Solid State Devices
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Lecture - 31
Bipolar Junction Transistor (Contd…)

So, we have been discussing the Bipolar Junction Transistor. In the previous lecture we started explaining the common emitter current voltage characteristics. Let us look at the slide which we were trying to explain. So, we want to explain the family of curves. In fact we started with a single curve, we took one of these curves and then we qualitatively explained how we get the various points on this curve. So, for example, this was the curve we obtained for one value of I_B. We obtained this curve by plotting the excess carrier distributions or different voltage and current conditions. So, for V_{EC} is equal to 0 then for I_C is equal to 0 and then this point corresponds to V_{CB} is equal to 0 which is the collector base voltage is equal to 0.

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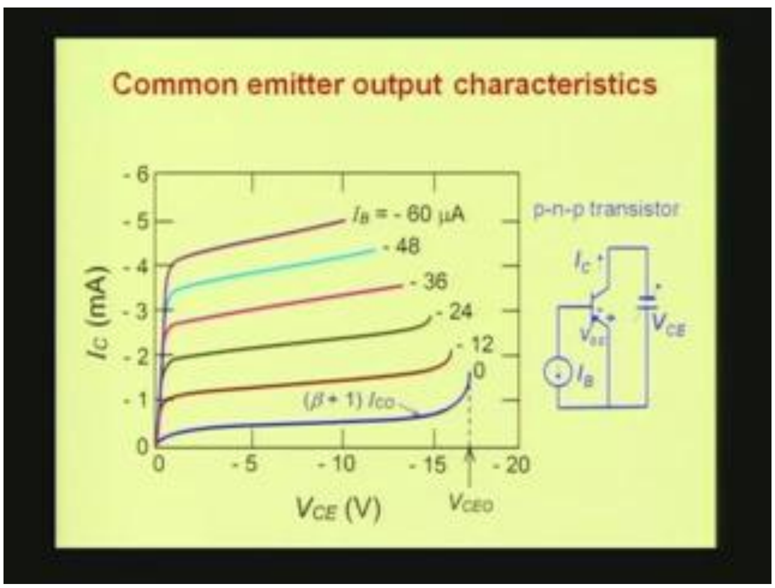

And then we went beyond this point and then we also arrived at an explanation as to why the current goes on increasing in this region instead of saturating. What we said is that the beta of the device goes on changing as you change your V_{EC}, this is because of base width modulation. In fact this was the formula for beta as a function of $beta_0$ where $beta_0$ is the beta when collector base voltage is 0. The delta X_B is the base width modulation the change in the depletion layer of the collector junction within the base which is this quantity and this is the delta X_B.

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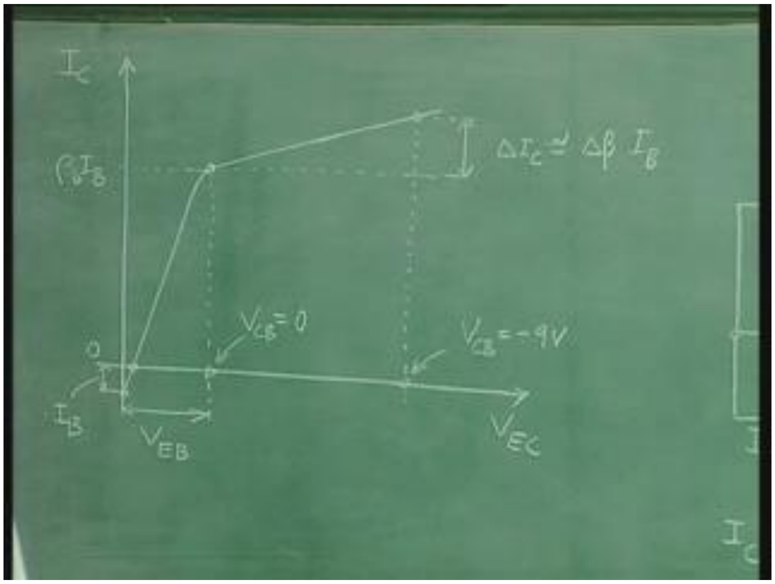

This delta X_B is also delta W_B because as this depletion region shifts the base width also gets modulated. So 1 minus delta X_B by W_{B0} where W_{B0} is the base width for collector base voltage is equal to 0. The reciprocal of this quantity multiplied by $beta_0$ is the beta for any collector base voltage. Then we made a calculation for the device in the solved example and we showed that beta for collector base voltage of minus 9 volts is approximately is equal to 1.4 $beta_0$. This means that from V_{CB} is equal to 0 two V_{CB} is equal to 9 volts and the change in beta is 0 .4 times $beta_0$. So this is almost forty percent of the value of beta and this is what we explained. If we try to put this information on this curve here then it would mean that when you go to the point corresponding to V_{CB} is equal to minus 9 volts then this change in current will correspond to forty percent change in the beta.

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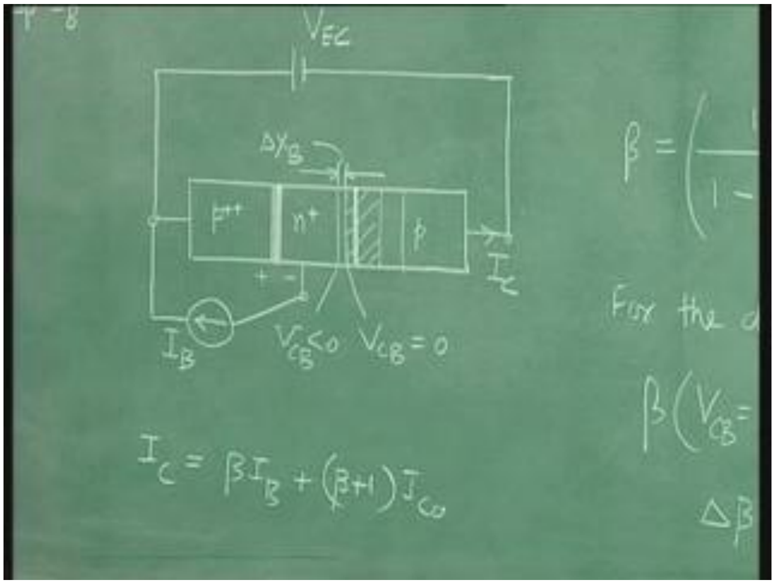

This is your delta I_C which is equal to delta beta into I_B. We are neglecting the contribution because of I_{C0}. So the equation is I_C is equal to beta times I_B plus beta plus 1 times I_{C0} and then you take increments you neglect this part because this is small. So when you take increments you get this equation so this is your delta I_C. Now obviously this diagram is not to scale because this delta beta is forty percent of $beta_0$. In fact this value is $beta_0$ into I_B because this is V_{CB} is equal to 0 so beta corresponding to this point is $beta_0$ so it is $beta_0$ into I_B. Whereas this is beta times I_B and delta beta into I_B is this increment delta I_C. This explains why the current does not saturate and it goes on increasing. Now, in our slide here we do not find that much of increase in current. You take any one of these lines.

Supposing you take the line corresponding to 36 microamps I_B the increment in the collector current from this point to this point is much less than what we have estimated here in the solved example. Here the change is forty percent whereas there the change appears to be only about some ten or fifteen percent that is this increment is some ten or fifteen percent of this in our slide. This obviously means that the practical transistor for which those current voltage characteristics are obtained has a higher value of doping in the base.

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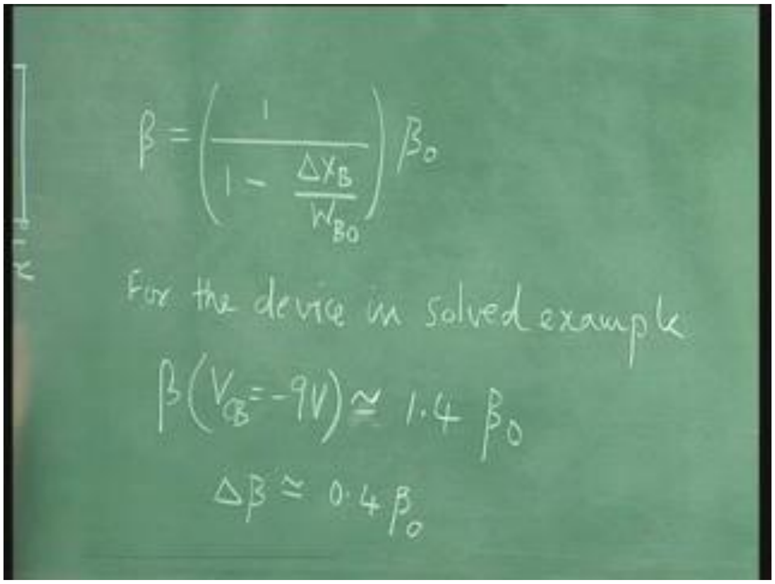

When the doping in the base is higher then this delta X_B will be lower. The modulation of the base width will be lower and the collector base depletion region will be smaller. Therefore beta will not change that much with collector base voltage. This is how the base width modulation and the slope of these characteristics here are related to the doping in the base. Now, proceeding further we find that this curve is going to breakdown at some point. Now what is the breakdown point? At what voltage will this breakdown occur? This is the next point we want to explain.

Now, to understand why the breakdown occurs let us look at the picture inside the device. This is your transistor and this is your collector to base depletion layer so this is p power plus plus, n plus and p. Now let us show the currents which are flowing according to the flow diagram. You have the hole current being injected and in the modern transistor in order to arrive at a simple picture we neglect that recombination in the base so this current goes right through like this, so this is the hole current.

Now there is a part of the hole current recombining here with the electron current which is injected and there is an I_{C0} here which is the generated current which will either be shown within the depletion layer or here outside. In fact in both these places there will be generation. There will be generation within the depletion layer and there will be generation in the neutral region. Right now we are not bothered about exactly where the generation is so we will just show the generation within the depletion layer for example. This is I_{C0} so these electrons move from collector to base whereas here the electrons are moving from base to emitter. This is reverse biased whereas this junction is forward biased and the base supplies the electrons. This is the picture below breakdown.

We know from the PN junction theory that, as you go on increasing the reverse bias across the junction impact ionization within the depletion layer sets in and because of the impact ionization the reverse current that is flowing through the depletion layer starts getting multiplied. We will show this here as follows: When this current moves through the depletion layer it gets multiplied so this we show as follows. Multiplied means electron holes pairs are generated. The holes which are generated will move up and join these holes whereas electrons which are generated will cross as something like this. This is the additional current because of impact ionization.

Similarly, there will be a multiplication of this hole current also which is injected from the base to the collector. Here you have holes which are generated, we join up with these holes and the electrons which are generated will join here. So let us show all these joining the same point. These are the extra electrons the electron hole pair which are generated because of multiplication. So, it is the multiplication due to impact ionization as shown here. It is this and this. Now we need to see the result of this multiplication. We can write a simple equation to explain the effect of this multiplication. But before you write the equation let us understand qualitatively why the breakdown occurs.

Breakdown means a sudden change in current, it is a rapid change in current. Here if you see carefully what is happening is the following. It is because of the multiplication in the depletion layer you have extra electrons coming in where all the electrons join together along with the base current and I_{C0} and all these electrons are getting injected here. Now since this electron current that is injected from base to emitter is increasing because of impact ionization in the collector the hole current which is this current injected from emitter to base also increases because the ratio of the hole current to electron current across a forward bias junction depends only on the ratio of the doping levels on both sides and also on other parameters such as the diffusion coefficient lifetime and so on.

Since these parameters are not changing here on this side and other side of the junction the ratio of the hole current and electron current the ratio of these two currents should remain a constant. Therefore if the electron current increases the hole current here that is injected also increases. Therefore the current that is moving in here is increasing and this increasing current is further getting multiplied giving rise to more electron hole pairs and these electrons again come back to the emitter and they increase hole current in turn. Therefore here you find a positive feedback. So the increasing current giving rise to more current which further gives rise to more current and so on. So there is a feedback from emitter to collector and collector to emitter. This cycle sets in and as this cycle sets in the current starts increasing very rapidly. So this positive feedback is present because of the transistor action and because of the presence of a reverse bias junction in close proximity to the forward bias junction. That is the reason why the impact ionization is causing a rapid change in current in the transistor and this is the reason for breakdown.

When there is no multiplication or impact ionization then we can write this in the form of an equation as follows: The equation is I_C is equal to alpha times I_E plus I_{C0} that is this white line and this white line. This white line is alpha times I_E and this is I. And this quantity is I_{C0} and this quantity is alpha times I_E. So, there is no impact ionization, I_C is alpha I_E plus I_{C0} we know this equation because we have discussed this in the context of basic transistor action.

Now, in the presence of multiplication what is happening? This alpha I_E current is getting multiplied so you have this additional current shown here by this yellow electron hole pair generation. Similarly I_{C0} also is getting multiplied because of impact ionization. So, in the presence of impact ionization we can simply write the equation as I_C equal to this quantity multiplied by M. So it is I_C is equal to M into alpha I_E plus I_{C0} where M is the multiplication factor due to impact ionization, so this is the difference between the situation in the presence of impact ionization and in the absence of impact ionization. The M is equal to 1 when there is no impact ionization. Now please note that we must start with this equation and we cannot start with this equation in the presence of impact ionization.

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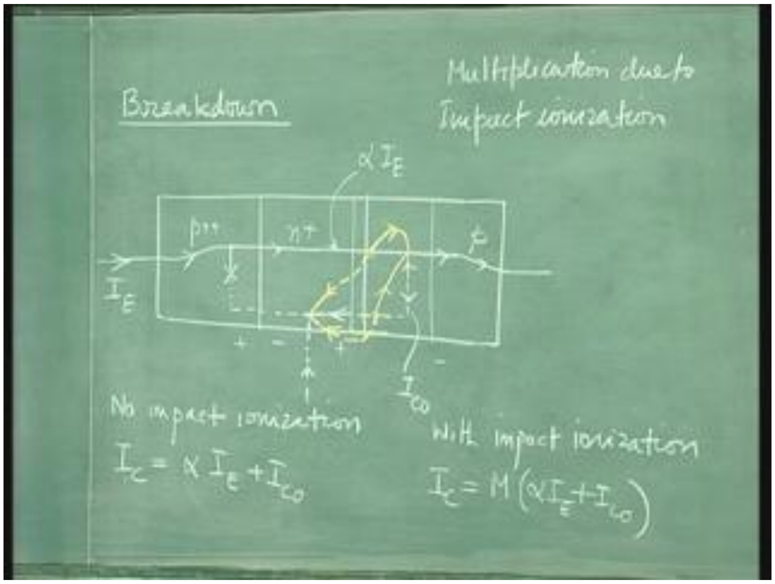

This equation is alright when the impact ionization is absent but in the presence of impact ionization you cannot have I_C as beta times I_B plus this other current. This is because here the situation has changed. You have additional electron current coming in because of the generation within the depletion layer because of this impact ionization. Therefore that equation gets modified so we should not start with that equation but you must start with this equation.

Now when we write this equation you can easily transform this equation to show when the collector current will start increasing rapidly. For this purpose we must write I_E in terms of I_C and I_B because I_B is being maintained constant. When you are tracing this hole curve your I_B is constant as shown here. That is why you must express this I_E in terms of I_B and I_C. When we do that let us see what happens. So I_C is equal to M and I_E alpha I_E plus I_{C0} where this I_E is I_C plus I_B so we get I_C is equal to M times alpha times I_C plus I_B plus M times I_{C0}. Now you shift this I_C on this side and you will get 1 minus M times alpha into I_C is equal to M times alpha into I_B plus M times I_{C0}. In other words, I_C is equal to M into alpha I_B plus I_{C0} by 1 minus M alpha.

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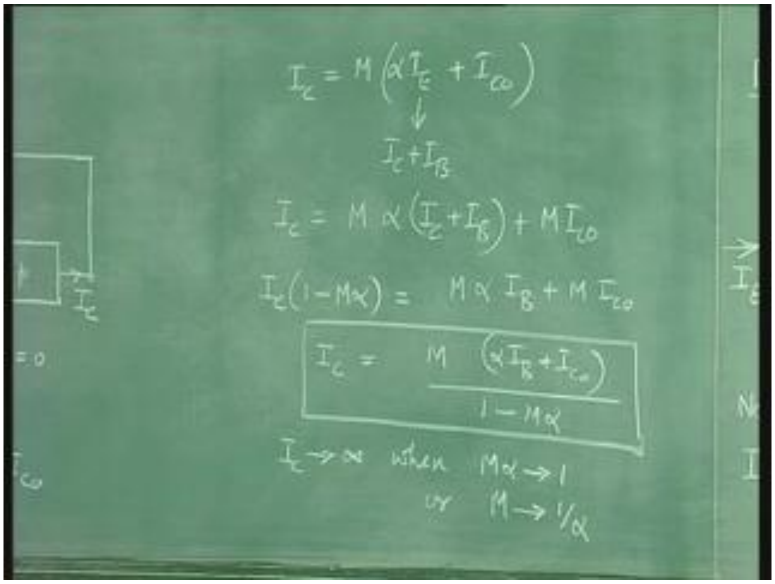

So this is your equation for I_C in the presence of multiplication. This equation shows the so called positive feedback action. In fact one can easily correlate the form of this equation to the form of a feedback amplifier. Now we will not do it in this course but when you do the feedback amplifier in the circuits course you can easily see that this is the loop gain M into alpha is a loop gain. M is a forward gain and M into alpha is the loop gain.

Now, coming back to breakdown here we see that I_C tends to infinity when M alpha tends to 1 in this denominator. Or this is same as saying M tends to 1 by alpha. So whenever M tends to 1 by alpha multiplication is equal to 1 by alpha. Please note that alpha is very close to 1 but less than 1. So 1 by alpha is a quantity which is slightly greater than 1. So even if there is a slight amount of multiplication what it shows is that the current I_C will tend to infinity. Now this is what is happening here.

At this point your multiplication is becoming equal to 1 by alpha and that point the breakdown occurs. This is how you can trace a complete I_C versus V_{EC} curve for one value of I_B. Now, to complete the picture we must trace the curve for another value of I_B and for the condition I_B is equal to 0. Now what is the curve for the condition I_B is equal to 0? That can be seen very easily from here. Note that I_C is equal to beta times I_B plus beta plus one time I_{C0} is valid in the active region. So from here that is V_{CB} is equal to 0 to breakdown you have the active region and this region is called the saturation region. We will see shortly why the word saturation is used here. But right now let us return to the active region and this is the equation: If I_B is equal to 0 your equation is I_C is simply is equal to beta plus one times I_{C0} so I_C is not equal to 0 when I_B is equal to 0 there is a small amount of I_C flowing. That will be the condition here when I_B is equal to 0 obviously I_C will be 0 for 0 V_{EC}. And here you will have something like this going and of course this will break down.

Now the breakdown voltage here is not the same as the breakdown voltage here for higher value of I_B. Now we will remove the other things, this is for I_B is equal to 0. The breakdown voltage for I_B is equal to 0 is more than breakdown voltage for any other value of I_B. We will discuss this issue separately. Now we just want to plot this curve for I_B is equal to 0. So this value is beta plus one time I_{C0} the value of the current here, this current is beta plus one time I_{C0}. There is a small slope here; it is not exactly plot because beta is changing with V_{EC}. Now let us plot for any other value of I_B as supposing we want to plot for a lower value of I_B than this.

Now obviously here what is going to happen is, this point is going to shift up for a smaller value of I_B and this point here is also going to shift to the left because for a smaller value of I_B the collector base voltage is equal to 0 condition occurs the emitter base voltage will be smaller. For small value of I_B the emitter base voltage that you have to maintain or to give the particular value of I_B is smaller. Since this is the emitter base voltage, for small value of I_B the emitter base voltage is smaller so your point will shift left so we start here at a point which is higher because this I_B is smaller and then here we end up with a point that is lower because your I_B is lower beta times I_B is smaller and also this V_{EB} is lower for a lower value of I_B. Now when we join we will find that this curve will almost go through the same point. We will not discuss this issue in much detail because it is not so important. We have seen that these voltages are very small. In fact this is the curve for a lower value of I_B up to the point where the saturation region ends. Now in the active region will the slope of the curve here be more than this or less than this?

Now it can be easily seen that this slope should be less as compared to this slope because we have seen that the delta I_C is equal to delta beta into I_B so delta I_C by delta V_{EC} is the slope here. We can write this in this form and delta beta by delta V_{EC} will not be very different for these two cases because when we estimated the delta beta if you recall we wrote down the fact that beta is equal to beta$_0$ into 1 by 1 minus delta X_B by W_{B0}. Now in the entire calculation the I_B did not enter into picture. We found that delta beta is dependent only on the change in the collector base voltage. And since emitter base is forward biased the change in the emitter base voltage is rather small because the change in the emitter collector voltage is almost the same as the change in the collector base voltage. So this quantity does not change much and this is almost constant therefore this ratio depends on I_B, it is proportional to I_B. Therefore the slope will be smaller for a smaller value of I which is very important to note. Therefore you will find that for higher and higher values of I_B your slope will go on increasing.

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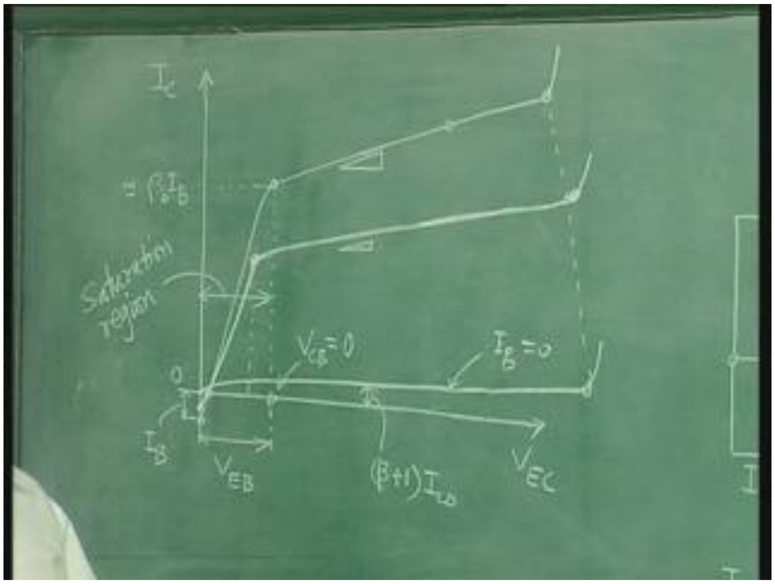

As we said earlier the breakdown voltage goes on decreasing as your I_B increases from I_B is equal to 0. Of course it decreases and then after sometime it becomes constant and then its starts increasing again. So this change in the breakdown voltage with I_B is happening because of the change in the beta as a function of I_C. So, as the collector current changes the beta does not remain constant but it changes. So far we have been assuming an ideal Bipolar Junction Transistor where the beta was independent of collector current. Please look at an equation for your beta it contains various parameters none of which depend on the collector current.

So in practice, however, this is a non-ideality that for a practical transistor beta depends on the collector current and that is the reason why the alpha also depends on the collector current. And if you use this equation for breakdown that is M 10 into 1 by alpha then if alpha is a function of I_C, M also is a function of I_C so breakdown will occur at different voltages for different values of collector current.

To summarize our discussion; we can go to the slide. Now we have explained how your I_B increases and when the I_B increases your collector current goes on increasing, for I_B is equal to 0 your current is beta plus one time I_{C0} collector current and then the collector current almost increases linearly with base current. That is how you have the increase in currents. And here you find that this slope of the characteristics goes on increasing. So when you start with the lowest curve you have a certain slope whereas you find a slope of this curve for minus 24 microampere I_B which is more than the slope of the curve for I_B is equal to 0 and finally a slope of 60 microampere curve I_B is equal to 60 microamps is more than this slope, so continuously the slope of the curve is increasing.

Now let us separate the various regions of operation here. This region to the left of this dotted line is the saturation region and between this dotted line and this dotted line here is the active region and beyond this dotted line to the right of this dotted line is the breakdown portion. Now, we want to explain why the breakdown voltage is decreasing here as your collector current is increasing. Before we do that let us shortly discuss why this region is called the saturation region. The reason for this is very simple. In this region here the collector base voltage is such that the collector base junction is forward biased. Now, when the collector base junction is forward biased you have a large number of excess carriers injected into the collector where the collector has got saturated with excess carriers.

It is this large number of excess carriers for which we use the word saturation. So, the collector is saturated with excess carriers and that is why it is termed as saturation. Therefore as the collector base junction is forward biased there is excess carrier concentration in the collector that creates the saturation region. In other words the collector is saturated with excess carrier creating the saturation region.

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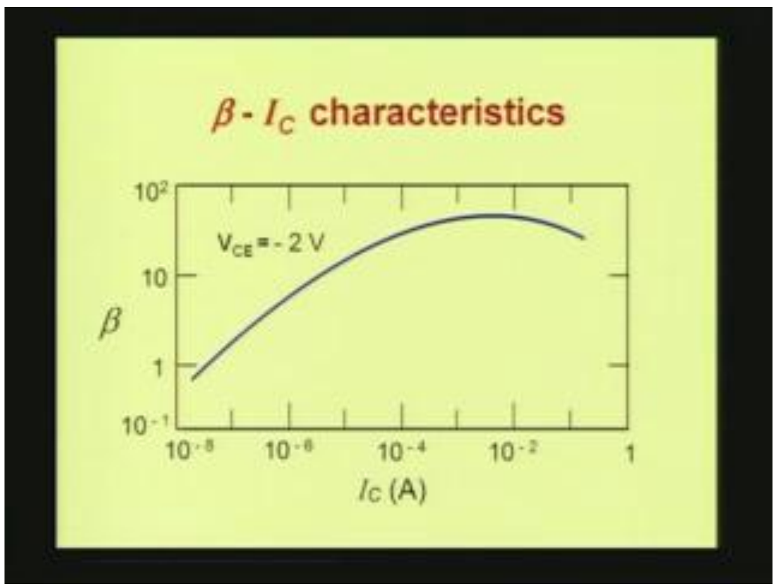

Now let us move to the explanation of the variation of the breakdown voltage with the collector current. For this purpose let us look at this slide, beta versus I_C characteristics. This slide shows how the beta changes with the collector current. So you find that for small collector current the beta is low and as you increase the collector current the beta starts increasing it reaches a peak at some value and then it falls again. So this curve has been shown for a particular value of V_{CE}. You can have similar curves for other values of V_{CE}. Why does this happen? Why does the beta change with I_C? So beta changing with I_C also means alpha changing with I_C. So you can either explain variation of beta with I_C or we can explain variation of alpha with I_C.

Let us explain why alpha varies with I_C. Look at your device again, the internal picture. Now we will show the emitter base and collector base depletion regions clearly. Let us show the currents. Now you will assume that the collector base voltage is 0 for simplicity to explain the variation alpha with IC, we do not need the collector base voltage so this is

the picture. These are the holes and these are the electrons, we have neglected the recombination in the base because that is the situation in modern transistor. So alpha is equal to gamma into base transport factor, injection efficiency into base transport factor is approximately gamma itself for modern BJT particularly for modern small signal BJT.
So concentrate on injection efficiency.

What is injection efficiency?
Injection efficiency is equal to I_{Ep} by I_E so this is I_E, this is I_{Ep} and this quantity is I_{En}. For very low collector currents what happens I, the recombination in the depletion layer which we have neglected is significant as compared to this current. So for low currents the picture is this. This current is normally denoted as I_{gr} generation recombination current. When talking about PN junctions we have explained this which is the deviation of the characteristics of a PN junction from ideal diode characteristics.

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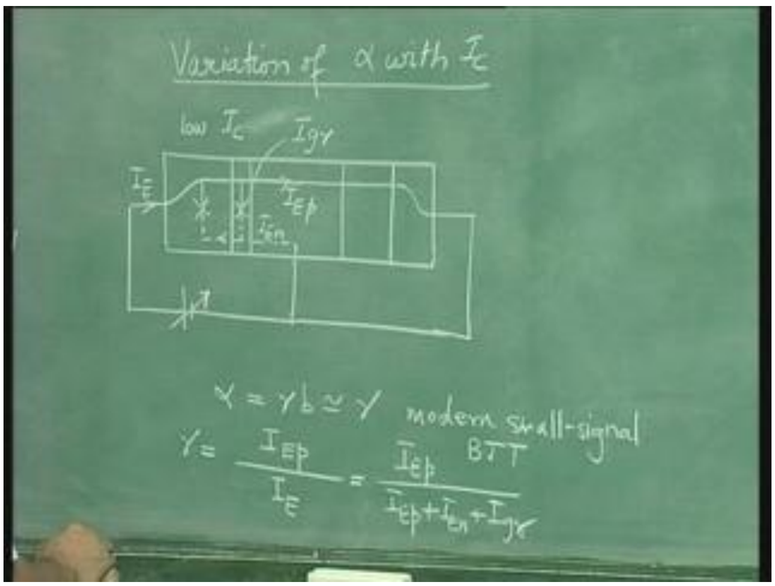

So real diode characteristics differ from the ideal diode characteristics and in that you must take into account the generation recombination within the depletion layer. Now that becomes important when the collector current is low. So when you write this equation for gamma this is equal to I_{Ep} by I_E is equal to I_{Ep} by I_{Ep} plus I_{En} plus I_{gr} so I_E is equal to this quantity plus this quantity plus this quantity plus I_{gr}. So far we have neglected this I_{gr} whereas if you want to find out the gamma at low currents then I_{gr} should be taken into account and that is why the gamma is low. And since gamma is low alpha is also low. So alpha is small alpha low at low I_C due to I_{gr}.

At very high values of I_C again alpha is low and that is because gamma is low. Let us see why? In this high I_C condition your gamma is again given by I_{Ep} by I_{Ep} plus I_{En} because I_{gr} is not so important. So this is low I_C. In low I_C I_{gr} is important but for high I_C I_{gr} is not important. However, when you take the ratio you can write this as 1 by 1 plus I_{En} by I_{Ep}. So when you take the ratio I_{En} by I_{Ep} this ratio I_{En} by I_{Ep} is not the same at very high currents and moderate currents. This is because of the fact that since base is lightly doped compared to emitter at high currents there is high injection level in the base. When the injection level in the base is high the amount of electron current that is injected from the base to the emitter is more than what you calculate assuming low injection level in the base. This is directly followed from the Boltzmann relation. When you go to the PN junction theory from there you can easily show that when one region of the junction is in high injection level the amount of current that particular region injects into the low injection level region is higher.

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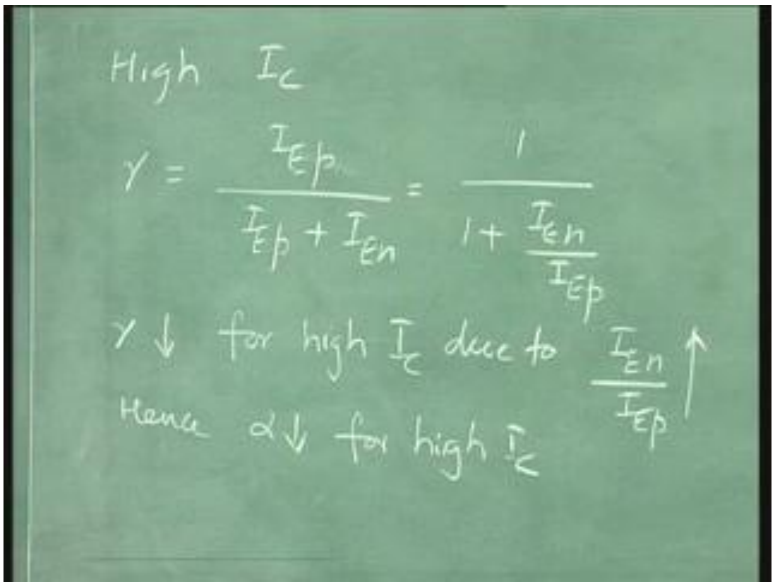

So the amount of I_{En} injected is higher as compared to moderate current conditions. So I_{En} by I_{Ep} ratio rises for higher values of I_C. So gamma falls for high I_C due to increase in I_{En} by I_{Ep} and therefore alpha also falls, hence alpha falls for high I_C. Now we can show this on a graph as follows. If you plot alpha the alpha is a function of I_C where I_C is plotted on a log scale. This is because you must show a wide range of I_C and only then for very high I_C and very low I_C you can show the behavior which looks as something like this. This is for alpha. So in both these regions alpha is low because of low injection efficiency. Here it is because of generation recombination in the depletion layer here it is because of high injection level in the base. So generation recombination in emitter depletion layer and beyond this here it is high injection level in the base.

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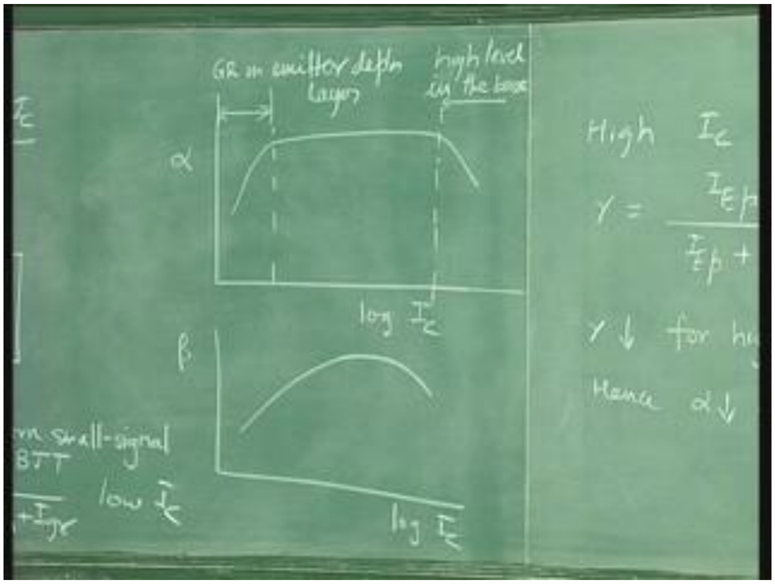

Now when alpha changes like this and if you plot the change in beta it will look something like this. So beta appears to be changing everywhere on this I_C axis although alpha appears to be fairly constant over a wide range. This difference in shapes of alpha versus I_C and beta versus I_C has to do in the fact that beta is very sensitive to change in alpha. So even for a small change in alpha there is a large change in beta. So the equation is as follows: beta is equal to alpha by 1 minus alpha and then try to express d beta by dI_C as a function of d alpha by dI_C just by differentiating and you can very easily show that even for a small change in alpha there is a significant change in beta. That is why even though in this range alpha appears to be almost constant but the beta changes. That is the reason for the variation of beta with I_C or variation of alpha with I_C.

Now once we know this variation we can easily explain why the breakdown voltages are decreasing when your collector current is raising to start with. If you look at the breakdown region in this region the breakdown occurs when multiplication factors tends to 1 by alpha. Now alpha is low for low values of I_C or low values of I_B so multiplication factor required for a breakdown is higher, 1 by alpha is higher so M is higher. As your collector current goes on increasing your alpha goes on increasing therefore multiplication factor required for breakdown goes on falling therefore the breakdown voltage falls. This means that this region here corresponds to this region here that we are talking about. We have really not shown the I-C V-C characteristics for this region, that is a very high I_C region.

So in the slide here this collector current range that is shown is the range where the alpha is increasing with I_C or beta is increasing with I_C so that explains why your breakdown voltage falls. With this we have completed the explanation of the I-C versus V-C characteristics. Now the breakdown voltage corresponding to I_B is equal to 0 this is called V_{ECO} or V_{CEO}. Look at this slide again, this voltage is the V_{CEO}. Why is it called V_{CEO} is because it means that it is the collector to emitter breakdown with the base open.

Please note that I_B is equal to 0 for that case and $0I_B$ means the base is open that is the transistor is connected like this. The base is open and this is the transistor connection. This is the bias when I_B is equal to 0. So about all this to show the condition for I_B is equal to 0, now I_B is 0. That is why this breakdown voltage here is V_{ECO} or V_{CEO} depends on how you show the axis. It is the collector to emitter breakdown with base open. There are two types of breakdown. Normally we come across a breakdown voltage called V_{CEO} and a breakdown voltage called V_{CBO}. Now this V_{CBO} here is higher then V_{CEO}.

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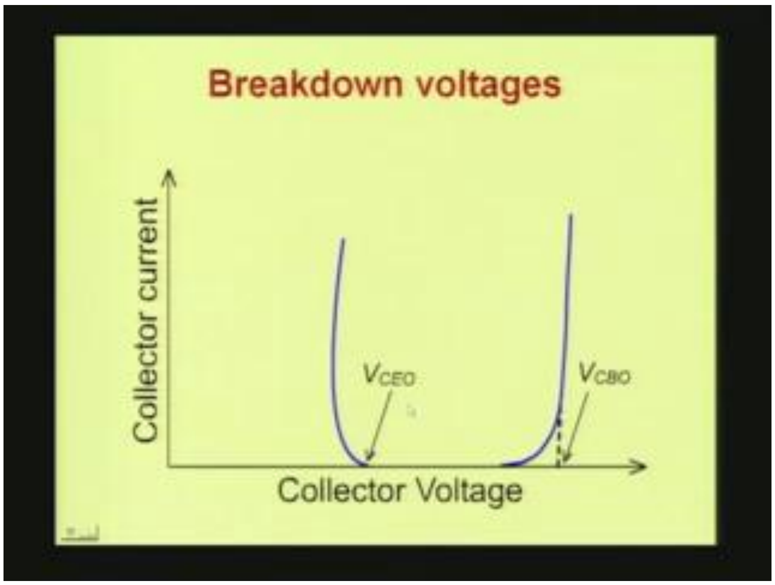

What is V_{CBO}? This is collector to base breakdown with emitter open. So, breakdown voltage for this condition is much higher than breakdown voltage for this condition, this is for V_{CEO}. For V_{CBO}, when you are talking of breakdown you normally use the B here so BV stands for breakdown. For BV_{CBO} the condition is as follows: You have this transistor and the emitter is open so you are measuring the breakdown voltage between collector and base. So this is V_{CE} and this is V_{CD}. This breakdown voltage V_{CBO} is much higher than this breakdown voltage V_{CEO}.

What is the reason?
The reason is very simple this breakdown voltage is the breakdown voltage of the collector base junction. So it is as though there is no transistor action. Breakdown voltage of this device is the same as the breakdown voltage of this device because the emitter is open which means the transistor breakdown is the same as the PN junction breakdown. So here breakdown voltage occurs when multiplication in this junction reaches infinity at breakdown whereas here breakdown occurs when multiplication reaches 1 by alpha.

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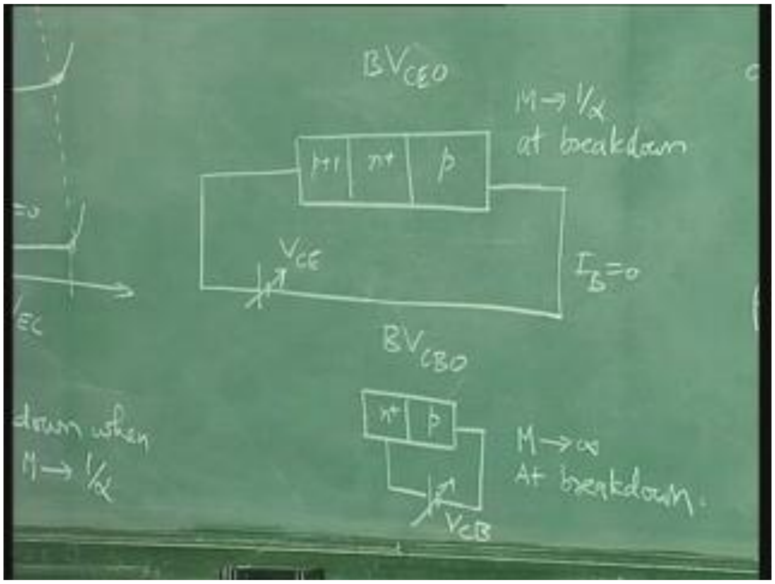

Clearly you will need a higher voltage to make the multiplication factor infinity because of in impact ionization than this case when you only have to reach 1 by alpha which is very close to 1. To reach a multiplication factor which is just more than 1 you need a much lower voltage. This is the reason why breakdown voltage between collector and base with emitter open is much higher than breakdown voltage between collector and emitter with base open.

In fact there is a relation between the two which we can derive very easily as follows: For this purpose we use an empirical relation for the multiplication factor due to impact ionization. The expression is M is equal to 1 by 1 minus voltage across the junction by breakdown voltage across the junction whole power M where M normally lies between 4 and 6, this is an empirical relation for multiplication factor. You find that when the voltage becomes equal to breakdown voltage this multiplication factor tends to infinity. Now using this basic relation for a PN junction let us see how we can express the relation between V_{CBO} and V_{CEO}.

Now, you go here V_{CEO} occurs when M tends to 1 by alpha that is this quantity is 1 by alpha. So I write 1 by alpha at breakdown when the base is open. M is equal to 1 by alpha is equal to so this quantity is 1 minus voltage across the collector base junction by the breakdown voltage of the collector base junction. So it is M is equal to 1 by alpha is equal to 1 minus (V by V_{BR}) to the whole power m. Now we can write breakdown voltage of the collector base junction as V_{CBO}. Now we need to find out for what value of voltage this quantity will become 1 by alpha. This voltage here is the collector base voltage of this device in this particular configuration.

Please note that V_{CBO} is the breakdown voltage of the collector base junction when it is isolated which is same as the collector base breakdown when the emitter is open. That is why V_{BR} is being replaced by V_{CBO}. But this V is nothing but the voltage across the collector base junction in this particular circuit configuration when the base is open. So, if you add this collector base voltage to the very small value of forward bias across the emitter base voltage please note that this is the polarity when you apply a voltage like this such as the reverse bias and forward bias which is very small. So, really the voltage here is approximately equal to this total voltage. That is why we can replace this by the V_{CEO} because at breakdown the voltage is V_{CEO}.

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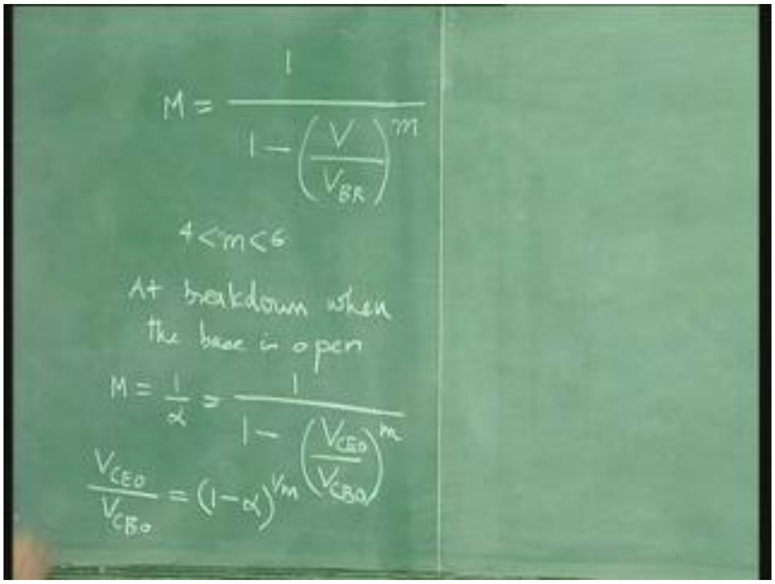

So this is the relation between V_{CEO} and V_{CBO}. When you solve this you will get V_{CEO} by V_{CBO} is equal to (1 minus alpha) to the whole power 1 by m. Now 1 minus alpha is nothing but 1 by beta plus 1 and therefore you have V_{CEO} is equal to V_{CBO} by 1 plus beta whole power 1 by m. This is the relation between the collector to emitter breakdown voltage of a transistor when the base is open and the collector base breakdown voltage of the same transistor.

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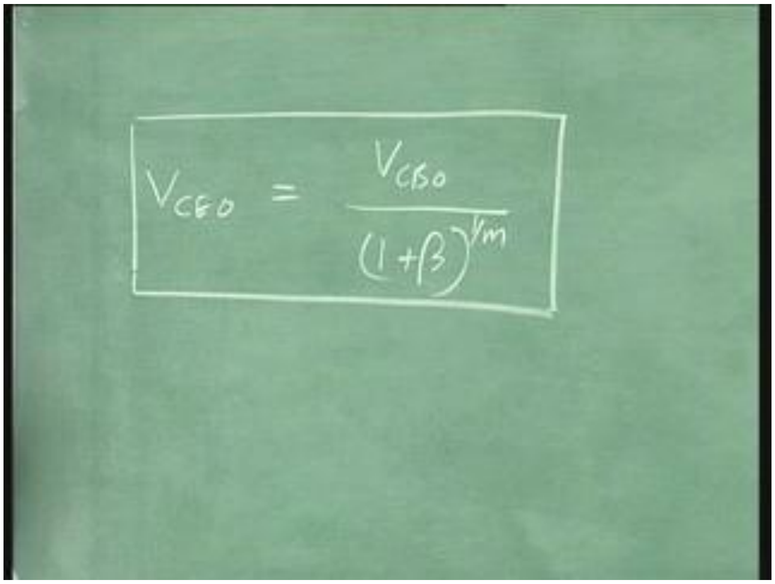

What is the factor here? If you have beta which is about 99 so 1 plus beta is 100 and if M is for example 4 then 1/4th root of 100 the square root of 100 is 10 and then square root of 10 so you will have the V_{CEO} as V_{CBO} by square root of 10. So V_{CEO} can be as low as one third of the VB_{CBO} as shown here on the slide.

Note here that the V_{CO} corresponds to the condition I_B is equal to 0. But as your collector current in the device increases your breakdown voltage falls because of change in alpha with I_C. And in fact here a slight raise is also shown for very high collector currents which is again because of fall in alpha. This region was not shown in our family of current voltage characteristics we showed. With this we have completed the output characteristics of the device in the emitter configuration. We shall continue with some more aspects of the DC characteristics in the next class following which we will discuss the small signal characteristics.