Experimental Physics - III
Prof. Amal Kumar Das
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture – 36
P-N Junction

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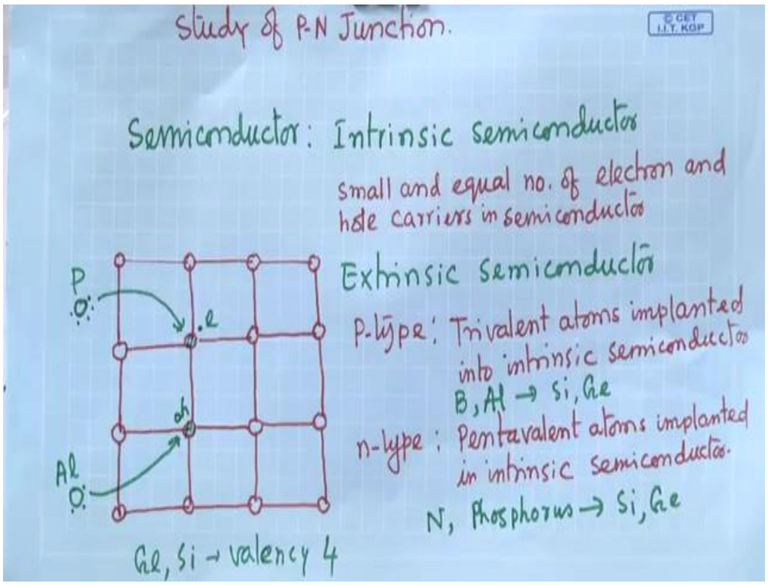

Today I will discuss about P-N Junction. We will study P-N junction 2 different experiment. P-N junction naturally it is made of semiconductor. Semiconductor intrinsic semiconductor, where small and equal number of electrons and hole carriers in semiconductor. And another type of semiconductor is extrinsic semiconductor. The 2 types; P type and N type. P type is trivalent atoms implanted into intrinsic semiconductor.

Trivalent these boron, aluminum, gallium, these are trivalent atom. these are implanted in one of them is implanted in silicon or germanium or some other semiconductor, intrinsic semiconductor then it will be p type. If pentavalent atoms implanted into intrinsic semiconductor, then it become n type semiconductor. nitrogen phosphorus, these are the pentavalent atoms if these are implanted one of them is implanted in silicon or germanium or other semiconductor then it become n type semiconductor.

This intrinsic semiconductor, the silicon, germanium is a valence is 4 and it makes covalent bond. 1 silicon, it has it will share with the 4 atoms. Each atom will share 4 atoms and; that means, that 4 electron valency of 4. 4 electrons 1 electron of these atom will share with the other atom.

From there it will share one 1 electron, 2 electrons. In outermost shell, they will have 8 electrons that is the condition 2 or 8 electrons in the outermost shell that gives the stable configuration. These 4 electrons are required; valence electrons are required to make covalent bond with the neighbor atoms.

Now if one of these 4 this one of this atom is replaced by pentavalent. Pentavalent of 5 electrons are there. This 4 valence electron this atoms is replaced by pentavalent atom. out of 5 electrons 1 will be; 1 will be extra after sharing other 4 electrons. This extra electron will be in the system. It will be it will be free electron. It will participate in the conduction.

Similarly, if trivalent atoms is implanted. Trivalent like say aluminum, outmost shell it has three electrons. When it will be replaced here. Now, here this for covalent bond 4 electrons are required, then 1 electrons will be; 1 electron will be shortage. that shortage of electron is treated as a presence of hole. It seems that this trivalent atom when it will replace this 4 valency atom. Then in system, it will contribute 1 hole.

Implanting pentavalent atom in intrinsic semiconductor one can get p type sorry n type and implanting this trivalent atom in intrinsic semiconductor one can get p type. this is the extrinsic semiconductor and this implantation it can be done in different way.

in chemical method by diffusion diffusing the atoms, chemically defusing the atoms one can replace, one can use accelerator and accelerate the atoms or ions of pentavalent or trivalent and this accelerated ions will hit the intrinsic semiconductor and it will be this atoms will ions or atoms will be penetrated into the system, into the target of these intrinsic semiconductor.

Then following the annealing of their sample it will give the replacement of the of some atoms original atoms of the semiconductor by this implanted atoms. These defined methods are used for getting this p type and n type semiconductor.

Now, P-N junction means that; a piece of a piece of p type semiconductor and piece another piece of n type semiconductor when they will be in contact then what happens.

that is what we want to study. This n type semiconductor and p type semiconductor also intrinsic semiconductor.

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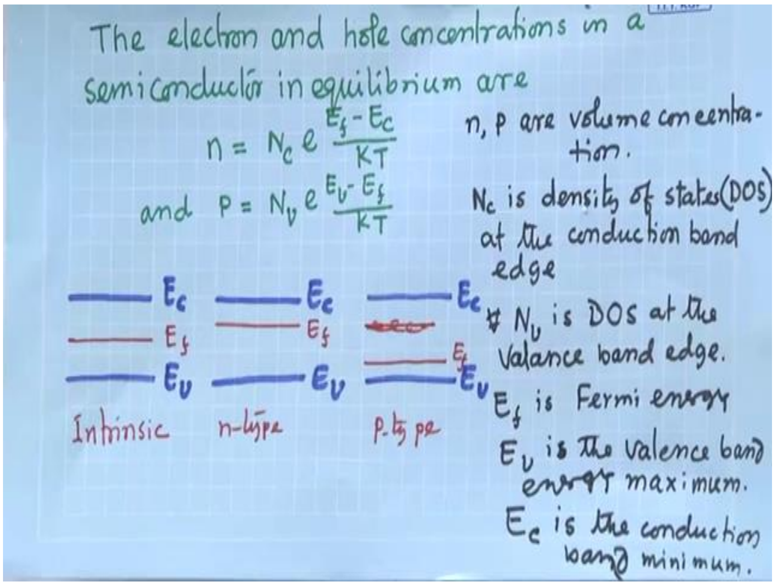

This you know that we present using the band diagram. electrons and hole concentration in a semiconductor in equilibriums or this is the; this is the expression. This electron concentration in equal to N c e to the power E f minus E c by K T.

And p equal to N v e to the power E v minus E f by K T. basically, this is for intrinsic semiconductor. E c and E v, these are energy level. The valence energy this is the it is called E v is the valence band energy maximum. It is band is not just epsilon not just like the straight line it has curvature. It is the top value of the maximum value of these valence band.

That is taken as an E v and bottom this of conduction bands. minimum energy of this conduction band. That is take energy E c; E c is the conduction band minimum. and E f is the Fermi energy. When this Fermi energy level is at the middle of this gap, these also we tell this energy band gap.

When it is in the middle of this band gap then, it is intrinsic semiconductor. This probability this generally we consider that this the maximum probability of having electron up to this energy level which is called Fermi energy level.

That is the outermost energy level, energy surface up to which this there are up to which there is the maximum probability to you have the career. from this, what is the distance of; what is the distance of conduction band. In case of electron, in case of electron from here it will it will jump to electron will jump to the conduction band then we will get conducting electron. in intrinsic; this gap from Fermi energy level to the conduction level or to the valence level energy level both are same.

Whereas, in case of n type this E f Fermi energy level, it is close to the E c. That means, the this gap is smaller. Electron density having the electron density the probability of getting electronic density will be higher and for n type p type, this E is close to the E v valence.

This gap is now compared to this intrinsic (Refer Time: 11:44) these are smaller. Probability to have the hole concentration as a career will be higher in this case. In p type why E f is shifted towards the E c and for p type, why it is shifted towards the valence band, valence energy band. seeing this band diagram one can tell whether it is n type or p type or intrinsic semiconductor.

Here this you can see this concentration of this electron will depend on this E c this energy difference between the E f and E c ok. in intrinsic case E c, E f this one is same this both are same. n and p will be same in intrinsic semiconductor. But, extrinsic semiconductor this E f minus E c, E c is the smaller value. E f minus E c is the smaller value.

n type that is concentration will be higher and for p type semiconductor. For n type semiconductor; if you consider what will be the; what will be the concentration of whole then in that case. The E f is close to this naturally that E f, E v minus E f these are larger. these this one will be larger. In n type, this one will be larger E v minus E f than the E f minus E c.

Naturally n will be greater than p or n will be very greater than p depending on the doping concentration. In p type, just other way p will be greater than n because this E v minus E f is smaller than the E f minus E c in p type. the concentration actually it is mainly depends on will mainly depends on this position of the Fermi level whether it is how close it is to the E c or E v.

N c and N v here I have (Refer Time: 14:45) the density of states at the conduction band and at the valence band ok. Density of state is nothing but the number of energy levels, number of energy levels. In energy density power in unit energy. how many how many energy levels are there? Number of states or number of energy levels in a unit; in a unit energy. that is the density of states.

Now, this density of states, this always in unit energy difference, what is the states? Now, these different is a function of energy at different energy that this number of states in unit energy difference will be different. This the state should be available only then electron can go there, if states are now not there electron cannot go there.

I have I should have sufficient number of states and in those states, how many electrons are there or how many holes are there. That is decided by this factor, exponential factor by this exponential factor.

each energy level it is. it can contain as per the Pauli exclusion principle; it will be considered that it can contain only 1 or spin up spin down that is maximum 2 electrons in accounted. Generally that is factor 2 1 1 1 can multiply or if you consider that one that each energy level is for is step for 1 electron. that way if you define then also.

Whatever the number of states in unit energy difference that is called density of states. among these density of states, how many electrons are there or holes are there. That is that this n is coming different value from N c because of this factor exponential this factor.

It is it is a like Boltzmann factor you know Boltzmann distribution factor. It will it depends on all on also this temperature T, it is there. When this n type and p type semiconductor are in contract.

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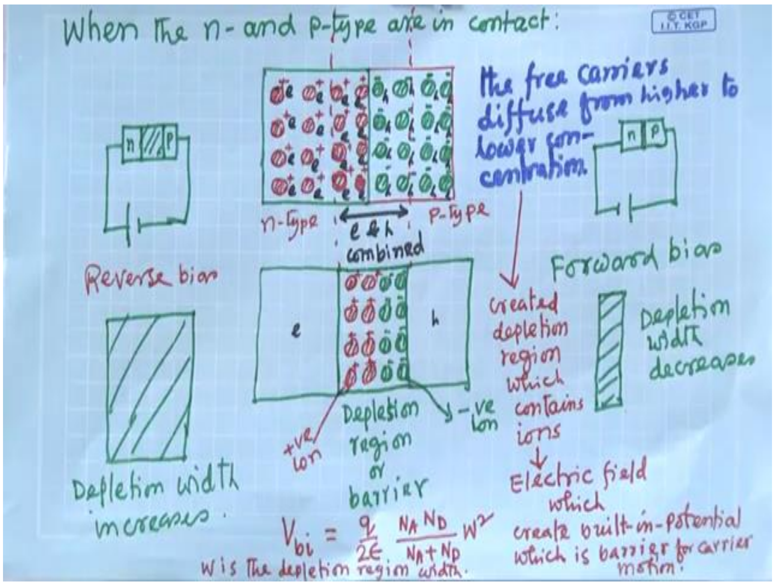

This is the p type and this is the n type ok. When they are in contract then, what happens? Electrons from this side from n type; it will diffuse into the p type semiconductor. And hole from this p type semiconductor; it will diffuse into the n type semiconductor. Why it will diffuse? Because, the always electron density at this side is higher and electron density on the other side is lower.

Always it will transport, it will diffuse from higher concentration to the lower concentration. When they will; when they will move then they will hole and electron, they will recombine and they will destroy. There will be space. after sometime there will be space like this where there is no careers, movable careers. Only this the ions this from atoms this electrons or holes they are recombined and they are not there in this region; in this region at the junction near the junction in the junction region.

Only in n type in that side this positive ions will be there and on the other side there will be negative ions. and in this region there will not be any career, free career. Now, further this career from this side, it will try to go to the other side. However, it cannot go because a region it is it will act as an it will act as a barrier or also we call it is depletion region.

This why it is barrier for this electron to move further again towards this other side it cannot do that because here electric field. Now electric field you see, it will be just from positive to negative, it will be in this direction, it will be in this direction. Electron it will because of this; because of this electric field and corresponding potential. That is not in favor of transport of electron to the other side or hole to move in this n type side.

This in natural way. there will be built in potential and it will act as a barrier to move electron or hole further ok. This built in potential or this barrier, it is a it is a equal to q by 2 epsilon. Epsilon is the dielectric constant of this junction of this semiconductor ok. And N A, N D by N A, N D. N A and N D, we say it is density this number density of acceptor and donor ok.

Acceptor; this atoms acceptor, which can accept electron, which can accept electron. That is N A is a it is a equal to the in case of doping case equal to the p concentration, acceptor. It can accept electron so; that means, there is a vacancy of electron which is equivalent to hole and N D donor. This pentavalent electron in it can donate in donate electron in the system. This density of donor is the density of the pentavalent or the tetravalent atoms we have used.

this N A and N D it is a it will be equal to N A will be equal to the concentration of hole in case of, in case of p type and in case of in p side and N D that is the donor ok, the. It will be equal to the N equal to the, density of electron in case of n type. This W square, W is the depletion region, depletion width; we tell this is the deletion width.

This depletion width is created because of this built in potential built in potential and physically what is the, what is the length of this depletion region or of this barrier. That is the we tell if it is W say, W is the depletion region width.

Now, there is a built in potential. Now if you apply potential, apply voltage in two way we can apply the one is called forward bias and another called reverse bias. In case of forward bias; it will reduce the; it will reduce the barrier height depletion region width and that will help to. This width will be now smaller, it will help. Barrier height in terms of barrier height it will be reduced and now this electron and holes, they can move; they can move in opposite direction opposite direction.

In case of forward bias this will happen, in case of reverse bias; actually, this width will increase will be increased and. barrier height will be higher. It will be more resistive for transporting the careers through the junction. this depletion width will be higher. This in terms of depletion width in terms of built in potential because; built in potential you see there this width is involved apart from this number density of acceptor and donor atoms.

External, using external voltage; we can have this two types of transport; one is under forward bias and other is under reverse bias. after touching after in contract of these two junction.

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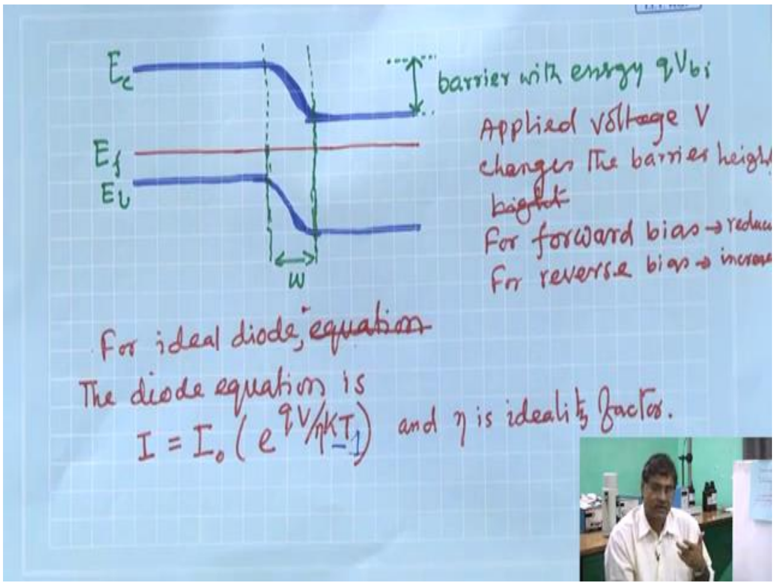

This the band diagram, initially it was like this it was like this. band diagram one can draw like this. In this case this when they will come in equilibrium means this electrons from this n type, this is p type. Now just opposite this I have from p type because, E f is close to the E v and this is n type because E f is close to the E c.

When they are in contact. in equilibrium condition means; whatever hole holes from this p type it will diffuse into n type and this electrons from n type it will defuse towards the p type and then these depletion layer or built in potential will be created and during this process during this process; the Fermi levels in both case in both n type and p type it will be aligned in one line.

When it will be aligned in one line, then only initially there was a difference. This difference will be changes this difference will be changes and in equilibrium they will be in align and as long as not they are in a single line. This diffusion of electrons and holes will continue and they will reach in final stage when this there will be single Fermi level for both n type and p type. and this very famous diode equation is the one can derive it. That is I equal to me 0, e to the power q v by eta K T ok.

This is when this is a v is the applied voltage when we will apply voltage. when it will be reverse voltage. v will be minus v when it will be forward voltage forward bias. v will be plus v ok. I did mistake. It will be minus 1, there will be minus 1 ok.e to the power q v by eta K T minus 1. I 0 is the saturation reverse current saturation. Reverse current I 0 and depending on the voltage see reverse bias is the it is the negative. It is the it is a smaller factor and for forward bias it will be plus.

It will be I think; it is the one case e to the power plus q v and another case e to the power minus q v. in case of minus q v, that will be 1 by e to the power q v ok. This, depending on this forward bias and reverse bias; this 1 has to take sign of v and one can study the I v characteristics of a P-N junction here you can see this v is here and I is here. one can vary the v and near the I.

Then from there from that measurement, one can find out this eta value. Eta is call the ideality factor or material constant. That I will discuss for different experiment. I will stop here, then I will discuss about experiment what we will perform.

Thank you.