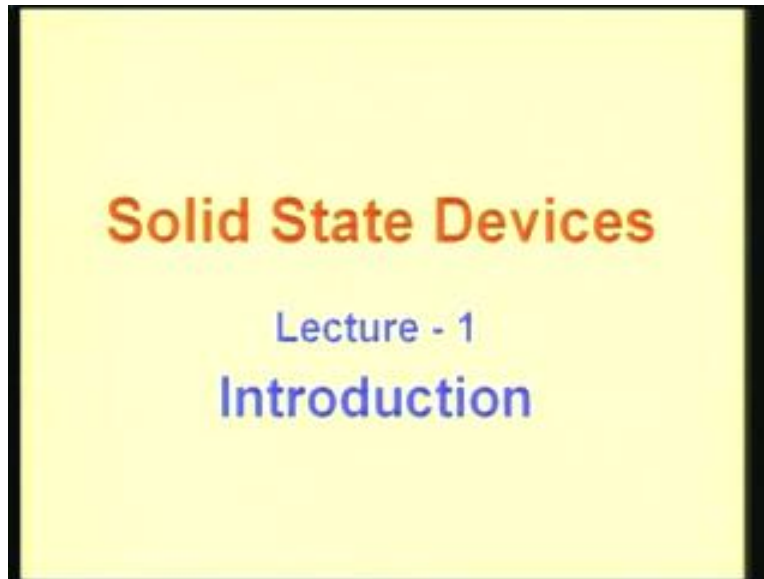


Solid State Devices
Dr. S. Karmalkar
Department of Electronics and Communication Engineering
Indian Institute of Technology, Madras
Lecture - 1
Introduction

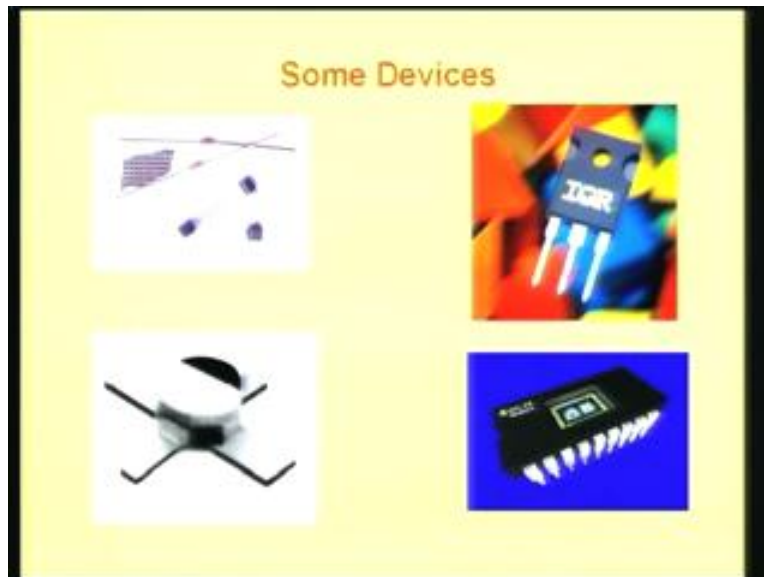
Welcome to the course on Solid State Devices.

(Refer Slide Time: 01:11)



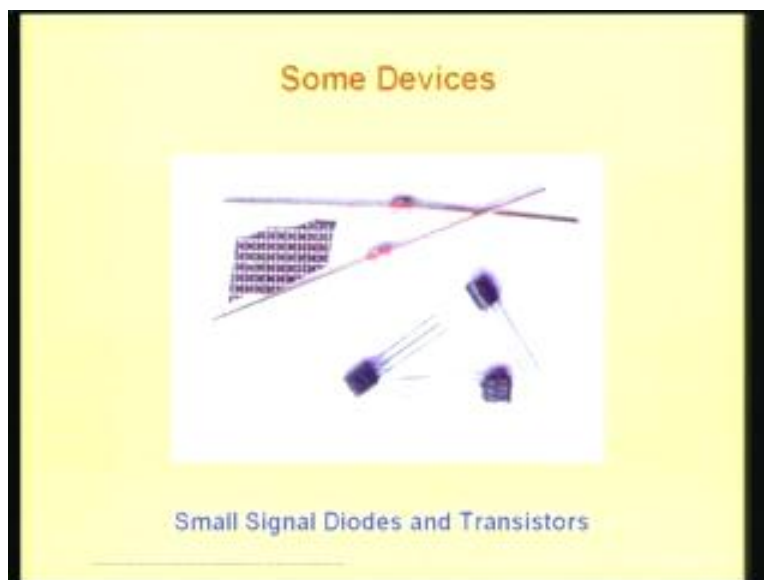
It is not uncommon to see electrical engineers treating Solid State Devices or semiconductor devices as black boxes to be used in the design of circuits. But, with the semiconductor technology spearheading rapid advances in newer and newer areas of electronics and day-to-day life, it has become necessary for an electrical engineer or an electronic engineer to know in some depth about semiconductor devices. That is why a course such as this is very important in the curriculum dealing with electrical or electronic engineering. In the first two lectures we will discuss about how we shall go about the various topics, the plan for the course, the importance of semiconductor technology and some unique features about this. Let us start with diagrams or pictures of a few devices.

(Refer Slide Time: 03:13)



So here are a few devices. Let us try to classify the various devices that we come across.

(Refer Slide Time: 03:25)



Here is a set of small signal diodes and transistors. So, you can classify devices based on the power that they handle. You have small signal devices and power devices. Basically all these devices try to modify and amplify electrical power.

(Refer Slide Time: 03:54)



This is an example of a power device; a high power insulated gate bipolar transistor. You see, the outward construction of this device is somewhat different from the small signal diodes and transistors which we saw. Mainly the difference is that a power device has to handle large amounts of power and therefore it must be able to dissipate heat efficiently. Also, since it manages large amount of power it is bigger in size. That is clearly evident in this particular diagram. So, this is a much bigger transistor than the small signal transistor we saw. You see here, this particular hole in this package is meant for attaching a heat sink which will enable us to efficiently dissipate the heat. So, one must remember when we are talking of devices, the package that is used for housing these devices is also very important. However, we will not be dealing with packaging issues in this course, but we must not forget that packaging is also quite important for semiconductor devices.

(Refer Slide Time: 06:03)



(Refer Slide Time: 05:12)



Here is another device:

The High Electron Mobility Transistor is a device is used for high frequency amplification. Note that the package of this device is quite different from the package of the devices that we saw just now for high power and small signal applications. So this kind of package is suitable for high frequency applications. So, this is another way of classifying the device: you can have high frequency devices and low frequency devices. Now, apart from this there are other ways of classifying devices. For example, you have discrete devices and you have what are called Integrated circuit devices. Let us look at one such diagram here.

This is a Monolithic Accelerometer. You see, there are two chips here. The chip on the right contains a number of devices integrated on a single semiconductor substrate. So this is an integrated circuit. On the other hand, the device on the left is an Accelerometer Chip that is a device which converts acceleration into electrical signal. These kinds of devices are called Mems devices, that is, Micro Electro Mechanical Systems; mainly they involve conversion of mechanical energy to electrical energy and vice versa. These are new kind of devices which are coming up and which have wide applications. Like the Mems devices which convert electrical energy to mechanical energy and vice versa, you can also have what are called Optoelectronic devices.

(Refer Slide Time: 07:22)



Here is a laser diode. It is an Optoelectronic device. Here you are pumping in electrical energy and what you are getting out is a ray of light, in this case, blue light. So here you are converting electrical energy to optical energy. These kinds of devices are called Optoelectronic devices. You can also have conversion of light energy to electrical energy. So you see these devices like the Mems and the laser diode are Optoelectronic devices which involve conversion of energy of one form to other energy.

This is how we can classify the devices: small signal power devices, low frequency by high frequency devices, discrete devices, integrated circuits, and then you have devices for Mems and Optoelectronic applications which involve conversion of one form of energy to another form. It will be necessary for us to understand why all these different kinds of devices have become so important. For this purpose it is useful to look at the entire spectrum of systems which are used in electrical engineering.

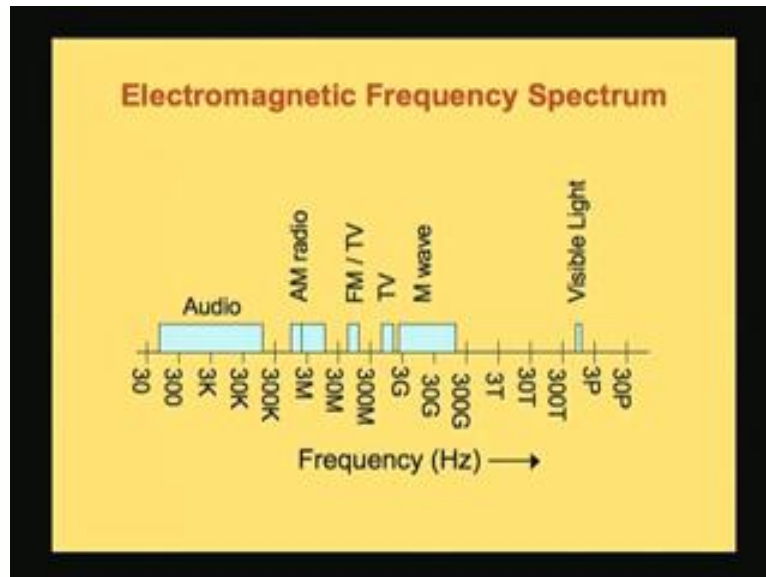
(Refer Slide Time: 08:49)



Now, what do the devices do in general? The devices serve to enhance performance, reliability, and cost effectiveness of energy systems and information systems. So the systems used in electrical engineering can be broadly classified into energy systems and information systems. Now, what are the energy systems? As you see energy systems are involved in generation, distribution and regulation of electrical energy. So here the aim is to manage larger and larger amounts of energy and power. As against this, the information systems store, process and communicate information. Here the aim is to manage larger and larger amounts of information using lesser and lesser amount of power. So you want to store large amount of information, you want to communicate large amount of information in a speedy manner and you want to do all these things using as low a power as possible.

So you can classify devices based on those which are used for energy systems and those which are used for information systems. But whatever the systems that may be under consideration the devices that are used in these systems, if they are made from semiconductors, they help you to enhance the performance, reliability and cost effectiveness. That is the reason why the semiconductor devices have become so important. Now, when we are talking of information systems it will be very useful to look at the Electromagnetic Frequency Spectrum used for communication purposes. This allows you to look at the entire spectrum of devices in another way.

(Refer Slide Time: 10:44)

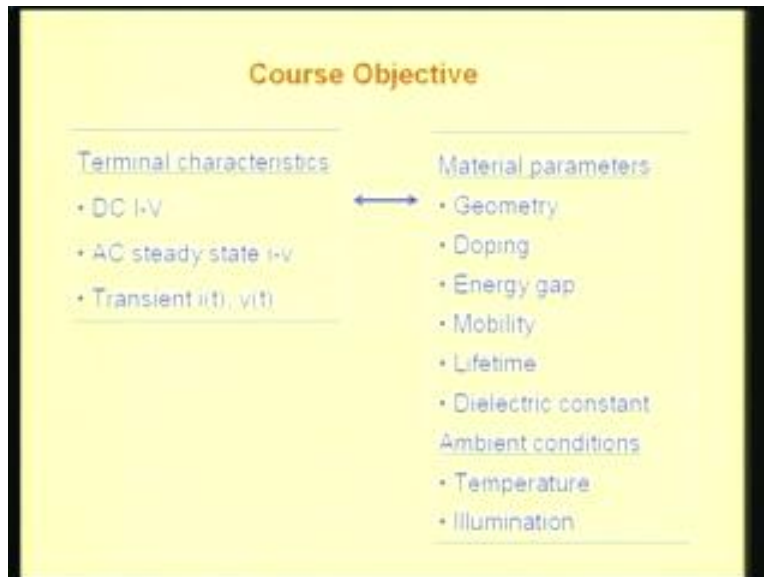


So, you see here the range of 300 to about 30 KHz frequency. This is the frequency of electrical or electromagnetic signal. This particular range 300 to 30k is used for audio applications. As we go higher you see around 3 MHz where you have the amplitude modulated radio - wireless communication. Then you have wireless communication for FM and TV applications, that is, between 30 MHz - 300 MHz. You also have another band of frequencies for TV communications around GHz range. Beyond this you have the microwave range. This range is normally used for communication using satellites and so on.

And ultimately you have a gap and then you have very high frequencies of the order of PHz, between THz and PHz which correspond to visible light and this range is also being now considered for communication applications and that is where you have the importance of optoelectronic devices. So, based on the frequency spectrum you can also see how a variety of semiconductor devices are required. So you require devices for audio applications in stereo systems, music systems and so on. You require devices which will be involved in wireless communication right from MHz range to 10 (GHz) ranges, that is the microwave range, and then you require devices at the frequencies which correspond to visible light. So this is another way of looking at the entire spectrum of devices. Now, when we talk about the frequency spectrum many of you may have doubts as to why there are gaps in this spectrum.

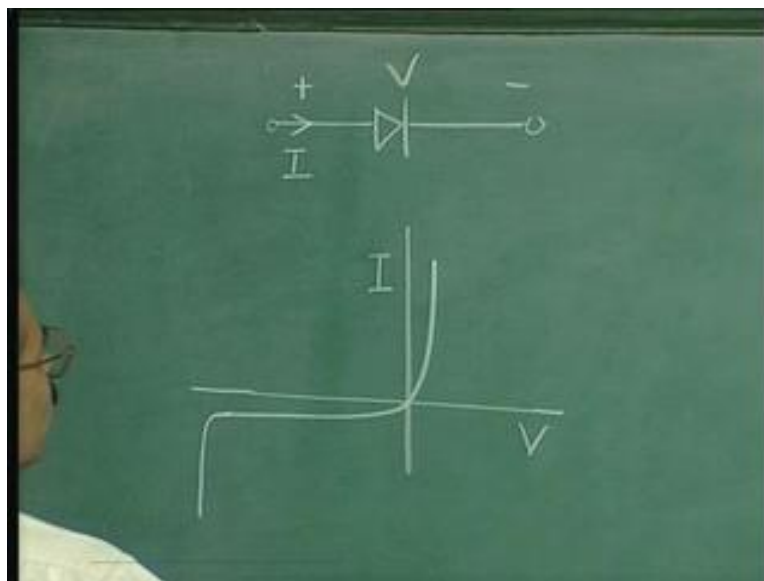
Now, this is an interesting topic as to why there are gaps in the frequency spectrum used for communication purposes. This is beyond the scope of the present course. You will come across this subject when you talk about communication. Having discussed the classification of semiconductor devices and also seen why these devices are important, it is because they enhance the cost effectiveness and reliability and performance of the systems in which they are used. We are now ready to look at exactly what are the objectives of our course.

(Refer Slide Time: 14:07)



The specific objective of this course is to relate the terminal characteristics of devices to material parameters and ambient conditions. Now, let us look at this topic or this course objective in a little bit detail to understand exactly what we are going to do. So far, we have been using the devices as black boxes, that is, until you have come to this course you have used various devices as black boxes wherein you know the terminal characteristics of the devices and you do not bother as to how these terminal characteristics are obtained, but you are concerned with using devices with specific terminal characteristics for particular circuit applications.

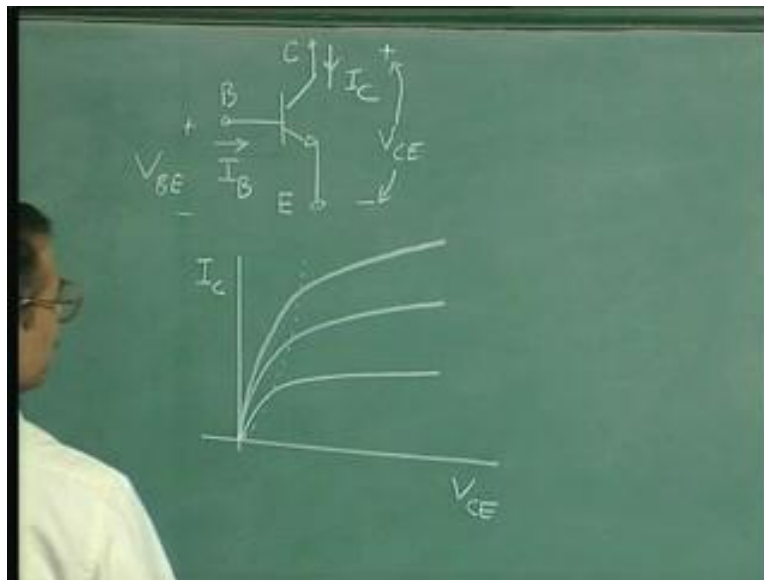
(Refer Slide Time: 15:13)



For example, let us look at the diode.

You are familiar with the symbol of the diode. Now, you are also familiar with the terminal characteristics of this device. When you are talking of terminal characteristics we talk about the current as a function of voltage. So you apply a voltage across this device and in response to this voltage a current flows. You try to relate this response, that is, a current to the stimulus, that is, the voltage, the current voltage characteristics. For all the Solid State Devices or semiconductor devices the important characteristics of interest are the current through the device as a function of the voltage applied. So far, you have treated diode as the black box which gives a rectifying current versus voltage characteristics. If you go to very high reverse biases you know the device breaks down. You know several application of this particular device. For example, you know that the diode can be used for rectifying purpose. Similarly a diode in break down can be used for generating a stable voltage independent of the current.

(Refer Slide Time: 16:48)

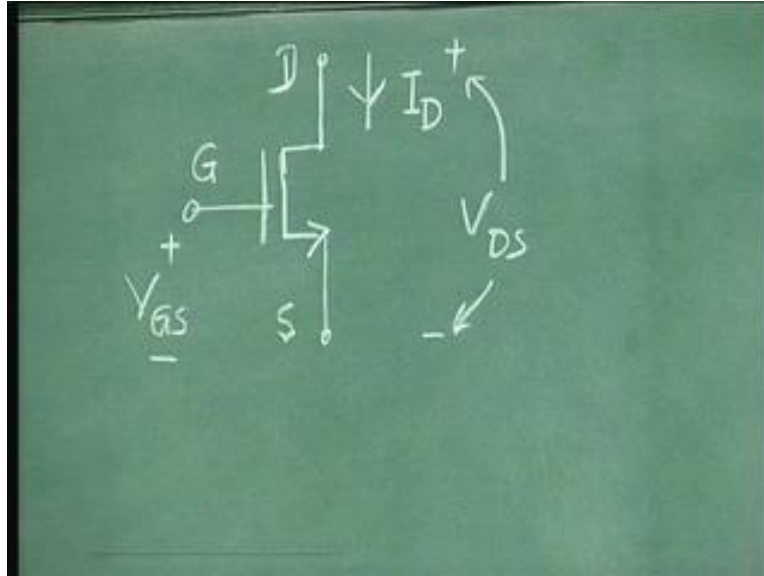


Another example of a device that you know is the transistor, the bipolar junction transistor. So this is a three terminal device unlike the diode which is a two terminal device. So here, you know the input is a current; this terminal is called the base terminal, this terminal is called the collector terminal and this terminal is called the emitter terminal. Now the input is between base and emitter, you have an I_B or base current as input and you have a collector current as output.

Now, you also have input and output voltages. For example here between base and emitter you have an emitter based voltage V_{BE} and similarly here between collector and emitter you have a voltage that is V_{CE} collector to emitter voltage. Now, the terminal characteristics of interest for this device are the collector current I_C as a function of the collector to emitter voltage V_{CE} so I_C versus V_{CE} which is controlled by the base current. So, for different base currents you have different collector currents as a function of the

collector to emitter voltage. Like the bipolar junction transistor you also know of the MOS field effect transistor. So the symbol for MOSFET is something like this.

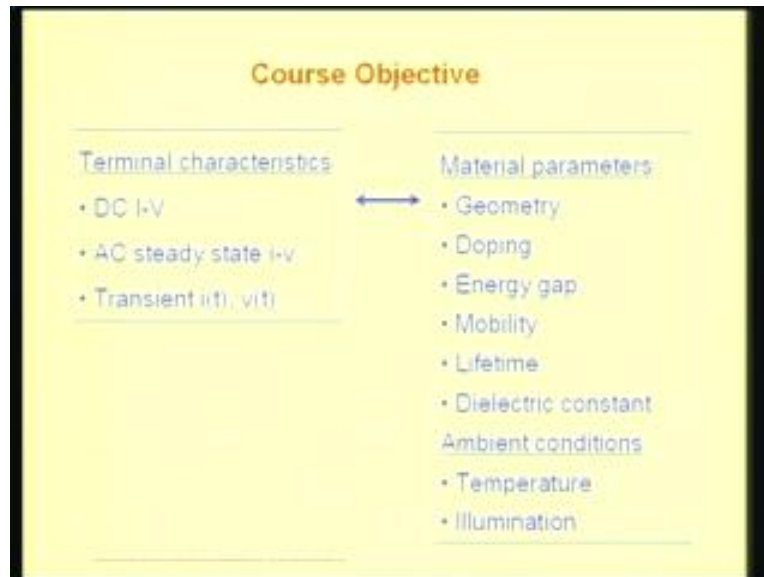
(Refer Slide Time: 18:48)



We will discuss the symbol in detail. Here I am drawing a very simple MOSFET symbol which shows it as a three terminal device and here you have the drain, the source, and the gate. Like the bipolar junction transistor the MOSFET also has input and output sides. On the input side it is a voltage. Unlike the bipolar junction transistor there is no current flowing in this lead in the gate. On the output side you have the drain current which is analogous to the collector current of a bipolar transistor and you have the drain to source voltage. Now, the characteristics of interest for this particular MOSFET also looks very much like this. If you replace I_C by I_D , V_{CE} by V_{DS} , and I_B , for bipolar transistor this is I_B increasing, instead of that in a MOSFET you have gate to source voltage increasing.

Now this is an NPN transistor where current flows because of electrons and this is an N channel MOSFET where also the current flows because of electrons. You can have PNP transistor and P channel MOSFET. So, here the current will flow because of holes. Now, so far we have been working with these characteristics - the current voltage characteristics - how to use them and make amplifying devices or amplifiers; how to use these diode characteristics and make rectifiers or stable voltage sources in this particular range which is called the breakdown voltage. Now, in this course we will try to get into these black boxes or these devices and try to understand what are the phenomena taking place in this device which gives rise to these kinds of characteristics. And we will try to use this knowledge of the physical phenomena to relate the terminal current to the voltage using an equation. So this is a terminal current and this is the voltage. Of course, you have another controlling voltage and current. So, that is the goal of this course. It is like trying to understand the psychology of semiconductor devices.

(Refer Slide Time: 21:47)



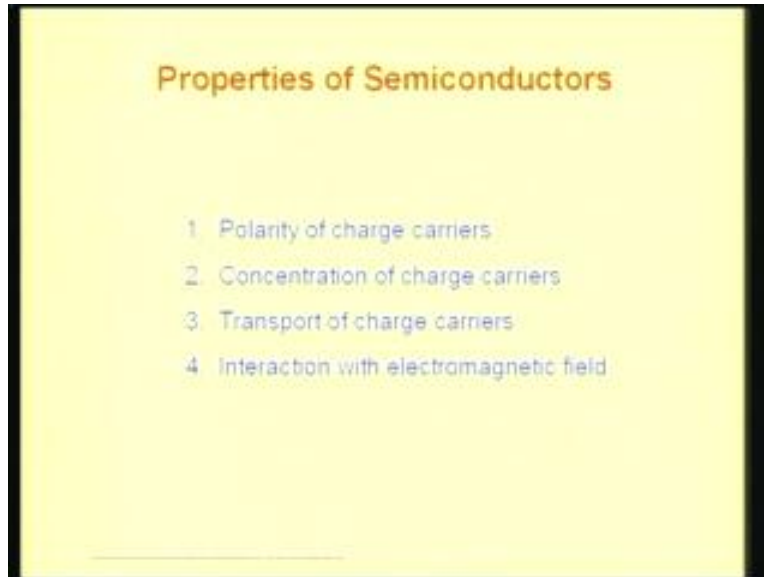
So as shown in the slide here the course aims at relating the terminal characteristics to parameters of the device and the ambient conditions. Now, what are the terminal characteristics? You see the terminal characteristics are the DC current voltage characteristics which we have drawn here. You also have what are called small signal characteristics or as shown in the slide the AC steady state small signal characteristics that is small “i”. “I” indicates a DC current, whereas “i” indicates an AC current. So a small AC current or in response to a small AC voltage is superimposed on the DC bias or DC currents. Another kind of terminal characteristics are the transient characteristics wherein you apply a time varying voltage, a sudden change in the voltage and you try to see how the current changes as a function of time.

Now, in this course, we will focus only on the DC and the small signal characteristics. We will not do the transient characteristics. Now these characteristics, the current voltage characteristics, will be expressed in terms of material parameters and ambient conditions. What are the material parameters associated with the device? As the slide shows these are the geometry of the device, the doping level, you know in semiconductors we use impurities to change the concentrations of electrons and holes, so that is called doping. Then you have other parameters about which we will be discussing in detail such as the energy gap, the mobility, the life time - this is a parameter associated with transient and small signal response wherein you have changing voltages applied, changing of the function of time, when things change in the function of time how does a device respond? Then you have another parameter namely the dielectric constant.

The ambient conditions of interest are temperature and illumination. So the characteristics of semiconductor devices are quite sensitive to temperature and also they may be sensitive to the intensity of light falling on the device if the covering on the device is not proper or sometimes intentionally we want to make the device very sensitive to light as in optoelectronic devices. So, that is the goal of our course: relating terminal

characteristics to internal physical parameters, material parameters and ambient conditions by equations, by understanding the various phenomena taking place in the device. So let us begin by understanding the essential properties of semiconductors which enable us to make various kinds of devices.

(Refer Slide Time: 25:29)



The properties of semiconductors:

We shall look at four properties, we will be looking at these properties in detail during the course, but here let us just briefly see some points about each of the characteristics of each of these properties. Now the four properties we have listed here are: the polarity of charge carriers, concentration of charge carriers, transport of charge carriers and interaction of semiconductor with electromagnetic field. Now, how do you remember what are the various properties of semiconductor devices that we should be concerned about? There is a very simple way of remembering this. You know as we have said, we are interested in the current voltage characteristics of the device. Let us look at current flow.

What is the current flow due to?

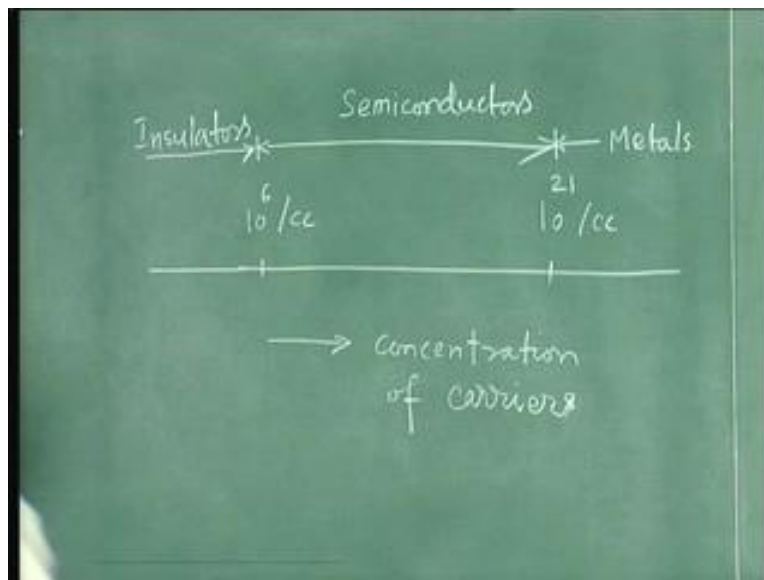
Now you know that current flow is because of flow of charges. So the first question that comes to our mind is: what are the polarities of charges? Do you have positive and negative polarities or do you have only negative polarities as we come across in metals. What is the concentration of these charged carriers, because if the concentration is more, the current flow will be more?

Then related to the current flow another property you know would be the velocity with which the carriers move because if the velocity with which the carriers move is more, the current will be more so that is where we come across the transport of carriers. And you would also like to know how the carriers are transported. So, that is how starting from the phrase “current flow” we immediately come to three properties: that is the polarity of charge carriers, the concentration of charge carriers and the transport of charge carriers.

Now as we have said you use devices also for converting one form of energy to another form; therefore you would like to know how a semiconductor crystal interacts with other forms of energy.

Most importantly: how does it interact with electromagnetic field? There are very interesting kinds of characteristics that we can get out of such an interaction. Let us start with the polarity of charge carriers. You know, in semiconductors you can have both positive polarity and negative polarity - that is one big difference between the semiconductors and the metals. In metals we only have negatively charged carriers. The positively charged carriers in semiconductors are called holes. Why are they called holes? Well we will see it during the course. Then let us come to the concentration. A very interesting property of semiconductors is that its concentration can be varied over several orders of magnitude. We can show this on a diagram as follows.

(Refer Slide Time: 28:36)



So supposing this is a scale which shows the concentration of carriers in different materials. This is a logarithmic scale so that you can show several orders of magnitude. Let us say this point indicates about 10 to the power 6 carriers per cm cube. When we talk of carriers it could be either holes or electrons because we are taking of semiconductors. But in metals it would mean only one type of carriers: the electrons. In metals your charge carrier concentration is beyond 10 to the power 21 per cm cube. These numbers here are given per cm cube. So beyond this 10 to the power 21 you have the metals whereas below 10 to the power 6 you have the insulators and in between 10 to the power 6 and 10 to the power 21 you have the semiconductors. So the concentration of charge carriers in semiconductors varies over almost 15 orders of magnitude; 10 to the power 6 to 10 to the power 21. Now note that these boundaries are not very hard and fast, these are rough boundaries. So this is not precisely below 10 to the power 6 that you have insulators but around 10 to the power 6 by cm cube is the boundary between

semiconductors and insulators. Around 10 to the power 21 is the boundary between metals and semiconductors.

Now, what are the various ways in which we can achieve this variation in concentration? You can achieve this variation in concentration by introducing impurities into semiconductor, that is, by doping, or by shining light that is by illumination. You can also vary the concentration by changing the temperature. So these are several ways in which you can vary the concentration in semiconductors: doping, illumination and temperature variation. Now let us look at the third property shown on the slide.

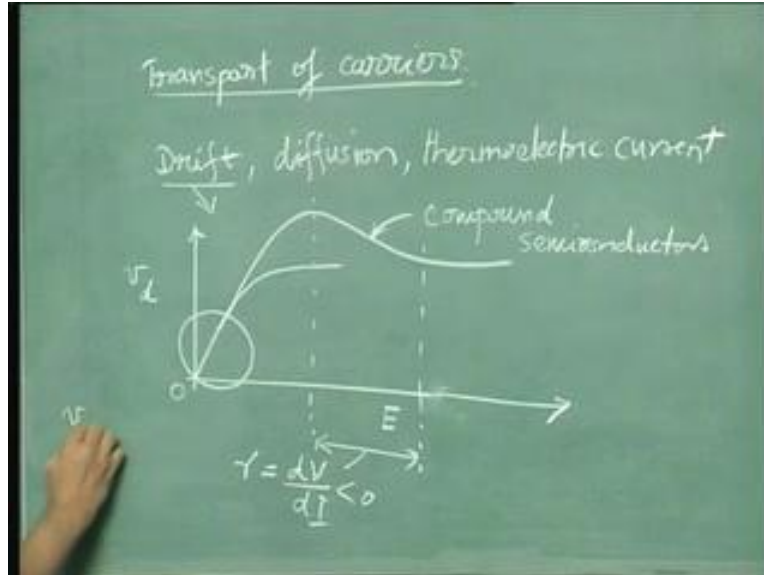
(Refer Slide Time: 31:36)



The transport of charge carriers:

In semiconductors you can have several ways of transporting charge carriers; in metals, you know that current flows whenever you apply an electric field. This kind of transport is called drift.

(Refer Slide Time: 32:03)



In metals your current flows only because of drift, but in semiconductors current can flow also because of what is called diffusion. So like drift is transport of carriers because of potential gradient, one point you have high potential and at another point you have low potential, you have potential difference between two points and therefore the carriers are transported.

Carriers are transported because they have charge and charge responds to electric field, that is why drift occurs. In diffusion you have flow because concentration of charge carriers is different at different points in a semiconductor. As we have seen the concentration of carriers can be varied over a very wide range in semiconductors; therefore, the possibility of diffusion in semiconductors is very strong. So diffusion current is the current because of concentration gradient as against the drift which is the current because of potential gradient. So diffusion is another mechanism of transport. You also have thermoelectric current. This is another mechanism of current flow and this is because of temperature gradient.

When you have different temperatures at different points in a semiconductor you can have significant flow. Thermoelectric currents and diffusion currents are not significant in metals so that is the uniqueness of semiconductors that you can have all these three kinds of flows. In fact that is why you can make different kind of devices and you have very interesting characteristics.

Let us look at the drift transport in detail. A characteristic that is associated with the drift transport is the drift velocity achieved by the electron in response to an electric field. This drift velocity versus electric field normally has a characteristic like this in conductors or metals. So the drift velocity increases as increase in electric field, in the small electric field region this variation is linear, but as you increase the electric field this becomes sub linear and ultimately the velocity tends to saturate. In most semiconductors this kind of a

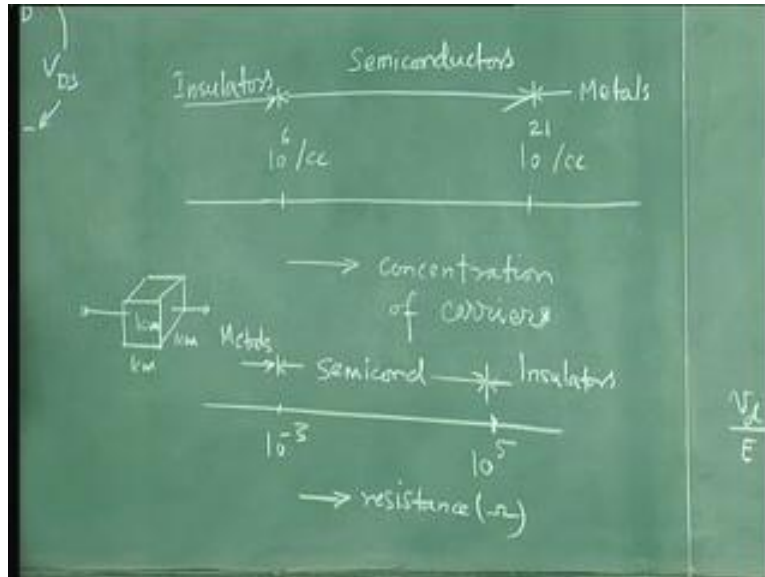
behavior is there, but in certain semiconductors, such as the gallium arsenide which are called compound semiconductors, you have an interesting kind of behavior, where the drift velocity increases with the electric field, reaches a peak and then it falls before saturating. This is what happens in compound semiconductors, this is a very interesting characteristic. Now, because of this, what happens is that in this region the current would be decreasing when you increase the electric field because current is proportional to drift velocity, so we are talking of drift.

If current decreases with electric field in this region, it is a situation of negative differential resistance because dI by dV is negative. So dV by dI is related to this drift velocity versus electric field characteristics because voltage decides the field and the drift velocity decides the current. A negative slope of V_d versus E would imply in this range, a negative differential resistance dV by dI , so r is equal to dV by dI is lesser than 0 in this range for compound semiconductors. There are very interesting applications of this property of negative resistance. This is something that you cannot get in metals. Negative resistance can be used to make oscillators. This we will not discuss in detail. We are only mentioning some interesting characteristics of semiconductors related to carrier transport.

Drift velocity versus electric field behavior for small electric field, that is this range; the drift velocity by electric field ratio here is a constant so V_d by E is a constant and it is called mobility. Mobility decides what is called the resistivity of sample, so resistivity depends on the carrier concentration and the carrier mobility. The mobility can be varied by the several means in semiconductors. When you vary the mobility you get a variation in the resistance or resistivity and that is of a very interesting application.

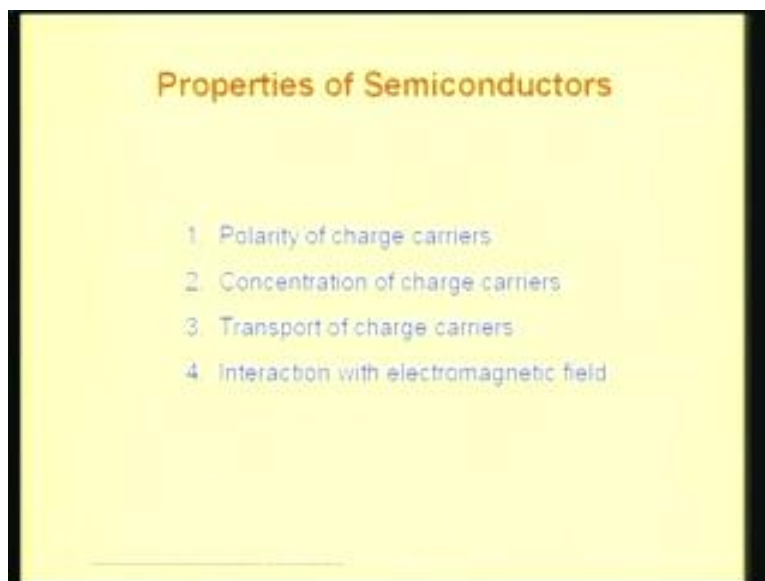
For example, piezo resistivity, where because of change in pressure you change the mobility and you change the resistivity as a consequence. So you change the dimensions of a semiconductor because of pressure and you get a change the resistivity because of change in mobility. This is called piezo resistivity. These kinds of interesting applications are there where mobility changes because of factors such as temperature, pressure and so on. As a result, you can have variation in resistivity, you can show that also on a diagram like this.

(Refer Slide Time: 39:06)



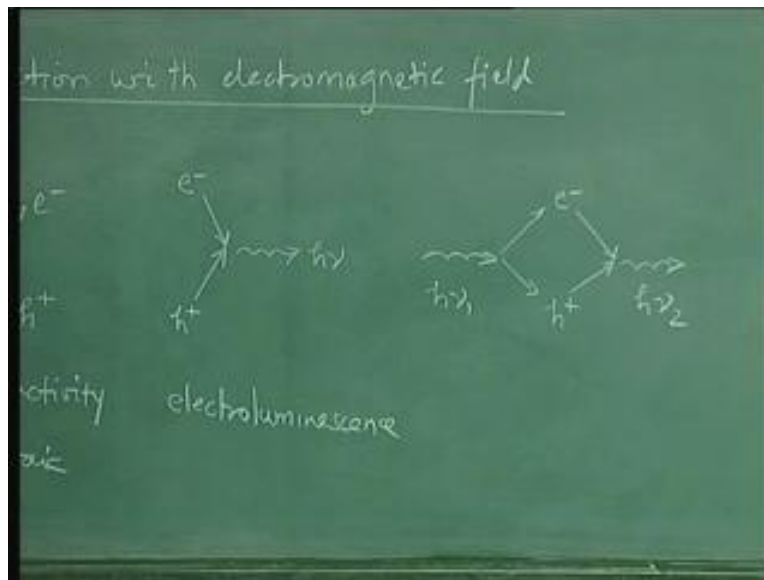
So here we see the resistance of cube which is 1 centimeter by 1 centimeter by 1 centimeter in size and we are measuring the resistance between two opposite phases and we are plotting this resistance for different materials. For semiconductors, the range is from 10 to the power minus 3 to 10 to the power minus 5 this is in ohms. So we are talking of resistance in blocks, semiconductors. Here you have insulators on one side and on the other side you have metals. So again there is a very wide range in resistance variation because of change in the concentration and also change in mobility. So these are interesting properties related to the charge transport.

(Refer Slide Time: 40:37)



Let us look at the 4th property on the slide that is the interaction of semiconductors with electromagnetic field. When the light falls on any surface, part of it is reflected and part of it is absorbed. When light falls on a wall for example, the part of the light that is absorbed results in slight increase in temperature of the wall; otherwise there are no significant effects. But when light falls on a semiconductor, the part of the light that is absorbed gives rise to several interesting phenomena.

(Refer Slide Time: 41:20)



Let us look at them. One possibility is, for example: This is the light wave, ν is the frequency of light falling on an atom of semiconductor. The bonds break and the result is an free electron and a hole, so electron and hole pair generation because of light falling on an atom. So energy is absorbed and it results in breaking of the bond and it gives rise to electron hole pair. As the result of this generation of free carriers, the conductivity of the semiconductor changes and therefore this effect is referred to as photoconductivity. This effect can also be called photovoltaic because this generated electron hole pairs can give rise to a voltage between two terminals of a device.

You can also have the reverse effect, that is, you can have the situation where free electrons and holes in semiconductors they recombine and the energy is given away as light. This effect is called electroluminescence. That is, input energy is electrical and output energy is light. You can also have a combination of effects as shown here, that is, light falling on an atom gives rise to electron hole pairs and this electron hole pairs recombine and give rise to a light output where input is light output is also light but obviously the frequencies of the two cannot be the same because there will be some energy loss, so ν_2 is lesser than ν_1 and this effect is called photoluminescence where input is light and output is also light. In semiconductors, you have all these possibilities of interaction of light. That is, you can have photoconductivity or photovoltaic effect, you can also have electroluminescence or you can have photoluminescence.

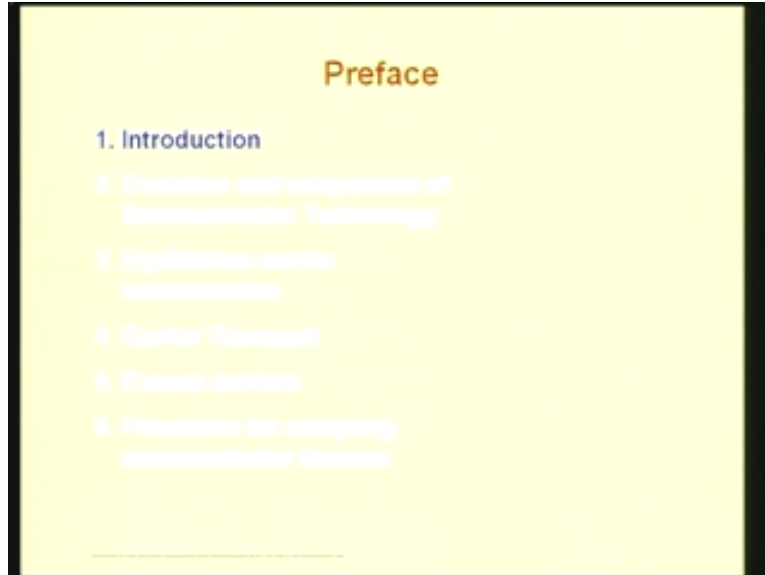
In fact the electroluminescence phenomenon is used to make the light emitting the laser diodes: input is electrical energy and output is light. Similarly, photoconductivity and photovoltaic effects are also useful. Photoconductivity is used to detect light so you have a resistor whose resistivity changes when light falls; change in resistivity is used for detecting the light. On the other hand, in the solar cells you have photovoltaic effect where light is the input and it generates an electrical energy. So you have a voltage source generated as result of absorption of light. These are the important properties of semiconductors. Now, let us look at the plan for this course.

(Refer Slide Time: 45:03)

Course Contents	
Preface	2 lectures
Part 1: Fundamentals	16 lectures
Part 2: Devices	24 lectures
	42 lectures

You have 2 lectures as preface and these lectures include the present lecture which introduces the course. Next lecture will deal with some interesting aspects of semiconductor technology. So these two lectures which form the preface act like appetizers for the course. Then we will discuss fundamentals of semiconductors in 16 lectures in part one and in the remaining part of about 24 lectures we will discuss the various devices. So total of 42 lectures are there in this course. Now, let us look at the details to be covered.

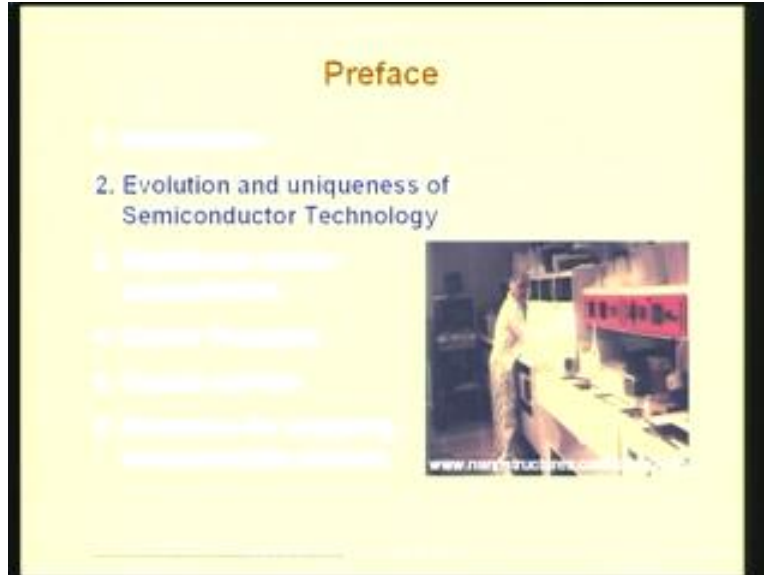
(Refer Slide Time: 45:58)



In the preface, first lecture is Introduction and the second lecture is Evolution and Uniqueness of Semiconductor Technology. In this, we will see many aspects of how this technology has evolved and become so important.

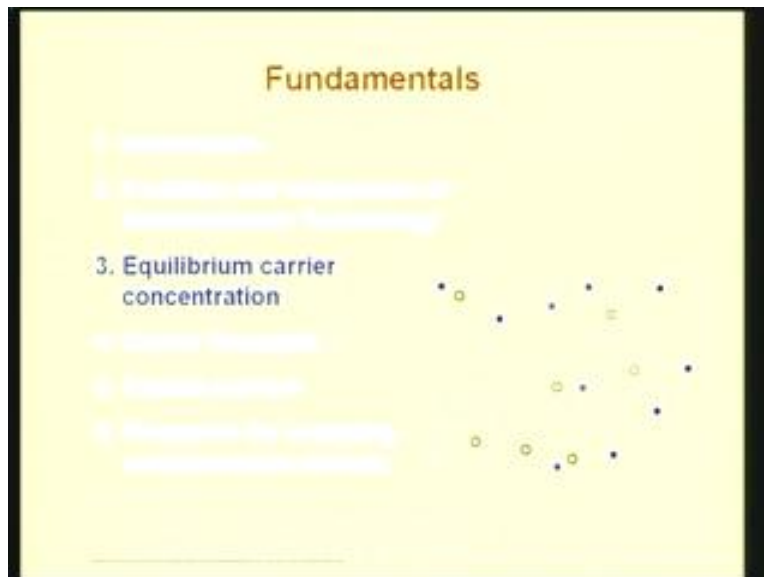
The next topic of discussion would be equilibrium carrier concentration - how the carrier concentration varies as the function of temperature in pure and doped semiconductors, to which no impulse other than temperature or thermal energy is important. We will find the generation and recombination of electron hole pairs give rise to a picture which looks something like what is shown in the slide. So you see appearing and disappearing dots and circles; circles are holes and dots are electrons.

(Refer Slide Time: 46:10)



Next we will discuss how the carriers are transported, so under equilibrium conditions, that is, when there is no impulse applied the carrier in semiconductor are in random thermal motion as shown in the slide. This movement is like the movement of dust particles. Over and above this random movement a directed movement is super imposed by several means.

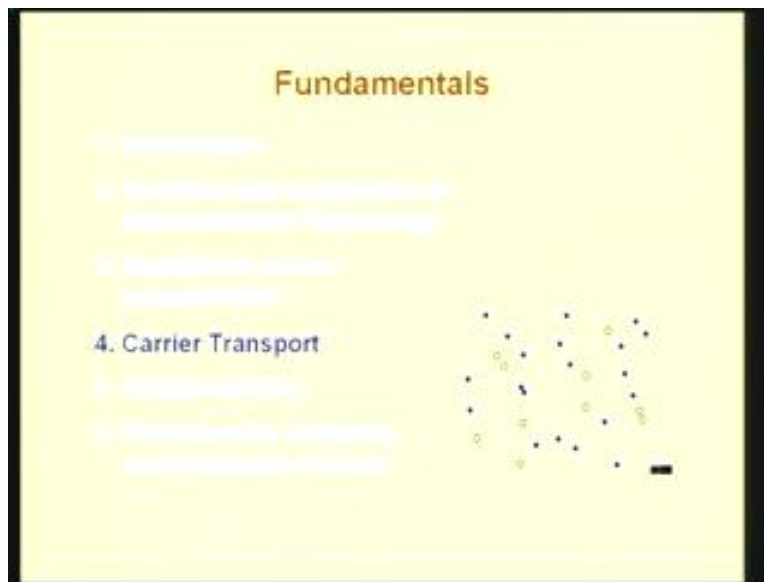
(Refer Slide Time: 46:20)



For example, if you apply an electric field, you find holes moving from left to right in a direction of electric field and electrons moving from right to left. This directed motion is superimposed over the random motion so you have a combination of the two. Now what

is the velocity acquired by the carriers? These are the issues that we will discuss in carrier transport. There are factors other than electric field which can give rise to motion such as concentration gradient and so on. Next topic of discussion would be excess carriers. So as shown in this slide for example, if you have the semiconductor at equilibrium and if you switch on a light source which is right next to the semiconductor, slowly the carrier concentration will increase as shown in this slide and then it will acquire a steady state. Now there is a finite non-zero time that elapses between the steady state and the instant at which the impulse is applied.

(Refer Slide Time: 47:04)

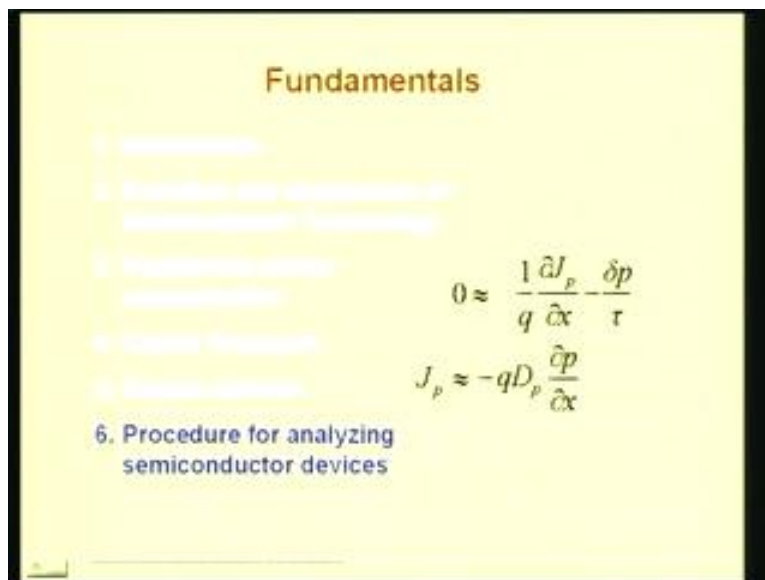


As we will see this time is related to a fundamental parameter of semiconductor namely life time. The life time also controls the decay of carriers when the impulse is switched off. Now you see that the impulse has been removed and the carriers are slowly decaying to their initial concentration that is concentration when there was no light source. This kind of response of carriers is what governs even the dynamic characteristics of devices where you vary voltages applied to the device. The next topic of interest would be procedure for analyzing semiconductor devices so we will combine the various ideas that we discuss in carrier concentration, carrier transport and excess carriers, and show how we can find out the currents and potential conditions within the device for given applied voltages.

(Refer Slide Time: 48:20)

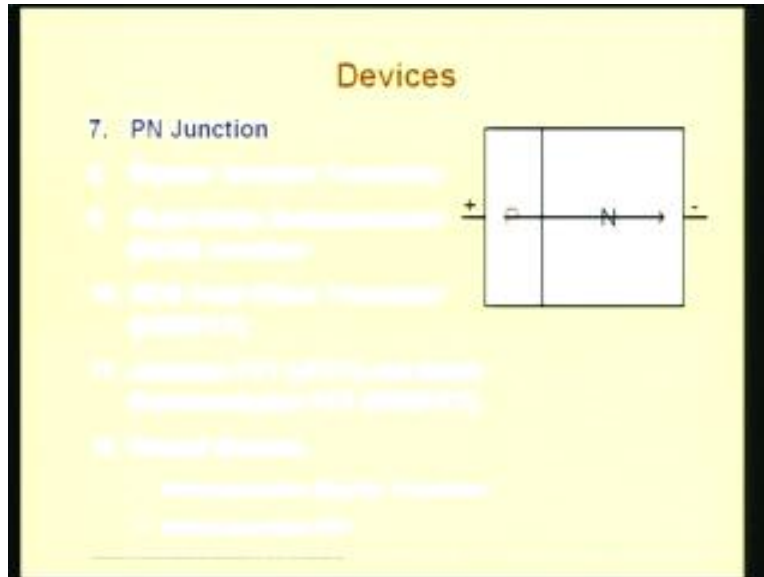


(Refer Slide Time: 49:40)



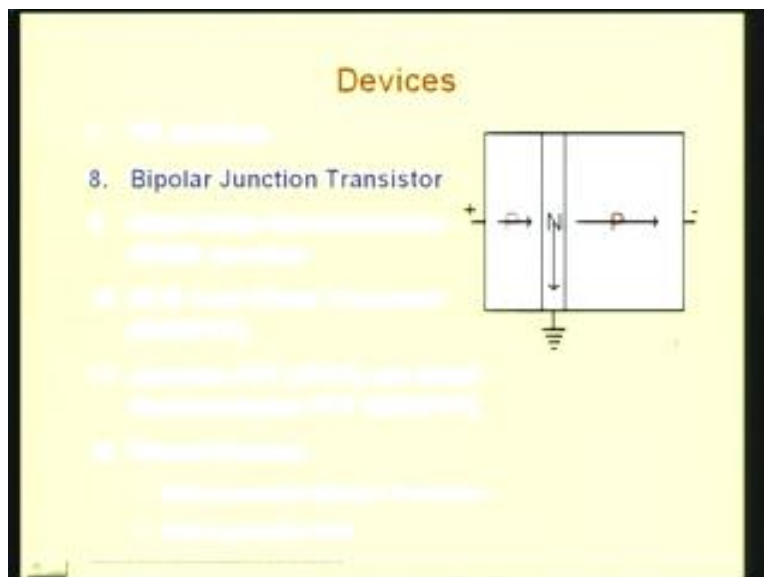
Essentially here, you will have a set of equations like the one shown here. These are some differential equations associated with for example hole current, P here in this slide, stands for holes. The main thing to be discussed in this procedure is how to approximate these equations and simplify them by ignoring various terms. It is said that engineering is the art of making approximations. So always you are dealing with the complex situations and you want to find out the variables that are really important to be taken in the account and what are the variables that can be ignored. This is essentially what we shall discuss in this procedure for analyzing semiconductor devices; how to get simple equations representing the phenomena.

(Refer Slide Time: 51:02)



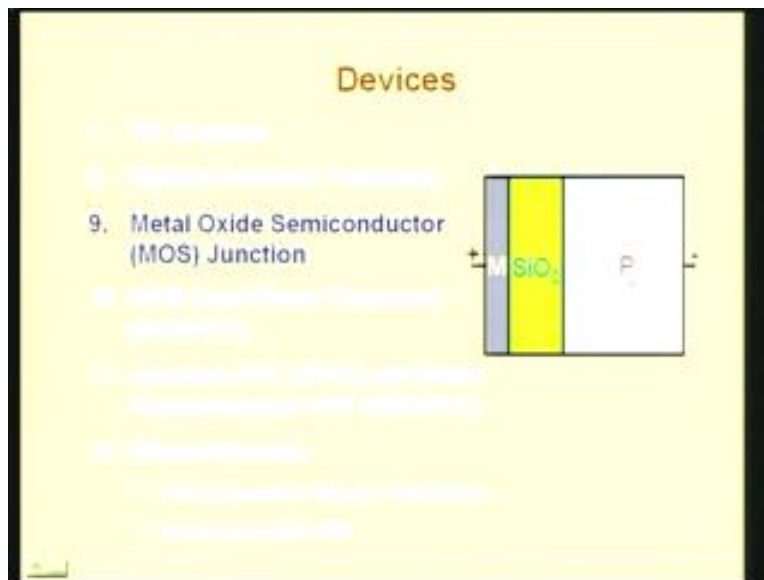
Next we will come to devices. So far, whatever we have discussed is a part of fundamentals and preface. The first device we will discuss is the PN junction - both forward and reverse characteristics of PN junctions will be discussed. Next we will discuss a characteristic of bipolar junction transistor. Bipolar junction transistor is a device that is obtained when you put two PN junctions in close proximity as shown in this slide. This is a three terminal device so you have what are called input terminals. In this case, it would be this terminal here, which is the positive terminal P and this terminal which is N this constitute the input and this terminal the negative terminal here, and the ground constitute the output.

(Refer Slide Time: 51:20)



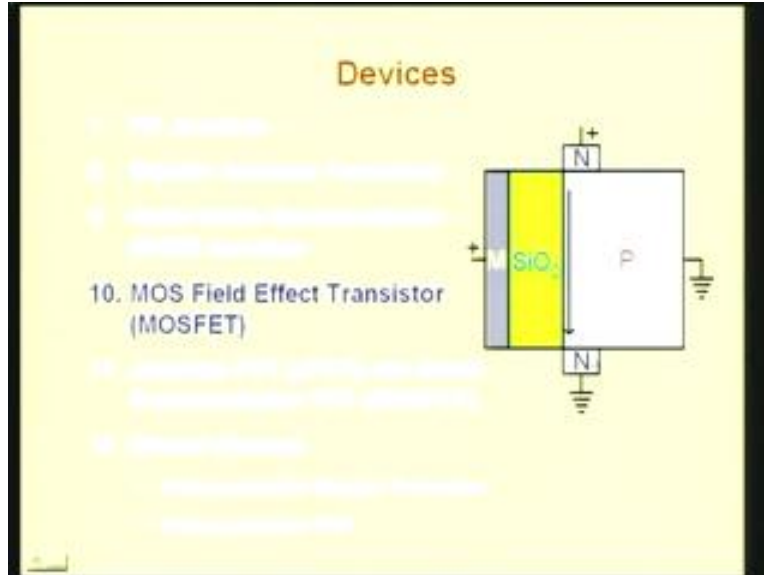
You have a common terminal that is the terminal which is common to input and output. We shall see the various characteristics of transistor. When we are talking of characteristics, we mean current versus voltage characteristics, that is, you apply the voltage and you see the current. That is what shown in this slide. Arrows indicate currents and the polarity indicate the voltages. Towards the end of the course, we will also discuss a variation of this device, namely the hetero junction bipolar transistor, wherein you see that this particular P region has been modified as shown by different color. The modification involves using a different material than a material used to form N and P regions adjacent to it. This is the so called emitter region of bipolar transistor. We shall see the advantages of such modifications. Here, what you have is a hetero junction between this P region and the adjacent thin N region and that is why it is called a hetero junction bipolar transistor. The next topic of interest would be metal oxide semiconductor junction, so like the PN junction this is also an important device.

(Refer Slide Time: 53:30)



Here, you see you have a metal electrode on an insulator and this insulator is grown on a semiconductor. You have a capacitance associated with this metal and the semiconductor this is also like a junction. So, what are the characteristics of this particular junction? Because of this insulator present here, there is no DC current flow. What is of our interest in our case is only the capacitance as the function of the voltage applied.

(Refer Slide Time: 54:10)

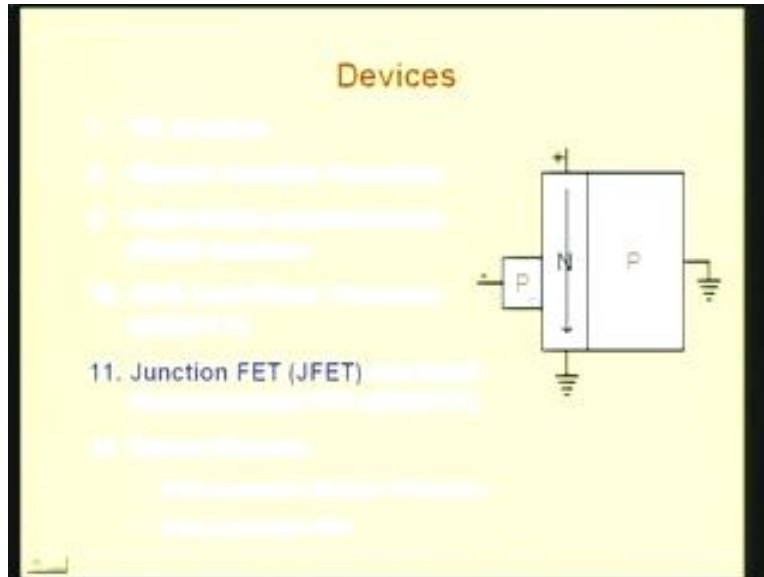


After this, we will discuss a related device that is the MOS field effect transistor. This is formed by applying two contacts N plus contacts, here as well as here, on the two sides of the P layer next to the interface. You have the current flowing between the positive terminals of these two contacts and on the ground or the negative terminal, and this current flow which is along the silicon dioxide semiconductor interface shown by the arrow is controlled by a voltage applied to the metal with respect to the N type contact here which is called the source. Next we will discuss another device very briefly, that is, the junction field effect transistor or junction FET.

Here it is like a MOSFET except that current flows in the N region which is very thin and this current is controlled by a PN junction here, so you are applying a voltage to this P layer with respect to N it is a reverse bias and as a result of which this current can be modulated. A variation of the junction FET is the MESFET as shown in the slide. You see here the P region has been replaced by a metal region, also the color of N and P has been changed. This is simply to indicate that normally the MESFET has been made using the material that is different from that used for making junction FETs.

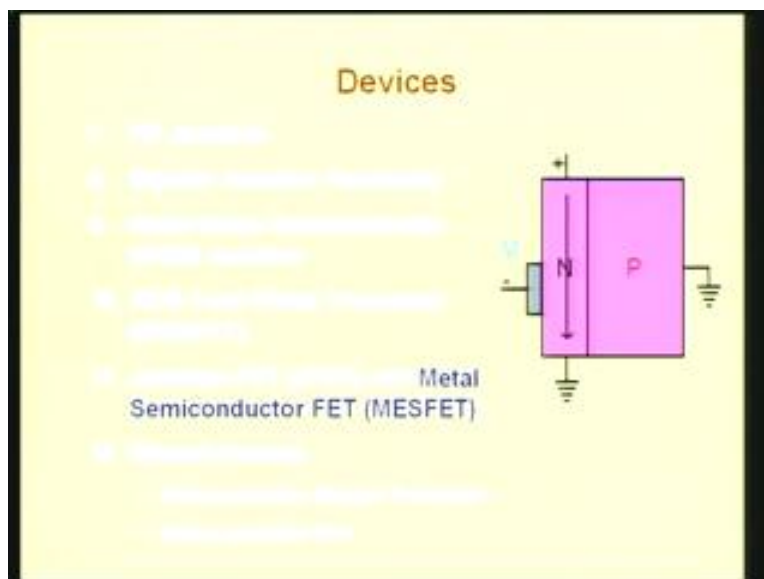
For example, most of the junction FETs are in silicon whereas the MESFETs have been made in gallium arsenide. Here the principle of operation is same as that of junction FET. A voltage applied to the metal electrode here modulates the current flow in this n region which is in the perpendicular direction to the voltage or field applied that is controlling this current.

(Refer Slide Time: 55:10)



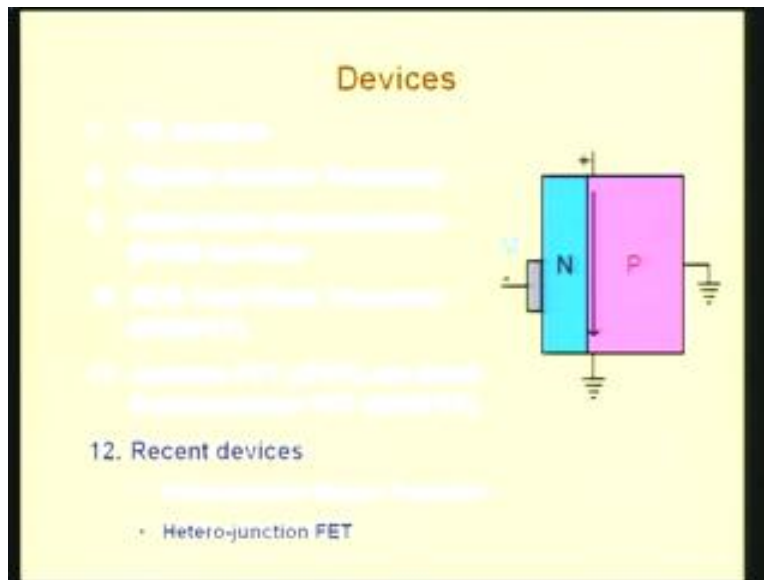
We will discuss a very interesting recent modification of this structure that is the hetero junction FET. This is shown in the slide here. This is similar to a MESFET except that the current has shifted from the N region to the NP hetero junction here, so NP hetero junction because the N region is now made of a different material than the P region unlike in the MESFET and that is why this is shown with different color. The color of the n region is different from p region, that is where you have a hetero junction here and the current flows along the hetero junction interface and this current is controlled by the voltage applied to the metal here. So that is the plan for this course.

(Refer Slide Time: 55:40)



To summarize this introduction lecture, we have seen in the beginning, what are the ways in which we can classify the semiconductor devices, then we saw the important properties of semiconductors that are of interest and then finally we provided a plan or a blue print for this particular 42 lecture course wherein we said we have two lectures of appetizing or interface or preface and then we have 16 lectures of fundamentals and 24 lectures of devices.

(Refer Slide Time: 57:20)



In the next lecture we will discuss the uniqueness and evolution of semiconductor technology.