Microfluidics
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Lecture - 25
Microfabrication Techniques (Continued...)

Let us continue our discussion on weight bulk micromachining. Let us consider one example.

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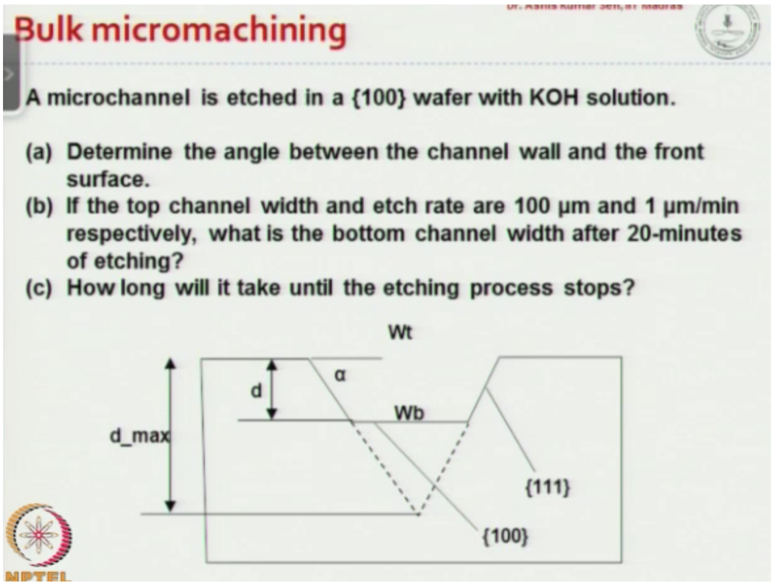

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Bulk micromachining

A microchannel is etched in a {100} wafer with KOH solution.

(a) Determine the angle between the channel wall and the front surface.
(b) If the top channel width and etch rate are 100 μm and 1 μm/min respectively, what is the bottom channel width after 20-minutes of etching?
(c) How long will it take until the etching process stops?

Here we have an example of weight bulk micromachining. We have 100 wafer, which is etched in potassium hydroxide, so this anisotropic etching to create a microchannel structure. Now we are trying to find out the angle between the channel wall and the front surface. It is asking what is this angle. And the second question is if the top channel width and etch rate are 100 microns and 1 micron/minute respectively.

So that means the top channel width Wt is 100 microns and the etching rate is 1 micron/minute, what is the bottom channel width after 20 minutes. We are going to find out what is the value of Wb after 20 minutes. And the third question is how long it is going to take until the etching process stops. These are 3 questions we try to answer.

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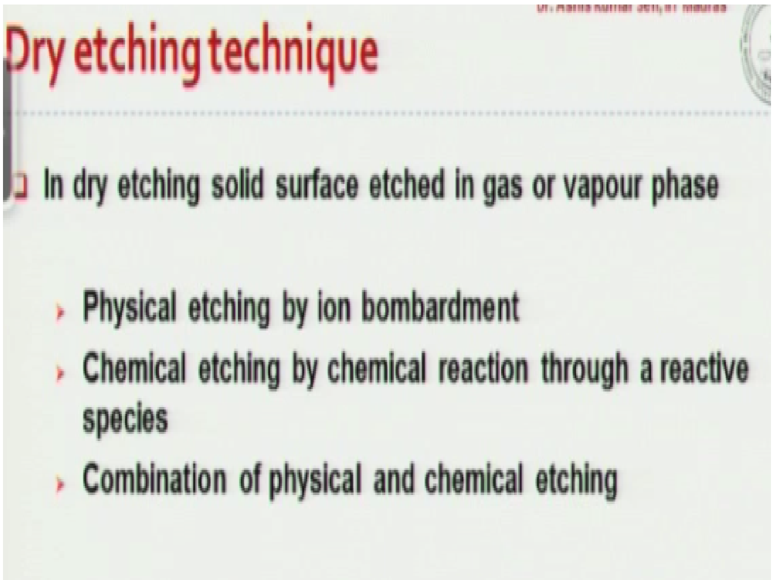

Dry etching technique

- In dry etching solid surface etched in gas or vapour phase
  - Physical etching by ion bombardment
  - Chemical etching by chemical reaction through a reactive species
  - Combination of physical and chemical etching

So if we look at here we know that based on the crystal structure of silicon, the angle between the fast etching plane which is the 100 plane and the slow etching 110 plane, the angle is 54.74 degree. So this is the 110 plane and so this will be 100 direction and this would be 111 direction. To find out this angle alpha, we have to find out the angle between these 2 directions, which is known to be 54.74 from the silicon crystallography.

Now let us look at what is going to be width of the bottom of the channel after 20 minutes. So the etch rate is given, etch rate is 1 micron/minute and we are etching it for 20 minutes. So after 20 minutes the etch depth will be 20 minutes * 1 micron/minute, so we would have 20 microns depth. Now we have this formula which relates the bottom of the width of the channel and the top width of the channel.

So Wb bottom width is Wt-2d cot alpha. That is from the geometry. So the top width is 100 microns-2*depth, d is 20 microns and alpha is 54.74. So the bottom channel width will be 71.7 microns. Now the third question was what is the time after which the etching will be stopped. So to find the etching process is going to stop when the 2 11 planes are going to intersect.

So the moment the 2 11 planes are going to intersect, the etching cannot proceed further. So when the 2 11 planes cross each other, in that case the width of the channel of the bottom will be 0, so we can say Wb is 0. So in that case the d or maximum d that we can achieve in that case will be Wt cot alpha/2 which is 70.71 micron. So that is the maximum depth that is possible before the etching stops.

Now if we can find there what is the time that is taken to create the maximum etching depth knowing the etch rate. So it is the d max/by the etch rate which will takes the 70.71 minutes for the etch to stop automatically. Now with that let us move on and talk about dry etching. So in the dry etching technique the solid surface, the substrate is exposed to either a wafer or a gas. So there are different dry etching techniques available.

One is a physical etching which is done by a bombarding ions onto the surface of substrate, which is protected by mask in the areas that we do not want to etch and then the second is chemical etching, which is done by the chemical reaction through reactive species and the third is we can use a combination of physical and chemical etching.

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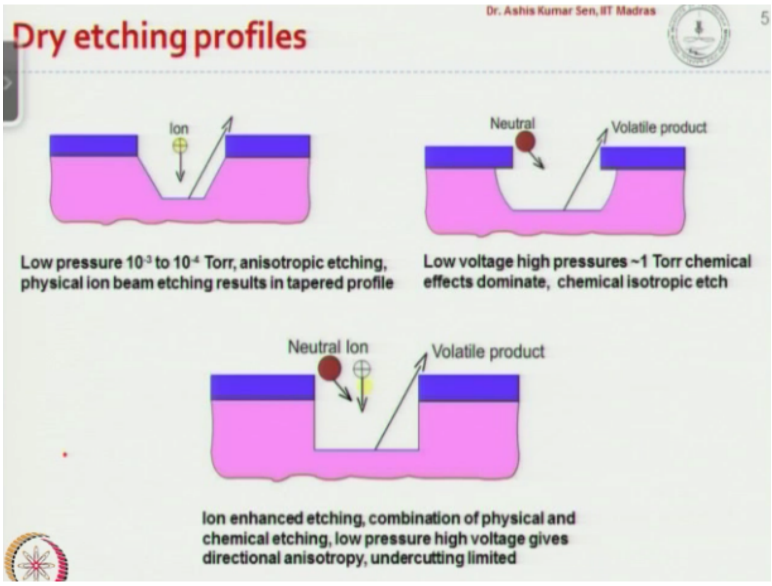

Dry etching profiles

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Low pressure 10^{-3} to 10^{-4} Torr, anisotropic etching, physical ion beam etching results in tapered profile

Low voltage high pressures ~1 Torr chemical effects dominate, chemical isotropic etch

Ion enhanced etching, combination of physical and chemical etching, low pressure high voltage gives directional anisotropy, undercutting limited

So let us briefly look at what these 2 different etching procedure mean. In the physical etching, we typically have a system like this. This is the silicon substrate and this is the mask and we have here the ions getting bombarded on the substrate in the exposed areas, unmasked areas the ion is going to bombard at high energy on the substrate and that happens typically at a low pressure between 10 power -3 to 10 power -4 Torr.

So this physical etching typically gives an anisotropic profile, which is looking like what is shown here. Now if we look at chemical etching this is an example of the profile that we get from chemical etching. The chemical etching is done at low voltage but high pressure. The pressure is about 1 Torr. In this case, we do not have any ion. We have these neutral atoms they come and react with the surface, the silicon substrate and it is because of the chemical reaction that the surface is getting removed.

So this chemical etching process results in isotropic profile. Now we can combine the physical etching with the chemical etching and if you do so, then we can have a scenario where we would have high energy ions getting collided on the surface, at the same time we would have the neutral atoms interacting with or reacting with the chemical substrate and this combination of physical and chemical etching is called ion enhanced etching.

This is done at low pressure and high voltage and that gives directional anisotropic meaning we would etch very fast in this direction and will be almost have 0 etching in the transverse direction. So this anisotropic etching benefits that there is no under etching of the substrate as opposed to what we see in the isotropic etching case, the chemical etching case.

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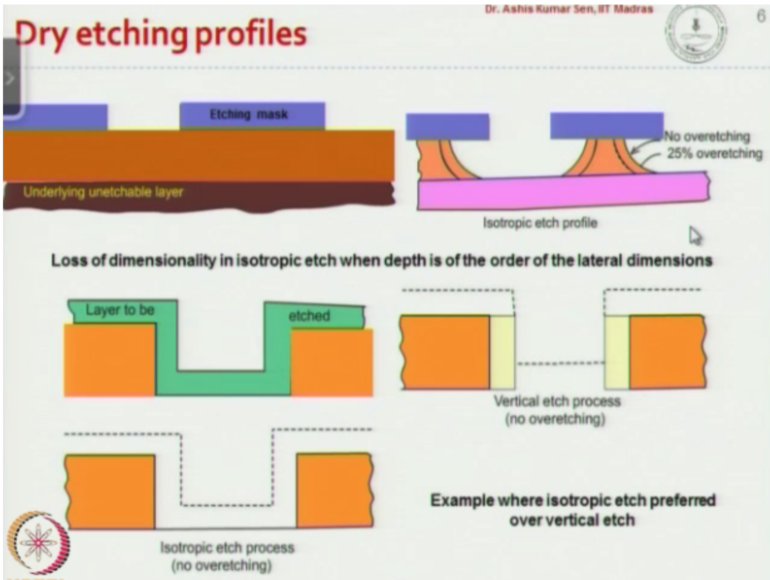

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Loss of dimensionality in isotropic etch when depth is of the order of the lateral dimensions

Example where isotropic etch preferred over vertical etch

So this is an example, here we are talking about etching of the silicon layer here. This is etching mask and if we do isotropic etching, this is the profile you end up with. There is always under cutting which you see here. This is not desirable. So the isotropic etch profile would always involve undercutting which is not desirable. But that does not mean that always anisotropic etching preferred.

There are some cases where isotropic etching becomes beneficial. For example, if you consider this case we have an layer of metal on the surface of silicon which you want to etch and if you follow isotropic etching method, then you can uniformly remove this layer from the entire substrate. Whereas if you go for anisotropic etching, the combination of for example of physical and chemical etching the profile, the material that we are going to remove will be removed in the vertical direction.

So all etching will be done in the vertical direction, so as a result the material from these areas are going to be removed and the material here cannot be removed because all the etching becomes in the vertical direction. So in that case we will be preferring isotropic etching as compared to the anisotropic etching.

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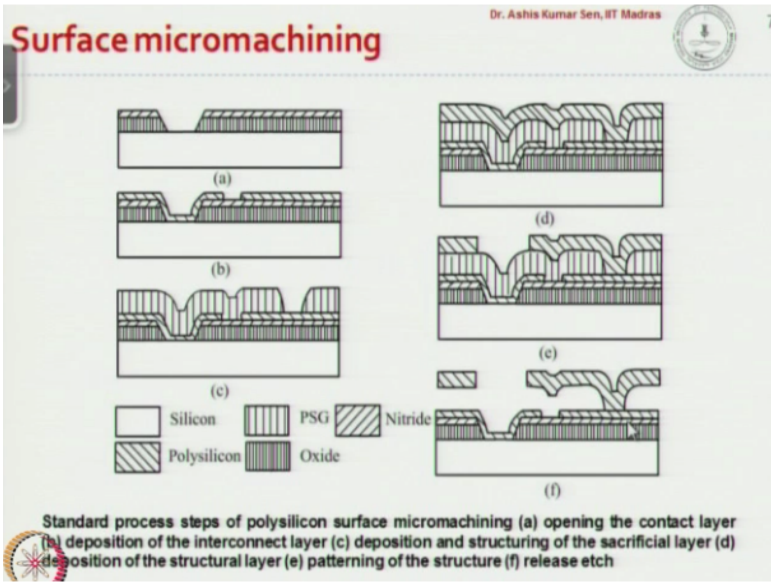

Surface micromachining

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Standard process steps of polysilicon surface micromachining (a) opening the contact layer (b) deposition of the interconnect layer (c) deposition and structuring of the sacrificial layer (d) deposition of the structural layer (e) patterning of the structure (f) release etch

So that let us talk about surface micromachining in the bulk micromachining the structures are created in the bulk of the silicon wafers, inside the silicon wafer we go for subtractive technique, meaning we remove the bulk of the substrate material to create channels. In surface micromachining we build structures on top of the silicon substrate. So many times in a surface micromachining technique is additive technique meaning we add materials metals from outside to create structure on the surface of the substrate.

So here if you look at this example, here this is a standard process to create polysilicon structure using surface micromachining. We are going to create in a polysilicon cantilever on the surface of silicon substrate. So the first step is to, this is the silicon and we grow an upside layer this is silicon oxide and on top we are putting nitrite for electrical pacivation. So this is the nitrate layer an then the second step would be to, after putting silicon dioxide and nitrite, we open an window here by etching to establish the contact layer.

And then we put in the polysilicon here for establishing electrical contact. So after the polysilicon layer, we go for putting a PSG layer which is phosphosilicate glass, and this is used as the sacrificial layer. This is the sacrificial layer. So step c is deposition and structuring of the sacrificial layer which is the phsophosilicate glass. And after that we go for the deposition of the structural layer, and this is nothing but the polysilicon.

As you can see here, so you deposit the polysilicon layer and then we pattern the polysilicon depending on the structure of the cantilever that you want, we selectively etch this layer of polysilicon and then the sacrificial PSG layer, is removed using an etchant selectively that can only take out phosphosilicate glass. So we end up with a polysilicon cantilever. So in surface micromachining is all about adding different layers on the surface of the substrate.

Many times we have the sacrificial layers to create hanging structures. And it is also about selectively etching 1 layer using a particular agent where it is not etching the other material.

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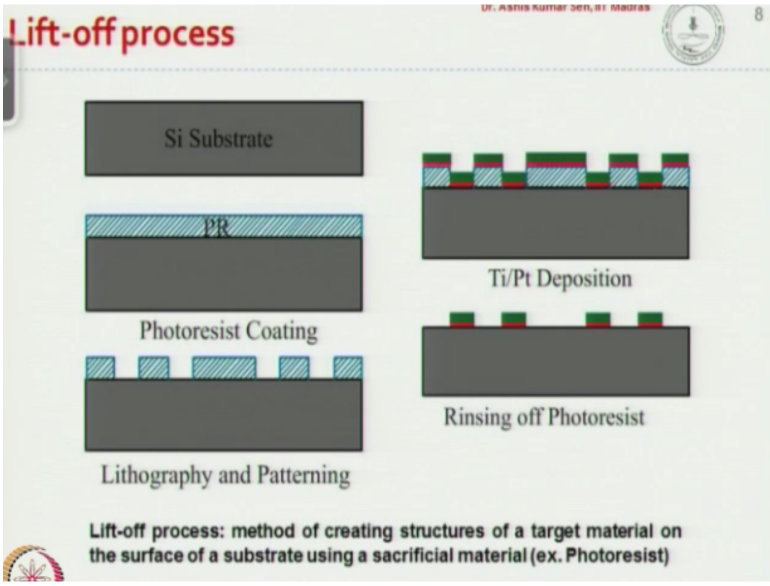

Lift-off process

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Lift-off process: method of creating structures of a target material on the surface of a substrate using a sacrificial material (ex. Photoresist)

So here we talk about lift off process. The lift off process is used to metalize a surface by using a sacrificial layer, for example SU8 or photoresist. So this is called lift off process, if you look at the process again start with a silicon wafer and coating with photoresist and then we pattern the photoresist using a mask, easy exposure through a mask. This is lithography and patterning. And then in the pattern to remove photoresist areas, we do titanium and platinum deposition.

So platinum does not stick very well to silicon. So we do initially a titanium deposition followed by platinum, so that is what you see here. So this layer is titanium and this is platinum, and after you do that, then we take a photoresist developer solution or a solution that will stripe off the photoresist. So all the areas where the photo resist is bonded to the silicon, the photo resist get stripped off.

So all the metal that align on the photo resist get stripped off. So you have a metal pattern coming on the surface of the silicon. So this is known as the lift off process to create a metallic pattern on the surface of the substrate by using a sacrificial layer such as photoresist.

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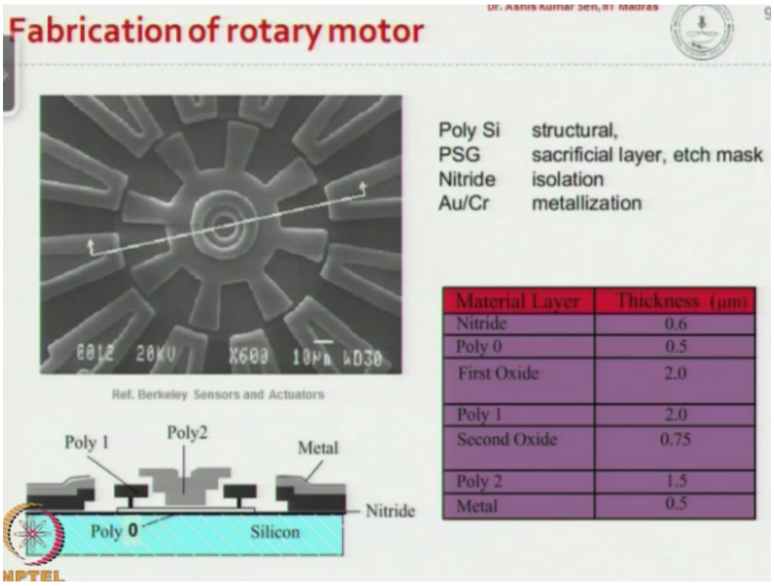

Fabrication of rotary motor

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Poly Si	structural,
PSG	sacrificial layer, etch mask
Nitride	isolation
Au/Cr	metallization

Material Layer	Thickness (μm)
Nitride	0.6
Poly 0	0.5
First Oxide	2.0
Poly 1	2.0
Second Oxide	0.75
Poly 2	1.5
Metal	0.5

Ref. Berkeley Sensors and Actuators

So here we take an example of a micro motor, how, what are the procedures that are available to fabricate a rotary micro motor. So as you can see here in the image here, so this part is the rotary part, this is the rotary part and this is the starter. So by applying an electric field, because of the electromagnetic induction this rotary part will get a force in the tangential direction, which will enable rotation of this part of the motor. This is similar to an induction motor.

So what are the different parts of the structure. If you take a section along this white arrow mark, this is what we would see, this is what we would see. The structure is of course is built on silicon wafer and this layer here is the poly 0 layer. And on the poly 0 layer this rotary part will be anchored, so this is where the rotary part is going to be anchored on the poly 0 layer. And then this is the hub, this is the hub that we see here.

So this part is the hub which is the poly 2 layer. And this rotary part is the poly1, the structure is made out of poly 1 and nitrite is this dark line here is the nitrite which is used for electrical pacivation between the top layers and the silicon, and so this is also the poly 1 as you can see here, this dark similar to the rotary structure, and on top we have metal, so this is the metal here, for example gold or chromium is used for electrical connection and this is the oxide layer.

So this many layers are there and how, we will see how we can fabricate this structure. So it is the polysilicon which is the structural layer of this micro motor. So you would see there are different polysilicon layers that are present here in the structure. We would be using phosphosilicate glass, PSG as the sacrificial layer and nitrite will be used as the isolation. As I was telling you the isolation between the substrate and the top layers.

And gold or chromium will be used for metalization, to supply the electrical connection to the micro motor. So these are the different layers and their corresponding thicknesses in micron, the nitrite layer will have 0.6 micron thickness and this is coming from this particular design that has been reported and poly 0 will have 0.5 micron thickness, the first oxide layer will have 2 micron thickness, the poly 1 will have 2 micron thickness.

The second oxide will 0.75 micron thickness, and the poly 2 will have 1.5 micron and the metal layer will be 0.5 micron. So you would see how the fabrication process steps are.

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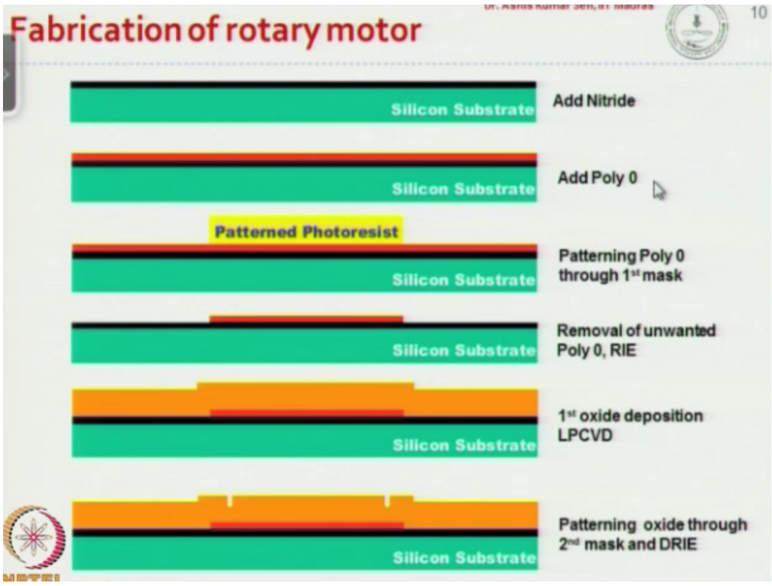
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Add Nitride

Add Poly 0

Patterning Poly 0 through 1st mask

Removal of unwanted Poly 0, RIE

1st oxide deposition LPCVD

Patterning oxide through 2nd mask and DRIE

So we start with a silicon substrate and putting a nitride layer on the top for electrical pacivation, so this is the nitride layer on the top. Then we add the poly 0 layer so this is the poly0 layer that we add, and then we pattern this poly0 layer using photoresist. So you have a mask which would pattern the photoresist, which would act as a mask for etching poly0, so we pattern poly0. So here the poly0 has been patterned using the lithography.

Then we remove unwanted poly0 using reactive ion etching. So reactive ion etching is used to remove poly0 in these areas. Then we deposit the first layer of silicon oxide. So this is the first layer of silicon oxide which is deposited using low pressure chemical vapour deposition. And then we pattern this oxide to create this hole using a second mask. So you would also see how many mask we need to create this motor.

So this is the first mask which is used to pattern poly0 and after you put the oxide layer here we will be using the second mask to pattern the holes in the oxide layer, using the mask dry reactive ion etching can be used to create this rectangular holes.

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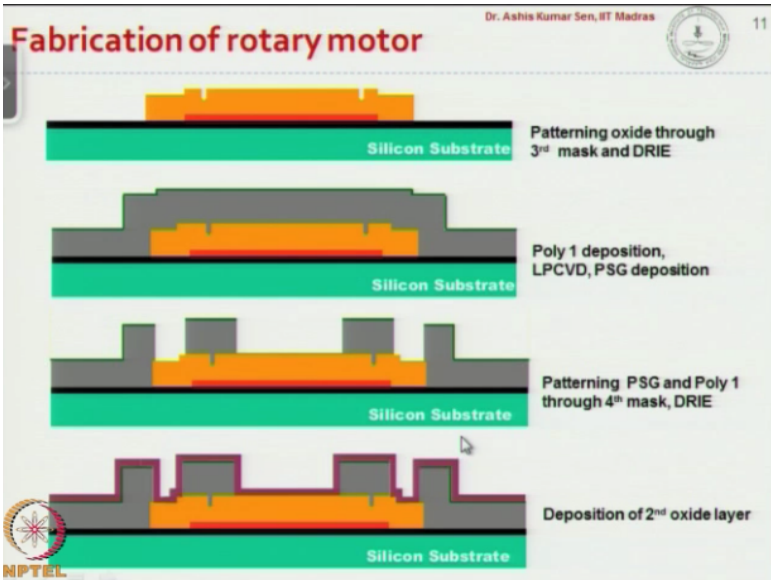

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Patterning oxide through 3rd mask and DRIE

Poly 1 deposition, LPCVD, PSG deposition

Patterning PSG and Poly 1 through 4th mask, DRIE

Deposition of 2nd oxide layer

So after we pattern the oxides through the mask, we would be patterning the oxide layer further. So you can see here this patterning is done to create these cylindrical holes, then we also would like to remove this part of oxides from these portions of the oxide we have to remove on both sides. So to do that, we will be using the third mask where you can see that this areas of the silicon dioxide have been removed using dry reactive ion etching.

And then we do the deposition of poly1, the first poly silicon layer is deposited using LPCVD, so this is the poly silicon layer, PSG. And on top of that we grow a layer of phosphosilicate glass. So this green layer here on top is the PSG layer. And then we pattern the phosphosilicate glass and pattern the poly1 through the fourth mask. So this is the fourth mask that will be requiring to first pattern the top PSG layer and then pattern the poly1 layer.

Then next we would move on and deposit the second oxide layer. So this is the second oxide layer we will be depositing on top of the PSG and everywhere we are doing a coating of the silicon dioxide.

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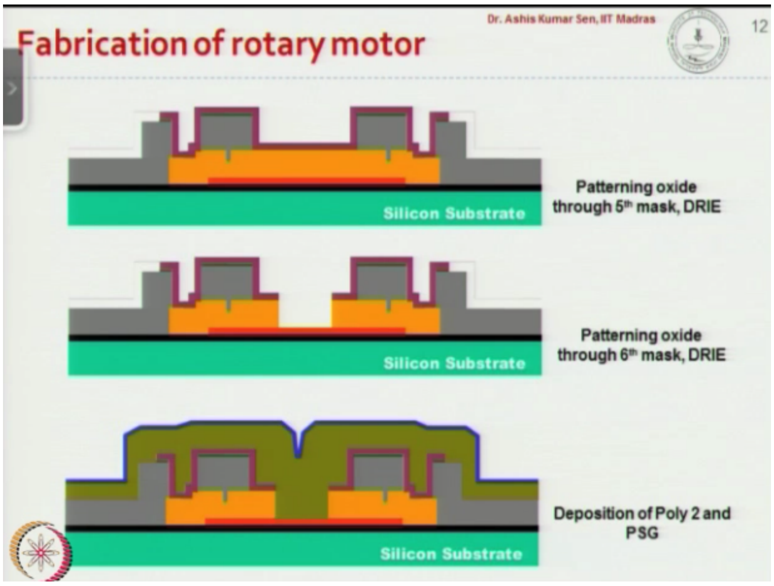

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Patterning oxide through 5th mask, DRIE

Patterning oxide through 6th mask, DRIE

Deposition of Poly 2 and PSG

So then we would be using the fifth mask to pattern the second oxide layer. This was the first oxide layer, and this was the second oxide layer. Then we will be using the fifth mask to pattern the second oxide layer, so you can observe that this areas of silicon dioxide are removed using dry reactive ion etching and then patterning the oxide the buried oxide, the inner oxide, this oxide layer using the sixth mask.

So after we have patterned this top oxide layer, then we want to pattern the buried, inside oxide layer, that is done through the sixth mask using the dry reactive ion etching. And then we deposit poly2 and PSG. So after we etched the silicon dioxide this is the poly2 layer, this is the poly2 and this is the PSG layer. This is the phosphosilicate glass layer on top of poly2.

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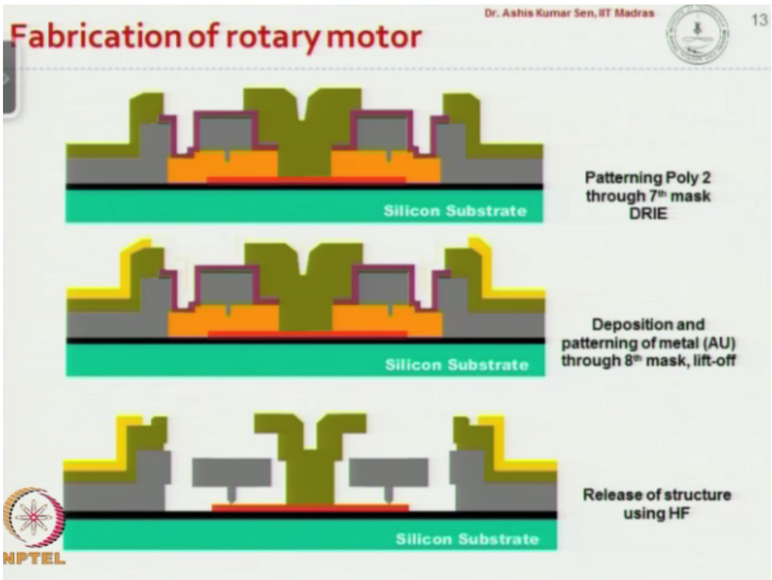

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Patterning Poly 2 through 7th mask DRIE

Deposition and patterning of metal (AU) through 8th mask, lift-off

Release of structure using HF

Next we pattern the PSG and the poly2, so the PSG layer and the poly2 layers are patterned. So the PSG layer is acting here as a mask to create, to etch poly2 layer. So after poly2 layer is etched the PSG has been removed as you can observe here. So that etching of poly2 is done using dry reactive ion etching. So on top of this poly2, we deposit the metal. So gold or chromium is deposited here, so this is the metal which is deposited on top of poly2.

And then the final step would be to remove this buried oxide layer. Actually remove oxide everywhere from the structure. So that we put in silicon dioxide etchant. So silicon dioxide which is this layer and this layer gets removed everywhere. So you can observe that so first this silicon dioxide removed and the etching gets in and removes this sacrificial silicon dioxide layer. So as silicon dioxide is removed this poly2 is moving down.

This anchor points, so this poly2 which is the router gets supported using these anchor points on the top of poly0 layer. This is the poly0 layer. So it gets supported here using the anchor points. So this is the motor that we wanted to fabricate. So this give you an example how to create multi layer structures, intricate structures, movable structures using a combination of photolithography, patterning, and selective etching of different layers.

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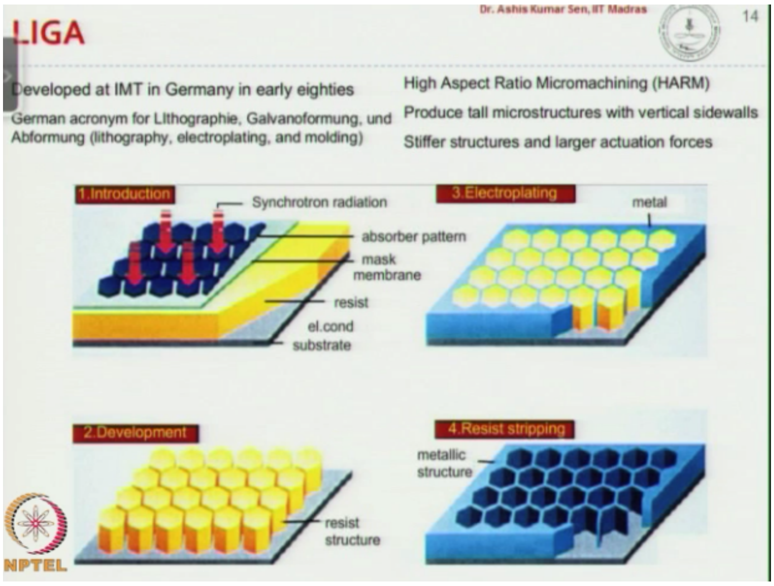
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LIGA

- Developed at IMT in Germany in early eighties
- German acronym for LIthographie, Galvanoformung, und Abformung (lithography, electroplating, and molding)
- High Aspect Ratio Micromachining (HARM)
- Produce tall microstructures with vertical sidewalls
- Stiffer structures and larger actuation forces

Now let us look at another technique which is called LIGA. So LIGA is used to create high aspect ratio structures. Typically, if you want to grow a metal layer on surface of a silicon the thickness is limited to maximum to couple of microns, in nanometre to couple of microns. But if you want to create these metal structures very thick enough of the order of 100s of microns to millimetre. The way to do is, to use LIGA.

So that technique we would be looking at here. LIGA technique was developed at IMT, Institute of Micro Technology in Germany. So it was developed around 80s, if the LIGA is an acronym for a German word which is Lithographie, Galvanoformung, and Abformung, that means lithography, electroplating, and moulding. So we will be doing all 3 different processes as part of LIGA.

And LIGA is used for as I said it is used for high aspect ratio micromachining, and it produces tall structures with vertical sidewalls and it is fabricated in metal, because to provide the structure that are stiffer and which can sustain large actuation force. So this is the procedure. This is the substrate and on top of that we have a resist layer. This is the resist layer and then we have a mask pattern, so this is the mask.

All those blue areas that you see, the hexagonal pattern are the absorber pattern so that will prevent the exposure of the light, typically x-ray is used for curing of high aspect ratio structures, because of higher energy as compared to UV, so here we are using x-ray. So after the exposure if you do the development, then you create this free standing photoresist structures and then we do electroplating. This substrate is electrically conductive.

It could be a metal that can be patterned using, that can be the layer can be, the thickness can be increased using electroplating. So you do electroplating to create this metal layer. So this is the metal layer which is grown using electroplating. So once we have done the electroplating, the final step would be to remove the resist layer. So this resist layer are removed after electroplating. So we have a honeycomb structure that we have to fabricate.

So any structure can be fabricated using this technique provided we design the mask accordingly, and the benefit of the LIGA technique is that the thickness larger aspect ratio structures can be manufactured using this technique.

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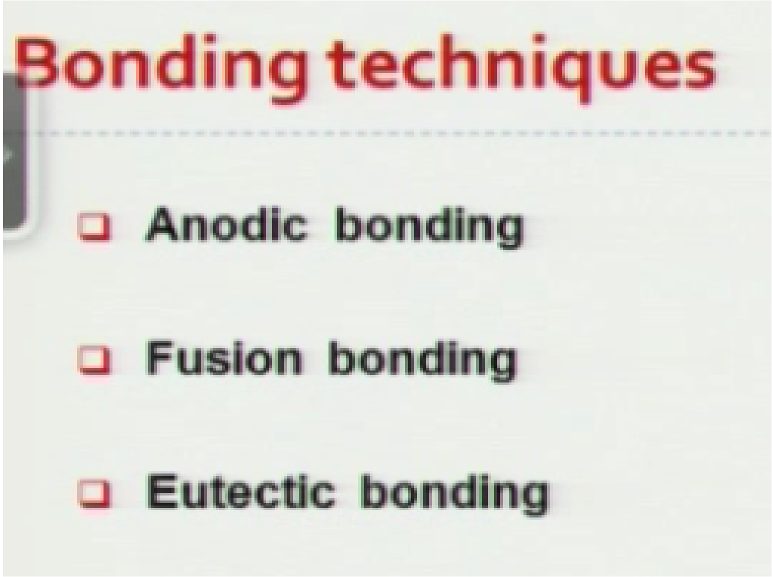

Bonding techniques

- ☐ Anodic bonding
- ☐ Fusion bonding
- ☐ Eutectic bonding

Now let us look at bonding techniques, many times we fabricate channels in silicon, but then the open channels are not suitable for fluidics. So we need to seal the channel, the way to seal the channels is to bond it with another plane or substrate. There are different bonding techniques that are available here we will briefly go over 3 of them. So 1 is the anodic bonding, the second 1 is fusion bonding, and the third 1 is eutectic bonding.

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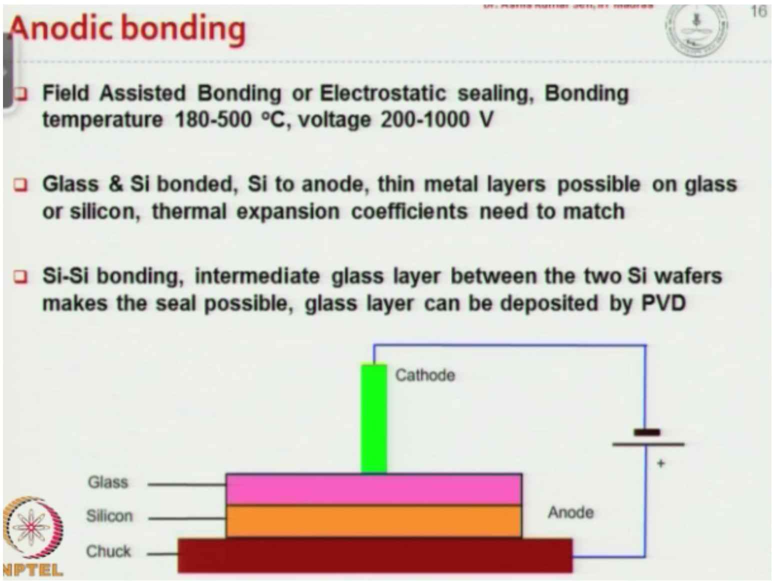

Anodic bonding

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- Field Assisted Bonding or Electrostatic sealing, Bonding temperature 180-500 °C, voltage 200-1000 V
- Glass & Si bonded, Si to anode, thin metal layers possible on glass or silicon, thermal expansion coefficients need to match
- Si-Si bonding, intermediate glass layer between the two Si wafers makes the seal possible, glass layer can be deposited by PVD

So this is anodic bonding as you can see here it is also known as field assisted bonding or electrostatic bonding as this uses electrostatic for the bonding action to take place. And typically the bonding temperature is between 180 to 500 degree centigrade, and the voltage is between 200 to 1000 volts. So in this technique glass and silicon can be bonded, as you can see in this picture, so this is the silicon substrate and this is the glass substrate.

Here the glass is connected to the negative electrode and the silicon is connected to the positive electrode. And when the voltage is applied, the atoms of glass and the silicon are the interface, they tend to penetrate to each other so we get a bonding that is taking place at the interface. Now what is required here is, in this case the thermal expansion coefficient of the materials that are bonded using anodic bonding have to be almost equal.

So glass and silicon have comparable thermal expansion coefficient, so they can be easily bonded using anodic bonding technique. Anodic bonding technique can also be used for bonding of silicon to silicon. So however in that case we would require an intermediate layer of glass between the 2 silicon wafers. So that would enable the bonding of them to achieve sealing.

And we can achieve a layer of glass on the surface of the silicon using for example physical vapour deposition technique.

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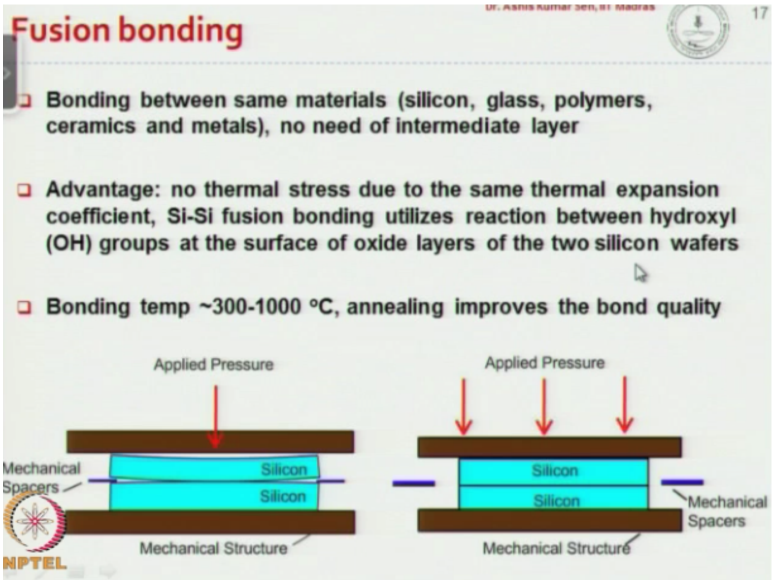

Fusion bonding

- Bonding between same materials (silicon, glass, polymers, ceramics and metals), no need of intermediate layer
- Advantage: no thermal stress due to the same thermal expansion coefficient, Si-Si fusion bonding utilizes reaction between hydroxyl (OH) groups at the surface of oxide layers of the two silicon wafers
- Bonding temp ~300-1000 °C, annealing improves the bond quality

Now if you look at fusion bonding, anodic bonding can be done between 2 different materials for example glass and silicon. However, the fusion bonding, in fusion bonding the 2 metal layers to be bonded have to be the same. So the fusion bonding is done between 2 same materials could be silicon, glass, polymers, ceramics and metals. So here there is no need for intermediate layer as opposed to anodic bonding.

In anodic bonding, we have seen that we need a layer of glass between 2 silicon wafers if we wanted to bond them, but here there is no need of intermediate layer. There are some advantages of this process, because we are talking about 2 similar materials, same materials, thermal stress is not a problem here, because they will have the same thermal expansion coefficient. And here you can see the example, there are 2 silicon wafers.

This is the top wafer, this is the bottom wafer and initially there are some mechanical spacers on both sides here. This is because to align this to silicon wafers, so that it can be moved related to each other. Once they are properly registered aligned with each other with very general pressure this alignment is done and once they properly aligned the mechanical spacers are taken out and the pressure is applied heavily to create bonding of the interface.

So what happens is that the bonding temperature is about 300 to 1000 degree centigrade. So the atoms of 1 substrate gets penetrated into another of the interface because of the high temperature and they fuse into each other, that is why it is known as fusion bonding. And the silicon to silicon fusion bonding basically utilises the reaction between hydroxyl groups at the surface of the oxide layer.

So silicon to silicon bonding would utilise the OH groups on the oxide layers on the top of the 2 silicon wafers. And after the substrates have been bonded we do an annealing process to improve the bond quality.

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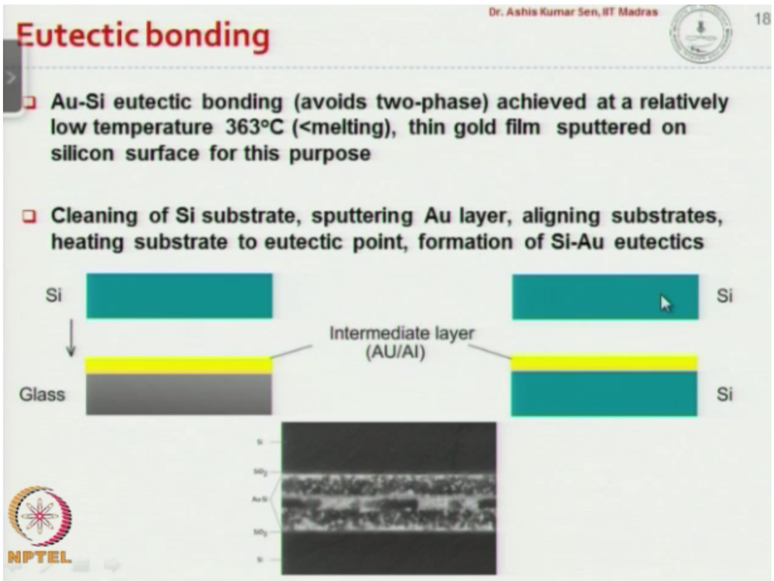

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Eutectic bonding

- Au-Si eutectic bonding (avoids two-phase) achieved at a relatively low temperature 363°C (<melting), thin gold film sputtered on silicon surface for this purpose
- Cleaning of Si substrate, sputtering Au layer, aligning substrates, heating substrate to eutectic point, formation of Si-Au eutectics

The third bonding technique is the eutectic bonding, in eutectic bonding is typically done at lower temperature less than the melting temperature. So here we do not have 2 different phases, before it starts melting the bonding is done, that is why it is known as eutectic bonding. So the temperature is less than the melting point temperature of the materials. Now in this case let us say we want to bond glass to silicon, silicon to glass if you want to bond.

So this eutectic bonding is to be done evaporate a thin layer of metal on the surface of the glass, for example gold and aluminium. So the steps, so the thin gold film is sputtered on the silicon surface to achieve eutectic bonding. So we clean the silicon substrate and then sputtered a layer of gold or aluminium and then we align the 2 substrate, the silicon and glass with respect to each other, and then apply pressure.

So when pressure is applied it forms an eutectic bonding at the silicon or silicon glass interfaces. So this is a photograph of eutectic bonding that has taken place between a silicon and silicon substrate. There is an oxide layer on the top of both silicons and there are gold also sputtered on both the silicon wafers, so at the interface the eutectic bonding is formed. So this eutectic bonding will be suitable when you are talking about electrodes on the surface.

Let us say we have a electrode which is very thick on the surface of the substrate, for example we have gold electrode or aluminium electrode, then the eutectic bonding can be suitable formed between the 2 substrate.

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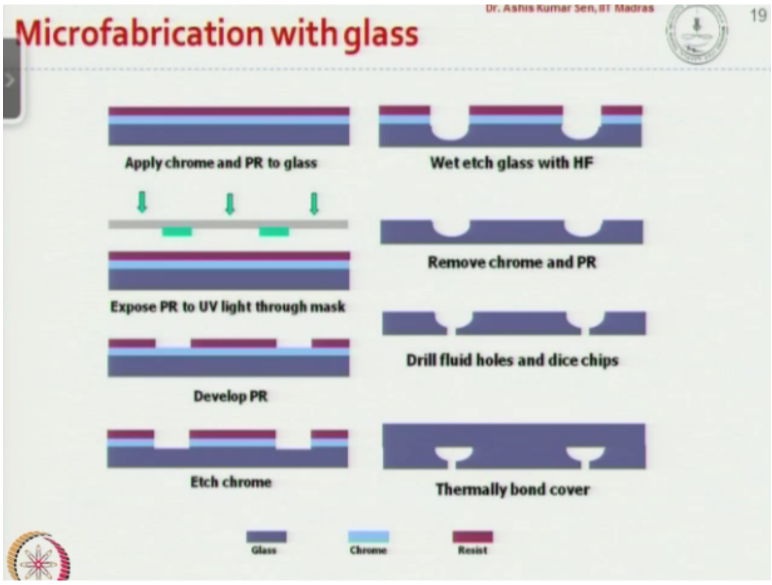

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Microfabrication with glass

Now let us talk about microfabrication with glass as we discussed in the beginning. Glass is a very good substrate for microfluidics application because in microfluidics, we deal with biological objects, and glass is biocompatible. So here how you can fabricate microfluidic devices using glass substrate, so this is an example. So we start with the glass substrate, so this is the glass substrate and we go through the photo lithography process.

However, the photoresist normally they do not stick with glass very well. So photoresist will not stick to glass, for that reason we evaporate a layer of chrome, a very thin layer of chrome of the order of nanometre on the surface of the glass and then we spin coat a layer of photoresist. So then depending on the channel structure we are going to achieve, we expose the photoresist to UV through a mask and then do the development process.

So after development we have a pattern of photoresist on the chrome coated glass surface, and then we etch the chrome layer, that we have used here as an additional layer between photoresistant silicon. So after removal of the chrome layer we do wet etching of glass with hydrofluoric acid. Now glass could be etched using hydrofluoric acid which is not very easy etchant to deal with. Hydrofluoric acid is a very dangerous liquid to handle.

So that is another reason why fabricating microfluidic device using glass substrate become very expensive as a manufacturing method. So once we etch glass with hydrofluoric acid, then we remove the chrome and the photoresist, so the chrome and photoresist layers are removed from the top and so we have created a channel, then we drill some holes to establish contact with the external fluidics.

Once the drilling of the holes is achieved, we dice the chips. As I have discussed before on a specific size of the substrate, we would have many such devices pattern depending on the size of the device and size of the substrate. So this etching of the channels are completed, we dice the wafers into individual chips and then we can thermally bond the cover. This could be done in many ways. You can first bond the cover and then dice it or dice it first and then individual chips could be bonded.

Here glass to glass bonding can be achieved using one of these three different techniques that we have discussed earlier, anodic bonding or protective bonding or perfusion bonding.

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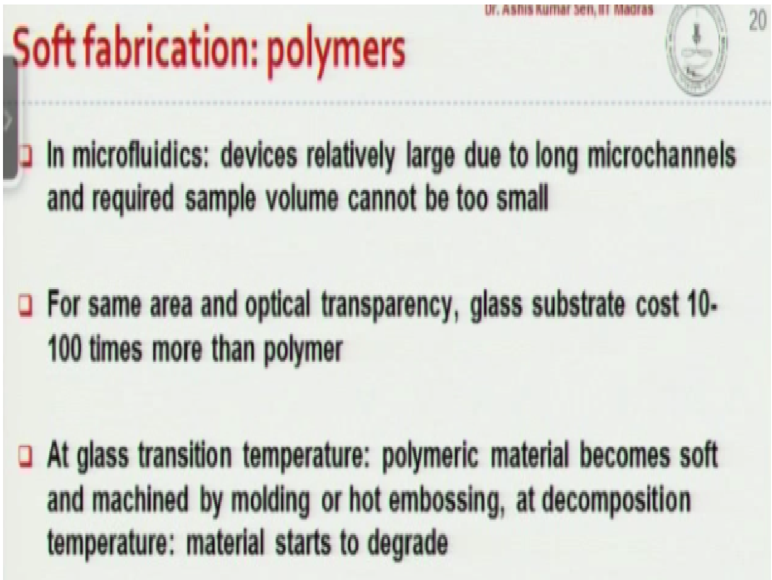

Soft fabrication: polymers

- In microfluidics: devices relatively large due to long microchannels and required sample volume cannot be too small
- For same area and optical transparency, glass substrate cost 10-100 times more than polymer
- At glass transition temperature: polymeric material becomes soft and machined by molding or hot embossing, at decomposition temperature: material starts to degrade

Now we move on to talk about polymers, how it can fabricate microfluidic device using polymers, which is also known as soft lithography. In microfluidics, the device sizes are relatively large if you compare with semiconductor fabrication in microfluidics, the device sizes are relatively large and this is because of the cross section of the microchannel and the length of the microchannel that we require to achieve a certain function inside the device.

The length and cross section of the microfluidic device are relatively large as compared to a semi conductor fabrication because the sample volume cannot be very small. There is always a minimum sample volume, which we discussed in the beginning of the lecture. There has to be a minimum sample volume for the kind of the function that we are performing on the chip. To satisfy that typically, the volumes are relatively large of the order of microliter to milliliter.

The device size in microfluidics is large, now if you compare the cost of glass versus polymer, the glass substrates for the same area and optical transparency, the glass substrate cost about 10-100 times more than polymer. So the polymers are very cost effective when we are comparing with glass and silicon. For the polymers, the glass transition temperature is very important. So at the glass transition temperature, the polymeric material will become soft.

By applying a force or a load, we can deform the polymer into the desire shape. So the polymeric material becomes soft and can be machined by molding or hot embossing if the temperature of the substrate can be increased beyond the glass transition temperature of the polymer. Another temperature to define for polymers is called decomposition temperature and if the temperature is increased for that high value, then if the temperature is of the order that decomposition temperature of the polymer, then the properties of the polymer are going to degrade.

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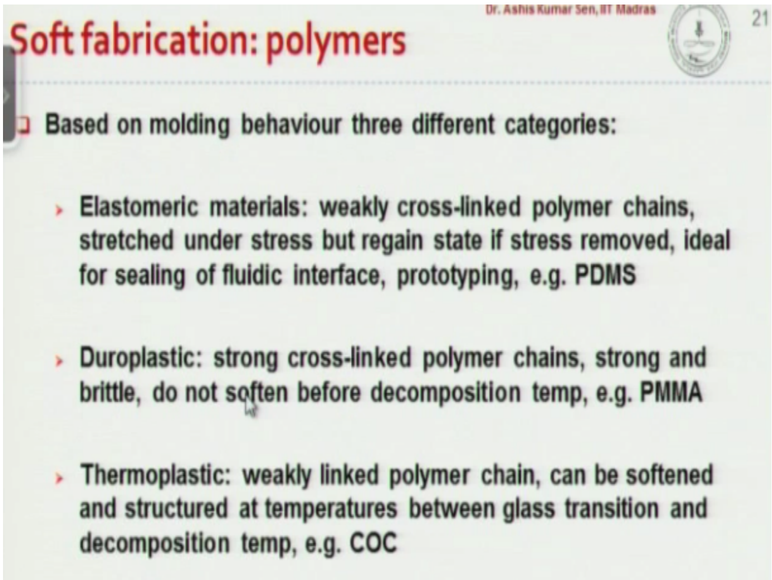

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Soft fabrication: polymers

- Based on molding behaviour three different categories:
  - Elastomeric materials: weakly cross-linked polymer chains, stretched under stress but regain state if stress removed, ideal for sealing of fluidic interface, prototyping, e.g. PDMS
  - Duroplastic: strong cross-linked polymer chains, strong and brittle, do not soften before decomposition temp, e.g. PMMA
  - Thermoplastic: weakly linked polymer chain, can be softened and structured at temperatures between glass transition and decomposition temp, e.g. COC

Now based on the molding behavior, the polymers could be categorized into three different categories. 1 is the elastomeric materials, second 1 is the duroplastic, and the third 1 is thermoplastic. So elastomeric materials, the example is PDMS, polydimethyl selection is the example of a polymer, which is elastomeric in nature, meaning the bonds are weakly cross linked. In the polymer, the bonds are weakly cross linked with each other.

By applying a load, the material can be stretched. What it exhibits is the material can be stressed under stress, but it will regain the state if the space is removed. For that reason, this elastomeric substance can be used for sealing of fluidic interfaces. For example, to make interconnection between the microfluidic device and external wall. PDMS is also used to create microfluidic device itself, for example for prototyping application.

The second category of polymer duroplastic, 1 example is PMMA and duroplastics are strong cross linked polymers. So if you compare, if you take a layer of polymer and PMMA, you compare in PMMA the chains are very strongly crossing, so we say harder substance as compared to PDMS. So it is strong and brittle and they do not soften before decomposition temperature.

They do not have a defined glass transition temperature where they can be soft and they become very soft only after the temperature increases beyond the decomposition temperature. The third category of polymers are thermoplastics. So thermoplastics have weakly linked polymer chains. It is little bit stronger than the elastomeric materials, but still weakly linked polymer chains and they can be softened between the glass transition and the decomposition temperature.

One of the examples of thermoplastic is COC, cyclic olefin copolymer and these materials can be softened if the temperature is between the glass transition temperature and the decomposition temperature. Whereas materials elastomeric materials like PDMS are normally soft.

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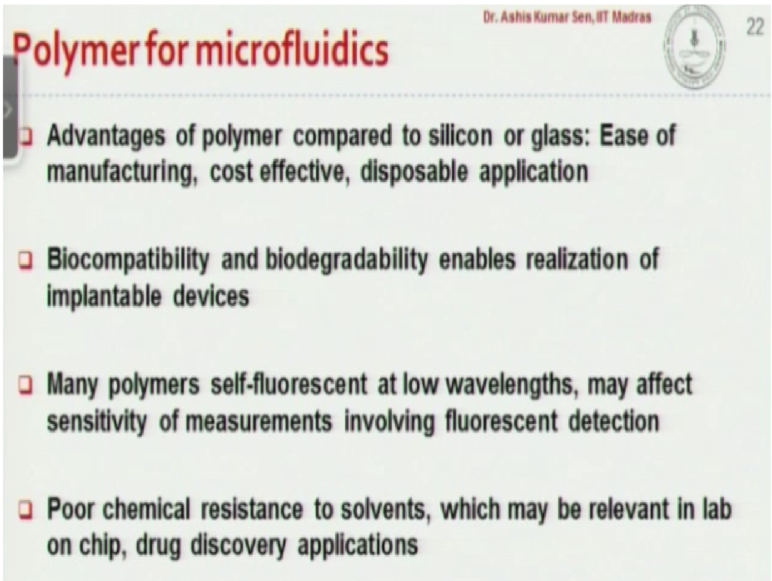

Polymer for microfluidics

- Advantages of polymer compared to silicon or glass: Ease of manufacturing, cost effective, disposable application
- Biocompatibility and biodegradability enables realization of implantable devices
- Many polymers self-fluorescent at low wavelengths, may affect sensitivity of measurements involving fluorescent detection
- Poor chemical resistance to solvents, which may be relevant in lab on chip, drug discovery applications

So here we outline some of the advantages of polymers as compared to silicon or glass that the manufacturing practice is much easier as compared to what we need to do using silicon or glass. Silicon requires a sophisticated setup to fabricate microfluidic devices using silicon wafer. Glass also requires expensive setup. It requires hydrofluoric acid based etching, so whereas polymers can be fabricated using inexpensive fabrication setup.

So the fabrication setup cost is less and the procedure is also easier to follow. Because of the cost issues since the polymers can be fabricated easily and cheaply, it is suitable for disposable applications. Polymers also, they have advantages in terms of biocompatibility and biodegradability, so they have proven to be used for implantable application. The two things here biocompatible means, they have to be compatible with biological substances with lift.

Biodegradable meaning they have to sustain over a period of time without degrading and oceaning the performance. So these are 2 important qualities of polymers, for which people have realized that for implantable application. Also many polymers are self, that is the downside of the polymers, that some of polymers like COC, PDMS, they are self fluorescing in nature. So if you are using a polymer microfluidic device in a situation where we have to deal with light or fluorescence.

We are majoring fluorescence, since the material itself is fluorescing in nature, it involves inaccuracy or it degrades the performance of the device and the other downside of polymer is poor chemical resistance to solvent, where silicon and glass are very good chemical resistance against solvents, polymers like PDMS, PMA and COC, they would degrade when subjected to corrosive chemicals and solvents. So that is another downside of polymers.

This may be important in different lab on chip and drug discovery applications where we will be talking about using different chemicals. With that let us stop. Next we will continue our discussion on different fabrication technique using polymer substrate.