Electronic Packaging and Manufacturing
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Lecture – 04
Semiconductors and Components – I

Welcome back everyone and we will continue with our course on Electronic Packaging and Manufacturing. Today what we were going to talk about is primarily semiconductors, their properties and as part of components we are going to look at one of the very simple electronic component which is known as a diode, ok. So, I believe all of you know what a diode is or would have studied at somewhere. So, we will just refresh that part and then that would provide a nice segue into our next section where we will talk about packages fabrication techniques and so on and so forth.

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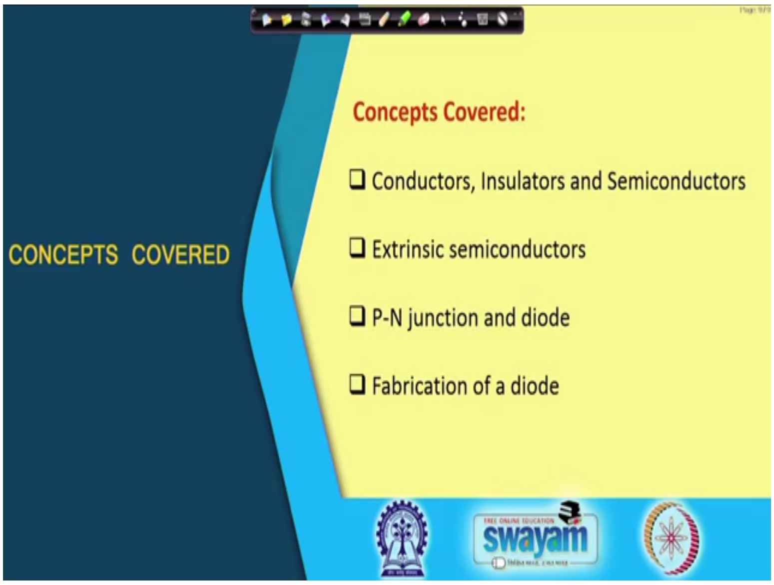

So, the concepts that will be covered today are primarily the very basic ones will start with conductors insulators and semiconductors and primary look at what are semiconductors and how are they different from conductors and insulators. We are then going to talk about what is called extrinsic semi conduction or eccentric semiconductors and then move on to P-N junction and diode and finally, as I said fabrication of a diode, ok. So, that would be primarily be the main topics under this module that we are going to discuss, ok.

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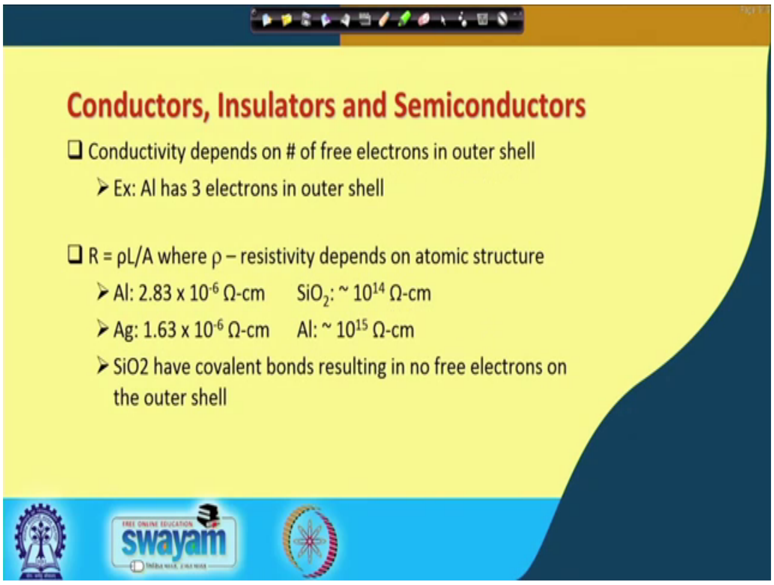

So, with that let us move on to the next one conductors insulators and semiconductors. So, how do you define what is the conductor, what is an insulator, what is the semiconductor. Again when we talk about conduction here we are talking about electrical conduction, ok. Can a material conduct electricity? So, that is what we are talking about electrical conduction or electric conduction, ok.

So, with that now if you say what is conduction, what how do I say that this metal or whatever this material is a conductor and something else is not a conductor, ok. So, for that we have to look at how is an electric current conducted, ok? Why does electricity get conducted? Electricity gets conducted because there is movement of electrons, ok. So, there is a movement of electrons from one point to another or in a certain direction and we said that the current flows in a direction opposite to the movement of electrons and that is how electrical conductivity or electrical conduction happens through movement of electrons.

So, if an electron has to move then we must have those electrons which are free to move, ok. So, in other words there must be free electrons typically in the outer shell of the atom of that element that we are talking about, ok. So, for example, we know that aluminium or copper these are very good conductors of electricity, right. Now, why are they good conductors of electricity, that is the question. So, in order to do that let us look at this one ok.

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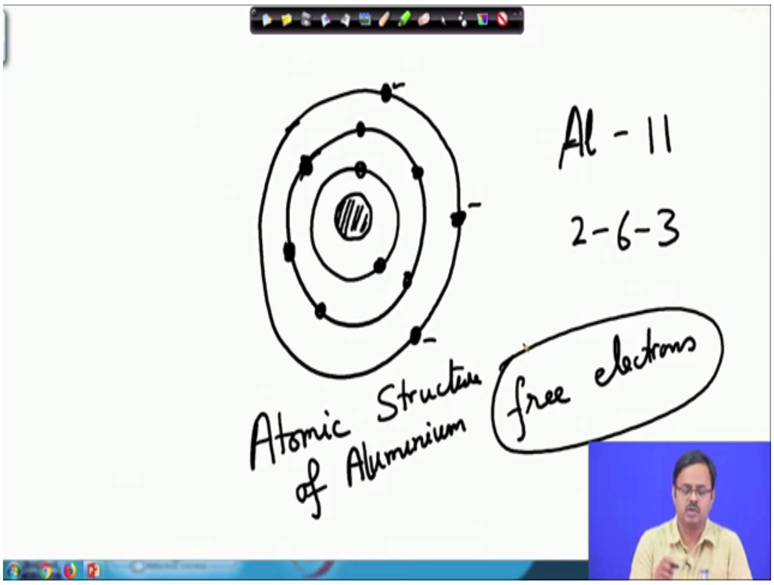

So, why are they good conductors of electricity? If we look at this and try to you know draw, ok. So, let us look at what is the you know how does an electro or how does an atom of a aluminium look like. So, let us say this is the nucleus, and outside the nucleus you have these shells containing electrons, ok. So, electro aluminium how many electrons does it have overall. So, aluminium overall is 11, ok. So, the first shell the inner shell will have two of those, let us draw that, ok. Then the next one which is also known as the first one is called k shell, the next one is also called the m shell oh sorry the l shell, ok. The l shell will have how many? 2, then it will have 6. So, let us draw those 6 electrons – 1, 2, 3, 4, 5 and 6. Now, 11 we still have 3 more electrons and those are in the m shell, ok. So, k – 2, l – 6 and m will have 3

Now, these 3 electrons that are there in the m shell, ok. These are free to move, right. So, these electrons these are free electrons. So, these electrons are free to move they are not you know tightly bound or held by the nucleus or they are not. So, these are the electrons that the free electrons and they help in conduction of electricity. So, this is atomic structure, let me write down here atomic structure of aluminium, and free electrons are the major ones that conduct or that contribute to the conduction of electricity, ok.

So, let us go back now to the desktop and look at this. So, what is now how do I know or how do I quantify what is a good conductor, what is a bad conductor and that is done by the property called resistivity. We know that the resistance of the electrical resistance of a wire that determines that how: what is the magnitude of the current that will flow through that wire or through that conductor for a certain unit voltage or for a certain given voltage, right that is ohms law V equal to I R. Now, what is that R? The R is electrical resistance, but electrical resistance is a property or is a function of a material property as well as a dimensions, ok. So, R is rho L over A as we can see here.

Now, what is rho? Rho is the material property which is known as the resistivity and that actually depends on the atomic structure, ok. Resistivity is the property that determines whether a material is a good conductor of electricity or a not so good conductor of electricity. So, if you take for example, aluminium, silver you can see the resistivity is are of the order of 10 to the power minus 6 ohm centimetres. So, these are low numbers. So, resistivity is low or in other words conductivity which is the reciprocal of resistivity is high and therefore, aluminium silver are good conductors of electricity we know that, ok.

On the other hand if we take silicon dioxide for example, silicon dioxide is an insulator we know that it is an insulator. So therefore, silicon dioxide if you look at the resistivity value it is of the order of 10 to the power 14 aluminium is 10 to the power minus 6 silicon dioxide is 10 to the power 14. So, 20 orders of magnitude higher, ok. So, that is what the last one this is a typo this is not aluminium, this is actually an insulated this is like an epoxy, ok. So, I will correct that. So, please note again here that this one this is wrong it is actually epoxy, ok. An epoxy which is an insulating material or an adhesive there typical electrical resistivities are of the order of 10 to the power 15 ohm centimetres, ok.

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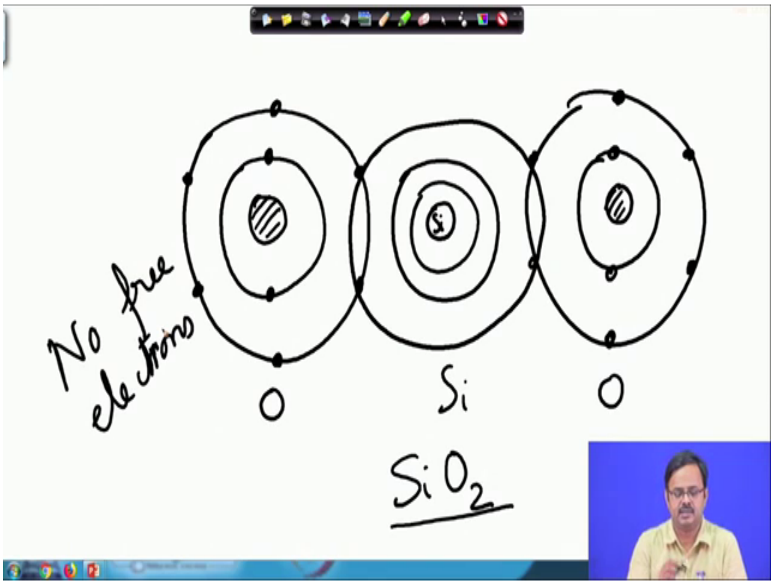

So, silicon dioxide if we look at it and again look at this silicon dioxide what does it have silicon dioxide has 6 electrons in the m shell, ok. But, what it does is it forms covalent bonds. If I take the first two shell and then the next one, it has 6 1 2 3 4 5 6 ok, sorry. So, this is sorry I am sorry I misspoke this is oxygen. So, this is oxygen and then this also is oxygen; so, with 6 electrons on the outer shell. What is silicon? Silicon has 4 electrons on the outer shell and then it has 2 plus 8.

So, therefore, if I write silicon it has two shells I am not writing all those and then it has this. So, what does it do therefore? It forms covalent bonds. This is O, this is silicon. It forms covalent bonds and that is how you have silicon dioxide, but what does it mean it means that there are no free electrons and therefore, silicon dioxide is not a good conductor of electricity.

So, with that now let us move on to the semiconductor.

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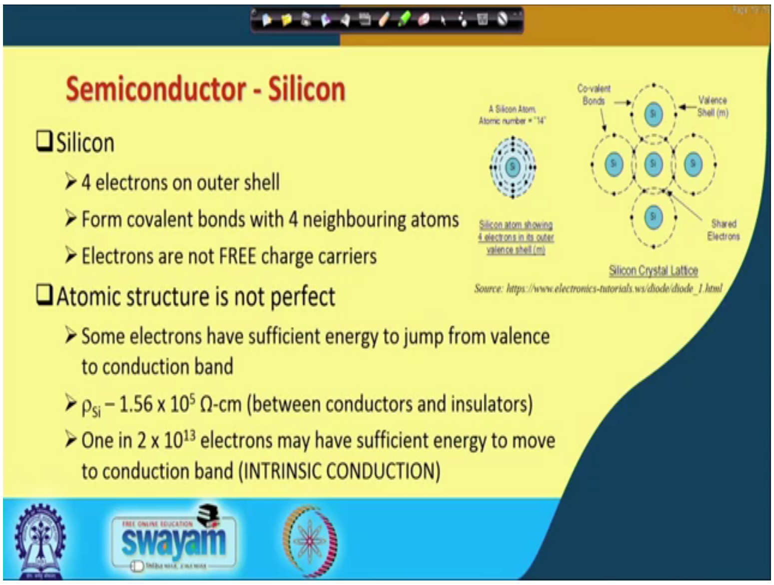

So, now we have know we know what is a conductor, what is an insulator. So, to recap conductor has free electrons on the outer shell and insulator does not have that. And therefore, when in the absence of free electrons we do not have the you know the charge carriers and therefore, p in the absence of free electrons we do not have good conduction of electricity, ok.

Now, what happens to silicon? Silicon, however, is very very interesting silicon if you see over here atomic number is 14. So, it has 4 electrons in its outer valence shell or the m shell, ok. Now, if that is the case then what happens here? What it does is silicon therefore, forms covalent bonds with 4 of its neighbouring atoms, where it shares electrons one electron each with one of this neighbouring atom and therefore, form a structure which I am showing here on the top right corner, ok. So, it forms four covalent bonds with four neighbouring atoms and therefore, the electrons are not free charge carriers, ok.

So, electrons are not free for carrying charge. So, the atomic structure is not perfect, ok. What do I mean by that? So, what it means is some electrons may be very few, but some electrons out of these may have sufficient energy levels to jump from what is called the valence band to the conduction band which means that it is no longer held tightly, but it has the energy to break free and become a free electron for conducting electricity, ok. So, the number is very few the number of such atoms is very few maybe one in 10 to the power 13 ok, that is the kind of these free electrons that I am going to talking that I am talking about. They may have sufficient potential or sufficient energy in terms of electron volts to move from the conduction band to the valence band and therefore, become available to conduct electricity, ok.

So, such presence of free electrons even though in minute details is what makes these semiconductors you know or what gives the semi conduction properties to these to these materials like silicon the other example is germanium, and then they are compounds like gallium nitride, gallium arsenide, gallium nitride so on these have what is called the semi conduction properties. They are neither conductors in terms of having a lot of free electrons nor are the insulators where there is no free electron at all. They have some number very small number very small concentration of these free electrons that can carry charge or that are that become charge carriers and therefore, can carry some electricity or some electric current, ok.

So, that is why the name semiconductor or semiconductor it is neither a conductor not an insulator somewhere in between. So, if you look at it what is the resistivity of silicon? Silicon resistivity is of the rough 10 to the power 5 ohm centimetre, ok. It is not like the 10 to the power 14 or 15 that we saw for insulators, but neither is it 10 to the power minus 6 that we saw for conductors like aluminium or silver, it is somewhere in between ok. So, that is the intrinsic conduction. Now, is that enough is that enough to have them or to brand them as conductors of electricity? Let us see.

So, as I said this is intrinsic conduction. These are already there intrinsically present inside these elements such as silicon and germanium which gives them some conduction properties. But, that is actually not enough, we have to do more.

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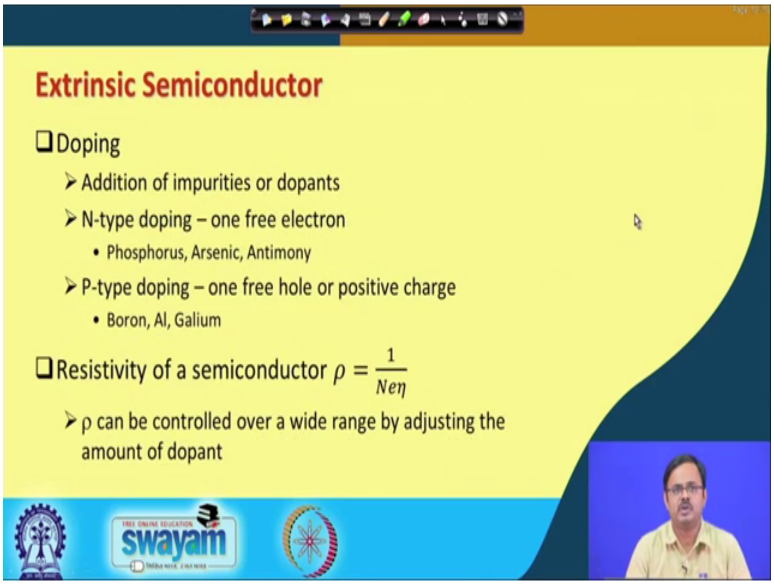

So, what can we do? So, that is where the eccentric semiconductor extrinsic semiconductors become important. How do I do that? Now, this is done by a method called doping. So, what this means is the semiconductors like silicon or germanium by themselves do not have very high conductivity a very low resistivity. But, if you can add in controlled amounts certain concentration of impurities we can we can impart better conduction properties to these semiconductors, ok. So, these impurities what are those will see that these are also called dopants and the whole process of adding intentionally adding or introducing these impurities into the pure metal material is known as doping, ok.

So, we have doped silicon where the silicon has minute traces of some other elements. So, what are those other elements is the next question, ok. So, some of those other elements if you look at the old periodic table which is what I learned when I was in the in school we used to call it group 3 and group 5 elements, ok. Those elements are like phosphorus group 3 phosphorus, arsenic, antimony, ok. So, these sorry these are group 5 elements, I am sorry group 5 elements phosphorus, arsenic, antimony. These are N-type doping, ok.

N-type dopants what do they have? They have one free electron on the outer shell which now becomes available for conducting electricity, ok. It is N why, because electrons we know and negative charge carriers negatively charged entities and therefore, that is where the N type dopant or n type doping the name comes from. So, it is an N type semiconductor we say. What is an N type semiconductor? It is a doped semiconductor which in which has been doped rather by elements which have free electrons, ok.

So, similarly we can also dope the silicon with group 3 elements where you have one free hole or positive charge, clear? So, because these are typically P-type dopants, these elements like boron, aluminium, gallium these have three electrons on the outer shell and whereas, silicon has four. So, 3 plus 4 becomes 7. So, there is still the place for one electron or this one electron which is short from the stable structure. So, that is a fun free hole or positive charge which can accept another electron, compare that to n type group 5 elements 5 electrons on the outer shell combine that with 4 so that makes it 9. So, 8 of them are in the outer shell and then there is one that is free, there is a free charge carrier.

So, this is how the doping or eccentric semi. So, when you dope it is now called an extrinsic semiconductor. So, the semi conduction properties are no longer intrinsic to the material itself, but you have done some you have you have to added something extra from external sources from outside and hence it is extrinsic semi conduction.

Now, the resistivity of a semiconductor especially, when we talk about doping and all that rho the resistivity is given by this expression 1 over N e eta, ok. Now, what is N? N is the number of charge carriers that is present per unit volume. So, therefore, what does it mean? The concentration of dopants in that silicon is going to determine what is N, what is the concentration of these free charge carriers whether it is electrons or whether it is holes or electron holes that are present. So, therefore, what I am trying to say is by adjusting the amount or concentration of dopants one can play around with the electrical resistivity of a semiconductor.

Then what is e? e is the charge on the charge carrier whether it is an electron whether it is an well or whether it is a hole. So, N times e; so, number times the charge per carrier that gives it that is that is the total charge that it can carry and what is eta? Eta is the mobility is called the mobility of the charge carrier. Now, what does it mean? Mobility of the charge carrier as a name suggests it means that how freely can the charge carrier move, ok.

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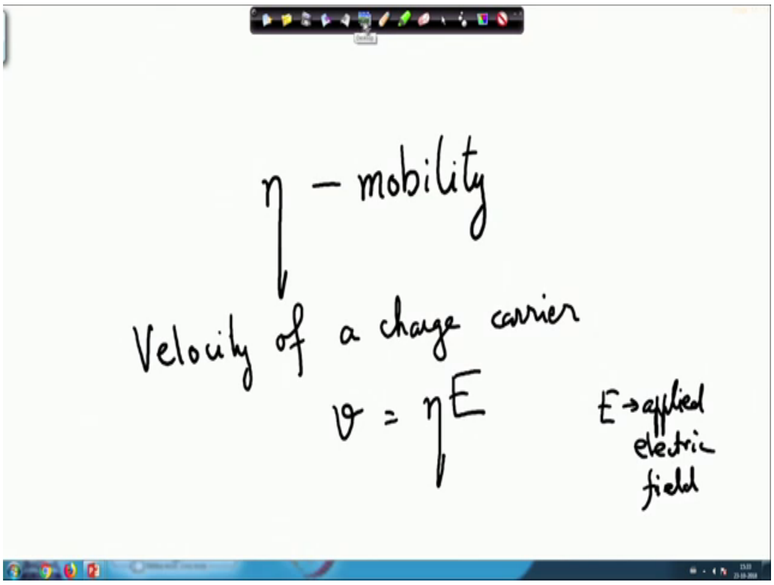

So, the mobility the way it is defined is if this go here, the mobility eta I can write that the we can also say what is the velocity of a charge carrier? So, the velocity of the charge carrier, if I write it as v that is given as eta times E; where e is the applied electric field, ok. So, what does it mean? It means that if the mobility of the charge carrier is high is velocity is also going to be high therefore, it is going to carry more charge E again is the applied electric field.

So, it is not just mobility the velocity will also depend on how much what is the electric field that is applied to the on or applied on the charge carrier, but then as you can see that the mobility plays a role. So, if I go back to the expression the resistivity is now 1 over N e eta, ok. So, it is evident that if you have more number of charge carriers your resistivity is going to be lower. So, that is why 1 over N or conductivity electrical conductivity is going to be higher and more is the mobility of the charge carrier the resistivity is going to be lower.

So, if you think about for example, we talked about N-type doping and P-type doping. In N-type, what is the charge carrier? It is an electron. In P-type, what is the charge carrier? It is an electron hole, ok. Now, the electron can travel much faster than a hole, ok, almost three times faster, ok. So, therefore, what it means is the mobility of an electron is higher than that of an electron hole, right. Therefore, for the same number or same concentration of dopants it means that the resistivity of an N-type doped semiconductor is going to be lower than that of a P-type semiconductor. Why because the mobility of an electron is higher than that of a hole, ok.

Now, why is that you may ask why is that why is that is it that the hole is it is mobility is not as high as that of an electron. To do that let us look at let us draw something and try to see that how is it that the charge is carried or the or the or the current is carried by a hole, ok.

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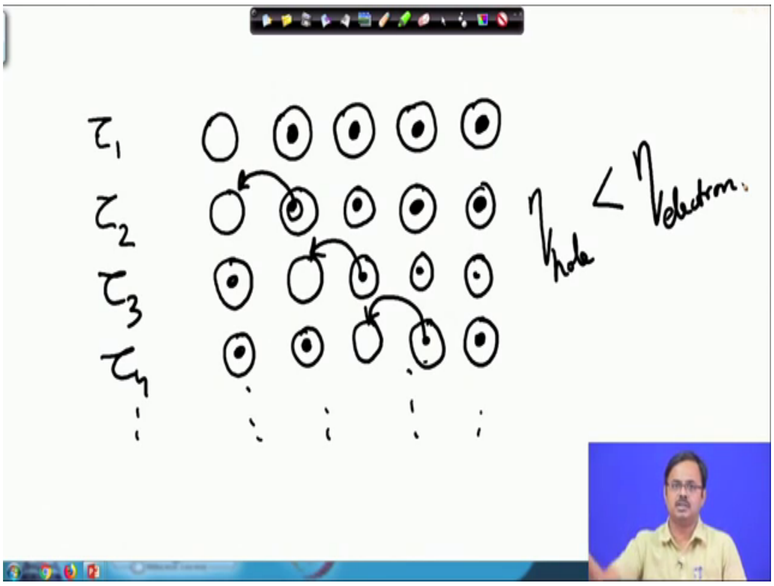

So, let us draw some of this. Let us draw these 5 electrons or 5. So, this is at a certain time instant let us say tau, tau 1 at a certain time instant this is where it is, ok. So, this is an atom with a hole. So, it can accept an electron this one and these already have electrons full. So, what happens is at time 2, if I again draw this guy is going to jump over here, ok. These three are going to stay at time 3 what happens therefore, is this is fill this is empty, but then this tries to jump over here time 4 this is full this is full the third one is empty because it has lost this one and the fourth an electron from the fourth atom will try to go into and fill it this void and this is how the motion continues.

So, therefore, this is the mechanism by which. So, what have we seen now? We have seen how the hole has propagated from here from the first atom to the fourth atom. So, this is the mechanism how a hole is propagate or current is carried by the movement of holes. So, hole by the way is just a concept there is nothing like that it is again electron movement in the reverse direction, ok. But, this is how a hole is propagating. So, this therefore, the mobility eta of a hole is much lesser than eta of an electron. Why because this is due to the mechanism of movement of the holes, but as an electron just can jump from one place to another one atom to another, ok.

So, that is the reason why the resistivity of an N-type semiconductor is much lower or is lower I would not say much lower it is lower compared to a P-type semiconductor.

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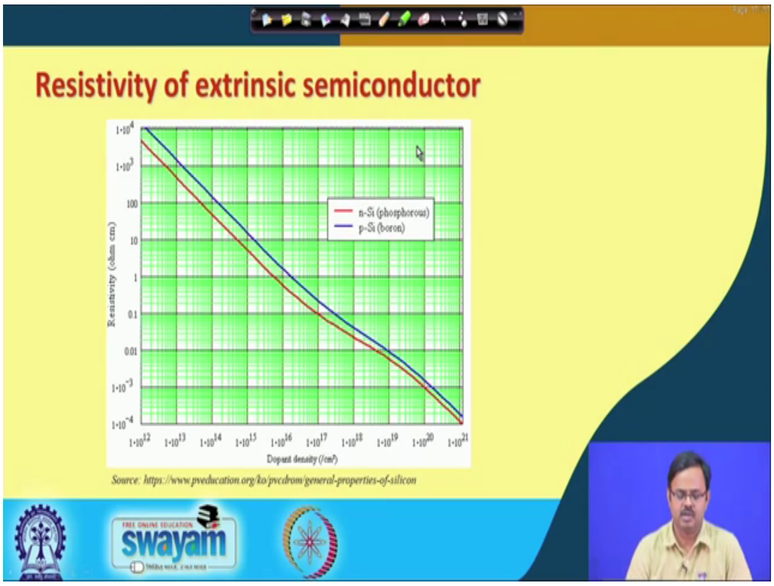

So, if you see that this is a plot that I have from a certain source and which is mentioned over here and what you see is on the x-axis is the dopant density. So, it is the number of atoms per cc or per unit volume and on the y-axis we have the resistivity in ohm centimetres, ok. So, it is silicon again the redline is an N-typed doped silicon where the dopant is phosphorus and the blue line is a P-type doped silicon where the dopant is boron and as you can see that the resistivity of boron.

Or the N-type semiconductor which is phosphorus sorry, of the phosphorous doped semiconductor or the N-type semiconductor is lower compared to that of the P-type doped semiconductor which has been doped by boron, ok. And, why is this because the free charge carrier for an n type semiconductor is electron whereas, the free charge carrier for a p type semiconductor is hole and the mobility of an electron as we just saw before is higher for an electron compared to a hole and therefore, the resistivity is lower, clear?

So, therefore, if I just now wrap up what we just discussed is the fact that we talked about conductors, insulators and semiconductors. Conductors have lot of free electrons and their resistivity electrical resistivity is lower and these electrons help in conduction of electric current. Insulators, on the other hand are very stable structures no free electrons on the outer shells and therefore, no free charge carriers and therefore, are not good conductors of electricity their electrical resistivity is therefore, are very high.

Semiconductors, on the other hand are a special type silicon germanium these are special type of elements which have you know four free electrons on the outer orbital and the form covalent bonds with four neighbouring atoms. So, as a result there are no free electrons per se, but then what happens is there is an intrinsic conduction where one in 10 to the power 13 electrons may jump across may have sufficient energy to jump across to the conduction band from the valence band. And therefore, become available for conduction of electricity.

So, that is intrinsic semi conduction and as a result of that semiconductors resistivity lies somewhere between the common conductors that we know of and insulators. But, what is the beauty about semiconductors and why it is so popular in our electronic components is that reason is the fact that this electrical conductivity can be artificially tailored by addition of certain impurities. And, depending on the number of electrons on the outer shell of those impurity atoms it can be an N-type semiconductor N-type doped semiconductor as we call it where you have free electrons or a P-type doped semiconductors where you have hole or electron acceptors, ok.

And, therefore, the resistivity of such a doped semiconductor can be controlled by controlling the concentration of these dopant atoms that is added intentionally to the silicon, ok. So, the resistivity can be lowered, they can be made better conductors of electricity and that is known as eccentric extrinsic semiconductor. It is no longer an intrinsic property of the material you have done you have added some additional external factors into the material and thereby increased it is electrical conduction properties, ok.

And, then we talked about how the electric and we saw that relation by which it is clear that by you know by controlling the amount of or concentration of the dopants the electrical resistivity of a dope semiconductor can be artificially changed or artificially controlled, ok.

So, with that what we will do is we will stop this lecture at this point and when we come back in the next one we are going to talk more about how what can we do with these dope semiconductors to form what is known as the semiconductor devices, ok.

Thank you, very much and see you in the next lecture.