this is E f p far away from the junction. You still have an n type semiconductor and you still have a p type semiconductor. Let me just arbritally mark and inteface between these 2 and we can show the band bending. So, that these 2 joints. So, this is E b this is E c this is E c and this is E v. So, you have the firmy level lining up and there is a built in potential. This is a straight line and there is a built in potential v naught found at the junction.

So, part b we need to ditermine the concentration of the impurities. So, we actually just did that. So, this is essentially part b, just by looking at the shift in the firmy levels we can calculate the concentration of the imputities. Part c, we want to calculate the built in potential. So, v naught is nothing but K T over e lone of N a N d over N i square. We can do all the substitutions and the numbers. So, if this works out to be 0.71 volts. We can also calculate the built in potential by looking at the energy band diagram.

So, in this particular case, the distance between E f n and and E f p. So, this distance is essentially 0.34 plus 0.37. So, this distance delta 0.34 plus 0.37 which is 0.71 electron volts. So, when the junction is found we know that the firmy levels has to line up. So, we can think of as either the inside shifting completely by 0.7 1 or the p side shifting up by the same 0.71. So, that they line up. So, the built in potential or the built in voltage is nothing but the diffrence between the firmy level possitions.

So, this is.7 1 electron volts if you devide by e it is 0.71 volts. So, instead of using the formula you can also calculate the built in potential by just looking at the energy band diagram. So, let us now go to problem 4.

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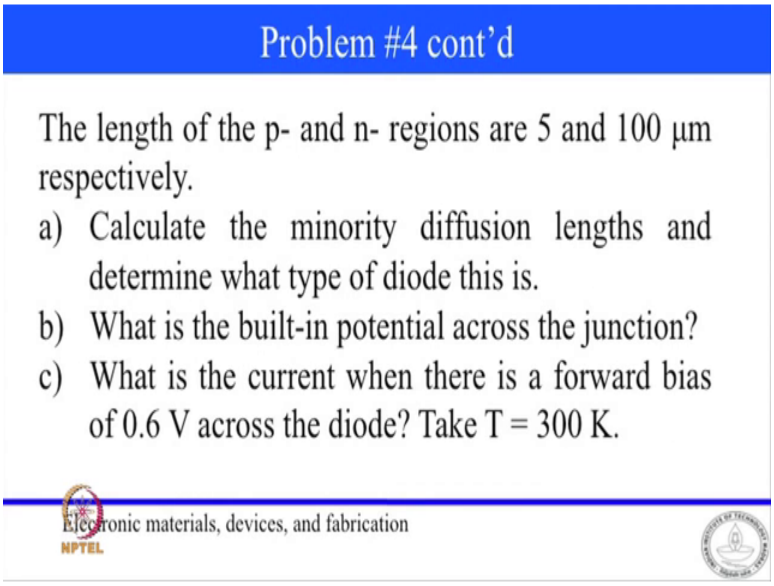

Problem #4 cont'd

The length of the p- and n- regions are 5 and 100 μm respectively.

a) Calculate the minority diffusion lengths and determine what type of diode this is.
b) What is the built-in potential across the junction?
c) What is the current when there is a forward bias of 0.6 V across the diode? Take T = 300 K.

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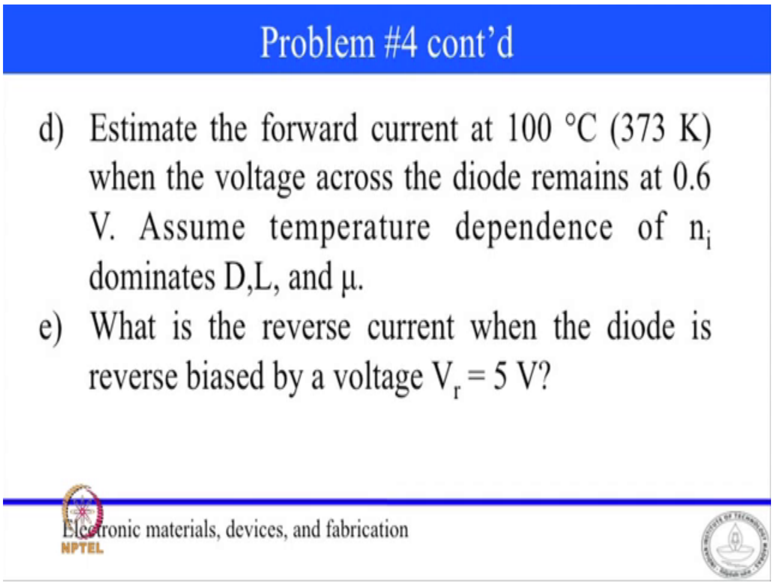

## Problem #4 cont'd

d) Estimate the forward current at 100 °C (373 K) when the voltage across the diode remains at 0.6 V. Assume temperature dependence of $n_i$ dominates D,L, and μ.

e) What is the reverse current when the diode is reverse biased by a voltage $V_r$ = 5 V?

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So, in problems 1 2 3 we looked at the p n junction in equilibrium. So, that there was no external potential, there was applied and no current. There was flowing through the junction, in problem 4 which is slightly a long problem. We are going to look at a p n junction that is essentially bias. And we are going to calculate some values for the current in the forward and the reverse bias. So, problem 4.

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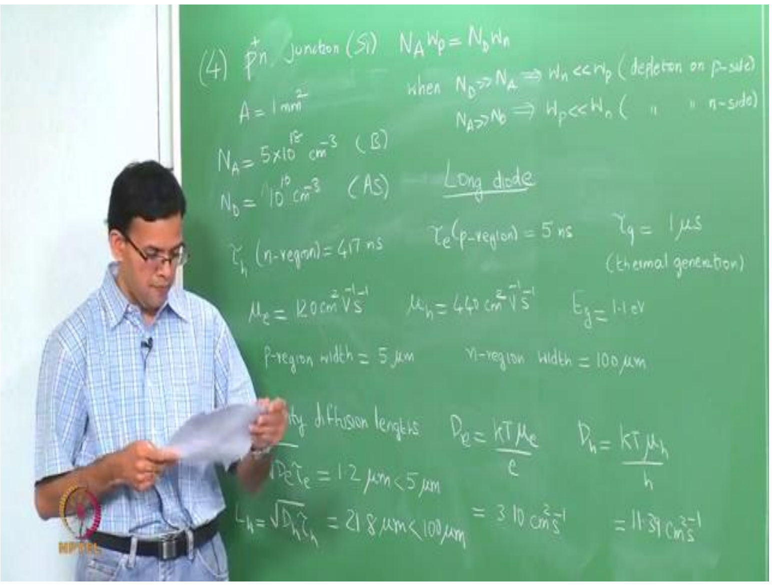

You have an abrupt p n plus junction. So, when we say p n plus or a N p plus N, the plus essentially denotes that this is heavyly a doped. So, when 1 of the carriers or when 1 of the sides of a p N junction is heavily doped, then the depletion region lies almost entirely on the other side. So, one way to see that is to go back to this equation. So, N a W p is equal to N d W n. So, when N d is much greater then N a, this implies W n is much smaller then W p. So, that the depletion width is almost entierly on the p side. I will also just write the reverse when N a is much greater then N d.

Then you have W p much smaller then W n and the depletion is almost entierly on the N side. So, we have an abrupt p n junction the cross sectional area a is 1 mili meter square. We will use to cross sectional area to calculate the current the accepted concetration of 5 times 10 to the 18 boron atoms on the p side. So, N a is 5 times 10 to the 18 per centimeter cube. And this is boron there is a donor concetration N d is 10 to the 16 per cente meter cube and this is arsenic. So, in this problem N a is much higher than N d.

So, this should actually read p plus and not p n plus, my mistake because N a is much greater then N d. So, we have 5 times 10 to the 18 boron and 10 to the 16 arsenic atoms on the N side. The whole lifetime values are also given. So, the lifetime of the whole tou h in the N region. So, these are your minority carriers. This is equal to 417 nano seconds. Similarly, the lifetime of the electrons in the p region is only 5 nano seconds.

And this diffrence is because of the diffrence in concentration of the dopents. The thermal generation lifetime is also given. So, tou g is 1 micro second. Some other values are also given for this problem. So, mu e which is the mobility of the electrons. So, 120 centimeters square per volts per second, mu h is 440 centimeter square per volts per second, E g is 1.1 E v, the length of the p and the n region also given. So, you have a p region width is 5 micro meters and the N region width is 100 micro meters.

So, these are the whole set of data that is given about silicon p n junction. So, the first thing we need to calculate is the minority defusion length and to ditermine what type of diode this is. So, we want to calculate the minority defusion length. So, in the case of the p n junction under equilibrium. We have a dynamic equalibrium. So, that electrons and wholes are moving across a junction and constantly get anhilated.

When we apply a forward bias the p side is connected to the possitive, the n side is connected to the negative. The firmy levels no longer line up, but essentially it gets shifted and when this happens the barrier comes down. So, v naught is the built in potential or the barrier during equilibrium. When you apply an external pottential, the barrier is v naught mine is v external. When the barrier goes down, we bassically have minority carriers moving across the junction. So, we have electrons from the n side moving to the p side, where there minority carriers.

We also have holes from the p side moving to the n side, there they are the minority carriers. So, it is this minority carrier defusion that essentially causes current to flow in a p n junction. So, the first thing we want to calculate is the defusion lengths. To know the defusion lengths we need to know the defusion coefficiency. So, D e which is the defusion coeficient of the electrons is nothing but K T mu e over e. So, it depends upon the mobility and D h is K T mu h over h.

So, the values of mu e is given mu h is given everything else is a constant. So, we can plug it in. So, the D e is 3.10 centimeter square per second D h is 11.39 centimeter square per second. So, D h is higher than D e because mu h is higher than mu e and this is because the holes are defusing on the inside and the concentration on the inside is 2 orders of magnitude less then the p side. So, because you have the less concetration of your dopents the defusion coefficient are higher from the defusion coefficience.

We can calculate the length. So, one is nothing, but square root of d times tou. So, L e is d e tou E l h is D h and tou h. So, once again D e and D h we have calculated tou e and tou h are given. So, we can substitute the numbers. So, L e works out to be 1.2 micro meters I am not doing the math. So, all your units are in centimeters. So, your answer will also be in centimeters, you can just convert that into micro meters. So, L e is 1.2 and L h is larger, it is 21.8 micro meters.

So, if you looked at the length of the diods on the p and the n side. On the n side the diode length is 100, on the p side the diode length is 5 micro meters. So, L e is smaller then the 5 micro meters which is the length on the p side L h is smaller than 100 micro meters which is the length on the N side. So, that this is essentially a long diode. So, a long diode is 1 in which the diffusion lengths are smaller than the physical lengths of the p and the n region. So, this is part a, let us go to part b. So, in part b we want to calculate the built in potential across the junction.

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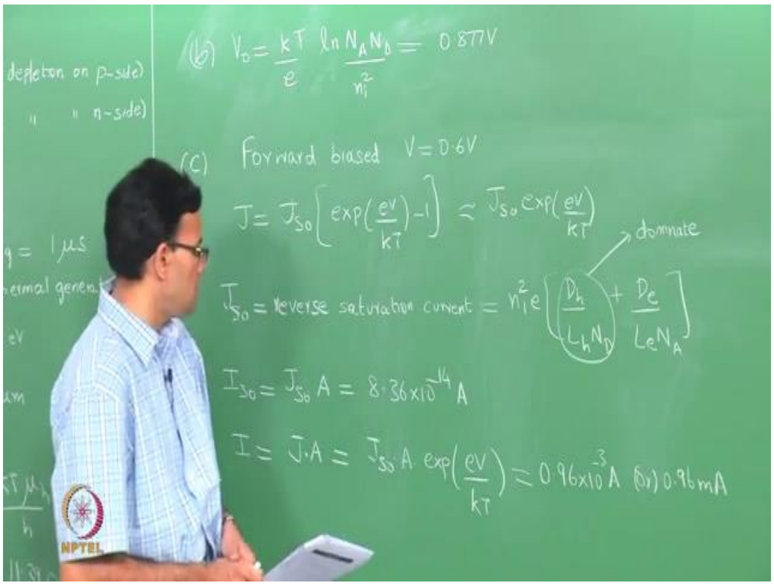

(b) $V_0 = \frac{kT}{e} \ln \frac{N_A N_D}{n_i^2} = 0.877V$

(c) Forward biased $V = 0.6V$

$J = J_{S0}\left[\exp\left(\frac{eV}{kT}\right) - 1\right] \simeq J_{S0}\exp\left(\frac{eV}{kT}\right)$

$J_{S0}$ = reverse saturation current $= n_i^2 e\left[\overset{\text{dominate}}{\boxed{\frac{D_h}{L_h N_D}}} + \frac{D_e}{L_e N_A}\right]$

$I_{S0} = J_{S0} A = 8.36\times10^{-14} A$

$I = J.A = J_{S0} A \exp\left(\frac{eV}{kT}\right) = 0.96\times10^{-3} A$ (or) $0.96 mA$

So, this is the potential when the junction is in equilibriam. So, this is fairly straight forward. So, just K T over e lon of N a N d over N i square. So, we have all the numbers we just need to substitute that this works out to be 0.877 volts. So, this particular problem does not ask you to calculate the depletion width, but you can go ahead and do the calculations. And you will find that the depletion width is almost entirly on the n side and that there is a very small depletion in width on the p side.

Part c, what is the current when there is a forward bias of 0.6 volts across the diode. So, now you have the diode to be forward bias the esternal pottential v is 0.6 volts. So, when we apply an external pottential, the barrier height is lowered. So, that there is an increase in current due to the minority carriers difussing across the junction. In this particular case the current density is given by a constant J s naught times exponential E v over K T minus 1.

Usually the exponential term is much higher than 1. So, that this can be written as J s naught exponential E v over K T J s naught is you reverse saturation current. And this is given by N i square E D h over L h N d plus D e over L e N a. So, we saw the derivation for this during the course notes, but this is your reverse saturation current and this is something that plugs in here. So, if you remember the assignment from the schottky junction to the metal semi conductor junctions.

We had a similar expression for this, except that the constant outfront had a diffrent value which depended upon the thermionic amition, but now here we have a p n junction. So, the constant here is you reverse saturation current. In this particular problem N a is much higher than N d and since they are in the dinominator this term will essentially dominate over the other term. So, if you this is the reverse saturation current density. To calculate the current we just need to multiply this by the area. So, all the numbers are here we calculated D h and L h in part a, N a and N d are known N i is also known.

So, that J s naught. So, instead of J s naught, I will directly write I s naught which is J s naught times the area. So, this is 8.36 times 10 to the minus 14 ampious. So, the reverse saturation current essentially a really small value. Once you know I s naught or J s naught you can calculate the current during forward bias. So, I nothing but J time a which is J s naught times a times exponential E v over K T v is 0.6 that is given. So, the current works out to be 0.96 times 10 to the minus 3 ampious or 0.96 mili ampious.

So, the current in the forward bias is 0.96 mili ampious. So, that is nearly 10 to the 11 orders of magnitude or 10 to the 10 orders of magnitude higher than the reverse saturation current. This is why we essentially call the p n junction to be a rectifier because it conducts very well during forward bias. And the reverse bias current is very small. So, let us now go to part d.

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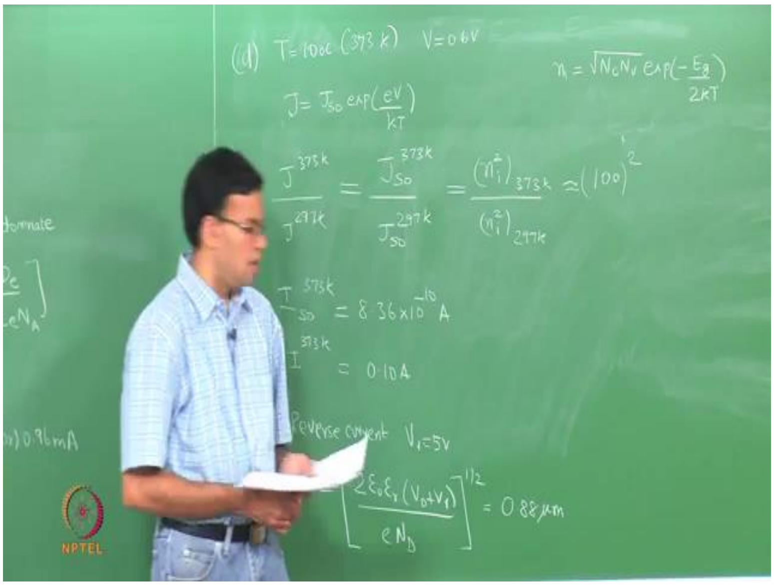

Part d, we want to estimate the forward current at 100 degrees. So, the temprature is now increased, you can write this in kelvin. So, that is 373 kelvin the voltage is the same. So, v is 0.6 volts. The question also says that assume the temperature dependence of N i dominates over everything else. So, over the defusion lengths, the defusion coefficient itself also the mobilties. So, if you only take N i into consideration. So, we can see that the current or if you write this down J is J s naught exponential E v over K T.

So, ratio of J at 373 kelvin to that a 273 or 293 kelvin this should be 373. So, 373 by 293 kelvin or 297 kelvin which is room temprature. So, let me just draw this, write this 297 is nothing but J s naught prime or J s naught at 373 kelvin divided by J s naught 297 kelvinso the potential is the same. So, the ratio of the currents or the ratio of the current densities is nothing but the ratio of the reverse saturation currents.

This is directly proportional to N i square. So, that this is N i square at 373 kelvin devided by N i square 297 kelvin, N i square is nothing or N i square root of N c N v exponential minus E g over 2 K T. So, for this problem we can take N c and N v to be independent of temprature. So, the ratio of N i is just given by the exponential term. So, if you do this ratio works out to be aproximately 100. So, that the reverse saturation current is increased by 100 when we go from room temprature to 100 degrees c.

So, the new values of I s naught be 100 square. So, the new values of I s naught at 373 kelvin just me write down the final answer that 8.36 times 10 to the minus 10 and current I at 373 kelvin is 0.10 amps. So, that the current essentially increases by 4 orders of magnitude. In part E, we want to calculate the reverse current. When you have a voltage of 5 volts. So, we want to know the reverse current when V r is 5 volts.

To calculate the reverse current we first need to calculate the new width when you apply a reverse bias. So, the width w is 2 absalon naught absalon r, V naught plus V r and we said that the depletion region lies almost entirely on the N side. So, I only have E and d whole to the half. So, this formula is something we have used before to calculate the width of the depletion region. When you have a p n junction under equilibriem. So, we only modified it to add the reverse bias voltage.

And we also removed the contribution due to N a because N d is much smaller than N a. So, we can plug in the numbers, the new depletion width comes out to be 0.88 micro meters and most of this is in the end side. So, when you have a reverse bias, you have thermal generation of carriers within depletion region. And this thermal generation of carriers is responsible for your reverse current.

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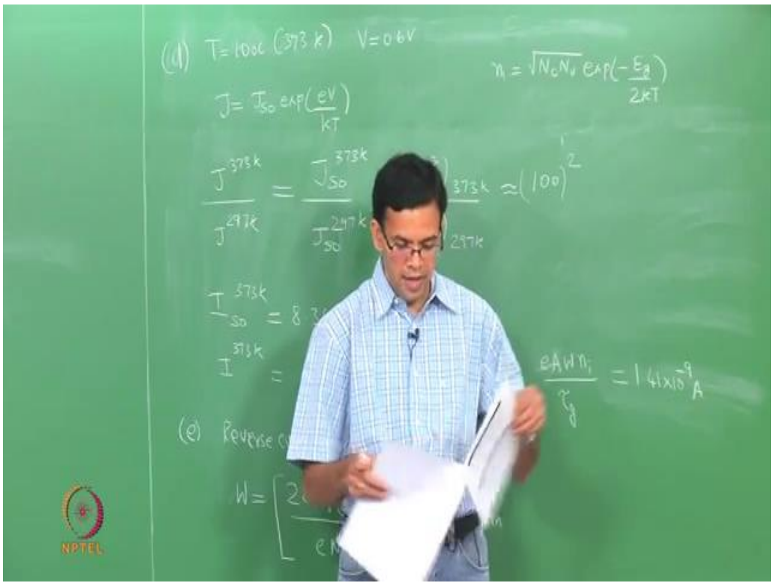

So, I gen which is the current due to thermal generation of carriers is E times a cross sectional area times depletion width times N i divided by tou g, where tou g is the thermal lifetime of the carriers. In the value is also given. So, everything here is known we can substitute the numbers. In I gen works out to be 1.41 times 10 to the minus 9 ampious. So, this number is again much smaller than your forward bias current which is of the order of mili amps. So, once again even if you take thermal generation of carriers into account, we essentially have a rectifying action in a p n junction.

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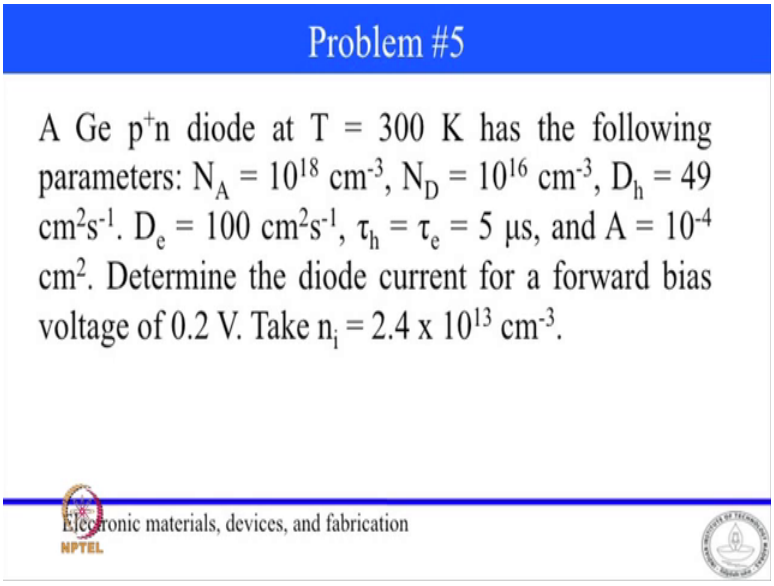

## Problem #5

A Ge $p^+n$ diode at T = 300 K has the following parameters: $N_A = 10^{18}$ cm$^{-3}$, $N_D = 10^{16}$ cm$^{-3}$, $D_h = 49$ cm$^2$s$^{-1}$. $D_e = 100$ cm$^2$s$^{-1}$, $\tau_h = \tau_e = 5$ µs, and $A = 10^{-4}$ cm$^2$. Determine the diode current for a forward bias voltage of 0.2 V. Take $n_i = 2.4 \times 10^{13}$ cm$^{-3}$.

Electronic materials, devices, and fabrication

So, let us now look at the last question. So, problem 5 you have a germanium p n junction diode. So, it is germanium p plus n the values are given.

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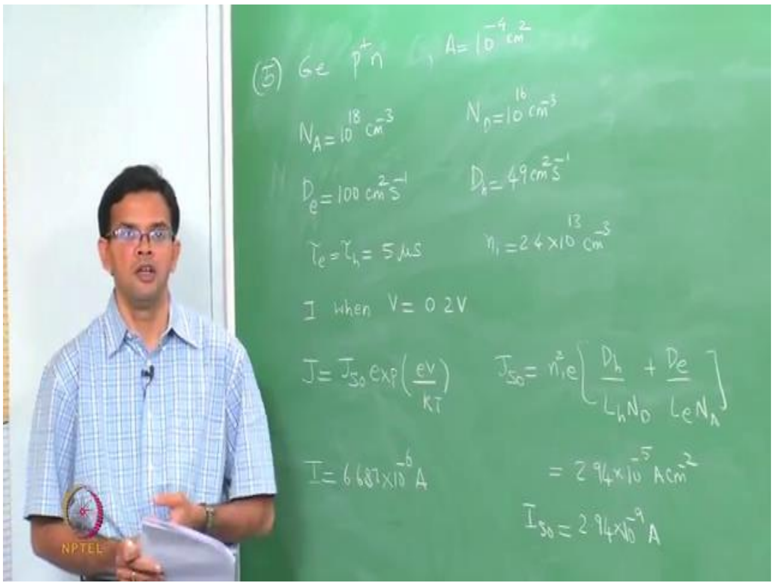

So, N a is 10 to the 18 per centimeter cube, N d is 10 to the 16 D h. So, D h I will write on this side. So, D h is 49 centimeter square per second, D e because we are looking at minority carriers that is 100 centimeter square per second, tou e is equal to tou h which is equal to 5 micro seconds. And the cross sectional area is 10 to the minus 4 per centimeter square. So, we want to calculate the diode current. So, we want to calculate I, when we have a forward bias v of 0.2 volts N i is 2.4 times 10 to this 13 per centimeter cube. So, this is very similar to the previous question.

So, J is J s naught exponential E v over K T and then J s naught is N i square over E d h over l h N d plus D e over L e N a. So, all the numbers are given. So, J s naught I will just substitute and write the final answer, but you can directly do the substitution. J s naught is 2.94 time 10 to the minus 5 ampier per centimeter square. So, the current I s naught is 2.94 times 10 to the minus 9 ampiers. Once you know I s naught, you can substitute here and you can get the current.

The current I is noting but 6.687 times 10 to the minus 6. So, in this particular case, the diffrence between the current and I s naught is not as high as in the case of silicon. One particular reason is because your applied voltage is very small. It s only 0.2 volts. Another diffrence is that the material is germanium. So, that the band gap is smaller. So, the builtin potential is also smaller at the same time N i is larger. So, that J s naught is also larger. So, these are some of the factors, you have to take into account when choosing materials performing p n junction.