Electronic Materials, Devices and Fabrication
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Lecture – 13
Assignment 4 - Metal semiconductors junctions

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Electronic Materials,Devices and Fabrication

Assignment - 4

Metal - semiconductors junctions

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In today’s assignment we are going to look at metal semi-conductor junctions.

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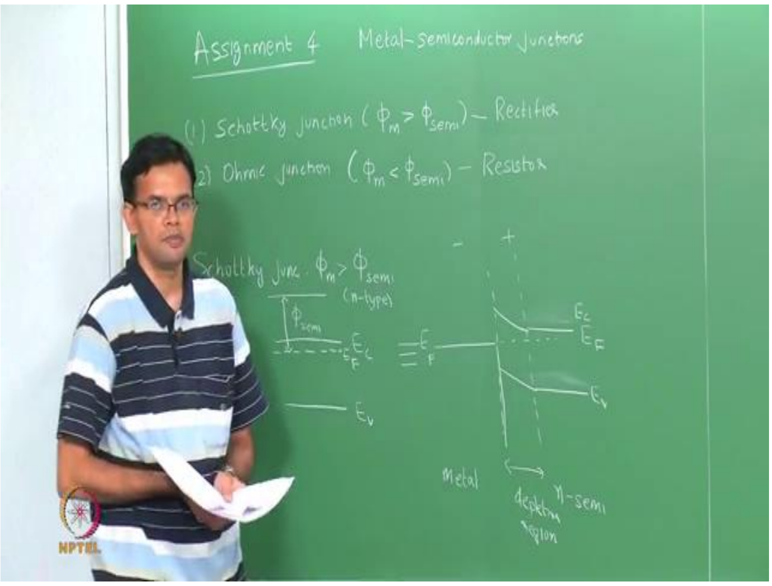

This is assignment 4. So, in class we look at 2 times metal semi-conductor junctions. One was the Schottky junction or the schottky contact and the other was the ohmic junction or ohmic contact. So, we saw that a schottky junction forms when the work function of the metal. So, phi m is greater than the work function of the semi-conductor. In the case of an ohmic junction it is the reverse, the work function of the metal is less than the work function of the semi-conductor. You also saw the schottky junction essentially behaves like a rectifier.

So, it conducts the current in the forward bias and does naught have any conduction in the reverse bias. So, in this way the schottky junction similar to a p n junction, which is also a rectifier. An ohmic junction on the other hand from the name is just appear resistor. It conducts both in the forward and the reverse bias and the conductivity is defined by the conductivity of the resistivity of the semi-conductor material.

So, in today’s assignment we will be looking mostly at schottky junctions. We will do some calculations in the schottky barrier, the contact potential and also the current in the forward and reverse bias. So, let us go to problem number 1. So, we want to show how a schottky junction is formed between a metal and a p type semi-conductor. So, we can do this by sketching the band diagram and the equilibrium forward and reverse bias. So, in class when we looked at the example of a schottky junction we look at a metal and n type semi-conductor.

So, let me draw that first and the equilibrium and from there we look at the metal and the p type semiconductor. So, said a schottky junction is formed when phi m is more than phi semi, so will start with a metal here. So, we just draw the slightly up. So, this represent the vacuum level. This is the fermi level of the metal and this space is the work function of the metal. So, all the energy level below these are completely full. So, we will start up with n type material. So, this is your n type material you have E c and E v. The E v is the valence band and E c is the conduction band it is an n type.

So the fermi level is close to the conduction band. Once again here the distance between the fermi level and the vacuum level is the work function of the semi-conductor. So, when these 2 are brought together in contact we know that in equilibrium, the fermi level must line up. So, we have excess electrons that are there in the conduction band of the semi-conductor.

These will go and occupy all the empty states of the metals. So, there is a net positive charge on the semi-conductor side and net negative charge on the metal side. The electric fields goes from positive to negative and bands bend up in the direction of the field. So, we were to draw this under equilibrium. So, I will just mark my junction, this is E f this is my metal side this is the m type semi-conductor. This is the E f of the semiconductor. So, far away from the junction the semiconductor is still be n type.

So, let me draw the bands slightly closer. So, this is n type E c and E v, there is a net positive charge on the semiconductor and net negative charge on the metal and the bands will bend up. So, this in term for depletion region and this is the band diagram at equilibrium. So, this is a case of metal and an n type, this is similar to what we saw in class. So, let us now draw 1 for a metal and the p type.

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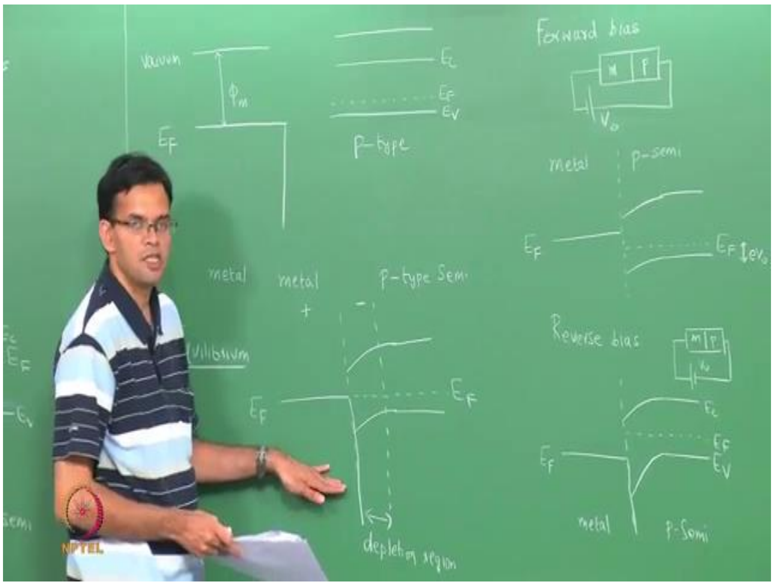

So, once again we have the vacuum level. You have the fermi level of the metal and this is pie m. So, this is the metal, you now have a p type semi-conductor. So this is E c, this is E f this is E v. So, it is a p type semi-conductor. So, that the fermi level is close to the valance pie. So, we can use the same argument that we used for a metal. And then end type now at the argument is reversed. So, once again when the junction forms the fermi levels line up, but instead of access electrons going from the semi-conduct to metal.

We now have the electrons moving from the metal to the semi-conductor all the wholes moving from semi-conductor to the metal. So, that there is a net positive charge on the metal side and net negative charge on the semi-conductor side and bands will bend down as we go from a semi-conductor to the metal. So, this if we draw equilibrium, the fermi levels must line up. So, I will put an interface. So, E f and E f metal and p type semi-conductor far away from the junction your material still p type.

And then the bands bend down. So, that there is a negative charge and the net positive charge. And this is depletion region. So, the band bending here is similar to that of a metal an end type, but it goes the other way. So, we now want to draw the energy band diagram in forward and reverse bias. So, in the case of forward bias. So, this is my metal, this is my p type the metal is connected to a negative charge p type is connected to a positive charge.

So, in this case the fermi level is shift and the barrier essentially is lowered. So, we can once again draw this my interface that is my metal. Now, the fermi levels no longer alien and for the p type fermi level shifted down. And this shifting down is given by the external potential that is v naught. So, here the barrier for the motion of the electron in wholes is reduced. So, that there is an increasing current when you apply an increasing voltage, the case of the reverse bias. So, m and p, the metal is connected to positive the semiconductor is connected to negative. Once again the firm fermi levels do naught line up, but instead of shifting down the fermi level now shifted up. So, that is my interface E v, E c and E f, this is the metal, this is the p type semi-conductor. So, this is the situation where we have a metal and p type in equilibrium is the energy band diagram forward bias and reverse bias. Let us now go to problem 2.

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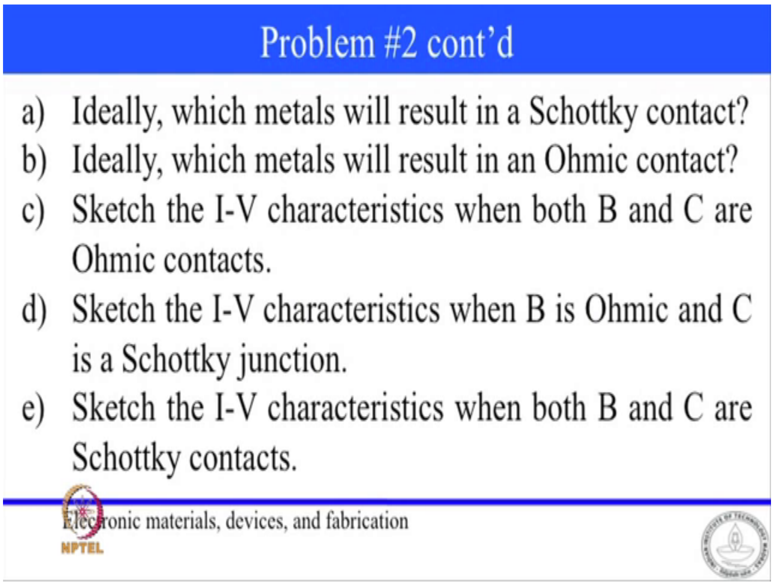

Problem #2 cont'd

a) Ideally, which metals will result in a Schottky contact?
b) Ideally, which metals will result in an Ohmic contact?
c) Sketch the I-V characteristics when both B and C are Ohmic contacts.
d) Sketch the I-V characteristics when B is Ohmic and C is a Schottky junction.
e) Sketch the I-V characteristics when both B and C are Schottky contacts.

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In problem 2 we have n type silicon with tend to the sixteen donors per centimeter cube.

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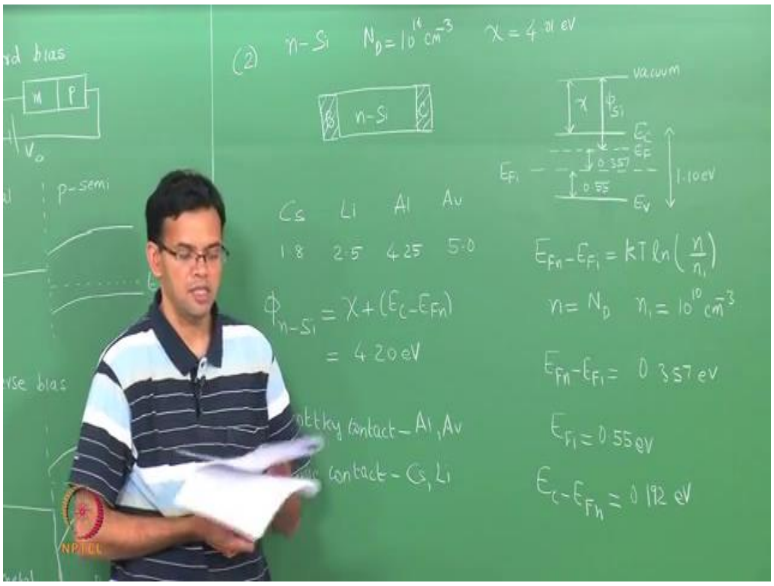

n silicon with n d is 10 to the sixteen per centimeter cube. The two ends of the sample are label b and c. So, we have two ends. So, there essentially 2 metals at the either end. So for that to draw schematic this is my n silicon and I have b and c on both sides. Let me just shade them to show you that there is essentially metal contacts. The electron affinity of silicon is given. So, xvi 4.01.E v and there are 4 potential metals which can be used for these contacts.

And their work functions are given. So, we have cesium, lithium, aluminum and gold and the work functions are essentially given. So, the first thing we need to do is to calculate the work function for the semi-conductor. So, we can draw an energy bind diagram. So, this is vacuum you only drawing the semi-conductor side E c and E v. It is an end type semi-conductor. So, the fermi level will be closer to the conduction band. Now, the electron affinity is the energy difference between the conduction level and the vacuum level.

So, this is essentially xi, we need the work function. So, we need psi of the silicon, to know that we need to know the position of the fermi level and that can be calculated from the concentration of donors in the material. So, we can just say E f n minus E f i is k t laun of n over n i. So, n is nothing but n d fully ionized, n i for silicon is given and you also saw this during the previous assignment. It is nothing but 10 to the 10, from this we can calculate the value of E f i minus E f n. So, E f n minus E f i we can calculate. We also know the position of the intrinsic fermi level. So, we can calculate from the values of N c or N v. In this particular case E f i is given to be 0.55 electron volts and the band gap of silicon is 1.1.

So, this whole thing is 1.1 E v E f i is given to be center of the band gap. And this is 0.55. This distance is also known the value for this is 0.192, 0.357 sorry this is 0.357. So, everything else is known accept for this. So, E c minus E f n is nothing but 0.192. So, from this we can calculate the work function of the silicon. So, 5 of silicon, since it is n type I will just write 5 of m is nothing but xi plus E c minus E f n which works out to be 4.20 E v.

So, if you look at the various parts of the question. Part a ask which metals will result in a schottky contact. So, we have a schottky contact when the work function of the metal is greater than the work function of the semi-conductor. So, those essentially go aluminum and gold. So, schottky contact will be aluminum and gold which metals will result in an ohmic contact.

So, in ohmic contact is one where it is reverse. The work function of the semi-conductor is higher. So, it is just cesium and lithium. So, part c, sketch the I v characteristics when both b and c are ohmic contacts. So, let me draw that. So, be and c are both ohmic contacts.

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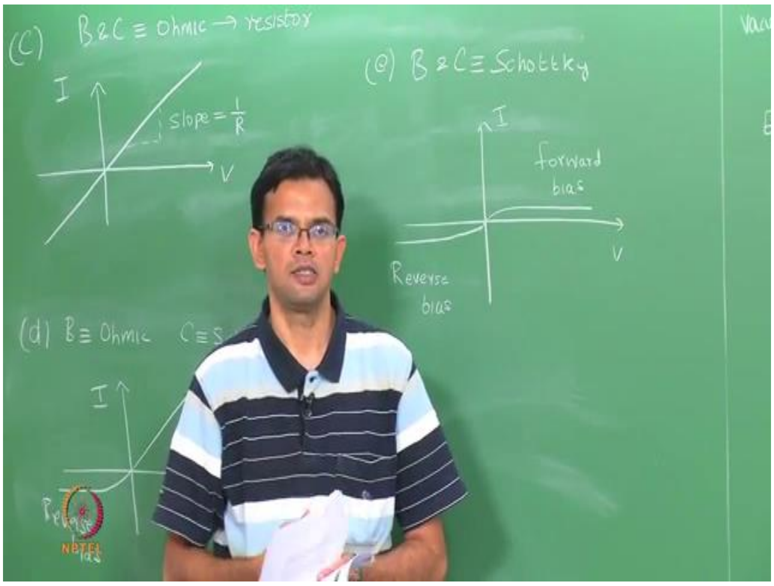

So, an ohmic contact is nothing but resistor. So, when you have both b and c to be ohmic then the whole thing just acts as a resistor. So, b and c are both ohmic then the whole thing is just a resistor. So, the I v characteristics will just be a straight line and the slope of this line will be just 1 over r part d sketch the I v characteristics when b is ohmic. So, b is ohmic and then c is schottky. So, we have 1 ohmic and 1 schottky junction. So, in the case of a forward bias you will have a schottky junction will be essentially a high conductor. So, it will start to conduct, in this particular case the resistance will be determined by the highest resistance point which is your ohmic contact. So, here in the case of forward bias.

So, if you write to draw I was s v you have a highly conducting junction which is junction c and you have a resistor which is junction b. So, this will essentially behave like a resistor. The case of a reverse bias c is essentially reverse biased. So, that there is very low conductivity through that. So, that will essentially determine the conductivity of the entire circuit. So, that you have a very low conductivity in reverse bias.

For the same as true when b is schottky and c is ohmic, the curve will be similar. In part E sketch the I v characteristics when both b and c are schottky. So, b and c are both short key. So, in this particular case as one of the junction is forward biased the other junction will be reverse biased and so on. So, whether you are in the forward or the reverse there always be one junction, that is reverse biased which will have very low conductor. So, I v characteristics in this particular case will be a very low current in both forward and reverse biased.

So, this kind of a situation is very important, when you are trying to make electrical contacts to a semi-conductor. Usually we have to make 2 contacts, ideally we want this contacts to be ohmic because we do naught want the contact itself playing a role in determining I v characteristics, but there could be diodes based on the schottky affect. These are schottky diodes in this particular case we would want 1 junction to be essentially a schottky junction and the other to bean ohmic junction.

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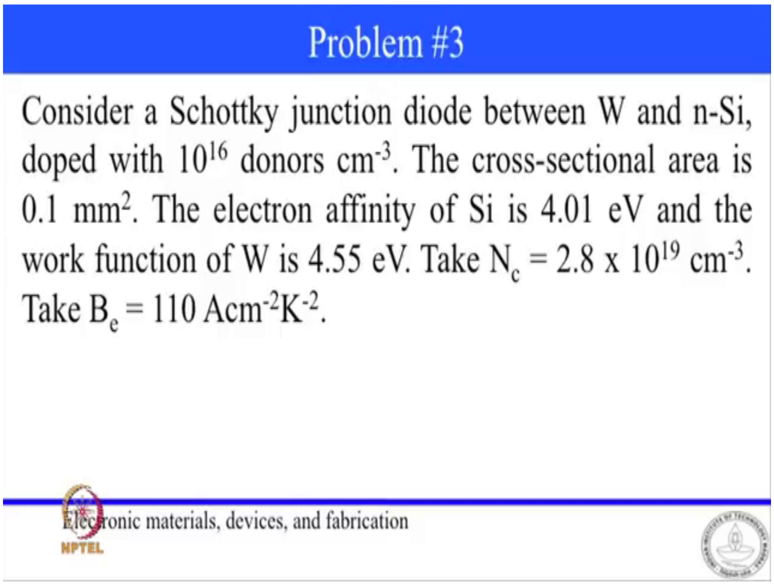

Problem #3

Consider a Schottky junction diode between W and n-Si, doped with 10^{16} donors cm^{-3}. The cross-sectional area is 0.1 mm^2. The electron affinity of Si is 4.01 eV and the work function of W is 4.55 eV. Take $N_c = 2.8 \times 10^{19}$ cm^{-3}. Take $B_e = 110$ $Acm^{-2}K^{-2}$.

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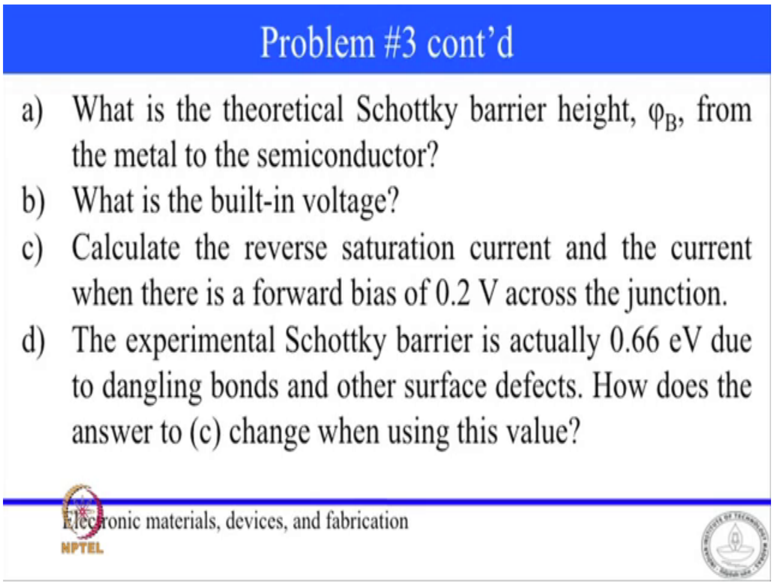

Problem #3 cont'd

a) What is the theoretical Schottky barrier height, φ_B, from the metal to the semiconductor?

b) What is the built-in voltage?

c) Calculate the reverse saturation current and the current when there is a forward bias of 0.2 V across the junction.

d) The experimental Schottky barrier is actually 0.66 eV due to dangling bonds and other surface defects. How does the answer to (c) change when using this value?

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So, problem 3. You have a schottky junction diode between tungsten and n type silicon the silicon is doped with 10 to the sixteen donors per centimeter cube.

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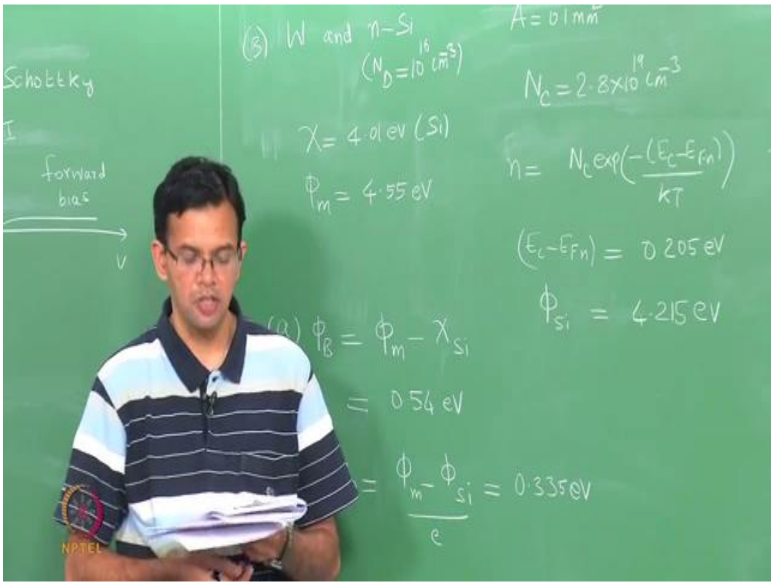

The cross sectional area is given. So, a 0.1 millimeter square, the electron affinity of silicon is given same as the last problem 4.0 1 E v and the work function of the metal is given to be 4.55 electron volts. So, once again we need to calculate the work function of the semi-conductor. So, we can do the same thing that we did in the last problem. In this particular case the affective density of states the conduction band is given. So, that is 2.8 times 10 min 10 to the nineteen.

So, we could use this directly to calculate the position of the fermi level. So, n is nothing but n c exponential minus E c minus E f n over k t from which we could calculate E c minus E f n. So, n is nothing but n d which is the concentration of donors n c is given I will think known. So, E c minus E f n is essentially 0.205 electron volts. So, from this can calculate the work function of silicon to be 4.215 electron volts.

So, we can draw this in a band diagram. So, I will just draw schematically, this is my tungsten work function of tungsten is given. So, phi 4.55 and this is my n type semi-conductor. So, E c E v this is 4.01 this whole thing this 4.215 this is 4.55. So, again we have a case of a schottky junction between tungsten and n type silicon. So, part a, we want to calculate the theoretical schottky barrier. So, you want to calculate schottky phi b is the schottky barrier and there is essentially the work function of the metal minus the electron affinity of the silicon.

The schottky barrier represents the barrier for the electron to move from the metal to the semi-conductor side. So, you have an electron going from E f to the conduction band. So, this is just 5 n minus xi s I, you can put in the numbers and this is 0.45 electron volts. Then we want to calculate the built in voltage. So, v naught is nothing but xi m minus 5 s i divided by E. So, E is just to convert from electron volts to volts.

It is the difference between the work functions. So, this we can substitute and the answer is 0.335 electron volts. In part c, we need to calculate the reverse saturation current and also the current when there is a forward bias of 0.2 volts across the junction. So, part c we want to calculate the current in the junction.

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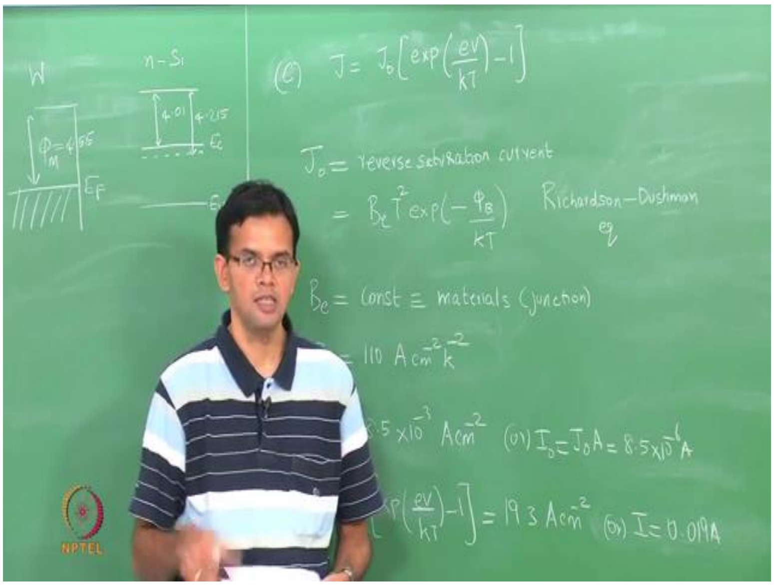

So, in the case of a schottky diode it is possible to write an expression for the current. This is something we do naught see during the course of the lecture. So, we can write the current J as some constant J naught exponential E v over k t minus 1. So, we here is your external potential J naught is your reverse saturation current and J naught is equal to b, E t square exponential minus phi b over k t. So, this is Richardson Dushman equation.

And there is actually used to calculate the current during thermionic emission from a metal. So, B e is usually a material constant it is a property of the interface. So, whether you have tungsten and silicon or platinum and silicon, platinum and germanium the value of B e will change. So, B e is a constant that depends upon the materials, which is basically it is a property of a junction. So, in this particular case the value of B e is given. So, B e as 110 ampere per centimeter square per kelvin square. So, the value of phi b, we calculated earlier this is nothing but a schottky barrier.

So, from this problem in calculate J naught is everything else is known temperature is 300. So, from here J naught is essentially 8.5 times 10 to the minus 3 ampere per centimeter square. We want to calculate the current you multiply this with the area. So, current i J naught times a, which is 8.5 tungsten to the minus 6 amperes are 8.5 micro amperes.

We can now calculate the current during the forward bias. So, J is J naught exponential E v over k t minus 1. So, usually the exponential term dominates the external voltage is given to be 0.2 volts. So, we can substitute the numbers and J comes out to be 19.3 ampere per centimeter square or the current is the 0.019 amperes. So, this is the current during forward bias, you can see that it is nearly 4 orders of magnitude higher, than the current during reverse bias. This is why a schottky junction is essentially a very good rectifier. In part d, the question says that the experimental schottky barrier is actually higher.

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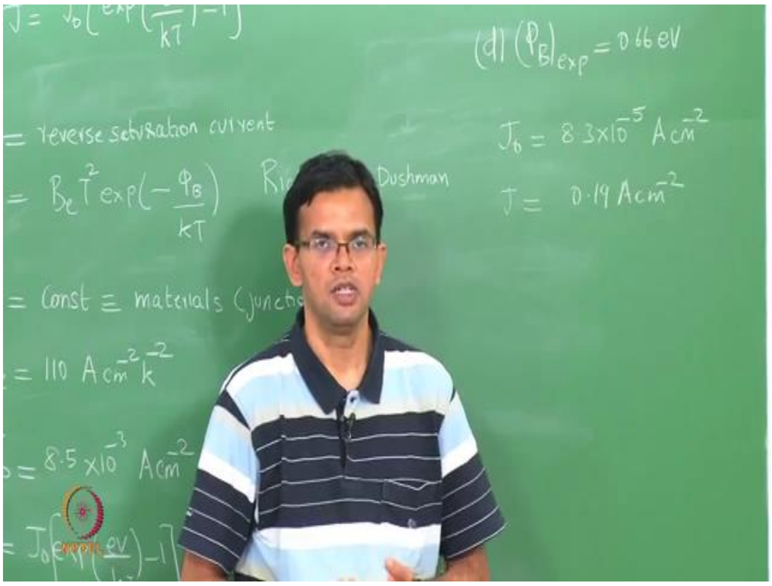

So, phi b experimental 0.66 E v. So, it wants us to do that recalculation. So, this experimental value takes into account the fact that the interface is never perfect, that you always have some sort of defects at the interface. So, if you use this, we can use the same calculation that we jested except that we now have to use the newer value of phi b.

So, in this particular case J naught comes out to be 8.3 times 10 to the minus 5 ampere per centimeter square and current J is 0.19 ampere per centimeters square. So, the actual current is slightly lower then what you would expect if use the theoretical values, but the important fact is that it is still 4 orders of higher than J naught. So, that the schottky diode to the schottky junction still functions as a rectifier.

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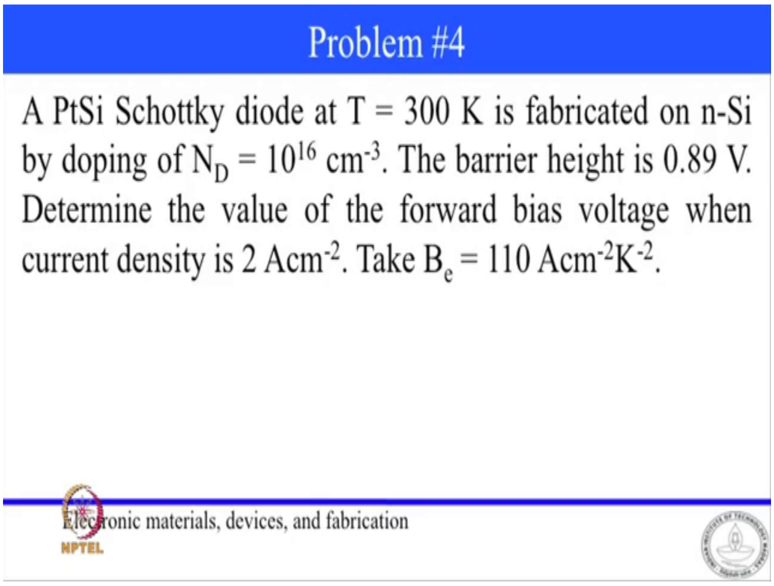

Problem #4

A PtSi Schottky diode at T = 300 K is fabricated on n-Si by doping of $N_D = 10^{16}$ cm^{-3}. The barrier height is 0.89 V. Determine the value of the forward bias voltage when current density is 2 Acm^{-2}. Take $B_e = 110$ Acm^{-2}K^{-2}.

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So, let us now go the next problem. So, problem 4, we have a platinum silicide schottky diode is fabricated on n silicon. So, you have platinum silicide on silicon. So, how this is usually obtained is by first depositing platinum metal usually it is done by some wafer deposition process by thermal evaporation or spattering or E b evaporation. Then the interface is un nil. So, that we have inter deputation between platinum and silicon which again react to form the silicide. So, depending upon the composition, you can get a single composition p t s i or you could get multiple composition.

Again depends upon the thickness of the platinum layer and the amount of the intermixing. So, these silicide layers are usually found by depositing the metal and then doing some sort of a post and healing treatment. So, in this particular case it is an n type silicon.

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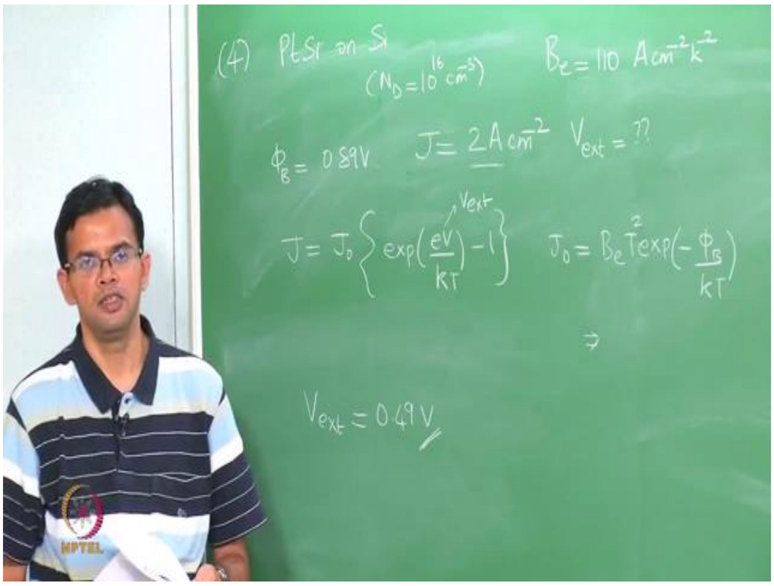

So, n d is 10 to the sixteen per centimeters cube. The barrier height in this particular problem is given. So, phi b is 0.89 volts. So, 1 of the advantage is of doing a post an is that that usually eliminate some of the defects. So, that the barrier is essentially very close to a theoretical barrier. So, once again we want to calculate. So, the forward current is known. So, J is given to be 2 amps per centimeter square and we want to calculate the value of the voltage.

So, we external is what we want to calculate. So, we can go back and use the same equation we know as J is equal to J naught exponential E v over k t minus 1, J naught is nothing but B e t square exponential minus psi b over k t. So, the value of B e for this problem we can still take this same value 110 ampere per centimeter square per kelvin. So, we can use this and calculate J naught. So, J naught is just guard by substituting B e t square exponential of minus phi b over k t.

Once we get the value of J naught, you can put the value of J naught here. We need to know the value of J is given to be 2 ampere per centimeter square the only thing that we do not know is v external. So, once we calculate J naught we can plug it here and get v external. So, I will just write the answer we external for this particular problem 0.49 volts, but the calculation is very similar to what we did with previous problem. So, let us now go to problem 5.

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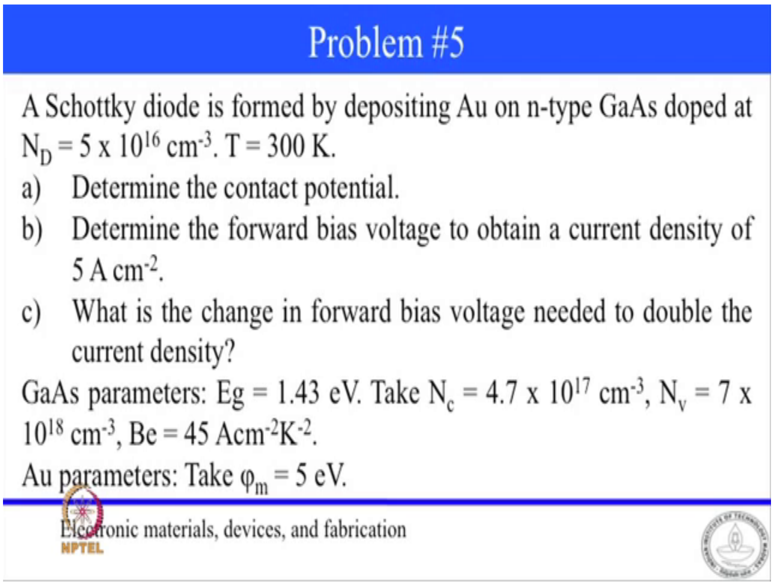

Problem #5

A Schottky diode is formed by depositing Au on n-type GaAs doped at $N_D = 5 \times 10^{16}$ cm^{-3}. T = 300 K.

a) Determine the contact potential.
b) Determine the forward bias voltage to obtain a current density of 5 A cm^{-2}.
c) What is the change in forward bias voltage needed to double the current density?

GaAs parameters: Eg = 1.43 eV. Take $N_c = 4.7 \times 10^{17}$ cm^{-3}, $N_v = 7 \times 10^{18}$ cm^{-3}, Be = 45 Acm^{-2}K^{-2}.

Au parameters: Take φ_m = 5 eV.

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Problem 5, we have a schottky diode form by depositing gold, but now the material is n type gallium arsenide. So, we have n gallium arsenide with n d is Five times 10 to the sixteen per centimeter cube.

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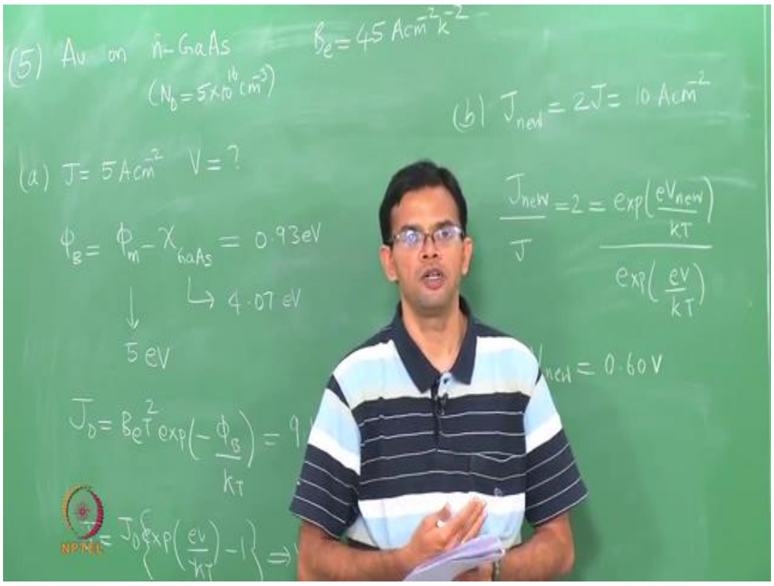

So, once again in part a, we need to calculate the forward bias voltage for a current density. So, J is 5 amps per centimeters square and we will need to calculate the voltage for that. So, this is again similar to the previous problem sub. Now, the material is gallium arsenide. So, the first thing we need to do is calculate the barrier potential. We going to assume that it is a theoretical barrier. So, we need to know phi b is nothing but phi m minus the electron affinity for gallium arsenide.

So, in this particular case E g of gallium arsenide is given, but more importantly we only need the electron affinity, this has the value of 4.07 E v. So, we can still use the other values to calculate the contact potential, but as far as part a is concerned the only thing we need to know is the electron affinity. So, phi m is given phi m is given to be a 5 electron volts, so this is the work function of gold.

The electron affinity of gallium arsenide is known. So, that the theoretical barrier potential is nothing but 0.93 electron volts. So, once we get that, we can calculate J naught. Again for the gold and gallium arsenide interface we can calculate, we have the values of B e, B e is equal to forty amps per centimeter square per kelvin square.

So B e is not only a material property with also depends upon what facet of the material you have. So, whether you have a 1 0 0 plain or a 1 1 0 or 1 1 1, that will also affect the value of B e. So, J naught is a number we can calculate all the numbers are known. So, this is nothing, but 9.1 times 10 to the minus 10 ampere per centimeter square. So, J naught is known J is known exponential E v over k t minus 1. So, again J is known J naught is known. The only thing that is unknown is v from, which we get v to be 0.58 volts.

In part b, we need to calculate the change in the forward biased voltage to double the current density. So, J new which is a new current density is 2 times on the old 1. So, this should be 10 amps per centimeter square. You can either take the ratio of the old and new J or you could use the same equation J naught exponential E v over k t minus 1 can calculate. So, if we take the ratio J new minus J which is 2 is equal to exponential E v new over k t by exponential E v over k t.

So, v is known, we just calculated that in part a. The only thing we need to do is to calculate v new and v new is 0.60 volts. So, in the case of a schottky junction, which is essentially a rectifier, we have seen how to calculate the schottky barrier voltage, the built in potential and also the current during both forward and reverse bias. And ohmic contact is much simpler, an ohmic contact is essentially a resistor and the resistivity is usually given by the resistivity of the semi-conductor material.