Advanced Neural Science for Engineers
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National Institute of Mental Health and Neurosciences (NIMHANS)
Lecture 38
Micromachining and Etching

Welcome to this particular course and the class in particular, here we are going to talk about micromachining and the micromachining is a part of the course, advanced neural science for engineers. Now, why we need to learn this micromachining, and how it is useful for fabricating the sensors in general because like I said, the heart of the entire course is lithography and sensors. Because once you understand how you have the sensors, transducers that can be fabricated for acquiring or applying stimulation both acquiring signals from the brain or applying stimulation to certain parts of the brain, you will be able to solve a lot of problems in this area.

Now, when we talk about micromachining, what does the word machining means? Machining means to work on a material or to fabricate a material or fabricate a particular design using certain tools. These tools can be milling; these tools can be drilling. In fact, when we talk about manufacturing then there are two aspects of manufacturing. One is additive manufacturing and the second one is subtractive manufacturing. So, here we will be talking about machining at a micro on scale and the use of this would be to create diaphragms or to create certain structures.

Now, when we talk about micromachining, there are two parts of micromachining. The first part is called bulk micromachining, b, u, l, k, bulk micromachining. The second part is called surface micromachining, so let us see how this bulk micromachining and surface micromachining would help us in the overall performance of the sensor in fact, for certain sensors without using this bulk or surface micromachining the sensors would be incomplete, we cannot realize the sensor.

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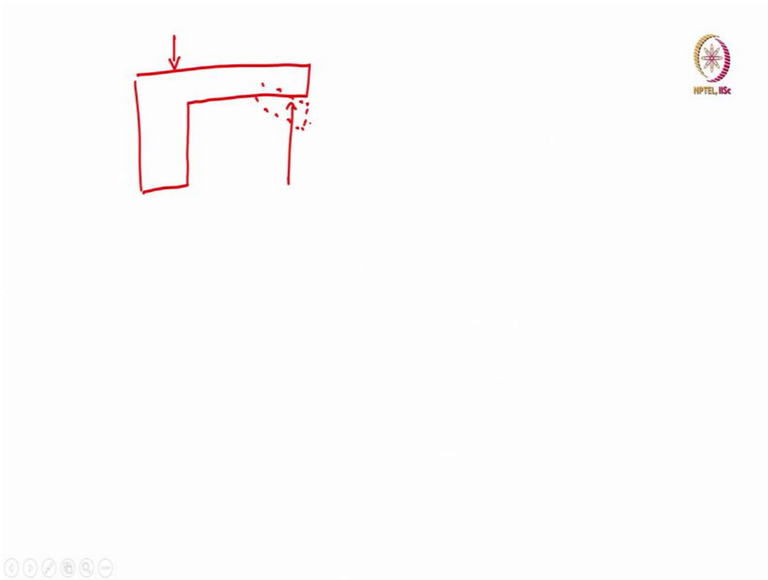

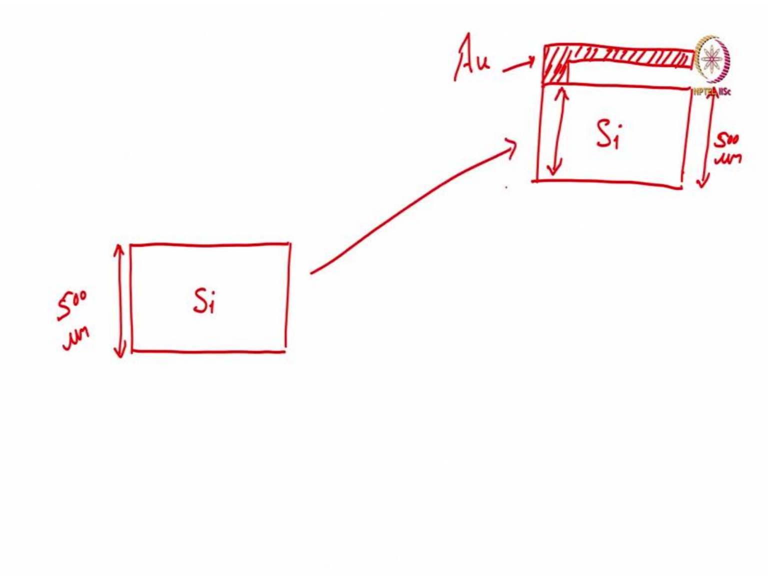

So, if you see the slide I will draw a cantilever. Now, what do you mean by cantilever? Cantilever is a structure that hangs on one end hence without support here and there is a support fixed support on this area. This is a cantilever to be as simple as that now, have you seen this kind of cantilever? Yes, we have a diving board when you have to dive that this is a diving board this is for the swimming. If you see the swimmers they jump on this and then this can deliver will flap like this it will do like this, but at a certain frequency we can utilize this sense can reveal for certain applications. Let us not worry about it now I want to fabricate this cantilever but without deteriorating my substrate. What does that mean?

So, I have a silicon substrate and what I want is a cantilever that looks like this the cantilever it looks like this. What is this cantilever made up of? This is made up of gold. Now, to do so, what we will do? What are the process to do so? Now, if you see the silicone to start with end to end at the end let us say it is 500 microns, here also is 500 microns that means we are not subtracting anything from the substrate we are not machining the substrate, substrate remains as it is now to from here, what is the route to go here.

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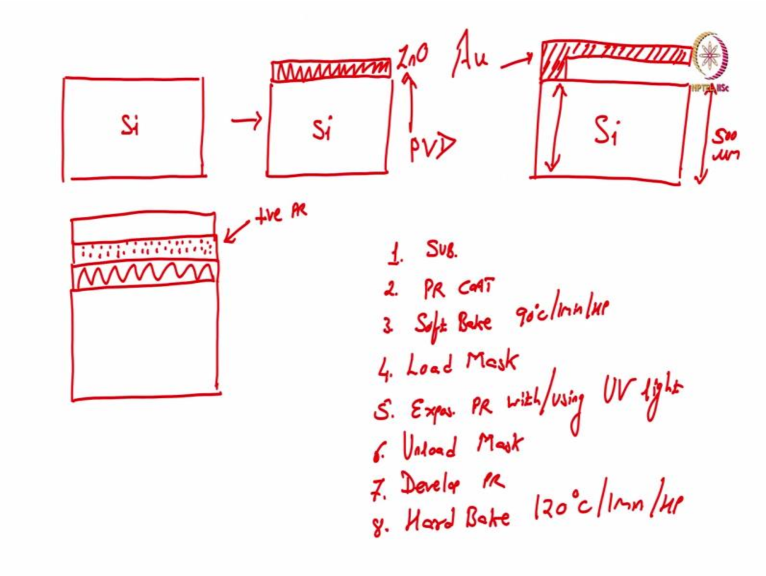

So, let us understand these particular steps so, that you understand what is surface micromachining, so I will draw here you have your silicon then on silicon we will deposit zinc oxide. This zinc oxide can be deposited using physical paper deposition we have seen physical paper deposition.

Now, on this zinc oxide, I will spin code photoresist, we all remember the lithographic section where we talked about the photoresist. I have positive photoresist. This is my positive photoresist, on this I will and I will do soft bake I will do soft bake and then load the mass. If you remember the steps, the first step for lithograph, you take a substrate then if there is a material deposition then deposit the material then PR coating then soft bake temperature 90-degree centigrade deletes 1-minute hot plate.

Fourth, what is next step? Next step is load the mask. Fifth step, expose photoresist with all using UV light, Ultraviolet Light. Next step is unload mask. Next step develop photoresist and next step is hard bake 120 degree centigrade 1 minute 1 hard bake, you have a substrate, you have PR coating then you do soft bake, reload the mass, expose the photoresist with UV light then unload the mask, develop photoresist, hard bake and then you are ready.

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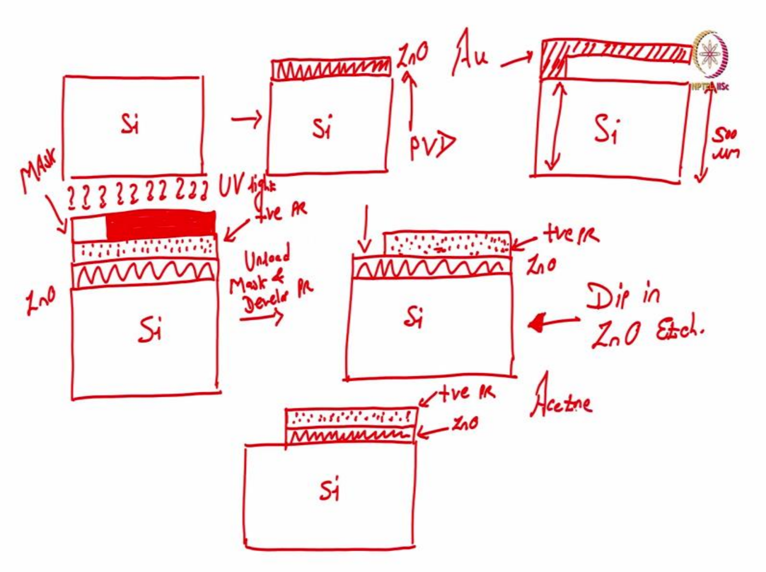

So, then I have positive photoresist and then I have a mask and my mask looks like this, this is my mask. So, after the loading the mask, what is the next step? You have to expose the photoresist using ultraviolet light, the next step is to unload the mask and develop photoresist So, if you do that the next step is your zinc oxide and then your photoresist is developed like this. So, this is your photoresist because we have used positive photoresist. So, whatever the pattern is there on the mask will be there on the wafer or the unexposed region becomes stronger. So, this is my positive photoresist.

Now, do not worry too much about the like the accuracy of this one what I am saying is anyway let me redraw it so that you do not get confused, that is. Now, the next step is we will dip this wafer we had to do hard bake of course and then we did the wafer in ZnO etchant if we did the wafer in ZnO etchant what will happen, the etch which is not the zinc oxide, which is not protected by the positive photoresist will get etch.

So, what we will have, if I have this and if I did this wafer this particular wafer in zinc oxide etchant, which is 1 percent HCl then I will have here is my positive photoresist this one would be zinc oxide, this is silicon because this region was not protected by photoresist so, it got H in zinc oxide etchant. Now, the next step is I want to strip off the photoresist so, for stripping off the photoresist, what is there, acetone we know. So, we can dip this wafer in acetone.

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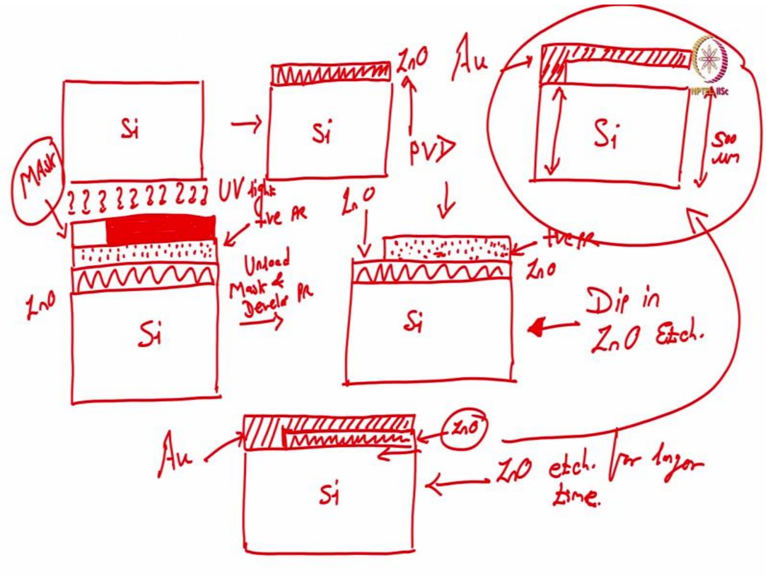

If you dip this wafer in acetone, what will happen? The photoresist will be stripped off and we will have the pattern of zinc oxide like this. The next step is I will deposit gold, chrome gold or gold whatever you want to say and this is my gold. Now, the next step is I will dip this wafer in zinc oxide etchant for longer time I do so, things the zinc oxide that you see here, will get etched and what we have, we will have this particular pattern.

Again I am repeating, you take a silicone, deposits of zinc oxide using PVD, once you deposits of zinc oxide using PVD then you can have your photoresist which is positive photoresist spin coated onto zinc oxide and then you perform soft bake which is done in 90 degree centigrade 1 minute on hot plate followed by your loading of the mask this is the mask that we have shown here and then you expose it with UV light, expose what, the photoresist with UV light.

Then you unload the mask, develop the photoresist by dipping the wafer in photoresist developer then you have the pattern that you can see in this particular case and then you dip this wafer then you would perform the hard bake, hard bake is a net 120 degree centigrade 1 minute on our plate followed by dipping the wafer in zinc oxide etchant then what you will have this zinc oxide from this area will be etched and then you strip off the photoresist by dipping the wafer in acetone followed by depositing gold.

And followed by again dipping the zinc oxide etchant for a longer time. If you have a longer time than the zinc oxide will etch in this direction. And that is why you will have something called or something looks like this which is your say gold cantilever on the silicon wafer.

This is an example of your micromachining or surface micromachining. I hope you understand how surface micromachining is.

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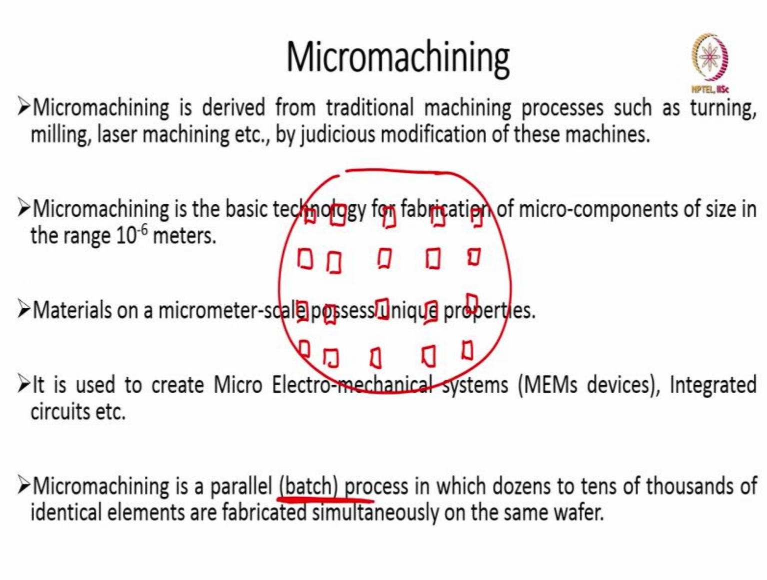

So, now if you just take the term micromachining. So, micromachining is derived from traditional machining process like I said, it can be your milling, it can be laser machining, it can be your turning, it can be your drilling by judicious modification of these machines, so, that now we can do not really drill or do the turning or milling but in a different way we are still machining the wafer at a micron scale. So, micromachining is the basic technology for fabrication of micro components of size in the range of 10 to power minus 6 meters because it is micro the size is around range of 10 to power minus 6 meters.

So, the materials on a micro meter scale possesses unique properties. It is used to create MEMs based devices or MEMs devices or an integrated circuit or and either you can use for MEMs devices or you can use for ICs or you can have sensors plus ICs everything on a single chip. This is called micro MEMs is Micro Electro Mechanical Systems. So, we are designing electromechanical systems at a micron scale by using a micro fabrication technology and also using the machining which is micromachining and photolithography and PVD and CVD and etching, so, this is a combination of micro technology.

So, micromachining is a parallel process in which dozens of tens of thousands of identical elements are fabricated simultaneously on the same wafer because if I create let us say this is a wafer. So, let me know just draw if this is a wafer and I want to create or etch then I can etch the same batch many many transistors or many many devices in one go. I can etch many devices in one go. And that is why we say that it is a batch manufacturing process, it is a batch process. So, since you can create many devices from the single wafer, we call it as a batch manufacturing process. So good.

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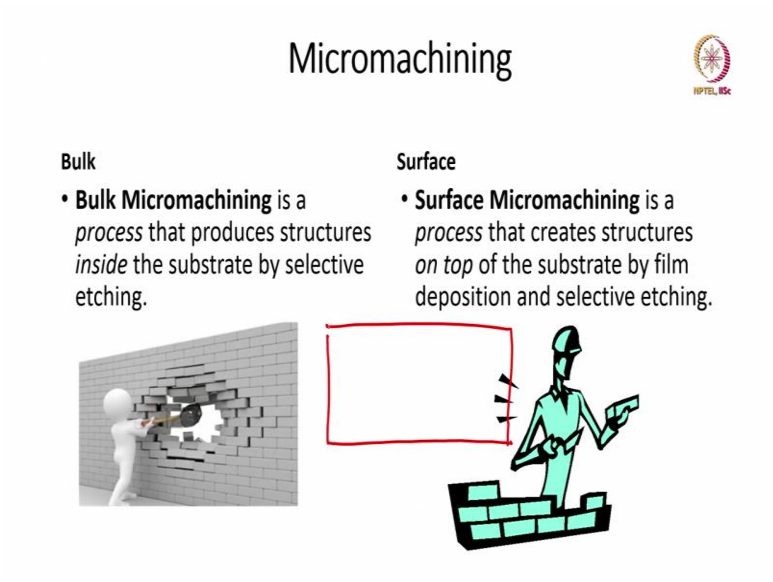

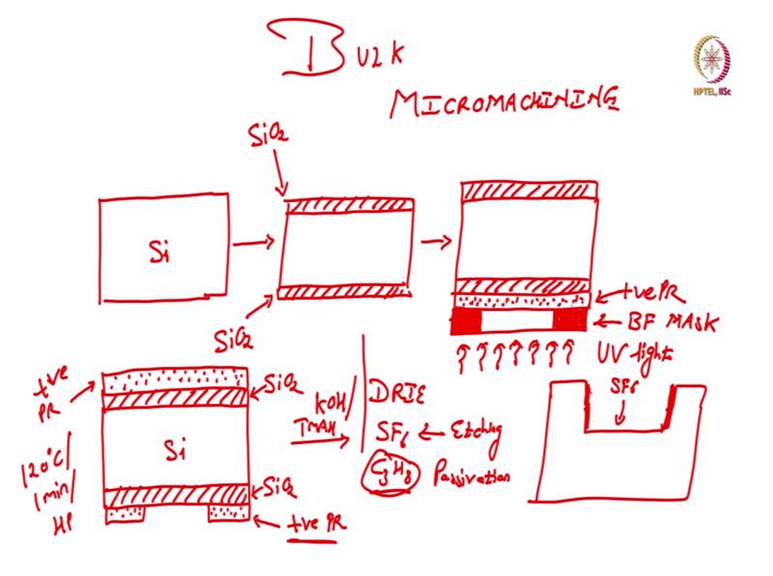

Now, we know what is micromachining, we know a little bit about surface micromachining let us understand the difference between surface and bulk micromachining. Now, I said that surface is to build something on the substrate without machining the substrate. The cantilever was fabricated on the substrate without changing the thickness of the substrate. So, bulk micromachining is little bit different. In this case, we can create different structure by eating the silicone wafer.

So, suppose let me just give an example of bulk micromachining for you. So, that becomes easier. So, just let me go back and let me have one more slide. And let me just show you do bulk micromachining. Earlier what we were looking at was surface micromachining. This time we are looking at bulk micromachining it is a difficulty with the pen so, do not worry about it bulk micro m, i, c, r, o machining m, a, c, h, i, n, i, n, g bulk micro machining this is what we are learning.

So, you take a silicon wafer then you grow a silicon dioxide, grow a silicon dioxide on silicon wafer, silicon dioxide can be grown using what, now you should know thermal oxidation. And what kind of thermal oxidation we are using? We are using wet oxidation because in thermal oxidation there are dry oxidation and wet oxidation, the next step in this case would be to create a window so, what we are doing is, we are spin coating positive photoresist.

Then we are loading a mask which is my bright field mask, then I expose this wafer with ultraviolet light, then I will develop this wafer. So, load the mask, expose the wafer, unload the mask when you do of course spin of photoresist always remember after that you would go from the soft bake.

So, if I do that, if I unload the mask and dip the wafer, how it will look like? If I unload the mask and develop my photoresist it will look like this, silicon dioxide, silicon dioxide it is silicon in positive photoresist. After that, what do we do? We do hard bake before we do hard bake, let us spin coat photoresist on the front side also and now, we perform hard bake. Hard bake is done at 120 degrees centigrade for 1 minute on hotplate.

After this the next step, I will leave this wafer in KOH or TMAH or I will use a process called deep reactive ion etching DRIE, these are chemicals, potassium hydroxide, tetra methyl ammonium hydroxide, DRIE is a dry etching process where we use SF6 as a guess and another guess for C3F8 I think C3H8 just let us cross check this later on. It is available if you write down DRIE and silicone etching, so, let us not worry about it, but the point is this one is used for passivation. I think we have seen this in one of the lecture the passivation and this is used for etching.

So, silicon gets so, if this is silicon wafer and the thing starts from the top then what happens is these etchs like this SF6 and then C3F8 H8 will create a passivation layer. It is a passivation layer here like that, then again there is an etching SF6 and again the passivation layer is formed. This goes on continuing so, what happens is your sidewalls are protected by the passivation guess or a chemical. This is DRIE or deep reactive ion etching but we are talking about let us say here in this case wet etching, wet etching can use either potassium hydroxide or tetra methyl hydroxide.

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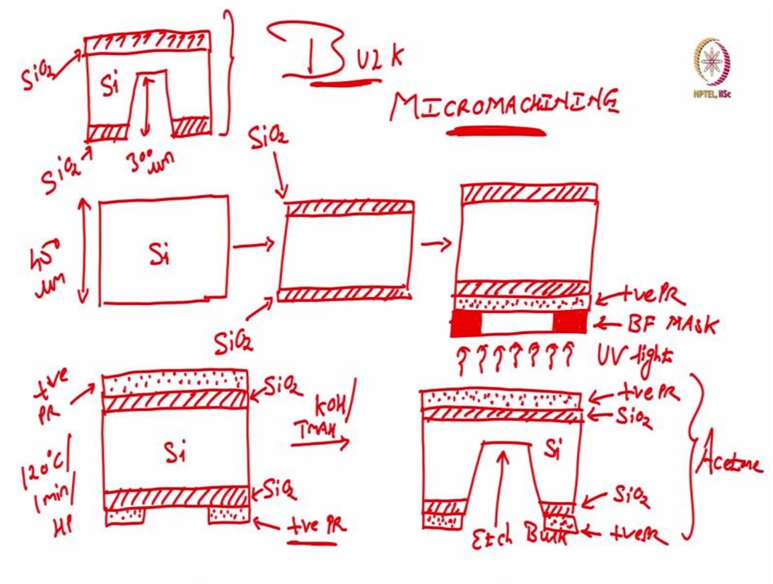

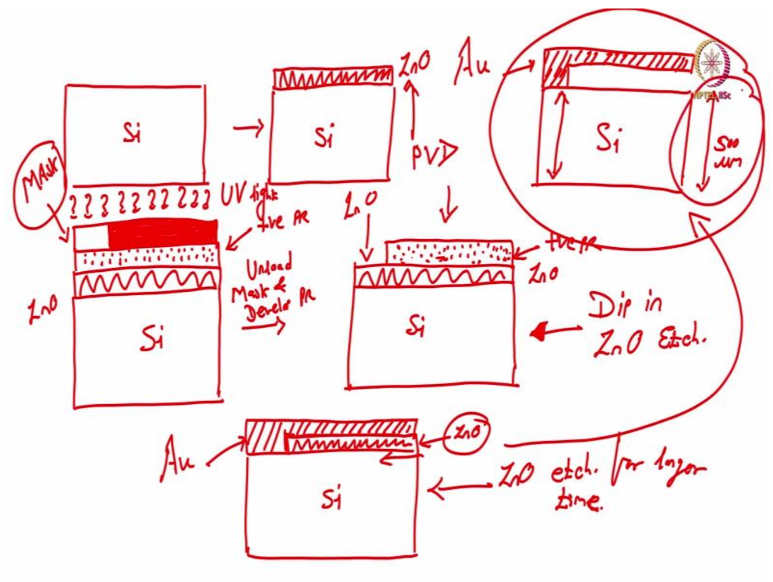

Now, the next step is if you do that, then what you have is pattern like this. So, what we have created, we have etched bulk of silicone material. And here what we have? I have this. Now, what is the next step? Next step is dip this wafer in acetone. If I dip this wafer in acetone, what will I have? I will have a pattern like this. So, from these 450 microns or 500 microns of silicon wafer if I etch 300 microns or I keep on etching it then I am removing the bulk of the material.

Since I am reviewing the bulk of the material it is called bulk micromachining. Do you understand now, the difference between surface and bulk, surface micromachining, we have not etched any material. In bulk, we have etched the substrate. We have not etched the substrate in case of surface, in case of bulk we etch the substrate.

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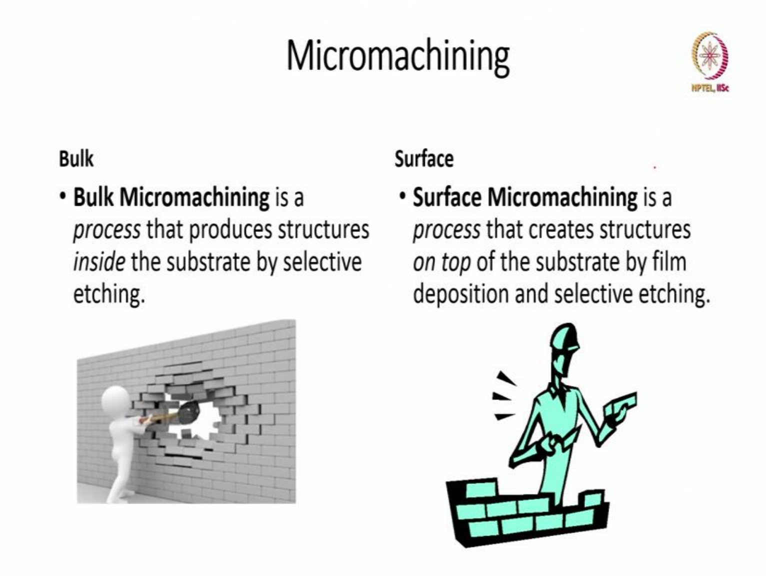

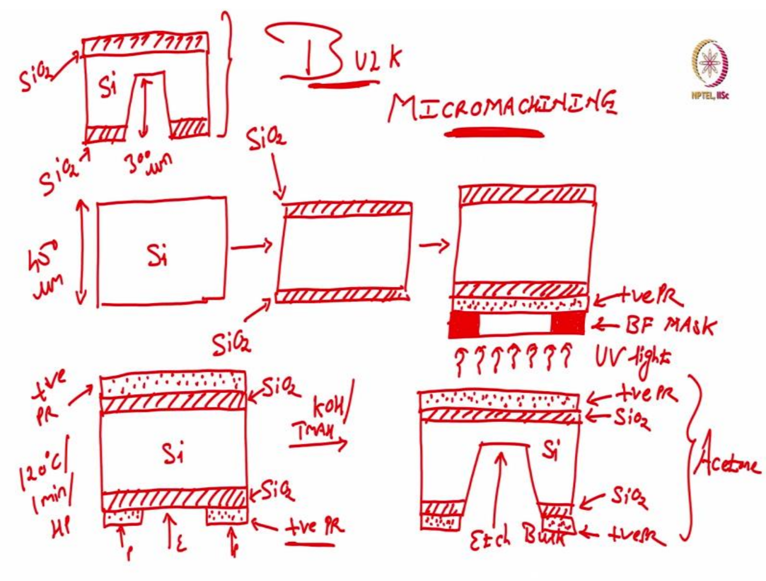

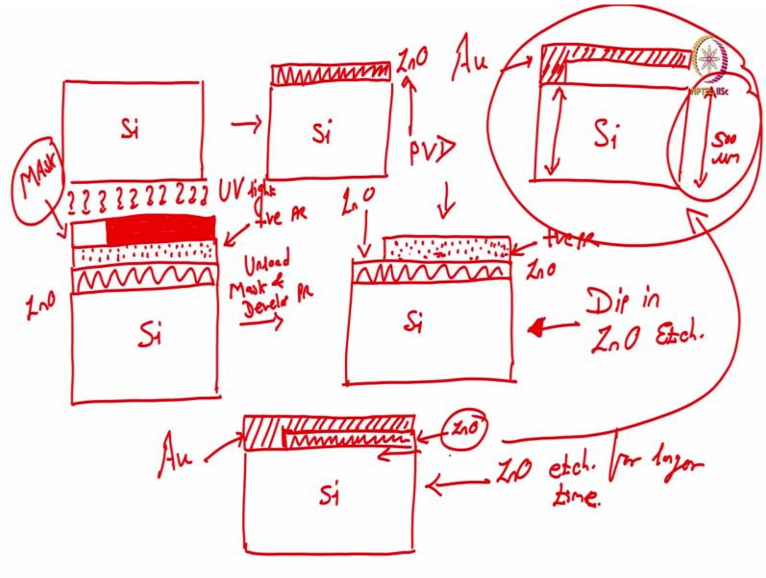

So, let us go to the next slide here we can now understand from the what is written here. So, bulk micromachining is a process that produces structures inside the substrate by selective etching, why selective etching? Because we have only etched this material this area and we protected this area, see this area is protected and this area is for etching.

So, we are selectively selecting an area which needs to be etch is a why selective etching. Surface micromachining is a process that creates structure on the top of the substrate by film deposition in selective etching. So, we had deposited a film and like zinc oxide and gold and only zinc oxide is etch, gold is protected. So, we had on a surface micromachining. Good.

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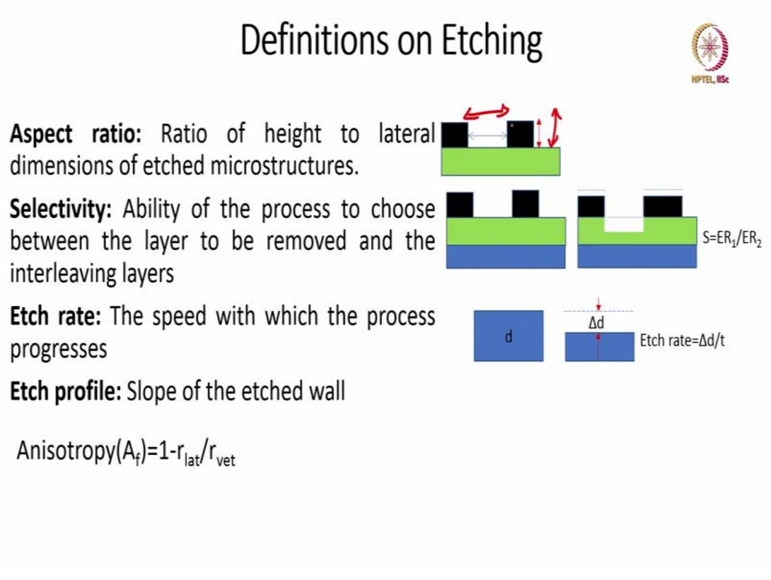

Now, we know two things. So, let us understand some of the definitions of on etching. The first definition that we need to understand is that aspect ratio was. What does aspect ratio means? So, the ratio of height to lateral dimension of the etch microstructure, you can see how much we are etching in this direction versus this one, so, height to lateral. This is called aspect ratio.

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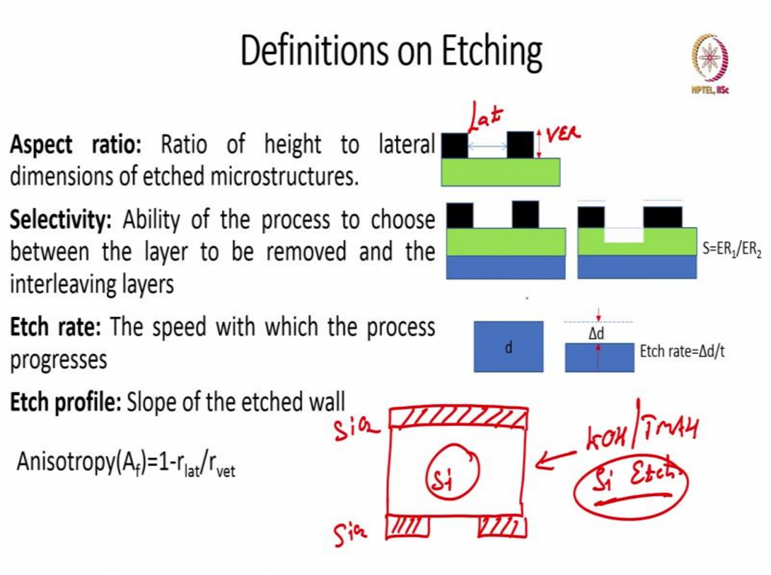

The next definition is selectivity. So, our ability or process to choose between layers to be removed and interleaving layers. For example, if I have my silicon dioxide pattern like this and if I want to if I did this wafer in KOH or TMAH co, this are silicon etchant, then what will happen? This process will only remove silicone and will not affect silicon dioxide. So, it is selective to only etch the silicon is silicon dioxide X as a mask, the next thing is etch rate the speed with which the process progresses, how fast you can etch the substrate is a etch rate.

Next one is etch profile, slope of the etch wall that is a etch profile. Anisotropy is given by 1 minus r lateral by r vertical. This is lateral this is vertical. So, the ratio of lateral to vertical and then anisotropy defined by 1 minus ratio of r lateral to r vertical, so, let us go to the next one.

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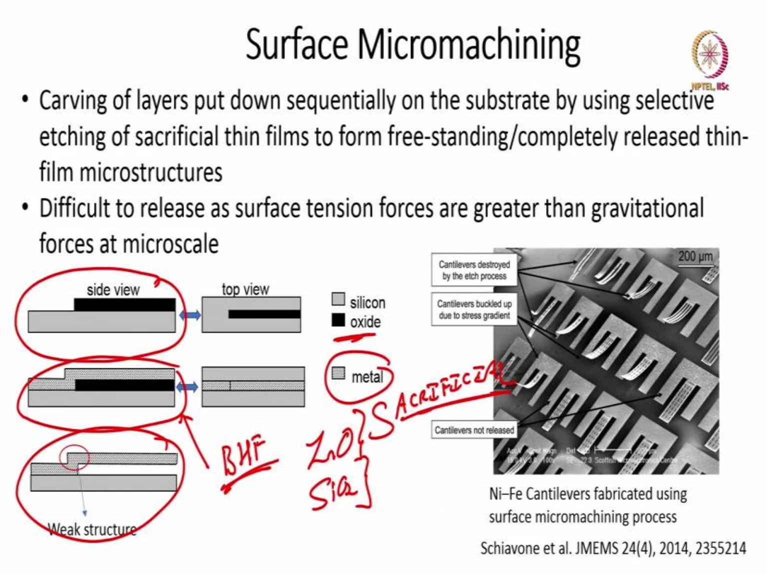

Now, in this case you can see this is an example of your surface micromachining. Let us see the definition, scaring of layers, put down sequentially on the substrate by using selective etching of the sacrificial thin films to form freestanding completely released the thin film micro structures. So, you can see here on silicon, we have silicon dioxide and silicon dioxide is black in color, silicon is gray in color.

So, we have pattern the silicon dioxide followed by a deposit of metal as you can see here, when we deposit the metal and then if we did this wafer, in the BHF sorry not this wafer, this wafer in buffer hydrofluoric acid, BHF then the silicon dioxide will get etch, in our case we have taken zinc oxide in this case, the example is of silicon dioxide.

So, zinc oxide or silicon dioxide, since it gets etched to form the structure they are called sacrificial layers s, a, c, r, I, f, i, c, i, a, l they are called sacrificial layers. So, we have silicon, silicon dioxide then we have metal on silicon dioxide and a new dip this wafering BHF because silicon dioxide BHF is a etchant for silicon dioxide to form your cantilever.

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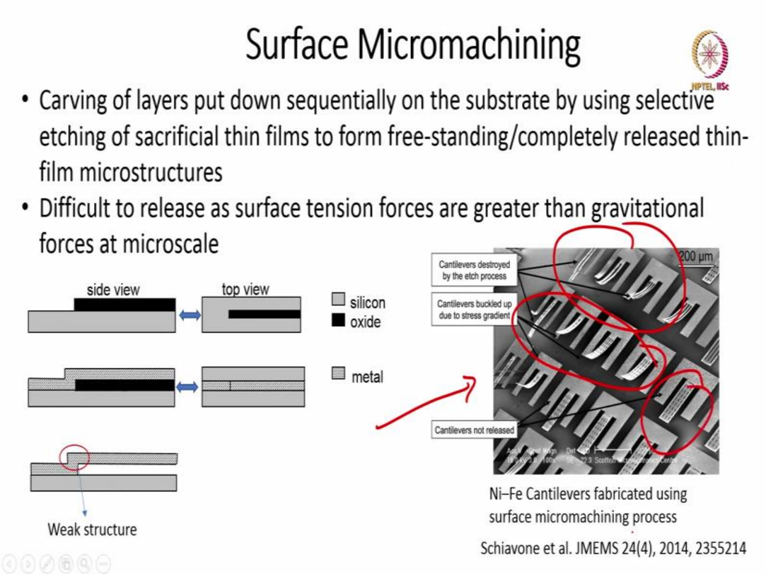

So, here the only difficulty in this case is the difficulty to release these cantilevers because of the surface tension forces which are greater than the gravitational forces at micro scale. So, you need to understand that that process should be clearly defined such that the cantilever gets completely released, if you see here there are some dots in the cantilever some dots, these are through holes, through holes means like here through holes are there, so that the silicon dioxide will get etched also from here along with in this direction. So, the three walls are created to release the cantilever completely.

In this case, what you see in this particular image, what you see is that there are certain cantilevers which are destroyed in the process you can see here certain cantilevers they get buckle up cantilevers which does not get released and some cantilevers gets completely released. So, there are process optimization studies or steps that are required to release the macro and deliver completely.

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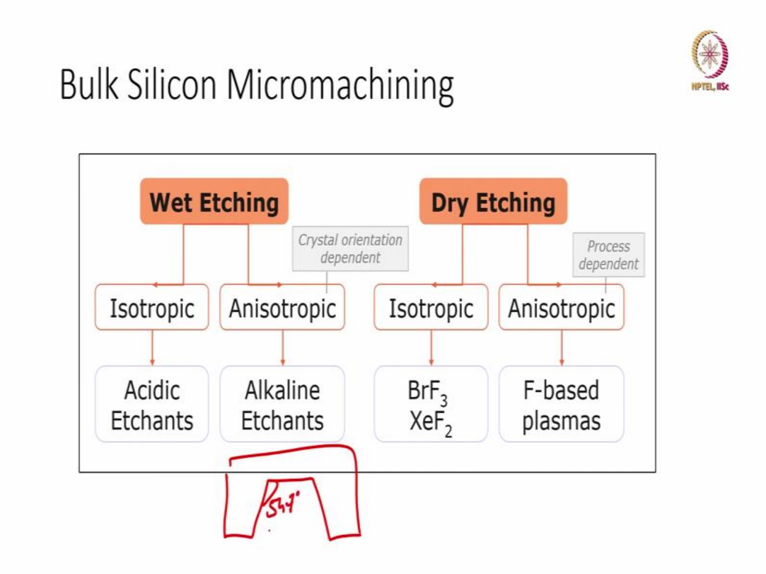

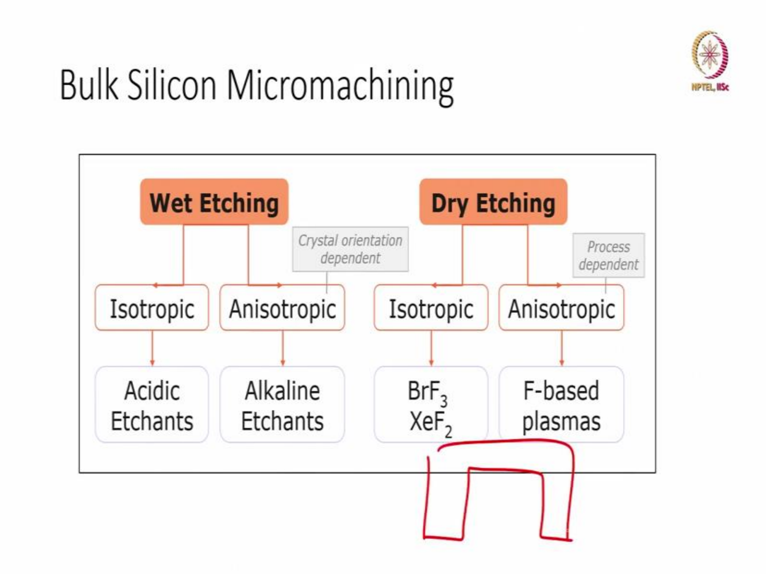

So, bulk micromachining can be divided into two steps further, dry etching and wet etching and both has isotropic and anisotropic processes. In wet etching, the anisotropic process is considered orientation dependent, while in dry etching the process is under process dependent, it is not depending on the crystals. So, that is why if you etch the silicone using wet etching you will have this 54.7-degree angle because the 111 will get etch differently compared to the crystals at 100.

So, there is a difficulty but in case of the dry etching when you etch you will always have etching like this because it is not a crystal orientation dependent, it is a process dependent step. There are plasma-based techniques for dry etching, one is called fluorine-based etching, second is called chlorine-based etching.

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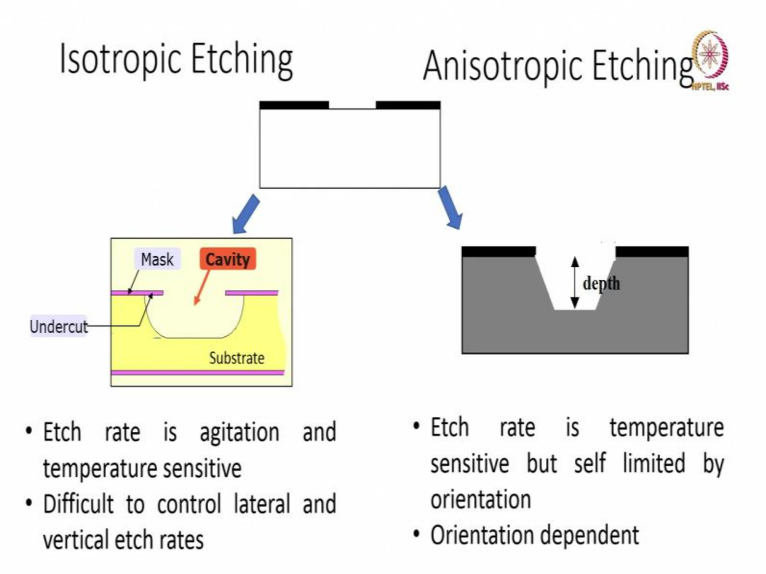

So, if you see here isotropic, anisotropic etching, the etching rate is agitation and temperature sensitive, difficult to control lateral and vertical etchs in case of the isotropic etching while in case of the anisotropic etching the etch rate is temperature sensitive, but self-limited by orientation and of course, it is orientation dependent.

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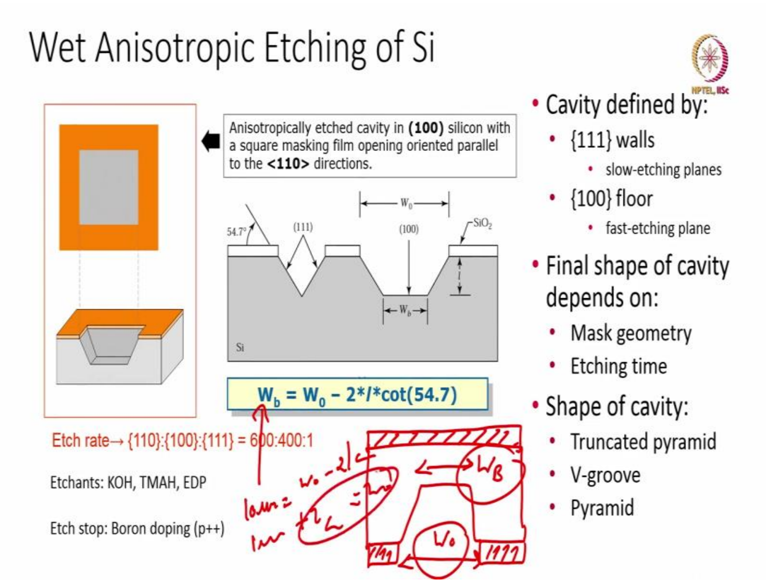

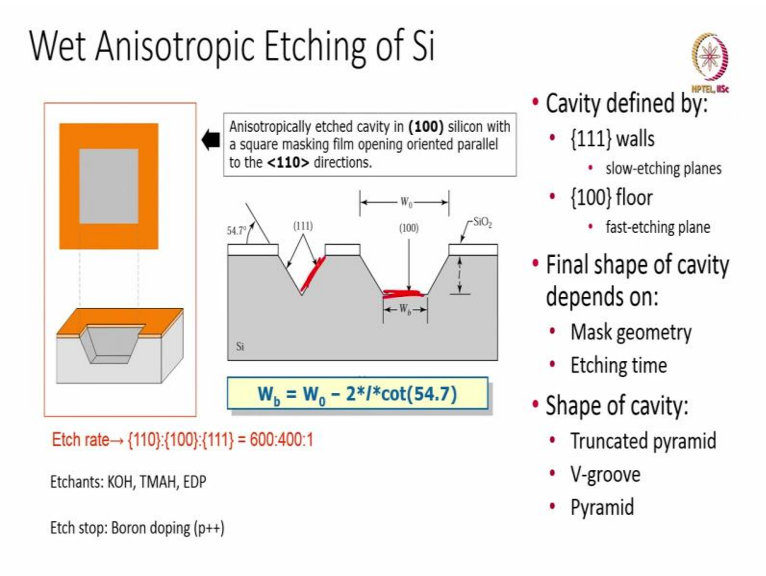

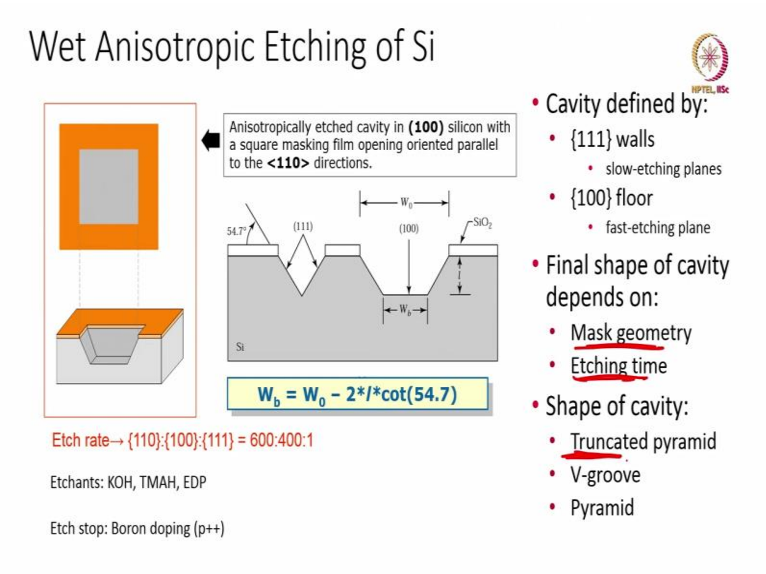
Wet Anisotropic Etching of Si
Anisotropically etched cavity in (100) silicon with a square masking film opening oriented parallel to the <110> directions.
Wb = W0 – 2*l*cot(54.7)
Etch rate→ {110}:{100}:{111} = 600:400:1
Etchants: KOH, TMAH, EDP
Etch stop: Boron doping (p++)
Cavity defined by:
{111} walls
slow-etching planes
{100} floor
fast-etching plane
Final shape of cavity depends on:
Mask geometry
Etching time
Shape of cavity:
Truncated pyramid
V-groove
Pyramid

Now, this is very important because, if I want to have let us say a window which I call WB, this is WB then how much should I open this one which is my Wo light, how much window should I open and protect silicon dioxide only in the remaining region, so, that I can reach the WB. Now, why it is important is because, like I said the wet editing of silicon is orientation dependent. So, I need to understand what should be the Wo so, to achieved by WB and so, is the equation given here that whatever WB you want should be equal to W o minus 2 by cot theta and here theta is 54.7-degree angle. So, that is how you calculate your WB.

So, if you put your values then if you have WB of 10 microns then you can have Wo of how much to get this 2 by cot theta so, that if you say it 10 micron plus 2 by cot theta equals Wo you had Wo value and the Wo value should be equivalent to the window that you are creating for etching the silicon wafer.

So, the etchants like I said KOH, TMAH, EDP, EDP is not used so, extensively now, the etch stop can be silicon dioxide it can be a boron etch stop as well. So, you can see here the 54.7 angle is created, 100 is the orientation which gets etched faster, 111 is slower so, 111 is a slow etching planes, 100 which is a floor this is a floor and this is a wall. So, the floor is faster etching plane, the wall is the slower etching plane and final shape of cavity depends on the mask geometry, etching time. Shape of cavity depends on a truncated pyramid, V-groove and a pyramid. So, these are different shapes that we can achieve using the chemical etching or anisotropy etching of silicon.

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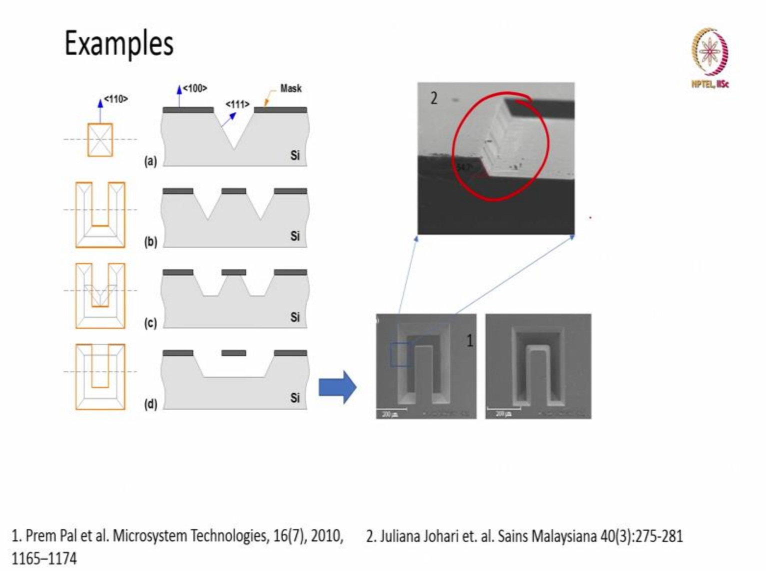

These are examples of some of the etch processes and the bulk mega machining purchases you can see that we can created a truncated, V-groove and then here you can very easily see a beautiful slope of silicone that is within the substrate is a cantilever that is created using the machining processes.

So, we will stop here and then we will take an example of how to utilize this particular micromachining technique for fabricating, let us say a pressure sensor because let us say we apply a pressure onto the scalp how much pressure should be given because in one of the case we will look into and then there will be TA class will be shown in detail about how to design the cap for near hearing screening very important topic. When babies are born, the we need to measure whether the baby can hear or not. And that is called hearing screening, screening of the hearing ability of a newborn. Newborn are called new units.

So, you need to design a system that can be used to capture the signal from the scalp whenever you are giving a stimulation is audio stimulation in technical term is called auditory brain response or ABR. So, when you apply or when you give the ABR to a baby's ear there is a EEG that is creating and then for that we need to take that signal or acquire the signal.

Now, depending on the age of a person the if you apply or if you design the cap with a dry electrodes rather than wet electrodes, then it will also make sure that it is not pressing too much, is not it? So, but how you measure, it is pressing too much or not. So, you can have a presence. So, now can we fabricate presents that using whatever techniques we have learned till now. So, we will look into that how to create a pressure sensor using a bulk micromachining technique.

So, we just go through this macro machining technique lecture and I will continue showing one example of the bulk micromachining technique followed by MEA which is Micro Electrode Arrays that can be used to acquire signal from the brain. And in this case, we will take an example of the rats brain and followed by some more examples. So, till then you take care. If you have any questions, feel free to ask us on the on the forum. We will be very happy to answer your questions. I will see you next time. Bye.