Fundamentals of Semiconductor Devices

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Lecture – 25
Introduction to transistors: BJT

Welcome, so we have been now equipped with the basics and fundamentals of p n junction of Schottky junction, we have studied most of the carrier transport processes and phenomena, things like mobility, velocity, drift diffusion, continuity equation, traps, recombination all these things are something that we are familiar with the basics of that we are familiar with.

What is the next step now we do? Because we have understood p n junction and Schottky junction well. The next natural course of action would be to study transistor ok, there are many kinds of transistor and we will start with a Bipolar Junction Transistor or BJT because that has a lot of similarities with p n junction. In fact, it is a p n junction in some way two p n junctions. So, a bipolar junction transistor if we study and understand it thoroughly we can understand almost any kind of transistor and for thereafter we will go to MOSFET another kind of transistors ok.

So, today's class we will start bipolar junction transistor, we will give a background of what a transistor should be or is it you know, what is a transistor, what is the function of a transistor and what so good about bipolar junction transistors that we have to study and we will come to the band diagrams and the physics of bipolar junction transistor so we will come through whiteboard now.

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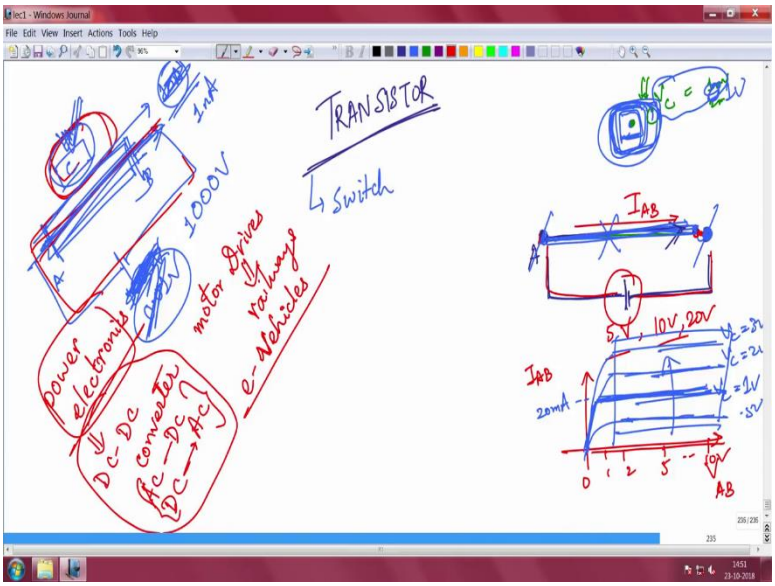

So, you have definitely heard the word transistor a transistor is a three terminal device broadly and loosely speaking is a three terminal device. So, essentially if you have a point A and point B, the objective of a transistor is that see in general the current that flows between A and B is controlled by the voltage that you are applying between A and B right, that is you know either it is linear which is ohms law it may be non linear does not matter, but in general universally the current flow in between two point A and B is controlled by the voltage between the two points A and B.

But in transistor the objective is that that current that flows between points A and B should be independent of the voltage that you applying here within some range. So, that means, does not matter whether you applying 5 volt or 10 volt or 20 volt or whatever of course, there is a break down, but within that limit say 5 volt whatever you are changing the you are changing the voltage between A and B points so I am writing it V_{AB}.

So, you are changing the voltage between A and B ok, but the current that flows between A and B ok, the current that flows between A and B should be independent of the voltage you applying between the two terminal which means, the current if I plot the current voltage characteristics it should be flat which means it is 0 suppose this is 1, this is 2, this is 5, this is 10 volt does not matter what voltage you applying between this and this point.

The current that is flowing is constant, maybe it suppose this is 20 milliampere. So, is constant current is flowing of course, at 0 it has to be 0, so it will come down to 0 like this

it will come down this 0 like this what is controlling them? What is controlling is actually a third point C either the voltage you are applying in C order current you are feeding in a C, should control the current between A and B.

So, if I am increasing the voltage at C point VC from say small 1 millivolt, 2 millivolt, I am increasing this current should keep changing. So, this suppose this particular plot corresponds to a third point you know a third terminal, a third terminal I am applying a voltage suppose I am applying 1 volt. So, this corresponds to VC equal to 1 volt third terminal ok.

So, if I increase VC equal to 2 volt this current should also increase VC equal to 3 volt, this current also should increase and VC equal to say 0.5 volt this current should decrease, but they should all come to 0 at 0 volt right so like that. So, you see the current between two terminal is independent of the voltage between the two terminal, but it depends you see you I am changing the current from this to this to this to this by changing the potential at a third point or maybe the current that you are putting a third point, this is transistor this is a transistor.

So, you are basically controlling this two with a applied of a third voltage this is what a transistor looks like. A transistor can have many function it can act as a switch which means whether current flows here or not I will determine by this terminal I can choose to have no current flows here does not matter what voltage you applying, you might apply hundred volt also between this point and this point you might apply 100 volt still get no current why?

Because, you are controlling that flow by the third control third terminal, in that case a transistor can behave like a switch either it can allow the current flow between A and B or it cannot allow the current flow between A and B just by controlling the knob at C just by controlling the knob at C. So, it can be a switch you can block the voltage, you can let the current flow it is up to you.

So, this kind of a switches are used in many applications specially is a power, electronics this switch allows you to block large voltage, suppose I have a transistor it is a you know transistor current flows from here to there and there is a third terminal here C which will dictate how much current flows, but if I behavior as a switch then between these two

terminal I might as well apply even 1000 volt, still the current that will flow is almost 0 nano amps.

Because this is the knob that is controlling the parent the mother knob; so by that you are actually blocking 1000 volt between the two terminal and moment you switch on it the switch it on by tuning this knob at very small voltage at very small voltage like say 0.01 volt at 0.01 volt very small voltage you can have very high current of say 10 ampere I am just giving an example.

So, at very small voltage between these two point you can get very high current 10 ampere or you might put 1000 volt and still get nanoampere. So, this is a switch by controlling the potential order voltage at C, I can change this a lot, I can block I can let current flow.

So, this kind of things are used in power electronics circuits and power electronic circuits need this kind of switches to make power electronics circuits such as you know DC DC converter; DC -DC converter is you convert one DC voltage to another DC voltage or you want to convert an AC to DC or a inverter from DC to AC which is inverter you can do all kinds of changes by using different small building blocks of this switches.

So, power electronic circuits of this kind of DC- DC or inverters and converters are hugely used in so many motor drives for example, and that can be used in railways to break a railway, to make the railways go fast they are increasingly now used in E-vehicles that you see on the road to charge the vehicle you know you see that electric posts are there you have E-vehicles you have two wheeler, E-two wheelers, you have laptop adaptors, you have chargers right you have windmills. So, many things are there that you can use the transistor as a switch.

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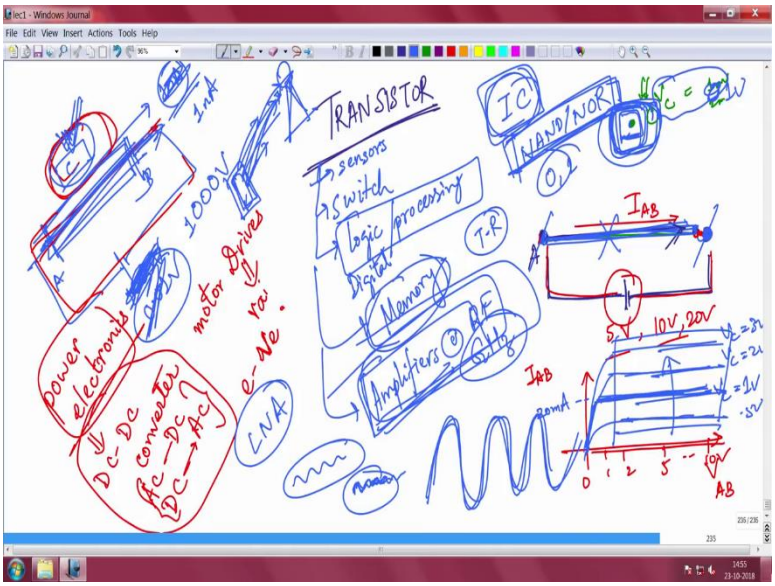

So, that is one application, transistors have many many applications actually that is why it is the most fundamental you know inventions of mankind, it can be used as a switch, it can be used for logic or processing you know all your IC Integrated Circuit revolution that has enable the computers, then laptops, mobile phones all the integrated circuits are built around transistors.

You can make logic circuits you know if you have read digital and analogue electronics this NAND, NOR logic gates that are there which enable your computer chips to actually perform the tasks the processes the Pentium processor, now they you have to Penryn and all the advanced processing processors from Intel, Samsung, Apple and so on right all these processors you depend on logic gates, you know 0's and 1's if you remember, all these logic gates are made possible by transistors only mostly almost always they have.

So, the logic circuits and this is digital logic; digital logic has allowed the internet all the computers everything, that digital logic is possible only because of transistor without transistor you will have no integrated circuit that makes your computers laptops and cell phones so compact and fast and efficient is not possible, so transistor is the heart of that.

Transistors are also used as memory units to store information you can use transistors to store information a combination of transistors that is as a memory device. Transistors can be used as amplifiers, specially power amplifiers power amplifiers at RF frequency you know RF frequency gigahertz 10 gigahertz, 1 gigahertz is a RF frequency, you can use the

transistors amplifier which means a small signal at the input can be amplified to a large signal of the output this is AC signal by the way.

So, when you have a cell phone your cell phone has an antenna whenever you talk you send an SMS or Whatsapp or you login to Facebook whatever that information, that data comes from the nearest base station through air by electromagnetic waves which carry this 0's and 1's in the forms of this amplitude and other modulation that you are there that is there in the wave, but this intensity of the wave that reach your cell phones is very small is very small, so this has to be amplified to process the data.

So, that amplifier you need an RF amplifier and that can be a transistor and once you amplify it you have to process the data there could be LNA it's called Low Noise Amplifier, you have to eliminate the noise there many stages of that. Finally, you process the data suppose you uploading a picture that uploading the picture we will have to again be an information that will be transmitted through the from your mobile handset to the nearest block you know base station, through air, but you need to send a large power out.

So, that by the time it reaches the tower the power is very low, if your power that you are sending out is very low then it will not even reach the tower with that it will reach the tower abysmally low power. So, you need to pump up you need to pump the power of the RF signal before you send it out to the base station, again for that you need an RF amplifier it is called RF transceiver unit transmission and receiver it will transmit it will receive.

So, that you know we can use the; a transistor as an RF transceiver at trans and amplifier also in the there will be many other elements the transistor is the heart of that. So, there are many more applications of transistors; transistors can also we use the sensors to sense and that sensors can be used for many things biological sensors, chemical sensors, light sensors there could be photo transistors right, it can sense chains, it can be switch, it can be logic, it can be digital logic, it can be memory, it can be low noise amplifier can be power amplifier a transistor has so many uses.

And different kinds of transistors are there to do these different kinds of working or different kind of device, a different kinds of objectives can be met with different kinds of transistors.

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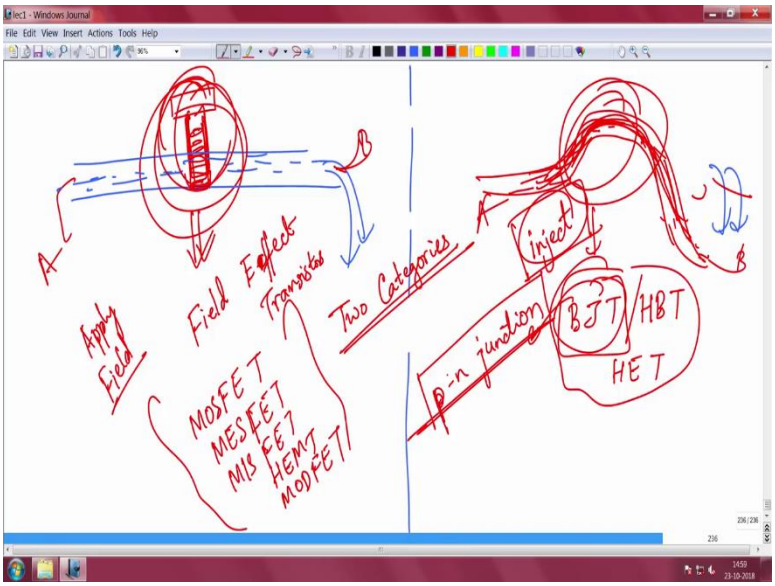

So, transistors you know loosely you can have two types of transistors, suppose you have you have you know you have a pipe through which water is flowing; you have a pipe through which water is flowing. So, water is coming here and water is flowing out here ok, suppose you have two kinds of pipe water is flowing here and water is flowing out here.

There are two ways there two ways to control the water flow; one is that you have a tap water tap that you put here this is screws are here. So, by putting the by the water tap you can either close the channel or you can partially open the channel right you can close the channel or you can partially open the channel depending on how much you tap it, that is one kind of you know that is one kind of transistor action you can say that is one kind of way to control the current.

The other would be that you know you can change the elevation of this thing, so that for example, the water pipe will be like that ok. So, you can change the elevation of the water pipe here so that the amount of water that goes can be controlled by this, you can make this much higher right and then the water may not be able to go may little water will come out. So, this is another way of changing the water flow and this is another way of changing the water flow.

These actually represent two fundamentally different kinds of transistors and each of these categories and these categories I can say two categories of transistor and each of these

categories of transistors will have many kinds of transistors between them, each of this will have many kinds of transistors with them right. So, this kind of transistor; this kind of transistor where you can actually completely pinch off the water these are like field effect transistors, these are like field called field effect transistors because you can actually completely pinch off the channel here.

And the where you can modulate the profile here where you can modulate the profile here, you can modulate the profile of the water pipes such that less water goes or no water goes. These are not field effect transistor these are like junction transistor, these are where you actually do not apply field here in this kind of transistors we apply a field apply an electric field we will come to that.

Here you do not apply a field you basically inject a small amount of a current you inject a small amount of current to change this profile and thus you control the output current ok. So, essentially this is your third terminal this is your point A this is your point B this is the third terminal similarly this is point A this is point B, this is your third terminal which you can actually change the current flow.

These are potential these are not field effect transistor this where does the transistors where you can inject a small current you can change this and you have the transistor action. So, this kind of transistors is for example, bipolar junction transistor there is also heterojunction bipolar transistor will come to that and there are many other kinds of you know hard electron transistor, it's kind of things are there and this has field effect transistor where you apply field to turn off the channel best example is MOSFET ok, there could be many others like MESFET Metal Semiconductor Junction FET there could be MISFET Metal Insulator FET, there could be HEMT MODFET there are many kinds of transistors that are there we will come to that later.

And these are some of the transistors where you basically use a small current to turn off on the channel by changing the profile. We will started BJT because BJT is more directly related to p n junction and because we have studied p-n junction, we will now be in a good position to actually understand how a BJT can be fabric I mean BJT can be realized or BJT can be achieved by using p-n junction to make a transistor. So, this is the basic idea of the transistor which I hope you are able to follow now ok.

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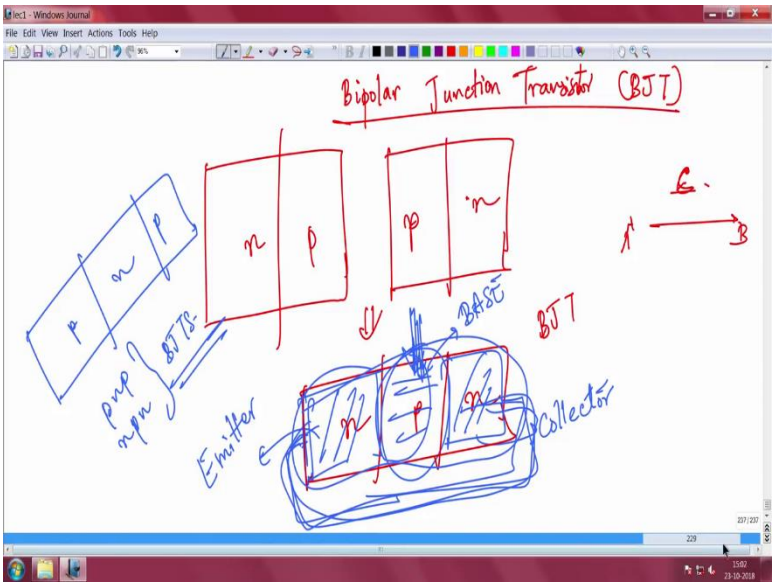

And we will see how a BJT is a Bipolar Junction Transistor the word popular says that both electrons and holes will be there, it is a Bipolar Junction Transistor it's call BJT and this is one kind of transistors which essentially changes the profile of the carriers. So, that you know you can tune how many carriers actually go down how many do not go and that way you control the current between two points A and B, A and B is controlled by the third point C.

So, essentially a bipolar junction transistor actually two p n junctions back to back sorry two p-n junction back to back. So, this is one p-n junction, let me write in the other way n p and this is another p-n junction n-p junction sorry this is p n. You join them together and make one which looks like npn, this is the basic structure of a BJT.

So, this contact this layer is called emitter thus the terminology, this is called collector and this is called base. So, you can see the actually the current between this emitter and the collector the current between emitter and collector can be controlled by putting small amount of current in the base or p type you can put the small amount of current here and control the current here.

So, that is why it is a transistor, this is by changing is very small current here you can make a large change of current here. Similarly you can the other kind of transistor also which is you have a p you have n and you have p, so this is pnp and that is npn both are BJT is only ok. So, you can have BJTs both this type of configuration we will study npn and details.

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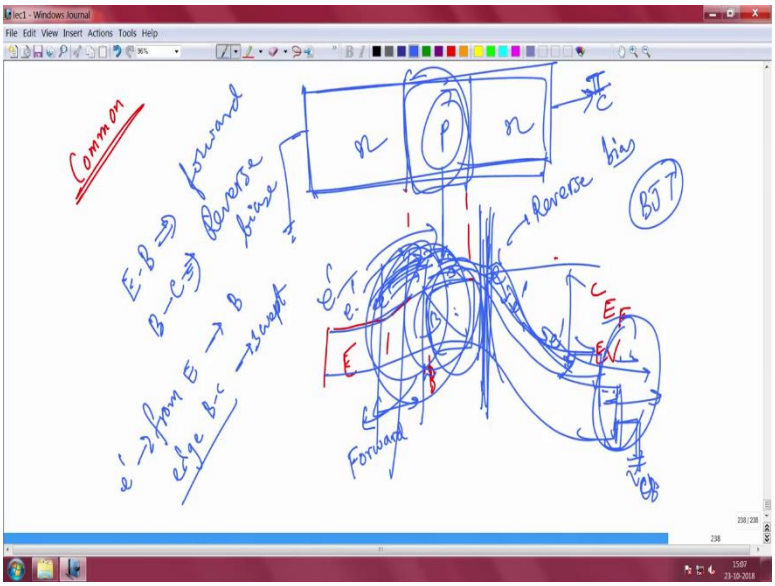

So, what happens is that if I have npn, I told you that the current between this and this emitter and collector can be changed by the you know the bias order the small current in the base we will come to that later. So, suppose you have this how will the and equilibrium, how will the band diagram look? Your Fermi level has to be constant this is n p.

So, in n-p it will look like this if you recall the p n junction like that, this is p-n smooth same band gap everywhere. So, this is how a this is conduction band this is valence band. So, this is how a npn BJT structure looks like ok. Now, how will this be a transistor this is your emitter this is your base, this is your collector ok.

Now for the BJT to operate in it can be operated in different ways, but the most common way to operate it the most common way to operate it is when you want to have some gain amplification and the way you operate this that you forward bias this junction this is a p-n junction know you forward by this junction and you reverse biased is base collector junction, you forward bias the emitter base junction this one and you reverse bias the base collector junction what happen then?

It will like that; it will like that, if you forward bias the emitter base junction electrons from side will go there, holes from this side will come here that is, but electrons from here will go there and the moment they reach and if you reverse bias this junction, if you reverse bias the base collector junction then this will increase know, there is the reverse bias junction you have a large voltage drop here you know.

So, you injecting electron from here to there so the depletion this region has become lower depletion or less depletion, electrons will go to the base they will diffuse across the base simultaneously combine of course, the moment I reach the edge here there will be quickly swept it to the other side.

So, no matter how much voltage you applying here the current will be dictated by the flow only. So, the input current is basically dictated by the base from a level we can say and the output current will not the output current that you are getting here we will not be dependent on the voltage that you applying and collector, here because this determines the current.

So, the electrons you are injected from emitter to the base side they will go across the base the moment I reach across this edge here there will be swept at to the collector side, that is how a transistor works, that is how a BJT will initially start to work ok. So, you forward bias the base emitter junction to the emitter base junction is forward biased and the base collector junction is reverse biased is reverse biased.

So, essentially you are injecting electrons from the emitter to the base and the and it will diffuse across the base and some of them will combine it the because the base as p concentration. So, holes and electrons will recombined some fraction will reach this edge of the base collector junction, as soon as that reaches the edge it will be quickly swept away and contribute to collector current ok.

As soon as it reaches the edge the base collector depletion region the base collector depletion it will be swept away and the current that you get at the output here will be those electrons that I have reach here and that do not depend on the collector voltage they are applying that they depend on the emitter base potential difference only. So, that is how you actually depend you can you can tune the current here by changing the base from a level here ok, that is what is happening basically.

Of course, if all the electrons that we are injecting from here get recombine and the base nothing reaches here then there is no current. So, you have to make a design rule actually you have to understand many of the things here, but this is the basic diagram of a p-n junction the controlling unit is the base the output current is this collector current. So, will call this JC or IC, this is the output current, this is the input current that you have putting to a the base and this is emitter which is usually grounded for example, ok.

There are different modes of operation though that we will come slowly one by one. So, let us end the class here today we will go it slow on the BJT front. So, what did we learned in the class here, we have introduced the concepts of transistor there are many kinds of transistors that we have learn today we have transistors that too many kinds of device working there are transistors that do memory, that there are transistors that do logic there are transistors that do amplification, that transistors that worked as switch ok.

So, transistor essentially is a three terminal device where the current between two terminal can be dictated by the potential or the current that a third terminal that is called transistor and we have introduced the concept of BJT as two back to back p n junction; p n junctions two back to back p n junction one of them is forward biased, one of them is reverse biased the idea is that the forward biased junction will inject electrons that will diffuse across the base some of them will recombined there in the base because the base is p type dope, some of them will reach the edge of the collector depletion as soon as they reach the edge of the depletion they will be swept away.

So, this is the basic functioning of a BJT we will come to the next class, in the next class and we will step by step learn what are the different current components in BJT how does amplification happen and how will a BJT work and what is the gain of a BJT so many things are there. So, next few lectures will be devoted to understanding BJT and where other areas where BJT is a practically used today ok.

Thanks you for your time.