Electronic Materials Devices and Fabrication

Prof. Dr. S Parasuraman
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Madras

Lecture - 39
Devices and IC formation

In the last few classes, we have looked at some of the aspects of fabrication process, we have looked at the various steps that are involved in fabrication. We have also looked at some elements of process control and heel, also how contamination can affect the fab process and the various steps that are used in order to minimize contamination, starting with the clean room and the clean room design. So, today and in the next class we look at the some of the elements that go in to your IC chip, and how all these various elements come together in order to form your integrated circuits.

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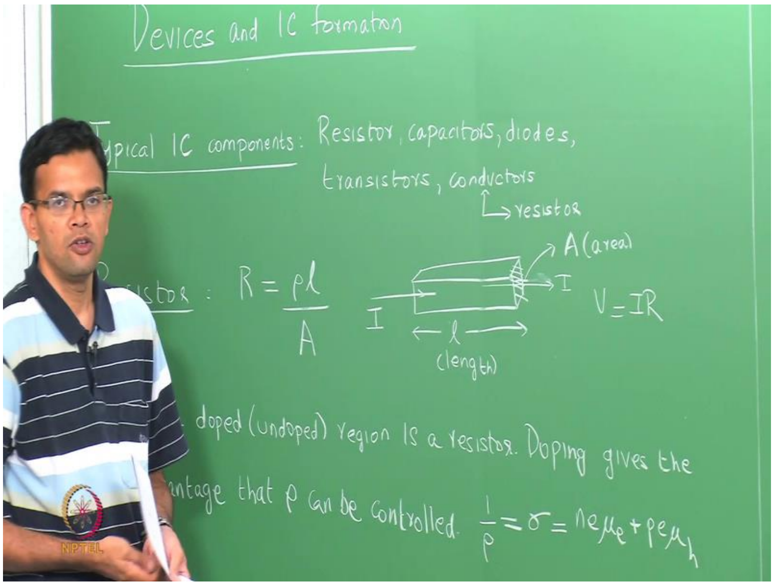

So, we will look at the different devices and how they come together to form the IC. We will not talk completely about the integrated circuits architecture because that by itself would be a complete course. But, we look at some of the elements of the architecture and also how the various devices play a role. So, what are the typical devices or the circuit components that form in IC?

We have seen this before typical IC components most common one is a resister, you also have a capacitors, diodes, transistors, you also have something called conductors. So, synonymous with your resistor, so these are some of the different circuit elements that go into forming your integrated circuit. So, all of these have to be fabricated on your single chip using the various fabrication methods that we have saw and all these come together to form your final IC circuits. So, we can look at some of these different circuit components the types of the circuit components and how these are fabricated.

So, let us start with a resistor, so then we think of a resistor the first thing, of course is resistance and resistance is related to the resistivity row times the length by a cross sectional area. So, this is something that we have looked at the very first lecture of this course, so if you think about it you have a small region this is area which is your cross sectional area, you have current flowing along the length. So, I and then I and l is the length, so if you have a block of length l and cross sectional area A.

We can define a resistance for that and if you know the current flowing through it, we can calculate the voltage across it and the voltage V is nothing, but I R which is your own slog. So, if you think about it every doped even an undoped region in your semi conductor is essentially a resister, so if you have a piece of silicon that is typically un doped that essentially forms a resistor. On the other hand, you dope it with some either electrons or holes your resistance goes down or resistivity goes down.

But, it is still essentially a resister with a different value doping is essentially used to control the resistivity or the resistance of the piece of the material. So, doping gives the advantage, the row can be controlled and again we have seen this expression one over row is nothing but the conductivity sigma which is n e mu e plus p e mu h. So, if you have not doping then n is equal to p is equal to n i which is your intrinsic carrier concentration and when you dope with either electrons or holes one of these terms dominate. So, we can look at the different types of resistors and how they are fabricated the simplest is doped resistor.

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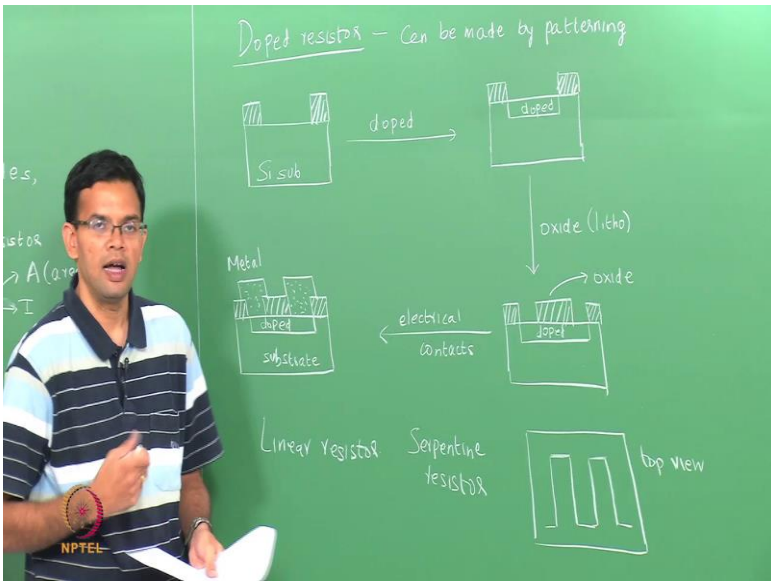

So, in this particular case, you isolate a certain section of your silicon usually by patterning and then you can dope it with dopened of a certain types whether electrons or holes and certain concentration which just give a resistor. So, this can be made by patterning, so the simplest idea is you have a piece of silicon, this is your silicon substrate, you expose a certain region of the substrate. So, this region which blocks can either be a hard mask, for example it could be a oxide layer or it could be a soft mask.

For example, it could be spun on layer of photo resistor this can then be doped and we have seen different ways of doping. So, we have seen could dope by thermal diffusion you could also dope by iron implantation and the method you dope will actually determine what kind of mask you use. So, you dope this to create doped region and then you still have your hard mask, you can then grow a layer of oxide. Again, this can be grown by patterning using lithography because whenever you form a resistor you always want to make electric connection to it.

So, this is the doped region this is your oxide layer, so you have the doped region you have the oxide layer and, now you can make electrical contacts we can make electrical contacts by simply wafer depositing metal on top of the dope player. Then by etching you can remove the excess metal away, so if you do this, this is the doped region, this is the oxide layer that you have grown in the previous step.

So, the dotted regions basically represent the metal contacts, so you could pass current from one region through the doped region, which is your resistor that is your substrate and through the other the oxide layer helps in creating in isolation between the two metals. So, that there is no electrical shortening, so this is the simple way of fabricating a doped resistor, you could control the resistance by controlling the concentration of the dopened. Again, the size of the resistor will also affect the value of the resistance and this again can be controlled by controlling how you do the pattern.

In this particular example your resistor is essentially linear, but you can actually make resistors more complicated could have something like serpentine resistor as well. So, this is an example of a linear resistor, you could also make a serpentine resistor, this is again just determined by how you create the lithographic pattern. So, of your pattern, so not a linear, but in a serpentine fashion, so just looking from top, so you could create a line where the line essentially goes in a serpentine fashion and, you could again create a serpentine resistor. So, the different resistor designs basically depend upon the complexity of the lithographic mask you use, there are other types of resistors as well.

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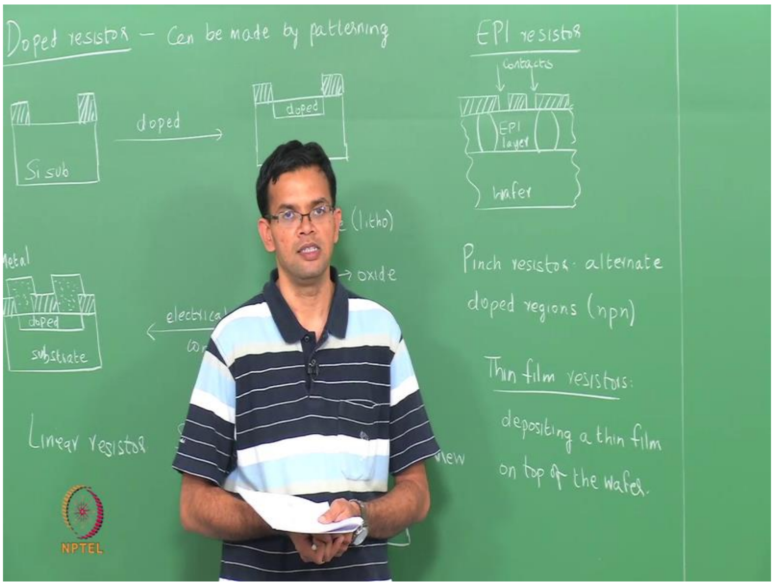

One of them is a called an E P I resistor E P I is short for epitaxial, so in this case instead of doping a certain region, you isolate a certain region from the wafer and that isolated region acts as a resistor.

So, I can draw the final diagram, so you have the wafer, there is an epitaxial layer that is grown typically that silicon this is then isolated usually by some sort of etching. So, that you have an E P I layer that is isolated and then contacts are made to this E P I layer, so again you have the oxide and these are the contacts. So, this is again a case of a resistor where a certain portion of the E P I layer is isolated and again depending upon the length it will change the value of the resistance. You could also have something called a pinch resistor which is typically formed by having alternate doped regions.

So, simple example of this is your bipolar junction transistor where we have an n p n region and, again you can have a different value of resistance. So, this we will see later when we look at how we fabricate transistors, but this again is an example of a resistor we could also call we could also make resistors by depositing a thin film. So, these are called as thin film resistors, so this is done by depositing a thin film, typically it could be a metal on top of your of your sample.

So, in case of thin film resistor, the resistance depends upon the thickness of the film, so you have depositing a metal layer, this is usually deposited on sums on top of an insulating layer. So, this could be an oxide or nitride and the thickness and the type of the metal film will then determine the resistance of the film. So, these are some examples of various resistors that I fabricated and used in a typical IC circuit, we will next look at some examples of capacitors.

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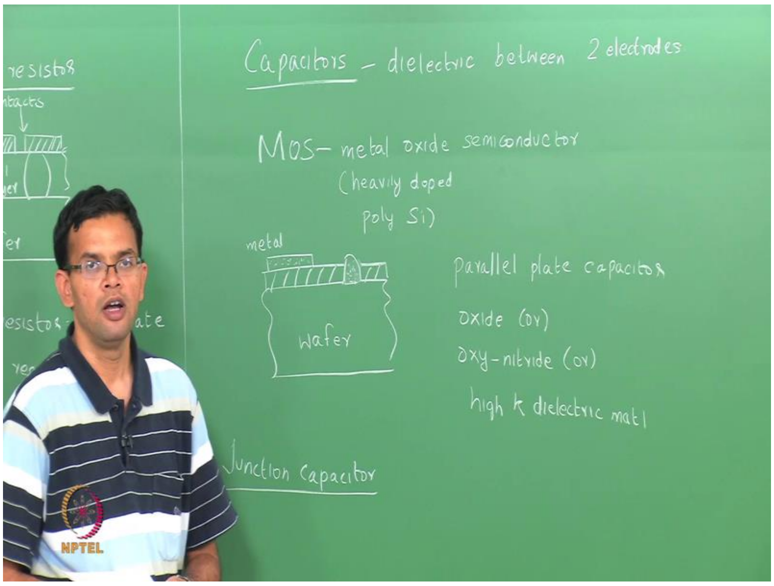

A capacitor is nothing but a dielectric layer that is sandwiched between two electrodes, so the simplest example of a capacitor system, you already seen before is your metal oxide and semiconductor in this case the oxide layer is essentially the dielectric. So, instead of metal layer, you can also use heavily doped poly silicon, so this will again act as one of the electrodes semiconductor act as the other electrode the oxide is the dielectric. So, we can fabricate this again by conventional wafer fabrication processes, so similar to a doped semiconductor you can once again grows an oxide layer and use lithography in order to open holes.

So, that you could deposit the metal and also the electrical connections, so this is just a schematic showing the formation of a simple metal oxide semiconductor based capacitor. So, we grow the oxide layer, a metal is then deposited on top and I will shown the same diagram that we can pattern a hole in the oxide layer and deposit a 2 metal. So, that, now we have the electrical connections as well and, we also have a metal dielectric and a semiconductor interface forming your M O S capacitor. So, this is an example of a parallel plate capacitor, again it need not be only an oxide layer we can replace the oxide by any other dielectric.

So, you could have an oxide which could be thermally grown you could have an oxy nitride layer which typically has a higher K value. This again can be thermally grown or you can replace it with any of the high K dielectric material the choice of your dielectric material. So, the thickness will determine the capacitance of this junction that which again can be controlled by wearing the thickness or the material, another type of capacitor is your junction capacitor.

So, if you think about it in any p n junction there is always a depletion region, so this occurs because electrons from the n side defuse to the p side holes from the p side defuse to the n side, these then meet and get annihilated, so that you have a depletion region.

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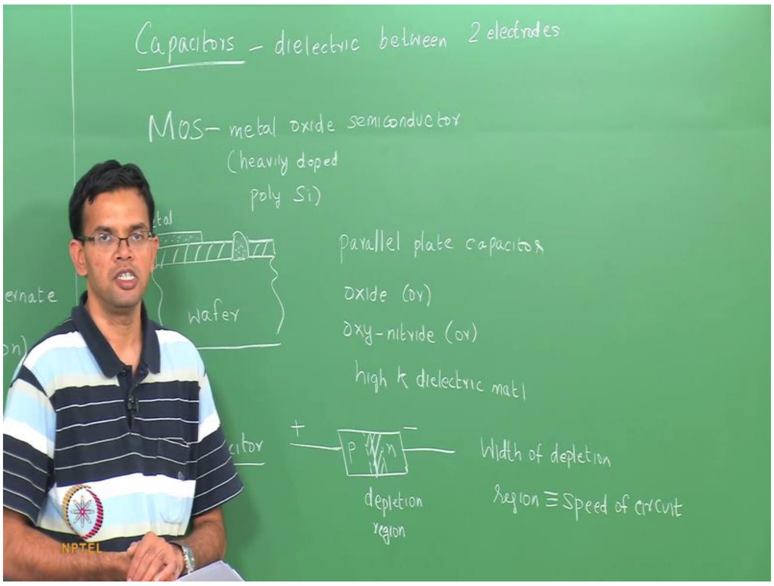

So, this a simple p n structure it is just a schematic, so you have p you have n and you have depletion region at the interface. Another way of looking at a p n junction is that you have a net positive charge on the p side because you have more holes than electrons. So, you have a negative charge on the n side because you have more electrons than holes and then you have a depletion region where there is no charge or it is essentially a dielectric.

So, you can thing of a p n junction in this format as a capacitor as well and this is basically your junction capacitor designing a p n junction is important because the width of the depletion region will control. The speed of the circuit will affect the speed because electrons and holes have defused through the p and n region and also through the depletion region in order to form your current. So, if you have a wide depletion region you could lead to a situation where the speed of the circuit is essentially lower. Another kind of capacitor is called a trench capacitor and these are usually fabricated in order to minimize the area of the capacitor on the surface.

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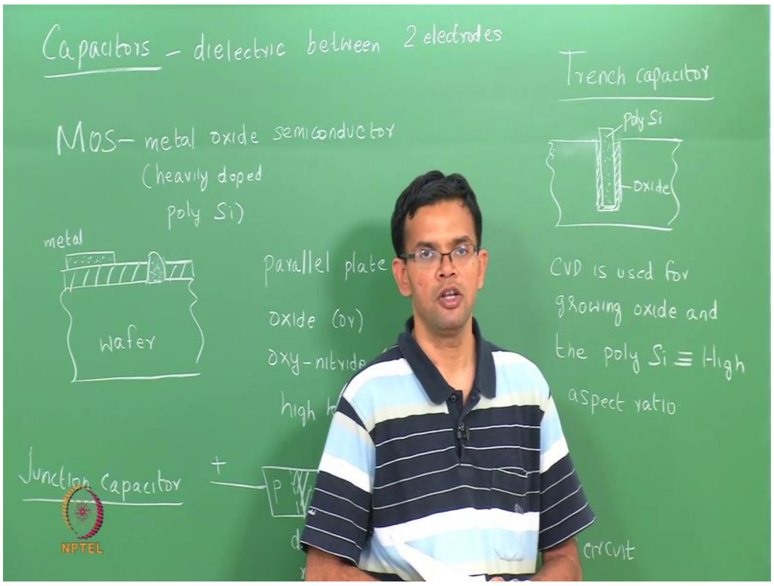

So, if you look at a simple metal oxide semiconductor based capacitor the capacitor is fabricated in such a way that the dielectric is parallel to the wafer surface. So, this has an issue because it essentially occupies a larger area and as we try to miniaturize the devices by packing everything smaller and smaller, it would be better if we could minimize the area of these devices on the surface. So, one way to do this is to actually have a capacitor that goes into the silicon rather than parallel to the wafer surface the schematic of trench capacitor like this.

So, this is your wafer surface at trench is usually formed in the wafer this is again done by lithography where lithography opens a certain window and then the window is protected by some sort of an oxide layer. So, this is the window, let me just re draw this where is an oxide layer that is grown within the trench this is the oxide poly silicon is then deposited. So, that poly silicon acts as one electrode the substrate acts as another electrode and the oxide layer acts as the trench as the dielectric. So, in this case, this capacitor has a minimal surface area because it is formed within the material.

The one disadvantage of having a trench capacitor is that it should be able to define deep trenches within the silicon and you should also be able to have conformal oxide growth. So, typically chemical wafer depreciation is used for growing the oxide and the poly silicon, so this is used especially when you have trenches with high aspect ratio.

So, we have looked at resisters we have looked at some examples of capacitors, the next devices we are going to look at is your diode, so the next IC device we are going to look at is the diode.

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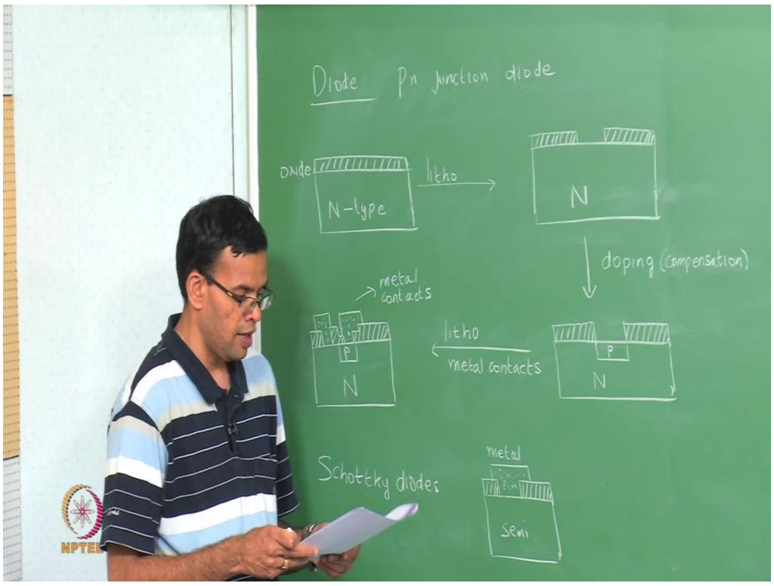

The simplest example of your diode is your p n junction diode, so we can fabricate the p n junction diode let us say you start with a substrate we can either have a substrate to be N type or P type. So, is an example of an N type substrate, using lithography we can again define a window within the substrate where we can do. So, for example let us start with the substrate, with an oxide layer we can do lithography in order to open a window in the oxide layer and this is done by using a particular pattern. Then doing some sort of dry edging, to remove the oxide we do this, we have the N type substrate and this is the window we can then dope through the window.

You can dope either by thermal diffusion or iron implantation in some ways this process is similar to the process for producing a doped resistor. So, there again we had a region where we opened a window and did a deposition and did a doping and, we are sort of doing something similar here. So, when we do this, we have your N type, you still have the window then I have my P type, so now you have a p n junction. So, p and n, so typically this kind of doping we have seen earlier is called as your compensation doping.

So, after forming the p n junction we can do some further patterning in the oxide layer to basically create the metal contacts and do lithography, create metal contacts. So, N type, here is my centre, P type these are the oxide layers which have been patterned and the dotted lines represent the metal contacts. So, this is the simple way of growing a typical p n junction which is acts as a diode, you could also use a similar process to grow a metal and a semiconductor junction. So, this could be short key junction typically typical metal contacts are Ohmic junction, but you could use a same process to grow short key diodes, I can draw a schematic of the short key diode.

So, you have the semi conductor, you have the oxide layer then you have the metal I am not showing the electrical connections here. But, we can once again imagine that you make electrical connections to the metal and the semi conductor and this junction here is essentially a short key junction. Let us next look at some examples of how to fabricate transistors, so when we think of transistor, the first transistors we looked at was your bi polar junction transistor.

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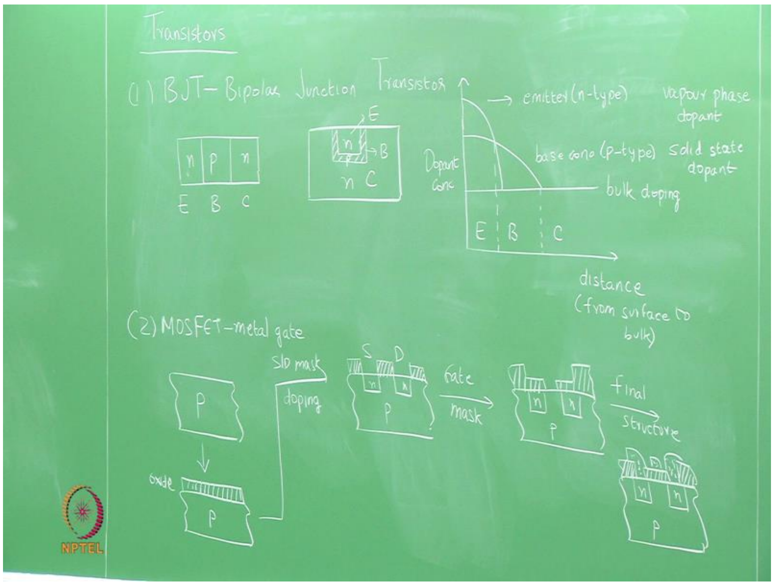

It is B J T which is the bi polar junction transistor, if you remember from before the bi polar junction transistors has two p n junctions and it has three regions. So, this could be p or this could be p n p or n p n you have an emitter region a base and a collector, so typically B J Ts are formed by a process called double doping.

So, if you, where to draw the configuration of this start off with an n type you dope a region, so, that it is p type this is p type and then you again dope, so that you have an n type. So, this essentially forms the emitter, the central p region, I will just shade, it forms the base and your substrate essentially forms the collector. So, we can draw the diffusion profiles, in order to form this bi polar junction transistor, now if you plot the dopened concentration verses distance, so this is distance within the semi conductor.

So, from the surface to the bulk and this is the dopened concentration, so this can represent both n and p with just a number. So, in the case of this bar starting sample, you have a uniform n type doping which is the bulk doping to create the p region, so to create the base we have dope this n type with a p type material. So, this is done typically by using a stolete state depends, so you can get a Gaussian profile, so this is the base concentration, this is p type. We now have to define the emitter region which is again n type, this region has to be closer to the surface, so we typically use a wafer source with a higher concentration.

In order to create your error function profile, let me just extend a access a bit, so we now dope with n type this is your emitter n type, so in the case of a base you use a solid state dopened, in the case of a emitter you use a wafer phase dopened. So, the boundaries where these lines cross will define the width of the emitter, the base and the collector. So, we have you three regions emitter, base and collector once again by playing around your diffusion concentration and also the time you can define the width of these individual regions the other kind of transistors that is commonly used.

In fact, most commonly used in your IC is the Mosfet, in the case of a Mosfet you can have a metal gate, we saw earlier that you can replace your metal gate by a poly silicon gate. But, the manufacturing process is slightly different if you have a metal gate, the gate is essentially doped or deposited at the end the source and the drain are first fabricated and then the gate is fabricated.

On the other hand, if it is poly silicon the gate is one fabricated and then the source and the drain, so I can draw a schematic of how a Mosfet of the metal gate is fabricated. So, you start off with your bar wafer, so we are going to make it p type we will then grow an oxide layer on top, we can then do the masking and the lithography to define the source and the drain, these are again doped to make it n type.

So, this is source and drain mask and then doping n, so we define the source and the grain and the drain, so this is S, this is D and both are n type. We again have to do another lithography step in order to open the area for the gate and then we can do the patterning for the gate. So, from here we can do a gate mask, so now we have opening for depositing the gate and then once again the electrical contacts can be patterned. So, if you do, this can get the final structure n, n and p, the dotted lines represent the metal contacts and the rest of it is the oxide layers.

So, the reason for going this to then gate at the end is because you have a metal gate and you cannot subject your wafers to high temperatures after depositing a metal. On the other hand, if you are using a ploy silicon then we can pattern in such a way that the gate is deposited first and then the source and the drain.

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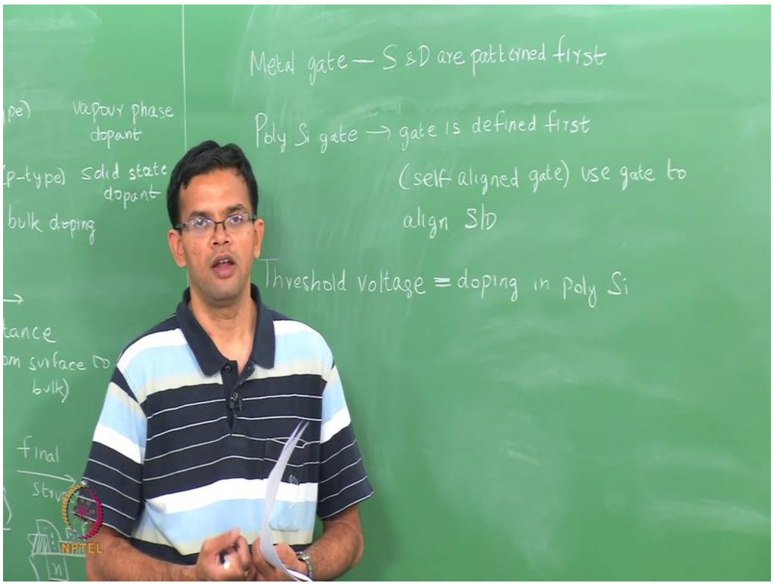

So, with the metal gate source and drain s and d are patterned first, on the other hand with poly silicon the gate is defined first and this has the advantage that we use the gate to align both the source and the drain. So, this is an example of a self aligned gate because you use the gate to align the source and the drain, so another advantage of using poly silicon is that the threshold voltage. So, the voltage for creating the n channel can be controlled by basically controlling the dopened concentration in the poly silicon voltage is controlled by the doping in the poly silicon.

Once again, your gate material your oxide material could be a thermally grown silicon dioxide or you can also replace it with other oxides like oxidizes with other materials like oxi nitrites or high K dielectrics. So, Mosfet essentially form the basic building block of your IC circuit and these essentially form the part of the logic component of the IC circuit. So, today we have seen some of the different components that are there in your

IC circuit, we started with resistors capacitor diodes and then finally transistors. In the next class, we are going to bring them all together in order to get some understanding of how they come together to form you IC circuits.

We will also look at some examples of packaging where once these components come together and form your circuit, we have to integrate the circuit with the outside device the outside world. For example, if you think about the computer having a chip, the chip has to be integrated with the mother board. So, that it can track with the peripheral devices, so we will also look briefly at case of packaging when we look at how these things come together to form the IC circuit. So, this is something that we will look at in the next class.