MEMS & Microsystems

Prof. SantiramKal

Department of electronics & Electrical Communication Engineering

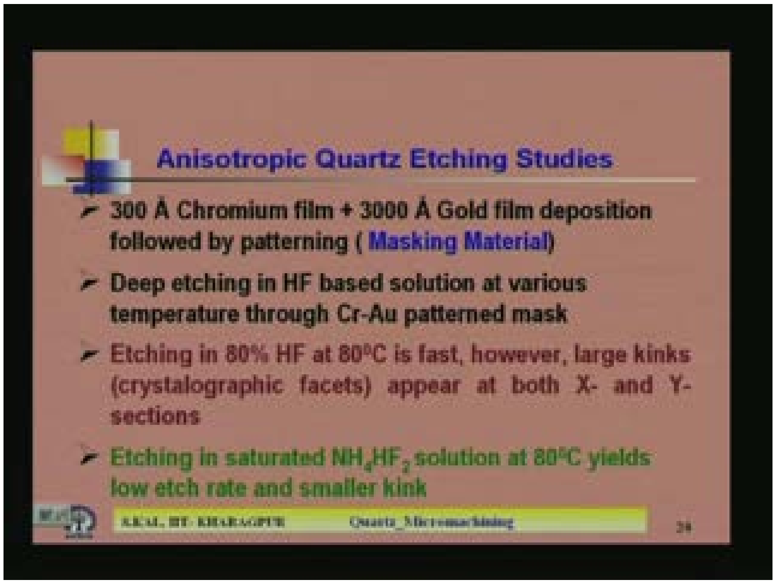
Indian Institute of Technology, Kharagpur

Lecture No. # 14

Fabrication of Micromachined Microstructure Devices

So we are talking about the etching solution, anisotropic etching solution of quartz. So one of the etching solutions used for micromachining quartz is hydrofluoric acid.

(Refer Slide Time: 00:57)



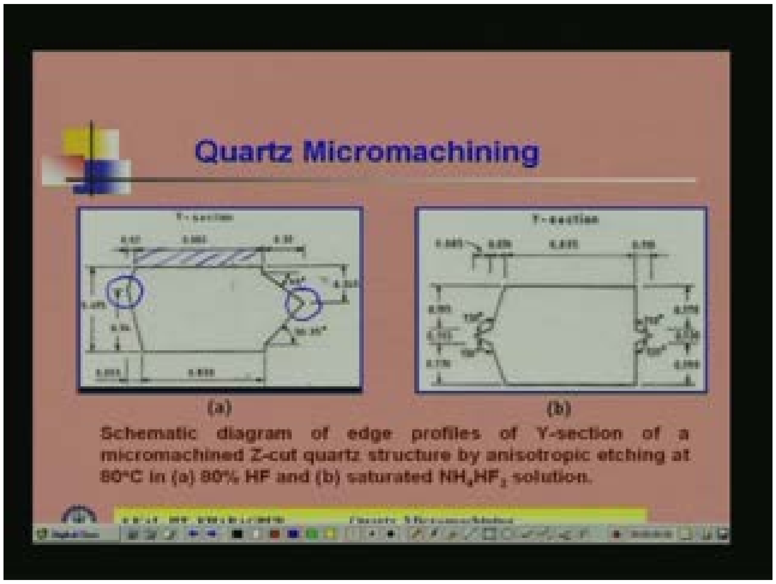
Anisotropic Quartz Etching Studies

- 300 Å Chromium film + 3000 Å Gold film deposition followed by patterning (**Masking Material**)
- Deep etching in HF based solution at various temperature through Cr-Au patterned mask
- Etching in 80% HF at 80°C is fast, however, large kinks (crystalographic facets) appear at both X- and Y- sections
- Etching in saturated NH_4HF_2 solution at 80°C yields low etch rate and smaller kink

S.KAL, IIT- KHARAGPUR Quartz_Micromachining 24

Etchant based solutions are normally used as an etchant for quartz micromachining and for that we used chromium gold as a masking material, chrome gold. Now one of the problem we face if we use only hydrofluoricacid is that it gives you some kind of crystallographic facet or kinks at the surface and if lot of facets and kinks are produced then the irregular structure of the quartz crystal will not be produced. In that case, if you use at a vibrator or the resonator, its frequency of oscillation or resonant frequency will change. Because resonance frequency of that crystal microstructure depends on its shape. For that reason we need the micromachining with regular feature vertical sidewall and lateral structure without any facet or kinks. For that another etching solution is used, that is ammonium fluoride $NH_4HF_2$and if you use at low temperature etching. Then etching will be very slow. But you can get rid of this crystallographic facets or kinks. So let us see,what the kinks that are produced in case of first are etching in hydrofluoric acid at higher temperature.

(Refer Slide Time: 02:50)

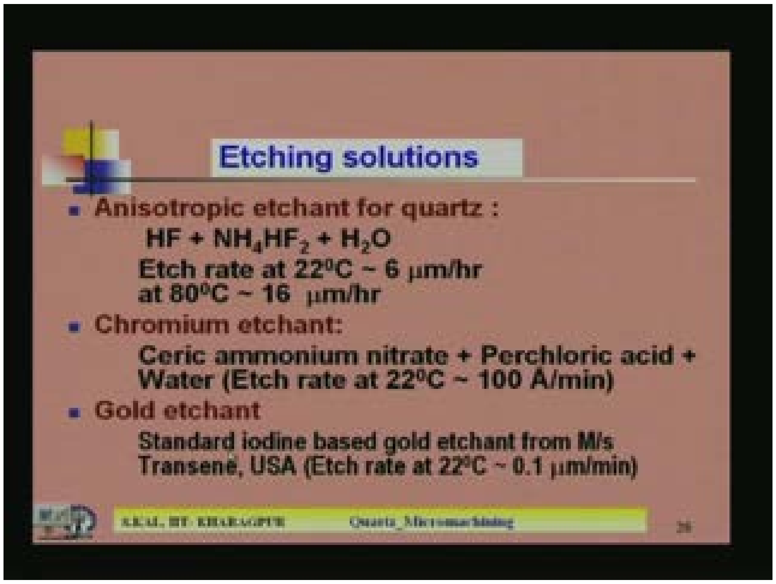


Quartz Micromachining

Schematic diagram of edge profiles of Y-section of a micromachined Z-cut quartz structure by anisotropic etching at 80°C in (a) 80% HF and (b) saturated NH_4HF_2 solution.

So here two crystals are shown. In the A you can see here, this is the masking layer. So this is the masking layer, we have produced here is a masking layer. So now it is going to etch here. So you get here some kinks, so this is the kink. Here this is the kink or it is known as the facet. It is because of the regular structureof the crystalloid crystal that is quartz crystal, it will produce like that. So this kind of things will disturb in yourperformance. If you use that the kink structured quartz in your piezoelectric sensorperformance will bea lot of deviation. Now if we use another etching solution which is saturated ammonium fluoride solution. If you use this solution, then you see in the left side B curve. So this kinks and facet size reduced into the small one. Here it was a large kink, here it is small kink and now at the same time if you go for low temperature etching, then those things almost will varies. Low temperature etching, the etch may be very slow. So you have to allow longer time etching and but you can get rid-off this kind of the problems which creates, which deviates the performance whichare really problematic in getting actual resonance frequency of this structure. As well as if you use that resonator in any of thetank circuit their Q value will not be very high.

(Refer Slide Time: 04:55)



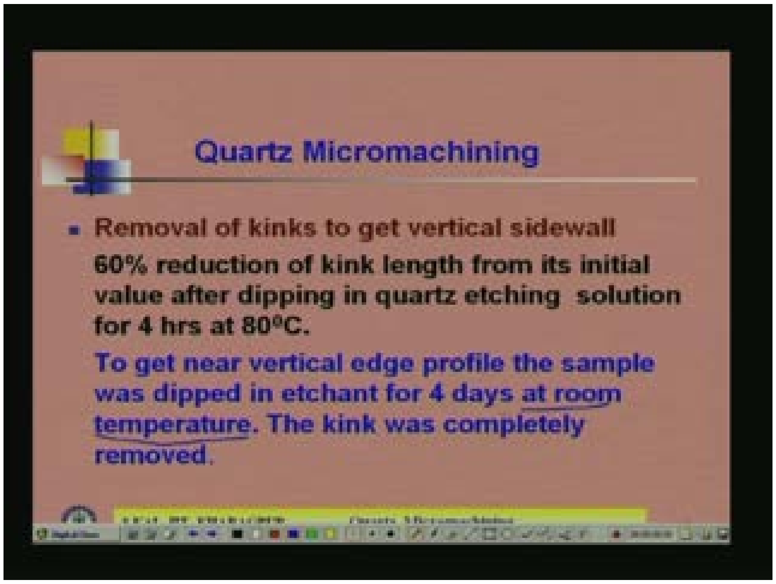
Etching solutions

- **Anisotropic etchant for quartz :**
  $HF + NH_4HF_2 + H_2O$
  Etch rate at 22°C ~ 6 μm/hr
  at 80°C ~ 16 μm/hr
- **Chromium etchant:**
  Ceric ammonium nitrate + Perchloric acid + Water (Etch rate at 22°C ~ 100 Å/min)
- **Gold etchant**
  Standard iodine based gold etchant from M/s Transenė, USA (Etch rate at 22°C ~ 0.1 μm/min)

Now here, what are the etching solutions that use the NH_4F, so the HF we take some amount then NH_4F_2,the ammonium fluoride plus H_2O and HF has been found at 22 degree centigrade means room temperature is 6 micrometer per hour and if you do the same etching at 80 degree centigrade, it is 16 micrometer per hour. So that means automatically in room temperature the etching is very slow. Chromium etchant to use because masking material is chromium gold. So you need etching gold as well as chromium also. For chromium we use ceric ammonium nitrate plus perchloric acid plus water. So ceric ammonium nitrate perchloric acid water mixture that will etch chromium with an etch rate of 100 angstrom per minute at room temperature, that is 22 degree Celsius. Then gold etchant we use here standard iodine based gold etchant from Transene in USA. That is one supplier who can supply lot of chemicals which is used in etchingof different kinds of materials.

So we have procured that gold etchant, that is an iodine based gold etchant and their etch rate at room temperature is 0.1 micrometer per minute. So these are the etching solutions for masking material as well as quartz which has been standardized in IIT Kharagpur, the quartz micromachining laboratory. So those parameters rate will bit changed depending on your temperature we use or depending on the chemical concentration you use. But overall principle will not change and the etch rate will be close to those values. So in any of the laboratory before you start any process of quartz MEMS, you have to standardize each etching step. Either, mask material etching step or quartz material etching step that you have to standardize, then you can go for a complete MEMS fabrication process.

(Refer Slide Time: 07:25)



Quartz Micromachining

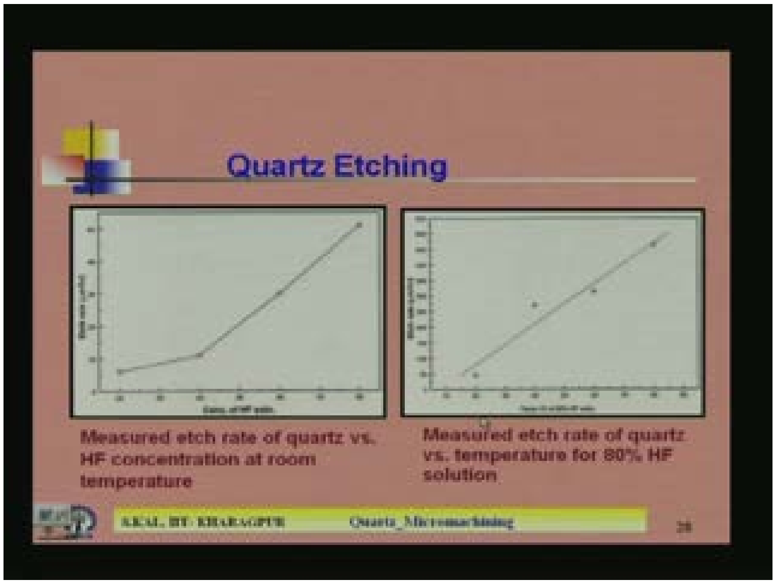
- Removal of kinks to get vertical sidewall

  60% reduction of kink length from its initial value after dipping in quartz etching solution for 4 hrs at 80^{0}C.

  To get near vertical edge profile the sample was dipped in etchant for 4 days at room temperature. The kink was completely removed.

Now just we can conclude here that removal of kinks to get vertical sidewall is an important issue. 60 percent reduction of kink length from initial value after dipping in quartz etching solution for 4 hours at 80 degree centigrade to get near vertical edge profile. This sample was dipped in etchant for 4 days at room temperature, kink was completely removed. That is very important you can see here, that kink was completely removed. But how much time, it took nearly 4 days. So that means etch rate is very slow at room temperature, we are using at room temperature. At room temperature for 4 days, it will take for the complete removal of the kinks on etching of the quartz is nearly said50 angstrom or 50 micron or 100 micron. That alsothe time also depend on how much thickness wafer you are taking. So that wafer which we are using in our laboratorythat is the 100 micrometer thick quartz wafer and that takes this amount of time.

(Refer Slide Time: 08:45)



Quartz Etching

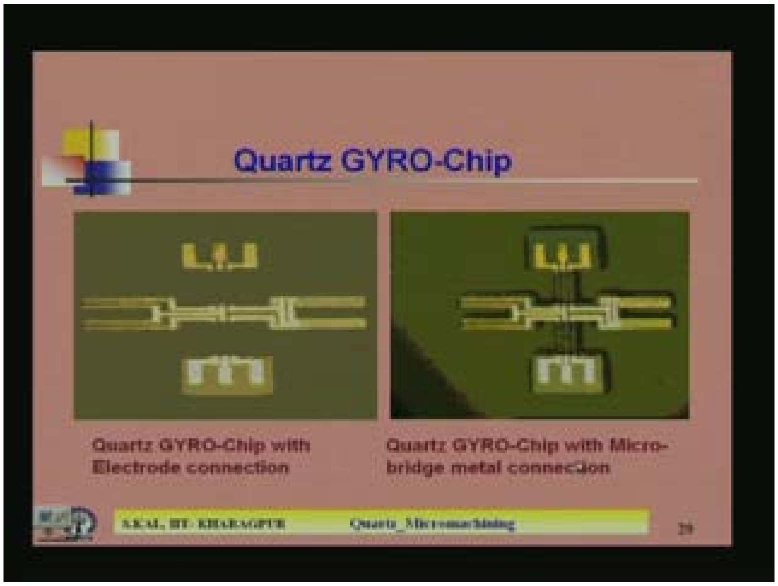
Measured etch rate of quartz vs. HF concentration at room temperature

Measured etch rate of quartz vs. temperature for 80% HF solution

S.KAL, IIT- KHARAGPUR Quartz_Micromachining 28

Now these are some standardized. For standardization you have to go for the etch rate measurement of our different concentration of hydrofluoric acid or different temperature of the hydrofluoric acid solution. So with temperature, the plot is here and with concentration the plot is here from there you can choose your data.

(Refer Slide Time: 09:10)



Quartz GYRO-Chip

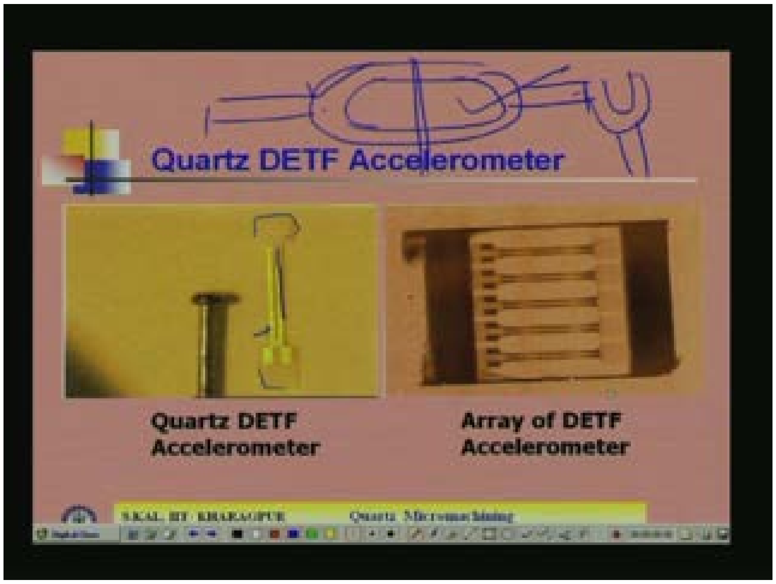
Quartz GYRO-Chip with Electrode connection

Quartz GYRO-Chip with Micro-bridge metal connection

S.KAL, IIT- KHARAGPUR Quartz_Micromachining 29

Now these are the some of the structures which has been fabricated in our laboratory using quartz micromachining technology. This is a GYRO chip with electrode connection. These are the electrodes. So details principle of the GYRO chip, I will discuss in in MEMS sensor lecture not here. So the structuresI am showing here, so you can see the white region things are the electrodes here. Also gold electrodes are visible. Micro bridges are there, you can seehere thickness and there thickness of the quartz is different. This particular region the thickness of the quartz is different compared to this region. This is thicker and this is a micro bridge. Here is 1 micro bridge here is another micro bridge we have found. So one that mean automatically you can get a step and metal line will go here. Then is step then it will go down there. Then it will go up, then again.So that means this step over. That metal lines will pass, so that is a really, is a tuff and critical technology to make the metal electrode interconnection. But with lot of effort we are able tofabricate not only the quartz structure as well as the electrodes and the results are also encouraging.

(Refer Slide Time: 10:42)



Quartz DETF Accelerometer

Quartz DETF Accelerometer

Array of DETF Accelerometer

S.KAL, IIT- KHARAGPUR Quartz Micromachining

Now the another structures which we make out of the quartz sensor, that is the dual ended tuning fork.So here you can see this is the quartz structure and there are all five pieces are there and on that this glossy thing here is the metal. This is the gold metal you are using for electrode. This is a gold metal and this is also gold metal and the shaded thing is basically the quartz. The whole piece of quartz, how it is etched and isbasically dual tuning fork. So tuning fork all of you know its structure is similar to that. Now if you connect one tuning fork like this, this structure if you made, so you cut it here. So here is one thing and here is another thing. So that means is similar to that. This side is held and this side also held. So if you cut separately here, soanotherone tuning from here, another tuning from here.

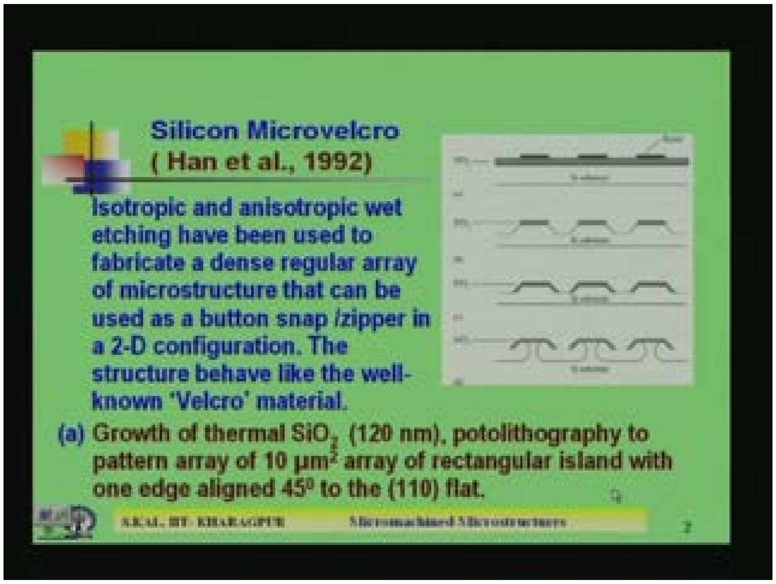
So it is a dual tuning fork is connected from this side. So this will act as a resonator or this will act as an acceleration sensor also. So the basic principle of the resonance or accelerationsensor will be discussed in MEMS device in MEMS sensor class not here. Here just I showed you the structure which has been made in our quartz micromachining laboratory. So with this,the quartz micromachiningI will not discuss more. SoI will now switch over to some other topic and that is the various microstructure fabrications using the micromachining technology. So, some of these structures alreadyI discussed and now I will continue some othermicrostructure which can be fabricated.
(Refer Slide Time: 13:28)

Fabrication of Micromachined Microstructure Devices

Santiram Kal
Department of Electronics & ECE
Indian Institute of Technology
Kharagpur – 721302
E Mail: srkal@iitkgp.ac.in

So fabrication of micromachining microstructure devices, few devicesI mentioned in my last lecture. So that is the microvelcro, the condenser microphone. Those are very simple structure full standing polysilicon cantilever beam. So nowI will go for a little bit complicated structure MEMSmicrostructures which are used as a device also, that I will discuss now.

(Refer Slide Time: 13:55)



Silicon Microvelcro (Han et al., 1992)

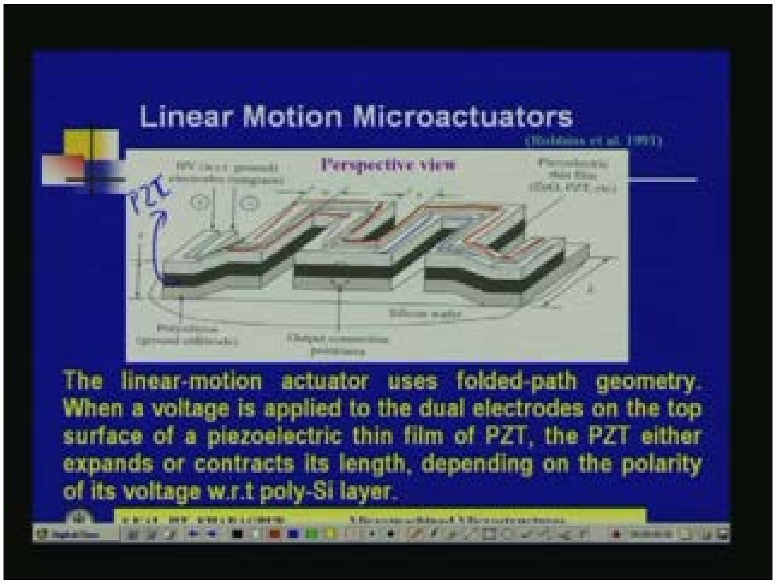
Isotropic and anisotropic wet etching have been used to fabricate a dense regular array of microstructure that can be used as a button snap /zipper in a 2-D configuration. The structure behave like the well-known 'Velcro' material.

(a) Growth of thermal SiO_2 (120 nm), potolithography to pattern array of 10 μm^2 array of rectangular island with one edge aligned 45^0 to the (110) flat.

S.KAL, IIT- KHARAGPUR Micromachined Microstructures 2

So first one is a microvelcro already we have discussed.

(Refer Slide Time: 14:00)



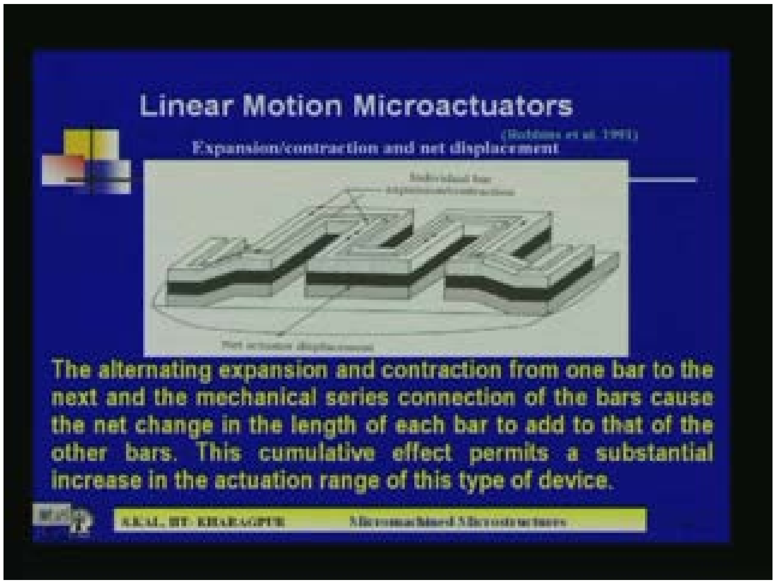
Linear Motion Microactuators

The linear-motion actuator uses folded-path geometry. When a voltage is applied to the dual electrodes on the top surface of a piezoelectric thin film of PZT, the PZT either expands or contracts its length, depending on the polarity of its voltage w.r.t poly-Si layer.

Linear motion microactuators. So let us spend some time on the linear motion microactuators. So sensor can sense andactuator can act something that we have seen. So that means some kind of theattraction or some kind of repulsion kind of thing in a microstructure. If it does by applying some electrical signal, so then it is called an actuator. So similar thing can be made using the micromachining process and applying some innovative ideas. So here is an example of the microactuator which is made out of the piezoelectric thin film, which is zinc oxide or PZT. So here you can see the actuator uses folded path geometry. When a voltage is applied to the dual electrodes, on the top surface of the piezoelectric thin film of PZT, the PZT either expands or contracts it length depending on the polarity of its voltage with respect to poly silicon layer. Where is the PZT material?In the black region, here is the PZT material here. This is the PZT; you can see this is the PZT you can use, zinc oxide instead of PZT.So now you have used some folded path geometry. That means some kind of structure folded path like this. It is coming here, then is here, then it is coming here, then here, here, like that.

So you are increasing the length. So you seethere is another geometry is there, so that is you can see it is coming like this. Now one is the blue color and another is, this one. Now you see both of the structure vertically its form on the PZT or zinc oxide material and now one thing is there. If the PZT or zinc oxide, the piezoelectric material if you apply some voltage with respect to a ground plane. So then what will happen? So because of the inherent nature of the material there will be some contraction. If it contracts, so then what will happen? So if the film tries to contract, the whole thing can be stretched. Becauseit is a folded structure or it can be either stretched or it can be compressed. So both are possible. The bottom is the poly silicon layer, the poly silicon ground plane, that is the poly silicon ground plane here, the hashed line here this is a poly silicon ground plane. Now if you apply with respect to the poly silicon ground plane, positive voltage is here and here negative. So depending on positive and negative you can change for actuation either contraction mode or is a repulsion mode you can make it. So that has been done here to get the microactuator and let us see how it can be done.

(Refer Slide Time: 17:32)



Linear Motion Microactuators

(Robbins et al. 1991)

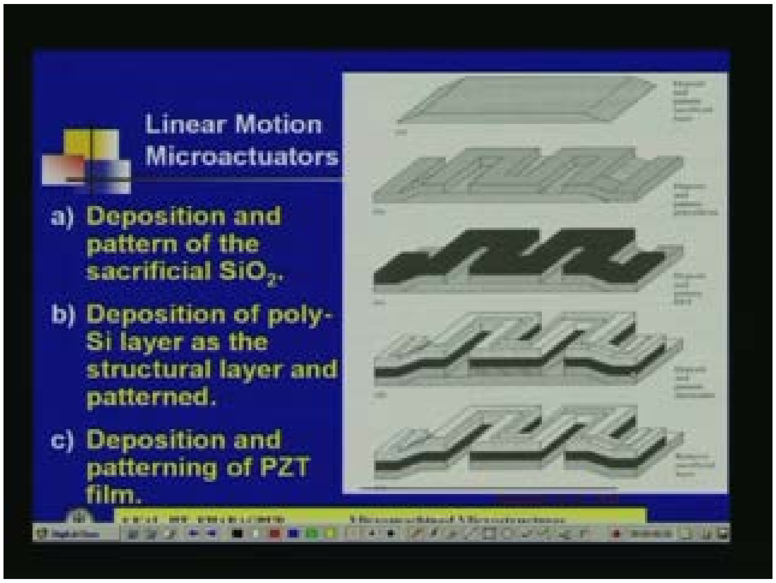
Expansion/contraction and net displacement

The alternating expansion and contraction from one bar to the next and the mechanical series connection of the bars cause the net change in the length of each bar to add to that of the other bars. This cumulative effect permits a substantial increase in the actuation range of this type of device.

S.K.LAL, IIT- KHARAGPUR Micromachined Microstructures

The alternating expansion and contraction from one bar to the next and the mechanical series connection of the bars cause the net change in the length of each bar to add to that of the other bars. This cumulative effect permits a substantial increase in the actuation range of this type of device. That is the basic principle. These two layers you see, this layer and this layer either it expands or contract and length has been added. So that the total, it is connected in the series the bars, so that you can get a substantial amount of increase and contraction. So that complete thing the whole structure can some mechanical movement you can get the from this structure. So that is the objective of that.

(Refer Slide Time: 18:29)



Linear Motion Microactuators

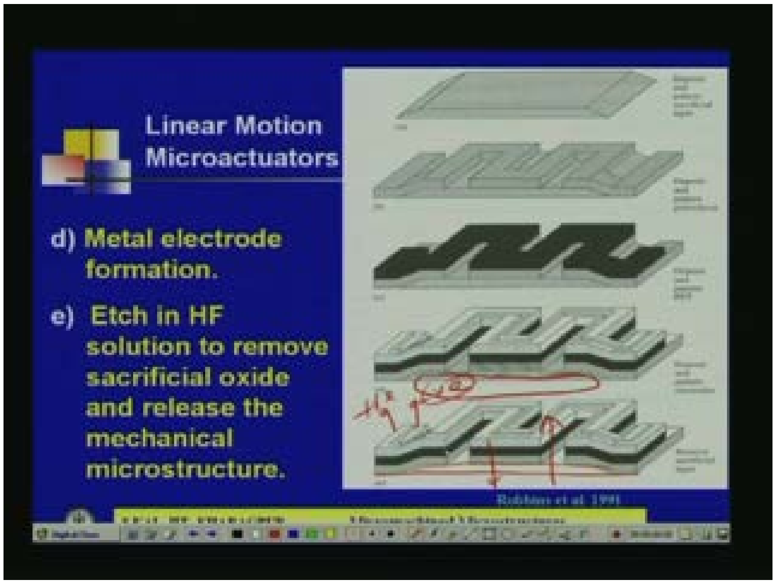
a) Deposition and pattern of the sacrificial SiO_2.

b) Deposition of poly-Si layer as the structural layer and patterned.

c) Deposition and patterning of PZT film.

So now these are the process steps of how do we make it so another first step? First step is thedeposit and patterns sacrificial layer depositional pattern of the sacrificial layer silicon dioxide. So that is the silicon dioxide layer first we made it.Then deposit and pattern of poly silicon. So you just poly silicon made it and then you pattern it. After making the pattern then the PZT film, the black one is a PZT film. Deposit PZT film then you pattern it. This oxide is a sacrificial layer. So if you remove it, so bottom thing will be whole. So when you contract, so there will be space so that it can get some space for movement. At the end stage you will find so bottom is etched then you will get some open space, so that through that most movement there is also possible. Now here after the patterning of this PZT film then you go for theelectrode formation. Because the black region is basically the PZT. Then on top of that you are getting the electrode formation.

(Refer Slide Time: 20:05)



Linear Motion Microactuators

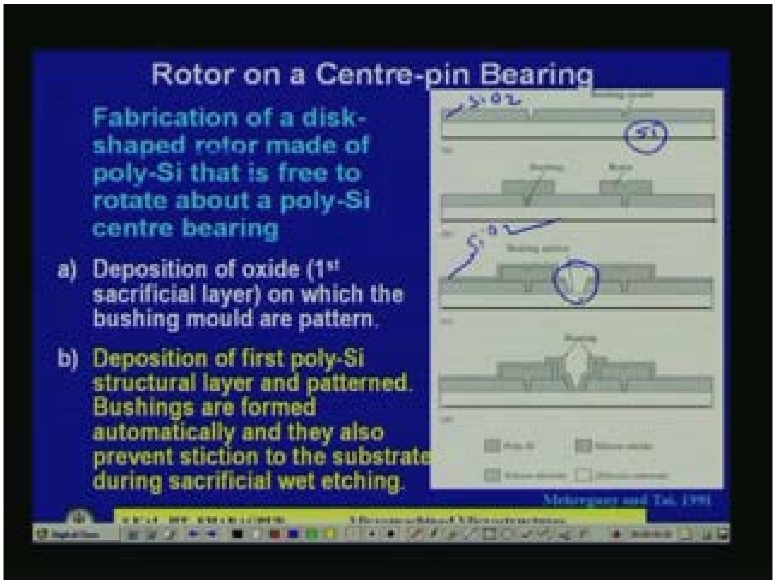
d) Metal electrode formation.

e) Etch in HF solution to remove sacrificial oxide and release the mechanical microstructure.

Robbins et al. 1991

Metal electrode formation, depositor pattern material electrode. Then last step here is the etch in hydrofluoric acid solution to remove the sacrificial oxide release the mechanical structure. You see, this particular layer which is oxide is not here. This oxide, complete oxide is removed so that you will get if you draw a line here, then there is an open space here. So when it contract or expand, so whole structure may go down or it can go up. Because you are applying electric filed either here positive or here negative. This is the one electrode, this is another electrode. If you do like that then the whole thing it can just contract some mechanical motion you can create and for that bottom you are aligning certain,top there are obviously some space is there. So bottom also we align some space, so that when goes down, so this kind of mechanical movement you can allow and it can get some space. So this is linear motion microactuator which may be fabricated following the steps.

(Refer Slide Time: 21:33)



Rotor on a Centre-pin Bearing

Fabrication of a disk-shaped rotor made of poly-Si that is free to rotate about a poly-Si centre bearing

a) Deposition of oxide (1st sacrificial layer) on which the bushing mould are pattern.

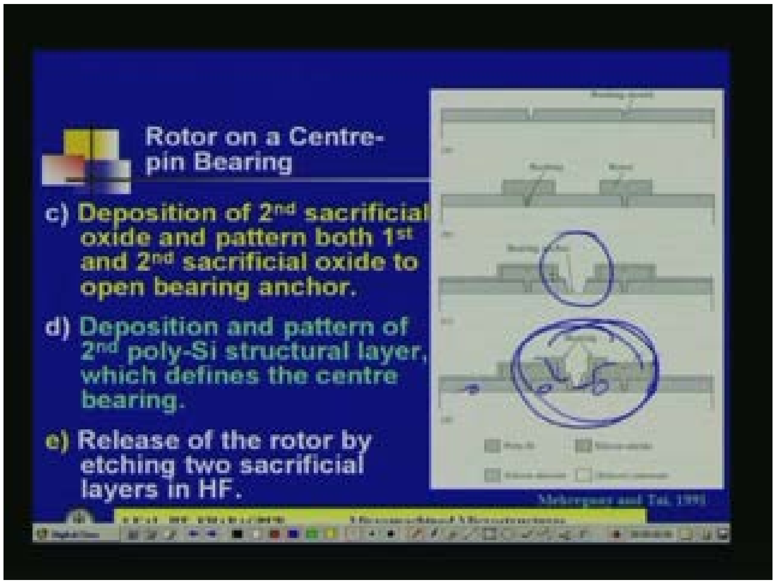
b) Deposition of first poly-Si structural layer and patterned. Bushings are formed automatically and they also prevent stiction to the substrate during sacrificial wet etching.

Mehregany and Tai, 1991

Now another example nowI will discussrotor on a center pin bearing is another mechanical structure which may be made using the micromachining technology, rotor on a center pin bearing. So a center point bearing will be there a structure will rotate basedon that bearing. That is used in many of the joints links whichI have showed in the introductory on MEMS. Many such structure there you need lot of the bearings. So there are lot of rotation motion is also required in many of the microactuators. So how it can be made? Disc shape rotor made of poly silicon and that rotor is free to rotate about a poly silicon center bearing. Now let us look into the steps, so first this isthe silicon material you took. You take silicon material and then it deposit oxide. This is the oxide silicon dioxide. On silicon dioxide you make some masking you go for some masking layer and then you etch little group here which is the bushing mold.

So after formation of that, then you go for poly silicon deposition and pattern which will be your structural layer. Because you are making therotor using the poly silicon. Poly silicon you were using, so this poly silicon is deposited and patterned. Now this is the case here. What is the that? That is the bushing point and it is a rotor point. Now you have to make the bearing anchor. So for making the bearing anchor, then again you have to go for deposition of some masking materialthat is here you deposited. That is that oxide silicon dioxide again and then you pattern. So you just get the space for anchor. This is the space for anchor. Bearing anchor space is opened and the rest of the regions are closed with silicon dioxide. Now what you did? Againyou deposit here, the poly silicon. You deposit poly silicon here then again you pattern it so that bearing structure is found.

(Refer Slide Time: 24:50)



Rotor on a Centre-pin Bearing

c) Deposition of 2nd sacrificial oxide and pattern both 1st and 2nd sacrificial oxide to open bearing anchor.

d) Deposition and pattern of 2nd poly-Si structural layer, which defines the centre bearing.

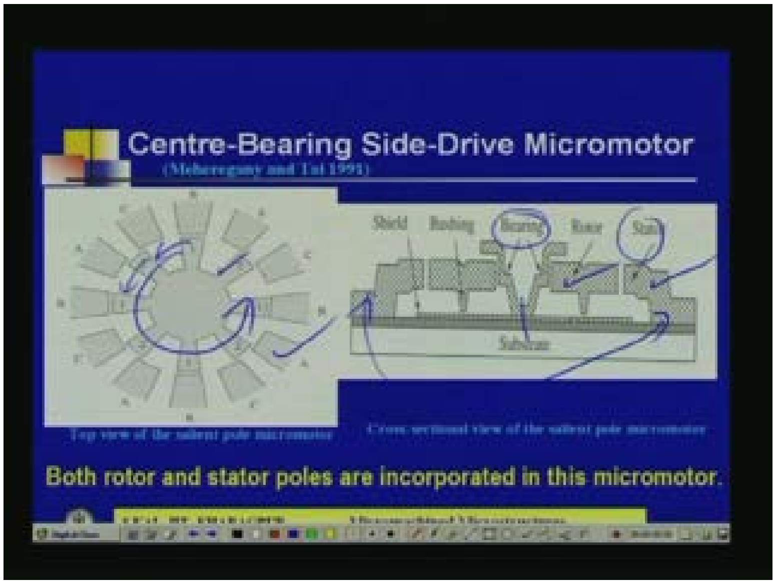
e) Release of the rotor by etching two sacrificial layers in HF.

Mehregany and Tai, 1991

Now, CDE are shown here C is here. So bearing deposition and patterning of second poly silicon structural layer which defines the center bearing. So the center bearing has been defined here. These are definition of center bearing, then release of the rotor by etching two sacrificial layers in etchant. So you see, after that what you did? You released two sacrificial layer; one is this sacrificial layer. This portion, this portion, this portion and this portion. So then if you remove that, so that means, this is the bearing and this structure willbeopen because you are removing this also. Then it will rotate here, you will get some hole,so that means two free structure which can rotate like this and the over the bearing this center bearing this area.

It iswhen you release that sacrificiallayer, the whole thing the poly silicon, the bear center pin bearing as well as the side the rotor are free now to move. So how we will rotate it by, how we will actuate the rotation? That is different story whether you apply some electric field or you joint, you can make some metal and thenusingsomejustattraction or repulsion by using attraction or repulsion electrostatically, that is a different story. But this structure you can form like that, by just themicromachining means, here we used again the surface micromachining process. So this is the free rotor and a center bearing. So this is one kind of thing which you can make.

(Refer Slide Time: 27:10)



Centre-Bearing Side-Drive Micromotor

(Mehregany and Tai 1991)

Top view of the salient pole micromotor

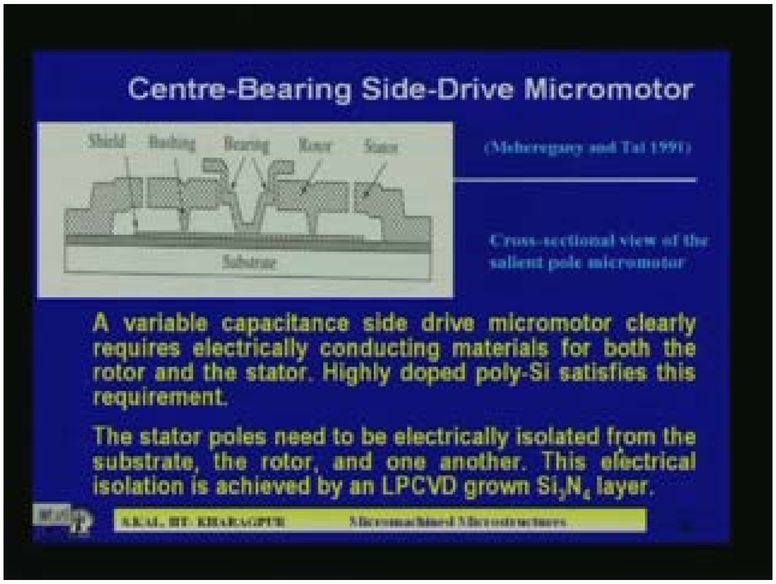
Cross sectional view of the salient pole micromotor

Both rotor and stator poles are incorporated in this micromotor.

Now we can go for some other structure, center bearing side-drive micromotor. Center bearing side drive micromotor is that is the very complicated structure. Bearing is a central and side drive and these are the stator, these are stator, this is the bearing, these two are the rotor. So this portion at the bushing material, this is the anchor. Anchor is here, so this is the bearing, this is a stator and this is also stator. These two are stator and this will rotate with a rotor on the bush and this is the bearing. This is the cross section view of the salient pole micromotor and here is the top view of the salient pole micromotor. So here these are the rotor and this is the stator ABC,ABC, ABC, ABC, these are the state stators this thing and these things are same. Now in a central is a rotor, this one and this one is there is 1 2 1 2 1 2 1 2.

Now the whole thing, the complete bearingsurrounding that and this bearing it will rotate and for rotation, the stator is there. In the stator you apply certain field. You have to make some electrode arrangements, so that the field will be more and more from A to B and B to C. So that here if you apply the positive and there one into negative. So this negative willattract towards the positive side. So there will be a little bit moment in this direction. Then again the much more field movement is in this direction. So once you started moving like that, so then it starts rotating if you apply the gradient field in that stator. So that is the basic thing and the structure is the cross sectional structure is shown in this diagram. Now let us see how this can be made steps.

(Refer Slide Time:29:28)



Centre-Bearing Side-Drive Micromotor

(Mehregany and Tai 1991)

Cross-sectional view of the salient pole micromotor

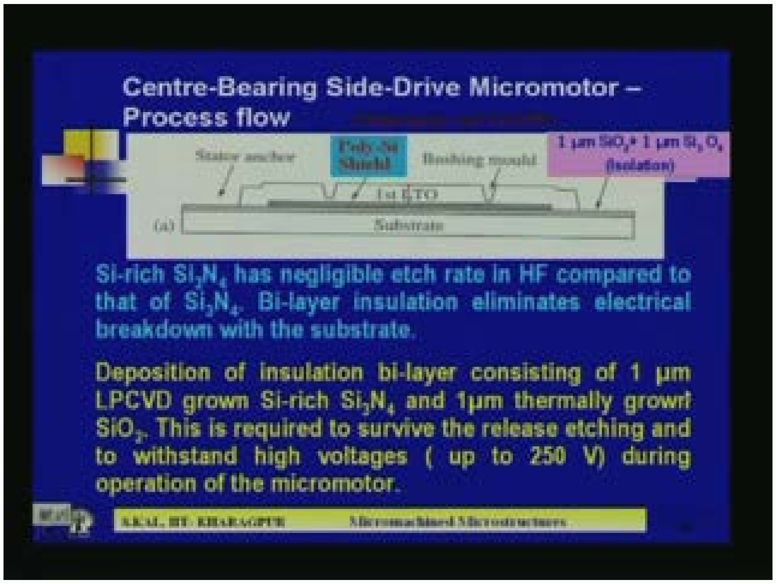
A variable capacitance side drive micromotor clearly requires electrically conducting materials for both the rotor and the stator. Highly doped poly-Si satisfies this requirement.

The stator poles need to be electrically isolated from the substrate, the rotor, and one another. This electrical isolation is achieved by an LPCVD grown Si_3N_4 layer.

S.KAL, IIT KHARAGPUR Micromachined Microstructures

A variable capacitance side drive micromotor clearly requires electrically conducting materials for both the rotor and the stator. Highly doped poly silicon satisfies this requirement. Stator and rotor you need some conducting. Because you are going to, this is actuated by using certain field. So it has to be some conducting material. Fortunately the poly silicon if you dope heavily, so that will work as a conducting material. Because, if you use some metal film, so their stability will be less compared to the polysilicon. Polysilicon stability is more compared to any of the metal frames. Either it is aluminum or some aluminum silicon or some copper or some other thing. So that is why they choose the doped polysilicon as a conducting material and the rotor and stator are both made of doped polysilicon. The stator poles need to be electrically isolated from the substrate, the rotor and because stator and rotor they have to be electrically isolated. This is the stator, this stator and this rotor must be electrically isolated. This electrical isolation is achieved by LPCVD grown silicon nitride. So this is one shield which is thewith the separation is the LPCVD grown silicon nitride is used as a shield material which will isolate the stator and rotor. So now process steps are shown here.

(Refer Slide Time:31:17)



Centre-Bearing Side-Drive Micromotor – Process flow

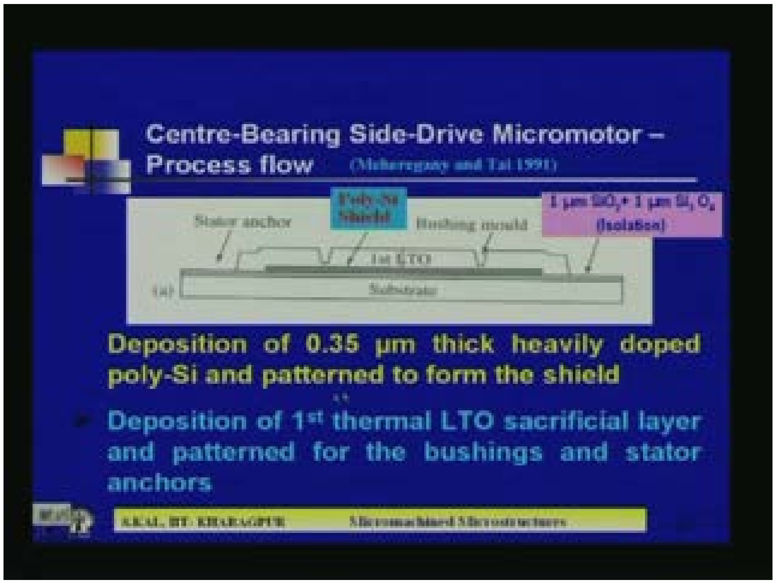
Si-rich Si_3N_4 has negligible etch rate in HF compared to that of Si_3N_4. Bi-layer insulation eliminates electrical breakdown with the substrate.

Deposition of insulation bi-layer consisting of 1 µm LPCVD grown Si-rich Si_3N_4 and 1µm thermally grown SiO_2. This is required to survive the release etching and to withstand high voltages (up to 250 V) during operation of the micromotor.

S.KAL, IIT KHARAGPUR Micromachined Microstructures

What are the steps? First they have used silicon substrate, then the anchor material for stator. What is that? That is a 1 micron silicon dioxide plus 1 micron silicon nitride. That will be Si_3O_4 sorry SiO_2 and Si_3silicon nitride N_4. So silicon dioxide and silicon nitride here is a stator insulating anchor. Then after that what you did, the polysilicon shield you have made something here. Then you go for first LTO low temperature oxide. This is silicon, LTO means low temperature oxide. This material is basically SiO_2. So on that first LTO you just pattern it so that you will get the bushing mould. So this kind of bushing mould you can pattern here. So this is a bi-layer you have used here. The silicon dioxide and silicon nitrate LPCVD grown that is the insulation bi-layer. Then you go for because thissilicon dioxide, silicon nitride, bi-layer structure has been used to withstand high voltage because a stator and rotor in between the voltage may go up to 250 volts. So that is why not all the oxide, oxides and nitrate combination has been used. So nearly 250 volt you can get it. It can withstand and after that you go for patterning other layers.

(Refer Slide Time: 33:11)



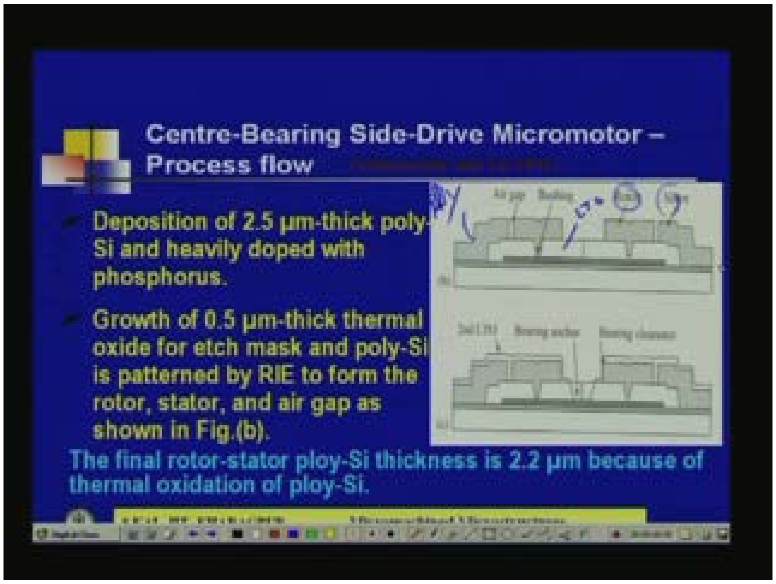
Centre-Bearing Side-Drive Micromotor – Process flow (Mehregany and Tai 1991)

Deposition of 0.35 μm thick heavily doped poly-Si and patterned to form the shield

- Deposition of 1st thermal LTO sacrificial layer and patterned for the bushings and stator anchors

Heavily doped polysilicon pattern is to form the shield. That is completed deposition of first thermal LTO sacrificial layer and pattern for the busing and stator anchors. So that these anchors are here stator anchor and here you can see here.

(Refer Slide Time: 33:36)



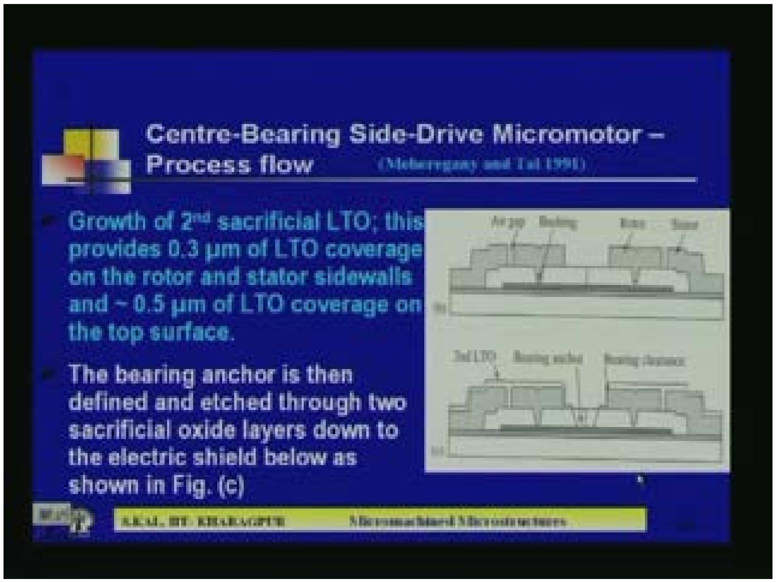
Centre-Bearing Side-Drive Micromotor – Process flow

- Deposition of 2.5 μm-thick poly-Si and heavily doped with phosphorus.
- Growth of 0.5 μm-thick thermal oxide for etch mask and poly-Si is patterned by RIE to form the rotor, stator, and air gap as shown in Fig.(b).

The final rotor-stator ploy-Si thickness is 2.2 μm because of thermal oxidation of ploy-Si.

So deposition of 2.5 micron thick poly silicon is heavily doped with phosphorous. Poly silicon are heavily doped with phosphorous,growth of 0.5 micron thick thermal oxide for etch mask and poly silicon is patterned by RIE to form the rotor, stator and air gap as shown in figure b. So here you can see, so this is the thermal oxide here and now the mask polysilicon. There is patterned by reactive ion etching to get the separate becausehere the total thing is there. So this is LTO where this is poly has been patterned so that now you can get the rotor and stator separately isolatedand in between the air gap. This is the air gap, to the air gapthen some air gap had been allowed here because the polysiliconthe rotation the temperature may increase. So in that case you have to allow certain space. So that it can freely move. So after that, what has been done is a second LTO. After this is a second LTO is there here. This portion is secondly in low temperature oxidation is filled by that by CVD technique and then you have to go for the sacrificial etching.

(Refer Slide Time: 35:33)



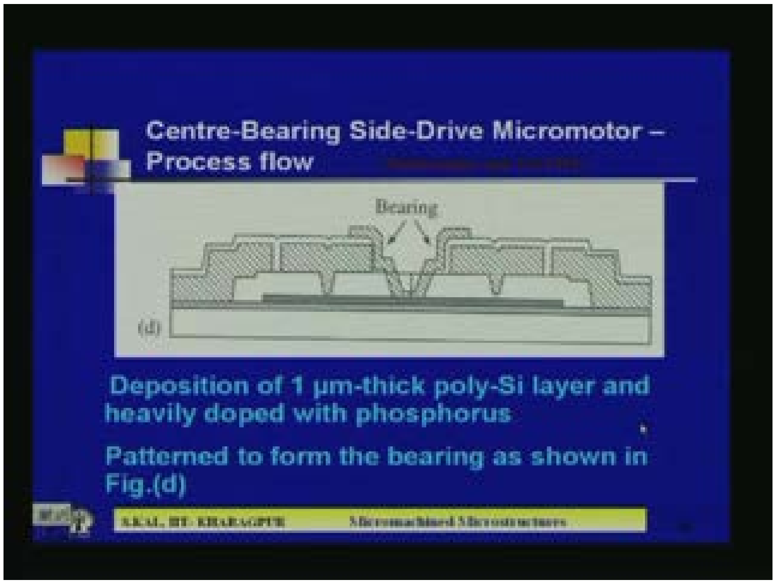
Centre-Bearing Side-Drive Micromotor – Process flow (Mehregany and Tai 1991)

- Growth of 2nd sacrificial LTO; this provides 0.3 μm of LTO coverage on the rotor and stator sidewalls and ~ 0.5 μm of LTO coverage on the top surface.
- The bearing anchor is then defined and etched through two sacrificial oxide layers down to the electric shield below as shown in Fig. (c)

A.K.M., IIT- KHARAGPUR Micromachined Microstructures

Second sacrificial LTO which are shownthere, the second sacrificial LTO is here. This provides 0.3 micron of LTO coverage on the rotor and stator sidewalls and 0.5 micron of LTO coverage on the top surface. The bearing anchor is then defined and etched through two sacrificial oxides down to the electric shield below as shown here. So now the bearing anchor will be defined means, it has to be sacrificial oxide which is formed by LTO. That is removed, then you will get this LTO sacrificial layer will be removed and you get the total structure here and here. Whereas if you remove this portion,if you remove this portion, this portion, this portion and this portion and then you will have the free structure which will be free, this will be free and this will be free after removing that. So that is done in the next step.

(Refer Slide Time: 36:39)



Centre-Bearing Side-Drive Micromotor – Process flow

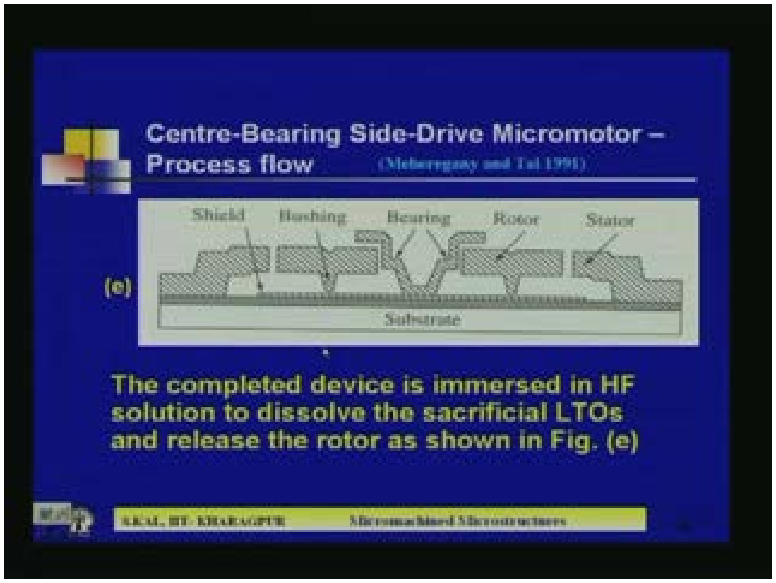
Deposition of 1 µm-thick poly-Si layer and heavily doped with phosphorus

Patterned to form the bearing as shown in Fig.(d)

S.KAL, IIT- KHARAGPUR Micromachined Microstructures

Here and then the bearing material is deposited 1 micron thick polysilicon layer and heavily doped with phosphorus. That patterned to form the bearing as shown in figure d. This bearing is found at the end step and then you will get the complete structure here.

(Refer Slide Time: 36:57)



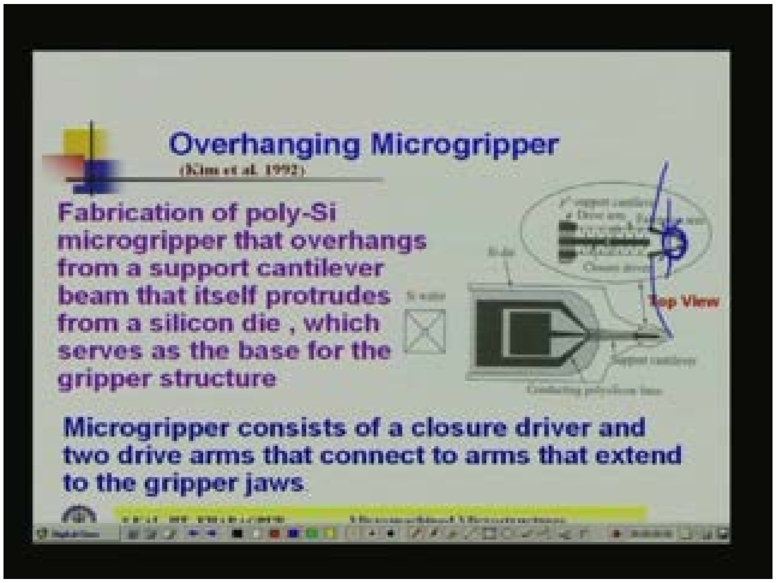
Centre-Bearing Side-Drive Micromotor – Process flow (Mehregany and Tai 1991)

The completed device is immersed in HF solution to dissolve the sacrificial LTOs and release the rotor as shown in Fig. (e)

S.KAL, IIT- KHARAGPUR Micromachined Microstructures

The computed device is immersed in hydrofluoricsolution to dissolve the sacrificial. All LTOs and release the rotor as shown in figure e. So this is the step by step you have togive little bit concentration on each step, how the structure is formed by subsequent lithography and etching to get the ultimate structure. That is a side drive micromotor and in that picture we will see many of the MEMS articles the electrically different micromotor using the MEMS technique surfacemicromachining technology. This is the process steps we used for getting such structures.

(Refer Slide Time: 37:51)



Overhanging Microgripper

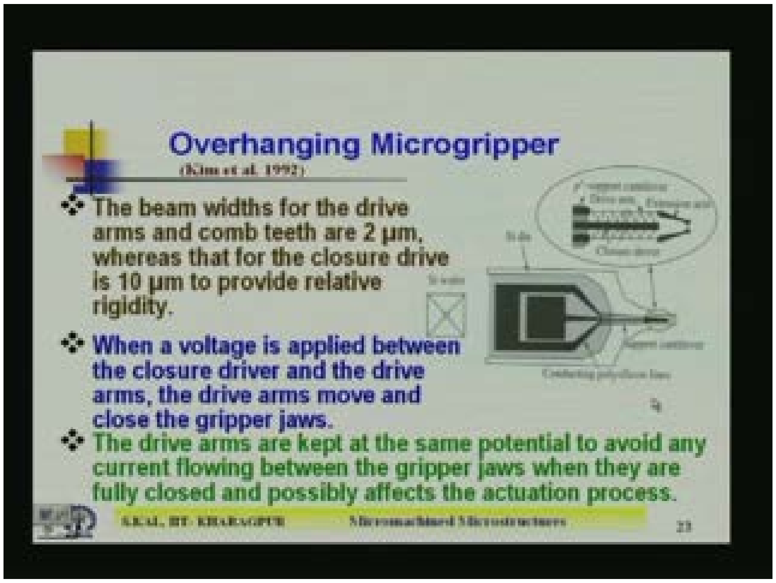
(Kim et al. 1992)

Fabrication of poly-Si microgripper that overhangs from a support cantilever beam that itself protrudes from a silicon die , which serves as the base for the gripper structure

Microgripper consists of a closure driver and two drive arms that connect to arms that extend to the gripper jaws

So nowI will discuss anothermicrostructure device. That is known as overhangnigmicrogripper. Because many time you have to hold some small things using some grip in case of actuation actuator mechanism. So that microgripper particularly used in micro robots. So there also whole technology is not so simple, difficult some of the salient pointsI will just mention here. If you look into the diagram then again the actuation is basically done with the help of some electrical actuation basically.Now here the microgripper is made of poly silicon and it overhangs over a, this is gripper you can see here. This exploded view exploded of this portion is shown here, this portion is shown here. Now you see here, there are three structures. If you minutely look into these structures, there in central there is a cantilever. This is one cantilever, top there is a drive arm which is fixed with thisbottom, there is another drive arm here which is fixed with this and in the center there is a cantilever. Now the basic mechanism is that you made lot of the electrode finger like electrodes are here.

Now you apply the field. Howyou can apply? The central the cantilever at certain potential, positive potential and then the upper support and bottom support. If you apply negative, so then what will happen? They will attract each other. So these are the electrode configuration now when it attract. So this will go down and this also will go down, go up, this will go up, say the upper and lower will be attracted by the middle one. When upper and lower is attracted by the middle one, then these things, so you can see. Now then this will go up and this will also go down. So as a result of which here gripping will be there it will hold just electric filed actuation so the total structure looks like this. So this is the microgripper, it consists of a closer driver. That is a the closure driver is shown and two drive arms that connect to arms, that extent to the gripper jaws, this is the gripper jaw. These this is one arm and this is another arm. Those are connected to a gripper jaw. This is a gripper jaw. So now this structure how can you fabricate, that some stepI will show you.
(Refer Slide Time:41:08)



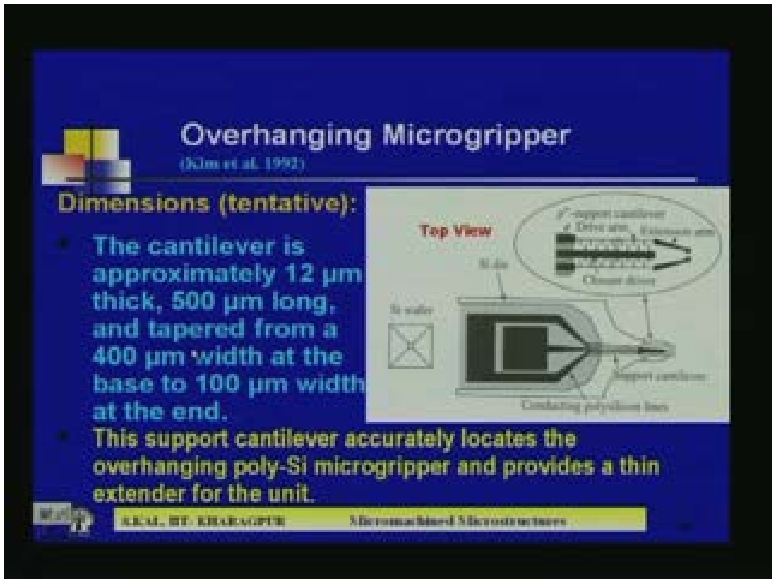
Overhanging Microgripper

(Kim et al. 1992)

- The beam widths for the drive arms and comb teeth are 2 μm, whereas that for the closure drive is 10 μm to provide relative rigidity.
- When a voltage is applied between the closure driver and the drive arms, the drive arms move and close the gripper jaws.
- The drive arms are kept at the same potential to avoid any current flowing between the gripper jaws when they are fully closed and possibly affects the actuation process.

The beam width for the drive arms and comb teeth are 2 micrometer. These are comb teethhere. It shown comb teeth, they are 2 micrometer. Whereas that for the closure drive is 10 micrometer to provide a relative rigidity. That is basically the closure drive, is a 10 micrometer width of this is 10 micrometer and this comb teeth are 2 micrometer,10 and 2. So that it will be much rigid. When a voltage is applied between the closure driver and the drive arms closure driver and the drive arm, the drive arms move and close the gripper jaws. You applying voltage then the closure, the drive arms will move and is close the gripper jaws. The drive arms are kept at the same potential to avoid any current flowing between the gripper jaws. That is very important. The upper and bottom the gripper jaws, so if they are on same potential there should not be any current flowwithin them, no current flow. So that has to be maintained and if there are current flowing through the jaws, it can affect the actuation process. That is why these two are maintained in the same potential.

(Refer Slide Time: 42:49)



Overhanging Microgripper

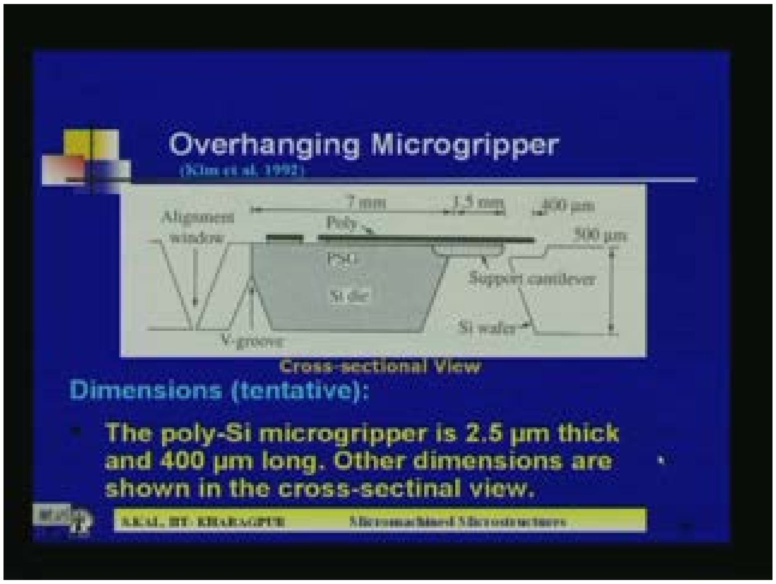
(Kim et al. 1992)

Dimensions (tentative):

- The cantilever is approximately 12 μm thick, 500 μm long, and tapered from a 400 μm width at the base to 100 μm width at the end.
- This support cantilever accurately locates the overhanging poly-Si microgripper and provides a thin extender for the unit.

Now the tentative dimensions are shown here. The cantilever is approximately 12 micrometer, thick 500 micron long. This cantilever is a 500 micron long,12 micron thick and tapered from a 400 micrometer width at the base to 100 micron width at the end, so this is tapered. Here is a 400 micrometer and to coming here is a 100 micrometer. Here is a 400 and coming to 100. So if you go like this.

(Refer Slide Time:43:49)



Overhanging Microgripper

(Kim et al. 1992)

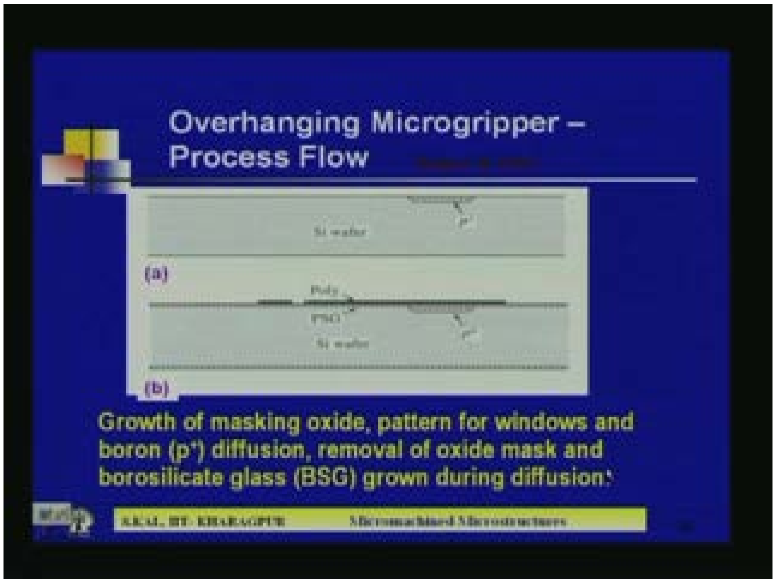
Cross-sectional View

Dimensions (tentative):

- The poly-Si microgripper is 2.5 μm thick and 400 μm long. Other dimensions are shown in the cross-sectinal view.

So this isthe finalform of the overhanging microgripper. Polysiliconmicrogripper is 2.5 micrometer thick and 400 micrometer long. Other dimensions are shown in the cross sectional view here. So from here it is a 7 millimeter,1.5 millimeter. So from this point to 400 micrometer,from here this is millimeter, from here to here is a 400 micrometer. So all these are v group, these are silicon die PSG is a phosphosilicate glass a support cantilever is here, so these are cross sectional view is shown here.

(Refer Slide Time: 44:36)

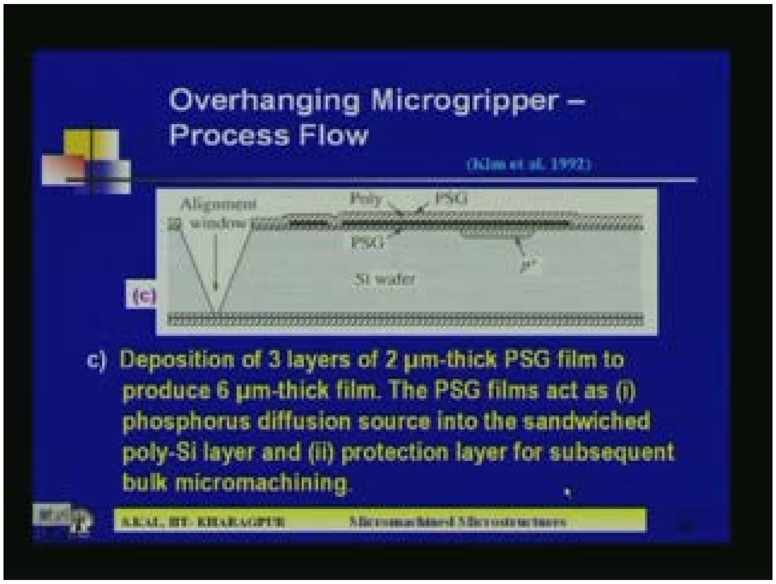


Overhanging Microgripper – Process Flow

Growth of masking oxide, pattern for windows and boron (p^+) diffusion, removal of oxide mask and borosilicate glass (BSG) grown during diffusion:

Now a process flow, how do you proceed? So first they are taking a silicon wafer, then diffuse p plus region and remove the oxide mask and borosilicate BSG. After p plus then the PSG this is a phosphosilicate glass is deposited in insulating layer, the polysilicon length, the poly silicon is patterned. After patterning poly silicon, then you gofor the deposition of the patterned polysilicon by RIE. This RIE poly silicon is patterned by RIE in CCL 4 plasma. At this step it defines the patterns of the gripper on the conducting lines. The poly silicon on the backside of wafer is removed subsequently. So because when we deposited the polysilicon, it will be there in the backside also. So after patterning this one, back side poly silicon is completely removed then comes this structure.

(Refer Slide Time: 45:42)



Overhanging Microgripper – Process Flow

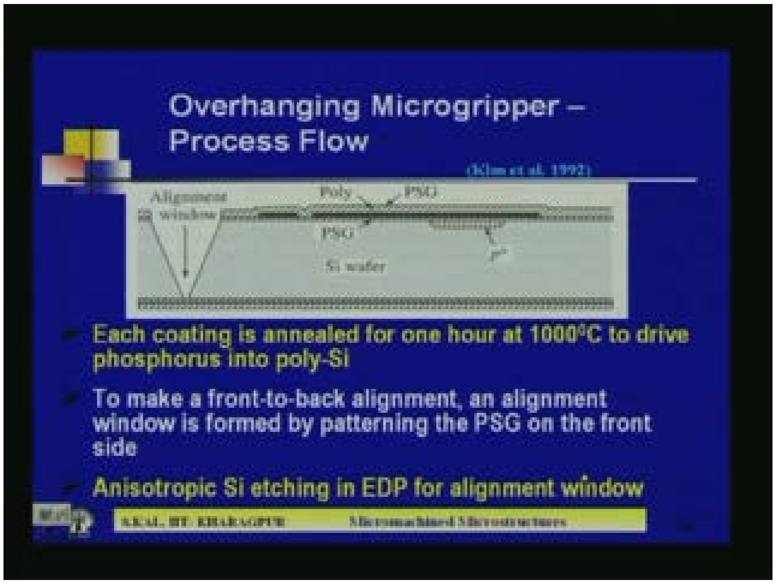
(Kim et al. 1992)

c) Deposition of 3 layers of 2 µm-thick PSG film to produce 6 µm-thick film. The PSG films act as (i) phosphorus diffusion source into the sandwiched poly-Si layer and (ii) protection layer for subsequent bulk micromachining.

S.KAL, IIT KHARAGPUR Micromachined Microstructures

Here deposition of 3 layers of 2 micron thick PSG, then the thicker PSG film will deposit to produce 6 micron thick film. The PSG films here acts as phosphorous diffusion source into the sandwiched poly silicon layer. PSG means phosphorous doped silicon glass. From there you can get the phosphorous diffusion in the underneath silicon layer then protection layer for subsequent bulk micromachining, that also because it is an insulating layer. So subsequent bulk micromachining step it will act as an insulated mask as well as it will act as a diffusion source for subsequent diffusion.

(Refer Slide Time: 46:33)



Overhanging Microgripper – Process Flow

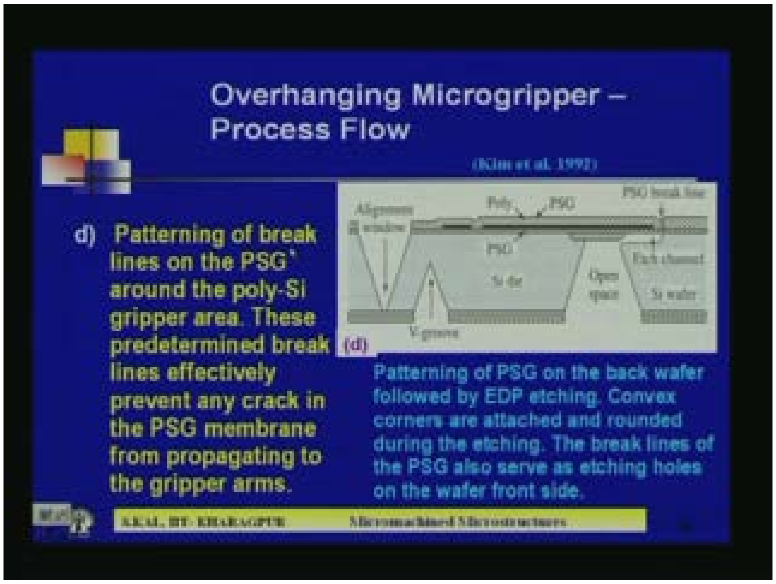
(Kim et al. 1992)

- Each coating is annealed for one hour at 1000°C to drive phosphorus into poly-Si
- To make a front-to-back alignment, an alignment window is formed by patterning the PSG on the front side
- Anisotropic Si etching in EDP for alignment window

S.KAL, IIT KHARAGPUR Micromachined Microstructures

So that is the step, then we go for the etching of coat. Coating material etch coating is annealed for 1 hour for 1000 degree centigrade to drive phosphorous into poly silicon. So from poly silicon phosphorous is driven to higher depth to make a front to back alignment and alignment windows is formed by patterning the PSG on the front side. Anisotropic silicon etching in EDP for alignment windows. So these are alignment windows, so a silicon wafer is etched by EDP.

(Refer Slide Time: 47:08)



Overhanging Microgripper – Process Flow

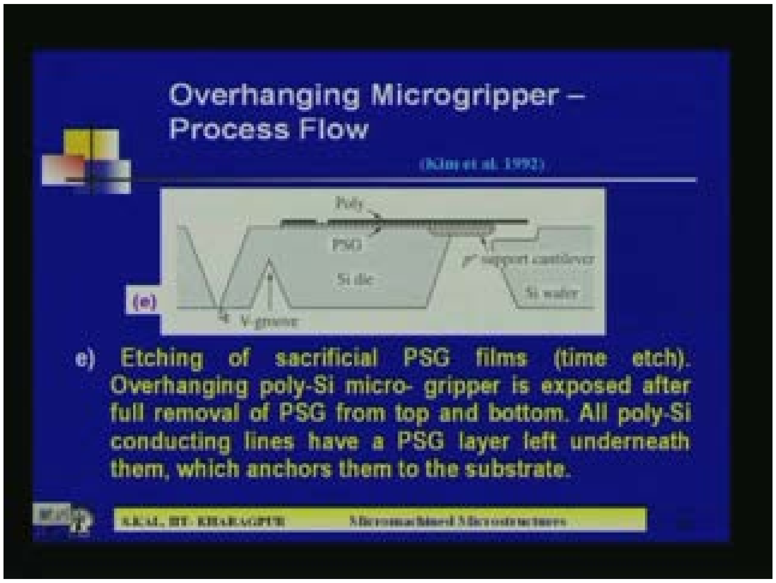
(Kim et al. 1992)

d) Patterning of break lines on the PSG* around the poly-Si gripper area. These predetermined break lines effectively prevent any crack in the PSG membrane from propagating to the gripper arms.

Patterning of PSG on the back wafer followed by EDP etching. Convex corners are attached and rounded during the etching. The break lines of the PSG also serve as etching holes on the wafer front side.

So now the last step here patterning of break lines. So because if you make many devices you have to make a,that is scribe line basically break line on the PSG around silicon gripper area. This means effectively any crack in PSG membrane from propagating to the gripper arm. So in many cases when you break, lot of micro cracks may appear and those cracks sometime propagate into a device and which willmake the device not usable. So that is why in many of thesemicrostructure devices some of the breaking lines are etched. So that easily we can separate without drilling much into the substrate. So that is why at the end step, always some break line is etched. So thatat the end you can easily separate those at those break line so that individual devices we will get it.

(Refer Slide Time: 48:23)



Overhanging Microgripper – Process Flow

(Kim et al. 1992)

e) Etching of sacrificial PSG films (time etch). Overhanging poly-Si micro- gripper is exposed after full removal of PSG from top and bottom. All poly-Si conducting lines have a PSG layer left underneath them, which anchors them to the substrate.

S.KAL, IIT- KHARAGPUR Micromachined Microstructures

So in this way you can get the structure and you can separate it. So like this here if the etching of sacrificial PSG film time etches overhanging poly silicon microgripper is exposed after full removal of PSG from top and bottom. All poly silicon conducting lines have a PSG layer left underneath them which anchor them to the substrate.

(Refer Slide Time: 48:54)

S.KAL, IIT- KHARAGPUR Micromachined Microstructures 32

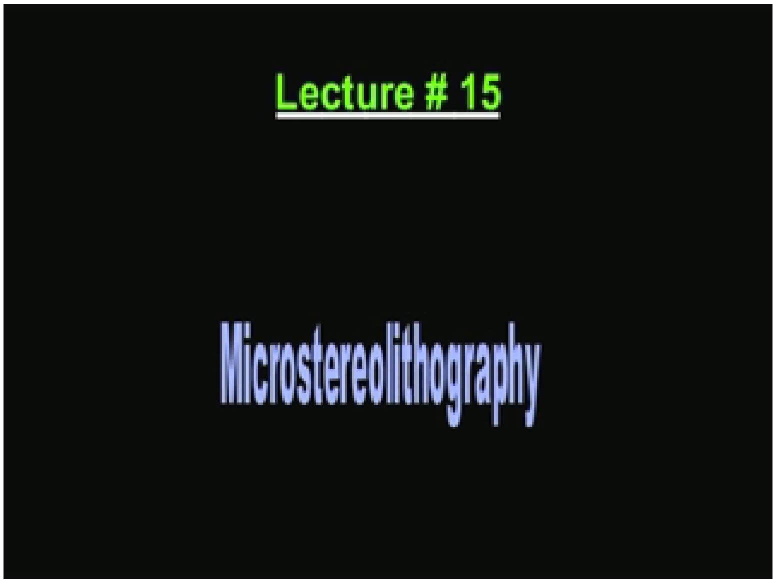
So with this we will getthe complete microgripper structure. Basically the microgripper structures and the micromotor; stator and rotor. Rotor at the same time fabrication, these two particular micro structure devices is not so simple. You have to give much more concentration to understand each layer. How the etching is taking place? So by now I hopeI have discussed many of the microstructure. Structures using surface micromachining process which have got direct application in many of the devices. I will not continue the micromachining chaptermicromachining topics further. So now onwards we will concentrate on microsensors and devices from next lecture. Thank you very much.

(Refer Slide Time: 49:51)

Preview of Next Lecture

Preview of the Next Lecture.

(Refer Slide Time: 50:02)



Lecture # 15

Microstereolithography

So we discuss today on microstereolithography which has not been covered in either your bulk or surface micromachining class or you have not come across this particular topic in you VLSI technologic course. So this is a lithography means basic principle of lithography is there. That means you are getting some structure from mask level on to the wafer level. But here we will not use any mask. This kind of structure fabrication is without using any mask. So that is why it is all together a new andbasically innovative technique of fabrication of various kinds of microstructure which is being used now a days.

Not only in silicon MEMS but also in polymer or ceramic or composite material MEMS and in my last lecture on materials for MEMSI told you that MEMS are getting fabricated. Now days not only out of silicon but also from other materials like polymer materials, like ceramic materials, like metals and like composite materials and so on. So if it is different from silicon, so that means that particular technology may not be compatible with the normal VLSI process. So we can adopt some other technology and there main emphasize is making a fabrication of microstructure and later on this microstructure, may bepasted or may be transported onto silicon wafer. But microstructures are fabricated separately using a certain technique and that particular technique is known as microstereolithography.

(Refer Slide Time: 52:04)

Microstereolithography for MEMS

Santiram Kal

Department of Electronics & ECE

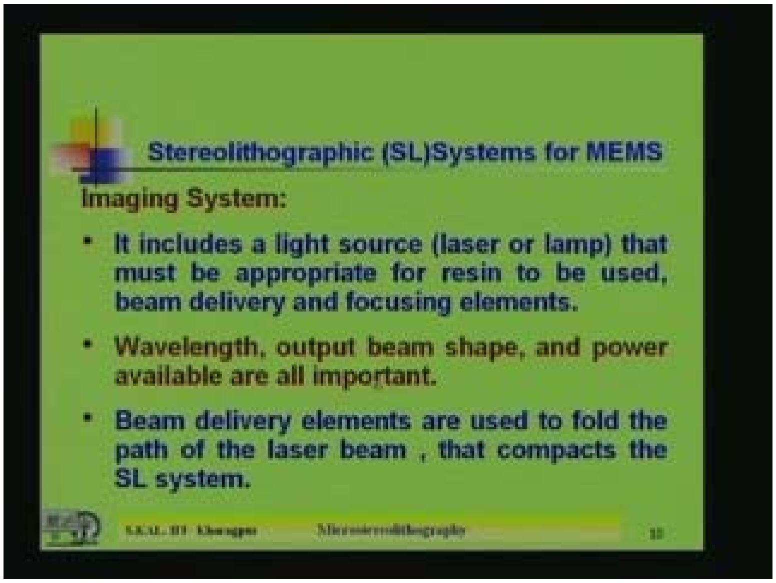
Indian Institute of Technology

Kharagpur – 721302

E Mail: srkal@iitkgp.ac.in

The name stereo is there, as the name stereo ,you understand that there it will be 3 dimensional structure. So normally the x, y and z in normal lithography or normal bulk and surface micromachining, there is a limitation on the thickness of the structure, means along the z direction thethickness of the microstructure or material, there is a limitation. But here in this particular technique which is known as microstereolithography, there that limitation is not there. So you can have larger thickness material without any mask, without any micromachining by etching.

(Refer Slide Time: 52:56)



Stereolithographic (SL)Systems for MEMS

Imaging System:

- It includes a light source (laser or lamp) that must be appropriate for resin to be used, beam delivery and focusing elements.
- Wavelength, output beam shape, and power available are all important.
- Beam delivery elements are used to fold the path of the laser beam , that compacts the SL system.

That is output beam shape and power available. That means it depends on the intensity. How much intensity is incident on the polymer, so those things are all important when you make the complete systems. Beam delivery elements are used to fold the path of the laser beam that compact the SL system.

(Refer Slide Time: 53:24)

Stereolithographic (SL)Systems for MEMS

Layer Preparation:

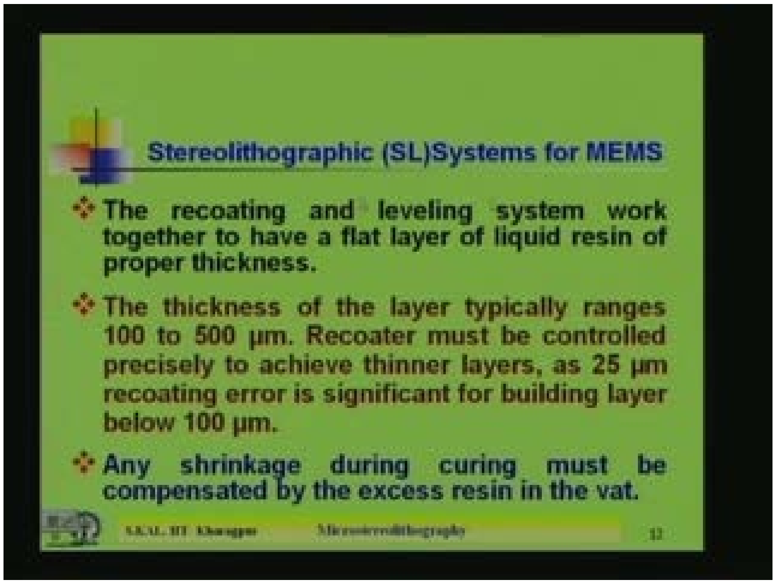
A uniform, flat resin layer of the desired thickness is prepared for curing.The liquid resin surface will be the foundation of each layer of the SL model. SL system should satisfy the following requirements of the resin surface.

- Uniformly flat, leveled, and free of extraneous features
- Maintained precisely at the focal plane of the imaging system
- Surface must be a controlled distance above the previously built solidified cross section of the part.

Now the layer preparation. The layer preparation means you have to have a very uniform layer of the resin or photo resist which are being exposed. Flat resin layer of the desired thickness is prepared for curing. The liquid resins surface will be the foundation of each layer of the SL model. SL system should satisfy the following requirements of the resin surface. What are the requirements? First is, it should be uniformly flat, leveled and free from extraneous features. Second is it should maintained precisely at focal plane of the imaging system. The resin layer must be at the focal plane of the imaging system. That means the focus spot where the beam is focused at a point, the wholelayer should be in that particular plane so that there, you will get maximum intensity. Surface must be a control distance above the previously built solidified cross section of the part that we previously built solidified cross section.

It is a layer by layer preparation. Solayer is prepared, it is exposed andit becomes hard. So on the top of that, again you are making another layer and then you are exposing that. So that means, the distance that means you see the focused beam, the focusing plane, it remain same. Layer is moving along vertical in direction. Isn't it? So in that way, that has to be accurately controlled. So that, when these move, it should not depend on the thickness of each layer, the z movement has to be adjusted. Sothat complete layer will be in the focusing plane and within the region of themaximum intensity width. So now, that is penetration drift which I called earlier penetration drift within that.

(Refer Slide Time: 55:44)

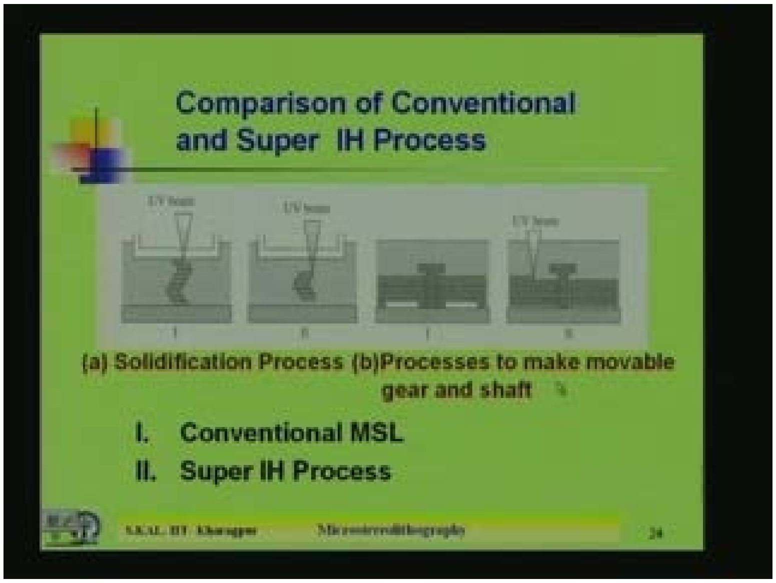


Stereolithographic (SL)Systems for MEMS

- The recoating and leveling system work together to have a flat layer of liquid resin of proper thickness.
- The thickness of the layer typically ranges 100 to 500 μm. Recoater must be controlled precisely to achieve thinner layers, as 25 μm recoating error is significant for building layer below 100 μm.
- Any shrinkage during curing must be compensated by the excess resin in the vat.

Now the recoating and leveling system work together to have a flat layer of liquid resin of proper thickness. Recoating and leveling because layer by layer you have to recoat after just recoating then leveling has to be done. That is done again by sensor electronic sensor.

(Refer Slide Time: 56:08)



Comparison of Conventional and Super IH Process

(a) Solidification Process (b)Processes to make movable gear and shaft

I. Conventional MSL
II. Super IH Process

Now here is one example to make movable gear and shaft. So using the first method is a conventional image. So there you see some support layer is there. In the second one is the super IH process the gear and shaft is made without any support layer or sacrificial layer. Justthis beam spot is scanned vertically and laterally and you can get this kind of structure. This is the comparison between IH and super IH process.

(Refer Slide Time: 56:41)

Ceramic MSL

- Ceramic materials have useful properties such as high temperature or chemical resistance, high hardness, low thermal conductivity, ferroelectricity and piezoelectricity
- 3-D ceramic microstructures are of special interest in applications such as microengines and microfluidics
- Unlike conventional silicon micromachining, MSL can be used to build the complex ceramic 3-D microstructures in a rapid free-form fashion without the need for high pressure / high temperature

Now the ceramic MSL ceramic microstereolithography. These are some ceramic structure you can see at the corner of the figure. So ceramic materials have useful properties such as high temperature or chemical resistance, high hardness, low thermal conductivity,ferroelectricity and piezoelectricity. Because of those properties ceramic materials are used in some MEMS devices. 3D ceramic microstructures are of special interest in application such as micro engines and microfluidics. These are the two application areas of ceramic microstructures. Unlike conventional silicon micromachining, MSL can be used to build the complex ceramic 3D microstructures in a rapid free form fashion without the need for high precision and high temperature. Here you have to use the IDD process. Because the ceramic material cannot beexposed and polymer chain reaction will not be there is not polymer. So basically it is little bit different and it needs at the end some curing process. The ceramic powders are mixed with polymeric material and after that you have to have cured and during curing process the polymeric materials will leave,will evaporate and the solid ceramic you will get.

(Refer Slide Time: 58:03)

Ceramic MSL Process

- The resin system for ceramic MSL is composed not only of the monomers and photoinitiators that are used in polymer MSL but also of ceramic powders, dispersants, and diluents.
- Dispersants and diluents are used to obtain a homogeneous ceramic suspension with a relatively low viscosity.
- Upon UV polymerisation, the ceramic particles are bonded together by the polymer and the ceramic body is formed.

So the resin system for ceramic MSL is composed not only of the monomer and photoinitiators that are used in polymer MSL, but also of ceramic powder whatI mentioned. Ceramic powders monomers and photoinitiator the photoinitiators are basically a reactive with theoptic system. Dispersants and diluents are used to obtain a homogeneous ceramic suspension with a relatively low viscosity. Upon UV polymerisation the ceramic particles are bounded together by the polymer and the ceramic body is formed. This is the complete ceramic MSL process. So with this let me stop here. I discussedthe overallstereo lithography system and microstereolithography also and extension of this method in this ceramic MSL process to get ceramic microstructures. Thank you.