Solid State Physics
Prof. Amal Kumar Das
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture - 48
Physics of Semiconductor

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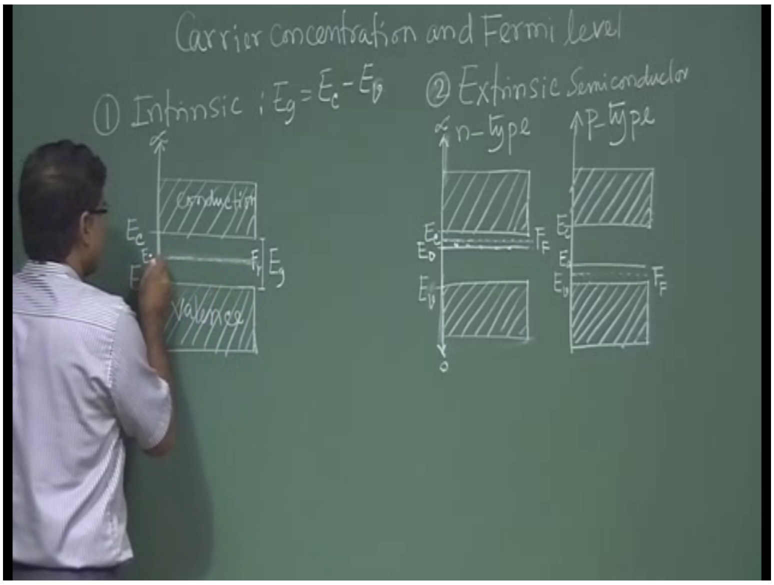

So, we will discuss about the carrier concentration in semiconductor, and Fermi level of that of that semiconductor right. I have discussed already that there are 2 type of semiconductor, one is intrinsic semiconductor this say we have band. So, this is valence band, and this is conduction band, this is valence band. So, this this energy scale this side it is 0 and this sides goes to infinity right. So, this edge of this lower edge of this conduction band this energy is defined by say E c. And this valence band edge top edge this energy is E v.

And Fermi level or some you can tell this theory E For intrinsic case. So, this energy is say E I, so for intrinsic semiconductor. So, this Fermi level I am defining here this by E I. So, I will show that E I will equal to f. So, in this case this is the band diagram, and this energy of this E c E v and E I. And another is this gap, this energy gap this we writes it is this is basically E g energy gap between the conduction band and valence band. So, E g equal to E c minus E F sorry right.

So, when for second type is extrinsic semiconductor. And in this case the 2 types either n type or P type; so n type so again this band diagram if I draw. So, in this case. So, this again E c this is E v. Now this for n type intervalent impurity we have dopped. So, this so that is called donor it can donate electron in the system it can donate electron to the conduction band. And it is assumed that this donor energy level donor energy level is close to the conduction event, generally it is these difference is very small say 0.01 to 0.03 electron volt. It depends on semiconductor and type of dopant of course; so this energy level of this donor which we can write E D right, and this Fermi level.

So, this donor level is having electron this atom is having 5 electrons. So, 4 are they have come bond with the silicon core silicon, and one extra is there. So, these one extra electron it is in this level. So, so this electron this electron from this donor atom it can it can go to the conduction band. So, for that these donors need some energy. So, that energy is difference is E c minus E D. Now this Fermi level, in this case it is considered that it is in between these in between these 2 that E D and E c E D and E c. So, is considered E F.

And for P type semiconductor. So, we have similar band diagram right. So, again this is E c E v. So, this P type trivalent atom is used for doping and it has 3 electron. So, to satisfy 4 silicon nearest neighbour 4 silicon. So, you need 4 electron. So, one electron is missing, basically one electron is missing. So that means, this atom which we use to dope the semiconductor intrinsic semiconductor so that in that it is trivalent, and one electron is shortage.

So, it can accept it is ready to accept one electron. So, that is why it is called acceptor. And it can accept from when the from valence band. It can accept electron is available in valence band. So, it can accept electron from the valence band. So, this acceptor level acceptor level it is goes to the it is close to the valence band. So, this energy level is there. So, it can accept electron from the valence bend. So, this again this energy difference E v and E a this is few very small a electing whole is 0.01 to 0.03 in the range. So, here this Fermi level again. So now, electron is accepting from valence band. So, is exchanged between this E and E v. So, Fermi level it is expected between these 2 energy levels. So, this is E F.

So, let me so make it solid let me make it solid. So, this is E D and here you whatever here given. So, that is basically it will coincide to the Fermi level C in E F which are same place [FL] because here electron is getting exchanged between this conduction band and valence band. So, E F also expected at the it is a middle. And it is it will coincide to this E i. So, E I and E F it will coincide. So, this is the picture of semiconductor band diagram of the semiconductor. So, here just I assume. So, this is the type of arrangement of this of these energy levels, but that we can find out. For that we have to we have to calculate carrier concentration of semiconductor.

So, if I do that. So, let me tell you that I think I will, so finding just. So, how we can calculate carrier concentration? So, carrier concentration means as I mentioned that density of function density of function D n by D E right, generally density of function.

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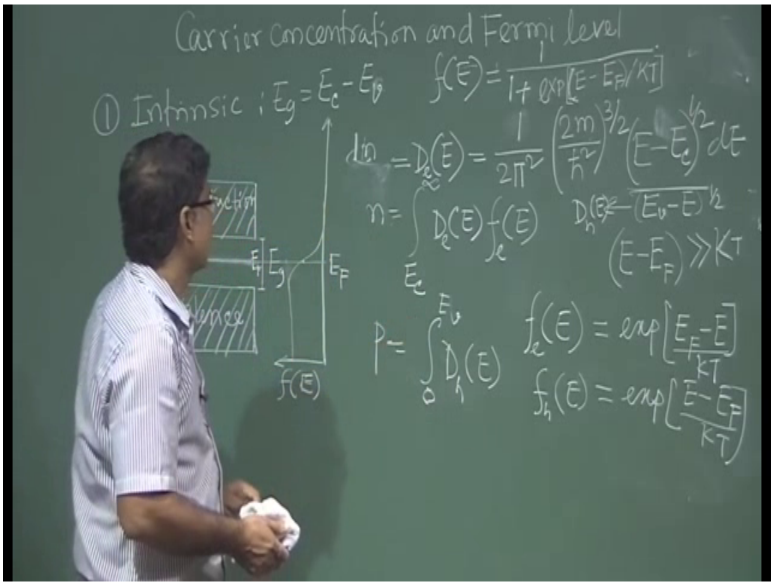

So, we remember for free electron we have calculated density of functions, what was that? So, v by 2 pi square.

Already we have derived this one v by 2 pi square 2 m by h cross square to the power 3 by 2. And it is basically proportional to the square root of energy. I think that was the expression for density of function. Yes, and Fourier function this that Fermi Dirac statistics. So, this is the density of states, now each state will have one electron, each state will have one electron because density of states we have. So, in this formula we have considered that this one level can take 2 electron spin up and spin down so that means, it has degeneracy. So now, if we multiply with 2 then 2 into that number of orbital's.

So, it will be you can consider double orbital then we have to take this one electron per state. So, that there is the one electron per state. So, that we have considered when we derived this one now. So, this we have to adopt for our system. So, here this is any energy right. So, here we want to consider that in conduction band in conduction band what is the density of states right; so conduction band. So, it is above E c above E c. So, any energy if I consider here so that is E. So, actually E means this E and minus E c will give this. So, here we have to modify this one.

Basically, we want to find out the density of states this energy range. And now number of electrons number of electrons; so D n in the in the energy range E 2 E plus D E so that will be the so D n is this. So, n will be n will be one has to integrate this one right, over d what is the range? What is the integration range? So, it will be E c to infinity right. So, E c to infinity density of states, and now we remember these density of states is basically for t equal to 0 t equal to 0. Now we have 2 for finite temperature to calculate density of states for finite temperature.

So, we have to multiply with the Fermi distribution function f E right. What is f E? F E is you remember f E is, f E is 1 by 1 plus exponential E minus E F by K T right, E minus E F by K T. So, it is not visible. So, I should write slightly. So, this f E I should write somewhere here. So, then I can keep it. So, f E basically 1 by 1 plus E to the power or exponential E minus E F by K T, right.

So, that is the case. Now in our case you see this if I consider that if I consider assume that K T that E minus E F is very, very greater than K T. So, temperature is such that temperature is such that you cannot see probably. So, if I assume that E minus E F is very, very greater than K T if it is equal or less than K T. So, electron will all electron will easily go to the conduction band right, but if it is temperature is such that this E minus E F is very, very less then is very, very greater than K T. So, that means this term is very, very high.

So, E to the power this is very high term. So, is it is quite high term compared to the this value will be quite high compared to the 1. So, I can neglect 1. I will keep it I can neglect 1; so this 1 by this; that means, exponential. So, this f E will be f E will be 1 by this means exponential. So, it will go up minus of this. So, minus so I can just write minus I include here. So, E F. Minus E right by K T right. So, for our system so we adopt this f E adopt this f E. So now, if it is for we are calculating this concentration of electron concentration of electrons; so here E c to this if I want to calculate concentration of hole; so concentration of hole.

So, this integration will be this integration for P this integration will be from E v from 0 to E v. So, 0 to E v right in case of whole. So, in valence band what is the number also or density of states. So, in that case so in that case I will put here E electron density I will put here E. So, this is for E right. So, density of states here we have written whatever this one E minus E c. So, that is for E. So, similarly for hole D h if I write hole D h if I write D h the function of E as a function of E, then what it will be. So, here this density of states per unit energy density of states means states per unit energy.

Now, if I divide by v volume of this material. So, it will be density of states per unit volume. So, we have saw this D n or n it is basically for per unit volume, density of states or density of electron because in each state one electron. So, density of electron is n; so per unit basically volume. So, here I make it one so D h so this here. So, for that this appropriate one. So, this is there here this or it was E to the power half right. So, in this case so this.

Here this between these 2 E F and this E v. So, that energy is here, I want to find out the density of states here. So, energy is here with respect to the Fermi level. So, then minus cc. So now, I have to write that one E F E minus E v minus E, in this case I have to write E v minus E. So, E is here the E v minus E. So, E values from origin this is what our E value from origin this is the E v value; so if E v minus E. So, this will be this range. So, within this range I want to find out the you know; so E v minus E; so in case of DE so this will be E v minus E E v minus E to the power half.

So, this will be for D h, it will be for D h, it will be for D h, this will be for D h, density of states of all in valence band. So, in that case we have to use E v value. So, and this expand this Fermi distribution it will be f h E equal to. So, in this case also we will consider that this term is very, very greater than this K T. So, this term is higher and you will get again this similar type of things here; so E F minus EE. So, in this case also you will get no, yeah, I think that way one can consider. Or generally what we do?

1 minus generally, what we do? Because density of this electron distribution this f E's maximum value is one right. So, for hole it will be it will be 1 minus f E whatever for electron; so this 1 minus this. So, so for Fermi level; so from Fermi level, if I draw here if I draw here. Oh yes this is the energy, this is the energy, this is the energy. Now this is the Fermi distribution, this is the Fermi distribution this, this side. So, this is f E, what was that for temperature at t equal to 0? So, this it was like this.

So, up to Fermi level, up to Fermi level it was it was 1, it was 1 and then 0 when temperature is not t equal to 0 then what happens; so from here whatever electron. So, it goes above Fermi level. So, it is probability decreases it is probability increases. So, that is why whatever probability decreases is increases here. So, total probability will be 1. So, that is why it is 1 minus f E. So, from here so just it is 1 minus this if you got up or you can get from here also 1 minus this, so 1 minus this means so it will be exponential; yes, so not f E just so I will start from here.

So, it will be f E. So, it is 1 by 1 plus exponential this term right this term. So, this it will give you E to the power exponential this term divided by 1 plus exponential this term right. So, if we divided by this. So, 1 by exponential plus 1 1 by exponential whatever this sign is there it will just reverse E F minus E it will be E F minus E, so E F minus E plus 1, 1 by E so E F minus E. So, in that case this term is very, very greater than 1. So, that is why you can neglect one here. So, whatever you will get. So, if you take up, so again minus sign. So, it will come in to original form this is. So, it just reverse.

Whatever exponential here it will just reverse of it. So, it will come exponential E minus E F by K T. Hopefully I have done correctly, but this is the way one has to do. So, one can integration that limit I have given. So, one can do. So, if you can do one. So, other one also you can do, but these are the things here to say just I want, I want to calculate for this n. So, let me just forget this part. So, in this case so this is the density of this is the f E I have to use f E this is the term, and dE is this one.

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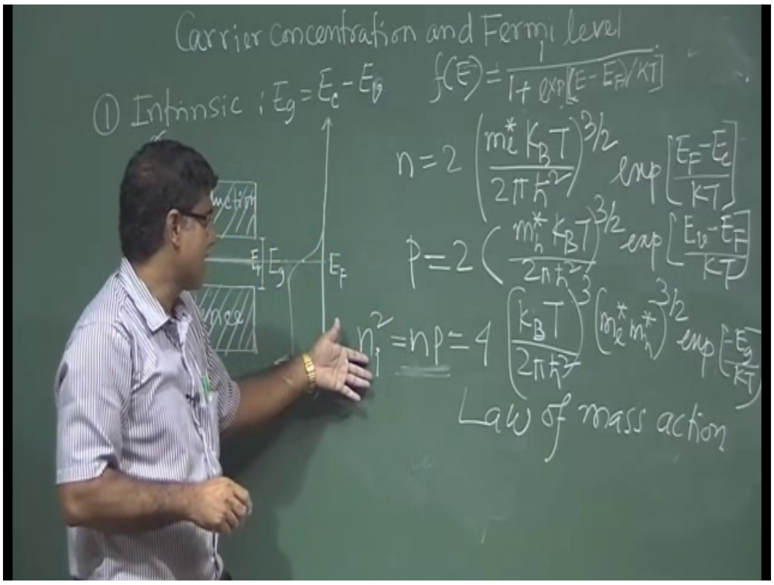

So, n equal to what I will get. So, this you take out from this integration, 1 by 2 pi square 2 m by h cross square to the power 3 by 2.

And you will get here integration E c to infinity E c to infinity, and then I am getting here E minus E F to the power half E minus sorry, E minus E c E minus E c to the power half, and what I am getting here exponential E F minus E by K T and D E. So, you will have this term D E right. So, D E with respect to D E, one has to integrate and then so this integration one can find out. So, what I will do here this term. So, exponential E F by K T I can take out, E F by K T I can take out. And then actually here I want to I want to set E minus E c E minus E c.

So, this I can add plus E c minus E c here. So, I want to keep it this E minus E c. So, if I take minus come on E this plus E c will go minus E c that we will be there. And E F minus E c by K T this will be another term. So, I can take out here I can take out multiplied here, exponential E minus E c then that minus sign is there E minus E c E minus E c sorry. So, E F minus E F minus E F minus E c, this term by K T by K T this term I will take out. And what it will be there it will be there E F minus E c I have taken out.

So, E c minus E it will be here E c minus E will be here, E c minus E will be here; so if I can take minus sign and then it will E minus E c. So, minus so this I can write minus E minus E c. So, if you take this E minus E c equal to x E minus E c equal to x so then D E equal to dx, no. So, I think take I need space. So, basically here if you take E e minus E c by K T equal to x. So, dE equal to K T dx. So, from here you will get dE equal to K T dx K T dx right, K T dx. So, K T term will come here, K T term will come here and this K T I can take out.

So, this x this dE basically you can replace by K T dx K T dx K T I can take out K T I can take out and this then x to the power half, x to the power half and E to the power minus x dx. So, this will be the integration, and this integration limit will be here when equal to E c E equal to E c. So, here E c equal to E c then x will be 0 right. So, integration will be 0 to this 0 to infinity. So, these are standard integral and this it is integration value. I think this 2 by pi square root of 2 by pi integration is square root of no pi by 4 square root of pi by 4 and yes.

So, this integration it will give you pi by 4 is the standard integral it will give you pi by 4 to the power half. So, actually you are getting this up to this integration. So, this term this term this, this will be there K T and this where ever. So, what all you will get over all you will get. So, I will I will get n equal to just if you 2. So, 2 I will get 2 m e, for electron m e For electron; so this basically effective mass effective mass K B T.

So, somewhere I am writing k or K B the same right. So, K B T divided by 2 pi h cross square to the power 3 by 2, to the power 3 by 2 exponential E F minus E c exponential E F minus E c by K T. So, this we will get after this calculation you will get this. And similarly, if you calculate for P you will get mh hole effective mass K B T by 2 pi h cross square to the 3 by 2 exponential be just E v minus E F by K T.

So, here if you product take product of this np take product of this np what you will get you get 4, 4 and this will get K B T by 2 pi h cross square to the power 3 by 2 3 by 2. So, this 3 and m e star m h star. So, this will get 3 by 2 and this exponential you will get so E F will go. So, you will get E v minus E c the exponential E v minus E c E v minus E c E v minus E c. So, this is. So, this will give you E g minus E g. So, E c minus E v is E g. So, E v minus E c is the minus E g. So, it is basically you get minus E g by K T. Now this product if you look at it. So, you see this is independent of this is independent of Fermi energy, you know this is the independent of Fermi energy. Now I have shown you that this Fermi energy this position depends on the whether it is intrinsic semiconductor.

Whether it is P type semiconductor, whether it is N type semiconductor depending on that this Fermi energy is shifted, but E g is always same E g is always same. So, this product, so this calculation I have not mentioned that it is for intrinsic semiconductor. So, it is in general this product is always constant for a particular temperature. And this is called the called this law of mass action, law of mass action, law of mass action. So, this product is always here.

So, if it is for intrinsic semiconductor. So, this product is intrinsic semiconductor n i; so this for hole and for this other. So, this electron so n i square intrinsic semiconductor if it is constantly n i. So, n i square equal to basically np equal to this. So, this is valid for all semiconductor because it independent of Fermi energy.

And this is called law of mass action. So, this is very importance finding. So, I will continue in next class. So, I will stop here.

Thank you for your kind attention.