Electronic Materials, Devices and Fabrication
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Lecture - 12
PN Junction Breakdown and Heterojunctions

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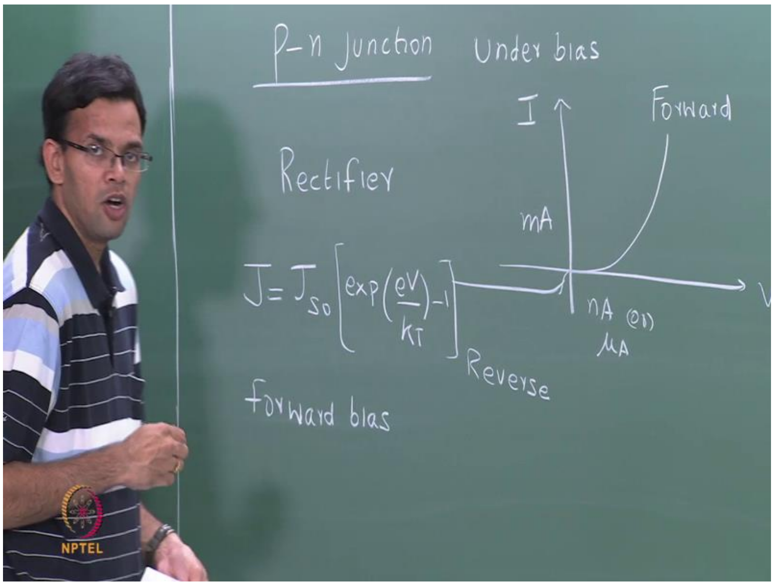

Let us start with brief review of last class. Last class we look P-n junction under bias. So, we apply both power and reverse bias and look and the id characteristic, we found that P-n junction is essentially a rectifier. So, that if were to plat I verses V; this is I this is V, the first quadrant is forward bias, this 1 is reverse he found that in case of the forward bias current go to exponentially as the voltage, topical value of current mile amps. Were if have reverse bias, we have a relay small current there is of the order nano amps or micro amps that is delay constant. We also wrote down the expiration for the current, in the case of the of p-n junction. So, the expression in is J is equal to some constant js not which is your reverse saturation current times exponential ev over kT minus 1. So, this is in the case forward bias js not in the reverse saturation current.

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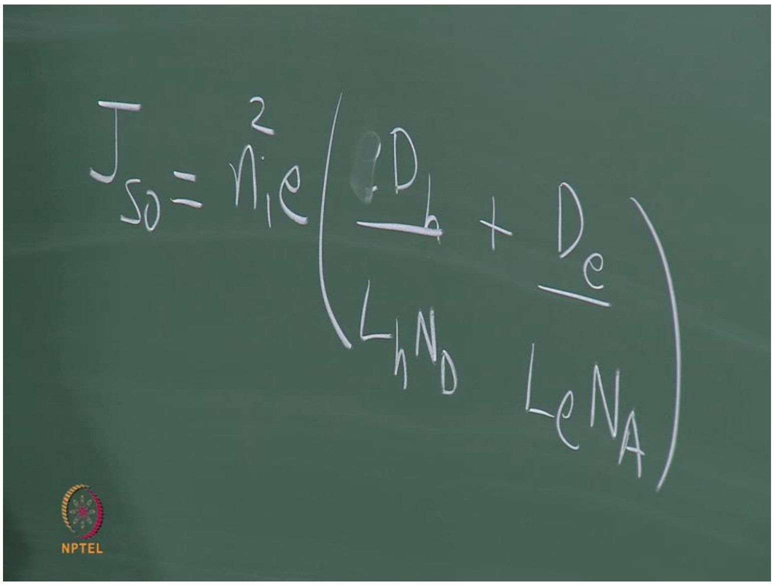

So, it is equal to ni square over e Dh oven e LhNd plus De over LeNa. So, Dh and De are the diffusion coefficients for the minority carriers within the P and the n region and Lh and Le are the diffusion less. So, today we are going to start the example, in order to calculate same of the values of the current in forward bias, also the reverse saturation current. But before we do that; I want see how this reverse saturation current will change if you change the material.

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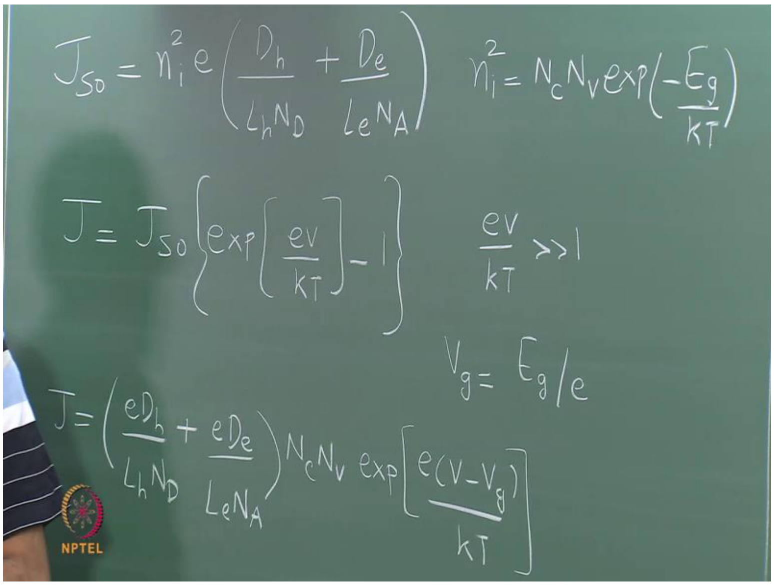

So, let me write this expression for js naught 1 more time, js naught ni square over e, Dh over LhND plus De over LeNA. Now, ni square which in the intrinsic carrier concentration is a material property, we now that ni square is nothing but, Nc Nv exponential minus Eg over Kt we can substitute for n i square in this expression.

So, that J this is nothing but, Js naught exponential ev over kT minus 1. So, I am going to substitute Js not hear and instead of ni square and I will go to re paces it Nc Nv exponential minus Eg over k; just for the sake of the argument in the find out Ev over Kt is usually much wait to greater than 1. So, that I can going ignore this term minus 1 hear an al. So, going to introduce another term vg is nothing but, the band d gap divided by e. So, if you do that J becomes equal to e Dh over LhND this is Ed over Le NA NC Nb exponential e times v minus vg over kT. So, v hear is the external potential that he apply doing forward bias vg is nothing but, band gap divided by e. So, plot current verses voltage for different semi conductors.

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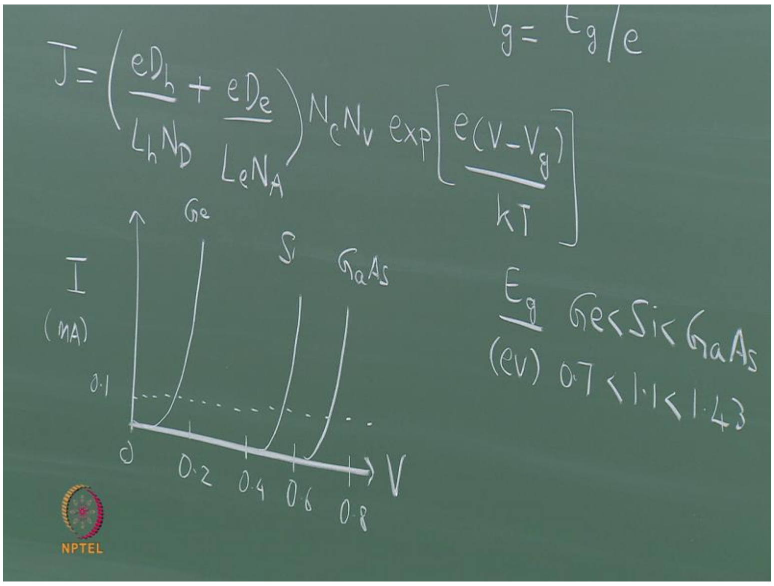

We find that if you want given a current the voltage will be higher, if the band gap is the higher. So, let me plot I verses v for 3 materials. So, he looks germanium, silicon an gallium arsenide. So, in terms of band gap eg germanium smaller band gap, than silicon which smaller than gallium arsenide some typical values we now germanium is around 0.6 electron volts. This in ev silicon is this 1.1 germanium our sent is 1.43. So, may current will be in milli amps; so, voltage 0.

So, if find that, the curve for germanium comes first then you have, silicon final you have gallium arsenide. So, germanium, silicon, gallium arsenide. So, that for given value of current. So, let say want current to be 0.1 milli amps the voltage is lowest for germanium, higher for silicon in even more higher for gallium arsenide. This is because you have vg, which is band gap in that expression. So, let us now go ahead, look at example of a P-n junction in silicon and calculate some values, for the reverse saturation current in also the current though the P-n junction in forward bias.

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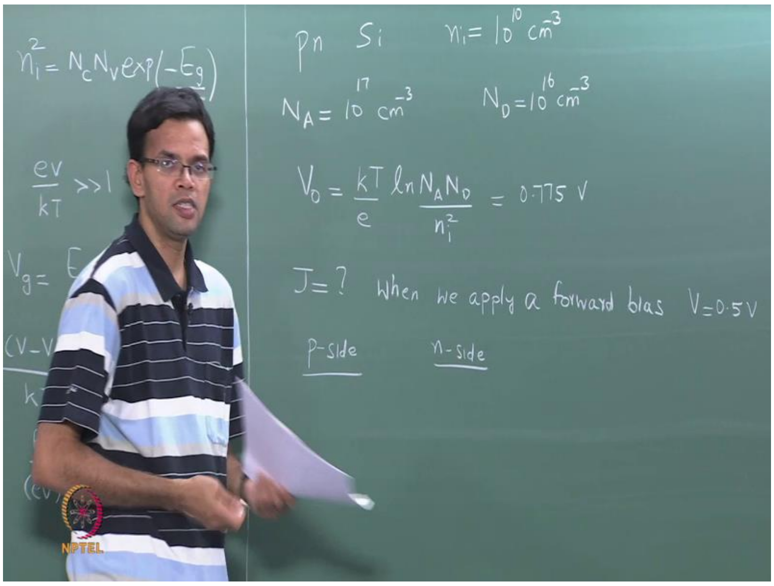

So, we are going to start with P-n junction at he that look at before we have Na is 10 to the 17 and we have ND is 10 to the 16, the material silicon. So, the intrinsic career concentration ni 10 to the 10. So, we calculate contact potential in the P-n junction contact potential v not, we did this last class is nothing but, 0.675 volts. So, he want know what the current is. So, we want know value of J, when he apply to forward bias and let me lake the value of the voltage to be 0.5 volts. So, let his write down the P-side an then n-side.

So, the first think we want to know, is how many carriers are injector because of the forward bias. So, from last class if you remembered, current in the case of P-n junction is due to the minority carriers. So, that we have electrons the inject in to the P-side; you have we have hole to the injected the in to the n-side that cost to the current.

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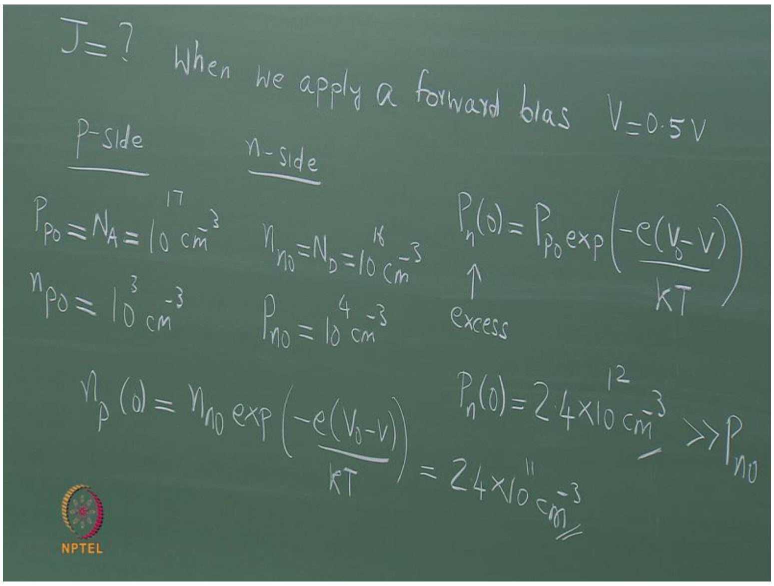

If the write down the values; Ppo is nothing but, na is 10 to the 17 the concentration of electrons will be just ni square over na that is 10 to the 3 same way we can write for the n- side; the formally for the excess carriers. So, that Pn of 0 is nothing but, Ppo exponential minus e v not minus v over kT . So, v not hears is the contact potential, v is the forward bias potential that is 0.5. So, Pno execs carriers. So, if you substitute the numbers and evaluate P-n and 0 turns out to b 2.4 times 10 to the towel percent to meet square, percent to meet you q. So, this number is much greater than the equilibrium concentration of holes of the n side which is hear. So, this is much greater, similarly we can calculate the excess electrons the P-side this is equal to 2.4.

So, this are the excess electrons on the excess holes, the injected due to the forwards bias. Now this are still minority carriers ultimately they will be diffuse the through material they re came band i with majority carriers and get eliminated. So, in order to calculate the diffusion length, we need to know diffusion co efficient. So, let me first write down the mobility.

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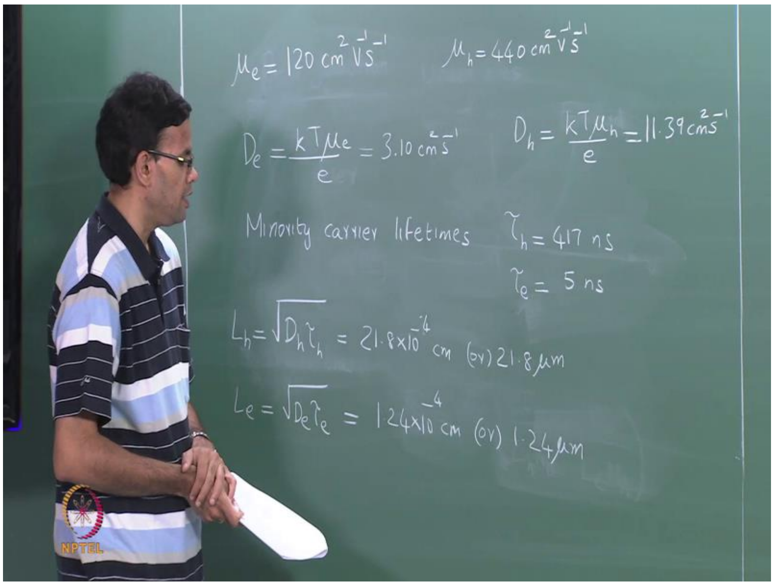

So, me that is the mobility of the electron mh to the mobility of the holes. So, mobility in the case of the semi conductor usually, goes down with increasing doping concentration. So, that stander tables form which we can get the values of me and mh as the function of the doping concentration. So, once we know m we can calculate the diffusion co efficient; think by kT me over e. So, the substitute the all the values this gives me diffusion co efficient of the electrons 3.1 centimeter square per second we can all. So, get the diffusion co efficient for the holes is 0.39 now, if you want to find diffusion length, we should also know how for how long this minority carriers an travel before the re combined. So, we need to know the carrier's life times.

So, let me take the values t h is 4 17 nanosecond t e to be 5 nanoseconds. So, this are again values that on know typically this will also defined upon the dopant concentration. So, tow h is the life time of the holes there traveling through the n side of the P-n junction tow e; this for the electrons traveling for the P-side. So, we than calculated the diffusion length.

So, we can substitute the values we have Dh here in a tow h. So, this is 21.810 to the minus 3 10 to the minus 4 centimeters or 21.8 micro meters le is nothing but, De tow; e which in is 1.24 as to 10 to the minus 4 centimeter or 1.24 micro meters. So, we have all the values the that we need for calculating the reverse saturation current and the current during forward bias.

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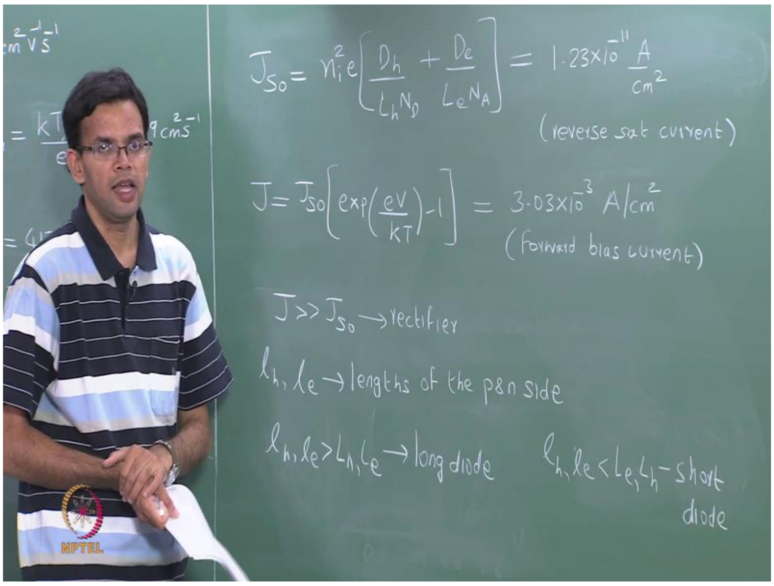

So, Js not we can calculate; so, he have calculated all this values the diffusions co efficient diffusion length. So, we can substitute the numbers and evaluate Js not. So, Js not terms out 11 and pear percent 2 meter square. So, this is the reverse substitute current. So, this is the current well, he flowing trough if I have reverse bias the P-n junction. So, the current during forward bias nothing but, Js not times exponential ev over Kt minus 1 the voltages that we applied is 0.5 volt. So, J comes out b 3.03 and 10 to the minus 3 and pares percent to met to square. So, this is forward bias current.

So, earlier year we said that a P-n junction is a rectifier and we can see that, is because J is much greater than, Js not; in this calculations we have assumed the length of the device, in larger than the diffusion length. So, let Lh and Le the lengths. So, this refers to the physical lengths of Pn n-side. So, we have assumed the Lh and Le are larger than the diffusion lengths. So, this kind of the diode called long diode.

So, the diffusion lengths are ward does in to this equation, if the psychical lengths is a actually shorter, if Lh and Le are smaller than the diffusion lengths then, it is called short diode only difference in the calculation is the in the equation for the reverse saturation current intend of the difference lengths in the case of, short diode we will put the psychical lengths of the p and n side. So, let is again look at the Iv characteristic, let us look at the reverse bias side.

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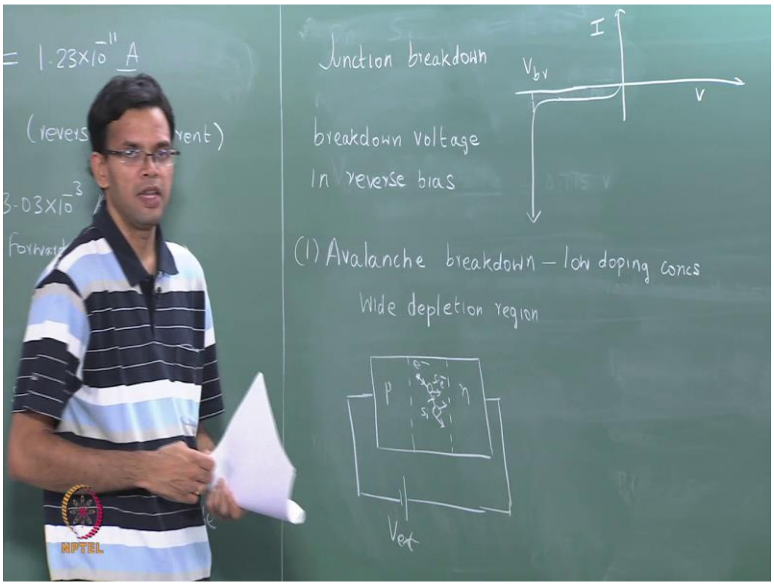

We said that in the case of a P-n junction in reverse bias the current constant does not demand upon voltage. So, we side that the current is a constant, which is the equal to the reverse saturation current, but he turns out a at relay large voltage values the diode breaks down. So, that we have a large reverse current flowing to through the material. So, this voltage was this happens called your break down voltage this happens in reverse bias. So, when this happens we said the P-n junction has broken down and they are 2 mechanisms for this 1 is avalanche break down. So, this occurs for P-n junction with low doping. So, we have low doping concentrations on the P and the n-side. So, that we have wide depletion region.

So, if we to draw this P-side that is my n-side this is under reverse bias. So, in this particular case an electron that is being accelerated by the fled we can essentially interact with silicon item and because it highest sufficient high enrage because of the large external potential that is applied that electron, can I niece silicon item an produce more electrons this in turn can interact with other in other silicon item. So, that you have an avalanche of electrons on productivity.

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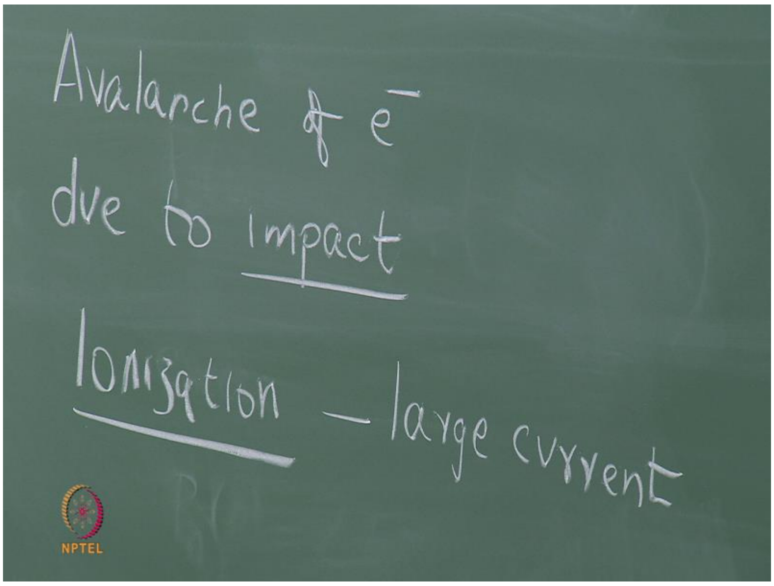

So, this effect were the electrons it is a silicon item, an ionization it called impact ionization and the assets of this is have a large current. So, 1 mechanism of breakdown called the avalanche breakdown, a acres a low doping concentrations another mechanism of breakdown called the Zener breakdown.

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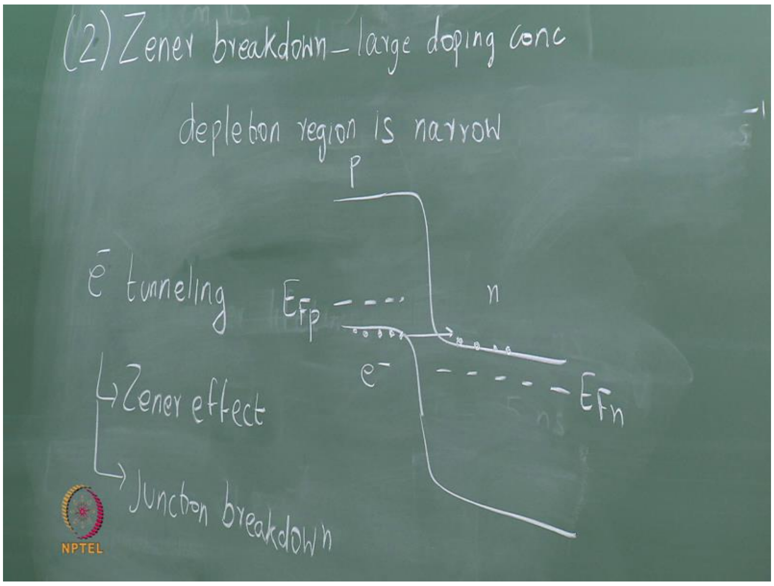

So, the Zener breakdown acres at large doping values; in this particular case, the depletion region our this narrow. So, if draw the enrage diagram for this, we just drag lightly. So, this is my P-side, that my n side these are the levels. So, we are in reverse bias. So, there is a large barrier for because your definition with, is small we can have electrons tunneling form P to the n. So, this electron tunneling is called the Zener effect an because of that, you have a large current. So, we have to breakdown of the junction this leads to.

So, we have at a look P-n junction first in equilibrium and than in the case of bias, both forward and reverse, you also look at the 2 breakdown mechanism that a possible in reverse bias. So, for in the P-n junction we are considers, if considers material to be the same. So, we have the P and the n type, they are both the same material. So, they could be germanium or silicon or gallium arsenide, but the material is same. The next think we are going to look at briefly is, what happens if you have 2 different materials. So, that you have hetero structure.

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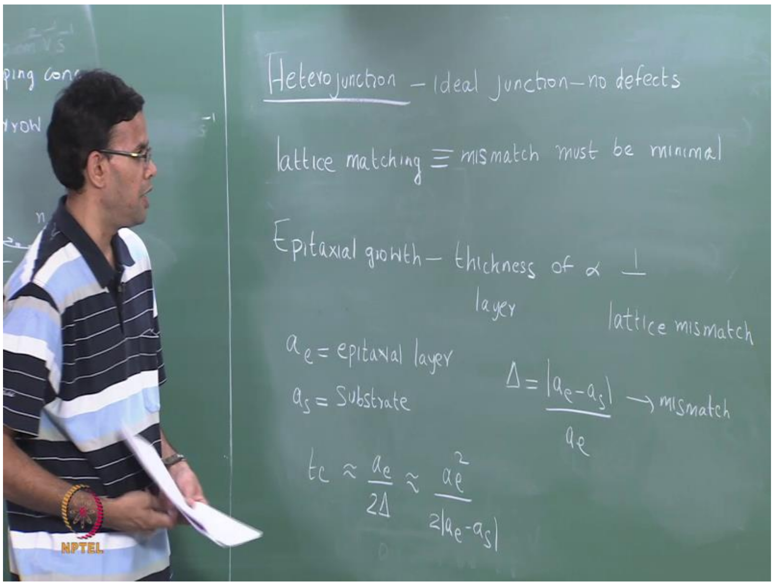

So, now he have hetero junction. So, that he have a junction farm, when P and n type of difference materials. Once again when we have such hetero junction, they're going to assume that, we have ideal junction with no defects. So, this infuses restriction on the types of material set we can choose, in order to have an ideal junction with no defects, we must have the lattice matching between the 2 materials or if you want to put it in a other way, the mismatch must be minimal. So, defending upon the degree of mismatch, we can control the thickness of the second layer on the first. So, if we look at, epitaxial growth the case of epitaxial growth, the layer you trying to grow as same lattice constant that of the sub strict. So, that if there is lattice mismatch there is inherage strain in the material. So, the thickness of the layer your trying to grow, is inversely positional to the lattice mismatch.

So, more the mismatch than the thinner the layer we can grow, ultimately if you mismatch large you are just going to have a large number of defects at the interface. So, ae is the latest contestant of the epitaxial layer and the as in the latest contestant substrate then, we define mismatch delta ae minus as divided to ae this is the mismatch. So, the thickness of the epitaxial layer the taken grow, tc is propositional to ae over to delta. So, this are the approximate expression. So, this is equal to ae square over to ae minus s. So, that is take an example, of silicon and germanium.

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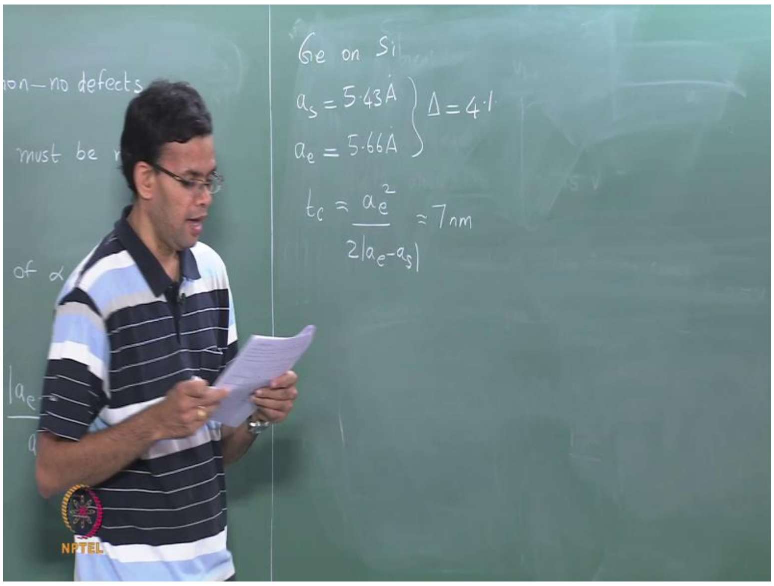

So, let a say I am trying to grow a germanium layer on silicon; the least contestant for silicon as is 5.43 for germanium. So, that is the epitaxial layer is 5.66; in this particular case, the mismatch delta if he try to put it in percentage is 4 percent. So, is nothing but, ae minus as divided by ae. So, the critical layer that we can grow, the thickness if you use the formula ae square, this work shot around 6 nanometers. It means; we can grow a layer of germanium on silicon of to 6 nanometers they are be same inherent strain in germanium per if you go beyond that, you are going to form defects in the material.

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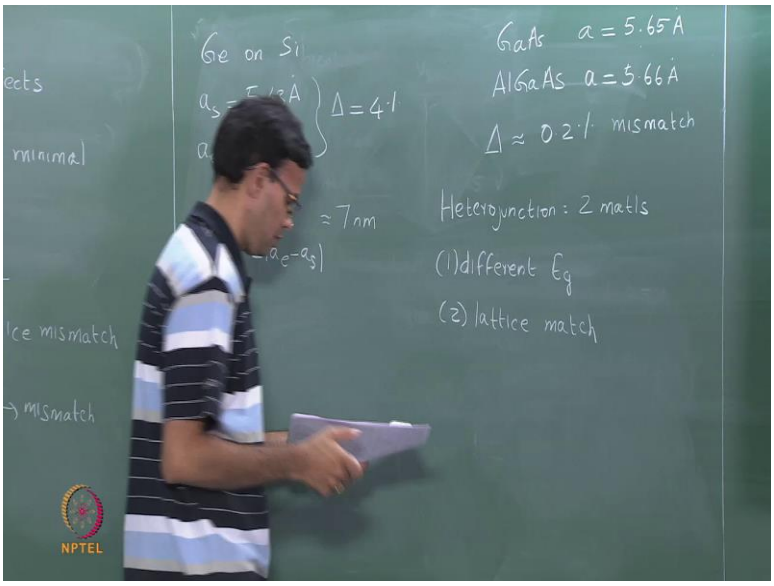

The case of germanium an silicon, you actually have élan formation, in this kind of growth called as transky cration of growth intrude of germanium silicon. Let say, I have gallium caccent growing on aluminum gallium accent or the other way, round this particular case, the latest constants how much closer this is 5.65 this 0.66. So, here the lattice mismatch delta is much smaller, typical around point 2 percent, silicon germanium it was 4 percent. So, the easier grow a epitaxial layers here.

So, in the case of a hetero junction we want to choose two materials with different band gaps, we want different band gaps, because we want to explode in this difference person interesting electronic properties, but at the same time we want a good lattice match. So, let is now look, at a band D diagram in the case of a P-n hetero junction.

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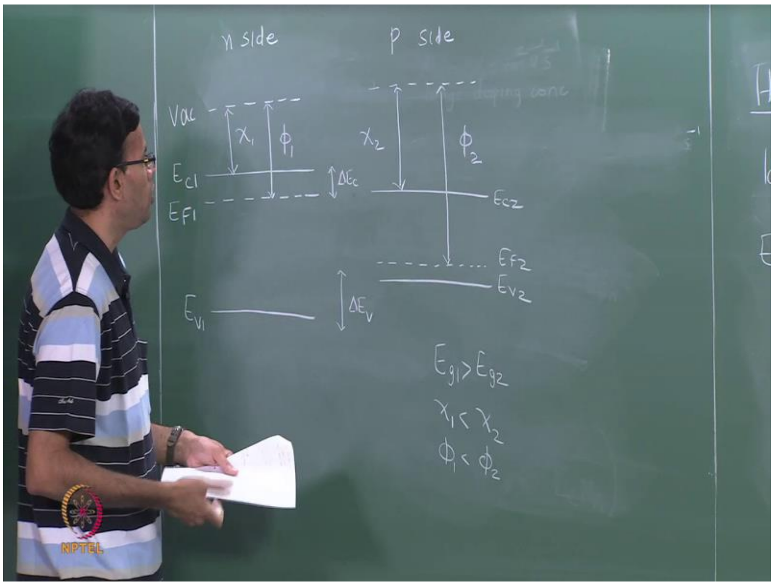

So, I am going to consider junction; so, the first let me draw the n-side and I am doing to say, the they n-side has the higher band gap than the P-side. This is my n-side, this dotted line represents vacuum, this is the contention band D; that is, the valance band d and this is the fermi level. So, will just called this for the subscript 1. So, that this is material 1. So, we can define, an electron affinity is nothing but, the energy from the bottom of the contention band d to the vacuum level, we can also define my work function. This is doing to form a junction with a P type material, which as a smaller band gap this is the P-side. So, this is Ec2, Ev2, this is Ef2. And once again, we can write down values x2 and the work function.

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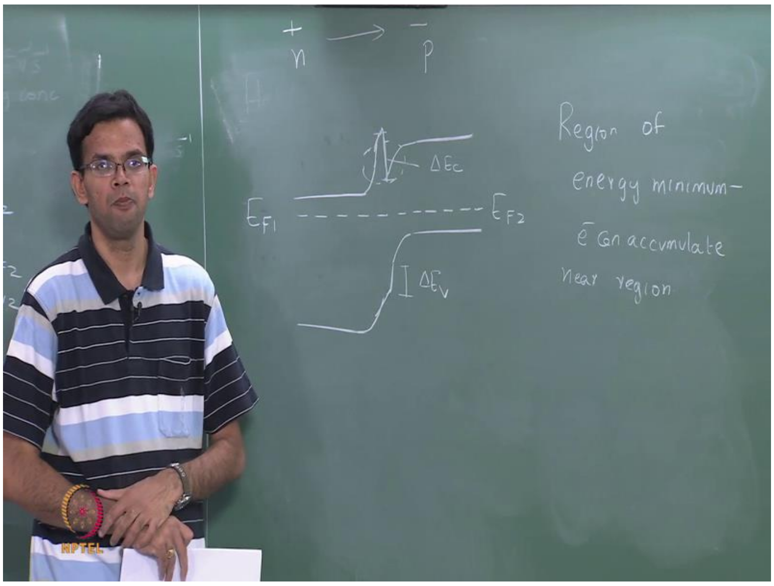

So, now, i am forming P-n junction. So, I have eg 1 greater than eg2; I have the electronic affinity going the other way, and the work functions also going in the other way. We can also define and the energy gap between the contention band Ds of the 2 materials. So, that is delta Ec we can also define energy gap, if in the valance delta Ev. So, we went to put gather this P-n junction. So, the first through less at equilibrium the form me levels must line up. So, let me draw the P-n junction, the firm me levels must line up. So, I have Ef and Ef2. So, I have material 1, which is my n-side semi conduction this is the material with a wider band d gap, than I have my P type material with a smaller band gap. So, if look at this P-n junction you see that, the electron go from the n to the P side.

So, that there is a net positive charge on the n-side there is net negative charge on the P-side. So, the electronic field goes from n to P this is the same concept in a regular P-n junction and we know the band Ds band d up in the direction of the electric filed. So, the bands have to bend up on the n-side and the bands on the bend down on the P side. So, we also said, the there is a difference between the energy of the conduction bands. So, delta Ec and the difference in the energy is of the valiance band d delta Ev. So, when the bands, bend the must make show that different. So, that this gap is delta Ev we just this and this gap delta Ec.

So, now if I joined the is 2; we just we can get the P-n junction and the equilibrium. So, if he looks at this, this is different from how a Jn junction would look. If we have, the same material, specifically if he looks at the conduction band there is a region, were this energy minimum. So, that electrons in the P-side, we can essentially accumulate in a region near the junction that the region of energy minimum, which means electrons we can accumulate near that region, also the energy barriers are different for the conduction band d and valiance band . So, the barriers are different for the electron is in holes.

So, this can again affect the conductivity of the hetero junction. So, hetero junction have some important properties, when we look at optical properties because of the fact that we can have electron accumulation, if intrude of a P-n junction, were the n has a higher band gap, if you choose a P-n junction with P as a higher band gap. You see, accumulation holes near the junction. So, this we are done with p-n junction.

So, P-n junctions are a example, were we have an interface between 2 semi conductors they could be the P and the n of the same material or they could be the P and the n of the different material. In next class, we are going to look at devices, were we have you more than 1 junction for a example, of such devices is a transistor. So, the next class we are going to start looking at transient.