Experimental Physics - III
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Lecture – 37
Topic: P-N Junction (contd.)

In last class, I have discussed about the junction, P-N junction, how it is formed, what is the depletion layer, what is the built-in potential, and what is the diode equation, current equation. Now using this P-N junction, we will do 3 experiments.

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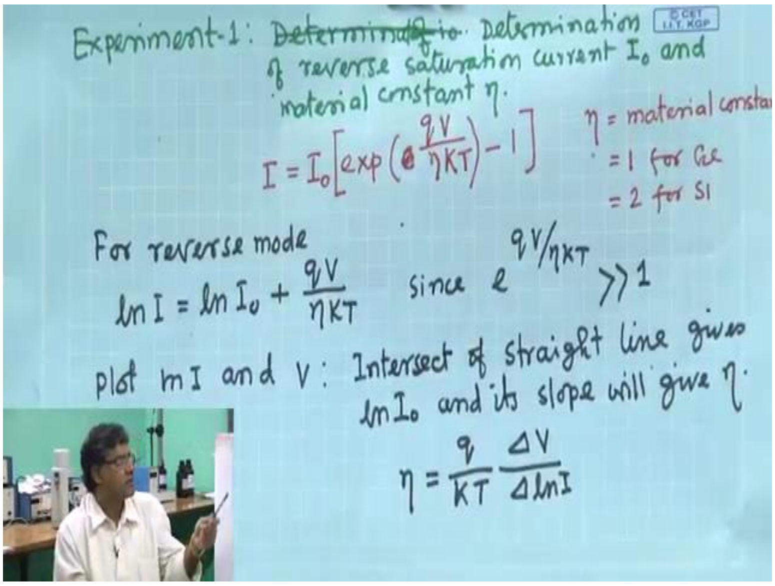

Experiment 1, the determination of reverse saturation current I 0 and material constant eta. ideality factor eta, ok. The current equation for diode is I equal to I 0 exponential q V by eta K T minus 1. Eta is material constant and for ideal case, for germanium material if P-N junction that is made from the germanium, then this this eta factor in ideal case it is the 1 or silicon it is 2. However, in reality in reality this factor varies, ok, this factor varies for different region, but it will be close to this value. From here also what can identify, what types of material it is ok.

As you are seeing here in for germanium it is 1 and for silicon it is 2, but it will deviate it will deviate of this value, that also tells the about the quality of the of the diode. that is a it is a called ideality factor. Above this experiment is to find out the saturation current, I 0 and to find out this ideality factor or material constant eta.

This experiment will be done in under the reverse bias condition, reverse bias condition. in reverse bias condition means this P side will be connected to the negative polarity of the source and N side will be connected to the positives with the positive electron of the source.

now in reverse for reverse mode, reverse bias mode here you can see this I taking log, I can write log I, ln I equal to equal to ln I 0 plus q V by eta K T because log I equal to log I 0 plus log exponential this exponential a log of these term. Now, this for since this is very greater than 1, and then we can neglect this 1. We can consider only this term, only this term. Why it is very greater than 1? Because in reverse bias case you need, we will we will apply say higher voltage and at that voltage, it will be this factor will be very greater than 1 and neglecting this one we can get this in log, taking log in both sides, ok.

now if you plot log I versus these V, from the measurement data now you can see this you will get a straight line, you will get a straight line and there that straight line will intersect will intersect the y axis ln I axis. that intersection that intersect will give this ln I value. From there you can get this I 0 and the gradient slope of the curve slope of the curve del V by del ln I q K T will be equal to eta. From here, one can easily find out that what will be the slope of this curve, slope of this curve. From the slope of this curve, eta is related like this.

If the experiment is done in room temperature. T will be taken as 300 Kelvin. Charge and K Boltzmann constant are known, for the graph we will find out this this slope, then one can get eta. From intersect one can get this I 0 and from the slope one can get this eta.

These are very simple experiment in reverse bias mode we have to do we have to take data, we have to plot graph. Log graph this ln I versus V voltage reverse voltage whatever we are applying. from there two important factor of this P-N junction will be will be found, one is this saturation current and other one is the ideality factor or material constant, ok. this is the experiment one.

Simple experiment, but from that experiment we can find out the material constant as well as saturation current of the diode. This is the; this both parameters are very important for P-N junction, for any P-N junction either it is in form of diode or it is in form of transistor; in transistor there are two junction, ok. P-N junction is very important whether it is in diode or whether it is in transistor.

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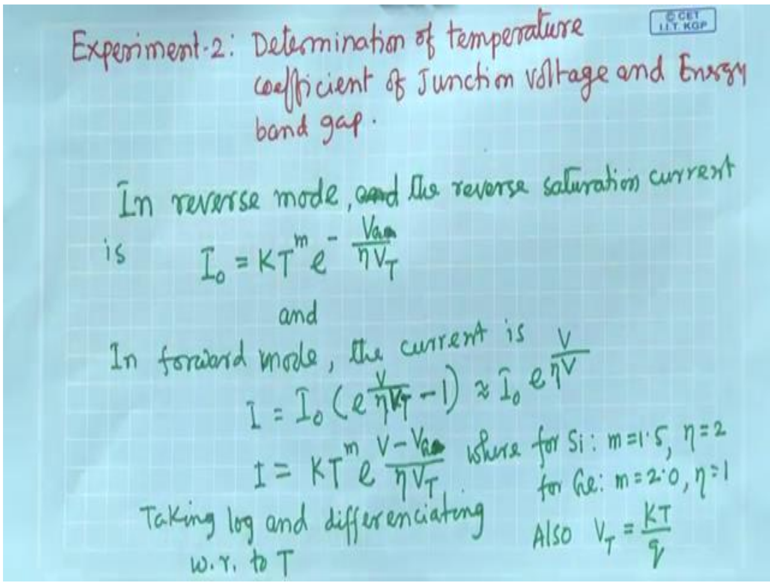

Now second experiment we will do; determination of temperature coefficient of junction voltage and energy band gap. This is the experiment to find out to measure the energy band gap as well as the temperature coefficient of junction voltage.

This energy band gap of course, it is very interesting to find out this energy band gap of energy band gap of a semiconductor. This junction of that semiconductor; semiconductor is either silicon or germanium. Junction is made just implanting trivalent and pentavalent atoms in both in two sides having a common junction, ok.

When; in the experiments also will be done in the reverse mode. In reverse mode the reverse saturation current I 0, it is a one can write like K T to the power m. here we are varying temperature. that if temperature is constant, whatever this here this term I equal to I 0 etcetera we wrote, there T term was there, but since I 0 at a particular temperature. That is why we have not written this T temperature explicitly, ok. It was in I 0.

Now in I 0 how, in which form this temperature term is there? this I 0, there in experiment 1, we have just written I 0 because in that experiment we kept temperature constant at room temperature generally we do the experiment, that is why I 0 was, just we wrote the I 0 without writing the explicit form of the of the expression. here I 0 is you can see this it is an expression is some Boltzmann constant K T, ok; T to the power m, e to the power minus V G by eta V T. here V T here T, V T we are writing this, it is an energy term. It is a defined K T by q.

Earlier explicit we wrote q V by eta K T. now, this just we have written in that same thing in different form. That whatever q, that q is has come here come here, ok. If the energy we are writing in terms of V voltage. V G, V G is an energy band gap, it is the V G is the band gap band gap and eta V T, V T as I told this is just we have written here K T by q. this dimension it is in volt you know. These V G it is an energy gap, band, it is band gap it is not in energy, but it is in in volt unit, ok.

If you multiply with q then it will be energy gap band gap in energy. but it does not mean, it just matter of just factor q constant if you multiply, then you can volt from volt you will get in energy unit. In reverse mode I 0 whatever saturation current we get, this is a form is this.

Now, this that equation we have seen this current equation of diode I equal to I 0, e to the power V by q V by eta K T, ok. That is again a same form we have written, e to the power V by eta K T, K not K T, V T because V T is defined with this. this will be equal to I 0, e to the power V eta by V T, I should write V T, just for it should be V T. now, because this term if this term is very greater than 1, 1 is neglected; I 0 e to the power V by eta V T.

Now if I replace this I 0 by this equation, this is the form of I 0. One can write I equal to this I 0 is K T to the power m, e to the power this minus V G. and here V is there, V minus V G by eta V T, ok. in case of silicone generally m is 1.5 and for germanium m equal to 2, ideality factor this is 2 and this is 1, ok. This one can consider of the earlier experiment one can use the value of eta. From this, this is the final equation, which will use for our experiment.

Now, taking log and differentiating one can differentiating with respect to T, one can get V G, it is a V G equal to V minus T, d V by d T minus m eta K T by q.

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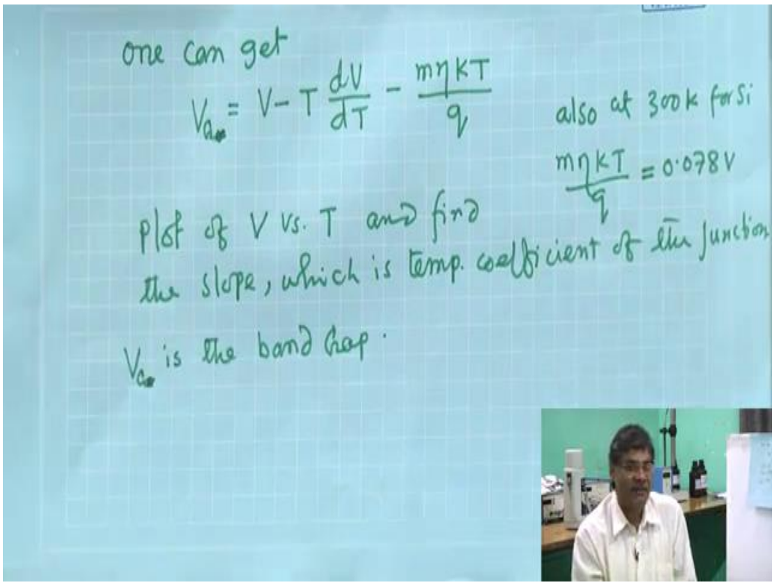

just that expression I have shown this one has to take log of this and then differentiate with respect to temperature, then V G. it is a as I told this this is the band gap in in not in energy unit, but voltage volt unit. From here, you can see that these are constant, these are constant. If temperature at room temperature these value is these 0.078 V volt voltage. As I told this this is a voltage, this will be voltage. Band gap it is not in energy unit, it is in volt unit, ok.

This expression will be our final expression for the experiment. In this expression, you can see this this this band gap that is involved as well as the d V by d T the temperature coefficient, what this what will be the our m temperature coefficient of junction voltage, temperature coefficient of junction voltage, d V by d T. if you plot if you plot V versus T and then we can find out the slope and that slope you that slope you will get, from there that slope itself V and T, V versus T. slope itself will give you this this d V by d T which is temperature coefficient of the junction. That will be able to find out. In addition, from this graph we will be able to find out V G, which is nothing, but the band gap.

This is the experiment 2, from that experiment one important parameter band gap we can find out, also temperature coefficient of the junction we can find out, ok.

Now, this another experiment we can do using this P-N junction. This also important, the study of experiment 3, the study of depletion capacitance and its variation with reverse bias, ok.

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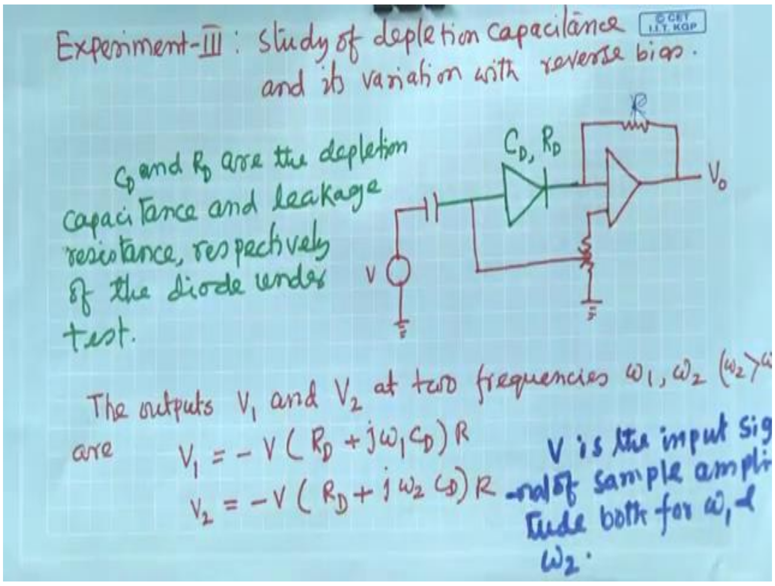

In these experiments, this is the diode P-N junction, ok. these P-N junction this this is nothing but diode. This will be, in the experiment we will use this this experimental configuration. Here I have, here I should write this is the resistance external relations. Capacitor, this is your AC volt source and this is the amplifier, ok. all configuration is given.

If you use this configuration of the experiment; if you connect this your diode with this resistance capacitance, resistor capacitor and the amplifier with this circuit diagram, then you see this is the voltage source, AC source. you can get this voltage signal of different frequency, different frequency.

Now, for two voltage V 1 and V 2, at two different frequency omega 1 and omega 2, omega 2 is greater than omega 1. That one can select. that then that V 1 output voltage V 1 will be V 1 equal to minus V, R D, this is the capacitance resistance plus j omega 1 C; you know this is for a capacitor the impedance, impedance and this is what is called this inductance for LCR circuit for LC circuit for RC circuit, ok.

This resistor resistance now in that case we tell the impedance. that hopefully you are familiar 1 by j j omega C, 1 by j omega C that is the in vector form that is the in vector form, ok. Now, if you multiply with this I, I square not I here we have written j, j square is equal to minus 1. j is imaginary square root of minus 1, ok.

In this circuit in this circuit for V 1 when you are using the frequency omega 1 this will be the, as a voltage into resistance kind of things. V 2 will be also minus V and this resistance part, ok. From these two equation; if you just do the experiment in in this with this two frequency. And now these two expression for V 1 and V 2 now, you square this these two expressions square it and take the difference of these two in terms of impedance in terms of amplitude, ok. When this type of relationship amplitude is square root of R D square plus omega 1 square C D square, ok.

If you take, difference of these two after taking square in both side of both the equation. This squaring and subtracting after taking magnitude as I told magnitude, vector j is there. When you will take magnitude, it is a square root of square root of omega square and C D square that will come; omega square and C D square will come.

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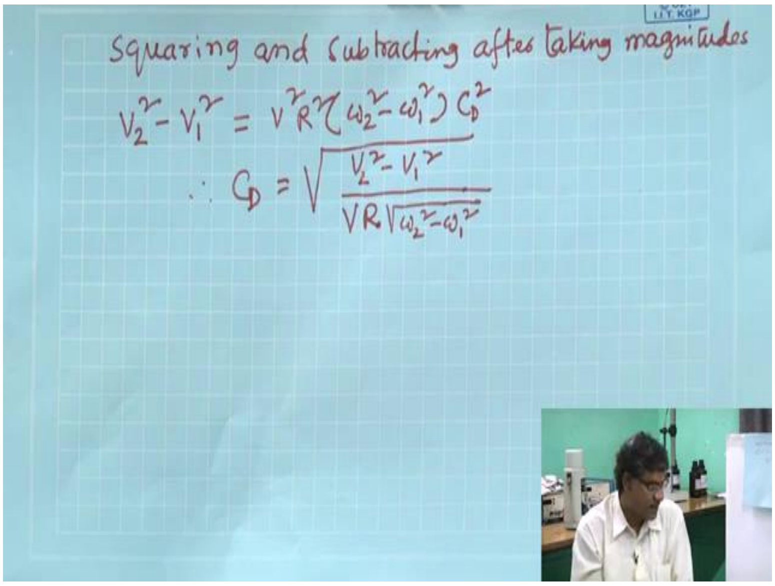

just taking difference after squaring and considering the magnitude only you will get this type of form and from here you can write C D equal to square root of V 2 square minus V 1 square by V R square root of omega 2 square minus omega 1 square, ok.

Here C D that is what we want to measure. The junction capacitance, the junction capacitance or depletion capacitance and one can study the variation of it variation of it with the reverse bias, ok. For that for different reverse bias how this for. for each for each experimental value of this to calculating the value of the C D, we have to do we have to do the measurement of two frequencies using two frequencies, ok. Now that we will do on the different bias condition reverse, bias condition and that will give the variation of C D as a function of reverse bias, ok.

We can find out the depletion capacitance and we can find out how it varies with the reverse bias, ok. this is the theory parts of the experiment. 3 experiment we will demonstrate using the P-N junction. You can see this is the very good experiment to know the band gap, to know the ideality factor, to know the junction capacitance and some other and to yes. these are the important parameters for P-N junction and just using a simple one diode doing experiment in very different configuration we can get all those important parameters.

Next, we will demonstrate the experiment. let me stop here this theory part.

Thank you.