

Electronics
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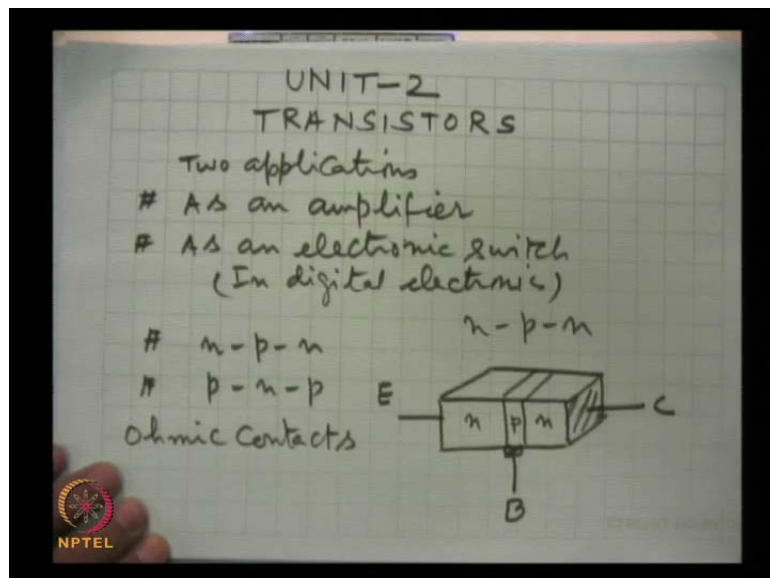
Module No. # 02

Transistors

Lecture No. # 01

Transistors

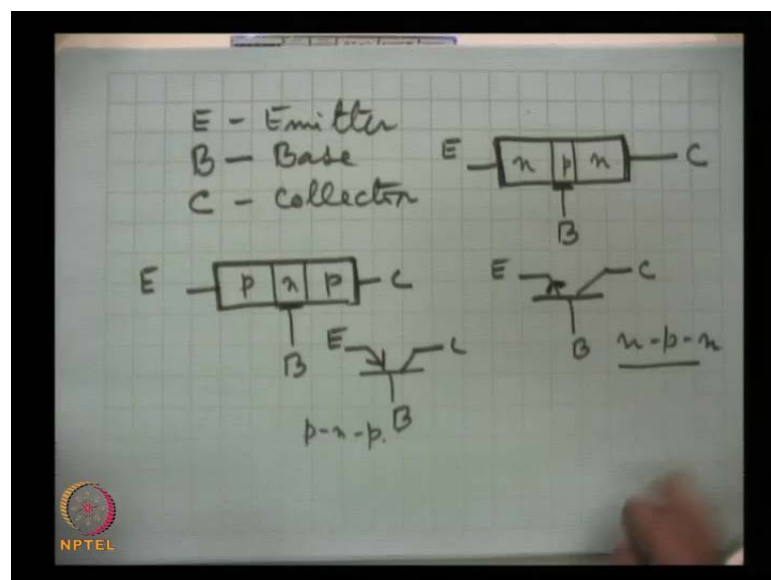
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The next unit is on transistors. We will see during our discussion that it has major two applications; the first one is as an amplifier and the second major use for transistor is as an electronic switch. Basically, a transistor is used in digital electronics. So, basically we will be concerned with the use of transistor as an amplifier. And of course we will specify the condition, under which it can act as a switch. But we will not go in details of switching behavior of transistor. Now, transistors are of two types; one is n-p-n transistor and the other is p-n-p transistor. These are the two types and you must know that the diode was a two terminal device, and two terminal devices cannot act as an amplifier. There should be, at least three terminals in fact, there are three terminals in transistor and the input signal is given which is amplifier. Amplification, we may consider the voltage amplification or current amplification.

But it will be good enough if we talk, mostly in terms of voltage amplification. Now, let us see first these two transistor, n p n and p n p. A n p n transistor can be shown for example like this, this is the three dimension figure for a transistor. We are talking of n p n, so this is n type semiconductor this is p type semi conductor and again n type semi conductor, there are ohmic conducts, and we mean that, the conducts are of two types, ohmic contacts and rectifying contacts. Ohmic contacts are the one in which, if we change the direction of the battery and the behavior remains the same, unchanged behavior for change polarity that is ohmic contacts. So, these are ohmic contacts, one here and the other here, on this surface, this is called emitter, this is collector, and this is base.

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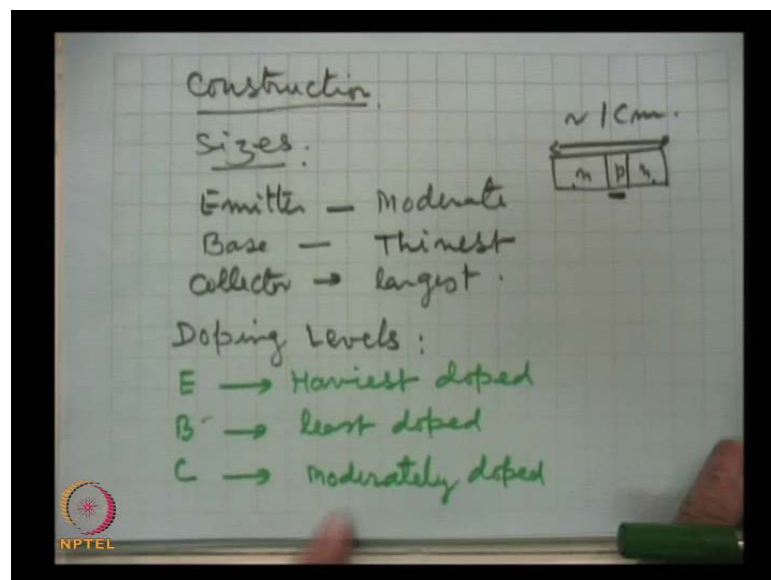


So, remember E stands for emitter, B for base and C for collector, instead of, drawing, three dimension figures, two make life simpler, we will normally, draw two dimensional figure. So, for a n p n transistor, these are ohmic contacts this is n p n this is collector this is emitter and this is base. And, in p n p transistor the structure will be like this p n p, p type emitter n type base and p type collector and again these are the ohmic contacts this is emitter this is base and this is collector. The circuit symbol for n p n transistor is, E that is emitter, collector and base. And, as we will see later, that this direction of the arrow is the direction of the emitter current in the transistor.

So remember, the arrow is pointing out wards in n p n transistor and for p n p transistor the arrow is in the reverse direction. So, this is the n p n transistors and this is p n p transistor,

now for general purpose, both the functions are equally good but, n p n at one point is superior to the p n p transistors, Let us, consider the silicon transistors for example, in n p n transistor, we will go through the working of a transistors, we will see, that the electrons are the major players in the transistor action. So, electrons are having higher mobility, n p n transistor will work up to a higher frequency as compare to p n p transistor. In p n p the major contribution will come from holes, while here, they are from electrons being of higher mobility, so n p n transistors can function up to higher frequency of operation. So, when we talk on physics of the transistor, we can talk, in terms of p n p or in terms of n p n but, one in the same thing here, in n p n when we talk the role of electrons that is to be replaced by the role of holes, when we talk of the p n p transistor, so remember, that we will confine our discussion, mostly to n p n transistors.

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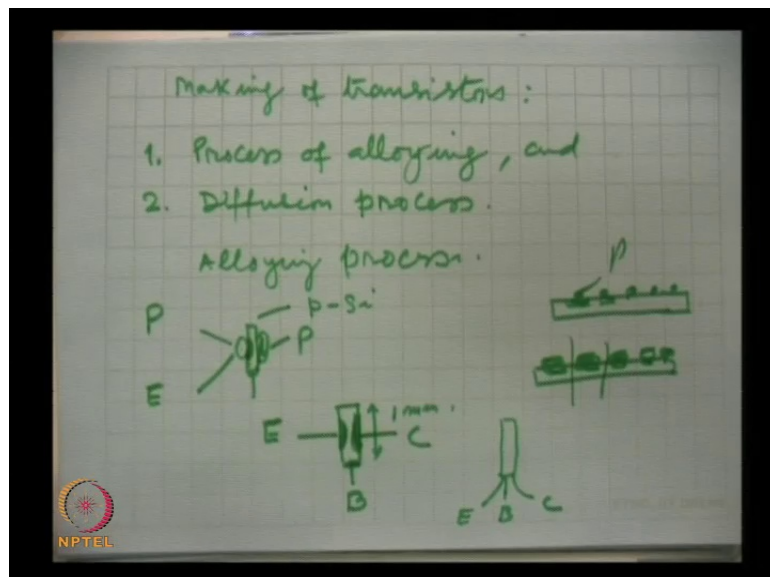


And, now let us see, first some construction aspects, let us talk of sizes first, the emitter, it is of moderate size, that is emitter has dimension between the dimension of collector and base, and the base is thinnest and the collector, as for us when we compare, the three size in the transistor, the size of emitter, base, collector, the collector has the largest size and to give you the actual dimension when we talk of n p n transistor, then in discrete device, the total length may be around a centimeter, this is of discrete transistor. And in integrated circuit, this all are on a chip, the sizes are reduced dramatically, the size may be smaller than millimeter. So, any way, for us this is good enough, that the size is around one centimeter, now the base is thinnest, this is moderate and the collector is largest why these

sizes are like that? That will become clear, as we proceed to understand the working of the transistors.

Now, let us talk about the doping levels, in the three regions. Emitter is heaviest doped, base least doped and collector is moderately doped, so remember in all transistor, emitter will have the heaviest doping and the base, the least doping and the collector has moderate doping, again this will become clear, why we need thin base least which is least doped, moderately sized in heaviest doping for emitter and collector is a largest in size but, it is moderately doped. How actually the transistors are manufactured?

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So, in making of transistors, there are two processes, which are widely used, the one is process of alloying and the other is the diffusion process. The earlier transistors, I'm talking of 50s and 60s the process of alloying was very popular but, it has been taken over by diffusion process, which is very widely used and one of the, mostly used process for making integrated circuits. In the integrated circuit, there is two or three different process, one is diffusion process and other is ion implantation and growth of the different layers.

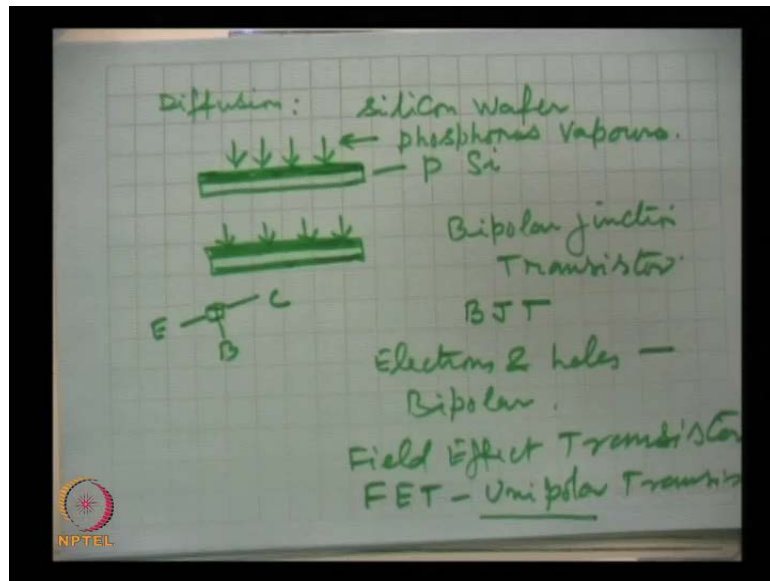
So, they are reserved for integrated circuit fabrication but, discrete device can be fabricated by process of alloying and diffusion process. Let us, first talk what is this, process of alloying, we will take a small crystal, of p type silicon and on one side, we will put a small dot of a pentavalent impurity, this is like phosphorus pentavalent impurity, and

now let take this, in this position, actually this is the large crystal and the thickness is very little, all most a millimeter but, the size can be two inches, four inches and this pallets in the form of a small dots, are put on one side of it and then the hole arrangement is put in a furnish, which is very well controlled in its profile and in its temperature.

So, this phosphorus, impurity will diffuse and will make here n type, so this will make n type region here, so this will behave finally, emitter and when we reverse the side, then we put bigger pallets of phosphorus and again when we heat it, it will diffuse and another n type semi conductors will be developed. And this, we will actually, cut ultrasonically, so from a two inch dia wafer of silicon, after this two treatment of a alloying process, we can save a few 100 transistors, a very small transistor. And, we will make the ohmic contacts, this will be the base so finally, what we have is, this is emitter, this is collector and the original one was, we will put a contacts here, this will act as base, this will be collector and this will be emitter and as I said, that these dimensions will be all most, the order of centimeter.

When you see it, from outside, the actual size of the crystal will be the fraction of a millimeter, just one millimeter in a cross section and less than a millimeter in thinness but, when it is put in a plastic or metal casing, this is what we see, the transistor when we handle it discretely and so, the size of that cane, in which they are contained is of the order of the centimeter, while the actual elements has dimension of the order, of hardly 1 millimeter. So, this is the process of alloying and these are encapsulated and finally, what we get is the metal can with three lids, one is emitter, base and collector.

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The other process is diffusion, in this again the starting point, is a silicon wafer which is having dia which may varying from 2 inches 3 inches 4 inches and even 6 inches therefore, wafers are wide used and that if we want to make n p n transistor, then this will be p type silicon, then this is put in a furnace, the temperature is raised above 500 degree but, much less than the melting point of the silicon and then this is exposed to pentavalent wafers, so this may be for example, vapors, so diffusion of this phosphorus will occur and this will make a n type silicon here, then it is reversed and we can change, because if this is emitter, then here, the doping density requirement is high.

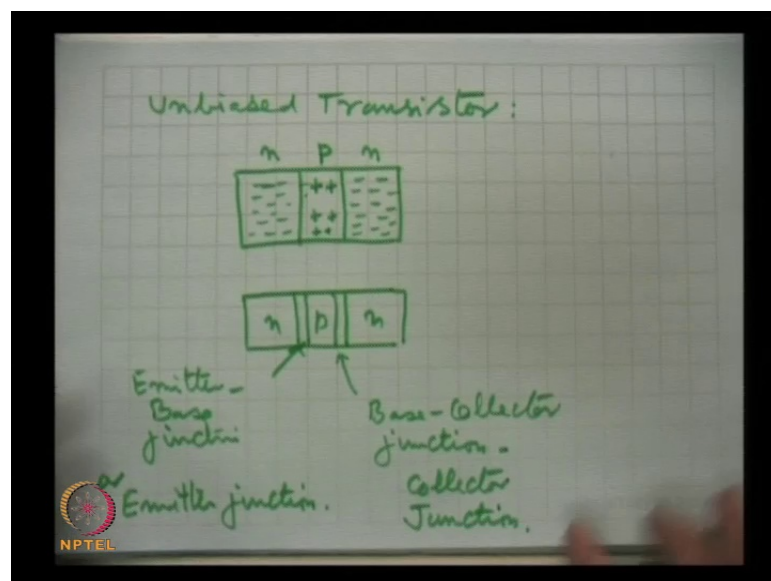
So, this will be having much high density of phosphorus and then when we reverse it, we can choose actually the concentration of the phosphorus in the vapor pressure, there are several controlling parameter, so when we reverse it, this already contains the n type semiconductor here, then we again exposed to a pentavalent impurity of different vapor pressure partly the content, so n type semiconductors will be created here, we started with the p type semiconductors, both sides now have n type but, they differ in their doping levels, in ultrasonically we can cut, each one will be small chip like this on which electrical contacts can be made and then this can be a transistor, this will be base, collector and emitter. This is much more popular, now-a-days to make device. So, this is the fabrication of transistor.

Let me make few more points clear, that this transistor is a Bipolar Junction Transistor or in brief very popularly, it is called as B J T. What is the meaning of bipolar? Off course, this is a junction transistor, there are two junctions, one is emitter base junction and other is the collector base junction. But, why it is called bipolar? This is called as bipolar because for the working of this transistor, we will see electrons and holes both are required for this operation.

So, because of the requirement of electrons and holes this is called Bipolar Transistor. In contrast to this, field effect transistor, which is popularly called as F E T, this is Unipolar Transistors. For the operation of F E T, either electrons are required or holes are required but, not both simultaneously and that is why, it is called as Unipolar Transistor.

So, this is the brief introduction to the transistors. Now, let us see what happens when a small region, what we called base is having on both sides, a n type regions.

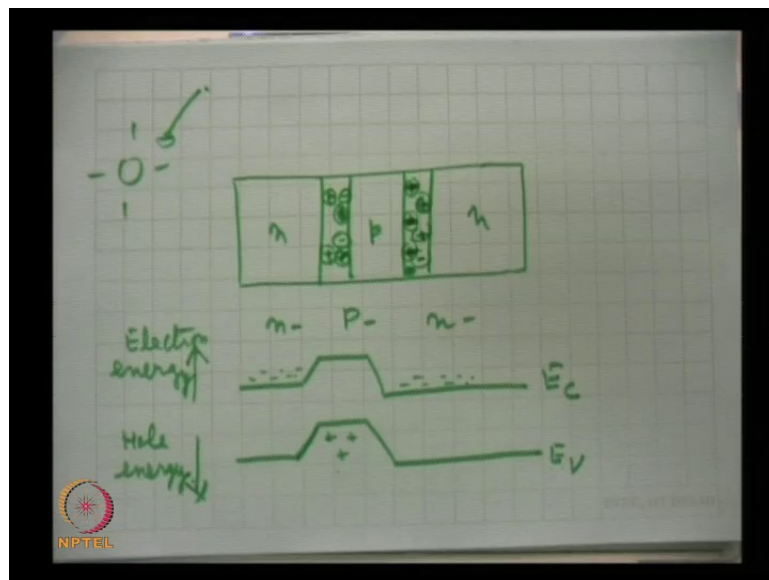
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So, first this is a Unbiased Transistor, by saying it as unbiased, we mean that, there is no external voltage applied to the device yet. So, let us see, what happens here, this is n emitter and this is p base and this is n collector. Here, there are majority electrons, here also majority electrons and in p type material, this is base and there are holes, very heavily doped, that means very high density of the electrons here, and this is very lightly doped, so there are few holes here and this is moderately doped and this is n type collector.

Now, we have discussed that, when n and p semi conductors, meet at any junction and if there is a stature continuity, then the diffusion process of the electrons and of holes will occur here and a junction will be formed, as we disused in the case of diode, so a junction is formed here and that junction is called Emitter Based Junction and popularly it is enough to write as Emitter junction. Similarly, the diffusion of the electrons will start from collector to base and a few holes will diffuse from base to collector and again for the same reason as we discussed earlier, the junction will be formed here. So, this is what we call as Base Collector Junction. Base Collector Junction are simply called as collector junction and now let me draw another diagram to illustrate that Emitter junction and Collector junction, are the space charge regions.

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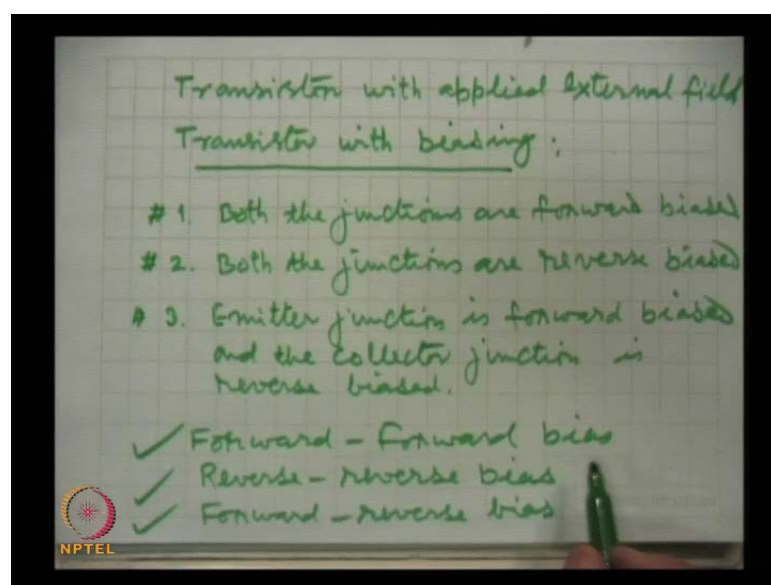


So, these are the bound charges, what is this? Because from this region the mobile charges electrons and holes have disappear, leaving behind the exposed space charge, earlier the electrons and holes were here, you remember the pentavalent impurity phosphorus now we have 5 electrons, 4 will make the covalent bonding with the silicon and the fifth electrons which is loosely bound it disappears, so on this side, it will be a positive ion and here on the piece side there will be a negative bound charge. So, this is the space charge region and high resistivity region, when we applied a voltage between emitter and base, then that voltage will give raised to field across this junction and similarly, here electrons and holes have disappeared leaving behind a singly ionize impurity atoms here, they are immobile, they takes the latest position, and they do not move but, there are ions, so there is a charge

associated with the negative ions on the p side, the positive ions on the n side and this is the electro static charge, which gives rise to conduct potential, which in the two cases, may not exactly be same, because the doping of this region and this region are different. So, a potential energy diagram for the transistor can be drawn and if we just see, this was the potential energy diagram, for this was p type in the case of diode, we discussed that, this is n and this is also n and here this is conduction band edge, this is valence band edge and this is Emitter, this is Base and this is Collector and here, there are electrons, here also electrons and here these are holes, these is the electron energy which goes in this direction, while hole energy goes in the opposite direction, this also we have discussed earlier this is the hole energy.

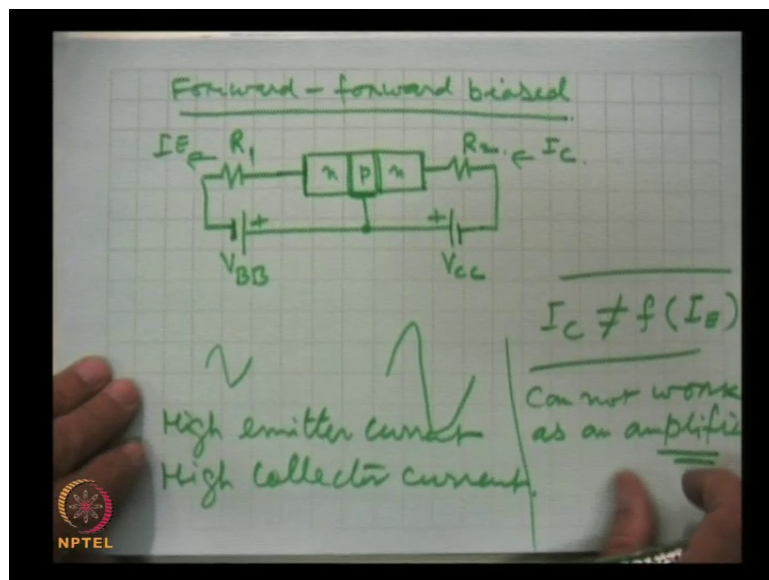
So, once the junction has been formed, these charges from inside, though they have higher population, so there is a density gradient but, they will be unable to cross over to the base region or to the collector region, because of this varies height, the contacts potential. Similarly, these holes, cannot flow towards the emitter or towards the collector, because this is not the downhill, this is also the uphill for the holes, here we have higher energy and they do not have this much energy, so they will also be unable to move, either towards n or p, so this is the picture of n p n transistor, in equilibrium. When, there is no external field applied to it and this is how the junction remains formed. Now, what will happen when we bias the transistors?

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So, transistors with applied external field, that means transistors with biasing, in the case of a p n diode, there was only one junction and there were two possibility to bias it, that junction could be either forward biased or reverse biased. Now, transistors has two junctions, one is the Emitter base junction which we are calling is emitter junction and other is base collector junction and we are calling that as collector junction, so there are more than two possibility, three schemes of biasing proof, very use full for the transistor, the one is when both the junction are forward biased, the other scheme is when both the junction are reverse biased and the third is scheme is the emitter junction is forward biased and the collector junction is reverse biased. These are the three schemes which we will be discussing now, when both the junction are forward biased this is also called Forward-Forward biased, then both the junctions are reverse biased this is also called reverse-reverse biased and the third scheme is when emitter junction is forward biased and the collector junction is reverse biased this is called Forward-reverse biased. So, these are the three schemes, which we are going to extended. First we will take, forward-forward biased,

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And simple circuit, we can draw, these are ohmic contacts, for the time being let us forget, about this part, so we just consider the emitter and base junction which is forward biased, now before discussing this forward-forward biased, let me say that, we are discussing basically, the application of transistors in an amplifier circuits, now what is amplification?

And what is required for getting amplification? For example, we will talk of voltage amplification, then normally our input signals are ac and we are interested in their amplification, so their output should be amplifier that means the magnitude should go up without changing shape and without changing the frequency, this is the meaning of amplification. If we talk of voltage amplification, that is voltage wave and if we talk of current amplification, this is the current wave. Now, when this will be possible, when the output current or output voltage, varies in accordance with the input current and voltage, I repeat the amplification is possible, when output current or voltage varies in

accordance with the input voltage or input current, if the currents are not varying, if they are independent we cannot expect amplification or if they are not varying linearly, they have some other relationship, then the output wave shape will be different from the input wave shape, so that will implies distortion and that distortion may be in terms of amplitude distortion, phase distortion or frequency distortion. We want true representation, of the input signal in the output then only the magnitude of the quantity of interest should be higher nothing else. In this case of forward-forward biased, for the time being we forget about the collector circuit, when we talk about the emitter.

The emitter junction is forward biased this n type semi conductor is connected to the negative of the battery. What will happen, that this will reduce the barrier height? We have discussed, now here, we can bring out our knowledge of p n junction, that when a p n junction is forward biased, a heavy current flow which varies exponentially with the applied voltage and the current will be arising because of the electron diffusion towards the base and because they are in a heavy density of electron, this component will be much higher, to that will be added a small components, which will arise because of the diffusion of holes, so this will constitute heavy current.

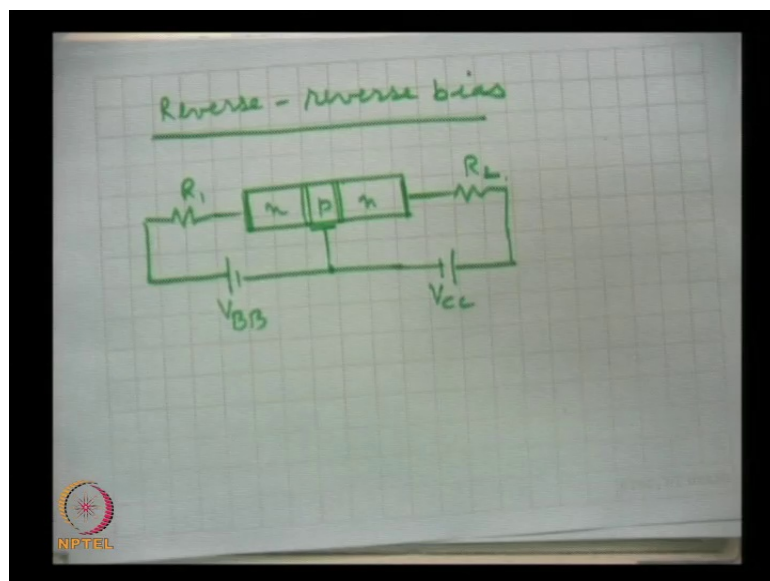
So, we will observe a heavy current I_E . Similarly, we will talk about the collector junction, the collector base junction, which is also forward biased, this n type collector is connected to negative of the battery, so this junction also is forward biased, here also heavy current will flow, then the influence of this is secondary a very little and that, we will see later, when we talk of current voltage characteristics of the transistor. So, heavy current will flow, so this will be heavy I_C . So, what we get in this forward-forward biased, is high emitter current and high collector current, the two current will be very high but, one thing which is very significant and important, when we talk of amplification, if

we made the current 0, for example, this is unbiased at the movement, then this current is still remains, almost the same. So, I_E will not dependent on I_C . Similarly, if we consider the collector junction, the current I_C , will continue to flow as long as this junction is forward biased and if we disconnect this or if we vary this voltage will it affect the collector current, in this situation no because they are almost behaving independently.

So, the output current will not dependent on the input, this is in violation of what we discussed about amplification. How amplification will occur? we are creating a signal here and this should be amplified, which is possible only when the output voltage or current varies, in accordance with the input signal, that will not happen, so, in spite of the fact that, high emitting current and high collector current flows in this, circuit of emitter junction, forward biased collector junction but, the two currents are almost, this is important, almost independent.

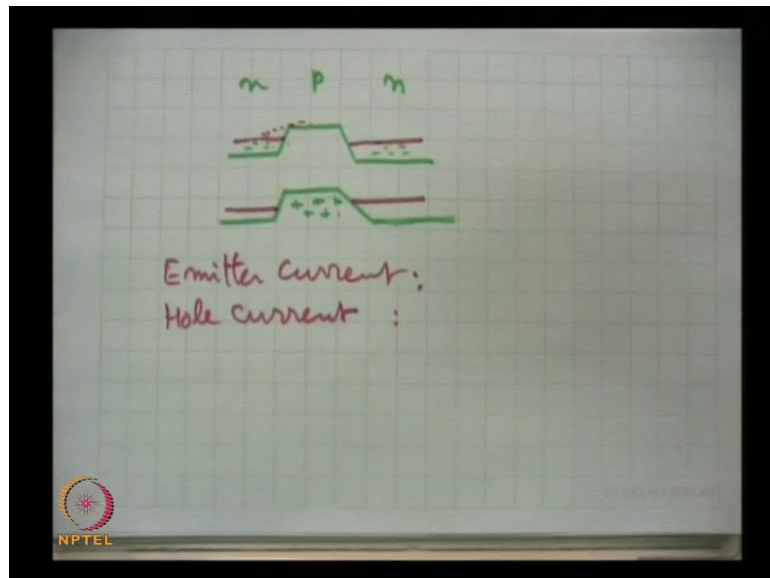
So, I_C does not dependent, is not the junction of the input current I_E , this is very important for this case. Since, the collector current is not the function of the input current, this arrangement cannot work as a amplifier but, we will see that in switching state, this situation will be representing, one of the states of the switch. So, as for as, the applications in amplifier are constant then this biasing scheme does not work.

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Next we consider the reverse-reverse bias, here in fact this point in forward-forward biased, we could have discussed by the potential energy diagram also, so let us first take that, and then I will take reverse-reverse biased.

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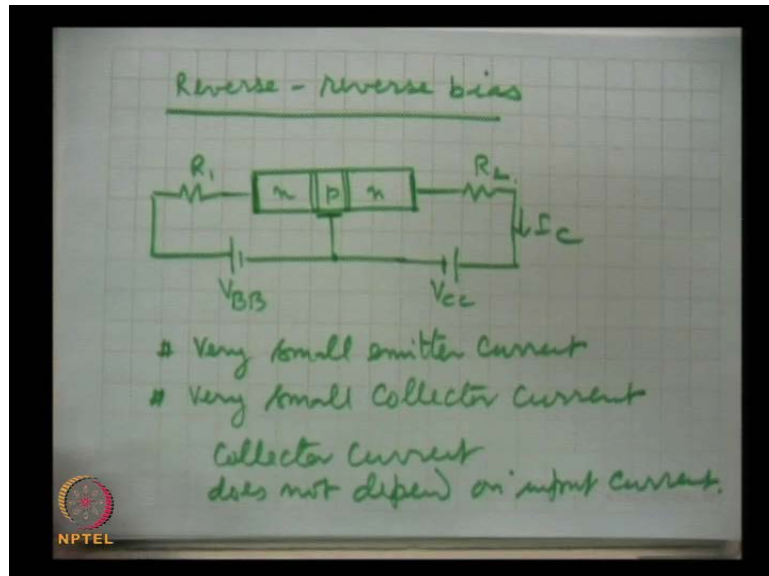


This was a unbiased potential energy diagram, now we have applied forward biased on both sides, so forward biased create, the field opposite to the building field, this point we discussed, in the case of the junction diode and the potential height will fall, this red ones are the new position, this is the reduced potential here, this is reduced and hence this electrons from the n side will constitute which we call the Emitter Current.

And similarly, a small number of holes, will also diffused toward the emitter, so that will be the part of the emitter current, they will also diffused towards the collector but, the major contribution of the collector current, will be from the electrons. So, that will constitute the hole current. But, the fact is, the two current are independent that makes the use of this biasing scheme not suitable, when we are going to use transistor as an amplifier. Then, we take reverse-reverse biased here, the emitter junction is reverse biased, the collector junction is a reverse biased and we understand from our knowledge of p n junction, when it is reverse biased then very few able current, at least three or four order of magnitude is smaller, than the current which we observed, when the junction is forward biased. So, such minute currents, arising because of the thermally generated charge

carriers, in the junction and near the junction, they constitute, what is known as reverse saturation current.

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So, what we will get here, is very small emitter current, which will be because of the thermally generated charge carrier, minority carriers, that means, holes inside an electrons, which are in minority on the p side, they both will drift with the applied field, this is positive, so the electrons will be dragged towards this electron and this electrons will be dragged to this, and they will constitute the current. So, that is why, very small emitter current. Similarly, let us see what happens at the collector junction? At the collector junction again, this is the reverse biased junction, so there will be very small collector current, which will be arising, because of the minority holes drifting from the collector base and minority electrons drifting from the base towards the collector. So, that will constitute collector current.

Here, also the situation is that collector current, I_C will not be dependent on the input current; that two currents are independent, if we switch off this current; still this current will continue to flow. And similarly, if we switch off the this current, then this current will flow, but the significant point is that I_C , the collector current does not dependent on input current, that is the emitter current. So, therefore this also cannot be used for amplifying purposes. So, we will continue this discussion of, the reverse-reverse biased from the potential energy diagram point of view, and then we will go further.