Microfluidics
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Lecture - 24
Microfabrication Techniques (Continued...)

We were talking about techniques for growing thin film of metal on silicon wafers and we discussed about thermal evaporation and EBM evaporation. Let us talk about sputtering. In thermal evaporation and EBM evaporation, the metal is evaporated due to high temperature. So many times the metal gets into vapour state and it coats on to the surface of the silicon. In sputtering, the attempts are physically knocked by high energetic collisions.

And then these metal atoms are penetrated at high speed on to the surface of the substrate. So the adhesion between the thin film that we grow is in sputtering is much better as compared that we get from thermal evaporation or EBM evaporation.

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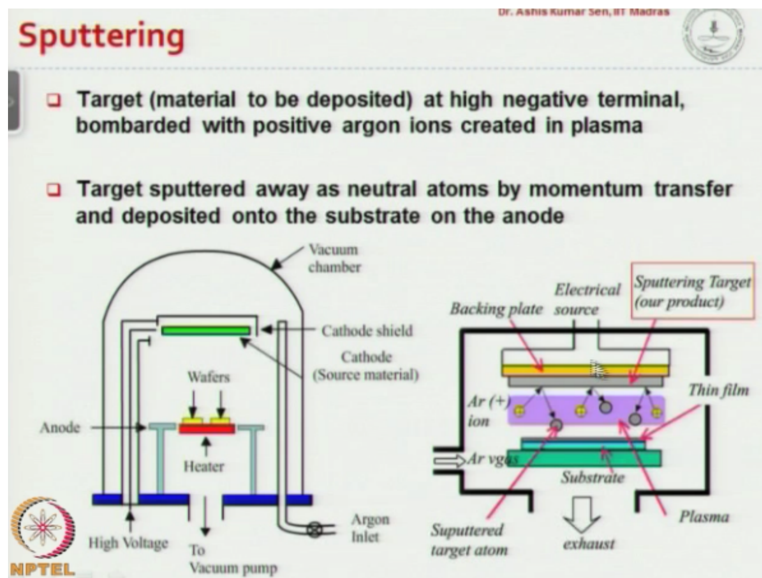

Let us look at the sputtering technique. So here in this case, as you can see in the picture, this is target, which is the source material. It is connected to the negative terminal and so the target wafers are enclosed inside a vacuum chamber and we create argon plasma inside the chamber. Argon plasma, they are positive ions and these positive ions will be colliding on to the source

material or the target, which is connected to the negative terminal at very high speed and they will knock of the target atoms.

And these target atoms will come at high speed and get deposited on to the surface of the wafer. So you can see this, the mechanism more clearly on the right hand side. So you create an argon plasma, the positive charged plasma, which collide on to the sputtering target and so in doing so the sputtering target will be knocked off around the target and they will be moving at high speed and get deposited on to the surface of the substrate creating this thin film.

So the sputtered target are neutral atoms and they will be knocked off because of the momentum transfer between the accelerating positive argon ions and the cathode target. So that will be deposited and these knocked off target atoms will be deposited on to the surface of the substrate.

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Sputtering

- Sputtering preferred over evaporation due to wider choice of material and better adhesion to substrate
- Sputtering employed both in laboratories and in production settings, evaporation mainly used in laboratories
- Amount of material W sputtered from cathode is inversely proportional to gas pressure P_T and anode-cathode distance d

$$W = \frac{kVi}{p_T d}$$

V working voltage

i discharge current

k proportionality constant

Typically, the sputtering is preferred over evaporation because the sputtering allows wider choice materials that is more different kinds of materials can be coated using sputtering as compared to evaporation and sputtering also provides better adhesion between the thin film and substrate. So while the sputtering is employed in laboratories, academic settings and production settings, evaporation is very slow. So that is mainly used only in academic class.

So for production in industry sputtering is referred because of better quality of the film, adhesion of the film as well as the speed of the through put of the film. So if you look at the amount of material sputtered from the cathode, how it is varying with the gas pressure and the anode cathode distance, so the amount of metal that is sputtered is dependent on the working voltage, it is proportional to the working voltage.

And it is going to be inversely proportional to the gas pressure and inversely proportional to the distance between the target and the substrate. The target is cathode and the surface, the silicon substrate is anode.

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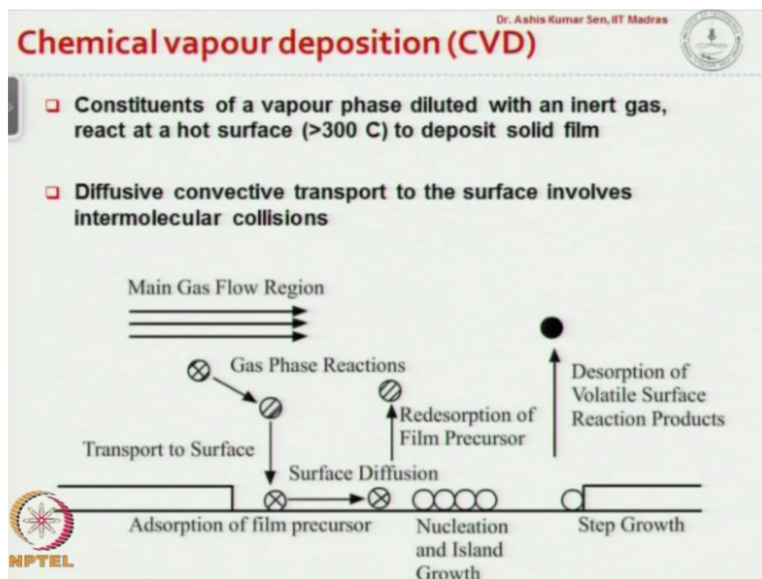

There is another technique for growing thin film on the surface of the substrate and one such technique is chemical vapour deposition, thermal evaporation and EBM evaporation are physical vapour deposition techniques. In chemical deposition technique, the metal will be in wafer form in a suitable gas and because of the chemical reaction, the metal will be extracted from the gas and will be deposited on to the surface of the substrate.

If you look at here, the constituents of the vapour phase of the metal will be present along with an inert gas and that would react on a hot surface. So this is the surface that we are talking about and the gas will react on to the hot surface typically about 300 degree centigrade and in that way,

the solid film will be grown on the surface. So the diffusive transport of the metal ion that is present in the inert gas will be transported to the surface using inter molecular collision.

So if you look at the process here, it involves a series of different states. As the first step, there will be mass transport of these reactants and the dilute gas and because of the gas phase reaction, it will reduce what is called precursor. So these are called precursors, which will be generated because of the reaction at the gas phase because of the presence of the surface at high temperature, there will be gas phase reaction, so these precursor ions will be generated.

These precursor ions will be transported to the surface. They will be coming to the surface because of the diffusion or the mass transport and on the surface, they will be observed on to the surface forming a film and gradually these precursors will move on the surface of the substrate to the nucleation site, where these ions will react with the surface material and there will be growth of the film.

Once this nucleation and the growth of the film occurs, the film precursors will be again deserved on to the gas and also there will be some volatile reaction products that will be reduced. So these are the different stages over which the metals that is present in gaseous form in an inert gas are coated on to the surface of the substrate.

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Chemical vapour deposition (CVD)

- CVD methods versatile, works at low or atmospheric pressure and low temperatures, variants of CVD: PECVD, LPCVD,
- Transport of gas through diffusion proportional to diffusivity of gas D and concentration gradient across BL that separates bulk flow and substrate, Flux of depositing material by Fick's first law

$$F = -D\frac{\delta C}{\delta x}$$

- Using BL theory, flux

$$F = -D\frac{\Delta C}{2L}3\sqrt{\mathrm{Re}}$$

$$\mathrm{Re} = \frac{\rho u L}{\eta} \qquad \delta(x) = \left(\frac{\eta x}{\rho u}\right)^{\frac{1}{2}} \qquad \delta = \frac{2L}{3\sqrt{\mathrm{Re}}}$$

Film growth rate ~ sq. root of gas velocity

GAS FLOW
LAMINAR FLOW
SLICES
BOUNDARY LAYER
x=0
v
y
δ(x)
BOUNDARY LAYER
x
dx
L

So this chemical vapour deposition method is quite versatile. It works at a low pressure and at low temperatures. So there is different variance of chemical vapour deposition, one is plasma enhanced chemical vapour deposition and low pressure chemical vapour deposition. Plasma enhanced vapour deposition, this deposition method is enhanced by creating the metal ions in plasma.

So the plasma actually enhances the deposition of the ion under the surface and helps in nucleation and growth of the surface on the substrate and this chemical vapour deposition can also be enhanced by lowering the pressure inside the CVD chamber, that is called LPCVD, low pressure chemical vapour deposition. So the transport of ions from the gas into the surface will actually involve the diffusion of this metal ions through the boundary layer.

Because of the static surface of the substrate, there will always be a boundary layer that is grown as you can see here and these metals will have to penetrate through the boundary layer to come to the surface and this diffusion would be proportional to the diffusibility of the gas and the concentration gradient across the boundary layer. So the flux of the depositing material that will come from the gas and deposit on to the surface would depend on the diffusion coefficient and the concentration gradient of these metal ions from the gas on to the surface.

So this is Fick's first law that we have seen earlier. Now to find out an expression for delta x. So delta x is of the order of the boundary layer thickness and we know from fluid mechanics that the boundary layer thickness can be expressed in this form in terms of the viscosity density, the x direction and the velocity. So from there we can calculate the average boundary layer thickness, which is given by 2L/3 square root of Re, where Re is Reynolds number, rho uL/eta.

So if you plug the value of delta in this equation here, so this is the expression for the flux that will get. So flux of the ions from the gas on to the surface is –T*del C/2L*3 square root of Re. So what we see here is the film growth rate. So the flux gives rise to growth of the thin film on the substrate, so the film growth rate is varying as the square root of the gas velocity or the Reynolds number.

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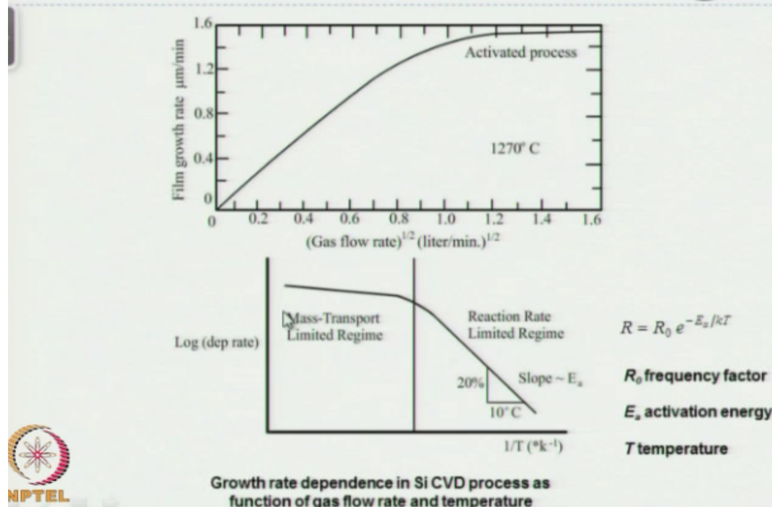

So this is what we see here, on the y-axis we have film growth rate in microliter per minute and on x-axis we have square root of gas flow rate, you can see that the film growth rate varies as the square root of the gas flow rate linearly and beyond a certain value, it increases asymptotically and achieves a steady value. Whereas if you look at the logarithmic of deposition rate for small temperatures, the deposition is reaction rate limited and at large temperatures, the deposition rate is going to be mass transport limited regime.

So at small temperatures, the reaction rate that happens at the surface after the metal ions have already come to the surface, so the reaction rate at the surface dominates at relatively low temperature and at high temperature, the diffusion of the ion through the boundary layer is dominant. So that is what we see from these characteristic curve.

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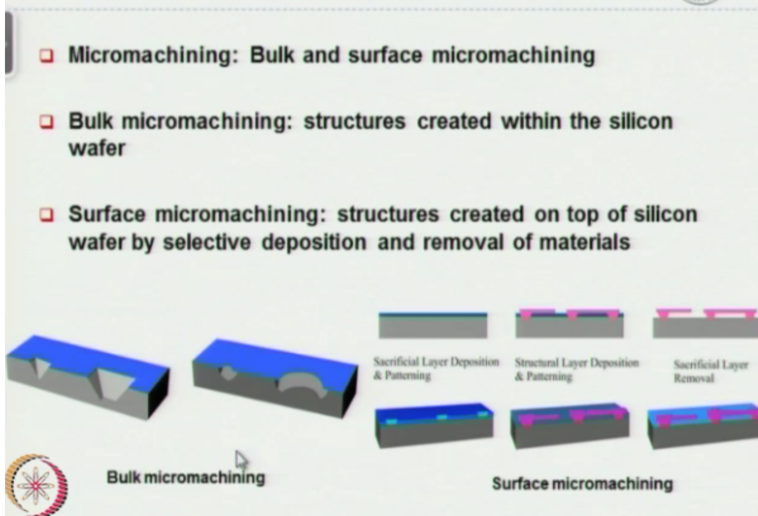

Now with that let us move on and talk about silicon micromachining. So micromachining can be divided into 2 components, one is bulk micromachining and the second one is surface micromachining. In bulk micromachining, we create the structure inside the bulk of the silicon substrate and in surface micromachining, we build the structure on the surface of the silicon substrate. So the silicon micromachining can be divided into bulk and surface micromachining.

In bulk micromachining, we create structures within the silicon wafer and in surface micromachining, the structures are created on top of the silicon wafer by selective deposition and removal of materials. So this will be understanding some time later, what we mean by selective deposition and removal of materials. If you look at here this talks about bulk micromachining where we create these grooves inside the bulk of the silicon either anisotropic or isotropic.

In surface micromachining for example, we are going to create a cantilever structure something like this here, the first step would be to put a sacrificial layer on the silicon and then grow the metal layer, the metal which is the structural component of the cantilever structure and so that is grown on the sacrificial layer. So this pink metal layer is grown on the sacrificial layer. Many times, this first positive silicon glass PSG is used as a sacrificial layer and then on top of which we can use some kind of metals like silicon nitrite is used for cantilever structures.

Once the structures are made, we can pattern and selectively etch the metal layer and after you have done that we can etch the underneath sacrificial layer to remove the sacrificial layer, so we would have the cantilever structure.

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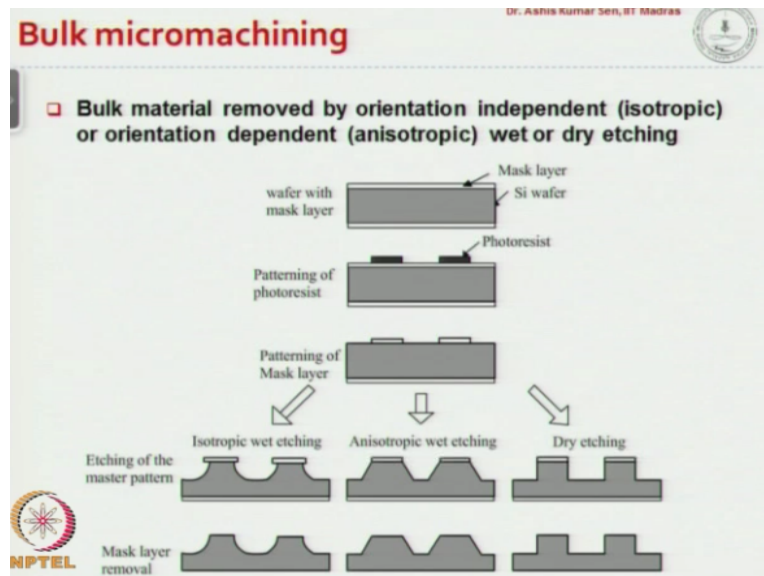

In bulk micromachining, the bulk material will be removed by orientation dependent which we call as isotropic etching or orientation independent or anisotropic etching. An etching could be both wet and dry. Let us take this example. This is a silicon wafer and we have masking layer on the top and bottom and on the top we pattern a photoresist layer and after patterning the photoresist layer, we pattern the masking layer.

For example, this is silicon dioxide, so photoresist is patterned to selectively pattern silicon dioxide and now silicon dioxide is acting as a mask to selectively etch silicon. Now here, if we do isotropic wet etching, the profile would look something like this, typically it is like a hemisphere if there is enough agitation present or it will be looking close to like an ellipse if there is no agitation. So this is what we get if we do isotropic wet etching.

So after you do isotropic wet etching and there is always an undercut if the etching time is more than what is required. Once the etching is done, we can remove the masking silicon dioxide layer, so this is the structure that we get. In anisotropic etching, the etching along different directions may be different depending on the crystal planes. In isotropic etching, the etching

solution is so strong, that it does not look for the crystal orientation and it etches all the crystal prints equally.

Whereas in anisotropic wet etching, it can select depending on the crystal planes, it can etch at different rates along different directions. So this is a typical V groove that you would encounter on a 100 wafer and once it is anisotropically etched, you can remove the masking silicon layer to get the structure. However, if you do dry etching, it makes use of energetic ions and they are bombarded in a certain direction normal to the substrate, so you can obtain square profile using dry etching.

It is very difficult to obtain square profile using isotropic or anisotropic wet etching.

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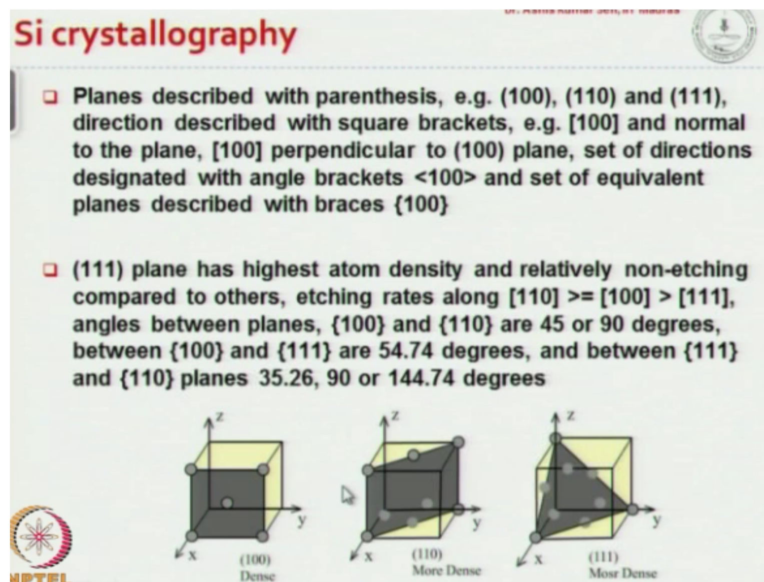

Now let us revisit the silicon crystallography. We have look at this silicon crystallography before. There are different crystallographic planes in silicon substrate and this particular configuration, there are different types of planes that we see here and these planes are described normally with parenthesis. So 100, 110 and 111 planes are described using parenthesis as you see there. The directions are normal to these planes and they are given by square bracket.

These directions are normal to the plane. For example, 100 within square brackets is a direction, which is perpendicular to 100 plane given in a parenthesis and state of directions can be

designated with angle brackets. So if you have 100 direction within angle bracket, what it means is that it is referring to many of the directions, specified by 100 within square brackets and the state of equivalent planes are described by the braces.

So these 100 within the braces meaning many of these 100 planes. It is known that the 111 plane has got highest atomic density. So you can see here different planes, 100 plane, this is the 100 plane, this is the 110 plane, which has got more dense atoms as compared to 100 planes, but 111 plane has got the maximum density of atoms. So 111 plane is very dense in atom. If you look at the etching rates, the etching rate of the 100 is higher as compared to 111.

Because along 100 the atomic density is smaller as compared to 111, but it is quite interesting which is a property of silicon that the etching rate along 110 plane is higher than 100 plane even if the atomic density along 110 is more as compared to that in 100 plane. At the different planes in silicon that is specific angles between them, the 100 and 110 family of planes in the angle between them either 45 degree or 90 degree depending on which particular plane that we talk about.

And the 100 and 111 planes the angle between them is 54.74 and the angle between 111 and 110 planes is 35.26, 90 or 144.74 depending on which plane we are talking about.

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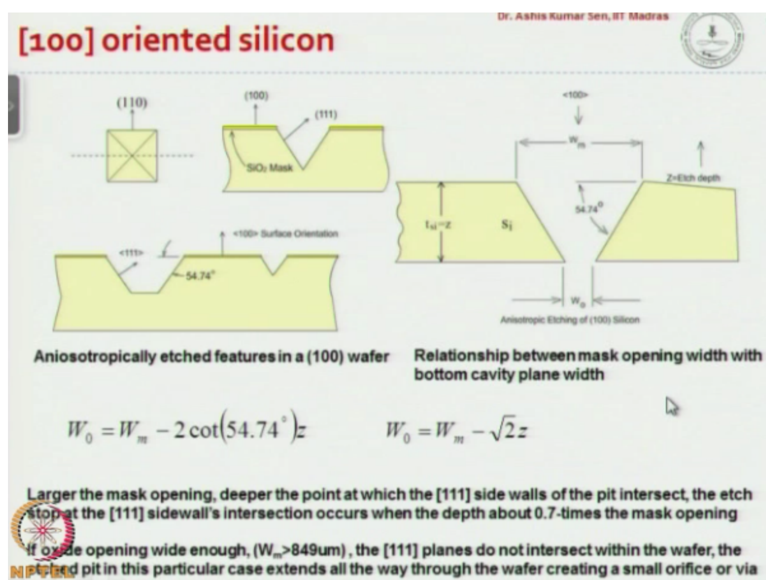

So this is a 100 oriented silicon wafer that we are talking about and so here you can see that this is the 100 plane. So for example, here we are using a silicon dioxide mask, so this is the silicon dioxide mask that is used to selectively etch this portion of the channel. Now if you use anisotropic agents for example something like KOH, potassium hydroxide, so we end up getting a V groove.

So the plane that is perpendicular to the side walls is 111 plane and normal to the substrate is 100 plane and we know that the angle between 100 and 111 plane is 54.74. So we end up getting a V groove or a trapezoidal groove if the etching time is not enough and here the angle of the side wall is 54.742 horizontal. So you get a relationship between the mask opening, the opening at the top and width of the bottom surface.

So the relation is established using this angle between the 2 different planes. So this is the width at the bottom, which is the mask width – twice of cotangent of 54.74* the height of the etching. So this is the etching height, which is Z. This is also shown here. This is Z, this is 54.74 and this is opening, we have done it through etch or it is the width at the bottom of the trapezoidal group. So W0 is Wm-2 cotangent of 54.74*the total etching thickness.

We can simplify that; we can write W0 is Wm-square root of J. What we understand from here is the larger the mask opening, if Wm is larger and the dipper will be the point at which the 111 side walls will intersect. So as Wm increases, the point at which these 2 side walls will intersect will increase. So if the mask opening increases, the point at which the 2 111 side walls will intersect will increase and typically the intersection would occur when the depth is about 0.7 times the mask opening.

If the depth is about 0.7 times the mask opening, these 2 are going to intersect. If the oxide opening is wide enough, if the mask opening is very wide, these 2 walls will not intersect within the wafer, but they will virtually intersect outside the wafer somewhere down. So in doing that, we would create an opening at the bottom and people use this technique to create orifices, nozzles in silicon wafer.

So if you have to ask how you can make nozzles in a silicon wafer, you would design your mask accordingly such that the 2 walls, the 111 will intersect somewhere outside the bottom of the silicon wafer.

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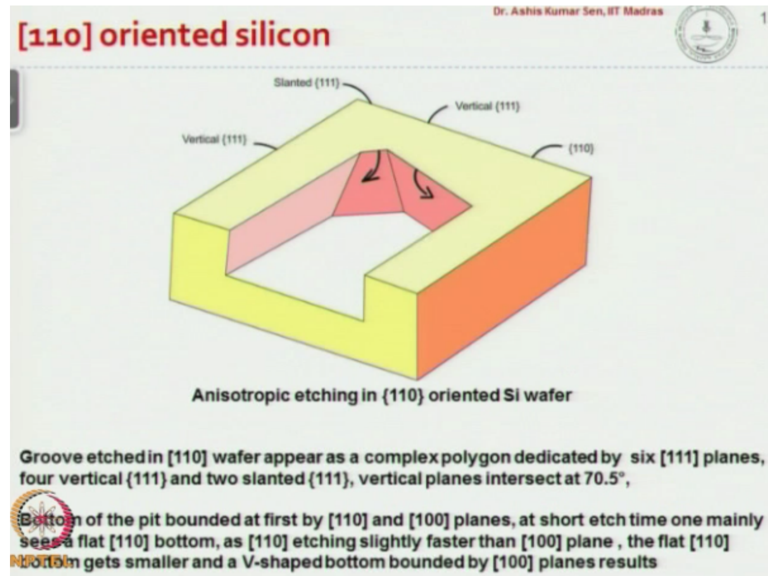

This is 110 wafer. So etching in 110 wafer is not practically used, but this is the structure that we get when you etch 110 wafer. We typically get 6 111 planes, so you can see this is 1 vertical 111 plane and these are 2 more. So typically there will be 4 vertical 111 planes, 1 is here, and 2 is on this face. So this is the second 1, the third 1 will be this 1 and fourth 1 will be on this side. That is cut, this will be fourth. That means this plane will be fourth.

There will be 2 slanted ones, this fifth and there will be 1 slanted 1 here. So there will be 6 111 planes, 4 vertical and 2 slanted and these vertical planes 1, 3, 2, and 4 would intersect at 70.5 degrees. The bottom of the pit, this bottom, this plane we are talking about here would be bounded at first by 110 and 111 planes and if the etching time is short, we would typically see a flat 110 bottom, this is for example, in this case you have a flat 110 bottom.

This means that the etching time is less, so as 110 etching is slightly faster than 100 plane and at a larger etching time, this flat 110 bottom will get smaller and smaller and you would get, this is for a smaller etching time, as the etching time would progress, this flat 110 will become like a V shaped where these will be the 100 planes and the 110 plane at the bottom will vanish.

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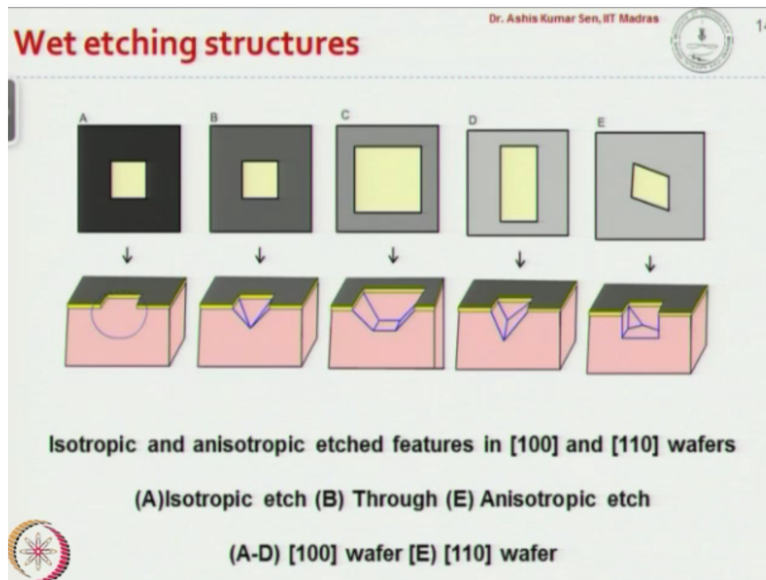

So these are the different structures that you get using isotropic and anisotropic etching on 100, 110 wafers. So as I said 100 wafer is most commonly used and let us look at how the profiles are going to be different by going for isotropic and anisotropic etch. So these are different masks that are used and here we used isotropic etching. If you use this mask for isotropic etching of silicon wafer, we would get a hemispherical shape here, hemispherical groove on to the bulk of silicon.

If you use this square mask and do anisotropic etching, you would get a V groove where the slanted wall will be at 54.74 to horizontal and if you use a larger opening and the etching time is not enough, instead of a V groove, we would get a trapezoidal groove, so here in this case the 111 planes have not met together and if you allow enough time, then this is going to be similar to a V groove what we see here and this is for a rectangular mask opening.

So instead of having a square opening as you can see here, if you go for a rectangular opening instead of a single point, you will end up with getting a line. So here you get a V groove, but it is same at different cross sections, we get a line instead of a point. So that is the difference between using a square opening versus a rectangular opening in case of anisotropic etching and if you use 110 wafer in anisotropic etching, you would get what we just talked about.

We would get 6 different 111 planes and a flat 110 plane if the etching time is not enough and that flat 110 plane will vanish for a larger etching time.

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Wet isotropic etching

- Isotropic etchants etch all crystallographic directions at same rate, usually acidic as $HF/HNO_3/CH_3COOH$ (HNA), used at room temp or slightly above (<50 deg)
- 49.2 wt% HF and 69.5 wt% HNO_3, water or acetic acid as diluents, typical formulation for HNA: 250mL HF, 500mL HNO_3 and 800mL CH_3COOH, etch rate ~4 μm/min but increase with agitation
- Highest etch rate for a weight ratio HF-HNO_3 of 2:1, 100-times faster than anisotropic etch rates, adding diluents slows down etching

So let us look at you know the etchants that we typically use in wet isotropic etching. As I said the isotropic etchants are so strong that they would not care about the crystallographic planes and they will etch all the planes at the same rate. So that is typical of the isotropic etchants. So typically HNA is used for isotropic etchants. So if you look at here, this is called HNA meaning you have 3 components, the hydrofluoric acid, the nitric acid and the acetic acid.

They are used at room temperature or slightly above room temperature, but less than 50 degree centigrade. Typical formulation of HNA would be 49.2% of hydrofluoric acid, 60.5% of nitric acid and they will be diluted either with water or acetic acid. So the typical formulation would be 250 ml of hydrofluoric acid, 500 ml of nitric acid and 800 ml of acetic acid. The etch rate of HNA is about 4 micron/minute, but if you agitate the solution, then the etch rate can be increased further.

The highest etch rate for a weight ratio of hydrofluoric to nitric acid of 2:1, so if you use 2 part of hydrofluoric acid and 1 part of nitric acid, you can get very high etch rate that will be about 100 times faster than the anisotropic etch rates. So a very high etch rate can be obtained using

isotropic etching, using this ratio of hydrofluoric to nitric acid and if you are diluents, for example water to the etchant, the etching rate may go down.

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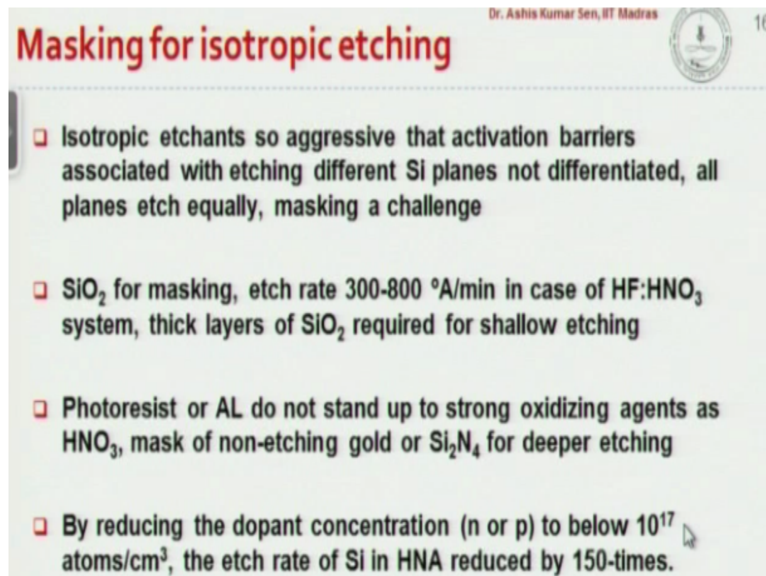

So as I said isotropic etchants are so aggressive that they are not dependent on the crystallographic planes, the activation barriers with etching different silicon planes are not differentiated and all planes are equally etched, so the masking becomes a challenge. How we can design a mask to make isotropic etching. So typically silicon dioxide is used as the mask for isotropic wet etching of silicon.

The typical etch rate of this mask have to be very small as compared to the etch rate of the silicon itself. So if you use HNA, the typical etch rate is about 4 micron/minute and if you look at the etch rate of silicon dioxide is of the order of several 100 angstrom/minute. So typically the etch rate of silicon dioxide mask is about 300-800 angstrom/minute. So you can use silicon dioxide as the mask using HNA.

If you want to do shallow etching, very deep etching, then you would need thick layer of silicon dioxide. So the thickness of the masking layer would depend on the thickness of the structure that we have to etch or the depth of the structure that we have to etch. Photoresist and aluminium, they are also used as masking layer in some cases, but they do not withstand the strong oxidizing agent, the nitric acid that is used in this case.

Whereas masking using non-etching goals are silicon nitrite, they are used frequently for deeper etching. Now if you can reduce the dopant concentration of the silicon, that is the initial stage before you do the oxidation, if you can control the dopant concentration below 10 to the power 7 atoms/centimeter cube, the etch rate of silicon in HNA can be reduced by 150 times. So 1 approach to reduce the etch rate in silicon using isotropic wet etching HNA is to increase the dopant concentration.

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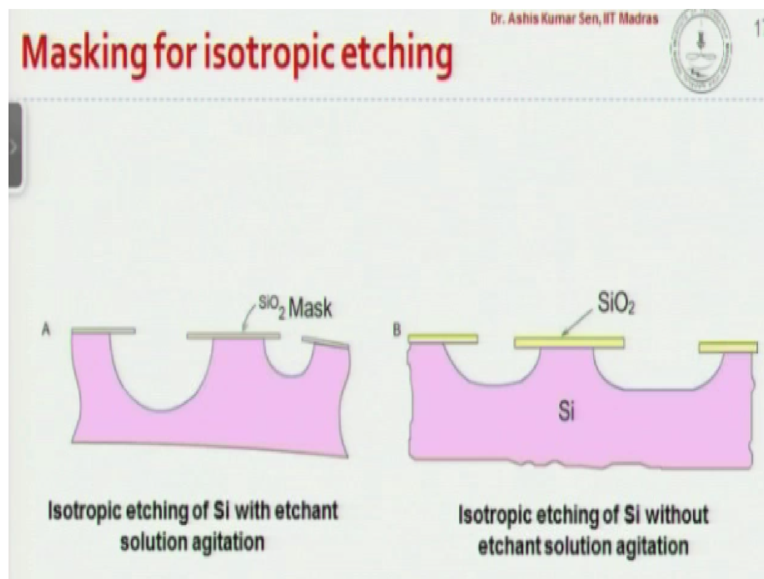

Now here we look at isotropic wet etching. Here we have a silicon dioxide mask which is going through isotropic etching and in this case we are etching with solution agitation that means we are putting the substrate into the etchant and we are constantly moving it, agitating the solution, so it is all because of the mass transfer, the etchant tries to get into the areas where it is not masked and it tries to remove the silicon from those areas.

So while it is removed because of the mass transfer, it needs to move out so that the fresh etchant can attack the fresh surface and if you do agitate, this is the profile, almost a hemispherical profile that you may end up with, but if you do not agitate the solution, the profile becomes flatter, more like half of an ellipse rather than hemisphere.

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Anisotropic etching

- Desired structures obtained through directional etching, i.e. etching much faster in one direction than other
- e.g. piezo-resistive pressure sensor, wafer starting thickness of 300-500 μm to form a diaphragm of final thickness 10-20 μm
- Anisotropic etchants: KOH, NaOH, NH_4OH, anisotropic etchant solve lateral dimension control lacking in isotropic etchants
- Etching slow: fast etching in <100> etch rate about 1 μm/min, time consuming, etch 300 μm wafer needs 5 hr

Now let us talk about anisotropic etching. In anisotropic etching, we can make use of the etch rate along different crystal planes, crystallographic directions to selectively etch 1 plane faster as compared to the other to obtain a desired structure. So in anisotropic etching, the desired structure is obtained through directional etching, so what we exploit is etching much faster in one direction than other.

The application is, we will see 1 such application where the silicon wafer is etched anisotropically to fabricate a piezo-resistive pressure sensor. So you start with typically a wafer which is 300-500 micron thick and in a piezo-resistive pressure sensor, we end up getting a thickness of the sensor, which is typically 10-20 micron using anisotropic etching. Some of the anisotropic etchants are potassium hydroxide, sodium hydroxide, ammonium hydroxide.

These anisotropic etchants solve the lateral dimension control lacking in isotropic etchants. So what that mean is that if you use an isotropic etchant, because it is equally etching all directions, it is also going to under etch the under the mask if the depth is more than half the radius of the mask, half the radius of the gap between the mask. This problem is avoided in anisotropic etching because there is directional dependence.

You can directionally etch more into the depth as compared to the sides. So in anisotropic etching, typically we get fast etching in one 100 direction, which is about 1 micron/minute. This

is very slow as compared to what we get in isotropic etching. In isotropic etching, we get something like 5 micron/minute whereas in anisotropic etching, we get only 1 micron/minute. Anisotropic etching is more time consuming.

If you want to etch a wafer, which is 300 micron thick, it would require about 5 hours. So it is quite time consuming to etch using anisotropic etching.

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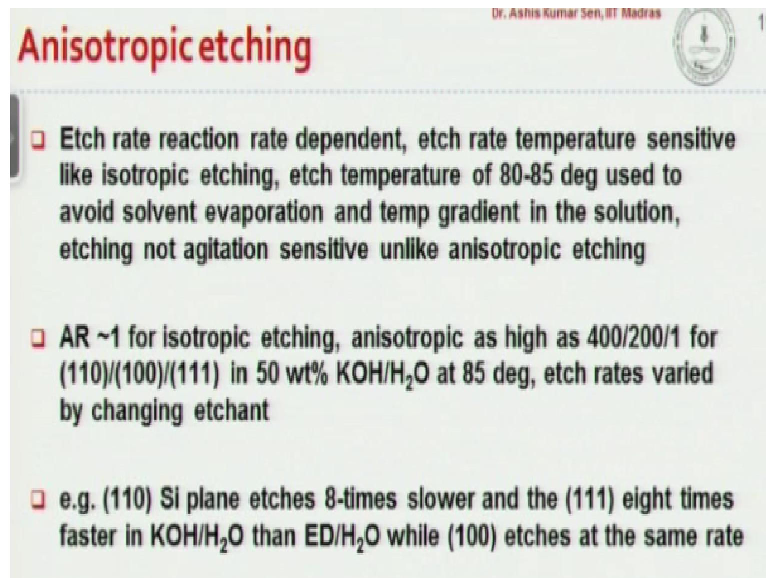

The etch rate in anisotropic etching depends on various parameters. So here I have different parameters, 1 is the reaction rate at which the etchant is interacting with the silicon crystal and it also depends on the temperature of the etchant like similar to the isotropic etching, but etch temperature is typically limited to 80-85 degree, otherwise the solvent, the etchant is going to evaporate quickly.

However, the anisotropic etching is not dependent on the agitation of the etchant. In isotropic etching, we have seen that the hemispherical structure becomes elliptical if we do not agitate the solution, but anisotropic etching is not dependent on the agitation of the etching solution. So we get the aspect ratio in case of isotropic etching is 1, but in anisotropic etching we can get larger aspect ratios.

For example, we can have selective etching along 110, 100 to 111 as 400:300:1, so that is the kind of anisotropicity we can get using anisotropic etching and that is possible in 50% by weight of potassium hydroxide and water at 85 degrees centigrade and the etch rate in anisotropic etching can also be varied by changing the etchant itself. For example, a 110 silicon plane would etch 8 times slower and the 111 plane will etch 8 times faster in potassium hydroxide and water as compared to ED and water.

So that shows the dependence of etching rate of different planes by changing the etchant itself. Whereas there are some planes like 100 plane, the etching rate would not be dependent on the etchant.

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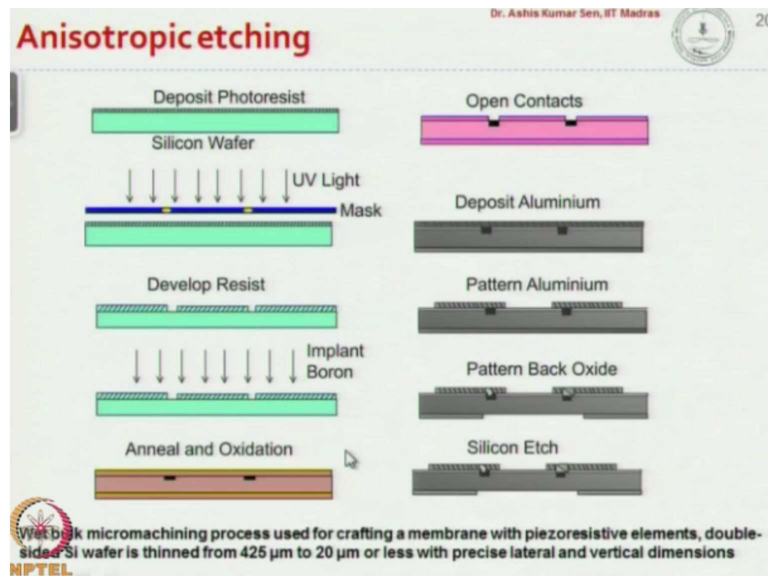

So here we look into 1 example of anisotropic etching. So we are trying to fabricate a pressure sensor and as you can see here, the first step starts with depositing a photoresist on the silicon wafer and then exposing it through a mask and then developing the resist and when we are talking about a pressure sensor, we need to make electrical connection with the silicon on the surface. For the electrical contact, we do doping of the silicon to control the electrical conductivity.

So here in this case we are implanting boron through this etch holes and after etching, we do annealing and oxidation. We put an oxidation layer to insulate these 2 electrodes. Then, we open

the contact and after that we deposit aluminium. Aluminium are the lead contacts on the electrodes and then we pattern the aluminium here to make contact with this boron implanted regions and then we pattern the back oxide. So the oxide at the back of the wafer is patterned.

Then, we do an etching. So this figure is not drawn properly, so there has to be an etching of the silicon. This portion of the silicon dioxide is removed, so you have a thin membrane here. So this is about 10-20 micron and the wafer is typically as we said is about 300 microns. This anisotropic etching is used to create this thin membrane that we need for the pressure sensor.

In some cases, we can do automatic etch stop meaning if you leave the wafer in the etchant for a longer time, still you should be able to do etch stop, meaning further etching will not happen. This is possible by doing doping the silicon substrate. One such example we are going to see here.

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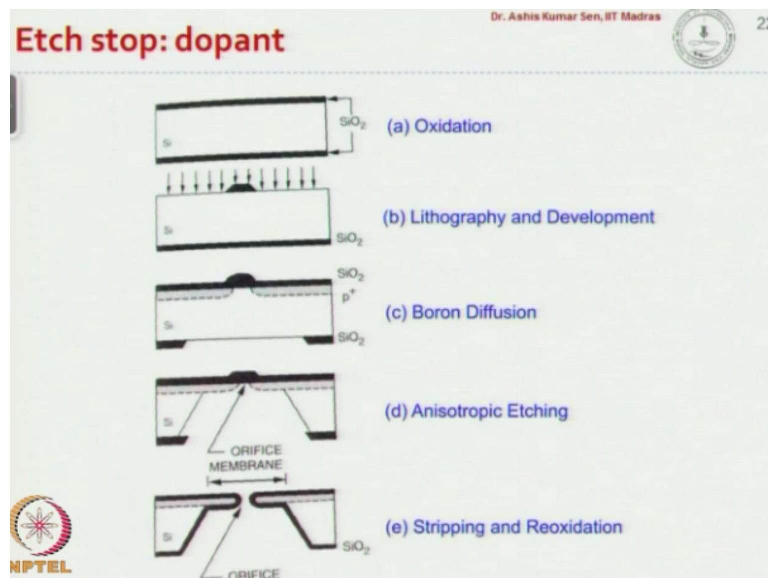

Here what we see is again the standard procedure oxidation, lithography and development, then in this case to do auto-etch stop, we are going to implant boron. The boron is going to diffuse into the silicon and in that way if you are doing anisotropic etching, when the etching is completed till this layer, after all the silicon is removed, it is not going to etch this boron implanted region. So their etch rate is very, very slow.

This etchant is not going to etch this boron implanted regions any further. So this is 1 approach you can use to make orifices, for example in case of inkjet printing application. You need a reservoir where to store ink and we can integrate electrodes and we need nozzles sticking out of the chamber to dispense ink.

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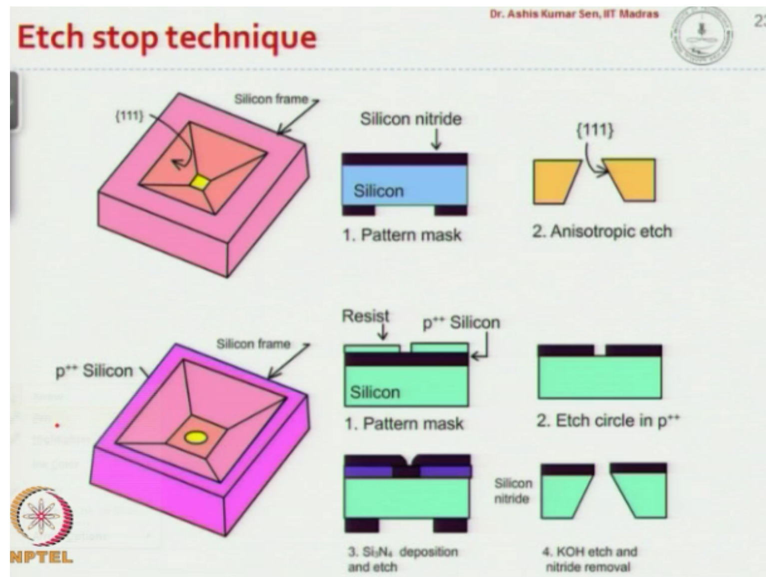

So here are some more examples of etch stop techniques. Here we are using silicon with silicon nitrate mask and if you do anisotropic etch, automatically, it is going to open out on the other side and the silicon nitrate is acting as the auto-etch stop technique and in some cases, we have the silicon implanted with P++ and which act as etch stop and in this particular case as you see here, here we are patterning the mask and here we are etching the circle in P++.

This is the P++ layer and then we are doing silicon nitrate deposit and then when we do etching as soon as it gets to the P++ layer, the etching is going to stop. After that, we can remove the nitrate metal to create a nozzle structure.

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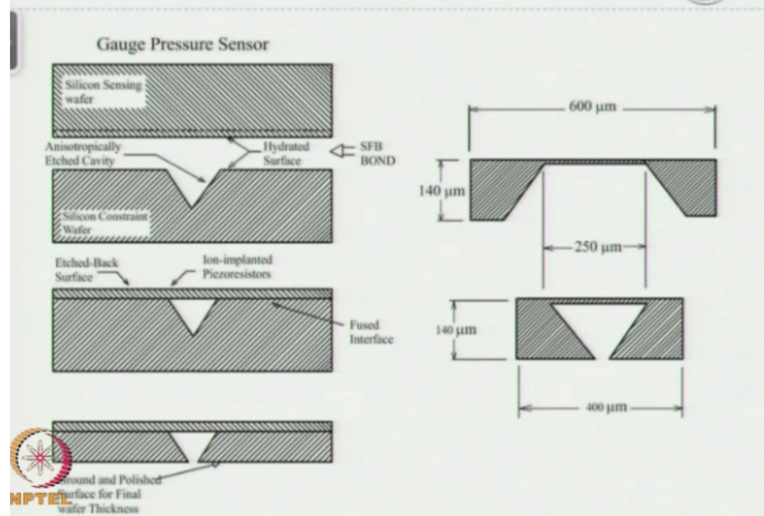

Here we talk about real estate gain using what is called silicon fusion bonding, 1 example that we saw to make pressure sensors where we use about 600 micron of the width and 140 micron of depth. So we do etching anisotropically to end up with this think membrane. 1 alternate approach using silicon fusion bonding technique to reduce the width required is what is shown on the left. So here you are taking one wafer which has a V groove and this is the second wafer which is flat and these 2 wafer are ready to bond.

You can do silicon fusion bonding to bond these 2 wafers and after bonding you etch the back surface. So you keep on etching the back surface until the surface is very thin. So this surface comes here and this thickness of the surface is same as the thickness of the membrane that you require here and then you again try polish from this end and after you polish, so that you get into something like that, so that you have this opening, which is connected to the source pressures, whose pressure you want to measure.

In this case, your thickness of the membrane which is critical for the sensitivity of the pressure measurement is same as this case, what you got from the anisotropic etching in a typical way that we had seen earlier, but the difference is that in this case, the width of the foot print that you require is 400 micron instead of 700 micron. So these areas that you unnecessarily use because of the anisotropic etching is not required in this case.

So that saves the footprint by 50%. With that, let us stop here. We will continue our discussion in the next class.