Advanced Neural Science for Engineers
Professor Hardik J. Pandya
Department of Electronic Systems Engineering, Division of EECS
Indian Institute of Science Bangalore

Lecture 28
Micromachining

Hello everyone, welcome to this lecture, this lecture is on Micromachining. Now I have known, what is Machining. And we have discussed a little bit about, what is machining additive or subtractive manufacturing. Now but when we talk about machining in silicon that becomes a part of MEMS, I told you Micro Electro Mechanical Systems. So if you understand the terminology of what is micromachining, it is generally traditionally derived from machining process such as turning, and milling, laser micro machining, etcetera.

By judiciously modification of these machines and this is the technology or basic technology to create micro components of size in the range of 10 to the power minus 6 of meters, 10 to power minus 6 meters. So the machining at a micro level is called micromachining and the materials on a micrometer scale process, possesses unique properties. And also we use micromachining technique for creating a micro electro mechanical systems based devices, integrated circuits, etcetera.

And finally the micromachining is a parallel, that means you can do a parallel batch process in dozens or tens of thousands of identical elements are fabricated simultaneously on the same wafer. So if you want to do this machining technique, let us take an example, so that you understand that how so many devices can be machined simultaneously.

(Refer Slide Time: 1:35)

Micromachining

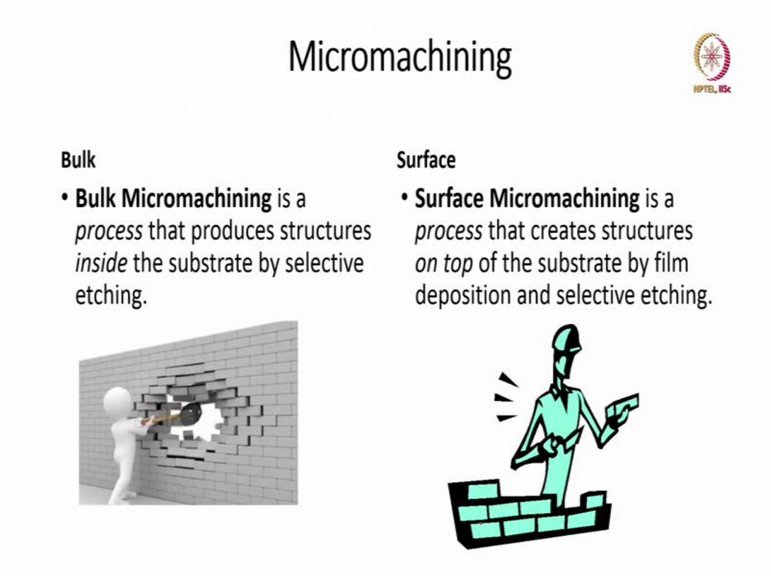
- Micromachining is derived from traditional machining processes such as turning, milling, laser machining etc., by judicious modification of these machines.
- Micromachining is the basic technology for fabrication of micro-components of size in the range 10^{-6} meters.
- Materials on a micrometer-scale possess unique properties.
- It is used to create Micro Electro-mechanical systems (MEMs devices), Integrated circuits etc.
- Micromachining is a parallel (batch) process in which dozens to tens of thousands of identical elements are fabricated simultaneously on the same wafer.

Micromachining

- Micromachining is derived from traditional machining processes such as turning, milling, laser machining etc., by judicious modification of these machines.
- Micromachining is the basic technology for fabrication of micro-components of size in the range 10^{-6} meters.
- Materials on a micrometer-scale possess unique properties.
- It is used to create Micro Electro-mechanical systems (MEMs devices), Integrated circuits etc.
- Micromachining is a parallel (batch) process in which dozens to tens of thousands of identical elements are fabricated simultaneously on the same wafer.

Micromachining

- Micromachining is derived from traditional machining processes such as turning, milling, laser machining etc., by judicious modification of these machines.
- Micromachining is the basic technology for fabrication of micro-components of size in the range 10^{-6} meters.
- Materials on a micrometer-scale possess unique properties.
- It is used to create Micro Electro-mechanical systems (MEMs devices), Integrated circuits etc.
- Micromachining is a parallel (batch) process in which dozens to tens of thousands of identical elements are fabricated simultaneously on the same wafer.



So if you see the slide, you can see that the micromachining term is traditional like I said turning, milling, laser machining, and minus 6 meters, unique properties, mems based devices and dozens and tens of thousands of the elements are fabricated.

Bulk micromachining, surface micromachining. Now why, what let us first understand this term dozens to tens of thousands. So I have a wafer, I have a wafer here, and what I want is, this kind of structure in my silicon wafer, silicon dioxide, silicon dioxide, silicon dioxide and silicon, this is what I want to create.

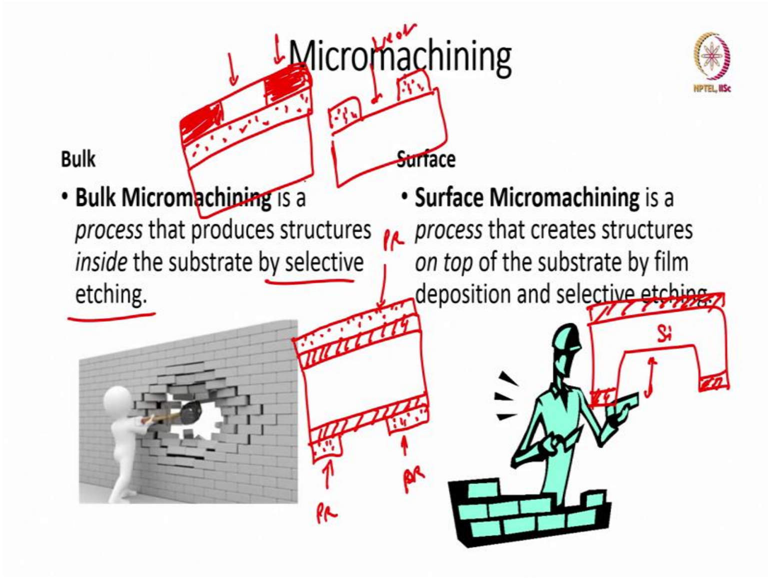
Each layer, each diaphragm here, sorry, the diaphragm is here, here. This is my this is the etched one and this is diaphragm, let us say this is 20 micrometers and this one is 480 micrometers. Assuming that the entire silicon wafer is 500 micrometers, out of 500 micrometers if I etch 480 micrometers that means I am etching bulk of silicon, that is why it is called bulk micromachining, bulk micromachining.

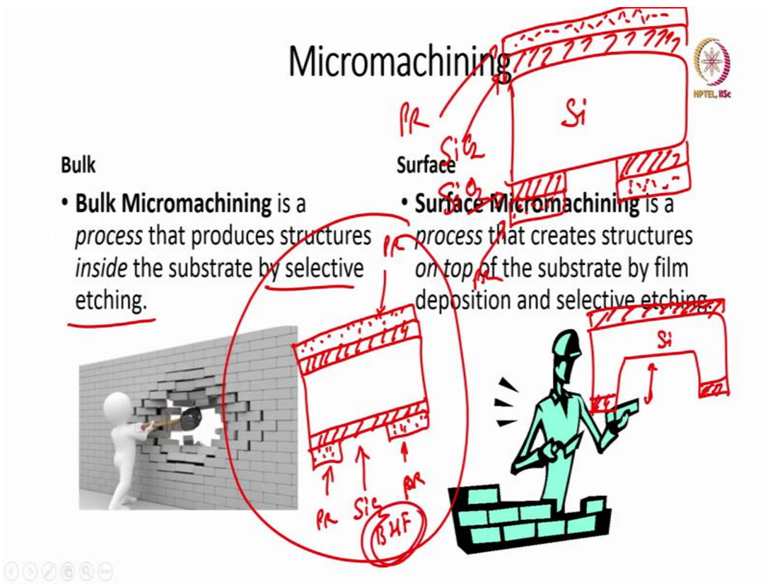
You want to create many many diaphragms on single, this is just a cross section but if I take a wafer, I can, so I will show you how can we create but I am just saying. So here if this is the back side of the wafer and I want to create diaphragms like this, I can make many in one go, I am just drawing is just to show it to you, but you can have hundreds of this diaphragm, at the same time you can create or etch silicon wafer at this particular point to create thousands of diaphragm in one single go.

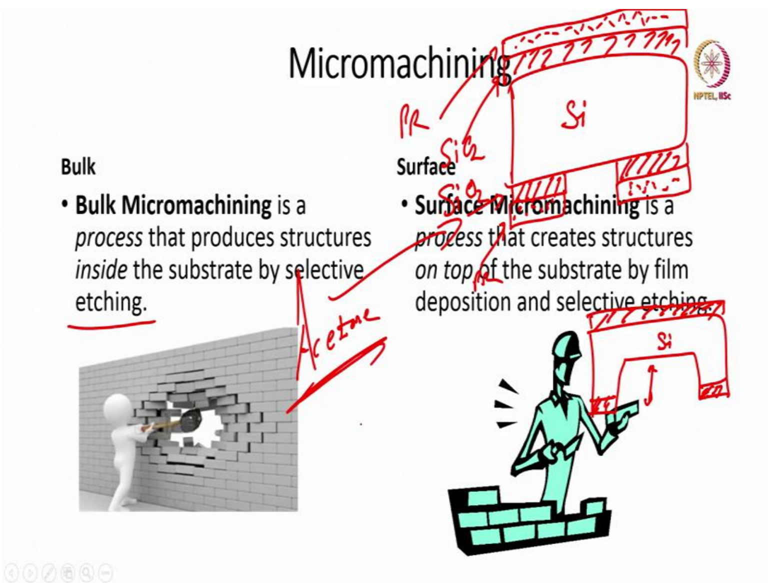
How can you create this diaphragm? You can create this diaphragm either with wet etching or with dry etching. This is something that we will learn as a part of micromachining course at a later time or micromachining section at a later time. So KOH or TMAH tetramethylammonium hydroxide, potassium hydroxide can be used for wet etching the DRI consists of deep reactive ion etching, where there are dry gases that are used to etch the silicon wafer.

So we can have thousands of this in one go, that is what is written dozens of thousands, tens of thousands of the structures can be created.

(Refer Slide Time: 4:31)







So as I told you the bulk micromachining is by etching bulk of the wafer but surface micromachining is to create something by using the micromachining at the surface. So if you want to have a definition, then bulk micromachining is a process that produces structures inside substrate by selective etching. I give an example, if you want to, if you have a substrate like this which is a oxidized silicon wafer and you want to create a diaphragm, you want to create a diaphragm which looks like, like this that means selectively you need to selectively you need to etch the substrate, but by etching the bulk of the silicon material, bulk of the silicon material.

So how we do that? See it produces structures inside substrate by selective etching, why selectivity, etching, so if you have photoresist cover in this region by performing the photolithography. Assuming that this is a photo resistor, now everyone knows how to perform or how to use photolithography, correct? We spin coat of photoresist and then you soft bake it, once you soft bake it you can expose with the help of UV, and you have a mask either it is (posi) bright field mask or is a dark field mask once you expose and then you use softly, then you use etching to develop the photoresist or to develop the photoresist use developer then the photoresist will get developed in this region depending on type of mask.

Here we are assuming that you have a mask which looks like this. You have the area like this and this one is dark and also this surface is also dark. And in center you have transparent region, if you have this and if you have photoresist below it, and you expose it, and you develop it. What you will have, the photoresist, let us say your substrate like this and the photoresist will stay only in this region and this region, correct?

So the area which is not exposed gets weaker the area which is not exposed in positive photoresist gets stronger as you can see here, but the area which is exposed gets weaker, weaker and so the photoresist will get etched from that area.

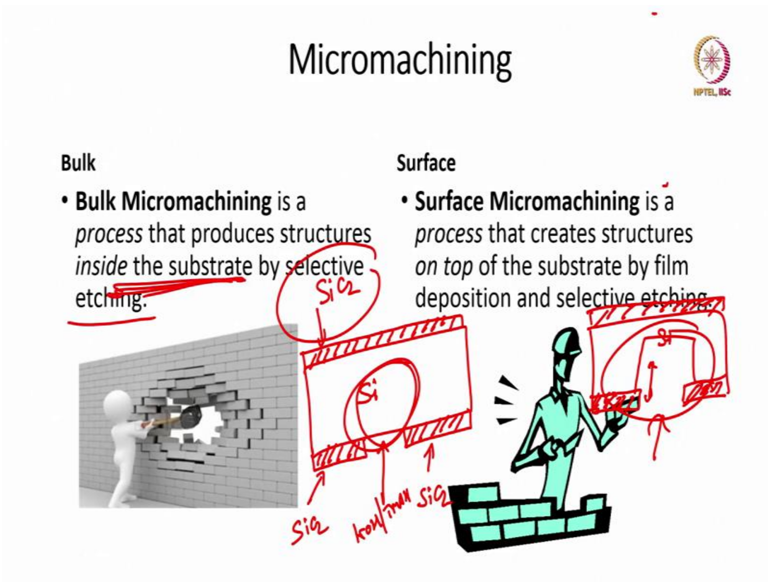
So now if you do this and you protect this area in the silicon, if I now dip this wafer and I have to perform hard bake hard bake at 100 degree centigrade 1 minute hot plate, then I dip this wafer in wet etching or dry etching material, what will happen, this first is I have to remove this, this silicon dioxide.

Silicon dioxide can be etched by dipping this wafer in buffer hydrofluoric acid, if I do that the silicon dioxide layer from this region will get etched. So what I will have, I will have silicon, silicon dioxide photoresist, photoresist on the top, photoresist, silicon dioxide, silicon, silicon dioxide, photoresist. Now how can I, how I have etch the silicon diaphragm here by dipping the wafer, this wafer into BHF, buffer hydrofluoric acid.

Once I have that I can dip this wafer which is my new wafer into acetone, if I dip the wafer in acetone, what will happen tell me. After BHF of course you need to rinse it, I have told you earlier that whenever you use chemical always rinse with DI, rinse with deionized water. So in this case, we have to rinse it and after rinsing we dip this wafer which is this wafer into acetone.

If I dip this wafer in acetone, what will happen? My photoresist will get stripped off, correct? My photoresist will get stripped off.

(Refer Slide Time: 9:01)

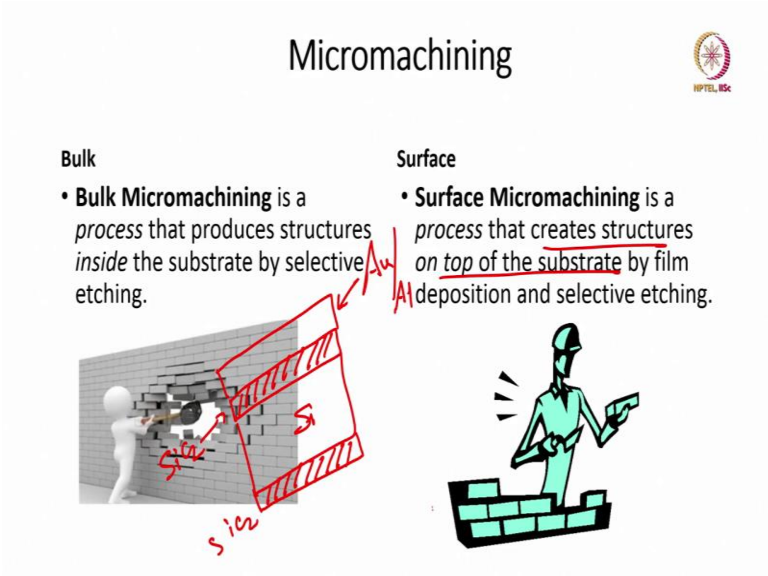


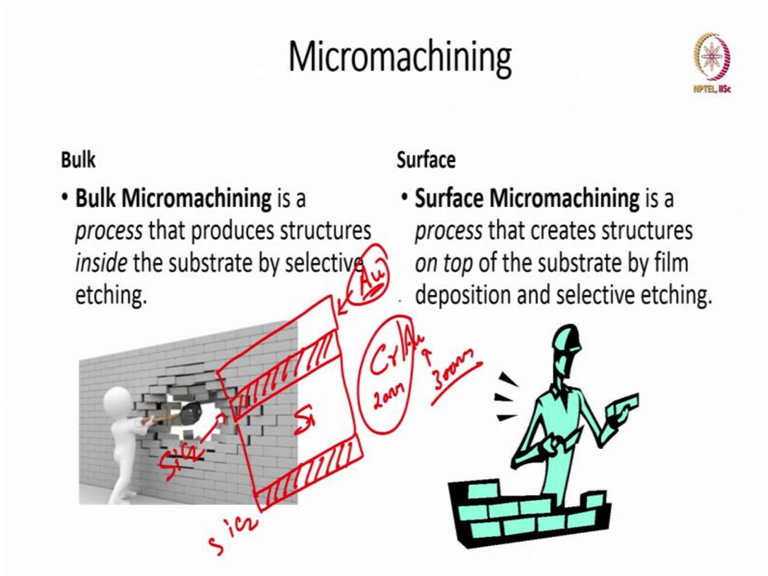
So what will I have, what will I have, I will have oxidized silicon wafer pattern in this manner. Now if I etch, if I dip this wafer into KOH TMAH, then this is wet etching, we will look at the wet etching and dry etching in one of the glass. So in wet etching, what will happen? Silicon will start etching and oxide will not get etch or it will etch at extremely low etching rate compared to silicon. So as to give us the diaphragm as you can see in this particular image.

Now how thin your diaphragm should be, depends on how long you are going to etch the wafer. So how long you are going to etch the wafer depending on that you will have your diaphragm. So if you are removing a bulk of silicon wafer using this kind of technique I am etching silicon wafer, since I am breaking it through it. So substrate inside the substrate, inside the substrate, this is the bulk micromachining technique.

But when we talk about surface micromachining technique, then the definition changes. Definition says that in surface micromachining is a process that creates structure on the top of the substrate by film the position and selective etching. So what does that mean, we will take an example, its so easy, micromachining, whole lithography is super easy, whole patterning is easy.

(Refer Slide Time: 10:50)

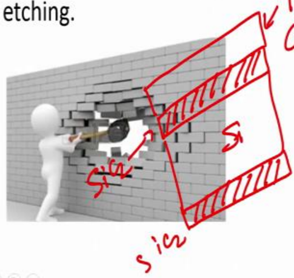




Micromachining

Bulk

- **Bulk Micromachining** is a *process* that produces structures *inside* the substrate by selective etching.



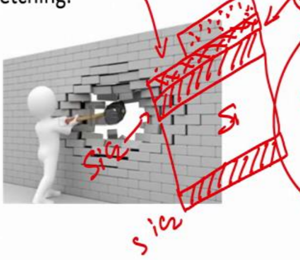
Surface

- **Surface Micromachining** is a *process* that creates structures *on top* of the substrate by film deposition and selective etching.

Micromachining

Bulk

- **Bulk Micromachining** is a *process* that produces structures *inside* the substrate by selective etching.



Surface

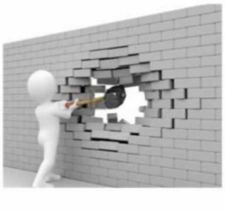
- **Surface Micromachining** is a *process* that creates structures *on top* of the substrate by film deposition and selective etching.

Micromachining

SACRIFICE

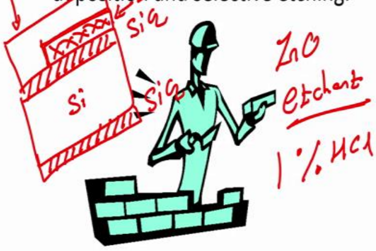
Bulk

- **Bulk Micromachining** is a *process* that produces structures *inside* the substrate by selective etching.



Surface

- **Surface Micromachining** is a *process* that creates structures *on top* of the substrate by film deposition and selective etching.



Let us see surface micromachining, what it says create structures on the top of the substrate. So what is our substrate or our favorite substrate is oxidized silicon wafer. So we have oxidized silicon wafer here, oxidized silicon wafer, we call this as a SiO2, we call this a silicon, this is silicon dioxide. And then I will deposit let us say gold. Why? Because we are rich, no we can deposit aluminum as well.

Now what we will do either gold or aluminum, what do you like, what you like everybody will say we like gold but if I directly deposit good what will happen, gold will get peeled off the adhesiveness of the gold improves, when we use chromium like this, the adhesiveness of the gold on the substrate improves when we use chromium. What is the thickness of chromium? What is thickness of gold? The chromium of, the thickness of chromium is about around 20 nanometer, for gold which is about 300 nanometer hundred and three nanometer, this chrome will improve the addition of the gold onto the substrate.

So whenever you will see or read any books or any literature, they will say either titanium gold or chrome gold. But chrome is not biocompatible, that is why we use titanium gold. So anyways but if I want to go for aluminum, no worries it is having it has a good addition on the oxidized silicon wafer. So assuming let us say this is aluminum this is aluminum, now what we will do. Can you do anything, we cannot do anything here.

So let us understand that what I want is, what I want here is a cantilever like this, this cantilever is aluminum and you have oxidized silicon substrate like this you can see and to do that but if I directly deposit aluminum there is no way I can etch like this. So what how surface micromachining will help, let us see.

What I will do is, I will deposit zinc oxide, I will deposit zinc oxide, then I will pattern zinc oxide. I will pattern zinc oxide SiO2, SiO2 zinc oxide and silicon. This is how I will pattern it, after patterning it, the next step that I will do, how to pattern it you can spin code photoresist, then you have to do soft bake, then you have to load the mask, how the mask look like, my mask will look like this. After loading the mask what is the next step, after loading the mask we will expose this wafer with the help of ultraviolet light, we will expose the wafer with the help of ultraviolet light.

So what is what is, what we will expect actually we expose the photoresist. Photoresist that is coated on the wafer, what is this? UV ultraviolet light when I expose the wafer through we is using ultraviolet light through the mask, what happens? The unexposed region which is this region will get stronger and the exposition will be weaker because this is positive photoresist, positive photoresist.

Now I will remove the mask and then I will dip the wafer in zinc (ox) and develop the photoresist when I develop the photoresist what will happen, what will happen because you remember the mask, if you remember the mask, we will have photoresist as I am drawing here photoresist will stay in this region. This is your positive photoresist then we perform hard bake after hard bake we dip this wafer in zinc oxide agent and if I dip this wafer in zinc oxide agent, what I will have, if I dip this wafer in zinc oxide agent I will have this wafer, this was easy.

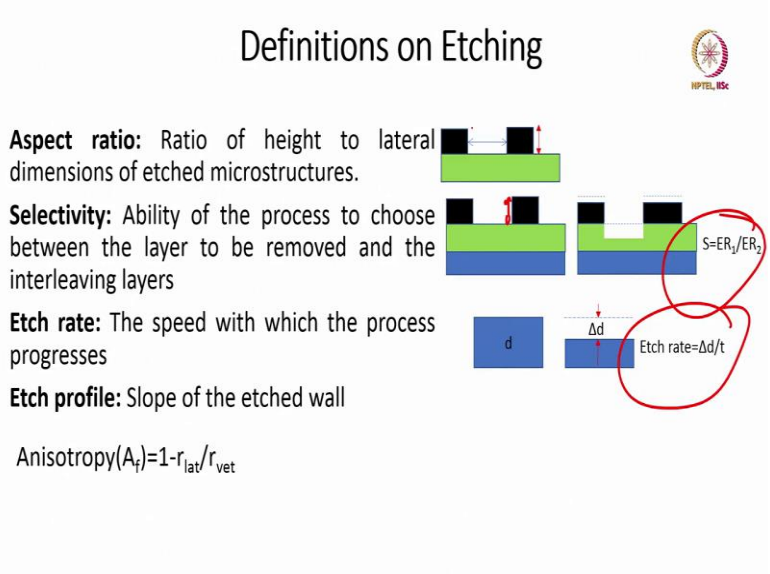
So what we have done we have deposited zinc oxide on oxidized silicon substrate and patterned it to form this particular structure. After this, after this I will deposit aluminum on to this zinc oxide, aluminum onto zinc oxide. How? I will deposit like this. What is this? Aluminum, aluminum after doing that I will dip this wafer I will do this wafer in zinc oxide etchant and zinc oxide, zinc oxide etchant is 1 percent HCL, using oxide agent is, 1 percent HCL hydrochloric acid, 1 percentage HCL.

If I dip this wafer in 1 percent HCL, what will happen tell me, zinc oxide will get etched but aluminum will not get etched. So if zinc oxide gets etched and aluminum does not get etched then what will I have, I will have this wafer and I have created a cantilever here, is not it? I have created a aluminum cantilever.

So here zinc oxide role is to sacrifice, sacrifice itself. So that is why zinc oxide in this case is called sacrificial layer. Zinc oxide in this case is called sacrificial layer, because it sacrifice itself to form the metal cantilever. In this case a metal cantilever is aluminum. This is the bulk, this is the surface micromachining we are depositing the different material on top of the substrate and etching it selectively to form structures, micro machine structures because you are created you see here is a hanging structure is a cantilever.

You created this cantilever with the help of silica, with the help of sacrificial layer and the process is called surface micromachining. So I hope that with this examples you understand what is the difference between bulk micromachining and what is the difference between surface micro machine. So again let us quickly read what is bulk micromachining and what is surface micromachining. Bulk micromachining is a process that produces structures inside the substrate by selective etching, while surface micromachining is a process that create structures on the top of the substrate by film deposition and selective etching.

(Refer Slide Time: 18:42)

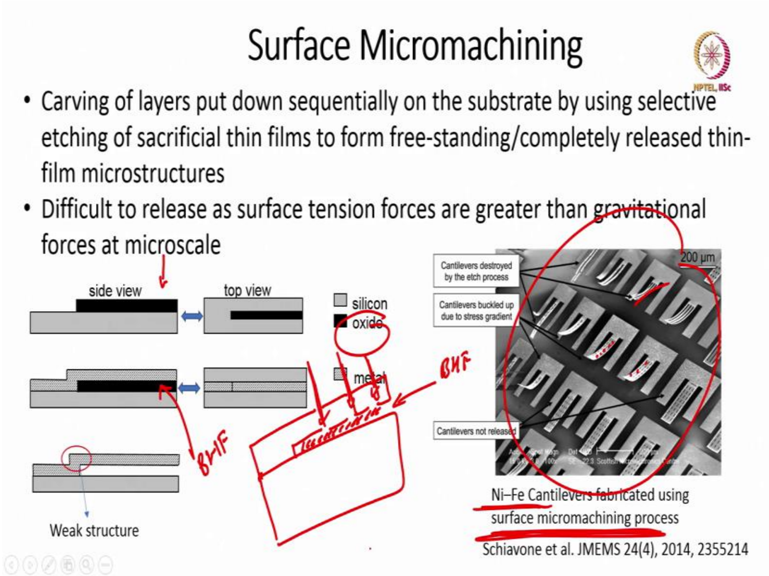


Now another term which we called aspect ratio. Ratio of height to little dimension of etch microstructure you can see, how much is the height with respect to how much is the lateral dimension, this is the aspect ratio. And then second thing called selectivity. So ability of process to choose between the layer to removed and interleaving the remaining line. So how to etch selectively only this region, you can see and then not etching the other region, that is called selectivity.

So selectivity depends on the ER 1 by ER 2, I selectively etching layer 1 by layer 2 also the etching rate, the etching rate is very important where certain chemical would have a higher etching rate compared to other the speed at with which the process progress is call etch rate, etch profile is slope of the etch wall. How well the slope of this etch wall is and it is given by anisotropy is equals to 1 minus r lateral by r vertical.

So etch rate, selectivity, aspect ratios and then etch profile, these are some of the, some of the terms that you need to know when you are looking at the etching definitions.

(Refer Slide Time: 19:59)



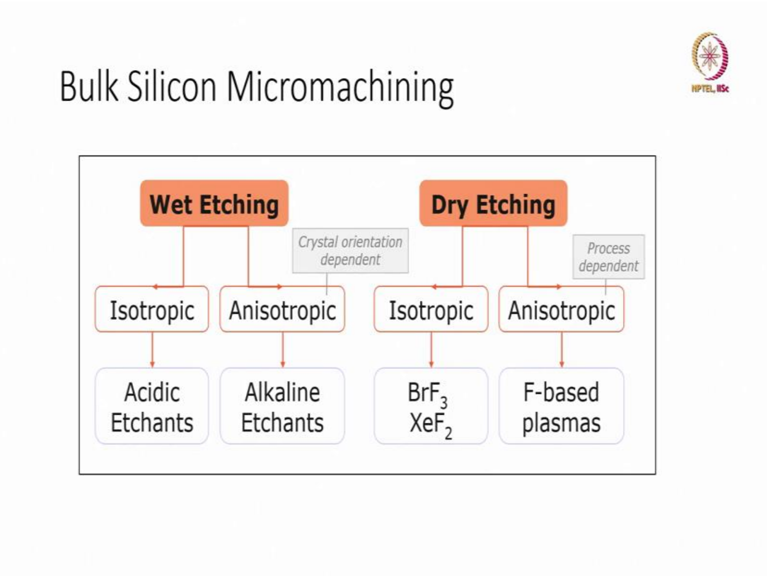
So now excuse me, let us see surface micromachining structure, the similar thing that I have shown that how to create you can see the side view is easier. So you have oxide and then you deposit a metal and then you dip this wafer in BHF, then here oxide, your oxide will act as a, act as a sacrificial layer as a sacrificial layer. So same thing like I took example of zinc oxide in this case is silicon dioxide.

You can see Ni-Fe cantilevers fabricated using micromachining process and sometimes what happens is that, when you do this, this oxide will not get etch. So what people do is, they create a hole in the wafer they create a hole in the wafer, what does it mean a hole in the metal. So let me just show it to you, how it looks like, sorry, like this you can see through walls, these are say side view, so do not get confused, see a dot dot dot dots on this image you see lines some dots. So that the chemical that is here there is oxide.

So see BHF will react from here but BHF can also penetrate through the holes and react and etch the silicon dioxide. So there are ways to make sure that the cantilever is completely released from the substrate and the carving of layers put down sequential and substrate by selective etching of the sacrificial thin frame to form freestanding completely released thin film microstructures is called surface micromachining, difficult to release a surface season forces are greater than gravitational force and micro scale.

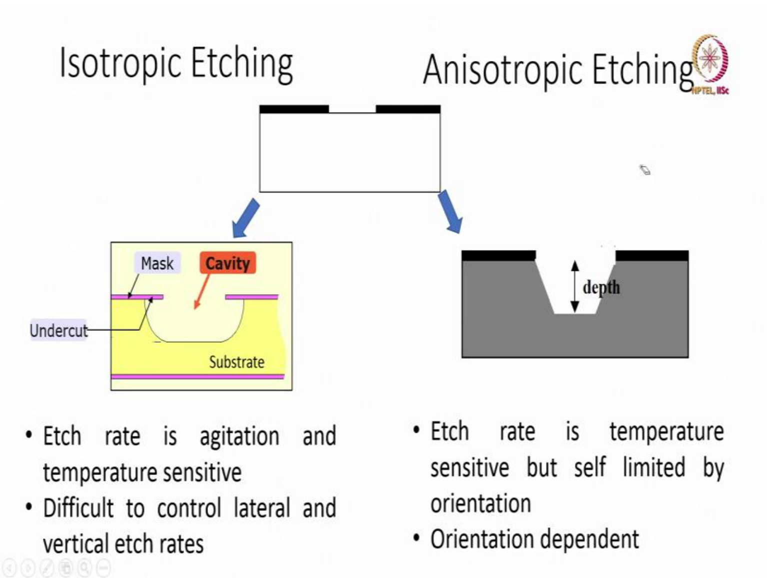
And that is why cantilever some cantilevers are destroyed by etching process, some cantilevers gets buckled, you can see this is destroyed then some cutting levels get buckled like this one, you say these are buckled and cantilevers some cantilevers does not get released at all as you can see here, it is straight just stick to the wafer. So there are, the optimization is a key we need to understand how the optimization should be done and then we can, we can continue from there.

(Refer Slide Time: 22:41)



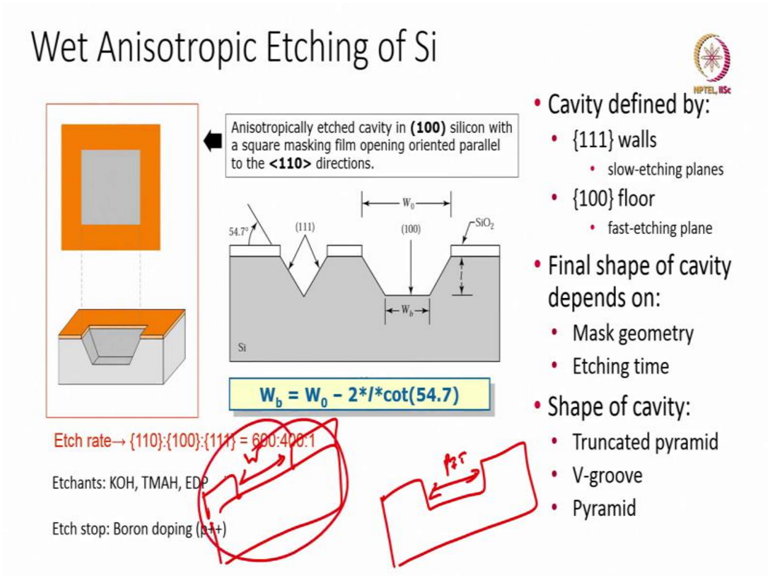
So let us see the next slide, bulk silicon micromachining. Wet etching and dry etching, in now, in this bulk micromachining there are two types of etching techniques, one is a wet etching, one is a dry etching. In wet etching there is isotropic, anisotropic. And the anisotropic is depending on the crystal orientation, while the in dry etching the anisotropicity, tropic the behavior depends or properties depends on the process depend is process dependent. There are acidic etchants and alkaline etchants, in this case there are fluorine based plasmas, there are BrF3 XeF2.

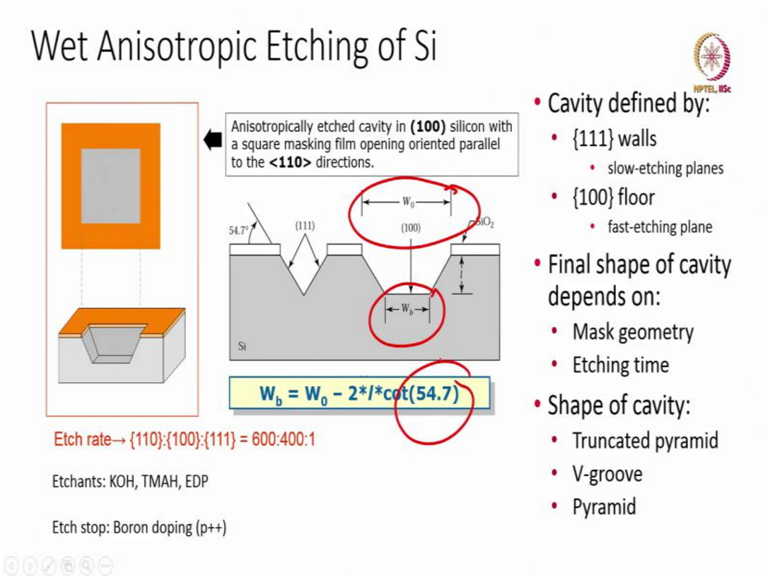
(Refer Slide Time: 23:16)



And isotropic etching versus anisotropic etching, the etch rate in isotropic etching is agitation and temperature sensitive, difficult to control lateral and vertical etch rates. While in the case of anisotropic etching, it is temperature sensitive, but self limited by orientation, and it is orientation dependent. Generally we use 100 orientation wafer, silicon n type silicon P type silicon 100 that is mostly used when we go for the machining of the wafer.

(Refer Slide Time: 23:43)



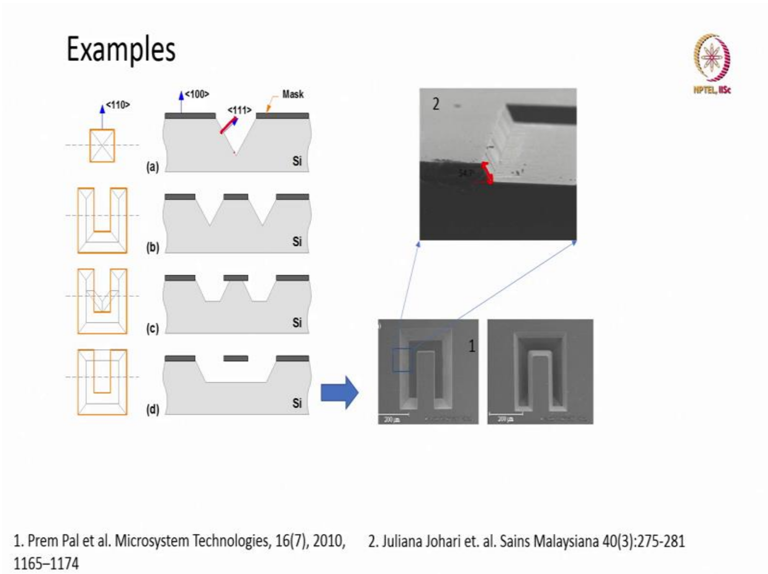


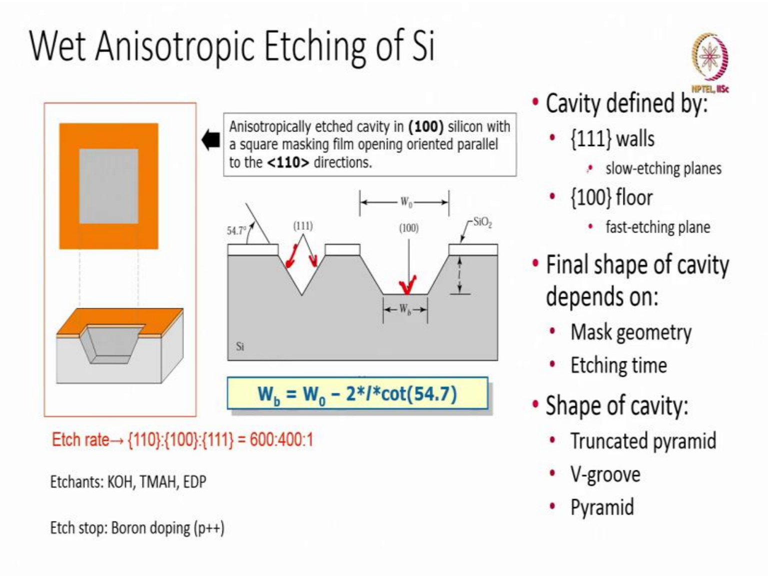
The another very important point is to understand what should be the window size of the opening area. That means, that if I want to create let us say diaphragm or a pit like this, in the silicon wafer how much area I should open it, is it exactly similar to this or it is more than this. So let us say this is a window and this is a pit. To create a pit of this width, how much and this depth, how much should be the window that should I open in the silicon wafer and the substrate.

So then this is equation is given by, this equation is given by you see the W is a final width and W is an initial one. So you can see W b equals to W o minus 2 by cot 54.7, 54.7 because the angle that is created in weight etching is 54.7 degree that you can see here. Angle that is 54.17 degree, 100 is orientation which goes here and 111 is this crystal orientation. So anistropically etch cavity in 100 silicon with a square masking film opening oriented parallel to the 10 110 directions.

And the etch rate, the etchants are KOH TMAH and EDP, EDP is not so often used now. Cavity defined by 111 wall slouching planes 100 of walls or floor fast etching plane, the floor is 100 as you can see the walls are 111 which are slow etch. Finally, we have cavity depends on mass geometry and the etching time. And what is the geometry of the mask, how much time you etch the silicon, it depends on that. And the shape of cavity can be pyramid, V-groove or truncated pyramid.

(Refer Slide Time: 25:42)

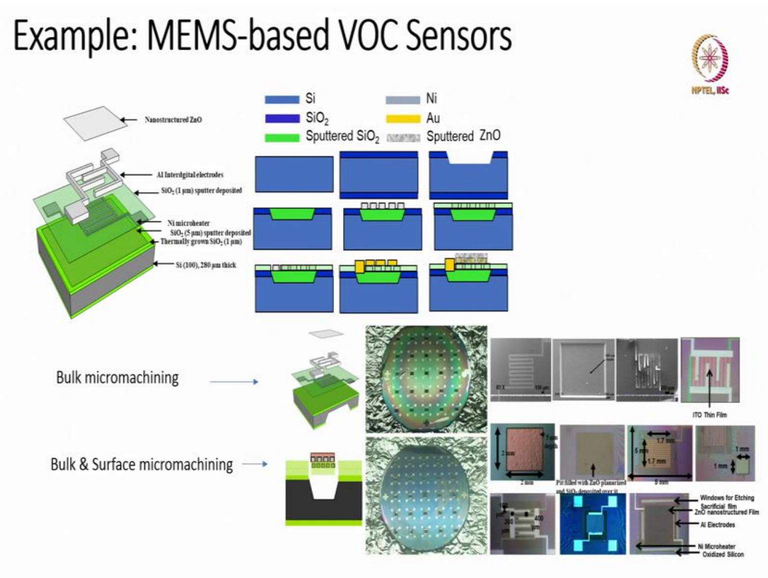


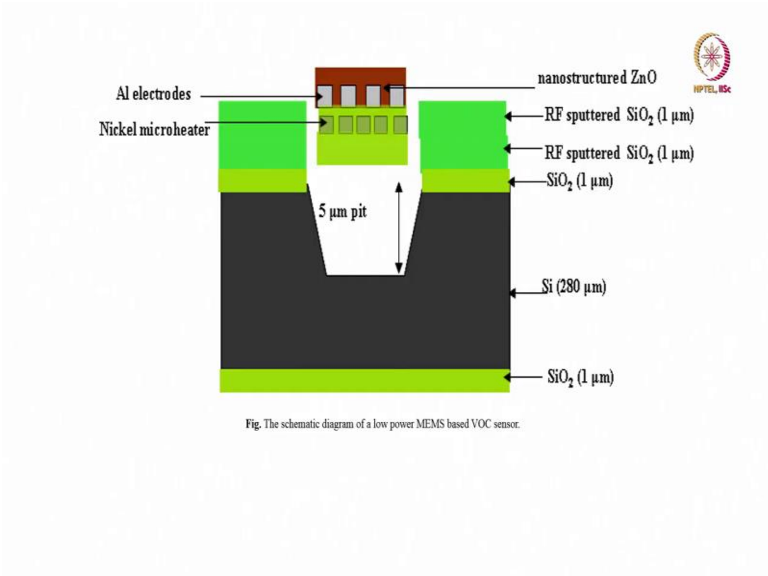


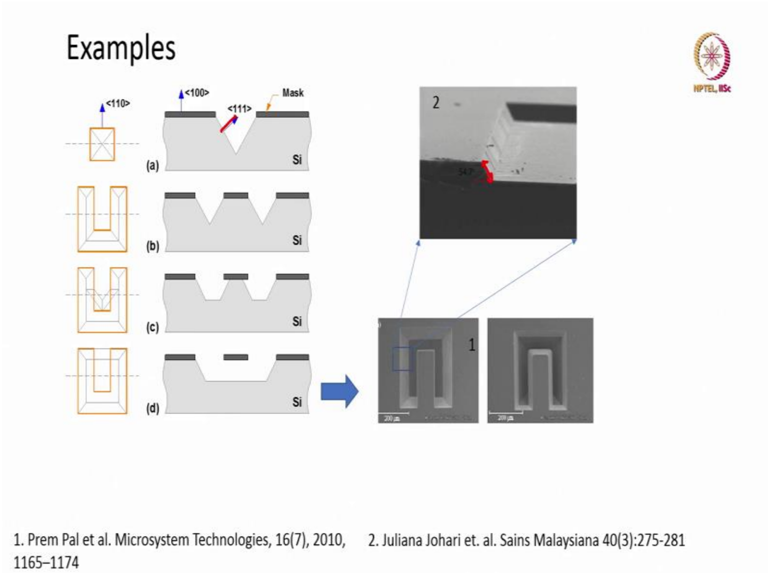
So these are the different shapes of the cavity that you can obtain with the help of the wet anisotropic etching. This is another example of the same and you can see the etch, the wet etching used or wet etching technique used in the silicon wafer and there are two papers by Prem Pal et al Microsystem Technologies and Juliana Johari et al in another Journal.

So if you see the walls then there is a step that is created you see beautiful step digger you can see here. This is how the etching is done and the angle is created and you can like I said the wall which is in this direction, in this, the wall orientation. So is for the 111 is the orientation of the crystals and for floor it is 100.

(Refer Slide Time: 26:32)







We if we see the another example, so we can have several examples of surface as well as bulk micromachining, one can be of VOC based sensors, one can be of another sensor that includes VOC bulk plus surface micromachining. So this example of bulk plus surface micromachining, we will not go into details about that. I am just giving examples that you can create several different kind of sensors, devices using bulk and surface micromachining.

I have given you a very clear example of how the cantilever can be fabricated or how we can create different diaphragms in the silicon wafer using bulk and surface micromachining. So we will stop here we will see one technique which is RI and DRI either in this theory class or in the TA class. So that you will not miss anything and in the next class I will start teaching you about ECG a little bit on that, but more depth into the EEG how the signals are oriented and how we can, and what is the difference in the terms of the amplitude.

The how the, how, what is ECOG, what is EEG, how the differences are there and we can take it from there. So till then you take care, understand a quick session on the micromachining like I said my machining is technically by which you can create different structures either by etching the bulk of silicon or by depositing different layer on the top of the silicon and machining it.

So if you have any questions please ask us through the NPTEL portal, I hope that slowly gradually you are getting into the depth of machining techniques, the devices techniques, the lithography, deposition techniques. And now since we have the base that we have created over last several lectures, now let us go into the depth of the application and let us fabricate some devices that have been used for acquiring signals from the brain. Till then, you take care, I will see you next class, cheers.