Solid State Physics
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Lecture - 47
Physics of Semiconductor

So, now we will discuss Semiconductor Physics or Physics of Semiconductors or Semiconductor Crystal.

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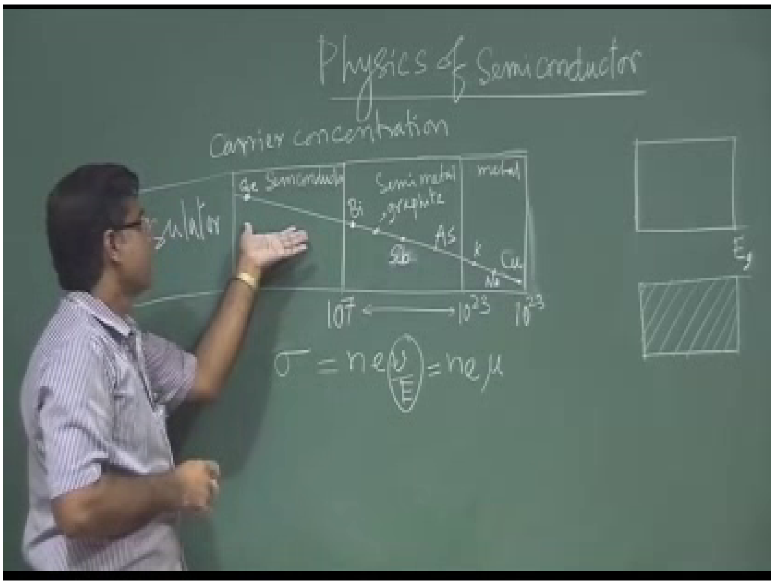

So, this we know the band structures, see in a crystal there are band many bands right now I have explained you that if we have . So, take just two band otherwise filled to take upper this filled one or partially filled and this empty band.

So, I think this has gone out. So, this is one band.

So, as I mentioned you that if this band is filled completely filled and this band is empty and these difference between these two is called band gap Eg right. So, depending on this Eg then we decide whether it is semiconductor or insulator right. So, if Eg is in the range of generally is say generally less than 3 electron volt more or less is not exact if it is less than 3 electron volt.

Then it is behave like semiconductor at room temperature or above room temperature, but at t equal to 0 all the time as I told axis there is no carrier to conduct. So, it behave like insulator; when Eg is quite high as I told is generally greater than three ev 3, 3 of volt electron volt whatever. So, then it will behave as a insulator right and when Eg can be 0 that means, this two overlap there is no gap between these two then it will have the this electron have many energy levels to move. So, we will get conduction electron and then it will behave like metal.

So, that I have discussed with you. So, in semiconductors basically this band structure whatever we got this band from band theory absolute sort where we got to this this concept of band. So, that will be useful to explain this physics of semiconductor means whatever the semiconductor shows defined property electrical property mainly, that will be explained based on this this band structure.

So, this is one way to distinguish or differentiate among the semiconductor and other insulator, but in terms of carrier concentration in a crystal that also one can use for differentiating the this metal electrical property of the material. So, carrier concentration really what is the range of carrier concentration? Carrier concentration carrier concentration what is this number of carriers it may be electron in case a case of semiconductor it can be hole also or this combination of these two. So, that is in general tell carrier. So, carrier can be electron or it can be hole also; so carrier concentration.

So, this now you just consider the electron concentration in the material. So, this generally this range for it is semiconductor, it is the range is resistivity its range is I think this is 10 to the power around 13 say to 10 to the power around say 10th or 17th its not a big (Refer Time: 06:24) this is the range .

In this range this and then this is the semiconductors in this range this semiconductor in this range this semi metal and in this case it is a metal say. So, this metal generally it is let us say 10 to the power 23, 10 to the power 22 to 23 I guess 22 2 22 to 23 yes this is concentration this is the concentration of electron. So, this per units cc, cc (Refer Time: 07:22) cubic centimeter.

So, this number of electrons per unit cube centimeter. So, there is the typical numbers. So, this is the this will be semimetal, semimetal this is metal this is semiconductor. So, its concentration if I just if I put concentration of electrons or carriers in some metal material, I can if I put a just line like this.

So it is this, the concentration of germanium and this is the highest concentration here this is basically ceramic it is copper. So, in copper this number of electron carriers is very high it is around 10 to the 23 and in germanium it is around 10 to the power 13 it is almost half of that copper.

And in semi metal basically here this copper and then I think sodium like this, this concentration and then I think this is another metal this is cop potassium these are concentration and this semi metal its arsenic antimony graphite bismuth arsenic is antimony graphite bismuth these are looks semi metal.

So, semiconductor and metal, their concentration is in between, if semi metal. So, this is what I told is the graphite, graphite this is the bismuth and this is the arsenic no antimony arsenic and there is the other one is anti this is the antimony and this is the arsenic ok.

So, this behaves like. So, this knowing the concentration of the material also one can tell about its electrical property, that because there is quantity concentration this (Refer Time: 10:15) electrical conductivity, it depends on this concentration what is the electrical conductivity? That is n this concentration of carrier n e v, n e v dipped velocity derived by because that n e v there is a basically current density, current density equal to sigma e right current density sigma e. So, it divided by this e. So, then there is a. So, v by e generally what is this v by e ne mu there is the mobility dipped velocity per unit electric field that is mobility.

So, this concentration depends on the carrier this conductivity, it depends on the concentration of carrier and the mobility of that carrier. So, thus this from concentration of the different material one also distinguish the that metal semiconductor, semi metal and this insulator basically in this side it will go to the north side. So, this side it will be insulator. So, forget we are not interested about insulator now. So, and also it the semiconductor when you increase the temperature. So, it shifts towards this. So, its concentration will increase its concentration of carrier will be higher at higher temperature.

So, this way one can. So, important one important fact is that concentration of electron or carrier in a material and the band gap of the material these two are very important for say in this case for semiconductor. So, concentration of carrier and this band gap and for semiconductor it is clear that all the time this lower band is filled upper band is empty. So, this band is called valence band.

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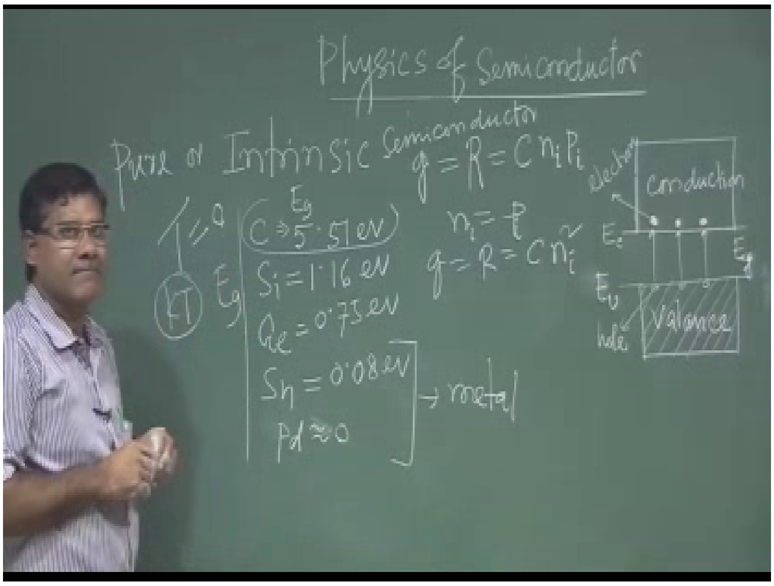

So, now I am going towards the just we will concentrate now for this semiconductor. So, these are basically these are valence band and these are conduction band conduction right. So, Eg is here their band gap now. So, this this energy generally we consider this. So, top edge bandage of valence band this energy is Ev and bottom edge of that conduction band that this energy we will consider at a E c right.

Now electrons are distributed in this band right electrons are distributed in this band. So, at t equal to 0 all electrons are here distributed here right. Now when t is higher when t is higher then what will happen? So, some electrons will be excited from valence band and we will go to the conduction band right then there will be vacancy here then it will be partially filled one right.

So, this absence of this; so from here this from electrons are there. So, that will go electron will go here due to applying thermal energy due to increase the temperature of this semiconductor then some electrons from top band from the upper edge of this valence band, will go to the lower edge of the conduction band right. So, now,. So, this absence of electron here this will behave as a hole and this will behave as a conduction electrons. So, two types of carrier will be present in semiconductor one is hole then another one is electron ok.

Now, what happen this electron from here electron is going there fine, but sometimes this electron also come back and re combine with the hole right. So, this called the combination process recombination process. So, then we lose a pair of electron pair of hole electron also when one electron goes from here to there. So, then we generate, we generate the pair of hole electron right. So, the generation of hole and electron pair of hole and electron and recombination of pair of hole and electron that all the time it goes on right in the system is goes on and at a particular temperature it comes at a equilibrium condition right.

So, where when it will come equi equilibrium condition, when rate of generation and rate combination this two are will be equal right. Rate of generation and have to be equal to the rate of combination at a particular temperature when the system is in equilibrium condition and this generally this generally this is proportional to the this generation recombination it is basically proportional to the concentration of the carrier this is proportional to the concentration of the carrier see if I take proportionality constant c and then this concentration of electron and concentration of hole if I talk n and p this n is hole electron concentration and p is hole concentration ok.

So, this now if in principle this number of this in principle this hole concentration must be equal to the electron concentration because all the time they are either they are gene generating in a pair or recombining with in a pair we are losing a pair or we are generating a pair. So, this n must be equal to p and then this g equal to R equal to c n square right n square.

So, now this case we are writing ni p i, p i just to define this type of semiconductor is called intrinsic semiconductors is called intrinsic semiconductors intin sic semiconductor or pure or pure or pure semiconductor impure or intrinsic semiconductor. So, this ohm meter. So, this you know this there are some. So, these are basically intrinsic semiconductor and there are very very familiar semiconductors are there. So, you know these group four atoms the only group 4 in periodic table group four atoms.

So, when they from pistols they are basically semiconductor. So, like in group or water the carbonate there, then silicon then germanium then you have tin and then palladium and then tin Sn then palladium. So, this carbon when they are the from crystal this carbon band gap we generally here band gap Eg of this material it is a around I thing 5.51 electron volt 5.51 electron volt for silicon it is 1.16 electron volt or germanium 0.72 0.75 electron volt and this tin it is very small 0.08 kind of 0.08 electron volt and this this nearly it is 0 it is 0 ok.

So, this electron volt whatever I mentioned that I had mentioned at T equal to 0 at absolute temperature T equal to 0, say at room temperatures this although it is in group 4, but this band gap is so high. So, its insulator at even at room temperature in insulator and a root room temperature these two shows in a its the metal behavior, metal the chemical band gap is almost negligible. So, its metal and these two behave like semiconductor because that is why I range I gave you this band gap range is very important is if it is less than less than two or less than three electron volt.

So, then only it will be because. So, that that range, whatever energy will give kinetic energy will give kt or the temperature in rage so, that temperature that that energy kinetic energy that that should be that should overcome this band gap Eg right. So, kt has to be is comparable to the Eg. So, if it is very (Refer Time: 23:15) very high temperature and in principle you cannot applied that high temperature it will not be useful ok.

So, these are intrinsic semiconductor and they are this concentration of hole and concentrations of electron are equal now. So, here this it is just because of thermal energy changing the temperature you can you can change the concentration of carrier, but another way is there to manipulate the concentration of carrier in the semiconductor. So, that semiconductor that is called the impure impurity purity impure impurity or what is this appropriate one impurity or exchange intrinsic extrinsic semiconductor dependence people tell in different way differently.

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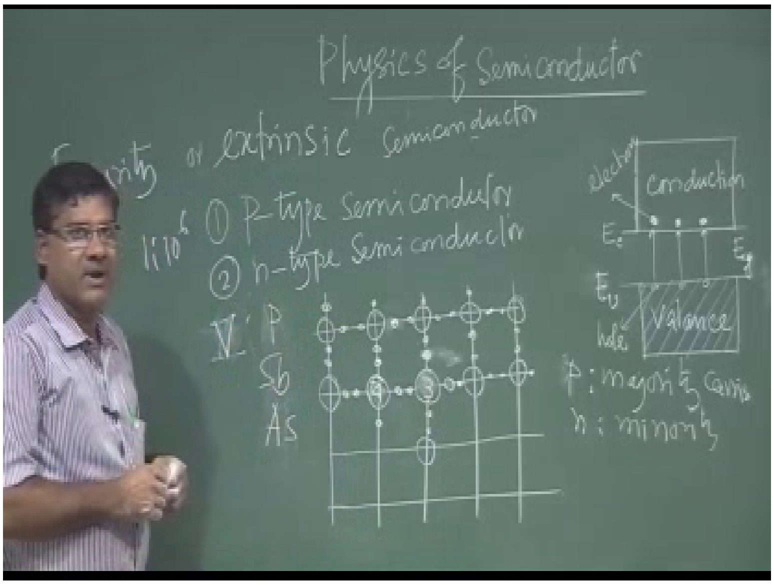

So, this impurity or extrinsic semiconductor in this case; so as if this carrier console controlling the carrier console is very important this semiconductor, I have a semiconductor say silicon semiconductor, it has band gap 1.16 electron volt and. So, it as intrinsic its depending on temperature and give some kind of concentration So, nothing else I can do, but there is a process it is called then you will be call that impurity or extrinsic semiconductor when, those intrinsic semiconductor are doped with some with some dopant with some atoms either which will give electrons to this semiconductor or it will give hole to the semiconductor. So, if you dope with some the impurity for some atom. So, that your intrinsic crystal intrinsic semiconductor crystal. So, it will have additional electrons or holes right.

When you will get additional electrons then we will get it is p type semiconductor p type semicondu p type semiconductor or when it will gain that after doping when it will gain this gain electron, then it will be called n type semiconductor right; so this either p type or n type. So, this is because of doping in the system and we will get we will get this more hole in this semiconductor or more electron in the semiconductor. So, that we can control when concentration of carrier will change in the system we can control the electrical property of this semiconductor right.

So, I think you in case of the si pick silicon, silicon have 14 electron right. So, it is distributor 1 is to 2, 2 is to 2 p 6 right 3 s 2, 3 p 2 right. So, these are field. So, these four are valence electron is for our valence electron. So, as per octet rule outside orbital always or sale always which each type you have the each electron. So, each silicon atom will have 4 valence electron. So, it will try to. So, it will try to share. So, they are just silicon the silicon atom silicon atom it will form a lattice; so how it is from lattice.

So, these are basically it is core of silicon having hole positive charge, having four positive charge right and then it will form bond it will form bond with other four silicon neighbor silicon. So, here also similarly we put this or basically positive four charge positive four charge. So, then it will again. So, these are they will share electron share electron. So, this way we will form coherent bond. So, they are sharing. So, this it has four electron and it is shared with other four electron other four electron right.

So, now, when you basically in case for intrinsic case intrinsic semiconductor when you increase this temperature it is at particular temperature, then basically you if this one of the electronic may leave this side leave this side. So, it come here then this is the absence of electron it is treated as a hole right. So, a fear of hole is generated. So, that is basically coming from this bond breaking this bond it is going and then is absence of that one. So, it will feel to have one electron to again make this bond to repair this procaine bond. So, that is why some other electron can jump here. So, this electron can jump here now it will be hole generated there.

So, as if this is the hole is moving this side. So, from here it is moving this side and electron are moving this side, electron are moving this side. So, hole and electron they are moving. So, they are this conducting in the system, anyway. So, what I want to mean here. So, now, if you talked with this this this silicon with some group 3 element what is the group three element I think aluminum is group 3 element, and then boron gallium indium right boron gallium indium; soaluminum, boron, gallium indium. So, these are group 3 elements, one of them if we pick up and doped with this. So, doping is very small I call it will face this issue is 1 is to 10 to the power 6 or 7 also ok.

So, here this out of 10 to the power 6 atom of silicon one will be replaced by this impurity one will be the replaced by this say group 3 element. So, now, it has three group three elements it has valence electron three it has valence electron 3. So, then this is the valence electron 3. So, its positive charge is three core one this core one is this positive charge is three and then. So, it will share this three it will share with the others these three we see electron, but one. So, this silicon will miss another electron. So, this this bond is not complete. So, all the time this silicon will try to have the one electron to complete this bond, but this is absence of this electron here. So, it will be act like a hole. So, there is the absence of electron here. So, is as if I say hole it is giving a hole to the system. So, it is the system now can take can accept electron right the system can accept electron yes.

So, this is the in this ratio I write it will one is to 10 to the power 6. So, in in the ratio if you doped say some amount of this one of them a group three element. So, you will get hole in the system you are generating hole in the system, depending concentration will depend on this. So, here now in this case you have intrinsic carrier all the time it will be there and they are equal now here additionally you are getting this hole in this system. So, hole concentration. So, this concentration is generally higher than the intrinsic concentration. So, this hole concentration here hole concentration here it will be higher in this system. So, it is that is why this in this system this carrier majority carrier is hole this hole is called majority carrier majority carrier and in what about the electrons are there these are called minority carrier minority carrier.

So, this type of semiconductor is called p type semiconductor, if you doped with this that is 5 group of element what is this for the phosphorus, phosphorus and then antimony antimony phosphorus antimony and then people use generally let me some others I have think yes phosphorus antimony arsenic yes because these are very whatever I am reading these are practical one. So, generally these are used frequently for this for getting this p type or n type semiconductor. So, this are penta pinta valent right earlier one of the tetravalent these are pentavalent. So, 5 valence electrons are there.

So, we need to put we went will put 5 electrons are there. So, its positive charge core on these five charge positive charge will be there and it will leave 5 electron. So, four electron will be taken by this this neighbors this four this silicon and one electron will be extra nobody is there to take it to form the bond. So, then the system will have this additional electron from the dopy.

So, now in this case this electron concentration will be higher and this hole concentration will be lower; so for n type. So, this n electron will be majority carrier and this hole will be minority carrier this hole will be minority carrier. So, now, in this band here these dopant whatever you are putting either this tetravalent or pentavalent. So, there they have energy level from where that they are giving the electron hence electron they are giving. So, that energy level of that one the donor, it just generally is below the conduction band below the conduction band, but close to the conduction band.

And this in case of silicon these differences this this is a very close it is in the range of 0.02 electron volt. So, these are called this is called donor level donor level this is for n type, this is for n type semiconductor this level this level can donate electron is donating electron to the silicon to the conduction band of the silicon. So, that says a donor it is very close to that one. So, it is donating. So, it is giving electron conduction electron for system.

And in case of this p type semiconductor; so tetravalent, it accept a level. So, this from there is a level there is a shortage of electron right shortage of electron three electrons are there because from for bonding we need for electron to satisfy the all silicon. So, one bond is top satisfied. So, as if, this is called acceptor level this is called acceptor level so that energy level from where these electrons are valence electron are coming from the tetravalent atom impurity. So, this it is close to this it is at the top of the management and also it is very close to the valence. So, this also energy is differences in this stage ok.

So, these are more or less this band structure of this band structures of this the structure of this that p type and n type semiconductor and this. So, we are doping the semiconductor intrinsic semiconductor because of temperature its concentration changes carrier concentration and in case of doping, because of doping type of doping the concentration of carrier changes either hole concentration on electing concentration. So, concentration is very important.

In next class basically we will try to calculate concentration of carriers in intrinsic semiconductor, p type semiconductor and n type semiconductor even this Fermi distribution.

Thank you for your attention. I will stop here.