Integrated Circuits, MOSFETs, OP-Amps and their Applications

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Lecture - 11
Process flow for Fabrication of MOSFETs

Welcome to this particular lecture and this lecture is very important since we are going to talk about how to fabricate a MOSFET right. From last several class, I am telling you that I will we are learning a process, and I will show you in one of the lecture how we can fabricate finally, a MOSFET. MOSFET is nothing, but your metal oxide semiconductor field effect transistors.

So, if I want to fabricate a MOSFET what should be my process right what should be my process to fabricate my MOSFET? In that particular case I had to understand what is oxidation, what is thermal evaporation right, what is lithography, and then only I can understand how the MOSFET can be fabricated all right.

So, we have already seen what are the steps for fabricating a device, now using this steps how we can fabricate a MOSFET; that is the todays class and then we will see several type of MOSFETs meaning enhancement type MOSFET, depletion type MOSFET, P channel MOSFET, N channel enhancement type MOSFET, P channel enhancement type MOSFET, same the P channel depression type, P channel enhancement type. Also we will see very short description or details about the complementary metal oxide semiconductor field effect transistor which is your c mos all right.

So, this is the important part or important chunk of the course, and we will also see an application of the MOSFET in terms of current period right. So, I will divide this particular lecture into few modules. So, that we do not get lost when we are going to understand what exactly the MOSFET fabrication is, and how they are applied for different applications all right.

So, let us see the first slide which you can see on the screen and that is your class number eight which is the MOSFETs all right. So, for understanding MOSFET what I told you, we had to understand the process, we had to understand the process which is our thermal oxidation which we already know right oxidation.

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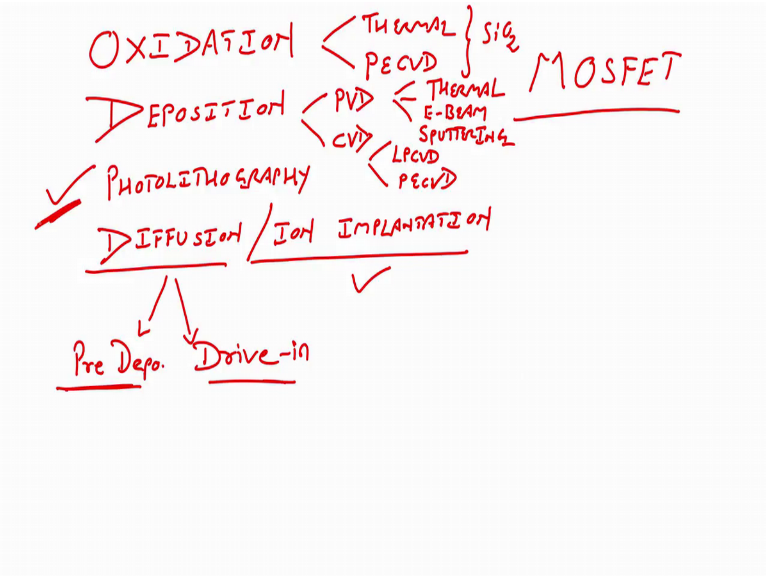

Then we need to know deposition, then we need to know photolithography right.

Now, this three things we need to know and if you know and when one more step, if you are not understand is diffusion or ion implantation. So, these are the 4 steps that you need to know if you want to understand how MOSFET is fabricated ok.

Now, oxidation, we have already seen 2 types of oxidation correct one is thermal another one is plasma enhanced chemical vapour deposition right. This using the oxidation we can grow silicon dioxide we can grow silicon dioxide deposition we have seen right. One is physical vapour deposition another one is chemical vapour deposition, in physical vapour deposition we have seen three types one is thermal evaporation, thermal evaporation second is e beam evaporation and third one is sputtering right and in CVD we have seen 2 types PECVD and LPCVD in CVD we have seen 2 types LPCVD, PECVD right.

Then we have seen photolithography and then this is the process that we need to see, but we not going in detail just understand that f diffusion is there is 2 process in diffusion process one is called pre deposition process 2 is called drive in all rights pre deposition and drive in ion implantation is another process which is heavily used instead of diffusion, since we can we can dope the impurities in much more accurate way, using at this technique called ion implantation all right.

Now, once you know this let us see quickly the section of lithography, yesterday what we have seen on last lecture what we have seen that if I use lithography if I use lithography I can understand how to inspect the pattern of photoresist; how to I can inspect the pattern created by the photoresist using what photolithography correct using photolithography.

Now, what if there is a metal, then how can we process; that means, that how can we pattern a metal. This again very important step because next slide I am going to show you the MOSFET. So, let us see how we can pattern the metal that is deposited on the oxide silicon substrate using photolithography, once you know this then we will move on to the actual MOSFET fabrication ok.

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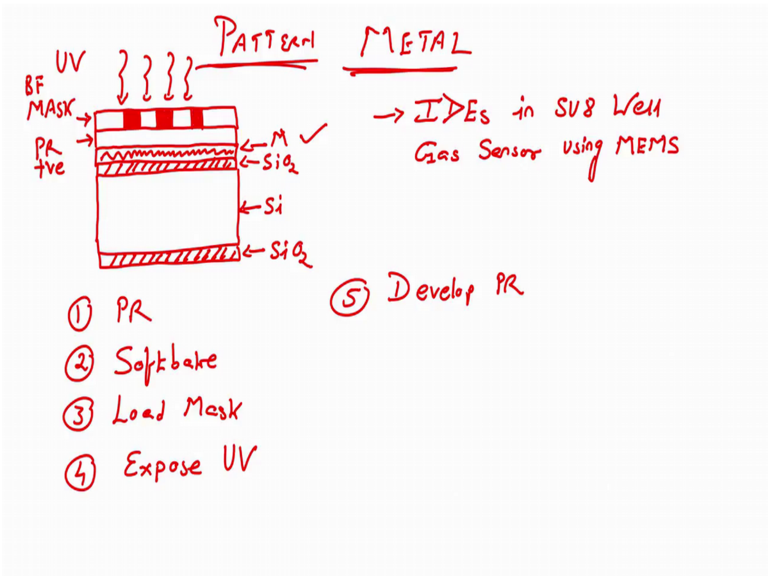

So, you come back to the screen and what you see. So, I am showing you how to pattern p a t t e r n pattern metal all right let me write out clearly metal all right pattern, pattern how to pattern the metal. So, we have already seen this example we have seen inter digital electrode standard right in S U 8 well. We have seen this example we have also seen how to fabricate gas sensor right using MEMS technology right.

Now, let us see quickly how to design a metal there is something like inter digital electrodes, we will just see. So, that you can get a refresher and you understand how the MOSFET is when I show you the process flow for MOSFET, you understand the process flow.

So, now we know that if we have a wafer right if we have a oxidise wafer and if I have a metal on oxidise wafer; metal silicon dioxide, silicon, silicon dioxide. If I want to pattern this metal then first thing I will do I will spin coat photoresist right then you know what is the next step after spin coating? Step one spin coat photo resist; step 2 is soft baking right soft bake right ninety degree one minute hot plate.

Step three load mask. So, we load the mask right mask of our desired pattern and then what we will do? We will next step is we will expose wafer, which is spin coated with photoresist right. Next step will be 4 step expose with u v light right u v this is your mask correct.

So, if I do this what is the next step? Next step is I will unload the mask and develop right next step is unload the mask and develop my photoresist. Once I develop my photoresist what will I have? Since this is a positive photoresist and my mask is bright field mask what will I have? The area which is not exposed this red one on the mask that area in the photoresist will be stronger, since it is a positive photoresist. Again the area which is not exposed will be stronger when we are using positive photoresist. So, what will I see? Once I complete my development step that is I develop my photoresist what can I see? I will see that the photoresist in the area that was not exposed will be there.

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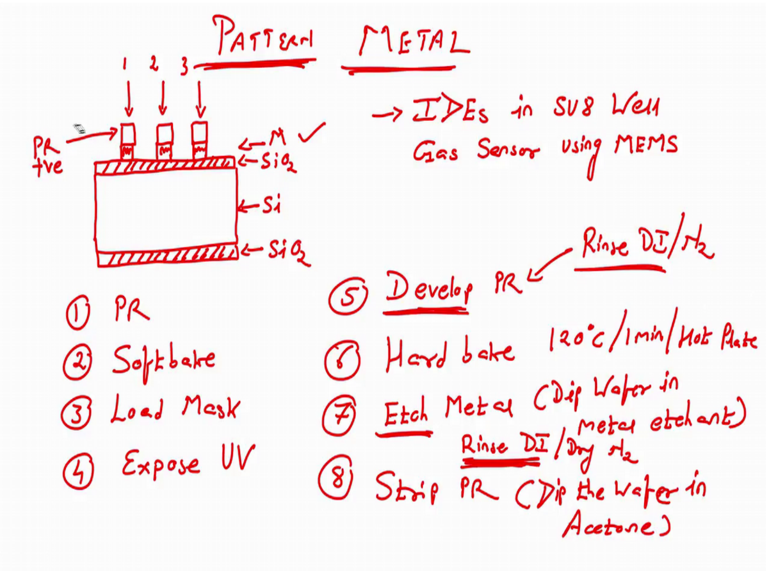

And the area which was exposed by u v light which is this one or this one or this one or this one right photoresist will be etched, photoresist will be developed, photoresist will get developed. So, now, you know that you have the photoresist.

Now, what is the next step? We want to etch the metal right because the idea is to pattern the metal. So, next step would be we after developing, next step would be we will do hard bake. Hard bake is done at 120 degree, 1 minute hot plate correct 120 degree 1 minute hot plate. Hard baking after that what is the next step? Next step is to etch metal; that means, we will dip the wafer in metal etchant. On dipping the wafer in metal etchant what will happen? The metal below the photoresist, you see the photoresist is right over here you look at this photoresist is right over here, the photo the metal which is below the photoresist will not get etched and the metal in the rest of the area will get etched right.

So, when I etch the metal the metal which is protected by photoresist this is the one, 1 2 3; the metal which is protected by photoresist where is photoresist is this boxes all right. So, metal which is protected by my photoresist will not get etched, but metal which is not protected by my photoresist will get etched. When I etched the metal I will have this particular thing what is the next step? Next step is of course, whenever you do my atom metal etching, after that you have to rinse it right you know that you have to rinse it in deionized water, and then you have to dry it using nitrogen. Rinse it and dry this is always there is always there after every step, you have to do it not after every step let us say photoresist, you do not have to rinse dry soft bake is loading mask, exposure is develop, after developing you have to again rinse it rinse with D I and then dry with N 2 then you have to do hard bake metal etch. After metal etching whenever there is a chemical involved you see there is developing PR there is a chemical to develop PR. So, we have to rinse with water. When we have we have is a metal again chemical is involved. So, we had to rinse it with D I and dry it with nitrogen.

What is the next step next step is we do not want this photoresist right we do not want this photoresist. So, we have to strip off strip the photoresist, we have to strip the photoresist for striping the photoresist. We all know we will dip our wafer dip the wafer in acetone dip the wafer in acetone what will happen when we dip the wafer in acetone you will see that the photoresist will be stripped off. Again you see what is there acetone;

that means, you have to again rinse after acetone you have to rinse, rinse with D I and dry with N 2 dry with N 2 got it.

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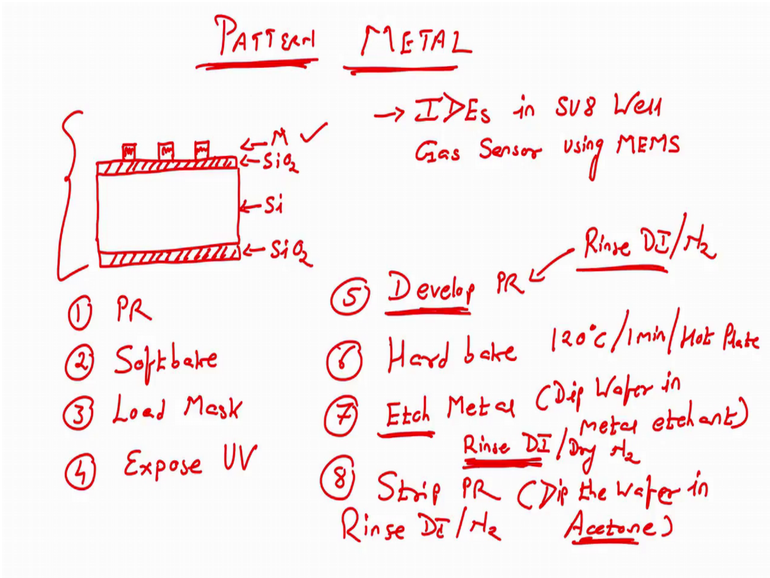

Now, how you can pattern the metal you can you know it very easy right very easy, super easy oxidation you know it metal deposition you know it lithography you know it. This is an example of how we can do a photolithography using or for pattering the metal; very important because now we are going to the most important point of this particular course and that is your MOSFET, and we will see how the MOSFET is fabricated all right. So, let us first see how MOSFET looks like in terms of schematic diagram ok.

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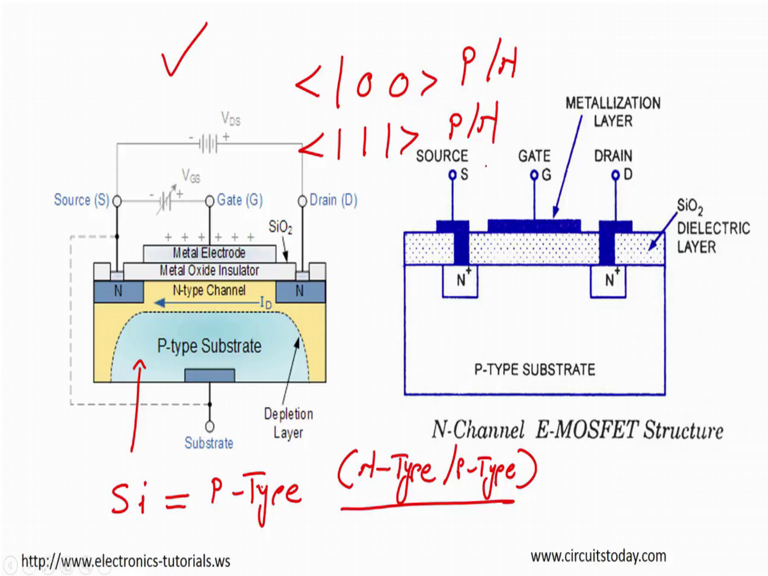

So, if I go on next slide you see. If you see on the next slide the MOSFET, what you see you see that on the left side just look at this MOSFET just look at this slide, what we see? There is a P-type substrate, substrate is P-type means silicon we have taken which is P-type. I have shown you types of silicon right I have shown you which type there is a N-type and there is P-type right. When I say types of silicon I have shown you; that means, that I have shown you 1 0 0 1 1 1 oriented wafers right in the previous lectures 1 0 0 1 1 1 oriented orientation of the crystal right and then it was P and N, P and N we can identify with this P-type 1 0 0 or N-type 1 0 0 or P-type 1 1 1 or N-type 1 1 based on the orientation or based on the primary flat and secondary flat, we are talking about primary flat and secondary flat. So, if you do not recall you can go back to that lecture look at how the primary flat and secondary flat, helps us to understand whether the wafer is P-type or the wafer is N-type and whether the orientation is 1 0 0 or the orientation is 1 1 1 all right.

Now, let us see this particular figure what we see there is a P types of substrate then there is a N-type. You see here source N-type diffusion right this is the source N and drain.

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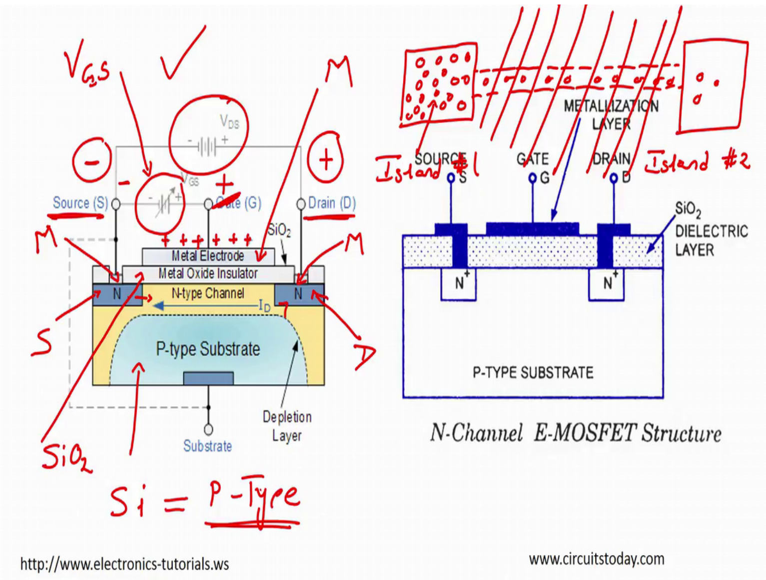

So, N-type diffusion is done to form source and to form drain right N-type is what? In P-type I am what I am doing I am doping my impunity which is N-type right. So, that this is my N-type source and drain after that I have a metal oxide you see here, this is my metal oxide and this metal oxide is nothing, but my gate oxide right then I have a metal here, you can see the metal here this is metal, this is my metal oxide which is SiO 2 this is my metal right because we need to connect it to metal to take out the external connection, this is my metal you see metal I am just showing you the schematic do not worry we will we will come back to the process flow where you will see step in detail just look at the schematic. So, we know how the MOSFET looks like right.

Now, I can apply potential difference or voltage; voltage between drain and source. So, here what I have done? I have applied positive voltage to the drain positive to drain negative to source right and if that is the case what will happen? My electrons from here right it will get attracted towards the drain and we know that when this happens we can show the drain current in this particular direction right. Electrons are attracted from the negative which is source to the positive which is drain right, because electrons are negative. So, it will go to a positive terminal and that positive terminal is my drain because my VDS is applied in this particular fashion.

Next is now you see here what is this? This is my gate to source voltage right. So, what I have done here? I have applied positive to gate and I have applied negative to source that means, the positive voltage here will cause the electrons from a P-type to go towards a gate right which is a minority carrier. P types substrate is there the minority carriers are electrons majority carriers are holes right.

So, the minority carrier which are electrons will get attracted towards the gate, because gate is positive. Since this will get attracted towards the gate, this electrons will form a N-type channel which is written over here right, which is written over here you see this is what is given. So, any schematic whenever you see even it looks complex in reality, when we understand it is not complex ok

Now, what we see is electrons are attracted from P-type towards the gate, and it forms a channel which will be our N-type channel. Now when we have N-type channel with the help of channel only the electrons can flow, if there is no channel how can electron flow from here to here not possible right not possible there is no channel right. So, if there is a channel electrons will start flowing towards the drain right.

So, what does that mean? See, I will give another example easy example suppose there is a there are a lot of people on this island you see, these are 2 islands island number one island number 2, there are lot of peoples on this island, there are lot of people on this island and they want to reach to this island. So, island one they want to go to this particular island all right.

Now, what we see is, there is a river in between 2 islands. So, and the river is very deep and it is a long river. So, if the people try to cross they do not know how to swim. So, they all will die. Now in this case if I have a bridge right connected between these 2 islands and what will happen? The persons can cross this bridge from this island to the next island right from island 1 island 2 correct, but what if there is no bridge? If there is no bridge then they cannot cross the island they cannot cross the island correct.

Same way if there is no bridge between source and drain, if there is no channel between source and drain here is a source here is a drain. If there is no channel between source and drain, electron cannot flow electron cannot go from source to drain, even if I apply V G S. So, I have to create a channel and that channel is created with a help of gate to source voltage, thus this bridge is created. So, that the electron can flow from here to here also this bridge is not only made just a for a facilitating the electron to flow, but this also made up of electrons the bridge is also made up of electrons right. So, these are all electrons lying in this fashion. So, that now when I apply a source to drain voltage which is positive towards source, negative towards drain then the electrons will flow from source to drain and the current will flow in the reverse direction, which is shown by the blue arrow all right easy understood very clear right.

One thing what we see is since you see there is a P and there is a N right this is the N this is the a P. So, there is a depletion layer, this is the depletion layer that is created right that is why it is shown here as depletion layer when you have seen P N junction right.

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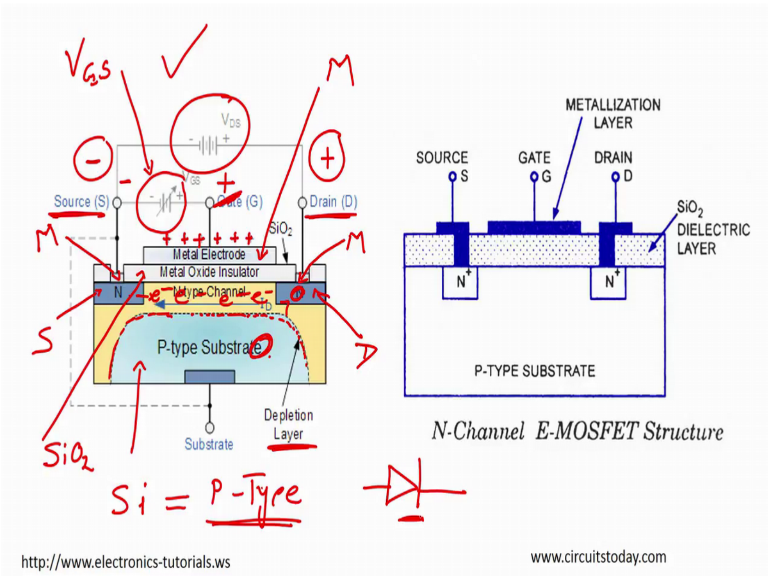

When you have seen P N junction diode you see that there is a depletion layer in the P N junction diode all right easy.

Now, one more thing is let me just remove all these things. So, that we can see the schematic clearly and I have taken this schematic diagram from electronics tutorials which is right over here so that you can understand what is a good schematic. So, I have used it for teaching you guys ok.

Now, what is the next step? Next step is you see here, there is a connection between source and the substrate right. So, you will see that the MOSFET generally when you see there are only three terminals source, gate and drain right.

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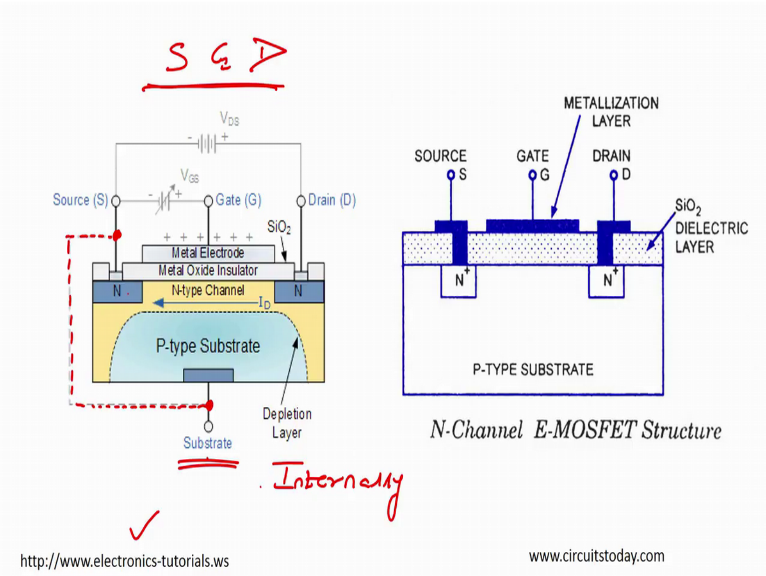

So, why there is no fourth why fourth terminal is not there, because substrate is internally connected to the source. My substrate is internally connected to my source, that is why you will find that there are only three terminals in most of the MOSFET I cs that you can get from the market all right very easy super easy right.

Let us go to the next figure next figure which we have on the screen, and that is our N channel enhancement type MOSFET structure this I have taken from circuits today dot com. Here what we see we again see that there is a P-type substrate, you see I will tell you a a beauty of what is here and what is here in just one minute or may be like 4 5 minutes 4 5 minutes because I had to explain this particular structure.

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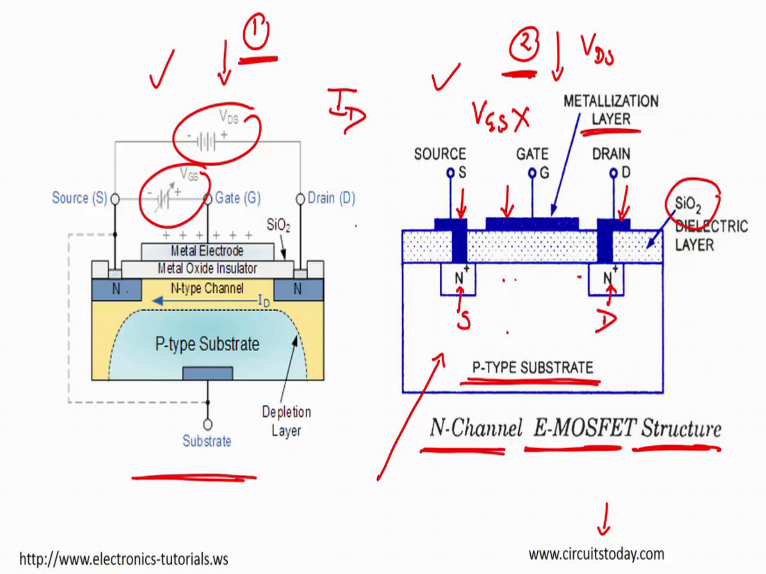

What is a similarity between this one and what is the similarity between these 2 one. This I say one and this I say 2 what is the similarity I will tell you in 4 5 minutes, let us see here what is here? It is P-type substrate all right and then we have N-type you see here N-type dopant it is a source it is a drain right and then we have here a dielectric material which is SiO 2, this written over here then we have a gate this is just a representative diagram right there actually the gate oxide is extremely thin, this gate oxide extremely thin then we have a metal contact from gate, we have metal contact from source, we have metal contact from drain and then you can see this is nothing, but your metallisation layer right this is nothing, but your metallisation layer.

So, this one which is figure number 2 is nothing, but similar to your figure number one right here P-type substrate, P-type substrate source drain of N, source drain of N. Now we are not apply the voltage we have not applied any voltage here. We are not applied VGS, VGS e VGS is not applied then we are not applied anything between drain and source VDS is not there, VGS is not there that is why you cannot see any formation of channel. In this case if I just apply VDS, then very minority carriers minority carriers that from here can we get, but anyway the point is until unless you apply VGS do not get confused with this, the until you apply VGS and VDS both. In this particular case you will not see any change in current that is your drain current ID drain current ID. We will also see what is the relation between VGS and ID, VDS and ID we will draw the characteristics we derive everything, but right now the point is now you should know how the enhancement type and channel MOSFET looks like in terms of at least schematic diagram.

So, for at least schematic diagram now, in the next slide what we will see is how we can fabricate a MOSFET, how we can fabricate an enhancement type MOSFET ok.

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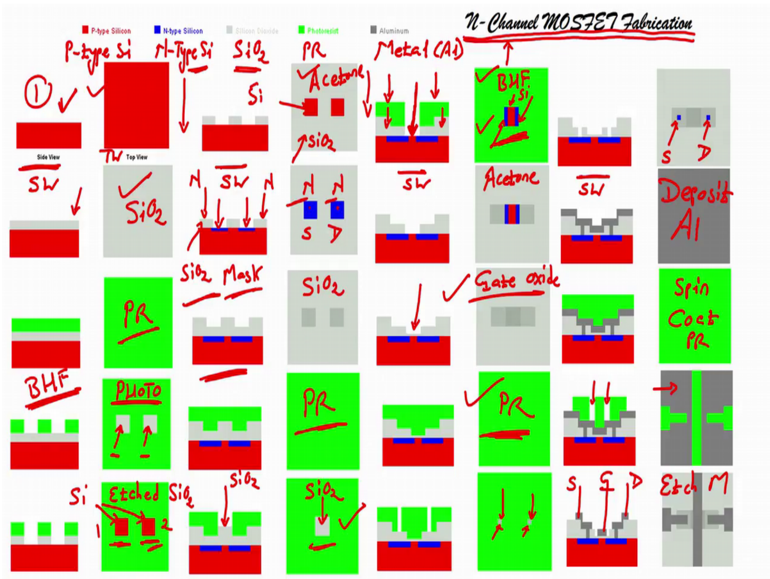

So, let us see the next slide and you take one minute, completely one minute to understand what is there on the screen all right. Look at this structure in particular this one. This is P-type silicon I will write in somewhere. So, that it is easy P-type silicon what we are looking at? We are looking at N channel MOSFET fabrication, what is this one? The red one the first one is P-type silicon and the second one blue one is N-type silicon, the grey one like light grey is your silicon dioxide, green one is your photoresist, dark grey one is your metal, in this case we have considered aluminium you got it what is that? Red one is P-type silicon, blue one N-type silicon, light grey is silicon dioxide, green is photoresist, dark grey is metal this much is there.

Now, this one is side view, side view, side view, side view. You see the 4 one I am writing s w. So, that you can understand side view, side view, side view, side view or you can say cross sectional, cross sectional view. This one is top view top view this one, this one is top view, this one is top view my arrows, this one is top view and this one is top view this one. I am putting right mark this 4 are top view we have side view we had top view.

Now, look at it and try to understand what is going on in this process flow. I give you 10 seconds to see, 10 seconds will be too less let us I will give you 20 seconds to understand what exactly you understand with this particular process flow. You have to just see the side view or you can see the top view and guess what is going on. And then we will discuss one by one what is actually happening all right. 20 seconds starts now let us see whether you can understand or not.

Time's up less time right less time to understand. So, let us see together what is given here, and we will see that you will understand the complete process flow. So, start one by one very easy. First step is you are taking a silicon wafer what kind of silicon? Wafer red colour is there. So, P-type silicon wafer you have chosen. We have chosen P-type silicon wafer.

Next step is we have grown silicon dioxide correct we have grown silicon dioxide. Silicon dioxide is written here right grey colour light grey next step. Next step is we have spin coated photoresist correct easy.

Next step; next step is we have performed the photolithography and created a window; that means, we have etched the photoresist from these 2 area correct you understood right. See first step is silicon, next step is silicon dioxide we have grown silicon dioxide, next step we have spin coated photoresist, after spin coating photoresist we have opened this window using photolithography you already know how to do that, I have shown it to you in previous examples. Once you create a window the next would be to etch the we have to etch the silicon dioxide. So, here the we have etched silicon dioxide.

So, you can see here silicon right what you can see here is silicon here and here why because we have etched the silicon dioxide. How can etch the silicon dioxide? I had told you we can use buffer hydrofluoric acid until here is easy.

Let us repeat only this section; see first is we take a P-type silicon, next step is we grow silicon dioxide right how we grow silicon dioxide by using thermal oxidation. Next step is we spin coat photoresist after spin coating photoresist we had to do prebaking right or soft baking then we have to load the mask, and then we had to expose the wafer, then we had to develop the photoresist, and when you develop the photoresist because your patterns are such that, you will etch the photoresist from these 2 windows this one and this one you can see here light. Grey colour light grey what does that mean? That you can see silicon dioxide below the photoresist. So, rest of the area of the wafer is protected by photoresist, the area which is shown by these arrows this 2 arrow right it is not protected by the photoresist.

Now, I will dip this wafer into the buffer hydrofluoric acid, on dipping this wafer buffer hydrofluoric acid what will I have? I will etch the silicon dioxide. When I etch silicon dioxide what I can see? I can see if I remove the silicon dioxide from here, what I can see? I can see silicon right that is what I am looking here; I can see silicon when I etch the silicon dioxide now it is easy this much easy.

The what we have done we have created 2 windows one and 2 right on the oxidise silicon substrate such that I can see silicon through this window what is the next step? Next step is that you have to remove you remove the photoresist. For removing photoresist very easy what we can do we can dip the wafer, we can dip this wafer into acetone photoresist removal you know it right. So, this is where we dip the wafer in acetone, and we can see there is only silicon dioxide this is SiO 2 and the red colour is nothing, but your silicon P-type silicon right. So, we have reached until here.

Next step is we have to diffuse or we had to ion implant what we have to ion implant or diffuse? We have to ion implant or diffuse N-type silicon. N-type silicon is this blue colour blue colour. So, we have to diffuse or implant the N-type silicon in to the P-type silicon why. So, that when we diffuse this and this, we are creating source and drain, we can see our cross section see we are diffusing here. So, the silicon dioxide the N-type silicon; this is silicon dioxide N-type silicon, the dopant cannot penetrate through SiO 2. The N-type dopant cannot penetrate through SiO 2 through silicon dioxide and that is why we can say that silicon dioxide acts as a mask protective mask.

So, that the dopant would not diffuse things, but the dopants can diffuse in the window that what we see here. And we can diffuse the dopant in the window created and thus we have the source and drain right the diffusion of source and drain this diffusion is N-type diffusion why, because we started with P-type substrate this is P-type substrate, red one is P-type substrate. So, we had to diffuse the dopant which is N-type dopant because we are creating an N channel; channel should be N channel MOSFET easy very easy right.

Let us see the next one what is the next one? Next is we again grow silicon dioxide you see we have again grown silicon dioxide. So, you can see here right what is the next step? Next step is we have spin coated photoresist, next step is we have create we have etched the photoresist from this particular area. This particular area is right over here ight after this after this I have to etch the window right

So, what is etch the window means? That you can what you can see here, I can see here SiO 2. I have I can see here SiO 2 right you can see here SiO 2 see why because there is a window created. So, once I see the SiO 2 what will I do? I have to etch SiO 2. So, when I etch SiO 2 how can I etch SiO 2? By dipping this wafer into buffer hydrofluoric acid I will get this particular image what you can see? You can see on the cross-section you can see a photoresist is there, photoresist is there, the gate oxide is there here gate oxide is there, here there is no oxide you see this region this region you see there is no oxide. So, we can directly see silicon this what you can see here right what you can see that you can see there is a N-type, N type in the centre there is silicon easy.

So, after this what we have to do? After this we have to etch the PR or strip off. The PR stripping off the PR is by dipping the wafer in to acetone correct. So, we are now dipping the wafer in to acetone, we will get this particular wafer. So, what we have? We can have silicon directly exposed here right and little bit of gate little bit of source and drain areas are also exposed you can see drain source and silicon three things you can see right.

So, now what we will do next step is we will grow a thin layer of oxide, where in this region in this particular region we will grow thin layer of oxide. So, because of my pen is red you cannot see, but what I mean is this layer. So, you can see here see thin layer of oxide we have grown why thin layer of oxide? Because this will be your gate oxide. So, what we are we have done we have grown a thin layer of oxide into this window, that is over the source and drain such that it overlaps region of source and drain. So, what we have done? We have grown thin layer of oxide which is our gate oxide, until this is clear yes no then you read once again. So, if you are with me we have here which is our gate oxide

What is the next step? After gate oxide we will spin coat photoresist, it is spin coat photoresist, we will open the window like this such that the window goes all the way to the silicon dioxide and the next step we will etch the silicon dioxide by using buffer hydrofluoric acid. So, you can see here we can see now oxide we can see here oxide. We can see here source, we can see here drain right. So, what we can see here? We can directly see source, we can directly see drain correct.

So, where were we see come here and where it get oxide. After creating a window we created a gate oxide, after creating gate oxide we have spin coated photoresist after the spin coating photoresist right we have opened the window such that we can get the access to the source and drain. So, when you open the window use silicon dioxide, here you can see silicon dioxide here. So, you have to etch the silicon dioxide, this silicon dioxide we can etch why lasing the wafer in buffer hydrofluoric acid and you can see source and drain you can see source and drain right over here.

Now, this source and drain in this region right this open it is it is accessible. So, what we have to do? We have to grow a metal because we have to take out the contact external contact right. So, for growing out the external contact for taking out the external contact, we have to deposit aluminuim or a metal we have to deposit a metal.

Now, once you what is the next step; next step is use spin coat photoresist. Spin coat photoresist do lithography and do lithography and open this particular area. When you open this particular area you can see here this is the top view, this is a cross section, then you etch the metal then you etch the metal you know how to etch the metal now right. So, when you etch the metal what you see here? There is a source connection for metal there is a drain metal is connected and here is your gate.

So, what you have done? You have now understood the process flow for N channel MOSFET. See this is how the N channel MOSFET is fabricated and here we now see that why we were understanding for hours, what is how can we grow thermal oxide how can we deposit metal, how can we do lithography, why to do lithography, why to etch metal. Now we can see why to learn all the steps before we can understand the process flow for fabricating N channel MOSFET. You got it guys, you got it is not easy to get it ok.

So, let me once again repeat it let me once again quickly repeat it, not in the same fashion little bit faster right. So, that we can understand our MOSFET process flow and if you observe if you observe I will show you a trick I will show you a trick, how many mask you have used here right because you have etch, you have done lithography, you have again deposit metal, you have again did lithography, then you have the dope the source and drain right then you have created windows. So, how many mask you have used; 1 mask, 2 masks, 3 mask or 4 mask you know you do not know right see how to find it.

Whenever we are depositing a photoresist that will be one mask; you see we are spin coating photoresist so, not depositing sorry spin coating photoresist.

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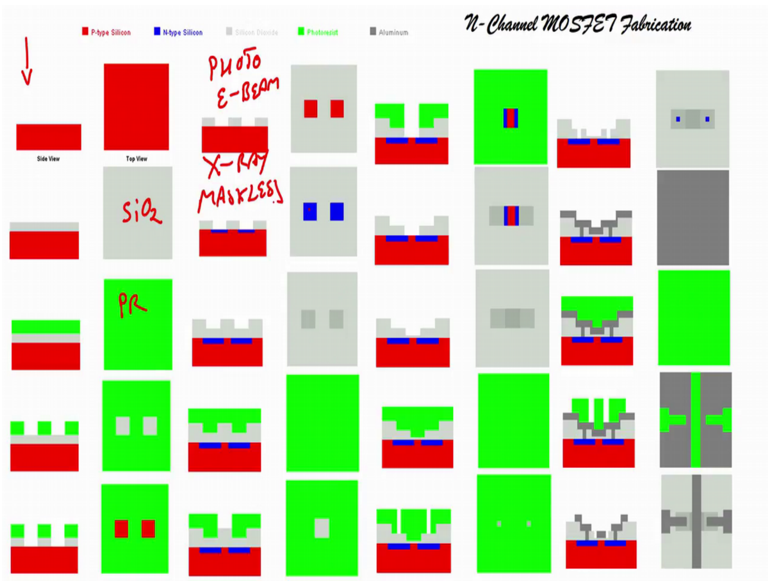

Whenever we are spin coating photoresist we will use one mask see photoresist. Spin coated 1, photoresist spin coated 2, photoresist spin coated third time, photoresist spin coated fourth time 4 mask process easy right easy.

What we will do generally when this kind of question is there and students are ask question, how many mask are masks are used for fabricating a MOSFET, then you calculate oh this is was first time I create a window. So, maybe this is the first mask, then when did I created window somewhere oh here a second mask, then oh here is it one more mask no no no it is not one more mask. So, this all confusion all confusion right you had to you have to see so many steps to understand how many mask very easy way of understanding how many mask are uses, just understand wherever spin coating or photoresist is done you had to use a mask.

Now, again thing is this is because every time the pattern is different right that is why we are using 4 mask. For MOSFET you can see very clearly 1 2 3 4; 4 mask. So, let us see let us see what we have done? Here starting with here concentrate silicon, P-type silicon we have taken then we have grown silicon dioxide right on this silicon dioxide we have spin coated photoresist, after that we have done lithography technique whenever I say lithography; that means, photolithography, it can be e beam lithography which we it is not part of this particular course, but there are several types of lithography, one is photolithography one is E-beam lithography, then there is x ray lithography, then there is a mask less lithography. We are not covering these things in this particular course, but you just understand that some lithography technique is used.

So, anyway, first step is silicon which is P-type silicon then we have grown silicon dioxide, then we have spin coated photoresist, we have performed lithography; that means, we have done soft baking, we have load the mask, we have exposed the wafer, we have developed the mask and then we have reached to this particular section where we have created 2 windows auto creating window we have to etch the silicon dioxide from this region.

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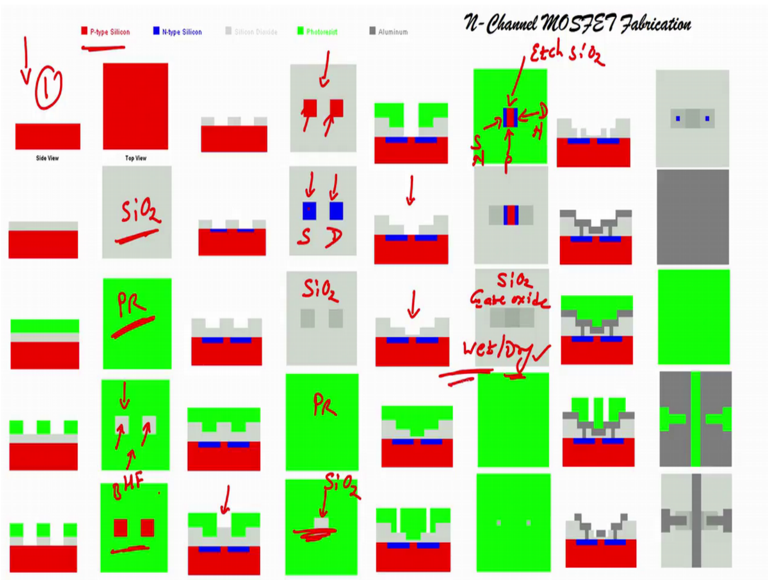

So, we are placing the wafer this wafer, this particular wafer into buffer hydrofluoric acid and we will see this particular pattern which is you can see the silicon in the wafer.

Now, you have to remove this photoresist. So, we have remove this photoresist by stripping it in by stripping the photoresist using acetone. After that you have to dope; you have to dope this area. So, we are using N-type silicon to dope these 2 area, and we can dope it by using diffusion or ion implantation. Once we do this we have source and drain now we will grow silicon dioxide once again we will spin coat photoresist, after spin coating photoresist we will open a window which is in the centre of the wafer, which in this particular fashion you can see here.

And then we will etch the silicon dioxide you can see here we are etching this is silicon dioxide already, and we had to etch the silicon dioxide; when we etch silicon dioxide, you will see this particular region where you can see source drain there is the N-type diffusion layer N-type right N-type and you can see here a centre this is a P-type channel right. So, this is what you see when you when you etch the etch SiO 2 right SiO 2 was here correct.

So, when you etch SiO 2 you reach to this particular region, after this what you do you remove the photoresist removing a photoresist or stripping a photoresist is done in photoresist stripper that is your acetone. When you do that what you will obtain we will obtain this particular wafer, where your window is open where you can grow the oxide. So, you have to grow thin layer of oxide right which is your gate oxide. Now we know we have studied 2 types of oxidation in thermal oxidation, one is wet oxidation and another one is dry oxidation. And when I was teaching you wet oxidation and dry oxidation, I told you that when you have to use gate oxide you have to use dry oxidation and when you have to use field oxide you have to use wet oxidation. So, here for gate oxide you will dry oxidation and you will form a thin layer of gate oxide, which you can see right over here right or right over here in this particular cross section, we can see the gate oxide is here and it is thinner compared to other oxide which is here or here right this is thinner which is gate oxide.

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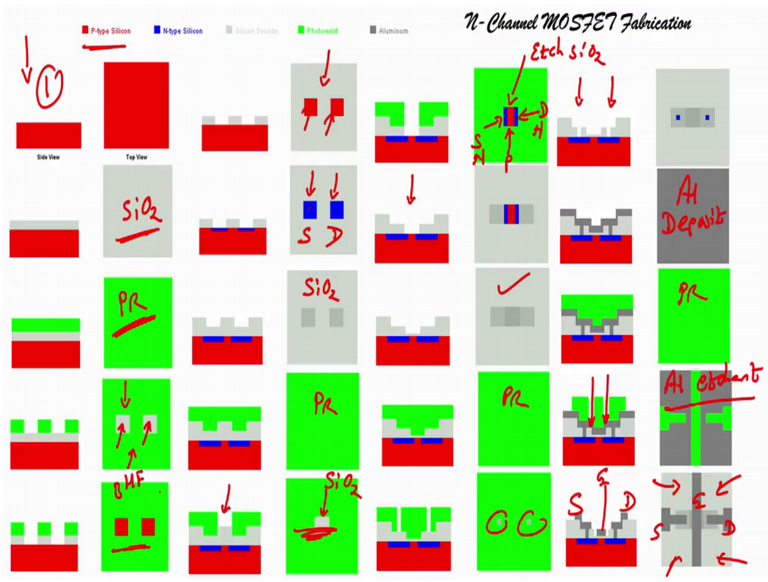

Now, after growing gate oxide we will again spin coat photoresist, we create a window, we remove the silicon dioxide so, that we can access the source and drain after that we will coat aluminium or a metal using we will deposit we will deposit, we will coat this wafer by depositing metal on this particular wafer. When we deposit the metal you can see this it is covering all the area source and as well as gate, then we have to separate the source and gate and drain; that means, source and gate should be separated, gate and drain should be separated to do that you have to again spin coat photoresist, do the lithography and then you can see there is a separation, then once the separation is there you had to etch the metal from here. So, you have to dip this wafer in a aluminium etchant. When you do that aluminium etchant then you will see that the aluminium from rest of the area will get etched right and only you see here; aluminium is etched, aluminium is etched, aluminium is etched, aluminium is etched except at the source at the drain and at the gate you can see here source drain and gate correct. This is how you fabricate your N channel MOSFET, right cool this is how you fabricated N channel MOSFET.

So, look at all the lectures that I had told I have taught you until now, and then and then only you will be able to understand how the N channel MOSFET can be fabricated. In a similar fashion try to fabricate or try to draw the process flow for the P channel MOSFET. Now what I have shown you? I have shown you an N channel MOSFET and what I want you to do what I want you to try at home is to draw the process flow for P channel MOSFET. In the similar fashion this is N channel you see this is N channel, I want you to draw a P channel MOSFET is there P channel MOSFET if yes draw it if there is no then do not draw it tell me whether it is possible or not try and let me know whether it is possible or not whether we can understand where we can write down we can write down the process flow of how to design or how to fabricate N channel and P channel MOSFETs all right.

So, you know now that what is a use of our oxidation, you know now what is use of our deposition, you know now how we were using photolithography and how we are merging all the things together to understand how we can fabricate a MOSFET. In general in quickly what we understood today is how the MOSFET schematic looks like, what is the role of source drain and gate and we have taken example of a N channel MOSFET right we will see in the in the next module which is part of the similar lecture, how we can understand the characteristics of the MOSFET and how we can derive the drain to source VDS, there is voltage versus or VD versus ID or VDS versus ID drain characteristics for enhancement type, for depletion type and we will also see the application of MOSFET ok.

So, I hope you understood what I have taught you today, understand this read this listen to it is not so easy to grasp it, at one time even you know the things. So, just understand what I have whatever I have taught you today, and if you have questions related to MOSFET or related to earlier lectures. Now you have you are free to ask me any query all right. So, you can ask me query I will get back to you with a proper solution so that we are all on same page.

So, till then you guys take care and I will see you in the next module, where we understand the MOSFET in further details and understand how it can be operated till then you take care, bye.