Fundamentals of Semiconductor Devices

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Lecture – 26

BASICS OF BJT

Welcome back, what did we learn in last class? We had introduced a BJT in the last class right and also the different kinds of transistor and the applications of transistors. There are wide variety of applications of transistors we had discussed about that and we say that we will start with BJT because of BJTs are the simplest a starting from p n junction it is actually two p n junctions back to back we just started BJT and the concept of BJT.

So, today we will start in full flow about BJT, there are many things to learn about BJT how it operates, what is the gain, you know how does it amplifies the signal, what are the various aspects of design that one should be aware of when you try to make a BJT and so on.

First thing we will learn is the working of a BJT and a BJT has several components of current, we have to carefully identify the different components of current and eventually we will try to understand what are the different parameters in the device that have to be optimized to get the best performance ok. So, first thing first, we will start with the band diagram of BJT where we stop last time we will come through right about now.

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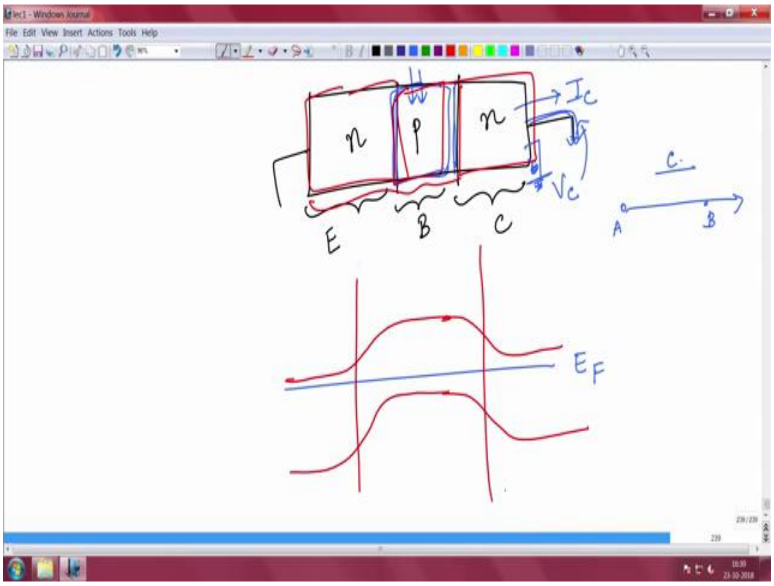

So, what did we tell in the last class I told you that a BJT is a transistor, it has two back to back p n junction diodes. So, I have an n p and then I have a p n I told you this is called emitter, this is called base and this is called collector. So, collector is typically the output where you collect the current and the current between and the current that is coming out at the collector is actually dependent on the input at the base, so that is how you control the current.

If you recall between point A and point B, the current that comes is controlled by third point C. So, that is why a transistor is looks like, the third point C raise the base. So, the base will control how much current comes out through the collector that is how transistor action will be achieved. So, I told you that if I have a p-n-p junction like that the whole idea is that the current coming out of the collector I will call it I_C is control not that of voltage at V_C here, but not that of voltage here, but by the voltage or a current that you are applying at the base.

So, the output voltage V_C will should not have an effect on the current I_C that is what the transistors about. So, if you draw the equilibrium band diagram then the Fermi level has to be same everywhere and n type this is a p-n junction the first one is a p-n junction. So, it looks like this right it looks like this and then next is an n-p junction. So, again it will look like this right look like this. So, I can assign the doping there are different dopings here this is a p type doping here, this is an n type doping here. So, I told you that this is the base emitter junction, this is the base collector junction and is equilibrium there is no current flowing.

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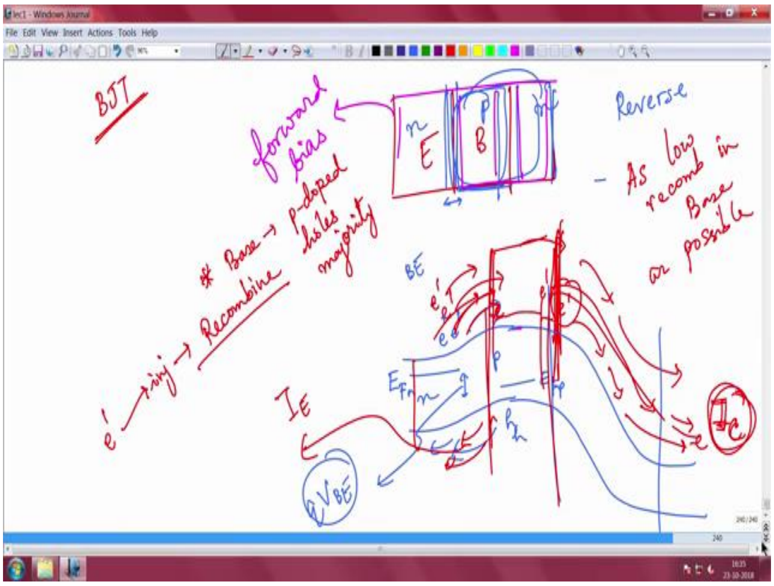

The way you operate a BJT the most common way to operate the BJTs so that you can get gain and other things is that your emitter and base this junction is forward biased. So, you will apply this is n, this is p, this is n, so you remember that this is a hole doping this is n. So, you forward bias the p this emitter base junction, it is a p-n junction that is a forward biasing.

So, put negative here, positive here you forward biasing this junction. So, the moment you forward bias this junction the depletion width will shrink will become very narrow, the barrier height also will reduce. So, you will have something like that ok.

So, this is the whole Fermi level, quasi Fermi level, this is the electron quasi Fermi level. There is a difference here, the difference is the applied voltage qV_{BE} this is called the applied voltage you are doing here V_{BE} and you are injecting electrons from the emitter to the base because this is n type, this is p type. And you injecting holes from the p type in the base to the emitter thats how a p n junction works that we have learnt. Now this junction is reverse biased. So, you will put essentially what you will do is that you will put a positive bias here and negative bias here sort of ok.

Now, you might think that I am putting a negative bias here I am putting a positive bias here, what is this going on in base why I am putting a positive bias or a negative bias right. Essentially, whatever voltage you are applying to the base you apply a more higher voltage at n type that is that makes n type more positively biased than p type and this junction sorry you are going to so that this becomes reverse biased junction that becomes reverse bias, this becomes reverse bias and this becomes forward bias this becomes forward bias and that is becomes reverse bias you want the base collector to be reverse bias. So, you apply a more higher positive bias here actually is that you can say.

In reality of course, there are different modes of operation we will come to there like common base, common emitter there are different modes of operation in which you can ensure that you know this junction is reverse biased and the base emitter junction is forward biased ok. I will just remove the bias right now so that there is no confusion so, this junction is reverse biased. The moment this is reverse biased what will happen remember a reverse bias junction looks like, a reverse bias junction has a very large depletion length with in a large barrier height like this is collector this is base so, the depletion is very large, the field is also very large.

So, these electrons that are injected from the emitter to the base and the holes are injected from the base to the emitter. So, this will come out through the emitter it will contribute to some emitter current. Now this electrons that are injected and I am telling you how BJT will work, the electrons that are injected this electrons will not diffuse across base some of them will recombine because base is p type dope right the base is p type dope which means holes are majority. If holes are majority; if holes are majority then when you inject electron from emitter this electrons that are injecting from emitter, they will recombine in the base some of them will recombine in the base some of them will not recombined.

Whoever whichever electrons as not recombine will reach this edge this is the depletion edge this is the depletion edge. As soon as they reach the depletion edge this reverse bias the huge field is there will immediately sweep away the electrons to this side. This electrons are coming from the emitter by the way, some of them have recombine in the base, some of them have not recombine the ones that have not recombine are swept away to the other side they contribute to the collector current.

So, to have a higher collector current or output current what are the things, one thing is that I want more electrons to be injected from here and secondly, I want very few electrons to recombine here. So, that most of the electrons reach the collector and most of them come out here you agree then most of them come out here right.

I do not it if most of the electrons recombine and die in the base then at this edge a very few electrons reach, then the electrons that are coming out here will be very few and the collector current will be low, the output current will be low you want generally the output current, high in many application ok.

So, you want that there should be as low recombination as possible in the base as low recombination in base as possible as possible, you want electrons that are injected from emitter should recombine negligibly in the base otherwise you will not get current in the collector that is one thing. Now there are different current components here actually we should take into account very carefully.

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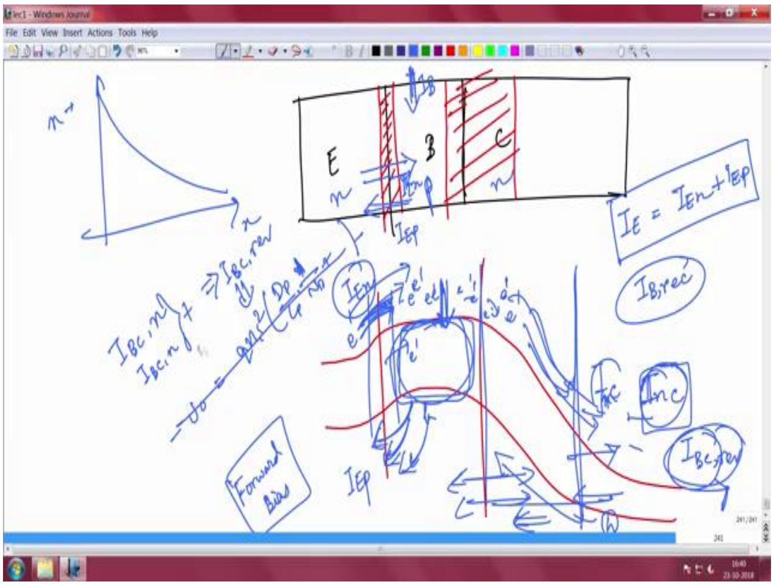

So, what I will do is that I will draw the schematic here and I will also draw the band diagram. So, that we know this is emitter base, this is collector, because the emitter base junction is forward biased; because the emitter base junction is forward biased this is collector because the emitter base junction is forward biased what will happen is that you will have very little depletion here the forward bias junction has very little depletion you can almost you know this is a very small depletion and a base collector is reverse bias. So, the base collector depletion is large; the base collector depletion is large. Now you see you know you have the band diagram that looks like this; the band diagram that looks like this ok.

This is the emitter, this is the base, this is the collector. So, what are the current components, see one component is that electrons are injected from here to there that contributes a current from the emitter I call it I_{En}. So, the electrons are actually injected from here, so I_{En} will come up this side forget the direction of the current now you just concentrate on the current the magnitude ok.

The direction can be think of thought of later, this is the electron current that is because emitter is injecting electron because of this junction is forward biased, this junction is forward biased right this junction is forward bias that is why electrons are injected otherwise they would not be injected.

So, electrons are ejected from emitter this is n type, this is p type, this is n type, again so electrons are emitted from emitter to the base. So, that constitutes the electron current of the emitter hmm. The idea is that most of the electrons should reach this edge so that they are immediately swept away this side, whichever electrons have reached this edge will be swept away and I call that collector current because of electrons that are coming from emitter I_{nc}.

The collector current that is coming because of the electron from emitter are coming here diffusing across the base and going here and getting collected in the output that is the output current while because this is forward bias this is p type dope know. So, lot of holes will be there which also will be injected across this right, holes will be injected across this, the current direction also will be in this direction, this kind also is actually in this direction, but that is not a problem let us not focus on the direction now.

So, holes are injected this way I call that I_{Ep} because that is also an emitter, current electrons going this side holes coming this side they are both emitter current one is the electronic component, one is the hole component. So, the total emitter current is actually the injected electron this one plus the back injected hole which is this one both are in the same direction which is this so that is the total emitter current. Now the some of the electrons that are going here will recombine in the base and decay remember whenever you are injecting electron to the p type base, this is x then the excess electrons will decay.

$$I_E = I_{En} + I_{Ep}$$

So, some electrons will decay here and the decay as in like recombine it holes and because they will recombine it holes that will give rise to a base current. So, here I told you that there will be an emitter current I_{En} , forget the direction, there will be also a injection of holes so the I_{Ep}, they both in same direction by the way because there will be some recombination in the base, there will be a base recombination current and to supply that holes that are recombining in this region.

Electrons and holes are recombining to some extent know to maintain the balance of the holes, you have to inject holes from the base contact ok. So, that is a base contact that will inject holes I call that $I_{B,rec}$ recombination. You are supplying some base current here because the electrons that are injected here are getting recombined within the base some of them.

So, you want to that is a component which is the base recombination current that will be responsible for electron hole recombination here and then the electrons which reach here will be swept away immediately. So, that is I_{nc}, I told you that is the electron current at the collector that has come out because from the emitter side that has come out and this is the current which is of most important to us because that will contribute to gain amplification output power everything.

Now because this base collector junction is reverse bias there will be a reverse leakage across this junction there will be a reverse leakage across this function. That reverse leakage will be I can say I_{BC} that will you know any minority carried at comes here is swept away that side any minority hole that is here comes here will be swept away that side.

So, direction of current is in this direction both of this, that is a base collector leakage current that comes, remember in a reverse bias junction $J = -J_0$ ideal diode even they can be recombination also generation recombination. So, this is the reverse saturation current this is the reverse saturation current that will be there I call it $I_{BC,rev}$. So, this is the reverse saturation current that is there across the base collector junction, one component because of electrons, one component because of holes.

You can actually do it in two way; one is that you know I be a this is the electron leakage current and this is the hole leakage current both of them together you add up you get the total base collector reverse bias current. This is basically nothing, but J_0 if remember which is $\frac{qn_i^2 D_p}{L_p}$ into you know $\frac{1}{N_D}$ all those things you remember that is actually this current ok.

$$-J_0 = qn_i^2 * \frac{D_p}{L_p} * \frac{1}{N_D}$$

So, that is a reverse leakage current there you know good BJT of course or in a good p n junction you want the reverse leakage current to be low, because if the reverse leakage current is high then you defeat the divisor that is no point of the devise. So, typically the reverse leakage that is happening across the base collector junction will be very low say pico Amp or femto Amp where is this current will be in the range of milli Amp or so.

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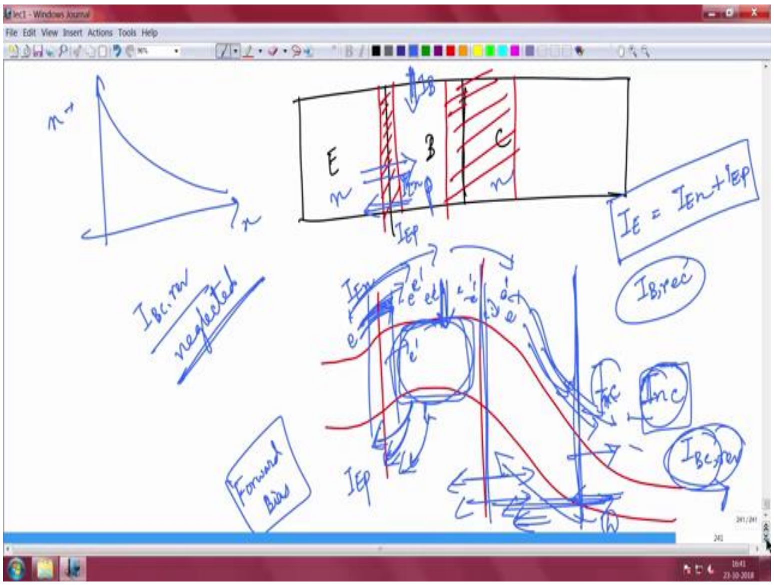

So, typically this base collector reverse current that is there can be neglected we can neglect that most of the time. So, the base collector reverse current that is there here we can leakage current can be neglected. So, what are the main currents now? We have discussed many currents right.

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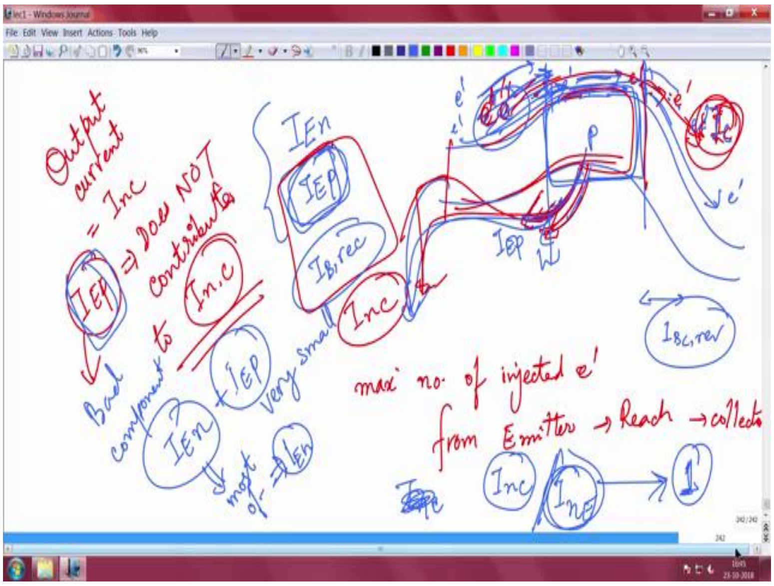

So, let us draw the band diagram again under operation. So, based emitter is forward bias and the base collector is reverse biased ok. So, electrons are injected from here there is some of them recombine they fall here and as soon as they go to the edge they immediately swept away here ok. So, I told you there is a base collector reverse bias here $I_{BC,rev}$ which we typically ignore.

So, the main components are electrons are injected from emitter to the base so that constitutes I_{En}. So, you are injecting electron from the emitter to the base, base also injects you know holes this is a p type so it injects back here so that is I_{Ep}. So, that is another component I_{Ep} this component is an emitter current, but we can also include that as a base current also because it is coming from the base.

So, by the way this component you know can be taken this is you can say emitter current. The base current is the current that is recombining here $I_{B,rec}$. So, there is some current that is recombining because the electrons are going here they are decaying anytime they decay, there will recombination current.

So, this is the base current sometimes as I told you we can also include this as this both as the base current and finally, the electrons they are reach here are swept away so that is your collector current. Now what are the things that you should look out for we want the see that output current is the collector current, output current is the collector current which is I_{nc}. You want maximum number of electrons that are injected from here to reach the collector.

I want maximum number of injected electrons; I want maximum number of injected electrons from emitter to reach the collector, I want them to reach the collector because if electrons emitted from the emitter do not reach the collector mostly then it means they all dying out here it becomes a 2 terminal devices, its not a 3 terminal device.

To increase the output current and hence the gain and many other things you want most of the almost all the electrons from the emitter that are injected should go and reach the collector; should go and reach the collector and this back injected holes that are there. This holes also contribute does a large current and this will come out from the emitter contact here, if I make a contact this will come out, this I_{Ep} this back injected whatever holes are coming out know these are actually when I say back injected this is basically a p-n junction the p will inject holes this side know you remember that from p-n junction yes.

So, this component actually does not contribute this does not contribute to output current toI_{nc}, I_{nc} is the output current. So, this does not contribute to output current. So, this is a useless component this is a bad component, this is a bad component of the current why, because this component comes out to the emitter here this does not contribute to the collector current. So, I want that in the emitter current this is the total emitter current know I want this component to be as small as possible compared to this component.

So, I want most of the current to be because of I want most of the emitter current to be because of electron current here right that is the first condition I want otherwise this is waste this is not coming out through the collector. And also I want that collector current should be you know I want the collector current has some of them has recombine here, some of them have reach whatever has reached is contributing to this current know the collector current.

So, I want that this ratio the collector current that I am getting here divided by this emitter current ($\frac{I_{nc}}{I_{ne}}$) that I am putting not the total emitter current, but the emitter current because of electron this electron emitter current. This should be as close to one as possible, [FL] 100 percent of the electrons that I are emitting here should be able to reach here that is the idea, because if this reach ninety percent of them reach here [FL] 10 percent decayed here ok. So, that reduces your efficiency and your gain. So, you want that maximum number of electrons from the emitter should reach the collector.

So, the collector current because of electron divided by that emitter current because of electron this ratio should be as close to one as possible ok $\left(\frac{I_{nc}}{I_{ne}}\right) \rightarrow 1$. So, that is a very important thing. So, there are some terms that people define there are some terms that people define we can also define those terms because those are very important in understanding the transistor.

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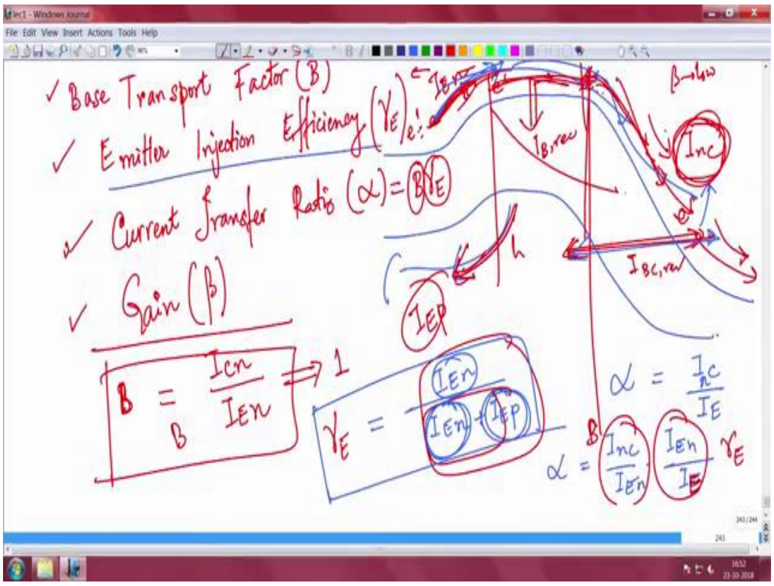

So, I will again draw the band diagram here. So, this is base emitter forward bias, this is base collector reverse bias, electrons that are injected here, some of them recombine, some of them reach here maximum reach here, once they reach here they are swept away here and collected here the holes also injected back injected which is a useless current component I_{Ep} , this components is I_{En} and the collector current here you get is I_{nc} .

So, there is a there are few things we define; one is call base transport factor; one is call the base transport factor, one is called emitter injection efficiency emitter injection efficiency, these are some the terms we will define ok. One of them is called current transfer ratio current transfer ratio and one of them is called gain ok. These are 4 things that we should be generally aware of because this 4 things will define how well your transistor will behave this 4 thing you will. So, what are these things? So, base transport factor is called capital B, emitter injection efficiency is called γ_E, current transfer ratio is called α and gain is called β these are important terms.

So, remember electrons are injected from emitter some of them recombine most of them reach here, whatever has reached there will be swept away to the collector they are the collector in the output current is constituted by electrons from the emitter. So, we call them collector current because of emitter electron current this is the I_{En} that is injecting I mean direction will be this side, electrons that are moving here and going there.

There will be some base recombination current here because electrons will decay in this as they move there is a base will also inject back inject holes here which is I_{Ep} that is useless And of course, there is a base collector reverse bias here reverse current which is very low and I am neglecting that we are sort of neglecting that.

So, first I will discuss what is base transport factor B, the base transport factor B is defined as the fact that the ratio of the collector current this one divided by the emitter electron current this one. If you look carefully in to this it is basically what fraction of this emitter electrons have reached this point and gotten collector as a collector current. So, this is the ratio of the collector current because of electrons that have come from emitter which is dominant current there is no other collector current this leakage is very very low.

$$B = \frac{I_{Cn}}{I_{En}} \to 1$$

So, this is an important factor and the base transport factor should be as close to 1 as possible; that means, most of the electrons that are injected from emitter should have reach the collector that is the base transport factor. The emitter injection efficiency γ_E which is this is defined as that the out of the total component of the emitter current $I_E = I_{En} + I_{Ep}$ ok.

This is also emitter current, this is also emitter current, out of these 2 components what is the fraction that is useful which is I_{En}, because this is the useful current that will go and come out of those collector this is a useless factor that will come out from the emitter only ok. So, what is this fraction, how well is the emitter injecting electron if this ratio is close to 1 it means most of the current in the emitter are because of the electrons not because of the hole. If this is half, it means there is you know equal number of electron equal number of hole that is a terrible device, you want this number to be as close as 1 as possible like 0.99 or so.

$$\gamma_E = \frac{I_{En}}{I_{En} + I_{Ep}}$$

Then the third factor is current transfer ratio α which is defined as the collector current to the emitter current ok, it is defined as the collector current to the emitter current. And what I can do is that I can define this as the collector current is mostly your collector current is because of the electrons that have come here this base collector component that contributes to collect the current is negligible I keep telling you.

$$\alpha = \frac{I_C}{I_E}$$

So, I can write this as the collector current because of emitter divided by I_{En} into I_{En} by I_E , I can write that the same thing now this quantity you know this quantity this is this actually because this I_E is the total current this is the current right. So, this I can write as γ_E and this quantity is actually β not β, B. So, I can say that your current transfer ratio α is base transport factor B times the emitter injection efficiency γ_E this should be also as close to as 1 as possible because this should be close to 1 this should be as close to 1 ok. That is the thing ok.

$$\alpha = \frac{I_{nC}}{I_{En}} * \frac{I_{En}}{I_E}, B = \frac{I_{nC}}{I_{En}}, \gamma_E = \frac{I_{En}}{I_E}$$

$$\alpha = (B * \gamma_E) \rightarrow 1$$

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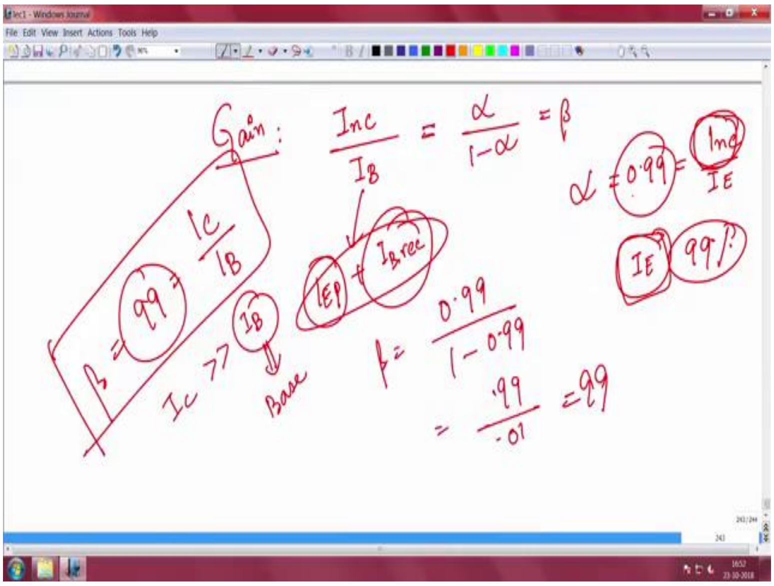

And finally, I have gain; gain is defined as the output current which is the collector current divided by the base current; divided by the base current. Now the base current technically has 2 component; one is the back injected emitter $I_{Ep}$and one is a recombination current one is the recombination current $I_{B,rec}$. But if you put the various expressions that you have learnt till now, this will come out to be α, this is β by the way $1-\alpha$ this is call β this will come out to be α by $1-\alpha$.

$$Gain = \frac{I_{nc}}{I_B} = \frac{\alpha}{1-\alpha} = \beta,\ I_B = \ I_{Ep} + I_{B,rec}$$

So, for example, if the current transfer ratio is 0.99 that is their current transfer ratio which is defined as total collector current by the total emitter current if this is ratios 0.99, it means out of that total emitter current; total emitter current both electrons and holes combine out of this 99 percent of them has reach the collector.

$$\beta = \frac{0.99}{1-0.99} = \frac{0.99}{0.01} = 99$$

I mean not a 99 percent of that the collector current is 99 you know percent of the total collector current ok. If this α is 0.99 then β will be 0.99 divided by 1 minus 0.99 this will be 0.99 divided by 0.01 which is 99. So, the gain of the device will be 99 which is the output current divided by the base current. So, a higher gain means you know the device is better gain basically. So, the collector current should be much larger than the base current in other words the base current should be very small.

And the base current can be small when this back injected component is small and the when the recombination is small. Please remember that if most of the electrons recombine in the base then the number of electrons reaching the collector will be very low, your β will be low, your gain will be low and you will have a very bad device it is you want the maximum electrons to reach and go ok. So, these are different terminologies that are used in the transistor in the BJT parlance ok.

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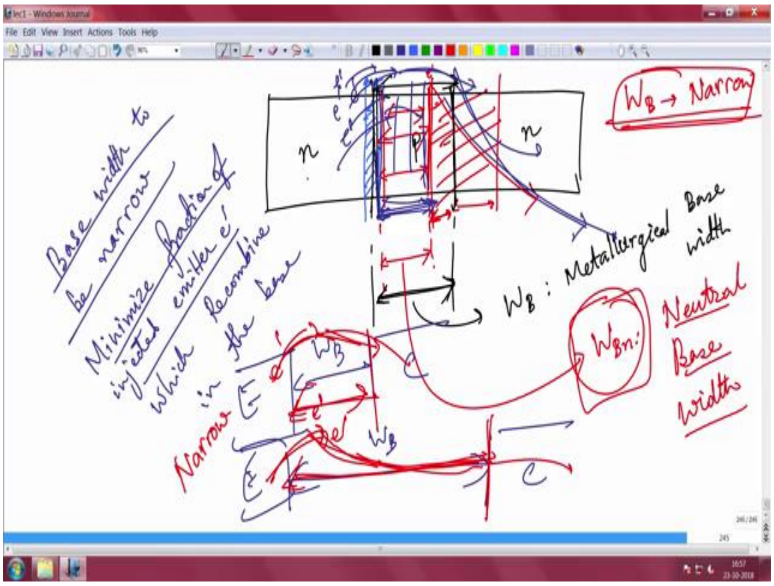

Now if you again look at the band diagram I will draw the structure again. So, this is suppose your let me draw a bigger structure so that I can correlate easily. So, this is your the schematic. So, suppose this is emitter n type, this is base p type, this is emitter again, this is collector.

Now, because there is depletion here a small depletion that is it is a depletion its a small depletion some part of this has gone in the depletion some part of this has also gone in depletion. Now this has a wider depletion the last part of that was the base has gone in to depletion this is the depletion towards the base and this is the depletion towards the collector.

So, you see a base is the most important part here you have to look carefully. This distance is actually the what has is left behind of the base, what was initially the base was this, but what has left behind in the base is this. So, this what was initially the base you know is called the metallurgical base width W_B is called metallurgical base width.

The reason is it is called metallurgical base width is because this is defined by the metallurgy like this is defined by the junction depth. So, this is the boundary of the base; this is the boundary of the base so this is the actual the metallurgical base width, but because of depletion in real operation only this part has remained as base the rest part has been eaten away by the depletion or you can say the depletion has taken by the way right depletion has taken by the way.

So, this part this shrunk is called W_{Bn} its called neutral base width it is called neutral base width ok. Neutral base width is that base width which actually matters in the device operation, because as soon as the electrons reach this as you know this will be swept away here. So, what matters is the neutral base width only, so neutral base width is the most crucial parameter we will come to see that, of course the doping is also very importance so, this will determine many of the things.

Now from your logical insight, you know from the intuition you know that when I am injecting electrons from the emitter side to the collector over the base, they will recombine in the base and there is a base recombination current we all know that. We want the base width this base width total I mean neutral base width whatever this base width to be narrow we want the base width to be narrow why.

So, that maximum electrons that I am putting can quickly go to the side and get diffuse this side, I mean they can be swept away this side; if the base which is large then what will happen is that most of the electrons that are injected will recombine.

I want to minimize the fraction; I want to minimize the fraction of injected emitter current which is recombine injected emitter electrons, I want to minimize the fraction of injected emitter electrons which recombine in the base; which recombine in the base. Because if most of the electrons that are injecting recombine in this base then the output will be very low and most of the electrons will recombine in the base if the base is large. So, the narrower the base width, suppose I have a base width like this, this is base versus another base that is like this and there is a collector here, collector here, there is a emitter here, there is a emitter here ok.

So, when I am injecting electron here some of them will recombine most of them will come here, but when I send electron here it is such a large base that most of the electrons will recombine, there is nothing left here. So, you want to shrink the size of the base you want to make the base narrow; you want to make the base narrow so that very few electrons recombine in this region most of the electrons come to the collector.

So, if you keep a wide base like this a very thick base like this then most of the electrons that are emitted injected will be decaying and they will lead to very low current. So, the rule a golden rule is that the width of the base should be very narrow, only a very narrow base we will give you a higher gain or higher current transfer ratio, a higher you know base transport factor you want this quantity to be very short ok. So, the base should be narrow ok, only then you will get most of the electrons that reach the collector you getting my point that this is a transistor we are talking about by the way.

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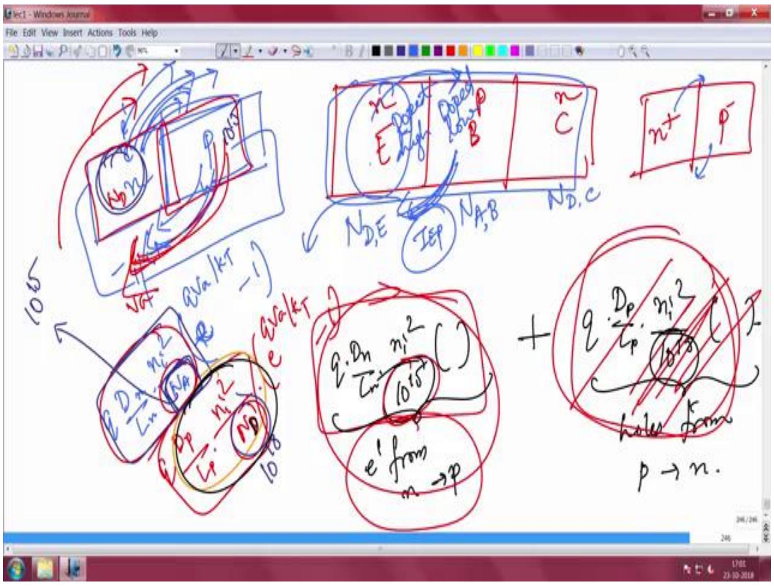

And this is emitter, this is base, this is collector each of this is n, this is p, this is n, you will have different doping this is n type doping, this is p type doping, this is n type doping, but the n type doping and emitter and collector could be different and the N_D N_D is not a good way.

So, I will put this is N_D emitter this is N_D collector they can be different doping and because I am giving this like this nomenclature I will say $N_{A,B}$ this is base doping. Now if you remember if you look at a p-n junction just a p normal p-n junction electrons when we forward bias the junction which means you forward bias the junction like this, electrons are injected from here to here, holes are injected from here to here.

How do you make sure that electrons injected this side results in a more dominating fraction of the current then holes coming this side, you want the holes coming this side to minimum because that is useless that comes here right. So, how do you make sure that holes injected to this side is much smaller in quantity and magnitude then the electrons injected to this side. Do you remember that, see the electron that is injected to this side will give you a current which is which goes as and density I am talking.

So, area I will ignore qD_n because the electrons are injected know by L_n into n_i^2 by the doping in this region which is N_A here plus this into $(e^{\frac{qV_a}{kT}} - 1)$ that is here you can say that is your electron current to this side $\frac{qD_n}{L_n} * \frac{n_i^2}{N_A} * (e^{\frac{qV_a}{kT}} - 1)$ and the hole current that comes this side is given by qD_p if you remember from your p-n junction classes n_i^2 square by the doping on the N_D this side this side N_D , $(e^{\frac{qV_a}{kT}} - 1)$, this is the V_a that we are applying ok $\frac{qD_p}{L_p} * \frac{n_i^2}{N_D} * (e^{\frac{qV_a}{kT}} - 1)$.

Most of the terms are equal here I mean there is small differences here you cannot you know differential except N_A and N_D you please look carefully. If you are doping on the if goes inversely as the doping on the other side if the doping on the p side which is N_A is very low suppose this doping is 10^{15}.

This and suppose the doping on this side is 10^{18} then this quantity will be much much larger than this quantity, then this quantity right because this is 10^{18}. So, this will go as $\frac{qD_n}{L_n} * \frac{n_i^2}{10^{15}} * ()$, exponential of something this is the current because of electrons from n side to p side plus this is electron you know this is the other component $\frac{qD_p}{L_p} * \frac{n_i^2}{10^{18}} * ()$ something. This is because of holes from p side to n side you see this is 10^{15}, this is 10^{18}, this quantity will be much much smaller because there is a 10^{18} in the denominator.

$$\frac{qD_n}{L_n} * \frac{n_i^2}{10^{15}} * (\,) + \frac{qD_p}{L_p} * \frac{n_i^2}{10^{18}} * (\,)$$

This quantity will be much larger because there is a 10^{15} in the denominator. So, electron from n to p will be much larger than hole from p to n. This is the hole component of the current here and this is the electron components of the current here which means if I doped the n type much higher than p type which means if I have a structure like this n is very highly doped n^+, p is likely dope p^-.

Then the electrons injected this way will be much more than the holes injected this way and that is how I can make sure that in a BJT this back injector current component of I_{Ep} useless current component is minimized by making sure this is doped high this is doped high and this is doped low. In that case electrons from here to here will be much larger and holes coming from here to here will be much smaller. So, we shall end the lecture here today we have had enough of discussion on BJT as of now.

So, what did we learn? We had gone ahead with the band diagram of BJT, the basic operational principle of BJT, we have defined the emitter base collector regions that dopings that thicknesses at least the base thickness we have not come to emitter and collector thickness here we will come to that later. We have also define some many a very important crucial parameters like gain, current transfer ratio, base transport factor, emitter injection efficiency and I told you that many of these how to increase many of these parameters.

We have discussed several current components in the device primarily the current because of electrons injected from emitter to the base recombination that takes place in the base and the electrons that reach the collector which contribute to collector current.

The back injector holes from base to emitter useless we want to is useless we want to minimize that, we discuss strategies to minimize that that you have to doped the emitter high and doped the base low, to make sure that most of the electrons from the emitter reach the collector your base has to be also narrow otherwise they will recombine and die mostly.

So, these are important things that we have discussed. Now we will go and write down the current equation in the next class derive the equation this is a very easy p-n junction equations by the way and the base is the most critical ok, when electrons are injected from emitter to the base they are minority carrier that is that are decaying. So, that part we will focus on the next class and we will take it from there ok.

Thank you for your time.