Integrated Circuits, MOSFETs, OP-Amps and their Applications

Prof. Hardik J Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

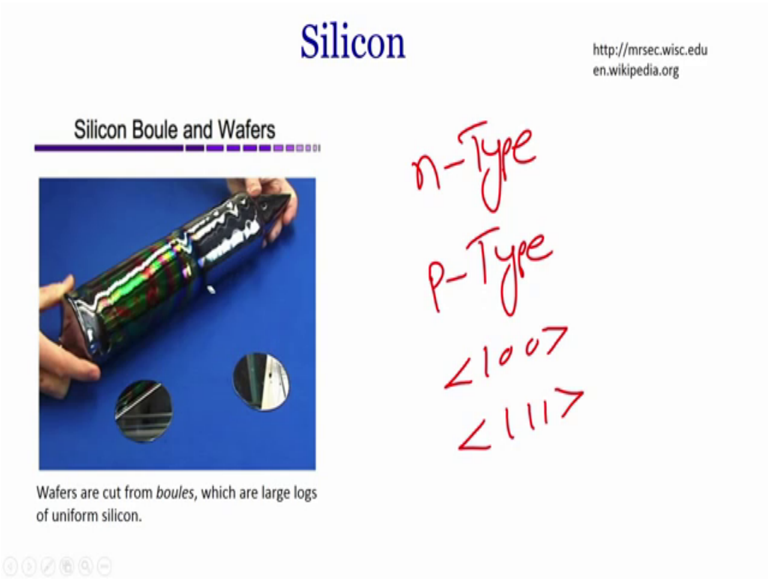
Lecture - 03
Introduction to IC fabrication

Hi. So, I hope that you have listened to my last lecture and we talked about the substrate and in that substrate we talked about silicon, we have seen plastic, we have seen glass, and I have shown you oxidized silicon wafer right. We also talked about the size of the wafers from 2 inch to 12 to 18 inch, and then we understood quickly how the silicon wafer is manufactured in a foundry.

Now, once you have the silicon wafer then what is the next process. So, today's module is to help you understand how you can fabricate an integrated circuit or rather what are what are the processes that are required to fabricate an integrated circuit. So, we will again quickly see the silicon formation and silicon we will use as a substrate and then I will teach you what techniques are there to fabricate a particular device, once you understand the process then we will move to the indicator circuits ok.

So, if you see the screen today's lecture is on process to understand fabrication of integrated circuits, all right this is our class 3. In class 1 we have seen the types of processes monolithic ICs then we have seen thin film thick film and then we have seen the hybrid ICs right. Then class 2 we have seen the substrates class 3 we are understanding the process to fabricate an integrated circuit. But to understand the fabrication of integrated circuit which is complex we will start with a easy example or a simple example right. So, what is that?

(Refer Slide Time: 02:42)

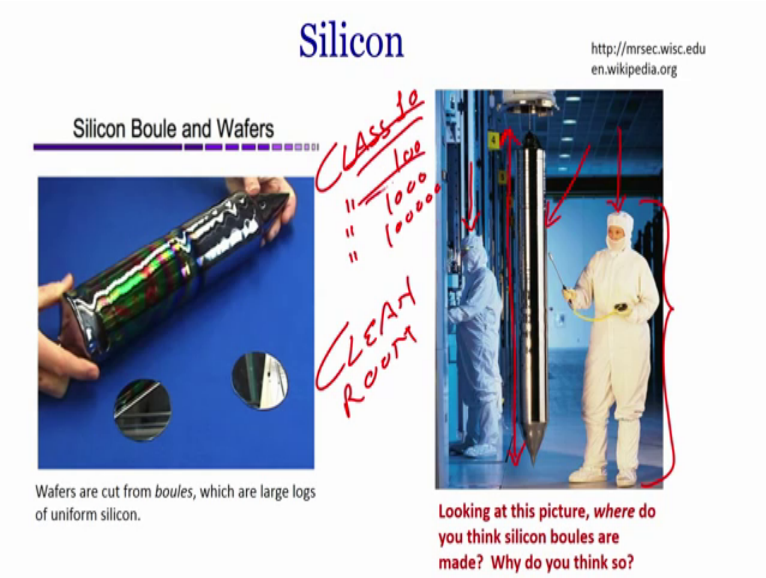


So, if you see, if you remember the last class we talked about silicon right. So, silicon and we talked about boule. So, if I if I show you this thing this is nothing, but a silicon boule and wafers that are fabricated from the silicon boule are manufactured from the silicon boule. This silicon boule that you see here right is made using a process called czochralski technique I told you yesterday or in the last lecture that there are two techniques, one is float zone technique and another and another one is czochralski technique.

This technique is used to form this single crystal silicon boule from the poly silicon material and the wafers are cut from this boule right after certain processes which are that we have to cut the wafers before we are cutting the wafers we have to form the primary flat on the boule right. Then we have to lap the wafers we had to polish the wafers and we have to etch the wafers.

Then we have seen the orientation of the wafers right. Here also if you see there is a primary flat, primary flat, here also there is a primary flat. There is a secondary flat here there is no there is a secondary flat here right. I have shown you in the last lecture if primary flat and secondary flat depending on the angle of the secondary flaht with respect to prime primary flat we can identify or we can easily identify the wafer, type of the wafer that is n-type, n-type or we can identify whether it is p-type or we can say whether it is 1 0 0 or we can say 1 1 1 oriented wafer correct, this we have seen in the last lecture. So, what is the, how this silicon boule is manufactured? And what kind of conditions are there to manufacture this particular silicon boule from the polysilicon, from the polysilicon material ok?

(Refer Slide Time: 04:57)



So, if you see what do you think looking at this picture where is the silicon boule should be made and why do you think, right. This picture shows that there is a silicon boule you can see a whole silicon boule right from here to here right and then you see an engineer working on this silicon boule correct, another engineer is over here you can see right. So, what do you think where this manufacturing or the or the fabrication of the silicon wafers or the process of the silicon wafers from polysilicon to silicon boule to silicon wafers occurs. What kind of environment it should be?

And if you have guessed or if you know it is called a clean room environment. We discussed yesterday or in the last class, clean in the last class number 2 clean room clean room. And then we have also seen class of clean room right. So, what is class of window it can be class 10, classroom 10, class 100, class 1000, class 100000 right and then we have our clean laboratory, all right. So, there are various class.

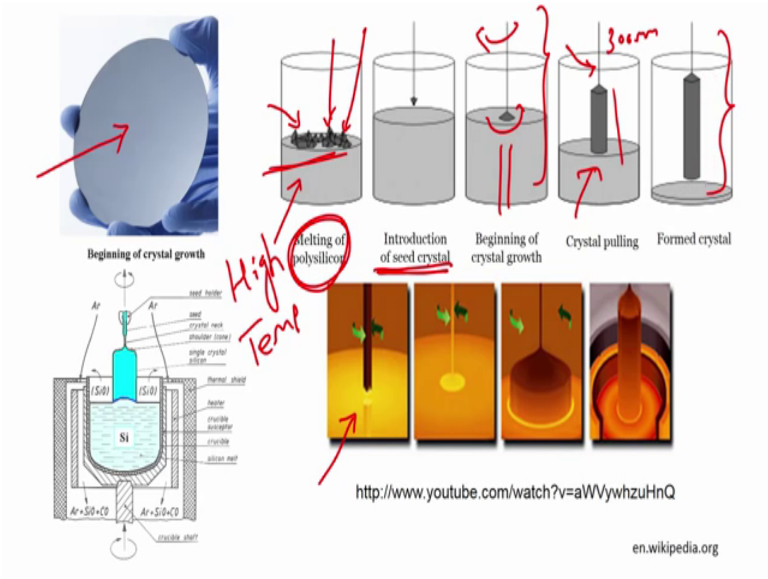
Now, this particular wave boules, silicon boule is manufactured in a clean room environment. So, the biggest contamination that arises in a clean room is through humans and that is why when you enter a clean you have to wear this bunny suit bunny suit right to avoid any contamination second is this is a clean room. So, already the air is much more cleaner compared to your outside environment and the point of keeping or manufacturing the silicon in this particular clean room is to avoid contamination right that is how the clean room is used to avoid any contamination. So, which kind of clean room you should use that depends on what kind of process you are using right.

If you talk about the MOSFETs or you talk about integrated circuits right then the clean room is about class 10, class 10. So, there is a link somewhere in this slides and if we can run that link its good if we cannot run that link then we will see you can do it at home where you will see how exactly this silicon wafer is fabricated, how the MOSFETs are fabricated, starting from the silicon oxide which is SiO 2 or we say it is sand to silicon boule, silicon boule to MOSFET or transistors to billions of transistors.

(Refer Slide Time: 08:07)

So, the journey of silicon dioxide to the final circuit right it is shown in that video. So, I will just give you the link if we can run it here you will see it here if we cannot run it then you can see at home, all right. So, one if now, we know that silicon boule looks like this we also know that we require polishing we require wire bonding, we require the cutting of the silicon wafers and finally, we get this substrate, this is the substrate right.

(Refer Slide Time: 09:01)



So, how this silicon wafer we can obtain. This is just a quick link. So, you can see how the silicon wafer we can obtain. You see this is the silicon wafer, as you can see in this particular image right and the process is this we start with melting of polysilicon, you see these are polysilicon, polysilicon. This polysilicon is obtained by heating the sand at very high temperature in the furnace and we get the polysilicon, this polysilicon is melted in a crucible. So, you can see here in the image below there is a crucible and the polysilicon is melted; that means, the crucible is at extremely high temperature it is at high temperature, high enough to melt polysilicon to melt polysilicon right.

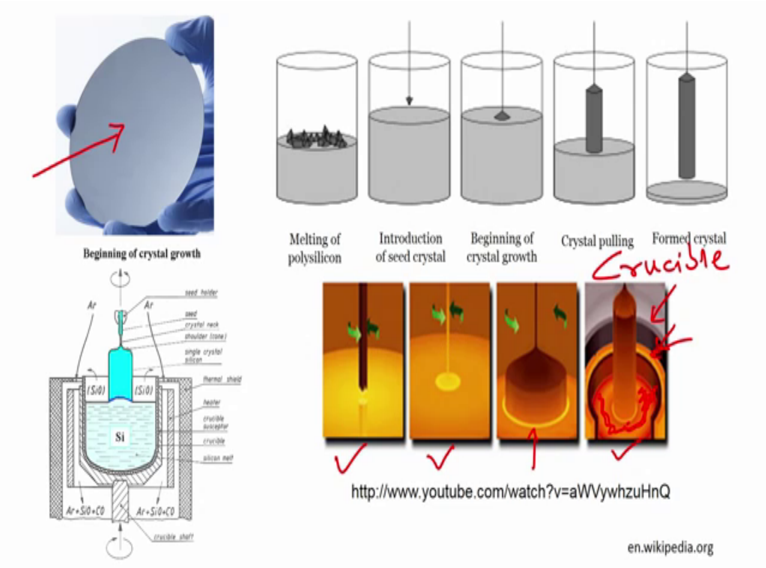
So, now, once we melt the polysilicon what we do? We have to introduce a seed crystal we have to introduce a seed crystal, all right. Now, when we introduce the seed crystal this spinning of se seed crystal is in opposite direction to the spinning of the rotor within them all its opposite direction, all right. We can discuss this detail sometime later or maybe in some other lectures or maybe other course.

Right now, what you understand is that you insert this silicon seed crystal in the molten silicon you pull it up because there is a temperature difference between the seed crystal and your molten silicon polysilicon you will start when you pull it up a formation of the single crystal boule. This is about 200 to 300 millimeter in diameter 200 to 300 millimeter in diameter and finally, when you when you are done you will see boule which is ready right for your further processing that is for your silicon wafers.

So, when you start with polysilicon right you melt it you introduce seed crystal you pull the seed crystal, when you pull the seed crystal there is formation of this silver crystal and then you will see a boule which looks similar to which looks similar to this one or it looks similar to this one you see, right. So, this is how the boule is form is manufactured from the silicon dioxide from the polysilicon if you want to say it is from the polysilicon.

So, now, if you compare the same thing with the images which are below right, which is right over here this one then you see this melting of polysilicon you see there is an introduction of seed crystal, you see the rotation, you see the rotation is in opposite direction and then you see here formation of this boule right. Finally, you are pulling out the boule from the molten silicon and here is your crucible this one is your crucible, crucible right. Let me draw it correctly this is your crucible, crucible. How do you spell it? c r u cru c i b l e crucible, all right. This is crucible, this, this one this one.

(Refer Slide Time: 12:38)



This is a very at very high temperature very high temperature. So, that this silic polysilicon is melted, polysilicon is melted, once it is completely melted then only we introduce you this seed crystal once it is melted then you introduce seed crystal ok, all right. So, this is how the boule is fabricated nice.

Now, this is the link if you guys can note down or when you the lecture is uploaded you can see this particular link in a YouTube and you will see how it is manufactured. How this whole process is done right. So, it will give you a better idea of what I am teaching right now, right because whatever you hear and whatever you see right when you see more things you learn more compared to what you read or what you hear, all right. So, when you watch this YouTube video along with that you will hear the information right you will understand more things rather than rather than reading something from the book this particular process I am talking about, all right. So, look at this YouTube video and you will see how the things are manufactured, how the silicon boule is manufactured from the polysilicon.

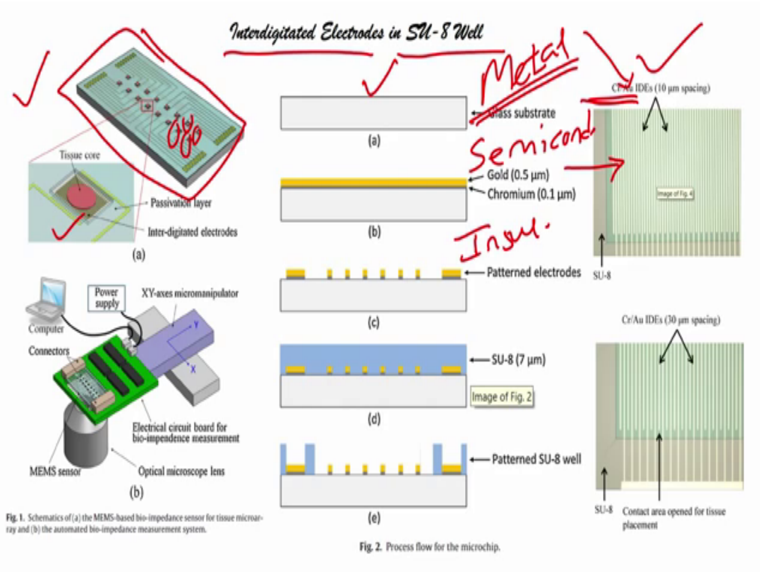
Now, let us see, let us see this process. This is same process right, but it is a schematic if you see argon is introduced here, argon is introduced this is the crucible shaft like I said crucible shaft and the rotation of this seed holder is in reverse direction you see if this is the anticlockwise this moves in a clockwise direction right. This shaft if moves in a clockwise direction, the seed crystal moves in the anticlockwise direction or vice versa right. So, now, what is that? You have seed holder right to hold the seed crystal you have seed, you have crystal neck, you have shoulder cone, you have single crystal silicon, you have thermal shield heater crucible susceptor crucible and silicon melt, all right.

So, what is the role of each of those? What is the role of each of those? So, let us go from the bottom silicon melt, silicon melt is nothing, but your polysilicon which is melted because the it is kept in a crucible which is at very high temperature crucible, crucible you see this line this one the one that I am drawing is your crucible ok, this one is the crucible. Crucible susceptor then this one is heater you see this one is heater this is heater. So, the crucible susceptor is heated at very high temperature crucible gets heated and then there is a thermal shield here, thermal shield this one is thermal shield ok.

Now, what is there? Silicon melt, we have crucible, we have crucible susceptor, we have a heater, we have a thermal shield, inside this crucible there is polysilicon which is in melted form then you insert your silicon single crystal or seed crystal right with which is connected which is attached to the seed holder and when you pull it up by rotating in a opposite direction to the direction of the crucible shaft. Then because of the temperature difference slowly you will see the formation of the shoulder cone, crystal neck, and finally, your boule will start forming, your boule will start forming, right. Once you have boule you already know how to obtain the silicon wafer out of it, all right.

So, I hope that you understand again this is not in depth just to make you understand that this is how the silicon wafer are are formed. The idea is not to really go in depth and understand how it is exactly done, but it is good to know right since it is not idea of this particular lecture or a course to make you understand how the seed crystals are formed what are the orientation what are miller indices and and what what will happen if I change from czochralski technique to float zone technique that is not the idea. The idea is that you should know that you have this silicon substrate, once you have silicon substrate then what you can use or what you can do with this silicon substrate. But, but we should not be under some kind of confusion that how the silicon substrate comes into picture. So, one is how you can form the silicon substrate and that is why I wanted to show it you to you that this is the process which we use to to form the silicon substrate, all right.

(Refer Slide Time: 18:18)



So, let us go to the next slide what we see we see an example here of an inter digitated electrodes in SU-8 well. Now, do not get confused right, that suddenly why Hardik is talking of inter digitated electrodes and why he is talking of SU-8 well right.

I told you in the last module that this kind of process once you know it will help you to understand how the MOSFET is fabricated right, how MOSFET is fabricated. So, just look at this slide carefully for 10 seconds and will continue just look at the slides. So, what is on the left side? Look at this, what is in the centre and what is in the right side.

Look at it and we will we will start in 10 seconds, done. So, we are on 8 second 9 and 10, all right.

So, what is it? What is it? So, you understand first the left side, all right left side is that you see this chip, you can see this chip, and on this chip there are the sensors like this right, there are sensors. If you magnify one chip you will see that there are some inter digitated electrodes within SU-8 well and there is a tissue placed on this one you see this figure. There are inter digitated electrodes, inter digitated electrodes. What does that mean?

So, if you can come back to the screen you will I will show it to you how it looks like. Yes. So, digits right, digits is one inter digitated you understand this thing ok, look at my finger. If I put my finger like this and if I have many many fingers then we have of course, I have 8, 2 thumbs 4 fingers if I put the fingers like this without touching without touching each other it becomes an inter digitated electrodes. So, without touching if I put it becomes inter digitated electrodes. Now, it should be it should be in a uniform fashion, in a uniform fashion.

Now, if I if I tell you that I have a metal, I have a metal right, let us say this is a metal and let us say this is a metal, this is a metal, 2 metals are there. If I want to, if I say what is the resistance between this and this I am not touching this metal, I am not touching, this metal right, this is a metal this is a metal I want to measure a resistance what will be the resistance of; if a device is like this what is the resistance? Infinite because it is not touching, it is not touching infinite, right. So, if I say impedance infinite impedance if I touch it then I see then you will see short right some ohms 2 to 3 ohms. So, when I measure the metal if I measure the resistance of the metal I will say 2 to 3 ohms, but if the metal is not connected then it is infinite resistance infinite impedance, correct. So, the point is that when you have this inter digitated electrodes the impedance would be infinite because they are not touching they are not touching, all right.

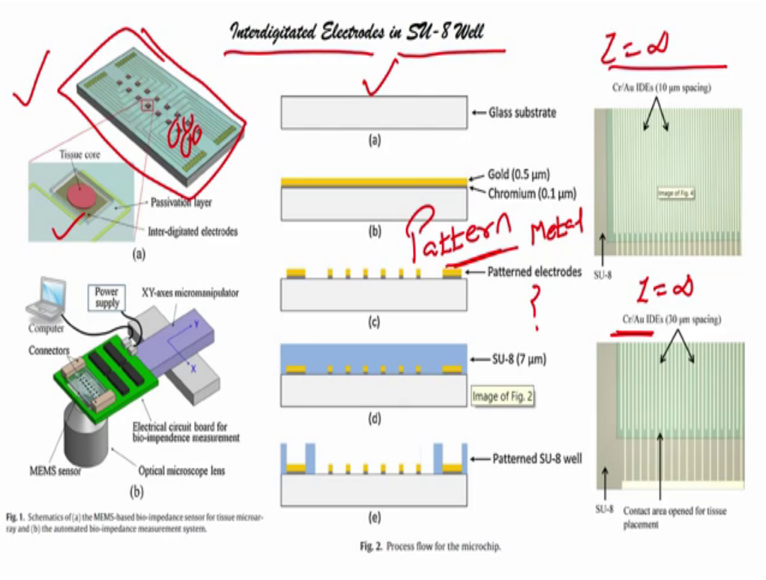
Now, if I place a material or if I place a tissue right tissue is nothing, but our body is made up of cells tissues I hope you at least know this right. So, we the tissue if I take let us say if I take a tissue from a prostate cancer right and I place this tissue on this inter digitated electrodes on this inter digitated electrodes. What will happen? What will happen? Because of the resistance of the tissue because of the resistance of the tissue right. Now, we since I am placing on this inter digitated electrodes right I am placing on this inter digital electrodes. So, what will happen? That because of the tissue this there is a conduction there is a conduction between this electrodes and finally, we will be able to see some change in impedance, we will see some change in impedance because of the conduction property of the tissue, because tissue can be a conducting depending on the resistance of the tissue.

So, the idea is until and unless you short both the things or you place something on the inter digitated electrodes you will see until you place it you will see infinite impedance once you place it you will see the change in impedance depending on the tissue property. That means, that what I am showing it to you today is a sensor that can be used to measure the properties of tissue amazing is not it, and it is a very simple sensor. But why we have to learn this sensor? Because once you understand the process of fabricating this particular sensor you will be it will be easy for you to understand how to fabricate a MOSFET right our focus is still there on MOSFET, but to reach to MOSFET, MOSFET is a 4 mask process right. This is just a 1 or 2 masks process, 2 mark process.

So, the point is if I want to understand a 4 mask process first let me understand a simple thing and then I make my life more complicated, all right. So, let us come back to the screen if we see the screen what what we see these are inter digitated you see this one right. There are lot of lines, lot of lines not connected with each other not connected with each other and this is what c r a u right. I had given you an example in the last module there is a gold there is a chrome right or if I not given you I will show it to you today what is chrome and what is gold and how chrome and gold and why chrome and gold are used for for making this inter digitated electrodes. Chrome and gold, when you say it is a gold it is nothing, but a metal, metal right.

We have seen and I hope that you know that what are metal? what what what is metal? What is semiconductor? semiconductor. And what is insulator? Right you you; I hope you know if you do not know read it what is metal, what is semiconductor, what is insulator ok. Now, sorry.

(Refer Slide Time: 25:07)



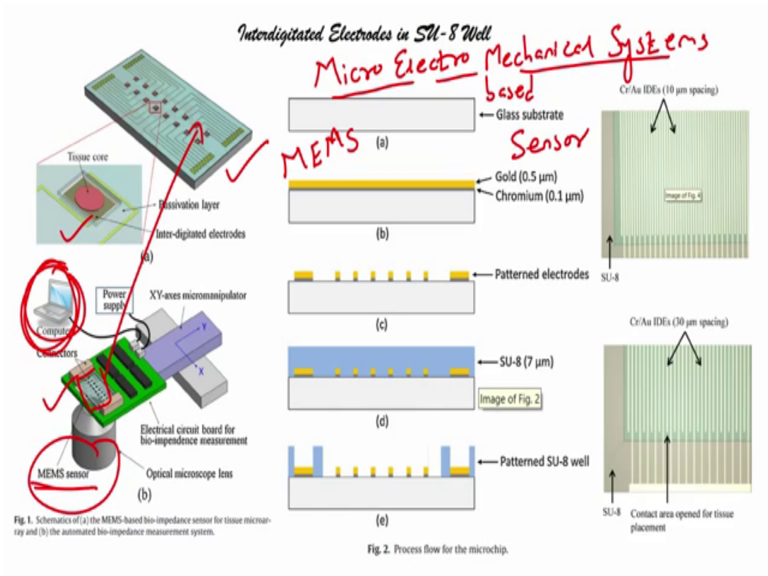
So, if I have a metal which is my gold which is my gold and if I have this lines like this right, like this, which are not connected which are not connected; that means, if I if I have a pad here and if I connect this line here that if I measure the impedance if I measure the impedance between these two point right impedance Z what will I have infinite impedance, infinite impedance. Why? Because this is not connected right this is not connected.

Same thing when you have when you have this inter digitated electrodes they are not connected these are not connected right that is why the impedance here would be Z would be infinite. Same thing here this electrodes as you see this electrodes are not connected with each other they are not touching each other and this are metal right chrome gold is a metal. So, when it is not touching again if I measure the impedance my impedance would be infinite, impedance would be infinite.

So, the point is how can I, how can I pattern, how can I pattern p a t t e r n, pattern this inter digitated electrodes from metal or using metal. How can I do this? How can I pattern it? Right. What are the processes? All right, that is the idea. the point is of making this interdigital electrode is like I have shown you on the left side of the slide which is this one there is a chip there are a lot of pairs for impedance here you can see the impedance right, you see here pairs for impedance measurement correct. And now, you can place a tissue on this; that means, if I place a tissue on this particular image right this is a tissue then my impedance would not be infinite anymore I will see some change in impedance, I will see some change in impedance right. That means, if you are able to design this particular inter digitated electrodes then you can measure the impedance of a tissue; that means, you have a sensor that can measure the change in impedance right and it is a biosensor, because we are measuring the impedance of a tissue right.

Now, before we go to the process of how can we fabricate this particular inter digitated electrodes right, inside the SU-8 well let us first see when we connect this chip, this chip here, right you see here then we have the x y z manipulator. We when you place the tissue you can see the change in impedance on the computer, on the computer ok.

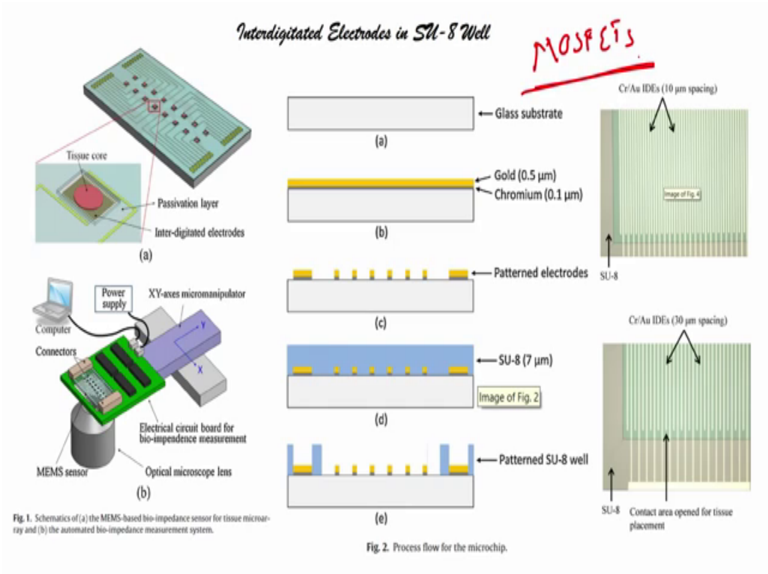
(Refer Slide Time: 28:19)



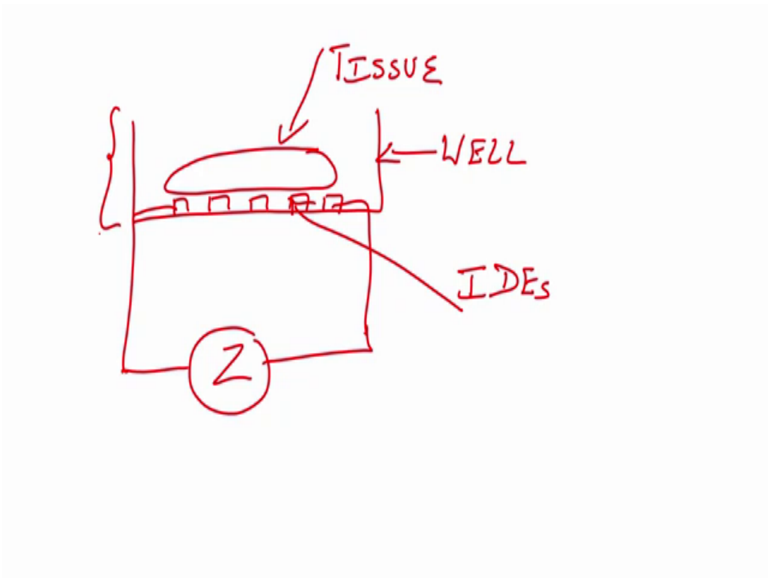
So, this is the these are the MEMS sensor, MEMS where is MEMS? MEMS because we are using micro electro mechanical systems right, systems. Let me write down one second micro electro mechanical systems right based sensor based sensor, all right. So, we when we do a process which is related to micro electro mechanical systems it is called MEMS, MEMS short form is MEMS, all right. So, MEMS based sensor, MEMS based sensor which is here which is nothing, but this particular chip which is nothing, but this chip, all right. And on this chip when we place a tissue we can see the impedance and that impedance we can measure by our system, all right.

So, the point is, the point is, the point is that how you can fabricate how you can fabricate this sensor how we can have you get the sensor. And let me again reiterate that we are learning, we are learning the sensor process so that you can understand how the MOSFETs are fabricated, all right with only one goals So that finally, you are able to understand how the MOSFETs are fabricated , all right.

(Refer Slide Time: 30:08)



(Refer Slide Time: 30:32)

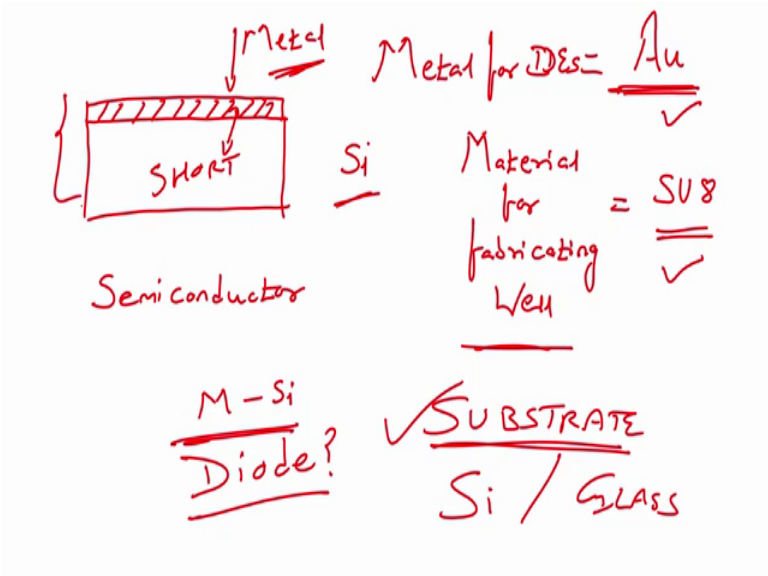


So, let us see. So, what is the idea? The idea is that let me just take the another slide. So, look at this.

The idea is that you have a well, you have a well, all right with inter digitated electrodes. So, this is a cross section, all right. And then on this well you place the tissue you place the tissue and you measure the impedance, you measure the impedance that is idea, all right you have a tissue right let me write it clearly. So, you understand tissue t i s s u e, we have a well w e l l, we have inter digitated electrodes, inter digitated electrodes IDEs we are measuring impedance, all right. So, to fabricate this particular sensor right what we need? What we need? All right. So, we will see what we need.

Now, certain things we understand is that the metal right, we need a metal.

(Refer Slide Time: 31:42)



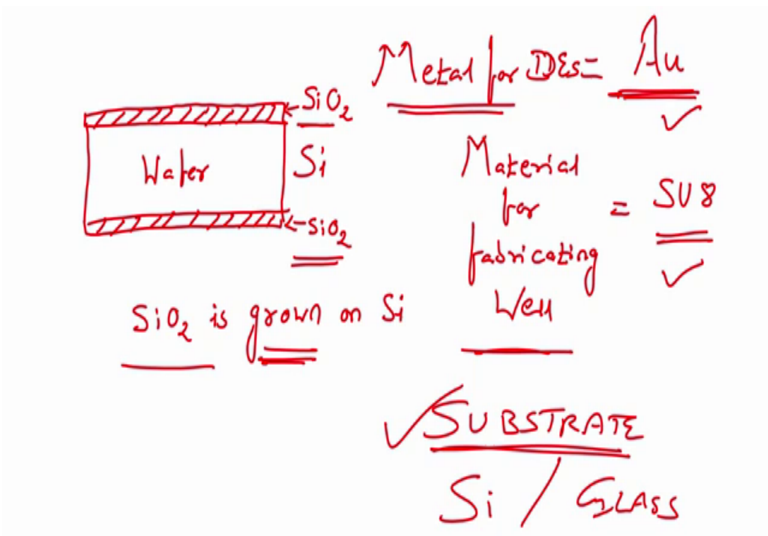
So, metal, let us write down here metal. Metal is what? Gold right, then it will we need material, material for fabricating fabricating well this material is SU-8, all right. What is this? First one is unique wire metal metal for inter digitated electrodes right which is our gold, metal for then material for fabricating well which is the SU-8. So, these two things we require, we got it.

Now, how you can fabricate this device? So, you need a substrate you need a substrate. So, third thing we require is substrate. The substrate can be, substrate can be silicon or it can be glass substrate can be silicon or it can be glass right, this thing we know. Now, we know what we require if you want to form a inter digitated electrodes within a well correct, it is very easy. Now, let us go one by one.

So, first we require is a substrate, we require is a substrate ok. So, I take a substrate and we will stick to silicon and stick to silicon right. Now, this is the substrate, all right. Now, let us see if I use silicon. Silicon is what? Silicon is semiconductor, semi conductor; that means, that if I deposit if I deposit metal metal on silicon then it will not work right because its semiconductor it will start conducting this is short this metal and this substrate is short right. For this particular application is not correct; you may know one of their diodes that uses the similar property or similar fabrication technique where you have metal connected to semiconductor; what is the red diode find it out. We have all studied this diode right where you have metal and semiconductor directly deposited like this find the name of the diode, diode find the name in which there is metal semiconductor in this particular fashion, all right.

So, one thing is ruled out one thing is ruled out that we cannot we cannot deposit metal directly on the on the silicon right. So, what we can do? We have to, we have to deposit we have to deposit, we have to deposit a insulator, insulator.

(Refer Slide Time: 35:32)

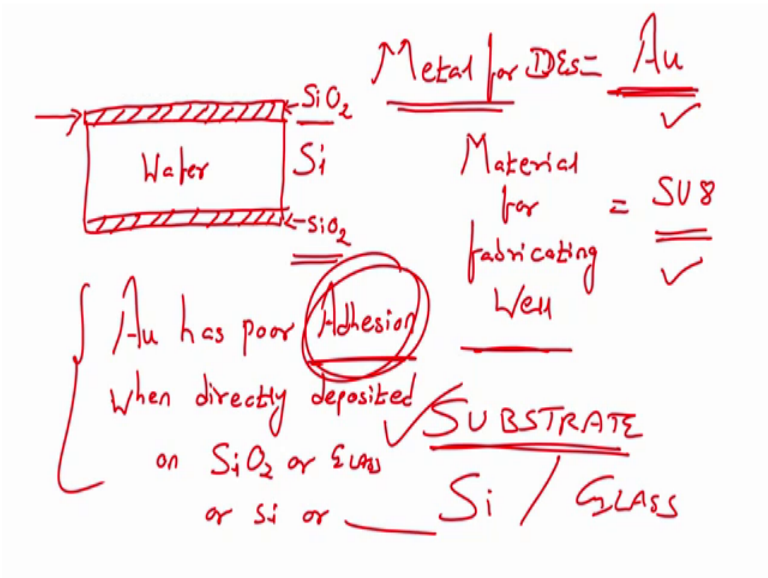


So, we will deposit silicon dioxide SiO 2, SiO 2 we will see. the point is it is very important to know the terms when you understand process it is very important to know the term. This is your substrate or you can say wafer silicon dioxide silicon dioxide SiO 2 is grown, grown on silicon, SiO 2 is grown on silicon, all right SiO 2. Let us design it, so that we can identify the difference between the silicon and silicon dioxide ok. This much is easy, that you cannot deposit metal on silicon directly because it will get shorted.

So, we have to use insulator and insulating film is nothing, but your silicon dioxide, awesome.

Now, what we can do? We have this insulating film on this insulating film we have to have metal we have to have metal. Now, what is metal for IDE? It is a gold, is gold right. So, next process would be we have to we have to deposit gold on top of this silicon dioxide, right.

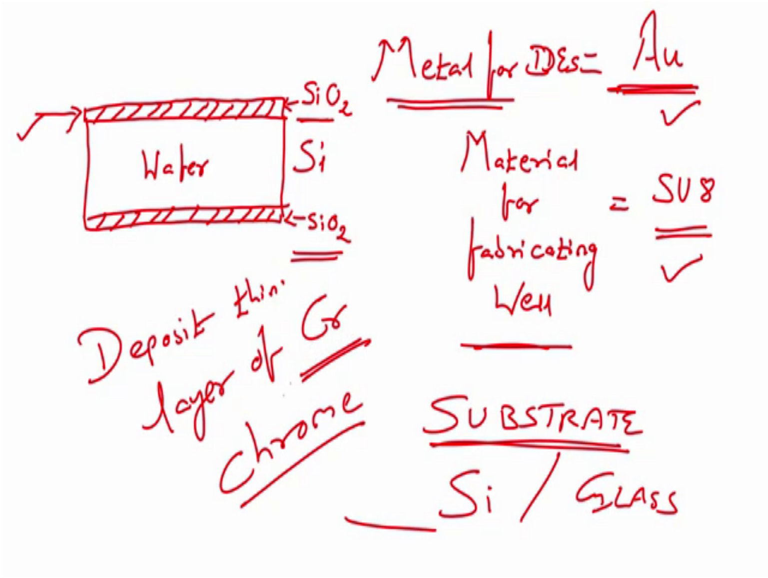
(Refer Slide Time: 37:16)



But if the gold has poor adhesion poor adhesion when directly deposited when we directly deposit direct, when directly deposited on SiO 2 or glass or silicon or any other substrate what is that; Au has poor adhesion. Adhesion is nothing, but sticking property, all right, if it does not stick properly then we cannot use it further. So, it has a poor adhesion, it has a poor adhesion.

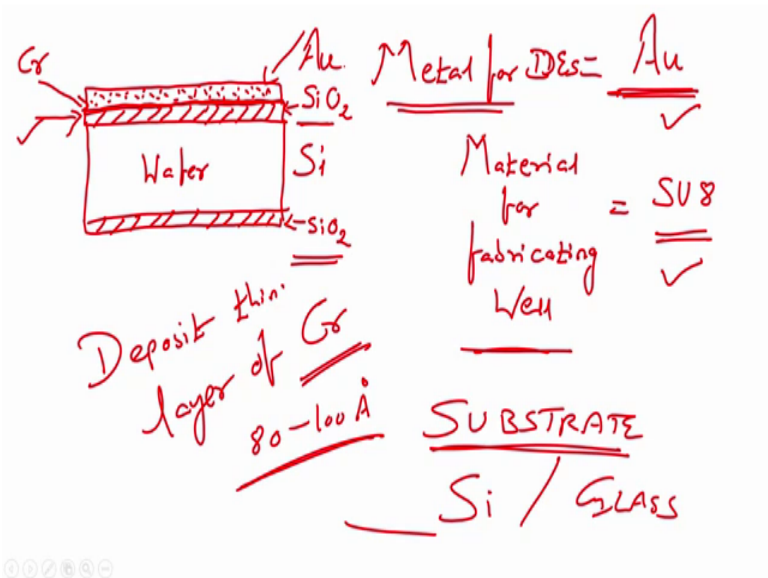
So, what we can do to improve the adhesion? What we can do to improve the adhesion so that it sticks properly on this silicon dioxide; on this silicon dioxide? Correct that is the question. So, to improve the adhesion of gold, to improve the adhesion of gold on the substrate, on the substrate right there is a process and that process is to deposit.

(Refer Slide Time: 38:39)



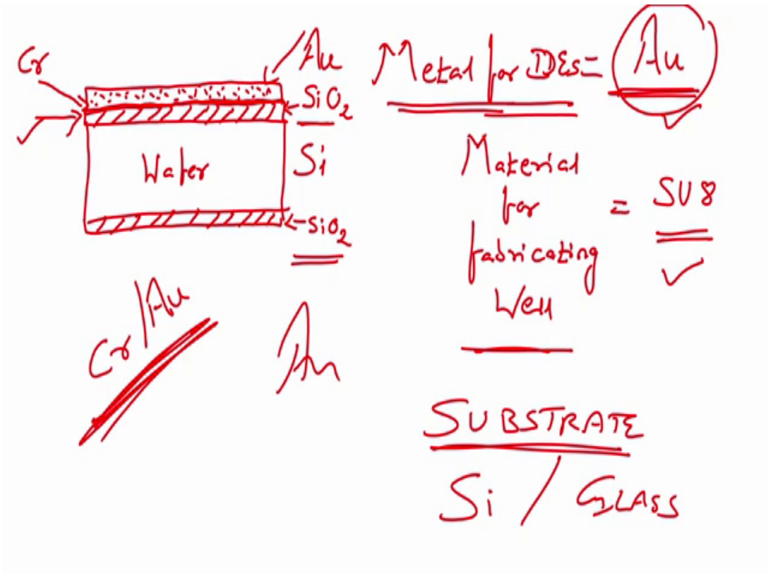
You deposit thin layer thin layer of chrome, chrome c H r o m e or chromium chrome, all right, thin layer of chrome thin layer of chrome on the oxidized silicon wafer. So, we will deposit thin layer of chrome, thin layer of chrome on oxidized silicon wafer. So, this is your chrome this is a chrome right thin layer how much about, about 15 to 18 and 80 to 100 angstrom 80 to 100 angstrom this much of chromium on the silicon dioxide we have to deposit and on that if I deposit, if I deposit on chromium right I have a chromium here chromium on this chromium I deposit, I deposit gold, gold.

(Refer Slide Time: 39:29)



Then the adhesion would be better, then the adhesion would be better, all right this much easy, this much is easy, right. What what we have said that if I directly deposit gold on the substrate it has a poor adhesion, but if I use a thin layer of chromium and then deposit gold the adhesion improves adhesion improves, right. So, that is a next step. Why? Because we wanted metal for interdigital electrodes right which is your gold, which is your gold, right.

(Refer Slide Time: 40:50)



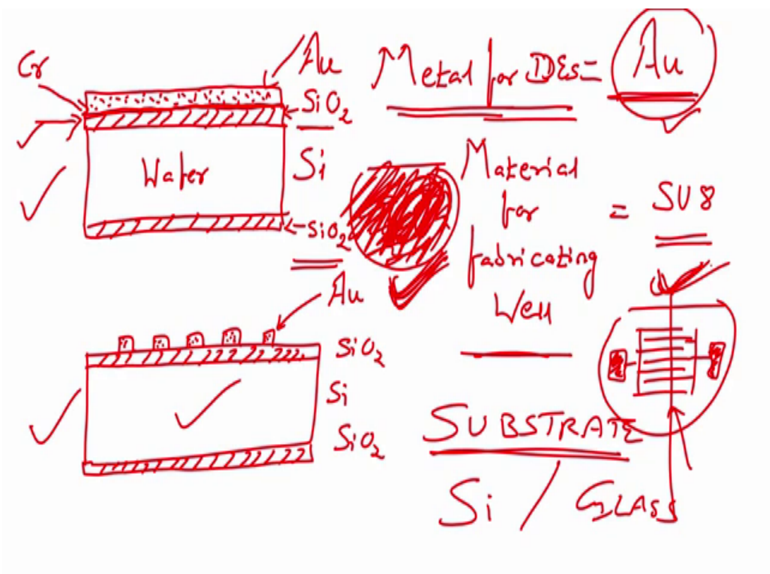
So, every time and any time and every time when you see there is a gold there is a thin layer of chromium, that is why we always denote chrome gold you always denote this thing by chrome gold. We never say there is a gold we always say there is a chrome gold because there is a thin layer of chrome extremely thin like I said 80 to 100 angstrom depending on what is the thickness of gold, but generally around 80 to 100 angstrom that we use for improving the adhesion of your gold right.

So, you understand that you never never deposit gold directly on the substrate, but you use a thin layer of chromium to improve the adhesion, right very easy to understand. So, once I have this oxidized silicon wafer first is I took a silicon I have grown the oxide and we will see its step we will see what how we can grow the oxide, how we can deposit the metal, what are the techniques to deposit the metal, and what are the things to grow the oxide. So, we will see one by one. Right now, just understand that somehow, somehow we have grown the oxide and on that oxide using some technique we have deposit a metal we have deposited a metal, all right.

What is it metal? Metal is chrome gold, its gold right deposited on thin layer of chrome to improve the adhesion to improve this stickness right it will not stick that is what I am saying. If you have, if you directly deposit gold on the substrate it will crack it will not stick, all right. But if you put a thin layer of chrome and then deposit gold it will stick properly, all right. So, the adhesion of the gold can be improved by using chrome. Remember this thing. It can be asked when you when you go for the interviews and these people will ask you why, why you need a chrome for before gold can you deposit gold directly you say no it cannot be deposited because it has a poor adhesion we had to deposit chrome and then we had to deposit gold easy answer, right, ok.

Now, let us go back to the screen and let us see further, let us see further ok. What we have? We have gold on the SiO 2, chrome gold on SiO 2.

(Refer Slide Time: 43:10)



Next step is we have to, we have to form the inter digitated electrodes right. So, what we want is this is a cross sectional right do not do not get confused when I am drawing cross section, this is your silicon dioxide this is your silicon dioxide right SiO 2, SiO 2, Si this is your chrome gold or I will just say gold. Make it easy ok. It is always a chrome gold, this is gold, this is what we want from this wafer, from this wafer, all right.

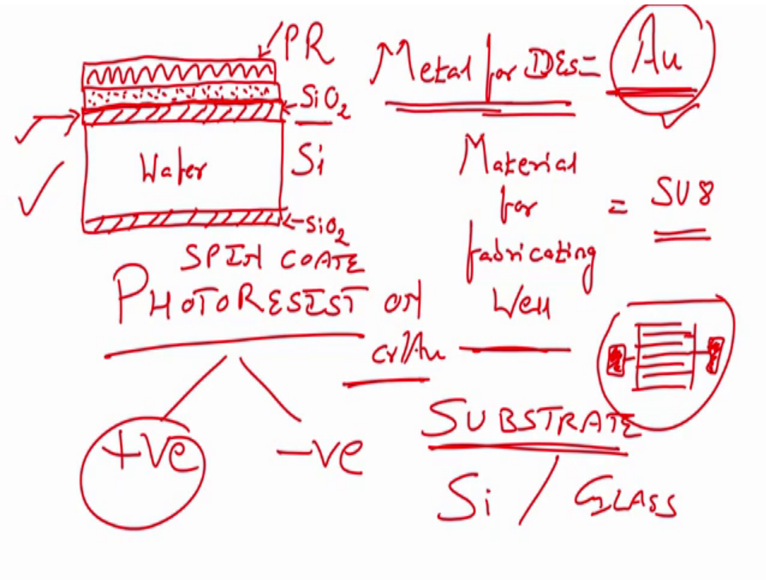
So, how can we, how can we get this pattern from the wafer that I have shown it to you where you have a thin layer of gold chrome and then you have a good layer of gold. From that glare of gold how can you get this inter digitated electrodes? So, assume that this whole palm is flat right you can you do not consider like this. So, assume that this palm is like this portion you consider, all right this everything is gold, everything is gold, from this particular part I want to fabricate electrodes like this right. So, I have two palms here and here right from this I want to fabricate like this. So, how can I fabricate this from just this area? That means, that I have a flat area let let us see on the screen I will I will take another example. So, you get a better idea. So, what I want is I have a flat area where everything is gold, in everything is gold.

From here what I want is a wafer you see here I am drawing, all right I want a wafer which will have which will have pattern like this, from here where everything is gold right everything is chrome gold whole wafer is coated with chrome gold correct here. From here I want this particular wafer. If I do a cross section it will look similar to this right if I do a cross section of this. So, if I do a cross section from here right and I see it will look like what I have shown here, got it.

So, the point is from this, from this you see here how can I obtain this particular design, this particular pattern that is the question, that is a question, all right. So, what we will see is a process called lithography. Very quickly we will see because we have to discuss lithography in detail in some other class. Here we will see how the lithography can be done on, on this particular wafer which is coated with your, which is coated with your gold and the gold is coated on silicon dioxide, is coated on silicon dioxide, right. So, from this wafer let us see the next step.

The next step would be on this wafer on this wafer where you have gold, you have chrome, you have chrome and gold right we will deposit we will spin coat we will spin coat a another pattern. So, that you can understand the different material is that we will spin coat photoresist, photoresist, all right or we will spin coat photoresist, photoresist, all right.

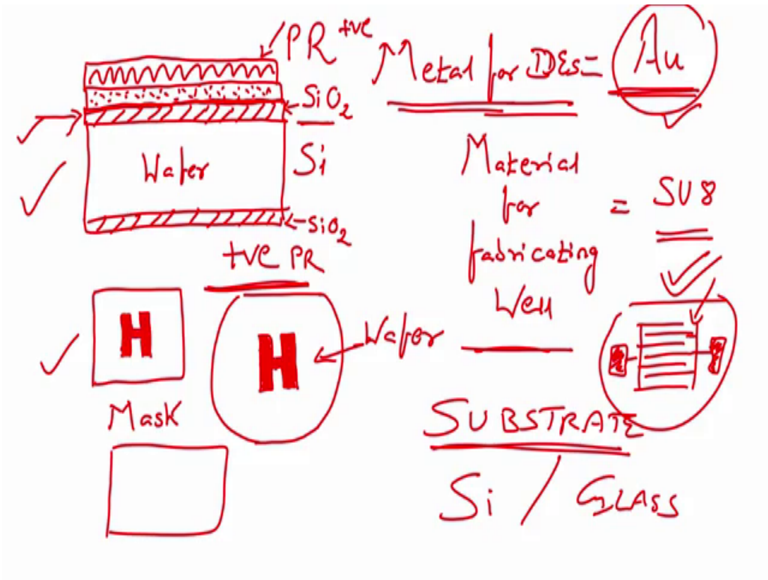
(Refer Slide Time: 47:04)



Now, you have to understand what is photoresist. So, we will talk in detail what is photoresist. For now what you understand is photoresist is two types, one is positive one is negative what you understood that we have spin coated.

We have spin coated photoresist right on chrome gold right which one we have used positive photoresist. I will tell you in detail how photo resist photo resist works, what is positive, what is negative in the following lectures right. Now, we just understand that we have spin coated a photoresist which is positive photoresist, all right. So, this much is ok. Now, what is positive photoresist? We will see a differential positive negative in other classes. Right now, let us just consider that we have spin coated for positive photoresist we have spin coated positive photoresist. So, what is positive photoresist? Positive photoresist is that if I have a mask, a mask which is patterned in this particular fashion right which is patterned in this particular fashion which is it has the design which says H, which says H right this is my mask, all right this is my mask ok.

(Refer Slide Time: 48:27)



And if I use positive photoresist, if I use positive photoresist, then I on my wafer on my wafer I can very bad drawing once again ok, on my wafer I will retain this similar pattern, I will retain similar pattern which is which is the same like my mask, which is similar to my mask, all right.

The point is photoresist positive photoresist will help us to retain the similar pattern which is on the mask, which is on the mask. That means, that means that using positive photoresist we can retain similar pattern which is on the mask on the wafer this is wafer ok. This much is easy. So, what we have seen we have spin coated photoresist on the oxidized silicon substrate and then we have seen a mask and then we see that when you use positive photoresist then you can retain the similar pattern on the wafer, this is easy, it is easy.

So, the next step would be to use the mask right because why we have to use the mask not this mask no not with this particular pattern not with this particular pattern our mask would be our mask would be with patterns for this inter digitated electrode right you see on the right side, on this interdigital electrode that we had to fabricate right. So, our mask would have this inter digitated electrode pattern on it, all right that mask you will use as a next step ok. So, I hope you understand.

So, let us see how the mask looks like, how the mask looks like, all right. So, I will show you the mask which has the similar pattern which has a similar pattern that we want on the on the oxidized silicon substrate which is the metal.

(Refer Slide Time: 51:30)

So, you see here in my hand I have the mask. So, if you can zoom, you can zoom in zoom in zoom in further ok. So, if you are able to see the pattern right you are able to see the pattern this is a mask this is a mask and there are patterns on this particular mask each are sensor each are sensor.

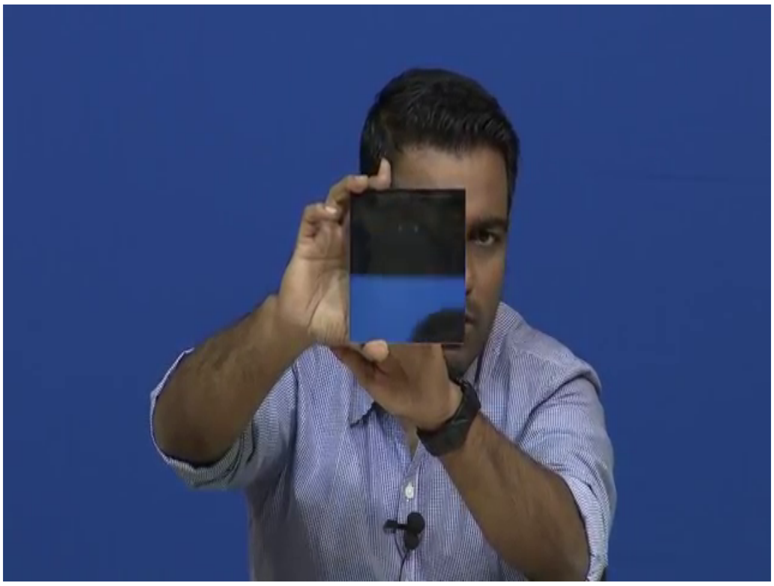
So, what is this pattern? This pattern is nothing, but an interdigitated electrode, this pattern is nothing, but an interdigitated electrode. This is chrome mask this is a mask you see is a mask chrome mask, all right chrome mask you see I am showing it to you in from other direction. So, you can understand right. This is a glass and it is a 5 inch mask, it looks like this right. Its chrome material is chrome. So, my mask is my chrome mask.

This mask, this mask I had to put on the wafer which is coated with photoresist, all right. What what was the wafer? Wafer was oxidized silicon wafer on that we have a chrome gold, on that we have photoresist that particular wafer, I had load this mask on that particular wafer I had to load this mask on that particular wafer ok. So, this mask as you see that are patterns within the mask right and other area is bright other area is bright correct, you can see my face you can see my face you can see my hand behind the mask you can see my hand behind the mask everywhere except except the pattern which are on the mask right. If you if I put a finger right here you cannot see my full finger correct, but if I move my finger here you are able to see part of my finger. Now, you can see full finger. Now, again you cannot see some area because there is pattern, again you cannot see some area, again you cannot see you may put it back here you cannot see complete finger that is because there there is a chrome material here.

Same way there are patterns here there are patterns here right; that means, if you can see the rest of my finger through the mask and only the pattern area you cannot see this mask is called bright field mask. What it is called? Bright field mask because the field is bright, field is bright, that is why you can see correct only the pattern area you cannot see bright field mask, all right remember name bright field mask ok.

Let me show you another mask. Let me show you another mask in which my field will not be bright field will not be bright and that is why I have given the name or not I have given the name that will be amazing.

(Refer Slide Time: 54:19)



The name of this mask is dark filled mask. Now, can you see my face? You can see, you cannot see right. Can you see my fingers? You cannot see right. But what about this particular area? Can you see this area which which is transparent? This is transparent right see this is transparent. So, this area is transparent other all the area is dark, is dark, you see is dark right.

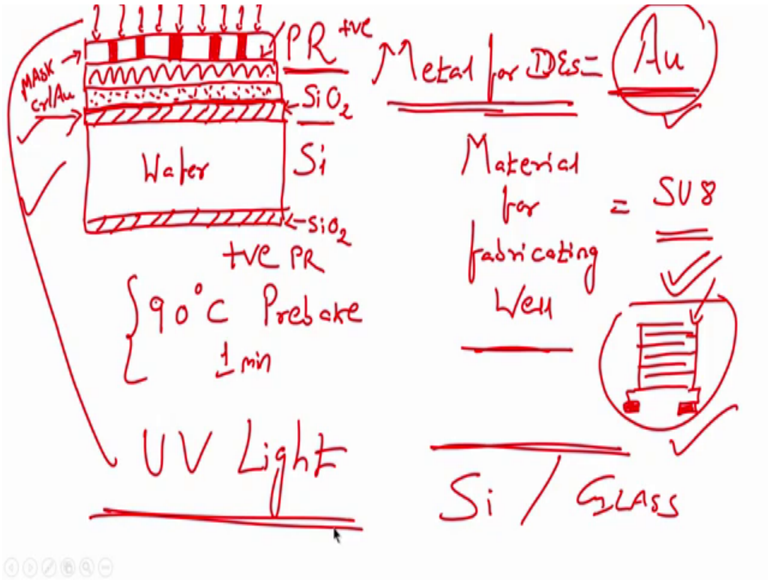
Now, again it is not a correct way of holding the mask with bare hands with finger touching here that is not correct absolutely not correct, all right, but but the idea of this particular module is not to how to handle the mask. The idea is that what is a mask that is why I am holding with hand and this is just a demo mask that is why it is otherwise if you are in the fab lab anyway you will wear a glove and you have to handle the mask with the tweezer or or with the hand but with a gloves.

So, the point is that this is the dark field mask. Why dark field? Because the field is dark you cannot see anything through the mask except the area which is transparent; that means, this field is dark. The earlier mask that I have shown it to you is bright field. Now, you can easily identify if there is a bright field mask or is a dark field mask. This is bright field this is dark field, this is dark field, this is bright field easy extremely easy extremely easy, is not it see bright field dark field, bright field dark field. Now, do not forget this, all right this is the terminology used for the masks. This is 5 inch mask; the last lecture we have seen is a 4 inch wafer, this is a 5 inch mask, all right 5 inch mask 4 inch wafer 5 inch mask.

So, depending on the size of the wafer, depending on the diameter of the wafer your mask size would change, your mask size would change. The point here is that now, we will be using the bright field mask with the pattern which are similar to what here is if you come come back on the screen they are similar to this pattern right with similar to this pattern or or to be precise or to be precise the pattern is like this it goes here, and then there is a it is similar to this. This is the pattern on the bright field mask that I have shown it to you, all right.

So, the next step, next step is I am removing this so that we understand what we have done until here we have we have spin coated positive photoresist.

(Refer Slide Time: 57:09)

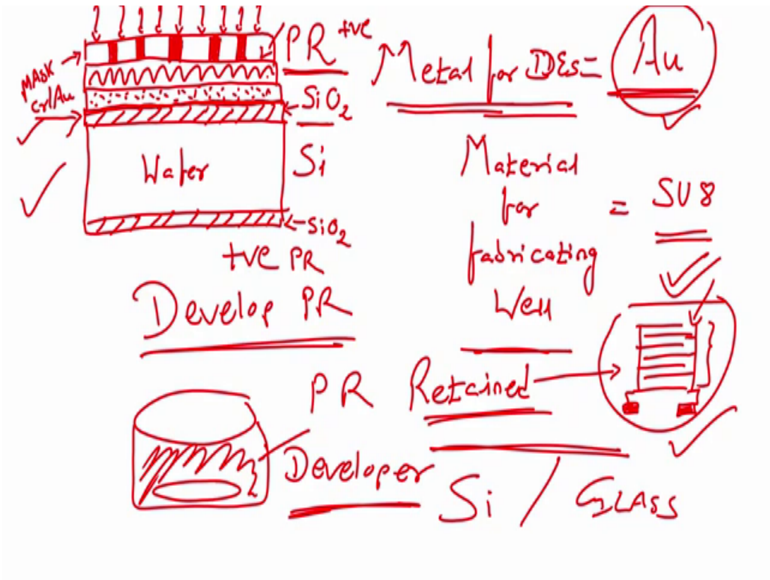


After spin coating photoresist you have to pre bake it at 90 degree centigrade, pre bake at 90 degree centigrade for 1 minute, all right pre bake at 90 degree centigrade for 1 minute. After pre baking for 90 degree centigrade for 1 minute, we will we will keep the mask we will keep the mask on the positive photoresist on this wafer the mask has the pattern right.

What patterns are there? The patterns for the inter digitated electrodes, the patterns for the inter digitated electrodes. So, let us draw it quickly like this, all right this is your mask, all right, this is your mask. So, what we are done? We had silicon on that silicon wafer, we have silicon dioxide grown silicon dioxide on silicon dioxide we have this one which is chrome gold, on chrome gold we have spin coated positive photoresist this one right. Then on positive photoresist after the spin coating positive photoresist we have we have pre baked the whole wafer at 90 degree centigrade for 1 minute, after pre baking for 90 degree for 1 minute we will we will attach the mask we will attach the mask to the wafer and we will expose it there is a UV light. We will expose it, all right. So, this whole wafer is exposed with this is nothing, but your UV light. You will expose the wafer with UV light.

What will happen? What I said, what I said is that if I use positive photoresist I can retain I can retain the pattern right, if I push positive photoresist if my mask is like this I will retain this area which is inter digitated electrodes sorry, this area which is inter digitated electrodes. And rest of the area will not be retained, the area which is transparent which is white will not be retained the area which is dark will be retained will be retained, r e t a i n e d, retained. It will remain there, it will remain there, all right when I use positive photoresist.

(Refer Slide Time: 59:56)



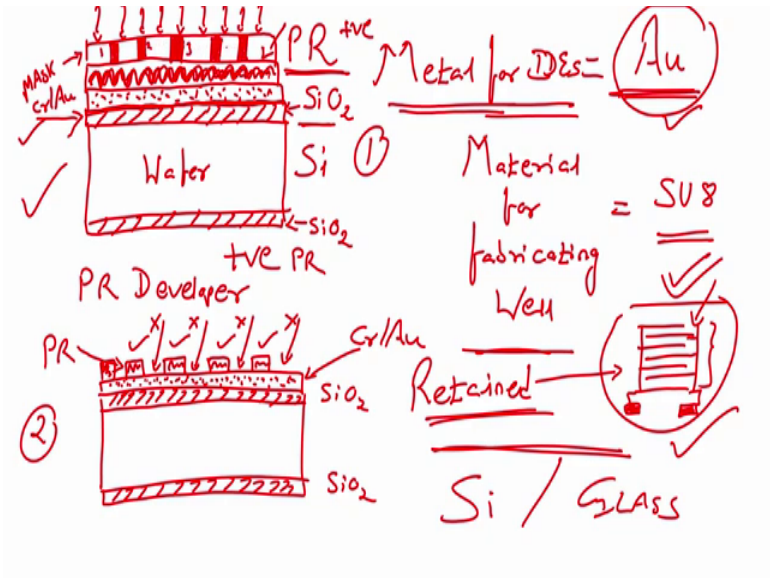
So, after positive photoresist once I load the mask once I load the mask if I do the UV exposure with UV light then what I will get after this one after UV light. So, after spin coating loading, loading mask the performing UV exposure I have to develop develop my photoresist, develop my photoresist, all right.

So, that develop is nothing, but I will lower this wafer I will remove the mask now, because I have already exposed it I will take the wafer and lower it in a beaker in a beaker with a chemical for developing the photoresist. So, there is a chemical here which is called photoresist developer, photoresist developer, all right. This is a chemical called photoresist developer.

Now, you see I am taking long time for this particular class because it is extremely extremely important that you understand this process otherwise you will not be able to understand how MOSFET is fabricated. So, just concentrate right if you want to take a break take a break come back, but but come back and concentrate this is extremely important steps that you have to remember, all right. These are steps that you have to remember do not forget read and listen to this lecture as many times as you can right because you have to understand what are these steps for for simple sensor.

Once you understand; what are the steps for simple sensor you can go for complex devices, all right. So, come back to this slide and what we see is once we have exposed the wafer we unload the mask and we keep the wafer in the photoresist developer. After that, after photoresist developer what we get what we get is, what we get is, let me I will draw it here I will draw it here after photoresist developer after photoresist developer. What I see is I see a wafer I see a wafer oxidized wafer I see oxidized wafer with chrome gold, chrome gold is intact chrome gold and here is my photo resist, here is my photo resist, here is my photo resist, all right. To be precise let us draw like this.

(Refer Slide Time: 62:02)



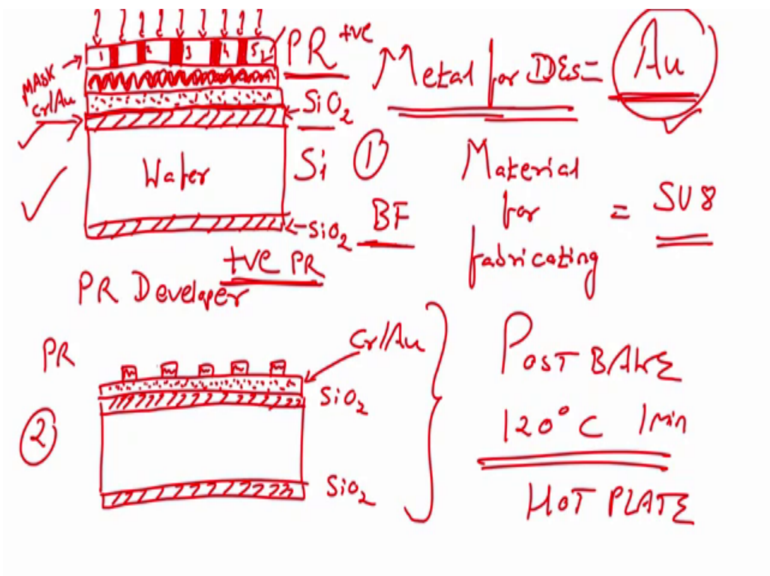
So, what happened? Tshe photo resist from this area photo resist from this area, photo resist from this area, photo resist from this area, it it got developed it is not there you see here you see here photoresist was everywhere, you see here photoresist was everywhere right, photoresist was everywhere.

Here in this, let us say 1 in the 2, in one you can see photoresist is everywhere same in its waves right this one this material correct. Now, in this too you can see that photoresist is developed, from this area it has gone, gone, gone, gone, only in this particular area it is there 1, 2, 3, 4, all right. I can draw one more to just have the same thing because there are 5 here in a mask.

You see mask where; where is the dark pattern in the mask? First dark pattern, second dark pattern, third dark pattern, fourth dark pattern, fifth dark pattern, same way the photoresist on this particular wafer photoresist on this particular wafer will be at 5 places intact 1 2 3 4 5, 5 places it will be intact. Why it will be intact because we are using positive photoresist, we are using positive photoresist. I told you that when we use for positive photoresist we can retain whatever the pattern is there we can retain whatever the pattern is there right that is why here you can see the positive photoresist remains in the area which was dark, which was this one right.

In the mask what you can see 5 dark areas 1 2 3 4 5 the mask that we have used is bright field mask, is a bright field mask right only the patterns are dark and other field is bright, bright field mask and you can see here that the photoresist is retained only on the area which was dark which was the pattern area, all right.

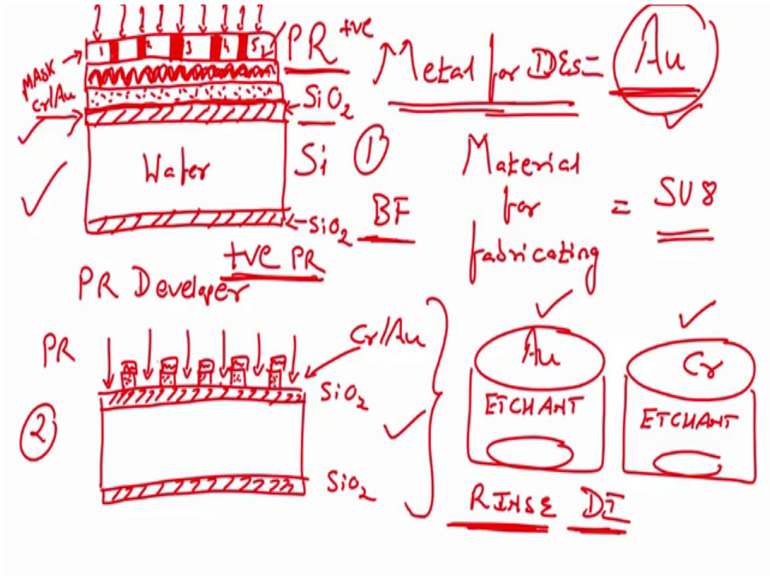
(Refer Slide Time: 64:59)



Now, what? Now what what is the next step? What is the next step? Next step is, next step is let us see what is the next step, next step is we will we will post bake this we will post bake. That means, we will take this wafer we will post bake at 120 degree centigrade for 1 minute. That means, we will heat this wafer on hot plate on hot plate for 120 degree centigrade for 1 minute, all right, that is to harden the photoresist that is to harden your photoresist make the photoresist stronger.

After this, after this I will I will dip this, wafer I will dip this wafer in the chrome etchant I will I will dip this wafer this is gold etchant, this is chrome etchant. I will dip this wafer first in gold etchant because the top layer is gold right the top layer was gold and the bottom layer here where I am drawing right now again is chrome correct, bottom layer is chrome top layer is gold.

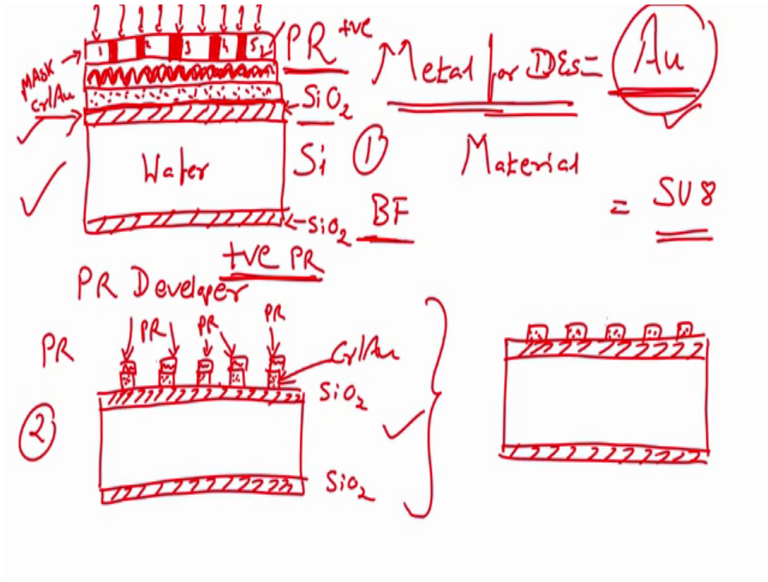
(Refer Slide Time: 66:18)



So, what I will do is I will first etch my gold first I will etch my gold by dipping my this particular wafer into the gold etchant Au etchant E T C H A N T, all right. After that I will take the wafer and and use DI water DI water right to rinse it to rinse it, r i n s e, rinse, right I will use DI water and I will rinse the wafer then I will dip this wafer in the chrome etchant in the chrome etchant e t c h a n t, all right.

Then again I take this wafer and and rinse it in DI, all right. So, once I do this, once I do this process first is I will etch gold then I will rinse it then I etch chrome I rinse it, what I will see, what I will see is, what I will see is I will see that the chrome gold has been etched or is etched chrome and gold is etched from the from the area which was not protected by photoresist. The chrome and gold got etched from the area which was not protected by photoresist right this was not protected by photoresist. So, it got etched very simple.

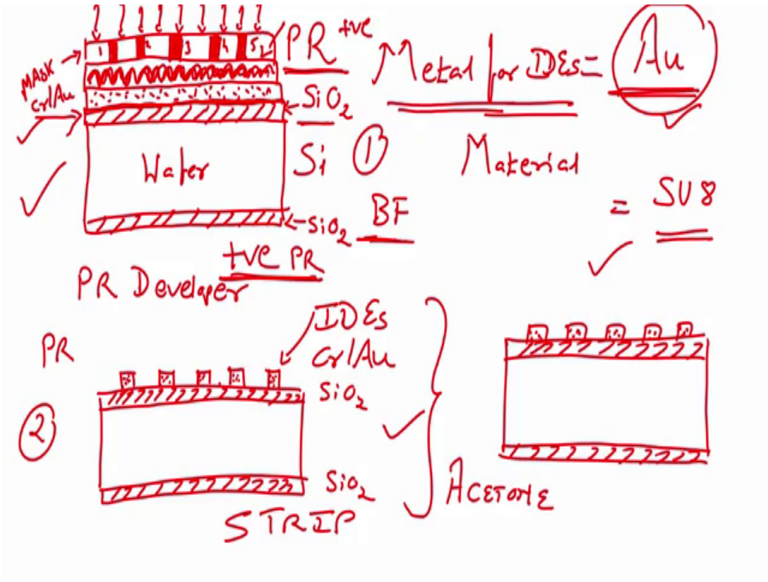
(Refer Slide Time: 68:49)



Now, what you have? You have, you have photoresist and photoresist is saving your photoresist is this one on the top photoresist, this one is photoresist, this is photoresist, on the top this one is photoresist, this one is photoresist, on the bottom, on the bottom this 5 blocks that you see these are nothing, but chrome gold right, this is chrome gold, this is chrome gold, this is chrome gold correct.

So, what we want? What we want? We want that we want; what we want we want to have a device wafer a wafer right wafer with inter digitated electrodes that was our idea right that was our idea. So, we want this as a final one. But what we got here, what we got here is a wafer is a wafer with photoresist is a wafer with photoresist covering or protecting the interdigitated electrons right you can see the top layer is photoresist.

(Refer Slide Time: 70:17)

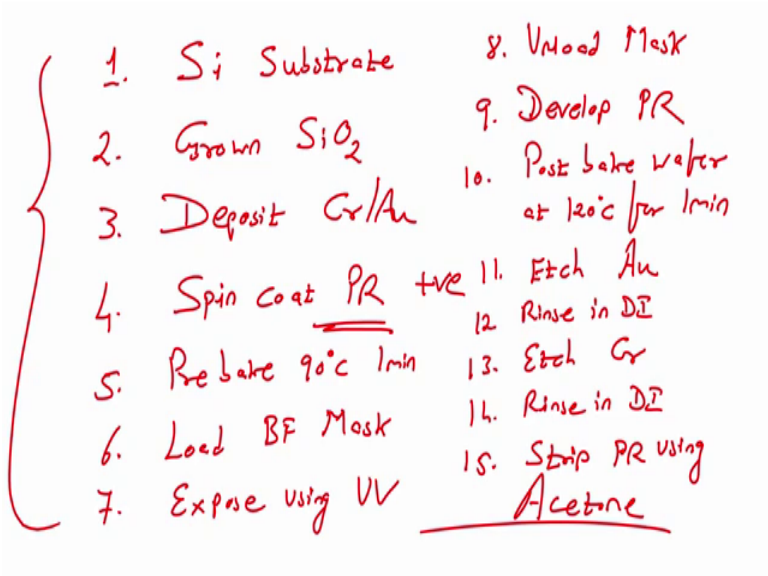


So, we have to strip the photoresist we have to strip, s t r i p, strip removing off we have to strip the photoresist for stripping the photoresist we had to dip this wafer, we have to dip this wafer in acetone, in acetone. When you dip this wafer in acetone what you will see this photoresist will get stripped the photoresist will get stripped and you will get a silicon or oxidized silicon with inter digitated electrodes made out of chrome and gold, you got it. This is just one mask this is just one mask.

So, when we are going to use or when we are going to fabricate a MOSFET this is a 4 mask process right. But it is very important once you understand the process it is very easy for you to further understand what are the process for 4 masks. This is a just one mask process because we have used just one single bright field mask right. But in case of MOSFET we will see there are multiple mask there are 4 mask and then in case of pressure register cantilever there are 7 masks. So, it becomes complex and complex.

But the point is once you know the process of lithography your life becomes easier life, becomes extremely easy. So, let us quickly recall what we have done and we will see the SU-8 well on this interdigital electrodes in the following modules in the next module, all right, right. Now, let us recall what we have done to to form this inter digitated electrode on oxidized silicon substrate, all right. So, let us come back to the screen, come back to the screen.

(Refer Slide Time: 72:07)



So, I will write it here what we have done first thing we have done is we have taken a silicon substrate. Second, what we are done we have grown grown silicon dioxide. Third, we have deposited, deposit, deposit chrome gold right, deposit chrome gold. Fourth, fourth was spin coat spin coat photoresist. What kind of photoresist? Positive.

Fifth, pre bake 90 degree centigrade 1 minute. Sixth, load bright field mask. Seventh expose using UV right. Eighth, unload mask; ninth develop photoresist, tenth post bake wafer at 120 degree for 1 minute. 11, etch gold; 12, rinse in DI; 13, etch chromium; 14, rinse in DI; 15, strip photoresist using acetone right.

When you perform this process then you are able to get; able to get what? You are able to get the oxidized wafer with inter digitated electrodes oxidized wafer with inter digitated electrodes, all right. How it looks like? It looks like it looks like this one this inter digitated electrodes or like this. You see this yellow line this is chrome gold spaced right interdigital electrons. Where are we? We are right now here, we are right now here ok. So, this is the step used to design or pattern your inter digitated electrodes using chrome and gold. This is one mask process.

In the next lecture, in the next module we will see how can you design the SU-8 well so that your inter digitated electrodes are within SU-8 well because that is our idea right. So, that will be your second mask process that will be a second mass process. So, let us quickly recall what we have seen. We have seen in this particular module how the silicon boules is fabric is design is manufactured and there is a clean room that is required. Then we have seen how we can slice it, how the how this czochralski technique or how the float zone technique used quickly not really in depth. Then we have seen that once you have the silicon wafer how can you do a process. So, we have taken an example of an inter digitated electrodes within an SU-8 well and then how you can fabricate this electrodes on the oxidized silicon substrate.

Then we have seen two masks which are bright field masks and dark field mask right then bright field mask and dark field mask bright field mask and dark field mask right. Then these are 5 main masks we have designed, then we have also discussed about photoresist, very quickly positive and negative. And we have not gone in detail that we will see in the next modules you have to just understand quickly that we have used positive photoresist that is it right.

Now, positive photoresist what was the advantage positive? Photoresist that you can retain the image of the mask on the wafer same image of the mask on the wafer you can retain if you use positive photoresist. Then we have seen the process the process is you take a silicon wafer you grow oxide on oxide you deposit chrome gold, on chrome gold you spin coat photoresist, on after spin coating photoresist you have to pre bake the wafer at 90 degree. Then you take a mask load the mask expose it, with the UV unload the mask take the wafer develop it so the photoresist that is that is exposed will get developed right and then the photoresist which is covered with the mask with the pattern of the mask will stay there.

Then you take out the wafer you do the post bake, after post baking you remove gold then you rinse it, etch the chrome, rinse it, then you put the wafer in the acetone and acetone will strip out the wafer, strip out the strip out the photoresist. So, after stripping out the photoresist the final thing that you can see is the oxidized silicon wafer with pattern gold inter digitated electrodes or gold or inter digitated electrodes with chrome and gold. That is what we have seen in this particular module right.

So, like I said it is very easy if you remember the process what is the first process, what is the second, what is the last process, how we can operate the system, it becomes really easy, all right. So, what we see right now is what we have seen is, we can we can now at least pattern a metal on the oxidized silicon substrate. In the next module let us see how we can form the SU-8 well, and what is a process for forming the SU-8 well, and then we will move to the next one where you you will level up one more thing and instead of one mask you use multiple mask or use 2 3 mask.

Do you you understand that single mask is ok, but when multiple masks comes into picture there is a process called alignment. And within the multiple masks or within the mask there is lot of defects. So, we will see in the next module. Till then you just look once again what I have taught you in this particular module, see it, learn it, right and if you have any doubts you can ask me any time that is not a problem. The point is once I finish the whole series I hope that you would be able to understand how we can fabricate that single MOSFET right. And when you are able to understand one single MOSFET you are able to understand entire fabrication, entire fabrication, most of the part, most of the part, all right ok.

So, till then you take care and I will see you in next module. Bye.