ROBOTICS
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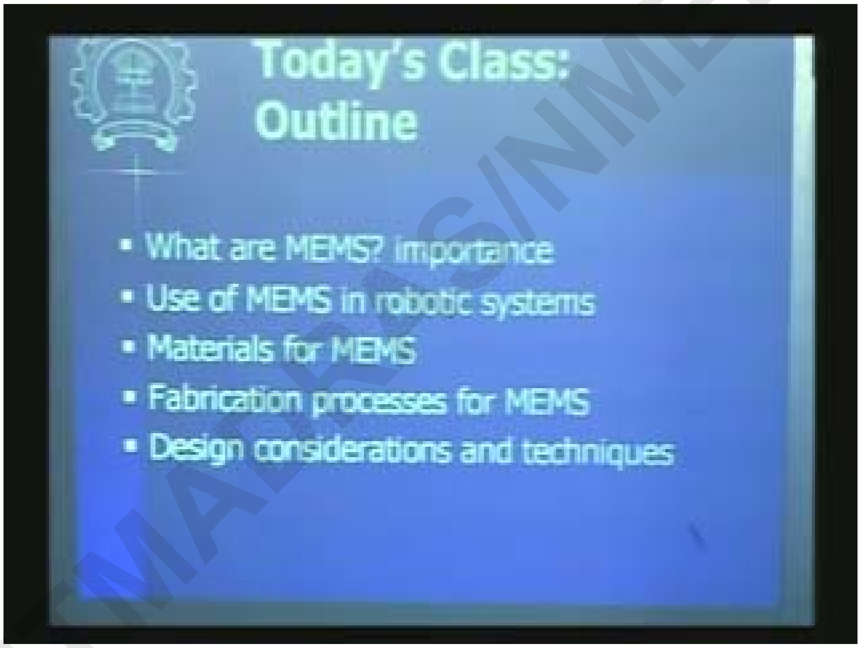
Lecture No-37
Futuristic Topics in Robotics: Lecture 1

Good morning today we are going to start with the new module which is titled futuristic topics in robotics will have two lectures in this module and then we will see this are what are the content of this module

Now today's class (refer slide time 00:01:40) we will see what are the MEMS devices okay what is this MEMS technology about see this is the futuristic topic for robotic applications like um



Actually MEMS is a area which has applications in many different areas okay so this MEMS technology is applied in many different areas and today we are going to see how it is useful for robotic applications and then we will see some details about this technology okay

So we will study first what are the MEMS devices or technology what is this technology what is its importance then use of MEMS in the robotics systems

Then we will go for materials which are used in the MEMS conventional or traditional MEMS [um] fabrication and then we will see some of the fabrication processes with MEMS okay

So these are the things which we will see in today's class and then in the second class like [um] the next lecture in this module will focus on non conventional MEMS technology okay and then how they are used for robotic applications

This is the area currently under research so you find at this technology though it is established quite well over last ten years like it has lot of mish areas where robotic applications are not much explored okay

So this is really a very futuristic topic for robotic application okay so let us see what are this MEMS devices okay

This MEMS or micro electro mechanical systems refer to miniature mechatronic systems which are bulk fabricated using VLSI technology okay

If VLSI stands for very large scale integration or in modern technology it is ultra large scale integration ULSI in short okay

This is a conventional technology which is used for traditionally it is used for fabrication of chips okay

Do you how many components are there on your Pentium chip any numbers guesses forty four million okay its its its of that order like there are millions of components in the Pentium chip or um four eighty six chips

So they are they are there is a technology that exist um that that can allow you to fabricate so many components or so many transistors electronic components on space which is two by two inch okay or much lesser than that actually okay

So in such a small space you can fabricate so many millions of components they are electronic component so the idea is why not fabricate mechanical components along with the electronic components okay you have the technology in place so use the same technology to fabricate mechanical components

That was that was the first driving factor to venture into this micro electro mechanical systems so some people prefer these techniques and processes that are used for fabricating macro scale components as MEMS

Some people refer to MEMS as conventional traditional silicon based two D two dimensional fabrication

So the the definition itself varies little bit here and there but essence is like you you can fabricate these macro components okay using this technology and you can fabricate both electronic and mechanical components together okay may be on a same substrate or may be on the different substrate and then integrate

But it's a combination of macro electro mechanical systems okay so why why it is necessary to study MEMS there are plenty of benefits of this technology
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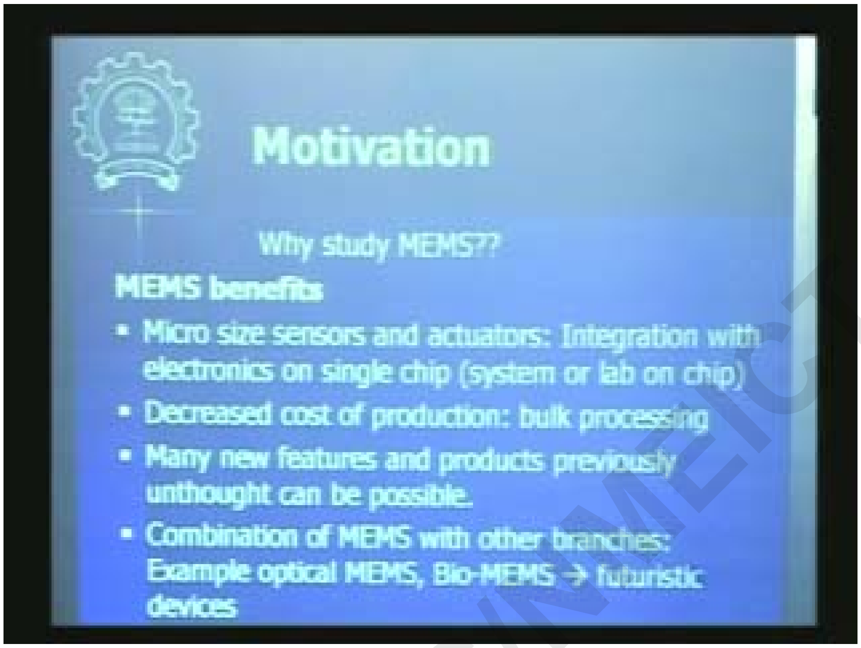


and some of them have already been industrially exploited like they are not at the research now they are in the industry like people have started fabricating some devices some components some systems based on this MEMS technology that are in market and that are actually revolution arising the economics okay

So now what are silent benefits you can have micro size sensors and actuators and integrated with the electronics on the same chip okay so its kind of a lab on chip concept so you have entire system in a single chip

Instead of having mechanical components separate and electronic components separate and then putting them together by connecting by wires and things like that you can have both the things together at a time on a single chip okay

So what is its use like say if you have a sensor which can like say some say acceleration or say pressure so you have a acceler accelerometer sensor or a pressure sensor these sensors if you have along with that electronics also on the same chip or the same sensor then you can have RF transmission electronics there and then you can sense like you don't need wires to connect these sensor now

That sensor can be placed anywhere and whatever sends signals they will be transmitted by RF technology to your central control system that is the advantage

So similarly these kind of sensors you can have in a robotic applications okay

Now other advantage is like MEMS has decreased cost okay like you can get both improvement in cost quality and like decrease in the cost at the lower cost to get a better quality at a lower cost okay [yes question]

RF is [um] radio frequency transmission like a radio transmission wireless transmission okay see RF based MEMS the device which can sensed and then it can process the same signal on the same chip and then it can transmit them wireless okay

So so all your sensors that are used in industry can be wireless sensors or and at the same time they are miniature its not like they they need like a bulk bulky transmitter to transmit the signal okay

There are many new features and products previously unthought of that can be fabricated by using this technology

So already like you might have heard about the application for [um] camera capsule say there is a camera which is in the capsule very small form that you can take swallow that capsule and it it will travel all your intestinal canal and it will capture the images two per second and then it will transmit it to a pager like a device which is on your belt okay

And then those images can be analyzed so you don't need that the [um] bulky [um] endoscopy kind of a techniques to it

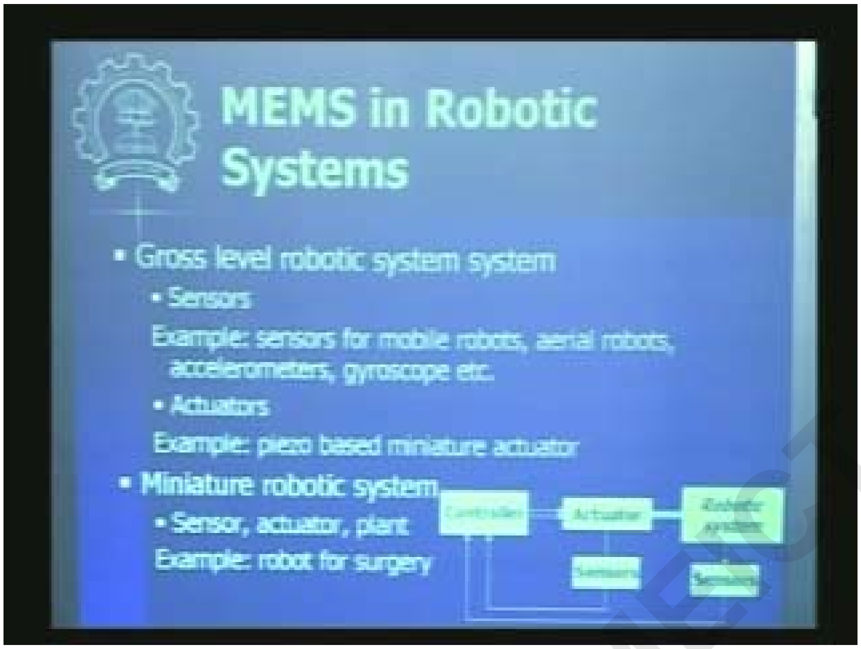
So so these are some of the applications which are already in the market and like they are very very useful for medical and other applications okay

So many new features and products that are previously unthought of can be fabricated by using MEMS and they they can be fabricated at a lower cost also okay

So that is also very important advantage of and then combination of MEMS with other branches like in in in today we today 's lecture we will see how it is combined with the robotics branch

But it can be combined with other branches like bio MEMS or opto MEMS so these are the different combinations with other branches sets that it can have many different applications in those branch okay

So that is the motivation why people are actually studying this area (refer slide time 00:10:10)



So so much in this text but robotic systems like where where you can find applications for MEMS okay at gross level robotic systems all the sensors they can be MEMS based sensors okay and then also you can have very very tiny actuators for very small movement especially for surgical robots okay

So sensors for example in mobile robots aerial robots okay where you have to sense like orientation you can use gyroscopes micro MEMS based gyroscopes or MEMS based accelerometers will be useful in those cases okay

Here are the some of the MEMS sensors that can be used in robotic applications directly and these sensors are already available in the market now okay

And then actuators there are piezo based actuators so these are miniature actua actuators which are used for basically micro manipulation applications okay

You have to move very small distance or see for surgical applications you have to move the cutter at very small distance for precise cuts things like that we use piezo based actuators okay

Then miniature robotic systems [um] like [um] is next is a gross level application okay so bigger robotic systems we can have these sensors and actuators based on the MEMS technology

Now at the miniature level we can have entire robotic system as a miniature robot okay so all the actuators sensors [um] the actual structure of the robot everything else is that of miniature okay

So these kind of robots people i have already started fabricating and then this miniature robotic why why people what is the motivation for doing this miniature robotics its basically people are seeing the need for microsurgery like you don't have to cut open patient for surgery you can just send these robots inside patient's body and then they will go at a appropriate place and carry out the micro surgery okay

That is kind of a big application that people are envi envisaging for doing the research in this area okay

So that is the basically motivation for [noise] people to research this and fabricate these micro robots and you find that at some universities these kind of [um] robots have already been fabricated and tested for their performance okay

So again the recall our standard control or robotic system we have actuators sensors and controller and actual robotic system here okay
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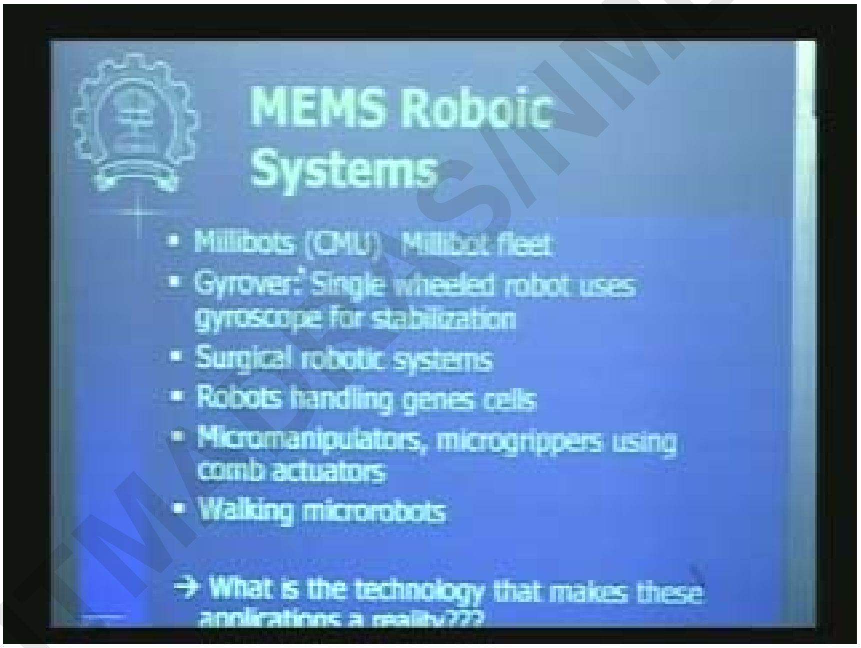

Now these are some of the applications which are already there at some universities or in the market or whatever there are different places

But these are already realized applications one is this like millibots or very small tiny robot okay

So there are n number of such robot they are working in coordination with each other okay so there is a millibot fleet okay set of milli robot okay

Then this is gyrover which is single wheeled robot which uses gyroscopic effect for stabilization so that has been fabricated and kept in

Then there are many surgical robotic systems in place like in other like in market or in auto research level in university okay then robot for handling the cells or genes okay

Then micromanipulators and microgrippers are very widely used these days for biomedical applications okay for manipulating cells checking one cell moving it to some other place for whatever application this micromanipulators are used ok and then there are some walking robot also that have been made okay out of silicon chip

So if this this walking robots are also very interesting application like how they are made this robot

So the question is what is the technology that makes these applications a reality okay

So this is the MEMS technology which is making these things possible so we will get into the details about this technology now okay

We will see what are the techniques for the fabrication in MEMS what are the different processes involved i mean we will focus on main processes involved

We will not go into detail characterization of these processes okay or what are the variables that are affecting these processes anything like that but you should have a general idea or overview what is possible which is and how it is possible okay so that is these are the two questions that we will try to answer today okay
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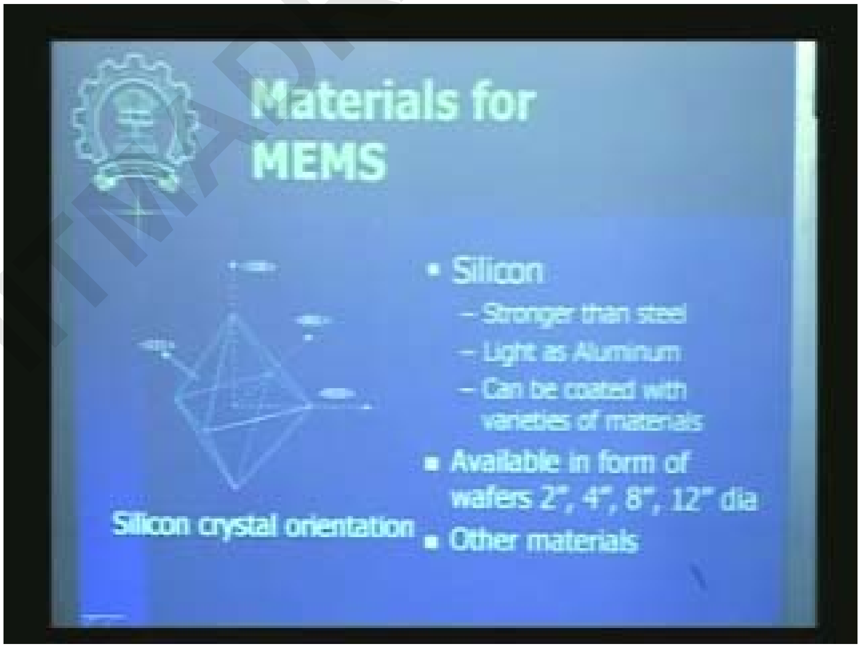

So firstly what are the materials that are used for this MEMS okay the primary material is silicon because this technology is driven by VLSI technology which is silicon based chip fabrication technology okay

So this silicon is conventionally or traditionally used material for all the MEMS systems okay

Some of the properties it is stronger than steel it is light as aluminum okay and it can be coated with various materials okay

It can like there is a good addition between silicon and many other materials for coating okay then what what what are the sizes it is available in it is in the form of wafers okay you might have already heard about that what are the wafers their their basically silicon chips are made out of wafer

So these wafers are circular shape silicon dy [um] dyes which are around five hundred micron thick

Five hundred micron is point five millimeter okay its its like about five times the size of your hair okay thickness of your hair it’s the total thickness of the chip okay

And then there are other materials various other materials [um] before we go into that i just want the shape that you can see here for silicon crystal okay

For this shape like there are this different axis defined okay we will come to that why this shape and what is the significance of this in terms of fabrications processes something like that

But you just keep in mind that you have this kind of a shape so at each each corner here one silicon atom is there okay so this is a crystalline silicon so this is a silicon crystal okay

Now what are the other materials for MEMS (refer slide time 00:17:50)

We can have look at polycrystalline silicon or it is called polysilicon it is a gra granular form of a silicon okay it is it is not crystalline it is has grain and grain modrincs and like that and then silicon dioxide silicon nitride aluminum you can have gold you can have okay

And there are many other materials nowadays possible for fabrication okay so other important thing is that you can have this doping of silicon for creating electronic components or for for example in some cases you can use this doping as a change of material properties like you want to change material property and then this is significant when you have stopping like you want to stop the some some process or a some chemical etching process

Then you can use dopant as a chemical etch stop okay where so whatever is doped it will not be getting etched and whatever is not doped it will get etched so we will come to that again when i i demonstrate you what is etching and how we can carry it out

Now let us come to different fabrication procedures for MEMS okay
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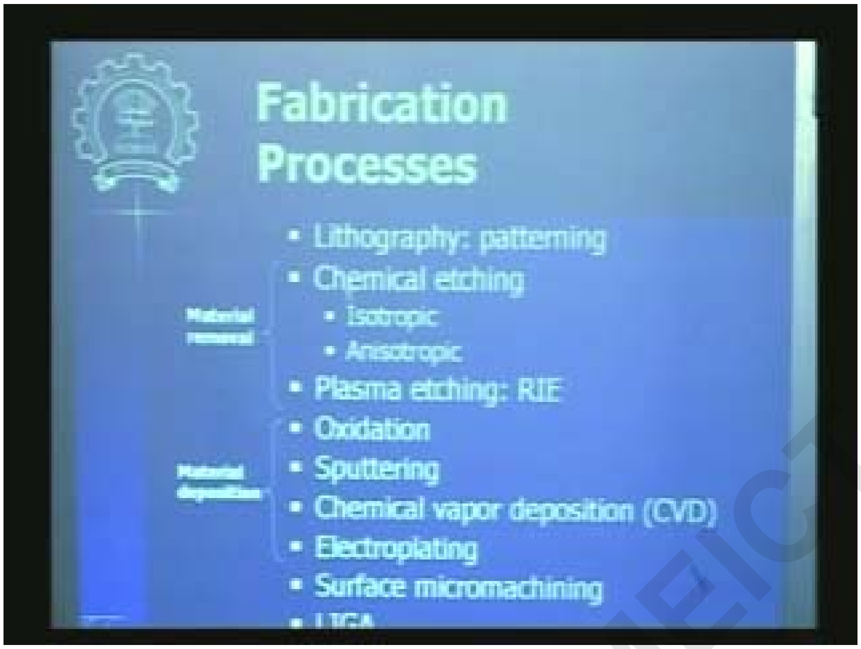


The central important process is lithography for patterning then there is a chemical etching

This lithography will come to in detail like but its its like [um] you have photographic film okay your camera roll basically it captures the image in some chemical form okay

So it is the chemicals there are getting affected by light in some cases okay so similar technology like you have this photo resist which you lay on the surface of the wafer and then you affect only some part of it by passing light and then you have a form of a structure okay or form of a pattern created okay
We will come to that in a minute in detail but that is kind of an idea we have in lithography then once you have the pattern created then you can use that pattern for etching elective etching so what your part is pattern it will not get etched but other remaining part will get etched okay

We can have this two types of etching is possible then this is plasma etching this other form of a etching process

Then there are material deposition processes these are all material removal processes okay etching processes are material removal processes and then you can have material deposition processes

There are various material deposition processes oxidation sputtering chemical deposition electroplating and then the combination of these material removal and material deposition along with lithography will form some additional processes like surface micromachining and then this LIGA is a special type of a process which we will get into detail

Now let us see what is the lithography in detail (refer slide time 00:21:10)

So when you have you have two types possible here one is positive photo resist you will understand now what is positive photo resist and what is negative photo resist but we will see first like with positive photo resist how is the lithography process will look like

So you have this wafer it is a silicon wafer on surface of that you have this photo resist which is pun okay you first put the drop of photo resist and then you give it a very high speed so that drop is spilled out okay

Now depending upon the speed at which you are [um] rotating or spinning the wafer and depending upon the um viscosity of this photo resist will get a number of like various possibilities for the thicknesses for this photo resist okay

So you can have like micron coating or you can have two micron coating that kind of a things are possible depending upon the speed and what kind of photo resist that they are using okay

Now you have this mask use this mask and then you expose only some surface to this ultra violet rays the surface will get affected okay

Now when you treat it chemically this part will get removed for the positive photoresist okay and then the remaining part you can bake in the oven to have it harden okay

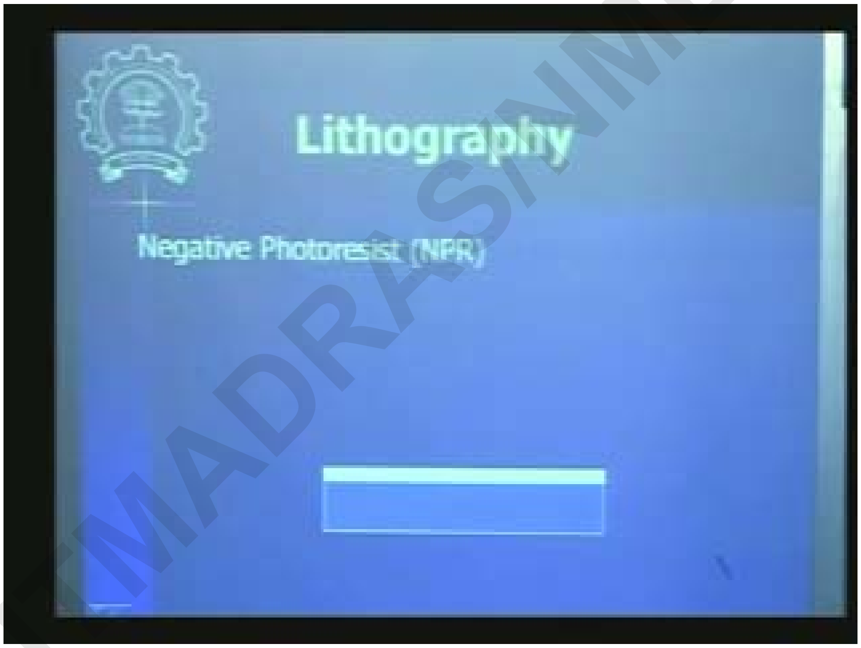
So that is the process for like patterning or lithographic process okay the important thing here is like you need this kind of a mask which is pre made or which is prepared a priory okay

So this mask actually making the mask itself is like a very complicated process it will not go into details but this mask are mask are a typically very costly things

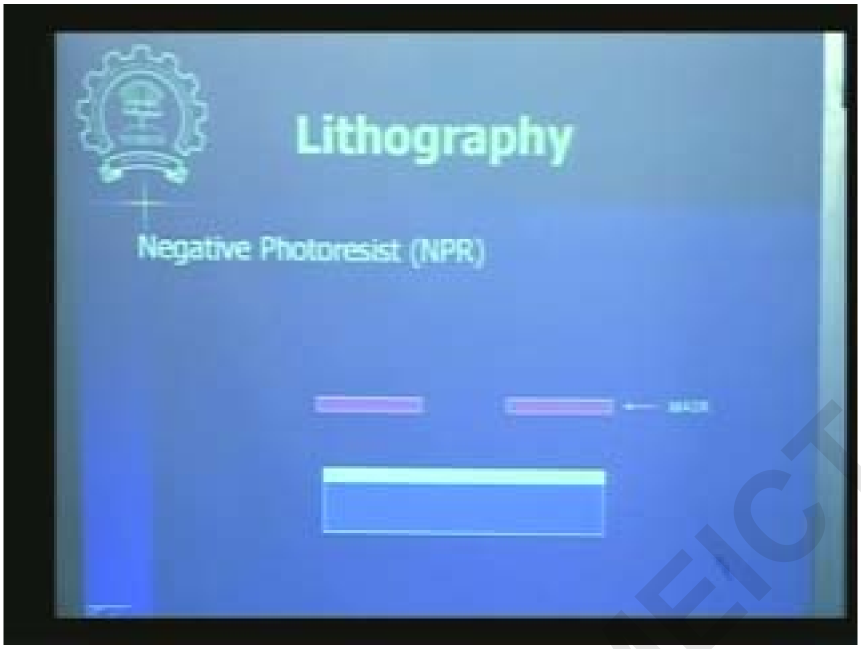
So you want to avoid number of masks that your particular fabrication process is using okay or you want to make them as small as possible number of masking processes okay that will bring down your cost so so cost is directly proportional to right number of mask that you are using in your method okay

Now let us have a look at negative photo resist

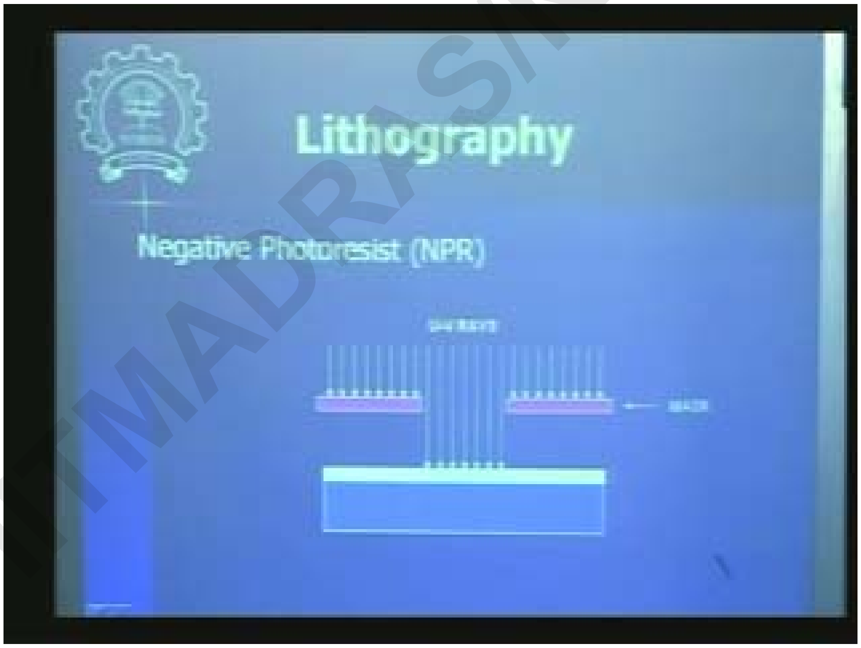
So again you have this your wafer and on the top you are spilling this negative photo resist now (refer slide time 00:23:46)



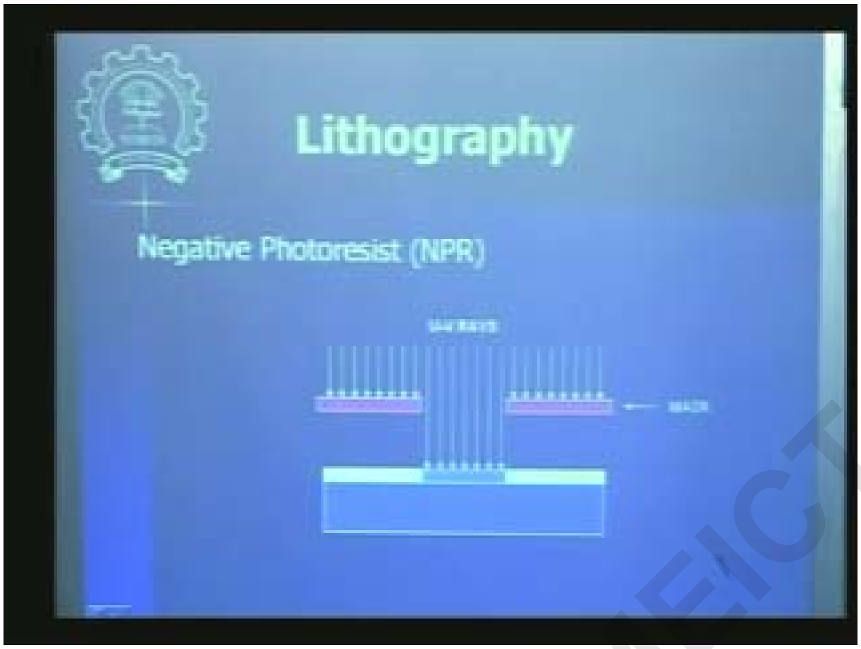
Then you have mask (refer slide time 00:23:50)



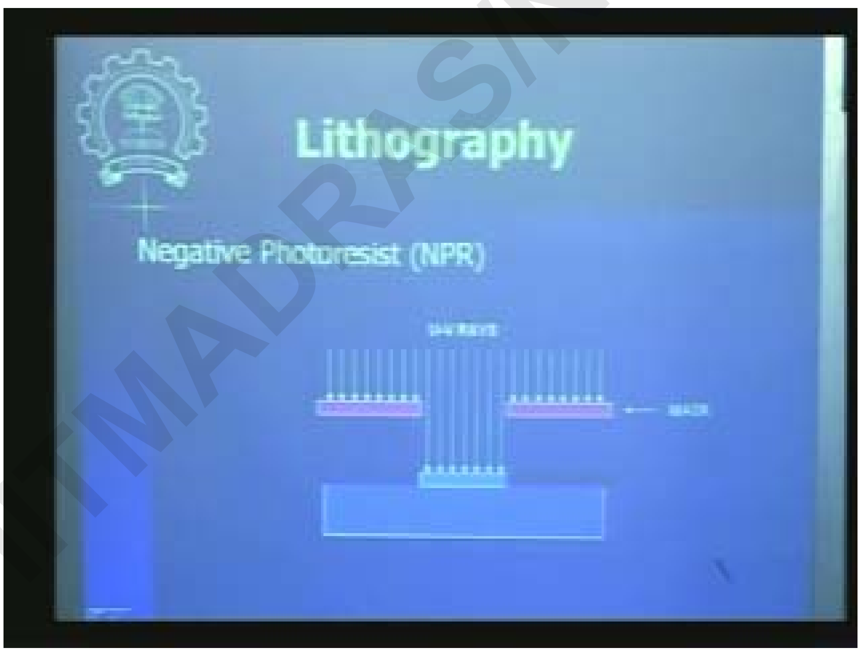
You are exposing now (refer slide time 00:23:52)



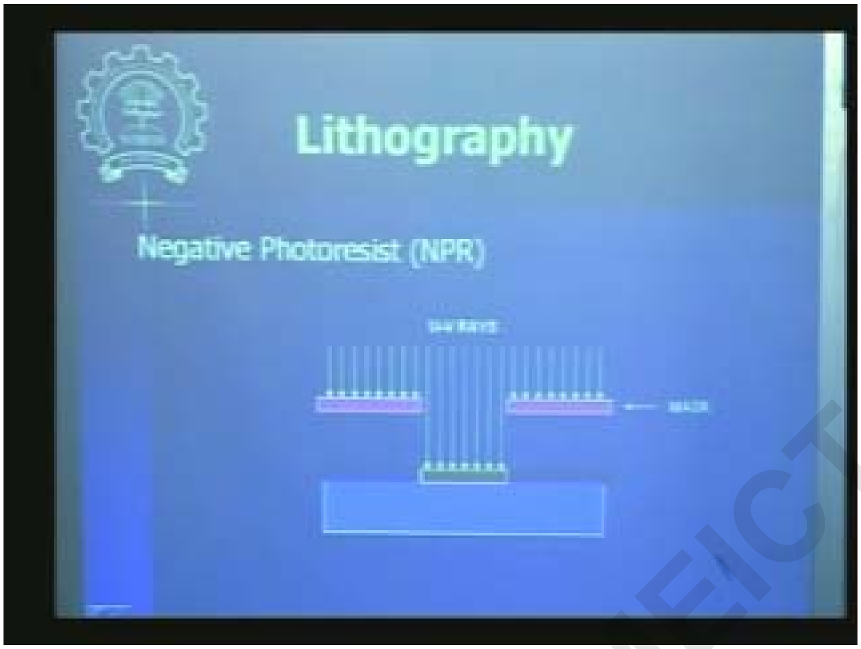
[um] area some area gets affected (refer slide time 00:23:53)



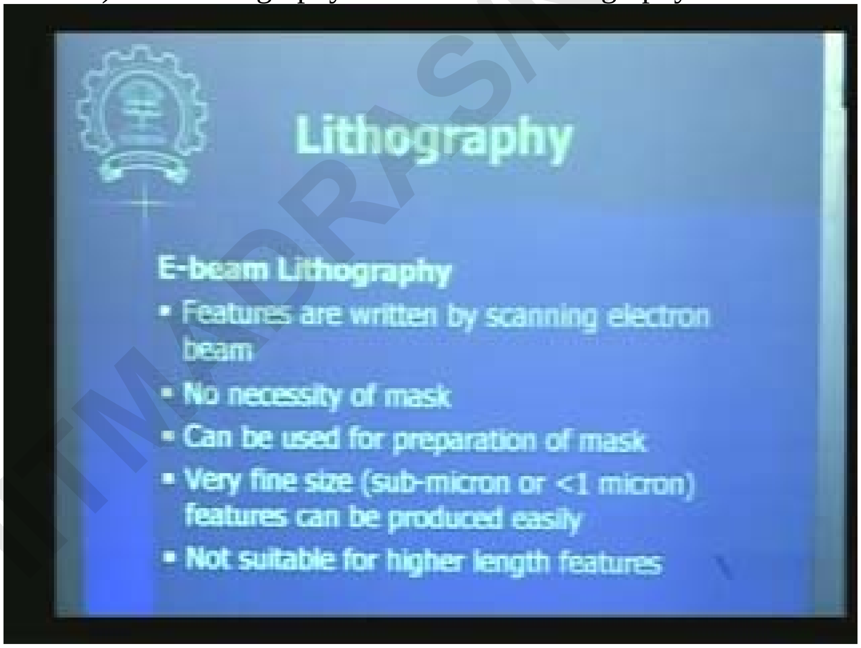
Now when you process (refer slide time 00:23:57)



The other part will get removed okay and this part will remain which we can break (refer slide time 00:24:05) to have the structure so or the pattern possible on the substrate



Okay so this is the process of lithography [um] now that is another process possible (refer slide time 00:24:17) for lithography called E beam lithography



So e beam lithography is basically you are using the electron beam okay and you are kind of scanning your pattern on your substrate okay

So this scanning is usually done vectors vector scan okay so you are line by line you are scanning a pattern on a surface

So this process will not require the mask okay its direct writing process okay some mask less process

So many research application when you are doing research applications like you first do with this kind of a be e beam lithography

So that once you are firm with your results then you can right now start making mask which is a costly affair okay

Now when i say mask is costly affair it is for the like low dimension size i am talking about very smaller dimensions like sub micro dimensions or like very close to ten micron kind of a dimension

Okay if you are making components with bigger dimensions like fifty micron or hundred hundred micron dimensions then its not that costly okay

So its its it has something to do with the size also that you should be you should have it in mind okay and then with e beam lithography you can have very fine size like sub micron dimensions possible very easily you can have these kind of a features possible and it is not suitable for very high length features like if you have say one mm feature then you should not use e beam lithography it will take lot of time to do that okay
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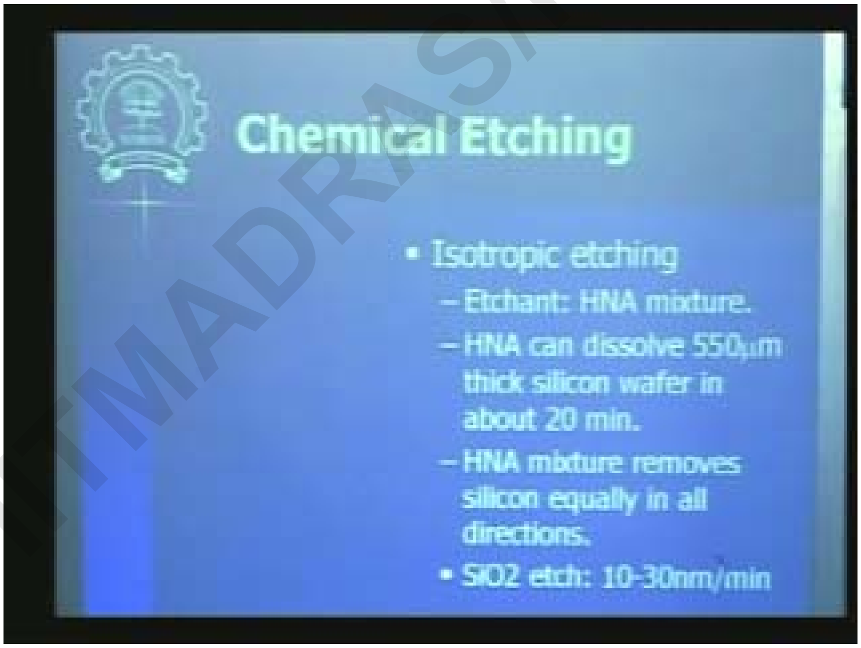


Now let us go to chemical etching process so in chemical etching you have two types of etching possible as i have mentioned earlier

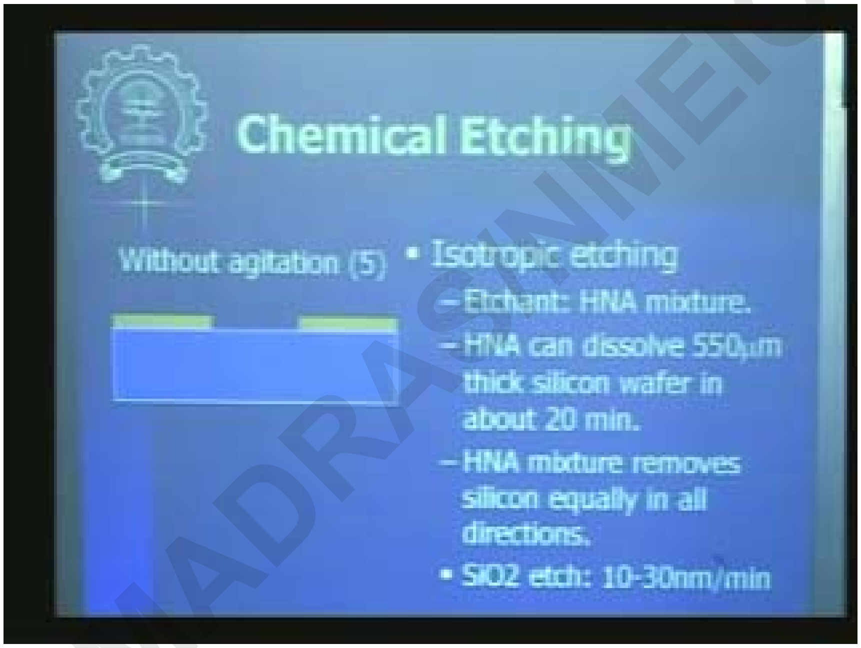
One is isotropic etching and other is anisotropic etching now [noise] [anis] isotropic etching you have this etchant which is called HNA mixture okay its HF nitric acid and acetic acid okay

This HNA mixture is there and it can dissolve like just to give you an idea how strong it is it can dissolve this five fifty micron thickness wafer that i was talking about

It can dissolve in twenty minutes entire wafer will be in twenty minutes okay so it is very strong kind of a etchant

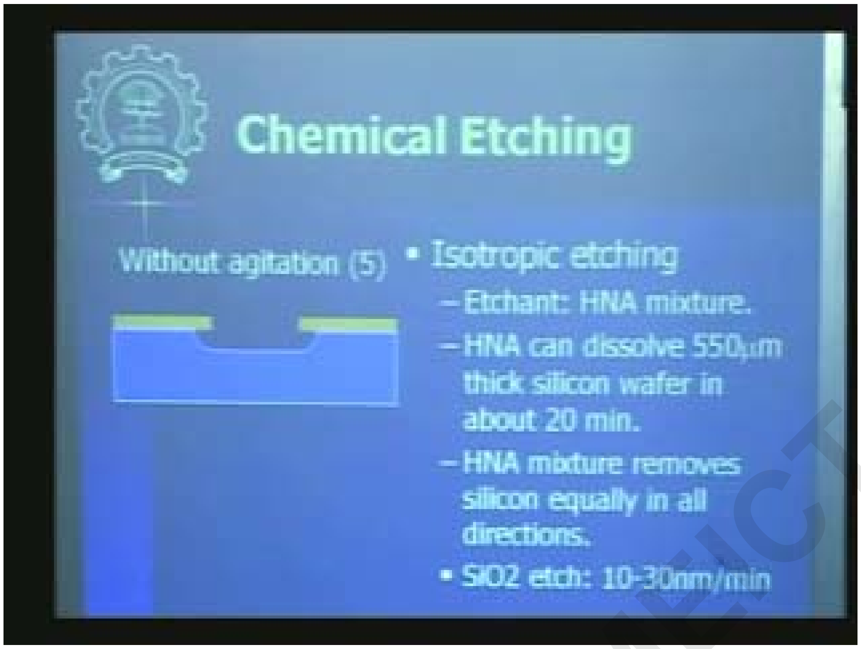
So you can now play around with the the the [um] concentrations in here and then like you can have like different etching times so that is called process characterizing we have to use different mixtures and see how much time it is taking to etch etching and characterized that that particular mixture okay

Now let us see how this process look like (refer slide time 00:27:25) you have this silicon wafer on which you have this window open



It is see it is very common to call it as a window open in the on the substrate okay when you do a patterning or lithographic process okay

That is why that is why this kind of a window which is open on the surface of the um photo resist and now (refer slide time 00:27:49)

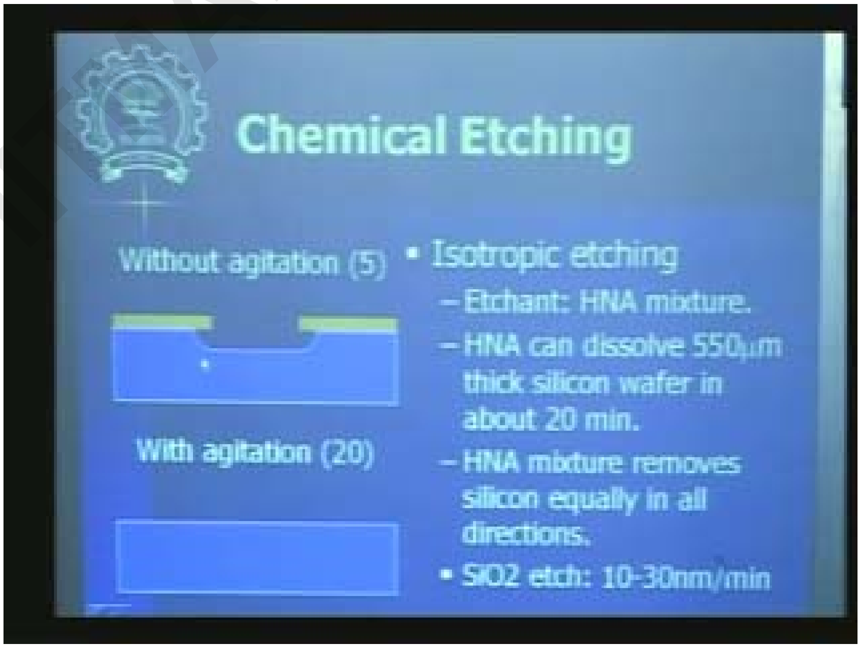


And now isotropic etchant it will produce a surface of the slot okay so you can observe here that there is some kind of a undercutting happening here okay

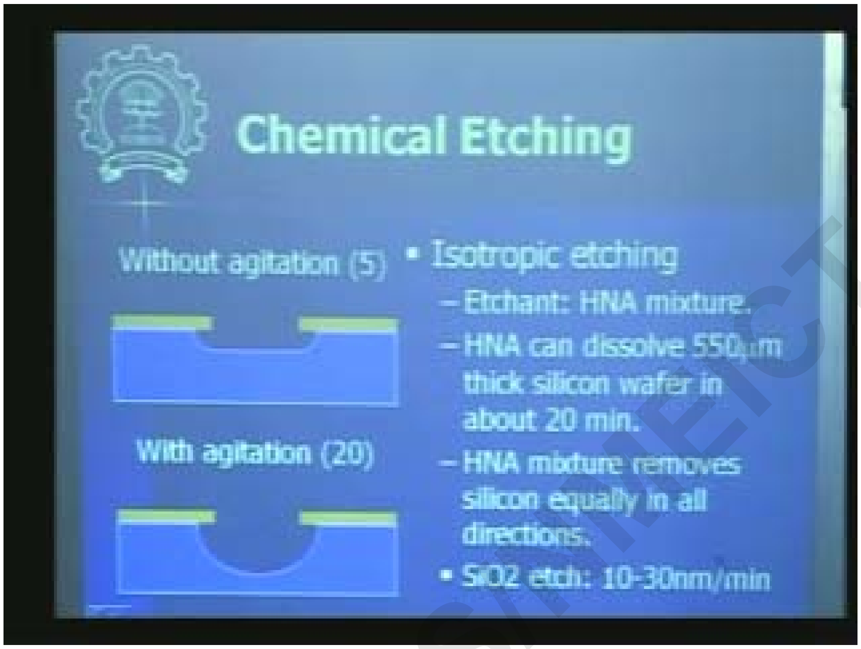
So you wanted to have some kind of a cut like this but it is cutting underneath your pattern produced okay

So you have to probably you have to take while designing these aspect into account so that you don't have this kind of a like discrepancy in the dimension okay

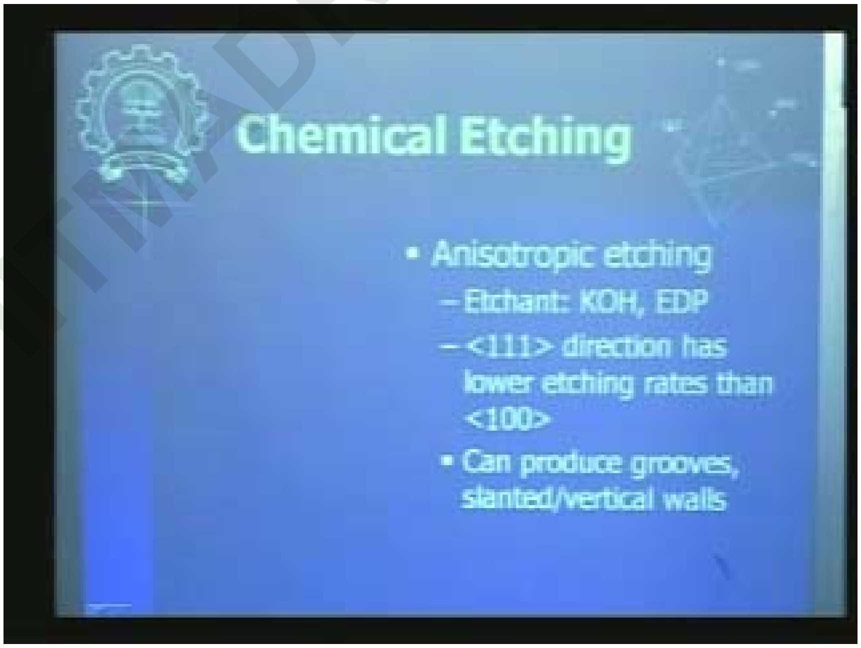
Now with agitation if you do for twenty minutes (refer slide time 00:28:31)



Okay this was a five minutes only so it is a small cut which is formed now with agitation if you do for twenty minutes (refer slide time 00:28:41) it is some some gap of this sort will be produced okay



Now let us see anisotropic etching (refer slide time 00:28:49) where now this crystal dimension or crystal structure becomes important okay

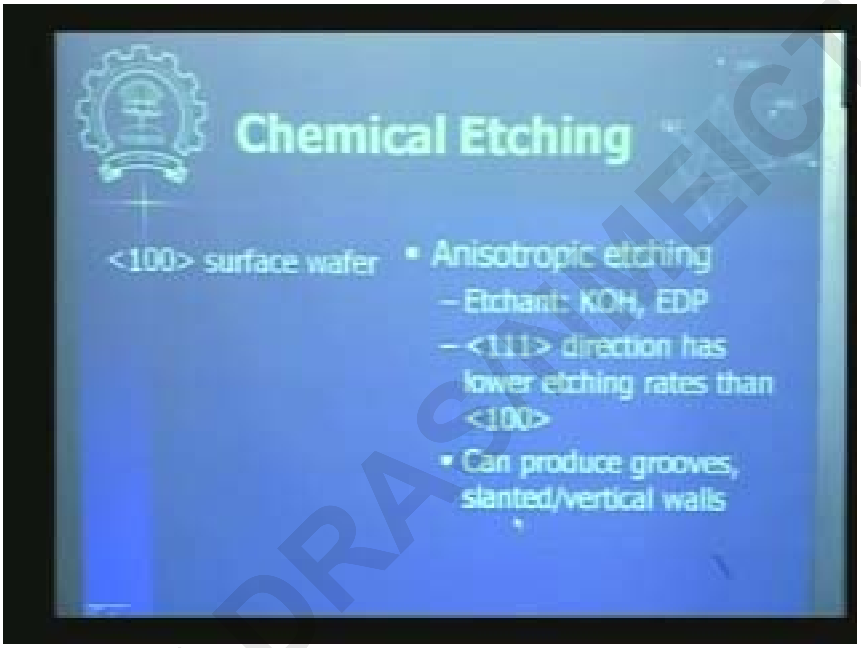


Along some planes along this crystal plane there is a density variation for the silicon atom okay

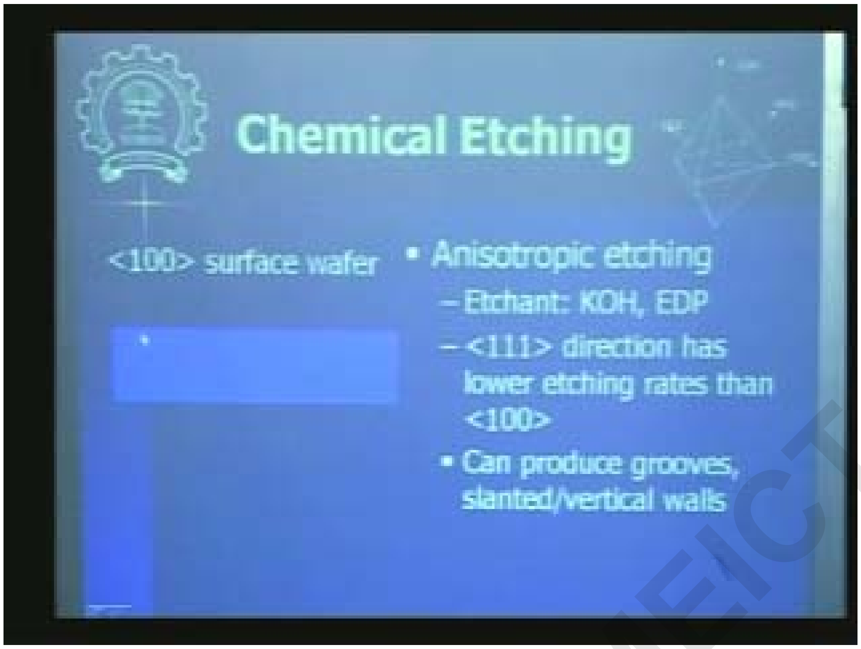
Because of that for some etchants which are sensitive to this direction or to this densities okay they will give different kinds of shapes in when you put these in a etchant like

When you put silicon in this kind of anisotropic etchant then one of the directions will be etched faster than other directions because of that you will get very typical shape on the surface of the wafer

So you can produce grooves slanted or strictly vertical walls okay while using this anisotropic etching (refer slide time 00:29:41)



So suppose you have one zero zero surface wafer meaning like you have this wafer (refer slide time 00:29:46) and this direction indicates this one zero zero direction of this crystal okay

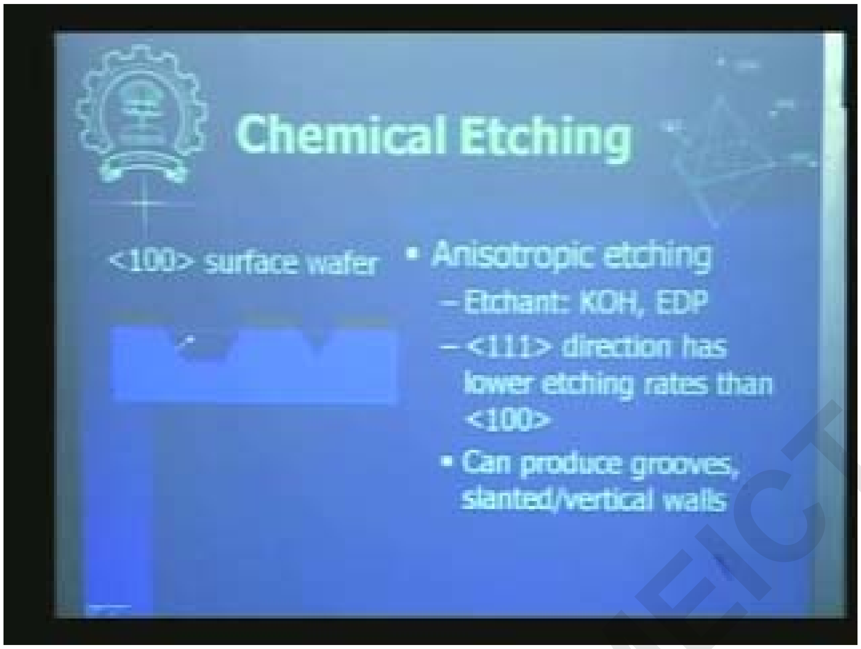


So all the crystals are aligned in such a way that their one zero zero axis is perpendicular to the surface okay

So that is how this this wafers are i mean there is a big process for fabrication of these wafers like how do we maintain these kind of a crystal structure and anything like that but these kinds of wafers are available

You you specify the one zero zero wafer you will get a wafer which is having all this crystal directions perpendicular to the plane of the wafer

So you have this windows open here and then if you etch you can see that you have this kind of a surface (refer slide time 00:30:36) [ ] slanted surface okay



Now same thing if you do with other type of wafer one one zero wafer
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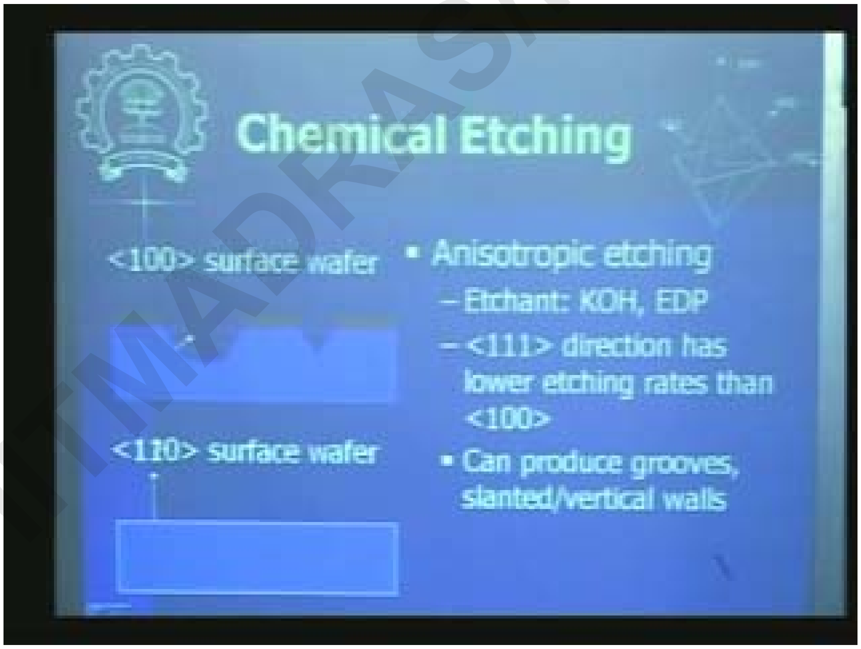

then again you have this windows open and then you will get some different shape okay
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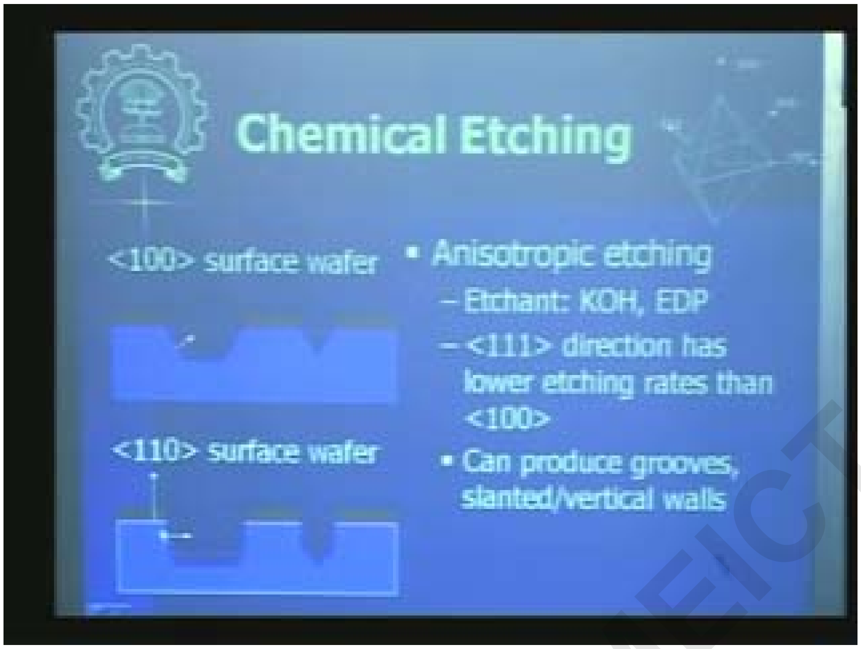
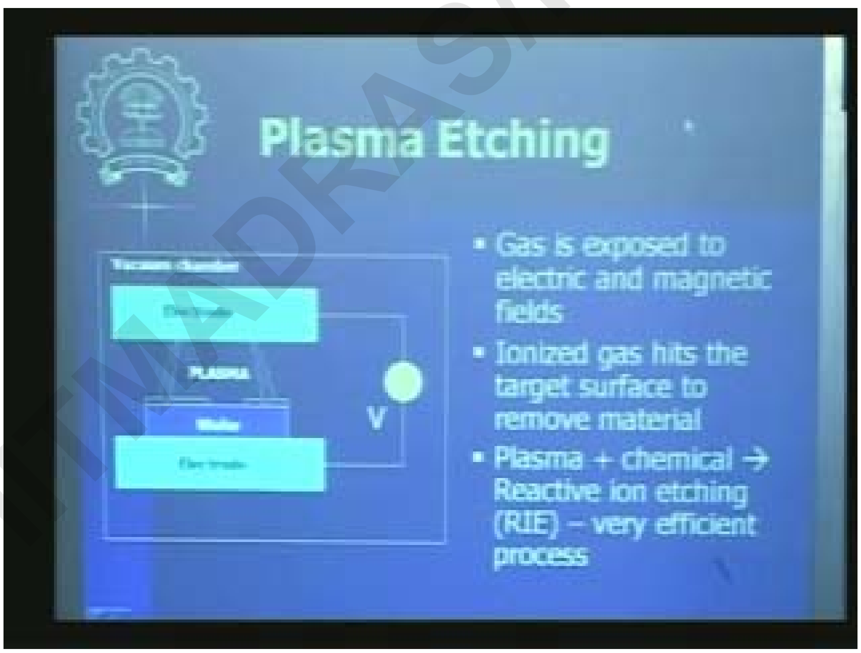


And then you can precisely calculate what kind of a shape you will get based on this crystal pattern okay (refer slide time 00:31:04)



And let us come to plasma etching so that was chemical based etching so this is a plasma etching okay

You have a vacuum chamber in which you have this two electrodes okay in between this wafer is placed and it has this pattern created on the surface of that okay

Now when you place this electrodes and we apply very high voltage you will create a plasma state or sparking kind of a state there okay

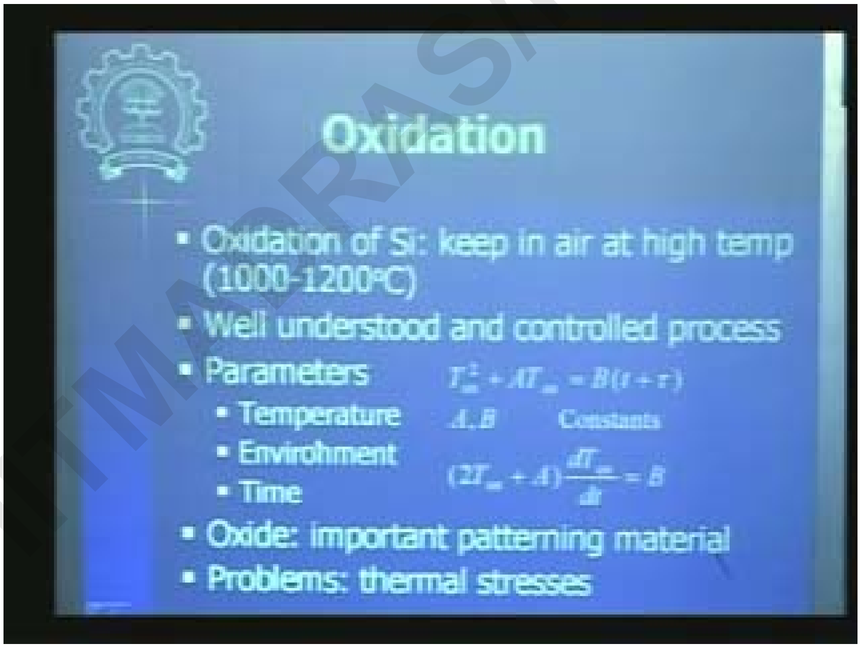
Now this distance between these two electrodes i have shown it very large but actual case it will be very small difference between the two electrode so that this plasma is created

And then this gas which is exposed to electric and magnetic field hits the target surface or this gas molecules will hit the target surface and physically remove the material there is no chemical action taken place over here okay

Now if you combine it with the chemical action it is called reactive ion etching so these ions are now reactive chemically

So then it is called reactive ion etching but just a plasma etching will not have the chemical action okay its physically removing the surface like whatever molecules on the wafer surface by using the physical hitting or targeting okay

And then then you combine it with chemical then it is called reactive ion etching so there is also reaction also going on and at the same time this physical bombardment is also going on okay (refer slide time 00:32:53)



Now let us see other process now this previous process is were like basically material removal processes now let us see some material deposition processes

So oxidation is very simple material deposition processes you just keep the wafer in air at very high temperature and then the oxide will be formed on the silicon wafer surface

And then this it is very well understood and controlled process like okay you you keep for this much time and you will get this much thickness of the oxide okay these parameters are very well well known okay

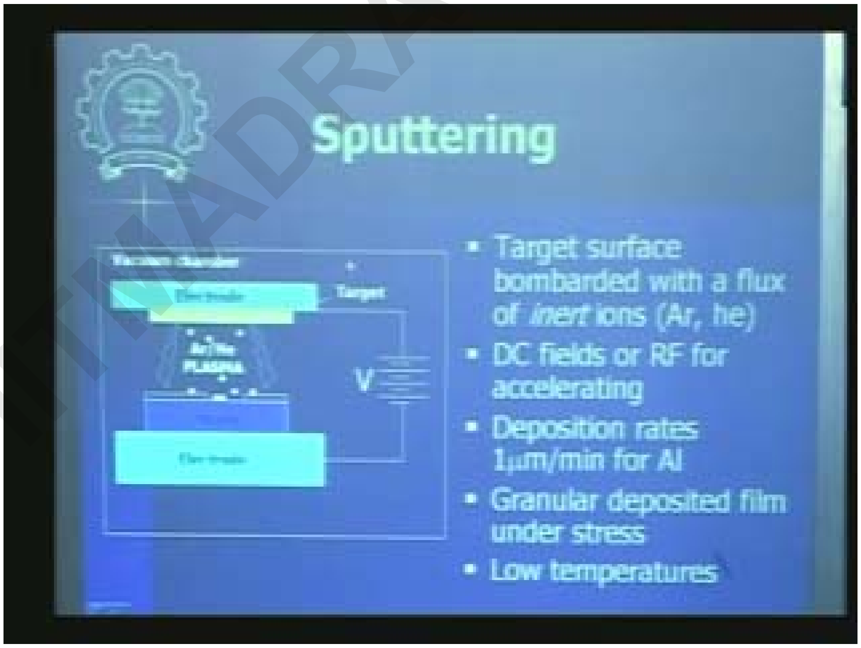
Then there are wet oxi oxidation and dry oxidation okay you can also enhance oxidation by passing like actually [ox] oxygen over the surface of wafer okay

In wet wet oxidation you do that but before that you pass it through a water so that it has some water [mo um] molecules also along with so it enhances basically the oxidation process

Now this oxide is an important material used for patterning it is not affected by many chemicals so you use it for patterning so the chemical which is affecting silicon but not oxide okay that can etch the silicon underneath the oxide or when silicon whatever is in the pattern it will start etching

And major problems with the oxi oxide using oxide as a patterning material or constructing material for various MEMS devices is the thermal stresses that one has to like your device has to go through

Because you have to heat for oxide oxidation at this high temperature thousand to thousand two hundred degrees okay
(refer slide time 00:34:52)



Now next process is called sputtering
Sputtering again it it has to be done in the vacuum chamber like you have this electrode and this argon or helium plasma formed between this electrode okay

And these are the inert gases okay so this dc field or dc voltage or RF voltage will be applied for acceleration

And then you can get this deposition see what what of the process is like you you are hitting now the target molecule or the target substrate here okay target metal by this high velocity plasma ion okay ions in the plasma okay

When they heat they will release some molecules from the surface of the target and those molecules will then get deposited over the wafer okay that is the process that’s happening in the sputtering

And then you will find that deposition rates of one micrometer per minute are typical so in one minute you will get one micron thick aluminum field on the substrate okay they are very they are very typical for aluminum

So for for each metal there will be different rates like there are different parameters to be controlled so as to get a good film okay

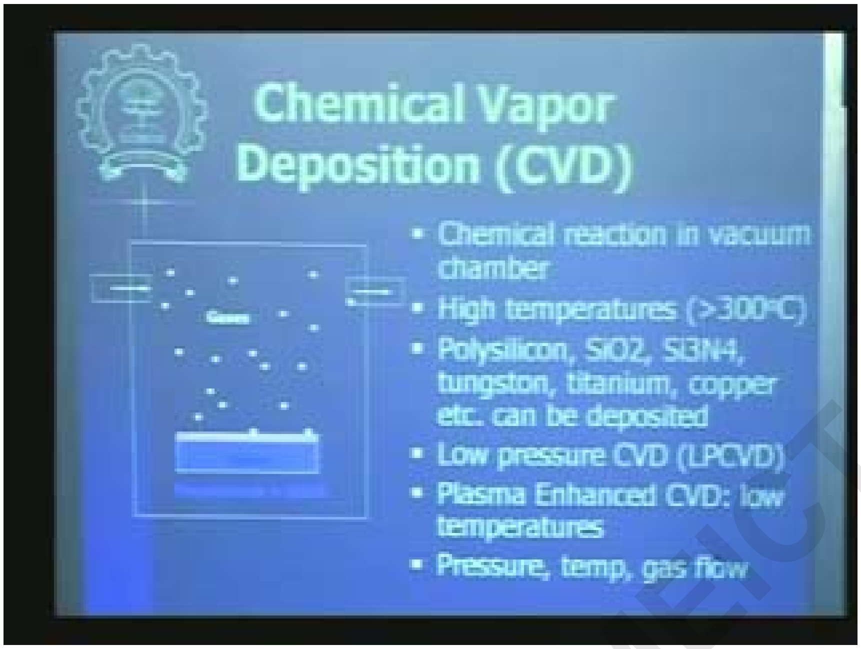
So we will not get into details of that but like those those parameters like you will go into details when they are when you need like when you are actually carrying out MEMS fabrication for any robotic system okay

Now the advantage major advantage of these sputtering process is it is a low temperature process okay oxidation we have we have seen that it is very high temperature process but this process is low temperature process okay

So generally in MEMS like low temp temperature process will be preferred to avoid the thermal stressing okay

So these thermal effects are very dominant when you go for very small scale device okay

Now the next process is this (refer slide time 00:37:09) chemical vapour deposition so it’s a it’s a chamber in which you keep wafer at temperature usually greater than three hundred degree centigrade



And then you can pass the the chemically active gases in this chamber they will react with each other and form whatever things you want to deposit okay

So for diff different things you will have different gases like for silicon poly silicon deposition you will have [salian] like that you will have different gases for different kind of deposition

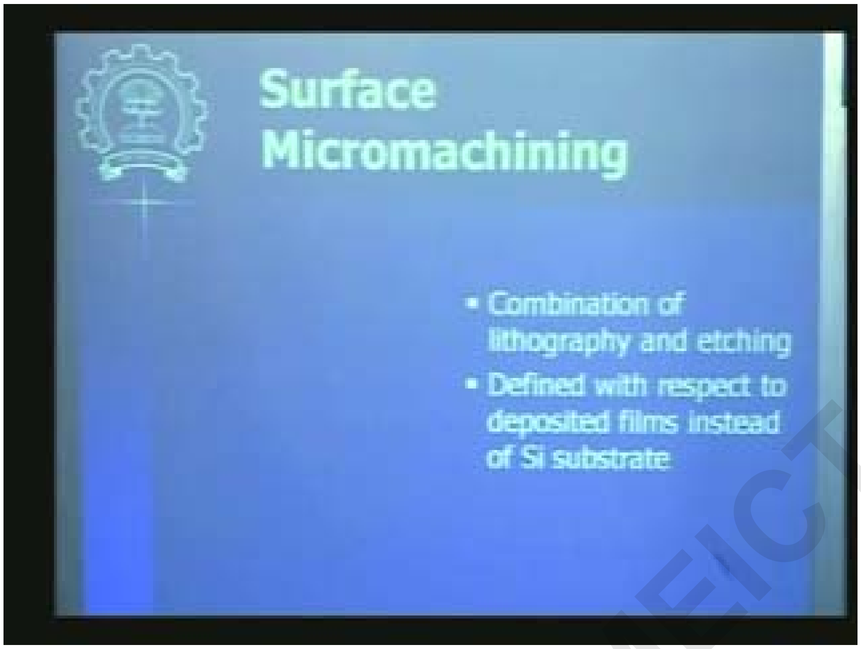
And then like these molecules will get deposited over on the surface and then like you can control the there are different [um] things that you can control is pressure temperature and gas flow to control the deposition okay

How thick the film will be formed is dependent on the all these parameters okay so that is called chemical vapor deposition

Now see the thing is that this chemical vapor deposition you can imagine like um if these molecules are forming in this chamber will get deposited not only on the surface but they will also get deposited on the chamber okay

So that is that is a kind of disadvantage of this process okay

You don’t want them to be deposited on the chamber so that cleaning or removing those things this kind of a additional job okay
(refer slide time 00:38:44)



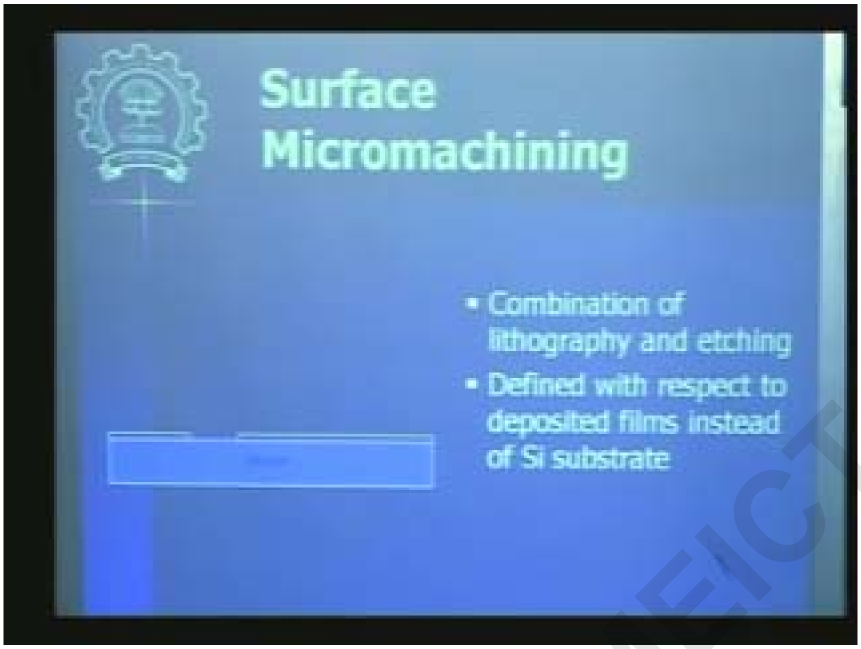
Now let us see surface micromachining which is the next process so it is the combination of lithography and etching processes okay

And it is defined with respect to the deposited films like like you don’t etch directly the substrate silicon and say that it is a micromachining

You etch some deposited film and then call it as a surface micromachining

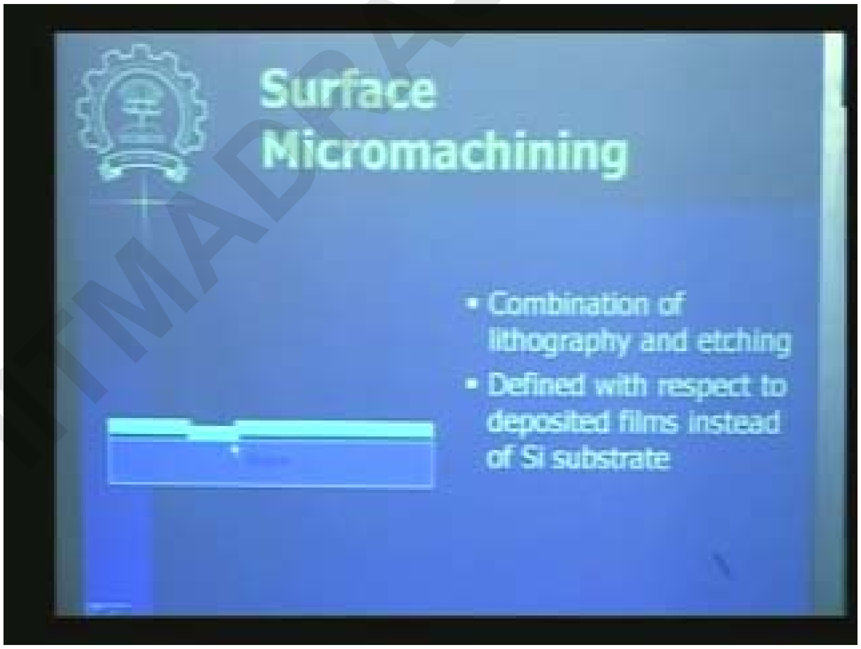
So surface micromachining refers to some deposited film etching okay

So its just one of the cases you can see the animation here (refer slide time 00:39:23)



You have this wafer on which you can have this photo resist which is patterned and you have this window opened over here

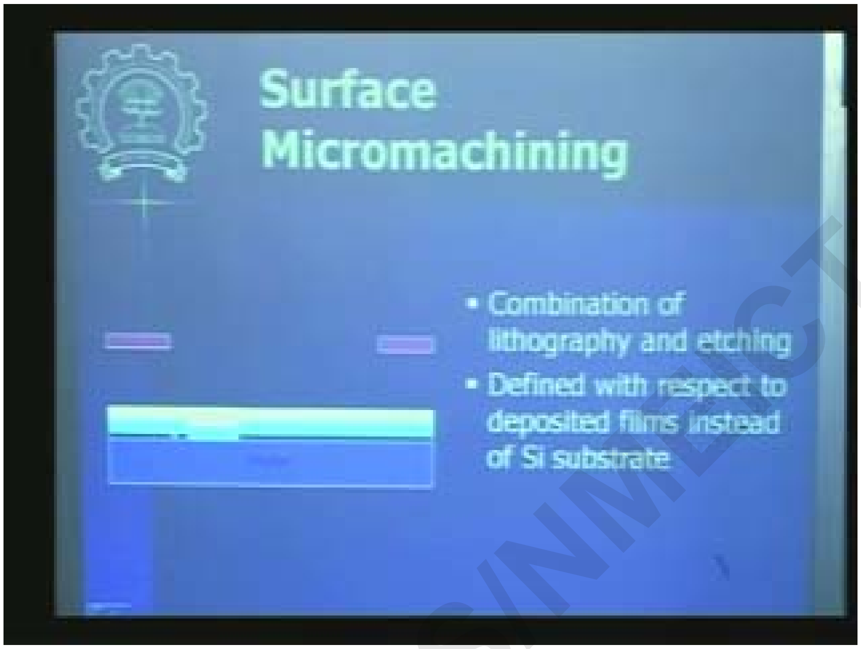
Now you deposit some material there [noise] (refer slide time 00:39:34)



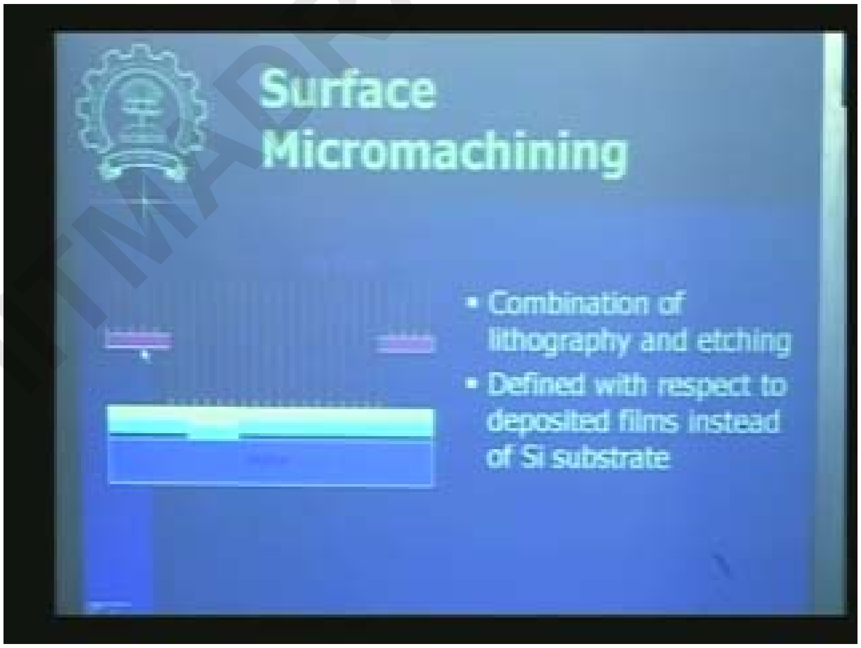
You will get deposited in this kind of a pattern you see i have drawn like these are the very sharp edges but in actual practice there will not be that sharp they will have very smooth edges there but they will have kind of a dimple or a thickness reduction over this area okay

Because you have this window where the material is depositing okay

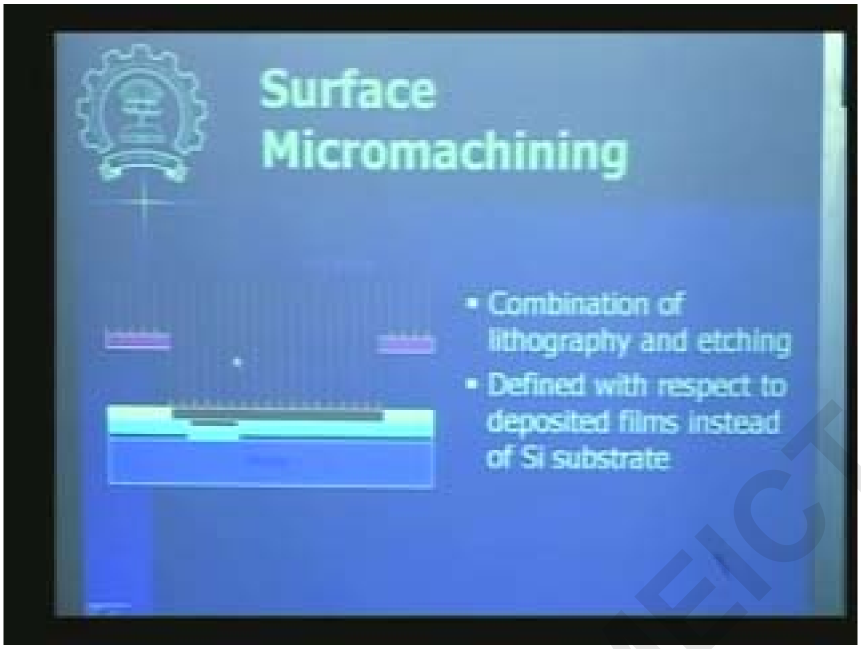
So now you pattern this (refer slide time 00:40:01) like you deposit the your photo resist and then you use this mask to pattern that photo resist okay



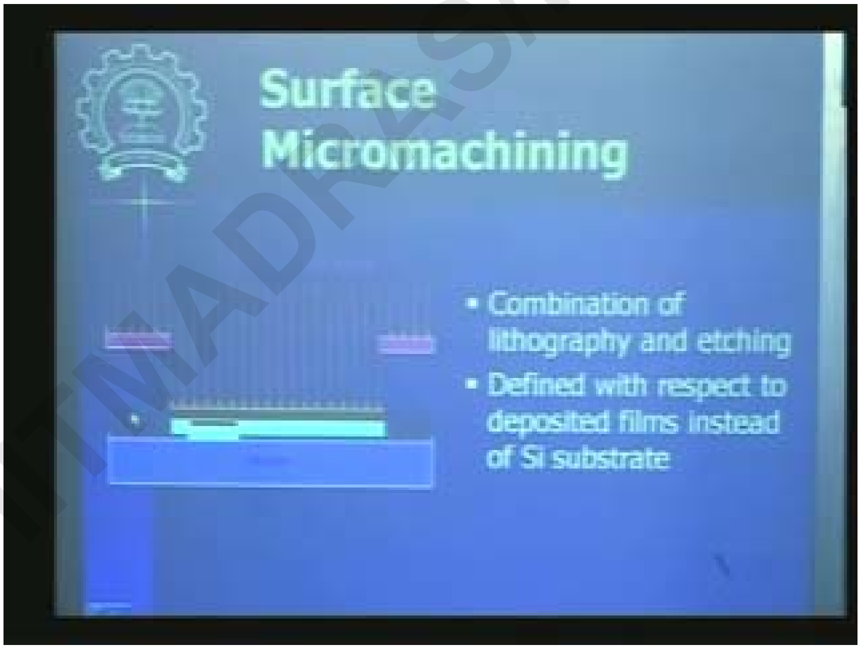
So you expose the pattern now (refer slide time 00:40:13)



And this will get affected okay (refer slide time 00:40:17)



So now you use some chemicals to preserve this part like whatever deposited part and then remove the other part okay (refer slide time 00:40:28)



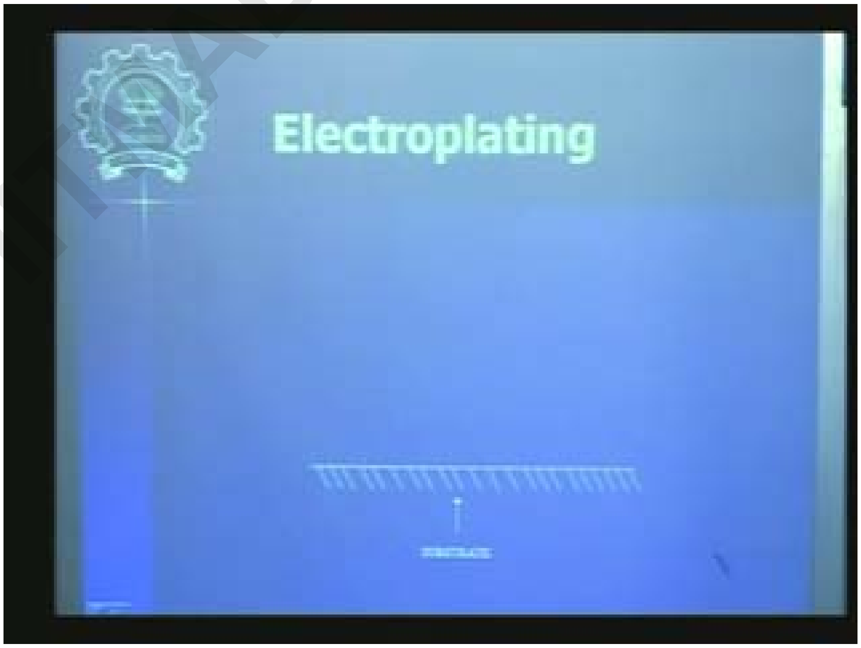
And finally you can use another chemical to release the structure okay when this passion is fabricated micro cantilever and the silicon surface okay and the surface [locomotion] okay

So this is a this is a like fundamental of the process of surface micromachining okay

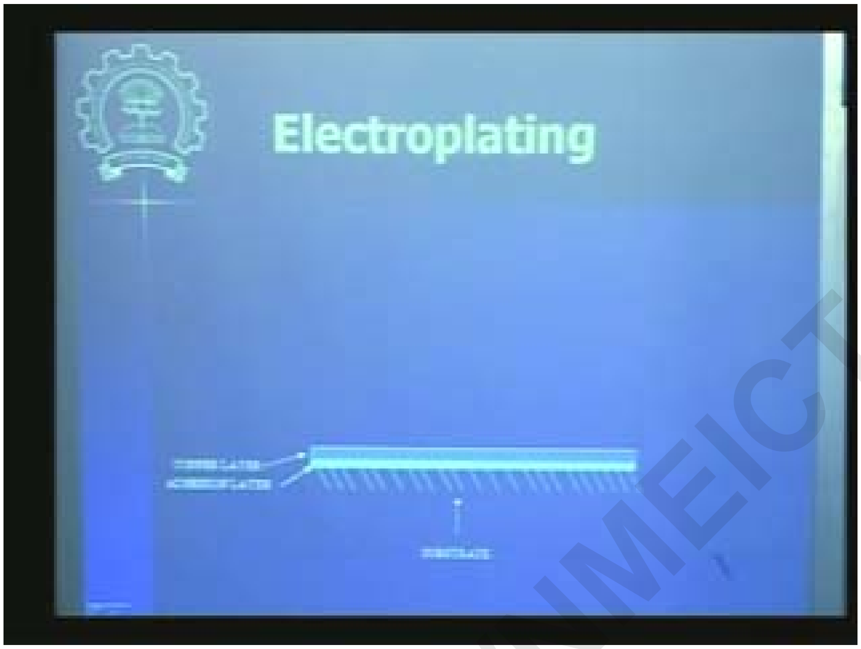
You can have not just like cantilever but you can have many different types of structures for surface micromachining okay

So let us now move on to next process which is electroplating process
(refer slide time 00:41:07)

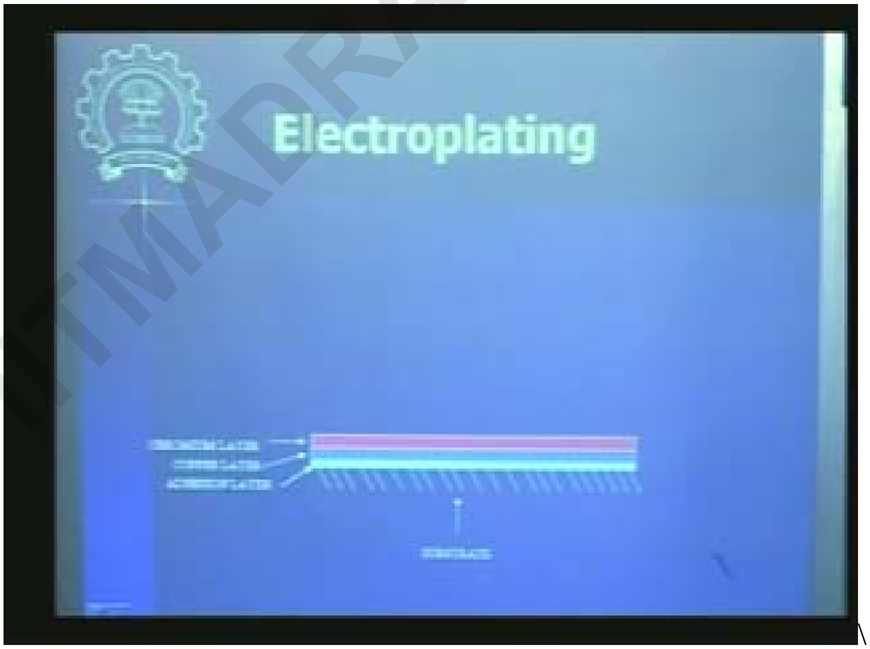
Okay in electroplating as the name suggests like it is again like you create a pattern and then process it and by selectively plate your substrate at some points okay
(refer slide time 00:41:22) here is your substrate



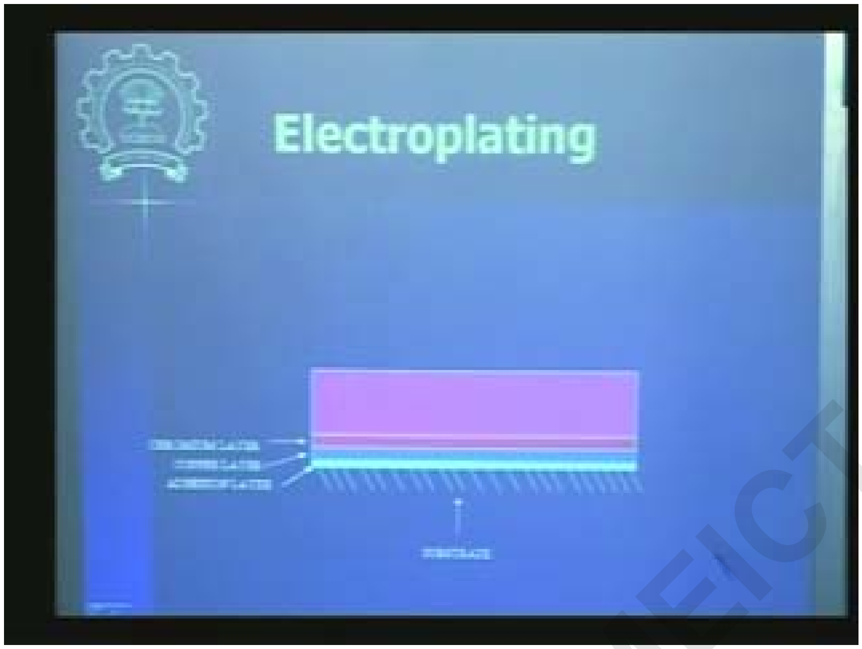
On that there is first there are different layers which are used for addition and some other um chemical effects (refer slide time 00:41:31) that you need in electroplating



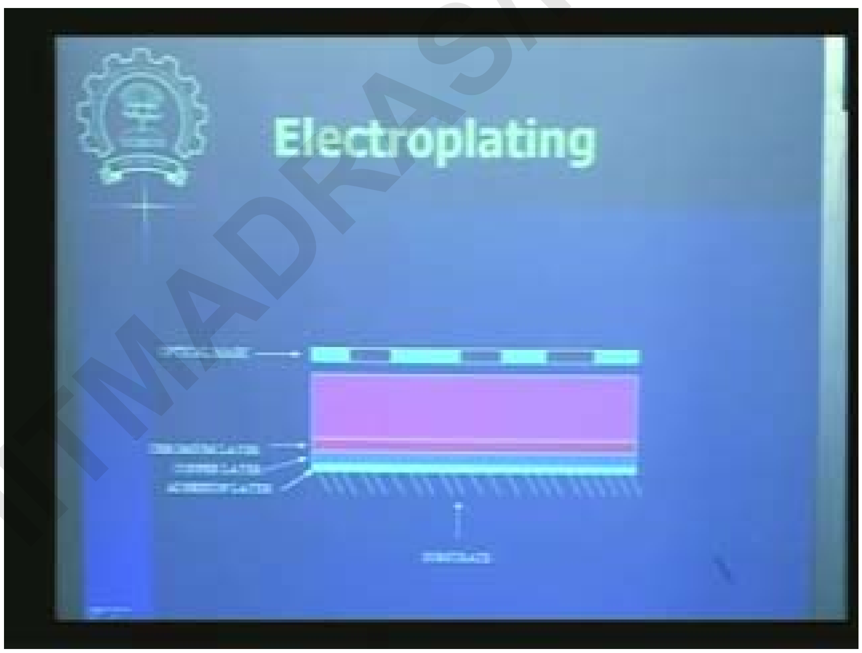
There is a copper layer or copper layer addition we use another layer
(refer slide time 00:41:40)



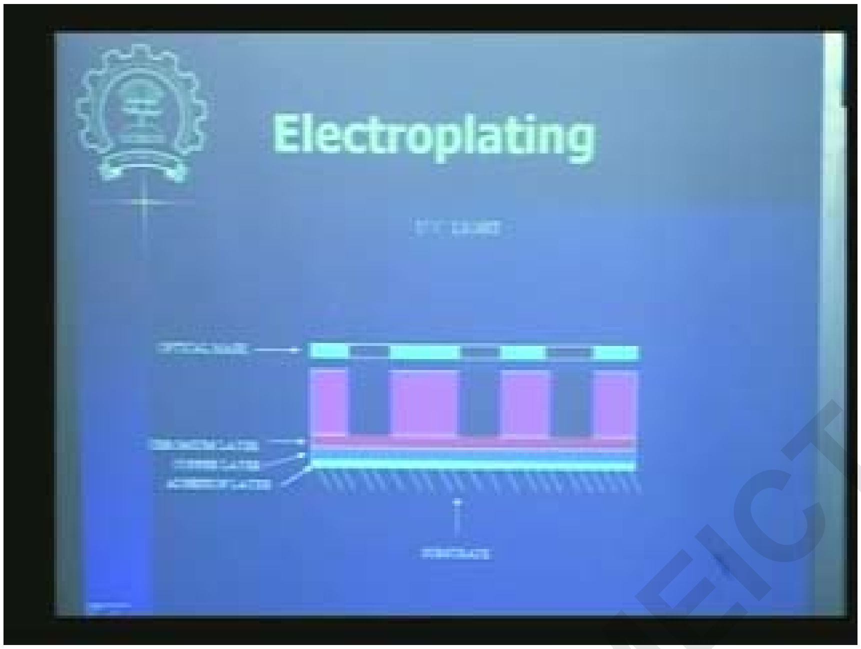
Then on that you have this chromium layer then (refer slide time 00:41:42) this is a photo resist which is called pmma photo resist



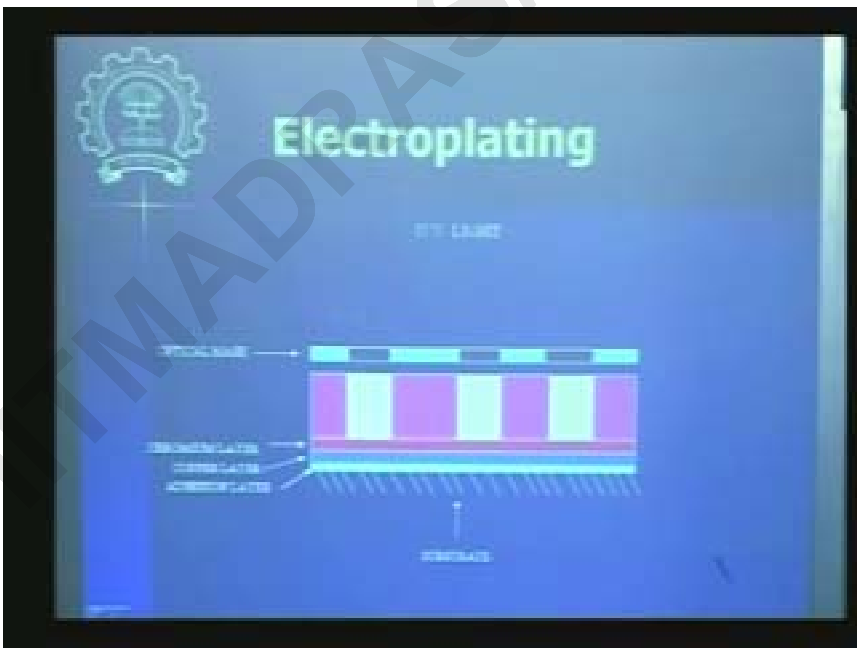
Okay its [noise] some kind of a polymer photo resist okay so you can really deposit very thick photo resist in this places (refer slide time 00:41:55)



Now you have this mask and you pattern the photo resist (refer slide time 00:41:58)

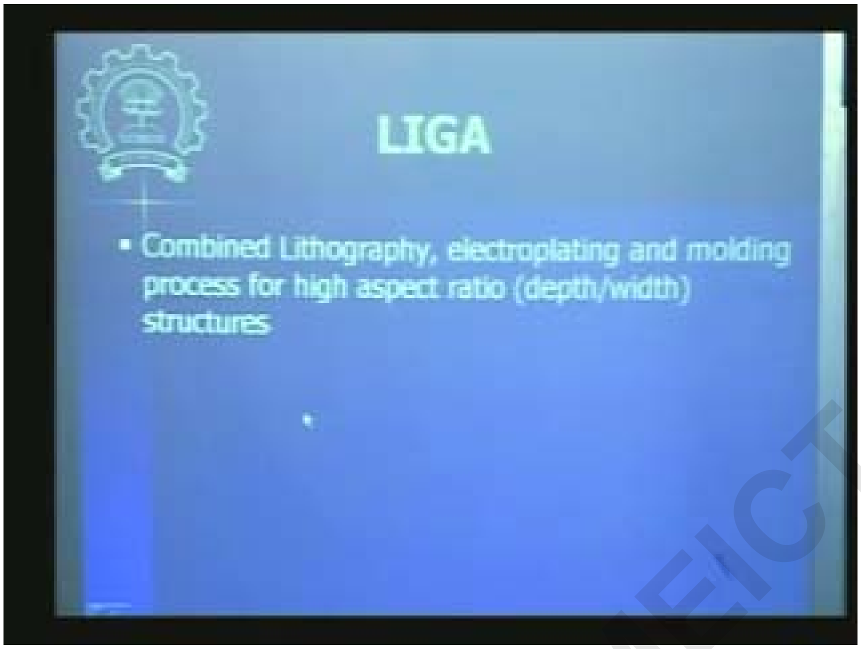


You get like this deep cavity because you have higher thickness and then in these cavities you can start electroplating and then you get this electroplated cavities okay (refer slide time 00:42:08)



Now you can remove the other materials this this part of the photo resist and get your structure okay (refer slide time 00:42:20)

This is a electroplating process now this electroplating process combined with (refer slide time 00:42:28) the molding process



See this electroplating will typically be a costly process and especially when you want to have very deep structures or very high aspect ratio structures it it will be very costlier um

So so these process along with molding process can give you a way to find out to form this molds and then use this molds for further i mean for for replicating the same thing again and again okay

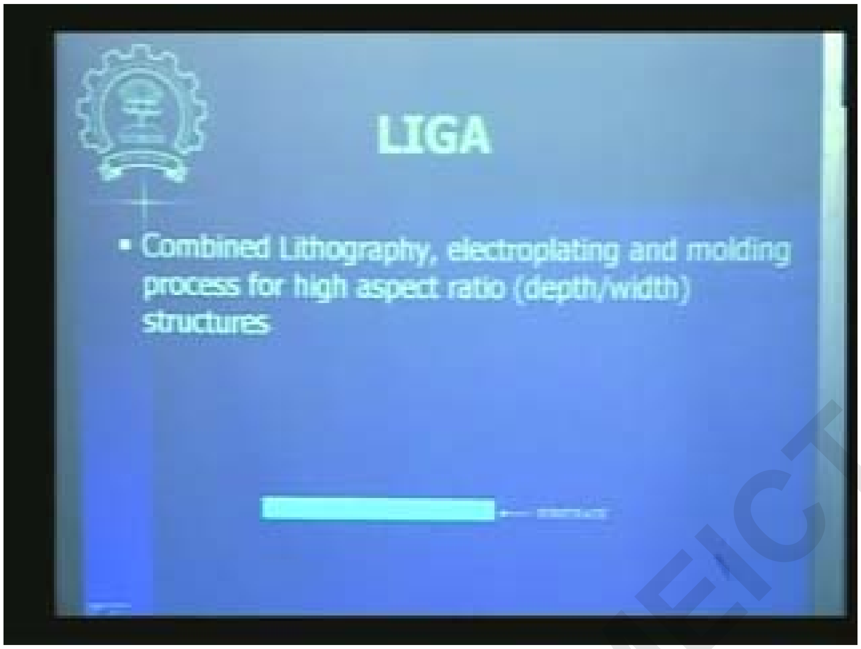
So that is the idea for this LIGA process it's a german name lithography and electroplating and molding combined will have this process okay

And very high aspect ratio how do we get that is basically by using x rays which have a deep pene penetrating property okay

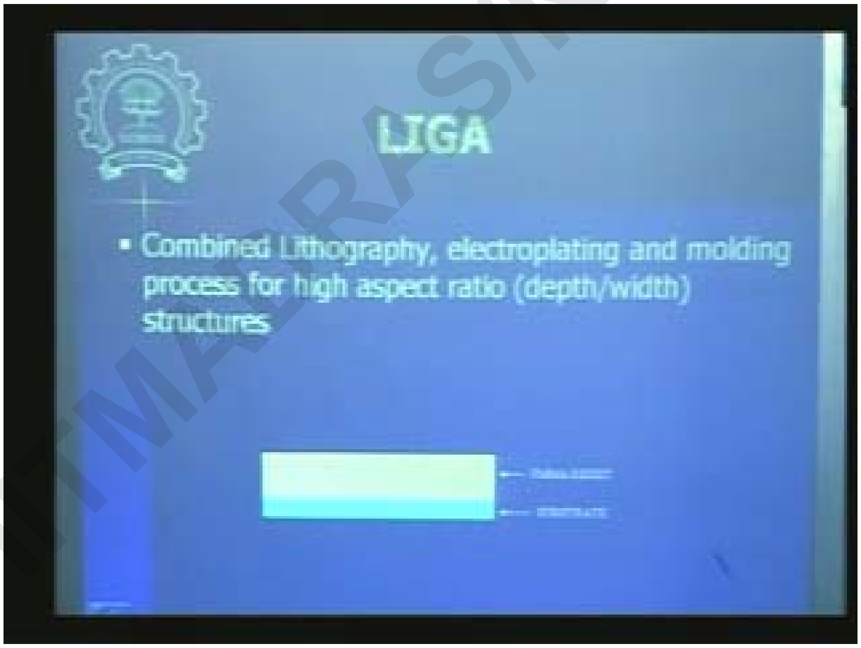
X ray can go really very deep okay so you use x rays and because of that this process becomes costlier and hazardous also okay

So that so this process of LIGA is not very popular in industry or its just at a recent level to form very deep or very high aspect ratio structures MEMS structures okay

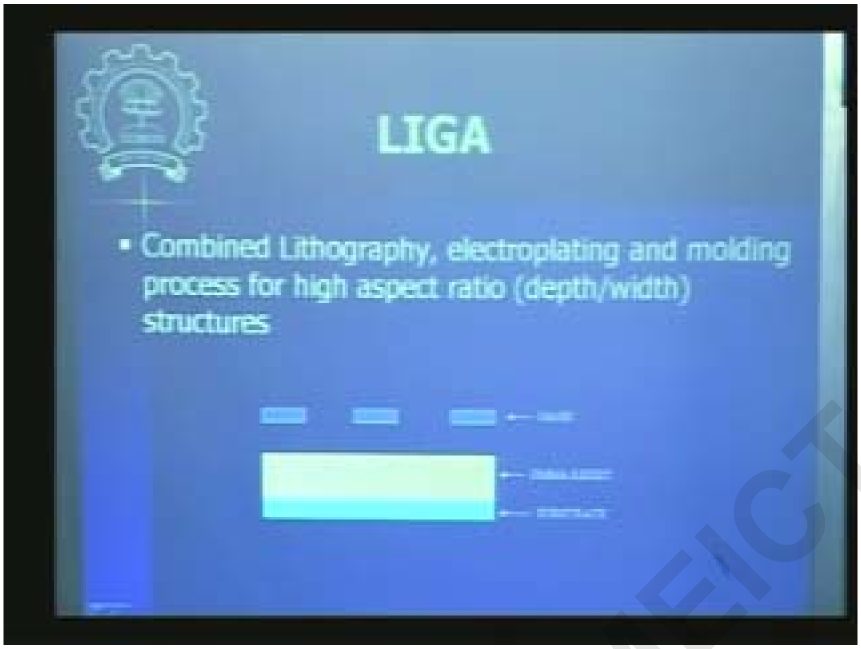
Now let us see what is in detail this process LIGA you have this substrate
(refer slide time 00:43:53)



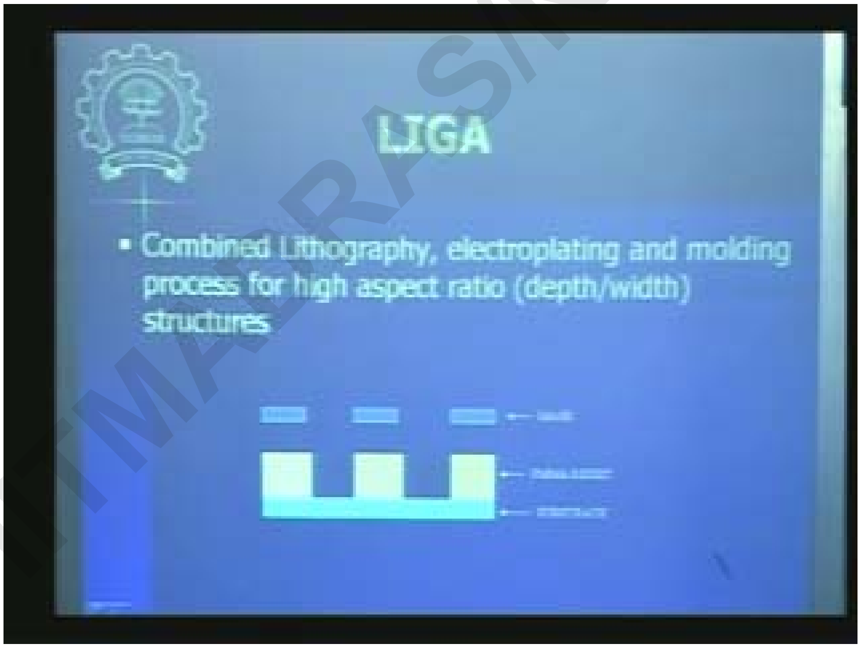
On that you have this e m m a photo resist (refer slide time 00:43:55)



And then you have this mask (refer slide time 00:44:03)

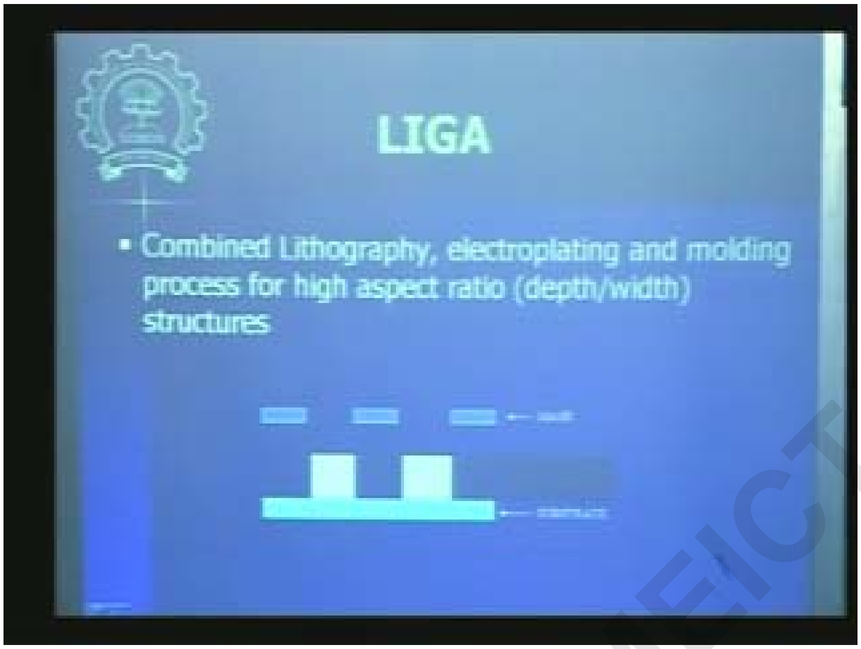


You expose to x rays and pattern produce this pattern (refer slide time 00:44:05)

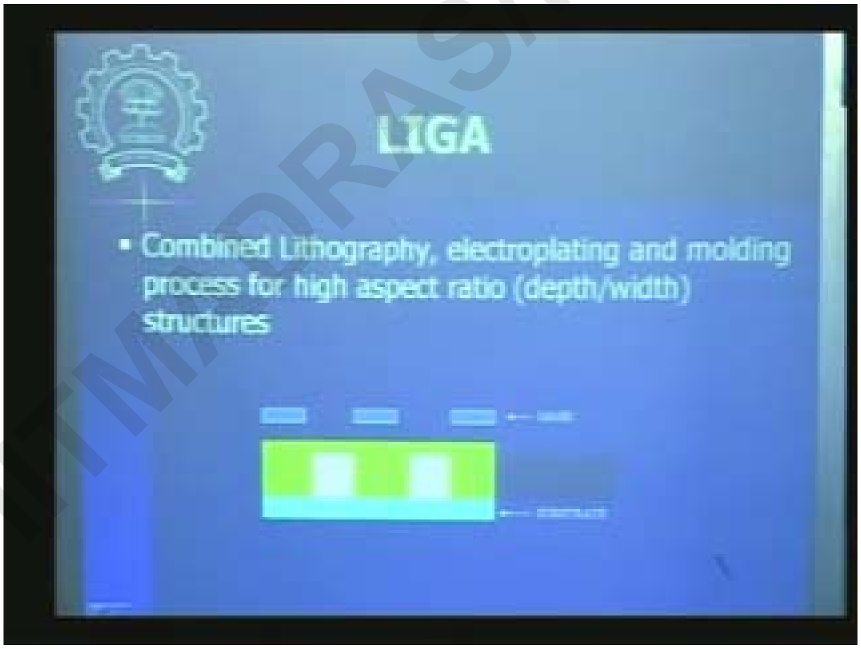


Now this pattern you can now electroplate of course i have not shown like the previous all the addition layers and all those things in in this case but they will typically be there okay

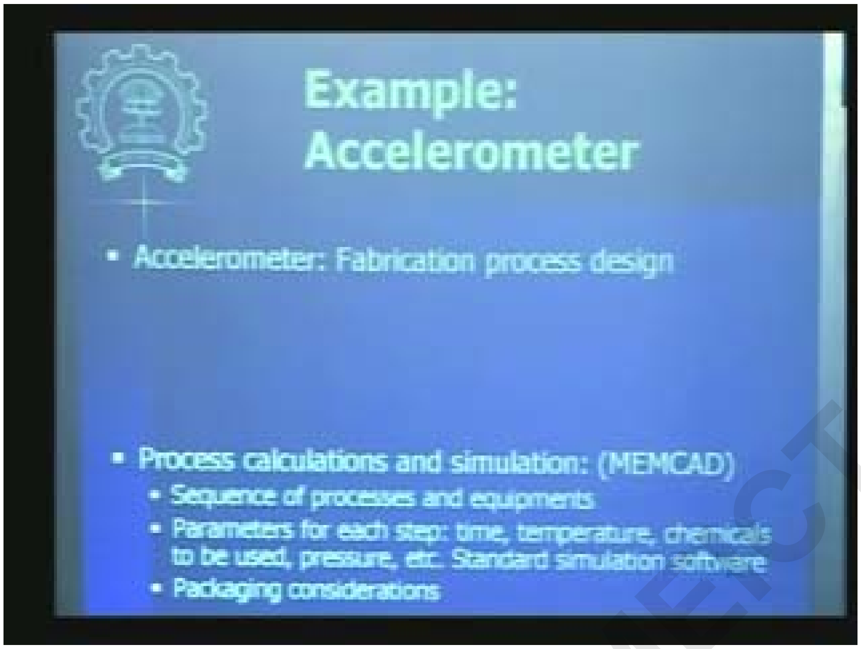
So you can now have this electroplating done to fill this cavities remove now your e m m a photo resist okay (refer slide time 00:44:29)



So now this is kind of a middle structure you have you want to replicate these structure so you produce a mold out of these (refer slide time 00:44:43)



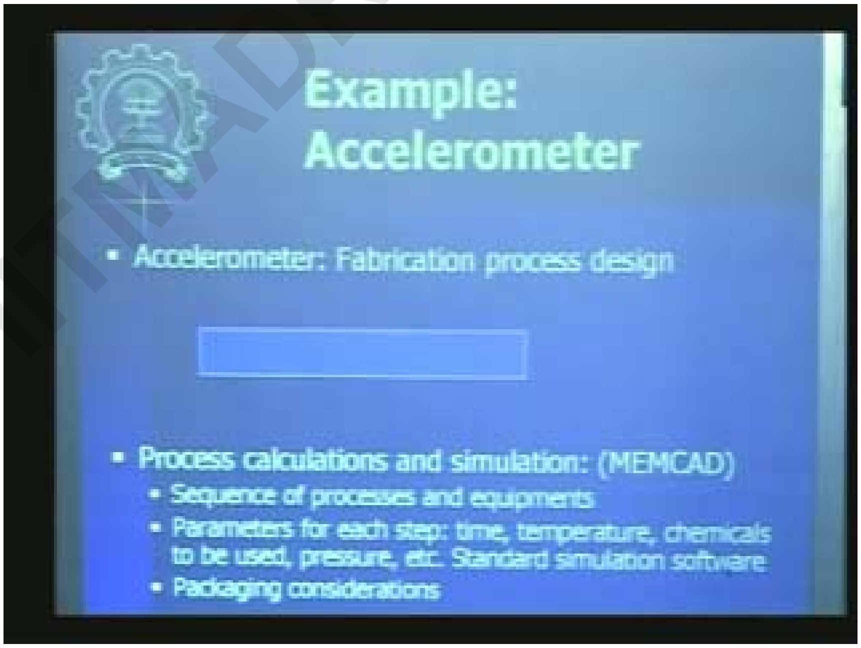
You have this molding material and then you release that to get this mold and then use this mold now to have more electroplating okay that is an idea okay
(refer slide time 00:44:57)



Now let us see one example how the accelerometer will be formed by using these combination of these processes okay

Will not get into many details about that but i can just give you a gist of how these process are used for fabricating the accelerometer

So you have this substrate (refer slide time 00:45:17)



Like this is just one of the procedures this is not the process okay

There are many different ways in which you can fabricate accelerometer okay

This is one of the procedures to demonstrate you the how effectively we can like use this whatever procedures we have studied so far to carry out this design of the or fabrication of the accelerometer (refer slide time 00:45:40)

So you have this silicon dioxide to obtain this wafer so whenever wafers are put in the furnace they will form oxide on both the surface typically okay

Then in this oxide you can open one window (refer slide time 00:45:55) by using like

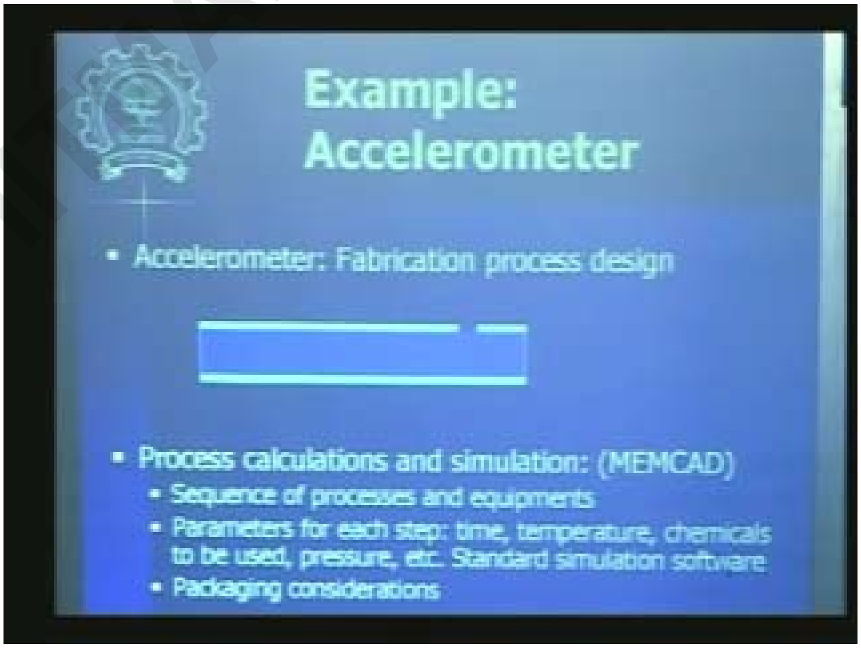
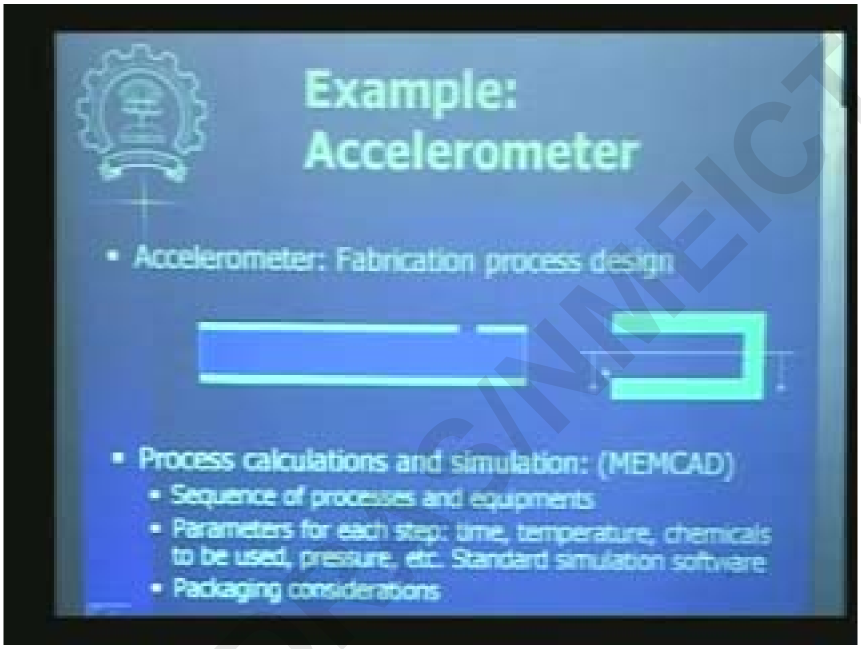


photo resist and then etching of the up head okay

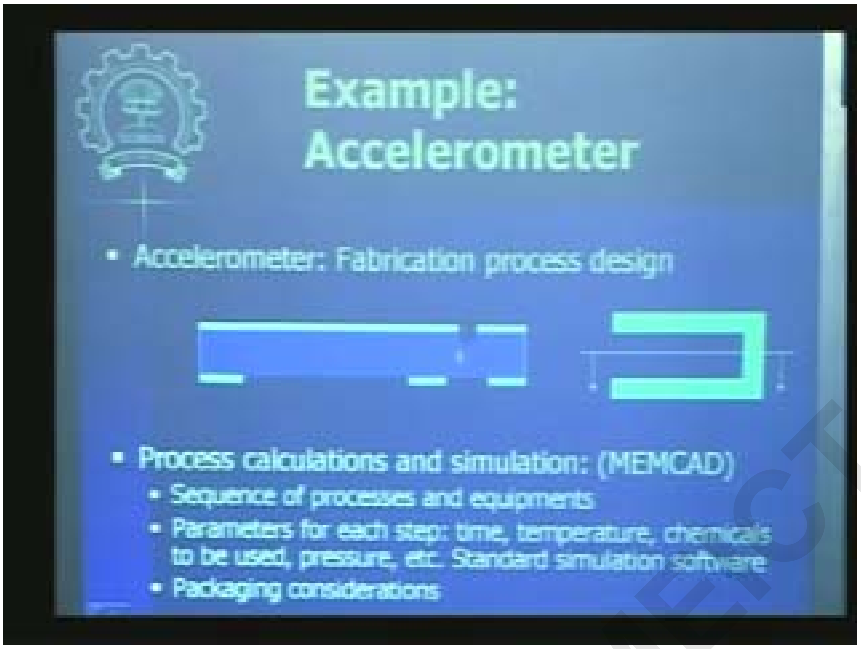
First photo resist etching of the oxide and then again remove the photo resist okay that is the process

On the other side so so so this window will look like this if you see from the top okay so this part whatever i removed here will come as a structure of this part like section of this part okay (refer slide time 00:46:27)

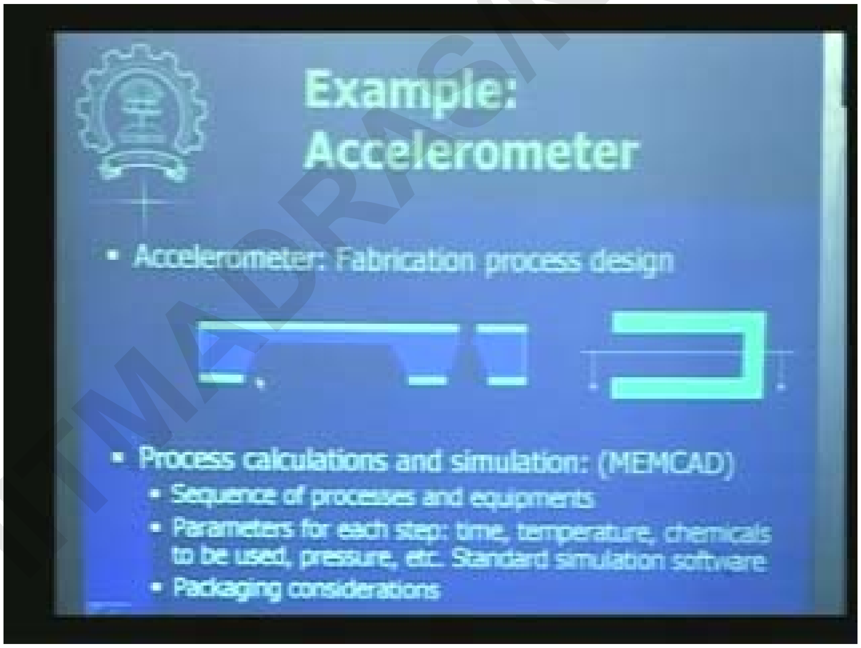


Now if we carried out further like [noise] the etching it will form this kind of a structure isotropic etching

Now you open (refer slide time 00:46:39) two more windows over here or this other window over here



and here we carry out anisotropic etching okay (refer slide time 00:45:50)



So it will form some structure of this form and now you can see that this is a form of your accelerometer and this is the mask which is attached to the end of that arm cantilever type of a accelerator and this is released now

It is of this shape so it is released from this side and as well on this other side in three dimension okay

This is how we have used this isotropic etching anisotropic etching lithography processes or fabricating the accelerometer okay

We are not used any deposition process here say for this oxide okay

Now like there are some separate packages available for process calculation and process simulation

One of them is like this MEMCAD kind of a package okay so this kind of a packages are available for this processing and actually simulating this process and finding out apory what will be the shape and size of your structure

Whether it is visible or not all those things you can find out by doing the a prior simulation okay

Before carrying out actually in the experiment you can do these and then you can carry out experiments and correct ratio procedures and things like that okay

And these these simulations will typically give you all the parameters that you need or actually fabricating the components for your device okay

And there are also packaging considerations which will not go into details again like how do you pack it together so that like it will not get affected by dust or dirt or whatever

So there are like a lot of packaging considerations are there issues are there in that okay so you can you can see that your chips that you get in the market are pack up packed up in some kind of a plastic material it's a black colour plastic material and you will just see the pins out there

The same same thing which we will have to do with all these mechanical components also so that they don't get affected by dirt or dust and in the air okay

So what are the design considerations we will just go over these design considerations for MEMS processes

They are very much different from what we have otherwise the design considerations at the gross level okay

So you you need to be sensitive to these issues okay what are the design considerations for MEMS like when you when you want to design MEMS based robotic system what are the things that you will take into consideration okay

So these are very important considerations that you should pay attention to

So the first point is like you have this design for fabrication okay so you cannot say that i want this this shape for a robot arm or this this kind of a thing robot arm without considering like if it is fabricable or not okay

So any shape like a sharp kind of a shape is not fabricable for the MEMS components okay you can like have mainly planar structure okay

There are some some procedure is now nowadays like we will see in the next class some process are there which can fabricate these higher spic ratio components but but not advisable to use them unless you it is very stringent need okay

If you can manage with changing your modifying your design for fabrication a little bit and produce a component is well and good okay

So you have to see like it in terms of a cost how much cost and see the procedures unconventional procedure that we are going to see then typically be more costly affair okay

So these long shafts cannot be possible now other thing is we have observed here that fabrication is the series of selective deposition and etching okay

You can selectively deposit or selectively etch and fabricate whatever structure you want to fabricate okay

So that is them that is the main essence of the fabrication of MEMS based components they are MEMS based devices

So you have to tune your design to take this aspect into consideration okay so how you can use this fabrication i mean [um] this deposition and etching processes with patterning effectively to get [um] whatever desired structure or component you need

We have seen one example of accelerometer imagine how this possessor are designed okay to get a particular so there are like you can imagine yourself like there can be many different ways you can form a accelerator accelerometer okay

And they design we see we saw was that candilever structure by or surface micromachining

So there is a different way of having the same kind of a candilever okay of course without mask at a end but similar kind of a candilever

Now other important point to remember is this like at a time you have array of devices that can be fabricated see at a time how much you expose or how many components you have like laid down on your mask we will define number of components that you can fabricate okay

So at a time you can fabricate like large number of components okay so conventional design like route where you initially design built the prototype test the prototype and then you modify the design and beat new prototype

Instead of that at a time you can have several prototype fabricated in MEMS okay that is the mature advantage of MEMS like at a type you can fabricate say number of candilever with variable lens

And then choose one which is a good for your design so that way like you avoid like this serial procedures of modifying your design okay

So you can select appropriate design and then now we can finalize on that particular design that is the idea okay

And then um other important thing is cost which we have to we have to consider this aspect like you have to decrease as many as possible number of lithography your exposure steps which involve masking okay

You should avoid mask like number of lithography steps okay

And then there are some other considerations which are like not all characterize their many of them are in research domain still

But there are considerations for thermal expansion then you have consideration for air damping like you see when you design at a gross level the component you don't bother about air which is damping here comp

Air damping effect is null i mean is almost negligible but when u go for MEMS base components this air damping becomes very significant okay

So when you carry out the experiments in vacuum and when you carry out experiments with ambient air then you will find like there is a lot of difference in the results that you get okay because of the air damping effect

So how to consider that this is an other consideration okay now integration of electronics with mechanical device that is other very important actually

Now now all the mechanical device fabrication processes they should be compatible or in many cases they may not be compatible so in that case like you can fabricate this mechanical part separately land electronic part separately and then like have some connection in between on the same chip you can have all those things

There is called hybrid technology you have both like electronics and mechanical together but I mean they are not fabricated together okay like individual I mean is mechanical part is fabricated separately electronic is fabricated separately and they are integrated on a single chip okay

And of course there are packaging and safety issues okay so these are typical design considerations that they have to bother about that by for designing is MEMS base [ ] (refer slide time 00:55:26)

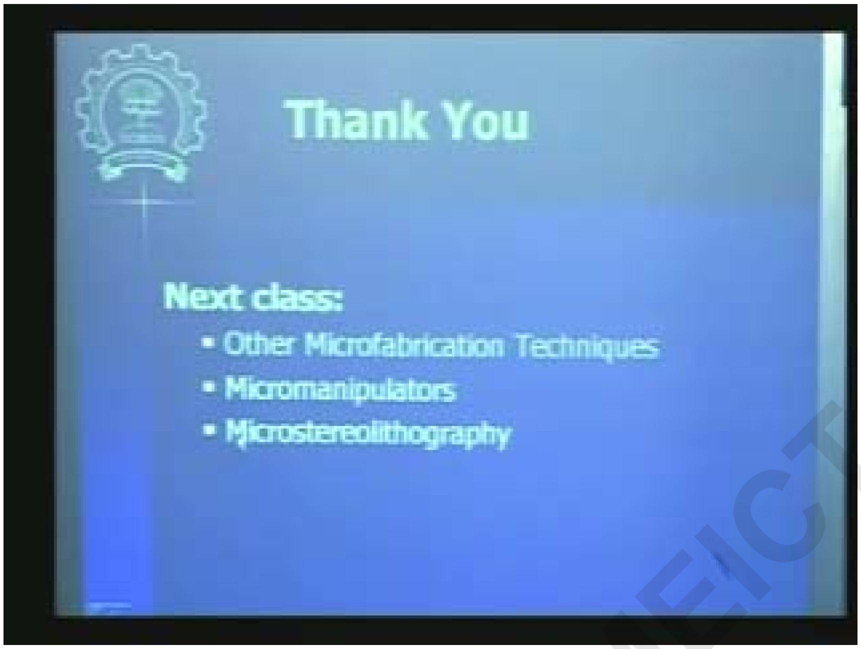
Now this is just the summary again of what all we have seen today

We have seen lithography steps basically for patterning then we saw this material removal processes chemical etching and plasma based etching processes

Then material deposition processes its oxidation sputtering chemical vapor deposition electroplating so you have to use appropriate process for whatever things we want to fabricate okay

And then we saw some design considerations along with this two surface micromachining and LIGA okay

Now in the next class we will see (refer slide time 00:56:11) um what are micromanipulator okay some some details about micromanipulator which are very much relevant to the robotics kind of fabrication



And then some um other micro fabrication processes which are micro stereo lithography which are not conventional like not MEMS or not silicon based

So these processes we will see in the next class okay

We will close for today

Thank you