MEMS and Microsystems
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Lecture No. #13
Surface and Quartz Micromachining

Last class we had a discussion on the bulk micromachining of silicon. Today we will discuss on surface micromachining of silicon as well as quartz micromachining. As I told in my lecture on MEMS materials that quartz is also an important MEMS material lot of sensors are fabricated using quartz because it is a very good piezoelectric material. So if you use quartz in MEMS sensor, you have to have some technology on micromachining of quartz. So that part also I will discuss in today's lecture.

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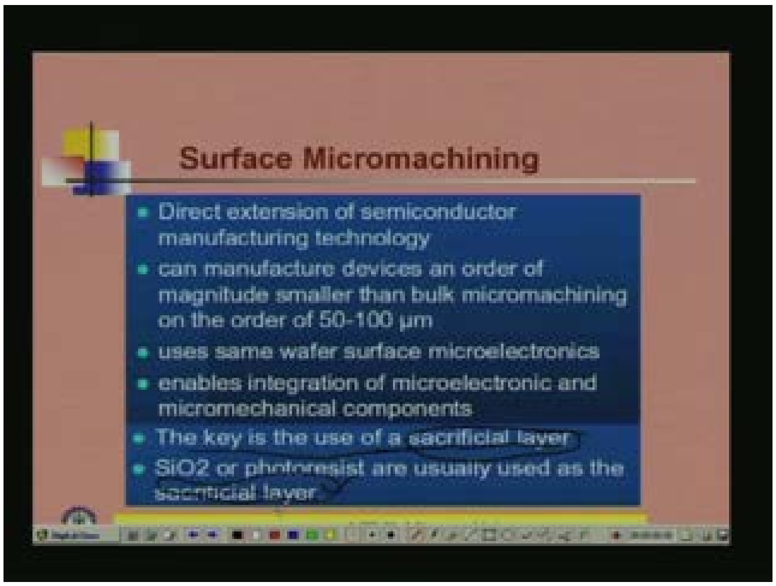

Now surface micromachining is a direct extension of semiconductor manufacturing technology. Direct extension means, it is coming from the normal etching which is used in VLSI processing. Bulk micromachining is not a direct extension because in normal VLSI processes do not require the etching up to 300 micron, 400 or 500 micrometer. But surface micromachining here etching is in the range of few microns 1 micron or 2 microns; in some cases may be 500 angstroms also. So that is why they mention that these surface micromachining phenomena is a direct extension of semiconductor manufacturing process because the etching dip are more or less same as the VLSI process. Next point is it can manufacture devices an order of magnitude smaller than bulk micromachining on the order of 50 to 100 micrometer. So where, that means here the order, the manufacturing devices you can made much smaller, one order smaller in dimension.

The reason is if you go for higher etching, higher depth etching, so then automatically there are some slant portion will be there which is not etching, 1 1 1 like that, pyramidal structure. So for that you have to allow certain space, but if you go for very small amount of etching in the range of say 2 micron or 3 micron, so that much space you do not have to spend in the silicon surface. So in that way you can reduce the complete area of device if you go for surface micromachining technology. Next point is use a same wafer surface microelectronics. That means same wafer surface microelectronic means, so wherever on the same surface you are making microelectronic devices as well as the MEMS sensors. That means you are going to use same wafer surface for making the structure as well as the microelectronic device means transistor, diodes, etcetera. That means it is highly comfortable with the IC process because it is surface micromachining which is mentioned in the following point also.

It enables integration of microelectronic and micromechanical components. Because everything on the surface your devices circuit is also on the surface. So the mechanical structure is also on the surface, so is very easily you can integrate these mechanical parts as well as the electronic or microelectronic circuit part, because both live on the surface without any problem. It does not mean that in bulk micromachining you cannot integrative. You can do it but with little bit more trouble you have to face there. Because in in case of some cases of bulk micromachine structure are very uneven surface where directly interconnection of lines, interconnect lines from the ICs and in mechanical devices cannot run so much depth which is of the order of 300 micrometer or 4 micrometer, some cases say 200 micrometer also. So that is why we call the surface micromachining process is highly compatible with VLSI normal process.

That means here smart sensor basically sensor and signal conversion circuit can be integrated very easily which is not that much easy in case of bulk micromachining and in surface micromachining process, the key the use of a sacrificial layer, it is mentioned. Here you can see, this is sacrificial layer means this is very important here, sacrificial layer. The key is the use of a sacrificial layer in case of this surface micromachining process. So I will discuss in detail what is a sacrificial layer, what is the structural layer. There are two kind of layer we use in case of surface micromachining; structural and sacrificial layer. Silicon dioxide or photoresist are usually used as sacrificial layer. There other also but this silicon dioxide and the photoresist are very popular material as sacrificial layer.

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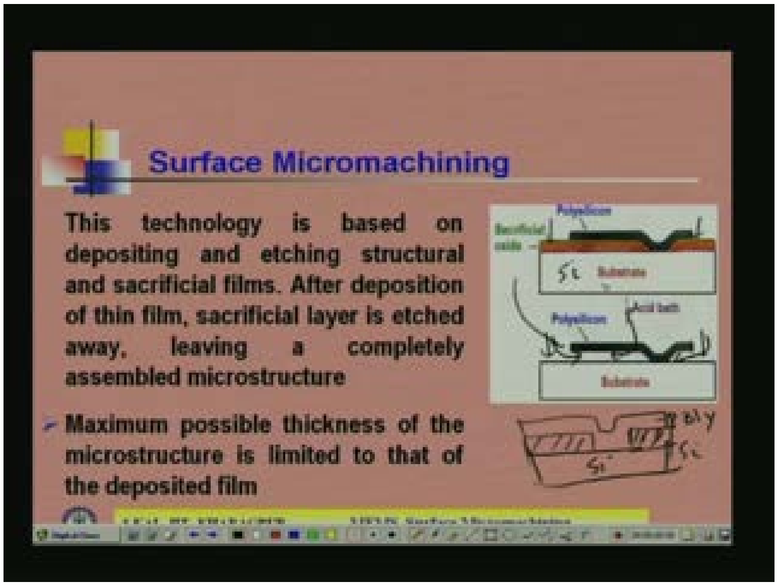

Now, surface micromachining here you can see some diagrams which explain how we can go for surface micromachine structures. It is basically based on depositing and etching structural and sacrificial film. After deposition of thin film, sacrificial layer is etched away leaving a completely assembled microstructure, maximum possible thickness on the microstructure is limited to that of the deposited film. So now let me little bit explain based on this figure. So now here, this is the substrate which is silicon, this substrate may be silicon. Now on silicon substrate, first the sacrificial layer which is silicon dioxide, that is either it is grown or deposited. Then you pattern sacrificial oxide that means here you will get after patterning, this case you will get like that because this is something like this you will get.This is silicon and this is oxide silicon dioxide U pattern.

Now you deposit here, this polysilicon layer that polysilicon will be the structural layer. Now you pattern polysilicon because while you deposit it will be deposited like this. This is the polysilicon. Now after that you just using photolithography you pattern it. If you pattern it will be like that. Now in like put whole thing in acid bath, if you put in acid bath which can etch the sacrificial oxide, so that you see oxide is not a crystal. That means that etching is here is isotropic etching. If you put in acid bath, so is not direction dependency like silicon etching means 1 1 1, 0 0 0 or 1 1 1 on 1 1 0. These anisotropy of etching depend crystallographic plain orientation and anisotropic etching. Those points are not coming into picture in this particular case. Because you are etching silicon dioxide whose etching solution is buffered hydrofluoric acid. So now if you EH the sacrificial oxide, that is basically the isotropic etching, so that means it will etch from top also and then after complete etching these particular location here and here then it will etch in this direction it will go here, it will go here, like that.

So that means wherever the oxide, complete oxide is removed. Then what will be there? It will be complete hang because this is isotropic etching lateral it will go. And your selective etching you are using, that is buffer hydrofluoric acid that will not etch silicon underline silicon. So it will go in this direction and again it will go in this direction, it is go in other side also like that. In this way the complete oxide will remove and this structure will hang. So that is basically the surface micromachining. In the next view graph I will show you in detail with respect to the mask, how the surface micromachining process steps basically one by one.

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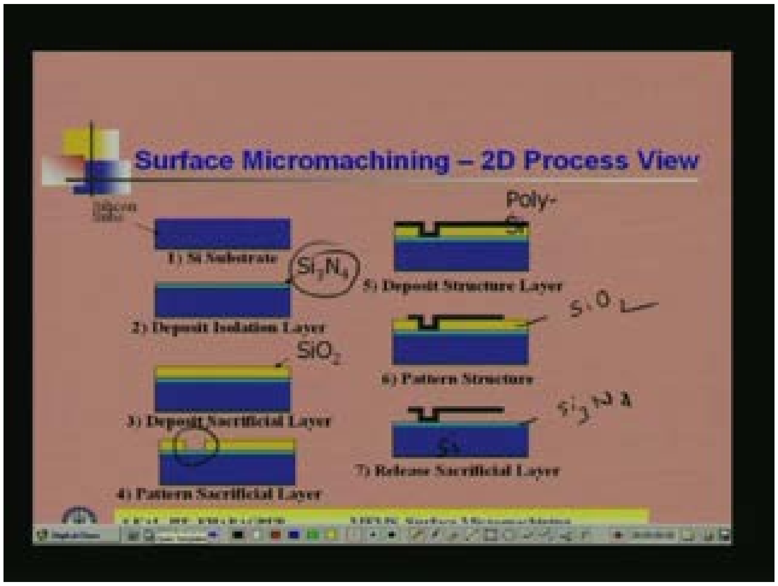

Now this is the cross section schematic process, the diagram two dimensional process of the surface micromachining. What I just told you there, you can see the first one is the silicon substrate first step. Then you deposit silicon nitride because in many cases the structural layer may rest not on silicon. But on some insulating layer, because if you rest the earlier diagram which I showed, that is resetting on silicon silicon is not an insulating layer, this is semiconducting material. So semiconductor material means that the hanging structure what you are making, that will have some contact semiconduct to polysilicon contact will be there. If I do not want it, if you want the isolated some free structure then we have to structure or we have to fabricate that one on some insulating layer. That is the reason why in this diagram first on silicon we have deposited a silicon nitride.

You can see here this greenish color, that is silicon nitride, this is silicon nitride here, after silicon nitride is deposited that is basically known as isolation layer which isolate the substrate and the structure. That is why it is known as isolation layer. Now you are coming to the third diagram which is the silicon dioxide deposition and then patterning silicon dioxide deposi8tion and patterning which is the sacrificial layer. Sacrificial layer is always later on removed. So this silicon dioxide is deposited, then by using photolithography technique we pattern here. We made a hole in this particular location; a hole is made here by photolithography technique. Now coming to this step now you deposit polysilicon; polysilicon is deposited here. Now if you deposit polysilicon, it will not be conformal because here some groups are there. So automatically here it will go the shape, will not be exactly plane on the top of the surface it will be something like that.

After that, you pattern polysilicon just I showed you in earlier view graph pattern polysilicon. Using the lithography technique, then you go for etching. That silicon, that side SiO_2 which is this is SiO_2 and that we remove completely and this is a hanging structure on nitride. So it is the this is isolated from the silicon substrate. This is basically silicon and silicon substrate, this is basically silicon nitride Si_3N_4. Now on Si_3N_4 you are just structuring that the polysilicon you can say cantilever beam you can make it. This is surface micromachining process.

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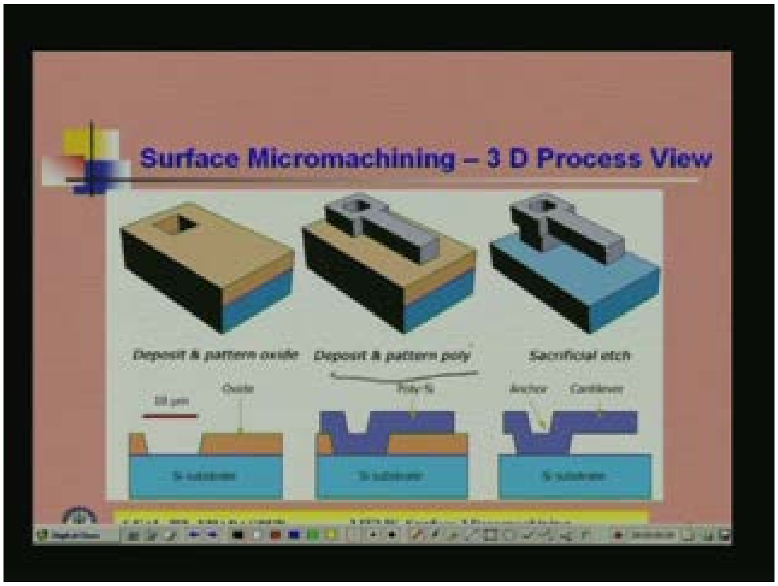

Now this is another view graph you can see the 3D process flow. So earlier view graph is a 2D process flow and this is three dimensional view is given. So that you will have good consumption regarding how the surface micromachining is going on. So 3D view that means, similar to that here again, there is no insulating layer is there. Only on semiconductor, the free hanging cantilever beam, how can you fabricate and is shown here. In the first diagram you can see here, this is basically on the on deposition pattern oxide. The similar earlier is a 2D view it is a 3D view that is the difference. So you oxide pattern then you oxide pattern is shown is a cross sectional also what you have seen say this is a 10 micrometer, this oxide this is, its look like this. If you see the cross section and if you do the 3D view, it looks that. Then you polysilicon your deposited and pattern deposit and pattern poly, so you will get polysilicon layer and pattern like that. Now you remove this, the silicon substrate at this is known as anchor. Anchor means when it is fixed with the substrate and you etch sacrificial layer it looks like this. Very simply the 3D you will have some clear picture, view clear idea how the complete thing is going on.

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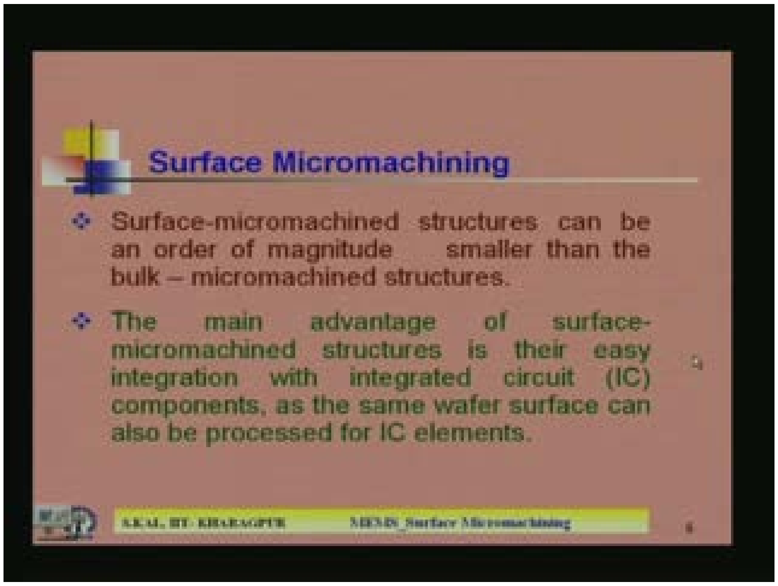

Now so thus after that the process of making structures using surface micromachining, you can see the main advantage of this particular method, is the integration with integrated circuit components. Because here the whole thing lies in the surface and we have got little thickness depth. So that is the main advantage of the surface micromachining process and I also told you this is your structure, is one order smaller than the bulk micromachining.

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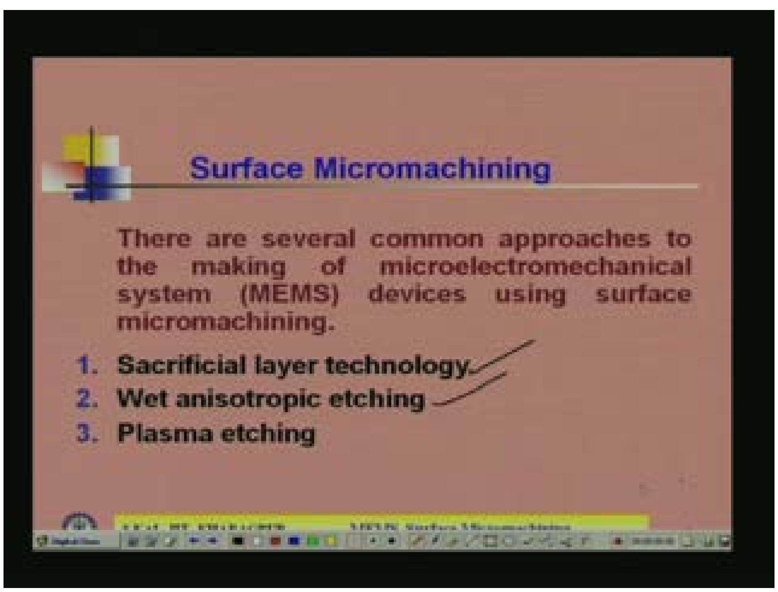

Now what are the common approaches to the making of micro electro mechanical system devices using surface micromachining? One is sacrificial layer technology, now here in this particular case the sacrificial layer technology just now I discussed how it can be done. Second is wet anisotropic etching. Some cases we use isotroping etching also. Because when you want etching from the side, so it is vertical etch as well as lateral etch, so that is isotropic. So the wet etching is much favored in making surface micromachining devices compare to the RIB or RIE. Because when you need isotropic then RIE is cannot give, you have to go for ion milling technique or the plasma etching technique which is isotropic in dry. But in normal liquid etchings are mostly the isotropic etchings. And third one is plasma etching. Plasma etching as I just now told plasma etching or ion milling etching. These are isotropic in nature but if you use reactive ion milling etching. Those are mostly anisotropic you cannot get the isotopic property there. So normally if you want to remove some of the layer film, below certain layer you have to go for the lateral etching also. Then best choice is plasma etching or wet etching.

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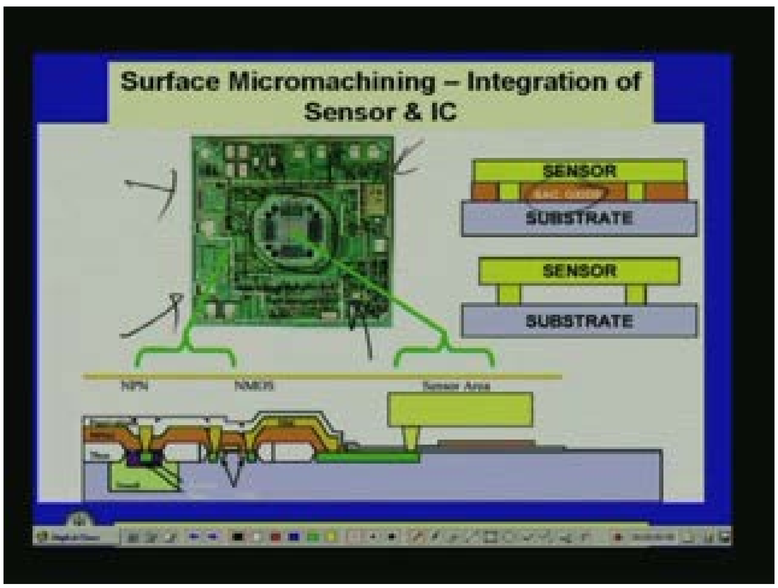

Now here is integration of sensor IC in surface micromachining, you can see here. So this is the complete picture of one MEMS where micromechanical system. So devices as I are all integrated on the surface of the silicon as I just now few minutes back I told you. So here highly possible integration of the components and circuits and micromechanical structures. So here, this device some cross section is shown here. So basically here you can see, say the devices say inclined transistor. So N most device and then it is connected with this layer the sensor area and the sensor area here how the sensor looks like it also shown here. So in the middle portion in this particular location you can get this sensor area is in here and the peripheral they are using the other this here, here, here and in this direction all are the circuits and some cross section how it can couple together the BJT the emitter base and collector.

That is also there and obviously their technology is not as simple as you normal transistor fabrication process. Because here you have to have some compatibility study. Somewhere you have to you had to forego some of your requirements. So in that case some compromise has to be made in process technology complete process technology and the sensor area how this is sacrificial oxide is shown here. How it is removed and just like that cross section if you see, the sensor area can be floating, some floating structure you can make like that by using surface micromachining. At the same time you are making devices here. So integration of sensors and ICs are shown in this diagram.

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Now then in a nutshell we can say what are the key processing steps? First step is a deposition and patterning of a sacrificial silicon dioxide layer on the substrate. Next step is deposition and definition of a polysilicon film. If you remember the cross section diagram just you can see after the sacrificial patterning. While depositing the polysilicon film, then removal of the sacrificial oxide by lateral etching in hydrofluoric acid. If you need select hydrofluoric acid is a choiceable thing if you do it on insulating layer. If you go for etching of silicon dioxide on silicon nitride then there is no problem in hydrofluoric acid. You do not need selectivity in silicon. But in some application if you want make this structure on silicon, then you have to go for buffer hydrofluoric acid because BHF does not attract silicon. It will attract only silicon dioxide. Now etching away the oxide underneath the polysilicon structure, here we refer to polysilicon and silicon dioxide as the structural and sacrificial materials respectively.

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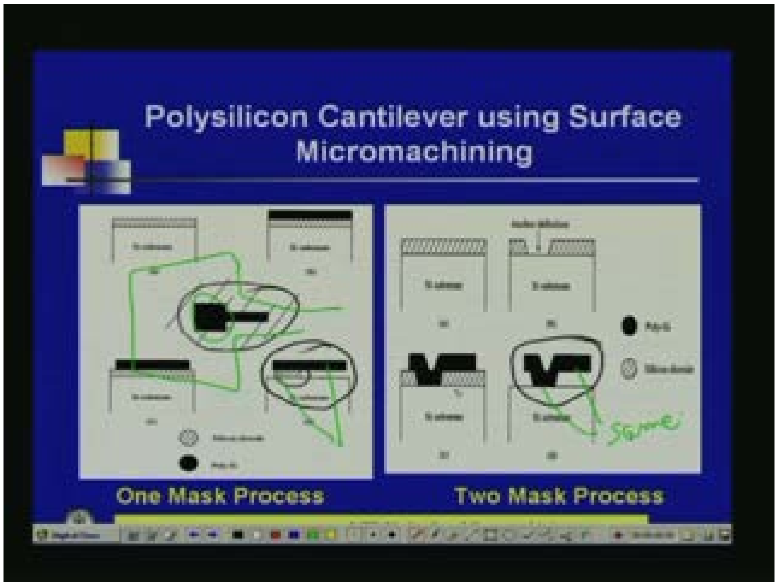

Now, the polysilicon cantilever using surface micromachining there are two methods. One is known as one mask process, other is known as a two mask process. So in some case you need two mask what I discussed in earlier view graph that required two mask. One you are patterning the sacrificial oxide one mask then you patterning the structural layer another mask. That means sacrificial layer patterning mask and structural their patterning mask. When you use both then it is known as the two mask process. On the other hand you can go for only one mask process also but with some limitation that is difference is shown here in the left side is a one mask process. You see silicon, silicon dioxide is grown then the structural layer is deposited and then after that the structural layer is patterned. This is the pattern like, this is the pattern of the structural layer. These are pattern of the structural layer here.

So now if you pattern, that structural layer then it looks like this. Then what they did? You just go for the etching. What etching silicon dioxide etching? Now here you see I told some limitation. What are those limitations? Limitation is that the beam is floating here, it supported on silicon dioxide. But if you go for two masks process that, this region is also made of the structural material. Like just side by side you see, here is the first mask you have anchored definition is the first mask in the structural layer. Then you deposit polysilicon, then you remove the structural layer you are getting this structure. Now if you compare this and along with this then what you will get? You will get here so, you see here this material and this material both are same. But here, this one and this one are different. On the other hand another limitation, if you go for longer etching, this particular point may also etched, the anchor region may also etched. So that means you are making a simple process by using only one mask at the cost of the some limitations.

So these limitations are these one. So here another point is there this kind of the surface micromachine structure. For example if the surface area is very large, for example instead of that if you want make like this. So this instead of this one if you wet larger area then what will happen everything is etched from the side. So that side etching gradually will reduce with time.

So even it is of a very small area, so immediate with the small amount of time it floats. But over a larger area complete removal of the underlying layer, it will take lot of time and then the problems of surface stiction will come into the picture is a larger area, longer length even is a narrower width and long beam. If you want to make, then surface stiction problem which I will again add this after few minutes in the same lecture, then you will find those are some added hazards or added problems in case of surface micromachining. But if you go for two masks, if you use another mask, also then the total thing is easy and both things are with polysilicon and then the removal of this particular layer with longer etching. That problem is also not there. This layer means oxide layer.

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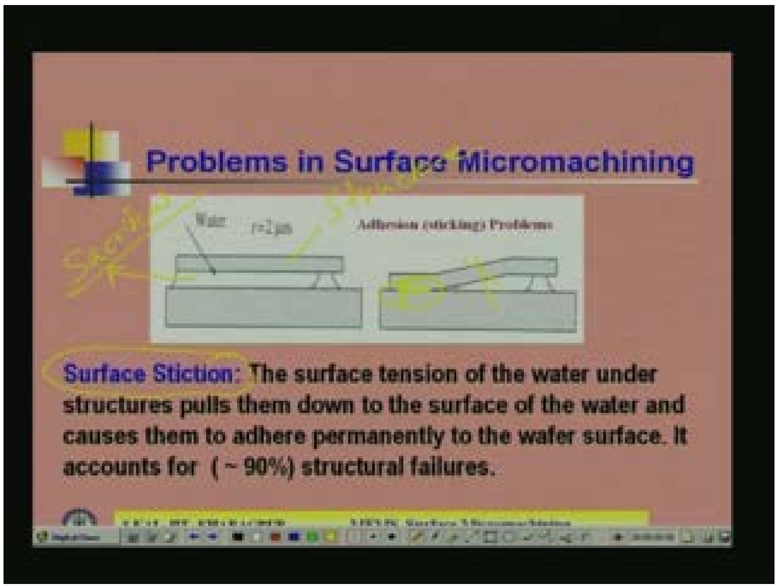

Now just I was mentioning regarding the problems of surface micromachining. One problem is surface stiction and that surface stiction you can just see here. So this is the surface stiction is mentioned here and in figure you can see. So when you are, this is particularly basically the, you see the top layer is a structural layer. This is a structural layer structure and this bottom on is a sacrificial. Now if you go on etching, so here long beam, so there is a possibility you see here because of the surface tension of the liquid HN. So if it is a small area this region, we will stick with that, you can see this portion sticking, that in surface of micromachining. Long beam will stick here and as a result of which it may break here. So that problem is known as surface stiction and the surface tension of the water under structures pulls them down to the surface of the wafer and causes them to adhere permanently to the wafer surface.

It accounts for 90 percent of structural failure, it accounts for 90 percent of the structural failure. That is the major problem of the surface micromachining. There are certain solutions also in order to get rid of that kind of surface stiction. And now days there are two way solutions people thought of addict. One is the in the etching solution you add some chemicals so that the surface tension will be less and less that is one because it is basically because of the surface tension. The second one, you modify the structure at the mask level. So that it can create some small bumps in some of the location and which will prevent bending down the structure. That is shown in the next view graph.

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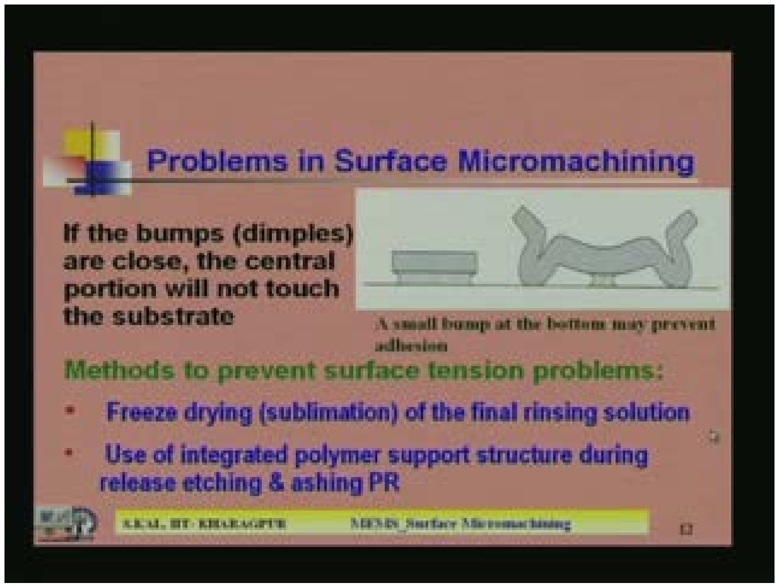

Here you can see bumps or dimples. Bumps or dimples are made. This is one bump, this is one bumps, small bumps if you made. So when you are etching, so if you make like that, you go on etching. So this kind of thing will help you to stop breaking at that point and that point. Sometimes some of the some other methods to prevent this sort of, this surface stiction are freeze drying with the sublimation of the final rinsing solution. This basically comes from when you are drying because when this the liquid in water, so when water is removed then it will drag, it will pull the small thin beam to the surface. But if that rinsing and drying if you do by sublimation method, then that problem for example if you can do it, complete in alcohol.

So alcohol will evaporate and their problem that surface tension of that is less compared to the water. So similarly some lot of R and D going on in this direction. Now to remove this surface stiction problem, use of integrated polymer support structure during release of etching and ashing of PR. Some support structure ashing of PR means there is photoresist ashing. That is in case of your dry processing, plasma processing. There we use the ashing technique means is a photoresist burned and removed. So or you can use some of small polymer. Polymer support structure like this, as mentioned here, so in order to prevent breaking of the structures. So these are some of the solutions of the surface micromachining.

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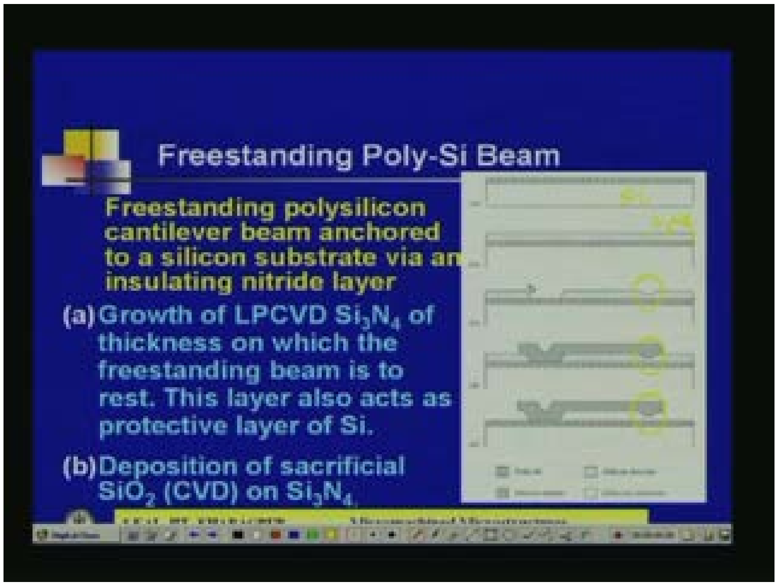

Now using that surface micromachining technology I will now discuss on few structures fabrication. How it can be done? How it can be processed? So that details two, three examples I will give. First example I have chosen is a freestanding polysilicon beam. Freestanding polysilicon beam, this is very simple because it is a direct extension of the surface micromachining process what you have just now we have discussed. So freestanding polysilicon cantilever beam anchored to a silicon substrate via an insulating nitride. Freestanding what is mentioned here, that means these cantilever stand freely without breaking. That means if you apply sudden jerk or sudden stress on that particular beam, it will not break. That is why here one small modification has been done in the thing, which is the dimple you can see, here this particular point was not mentioned earlier here and here dimple structure. So here then what are the steps, first you take the silicon.

This is silicon this is silicon now on silicon you are LPCVD silicon nitride of thickness on which the freestanding beam is to be is to rest is deposited. This is the silicon nitride Si_3N_4. Si_3N_4 is there, then after that you pattern this Si_3N_4 not only the anchor region but here some dimple is made you see. That dimple will help. What help? So it will not allow this structure to break during the surface stiction problem. Because some dimple is made here or not surface stiction. Basically here if sudden jerk if you give or sudden pressure you put on the freestanding mean it should support here. So it should not break, so that is why here, also you made some group and here complete removal of the nitride. Then you deposit the sacrificial oxide in CVD technique on silicon nitride. On silicon nitride only CVD is the only way to get the layer. Why because, there you cannot go thermal oxide. Either you go to CVD is an external reaction and the deposition of oxide or you can go for sputter deposition. Isn't it?

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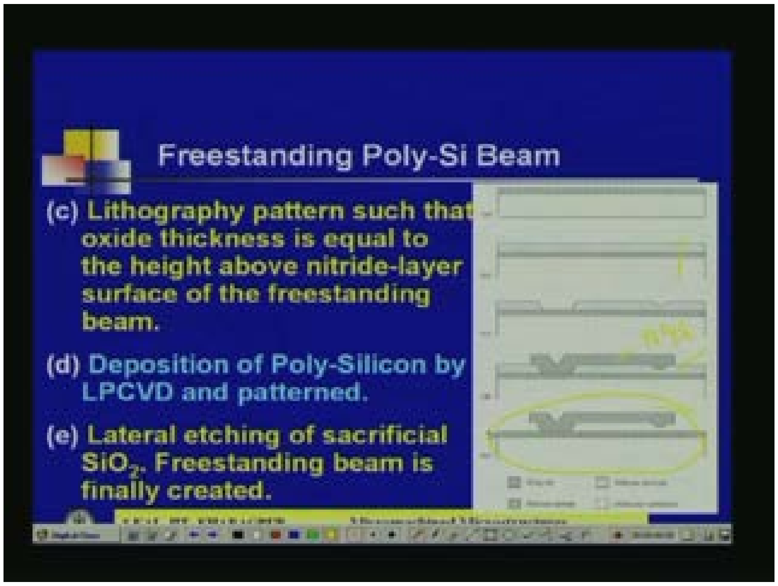

So then you go for the basically lithography pattern such that the oxide thickness is equal to the height above nitride layer surface of the freestanding beam. So now this is lithographic pattern deposition of polysilicon by LPCVD. This is the bottom was a nitride. Bottom was the nitride you can see nitride. Then this is a silicon dioxide then you are getting this is polysilicon. Polysilicon, this one polysilicon and then you pattern it. Then you remove this layer which is oxide layer remove it and it is your getting like that. Lateral etching of sacrificial silicon dioxide, freestanding beam is finally created. So step by step if you go like this you can get this structure which you are aiming for.

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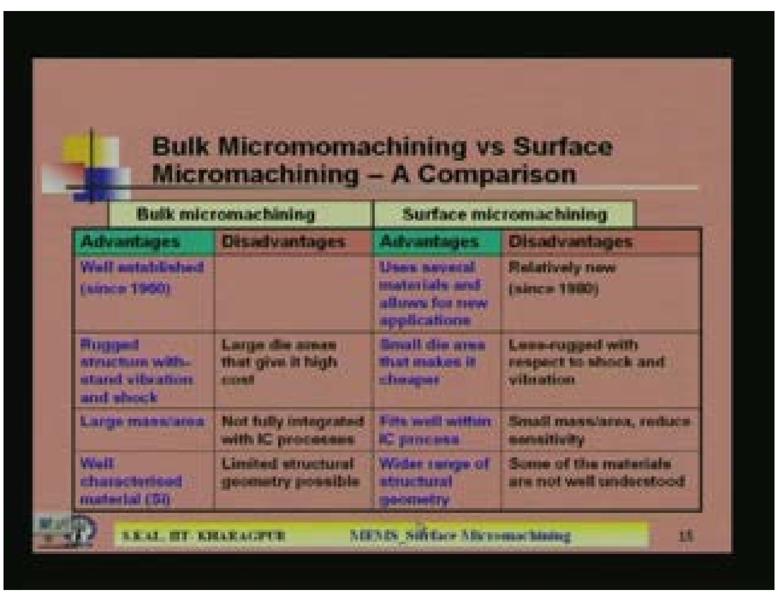

So now let us now compare on these methods of micromachining; one is a bulk micromachining and surface micromachining. Advantage and disadvantage of both the process are mentioned in this view graph. So advantage for bulk is, it is well established technology since 1960; is a rugged structure, withstand vibration and shock by micromachine structure. But disadvantage is large dry area that gives it high cost. Dry size will be more because its size is one order more than the surface micromachine structure. Another advantage large mass or area you are going to use. Disadvantage is not fully integrated with IC process is large mass and area you can use. Why I call it an advantage, large mass or large area must be disadvantage. But here this point is this particular point, is put in favor of the bulk micro because some of the devices you require heavy mass large area. Heavy mass those are mainly in case of inertial sensors. One example is there the escalation sensor. So they are you need the proof mass more heavy so that sensitivity it will be more. So that is why in some cases large mass or large area is advantageous compared to other so.

But at the same time it is not fully integrated with IC process. Well characterized material silicon in case of bulk, limited structural geometry possible. But in surface micromachining advantages are uses several materials and allows for new applications. Relatively new since 1980, it is there. It is from 1960, it is from 1980 small die area that makes it cheaper. Just compression with that and this, less rugged with respect to shock and vibration, fits well within IC process is an advantage in surface micromachining. Disadvantage small mass area reduces sensitivity. Just now I told you that sensitivity it will be more if you increase the full mass weight more heavy. So if since a small mass area its sensitivity will be less. Wider range of structural geometry in surface micromachining it is possible some of the materials are not well understood. In case of surface micromachine particular ceramic and composite materials if you go for micro structuring in surface micromachining, some of their materials are not fully known characterized. So these are a compression of bulk and surface micromachining process. Now I will discuss on again some example of the surface micromachine structure.

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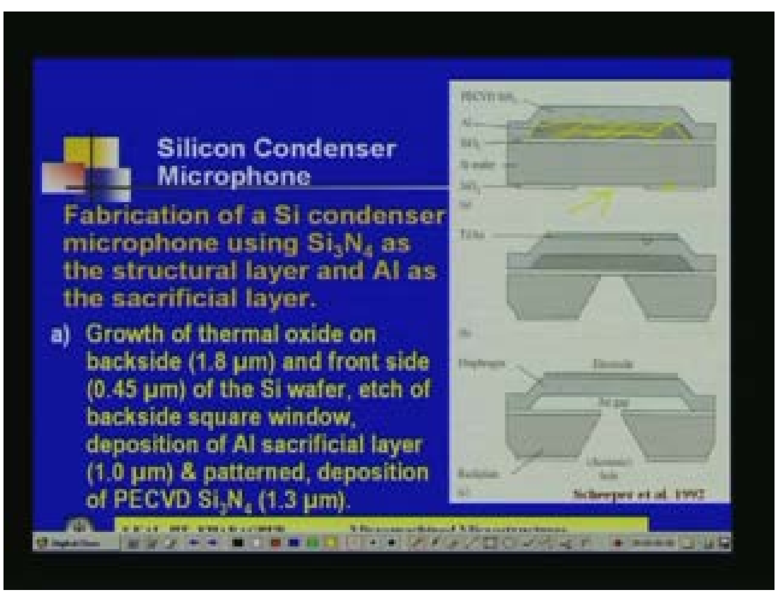

One example now I will discuss that is silicon condenser microphone. This is one important application of micromachine devices is a condenser microphone. Small microphone, miniature microphone is the demand now days. So that miniature microphone can usually be formed using surface micromachining technology and how it is made that is shown here. You can see here in this particular case we have used silicon nitride as a structural layer and aluminum as a sacrificial layer. The condenser microphone basic principle you know, you have to have a diaphragm. On the diaphragm, there is an electrode, metal electrode so the diaphragm when it moves, depending on the acoustic signal. So in presence of some magnetic field, so some signal will be generated. Electrical signal will be generated. That means a diaphragm when moves vibrates in presence of a magnetic field, then it generates some electrical signal and then vibration of the diaphragm on membrane frame, diaphragm depends on the acoustic NH, if you say something in front of the condenser microphone so then it will vibrate. So how this kind of thing is made using the MEMS technology? Now here, we use the silicon nitride as a structural layer aluminum as sacrificial layer. Now you see what is being made. First a silicon wafer is taken then you oxidize the silicon wafer.

So you can see the white region, this region and this region here. These are the thin layer of silicon dioxide which is shown here. After that, growth of silicon, thermal oxide backside and front side, backside is 1.8 micrometer and front side is only 0.4 micrometer of silicon wafer etch of backside square window. You see you are etching backside square window. Here etch of backside square window, deposition of aluminum sacrificial layer. After that what you have done? You have deposited, first you did the etching of backside here. Then you deposited the aluminum, this is the aluminum, this is the aluminum then you pattern. 1 micron aluminum is deposited here, 1 micron aluminum then this aluminum you pattern. Then you deposit PECVD silicon nitride Si_3N_4, 1.3 microns. So that means, first what you did, silicon dioxide is grown from top and bottom then window is opened by lithography technique bottom. Then on the top you deposit aluminum of 1 micron thickness then pattern this aluminum. Then on this patterned aluminum you deposit PECVD silicon nitride. After that on PECVD silicon nitride we deposited titanium gold as electrode.

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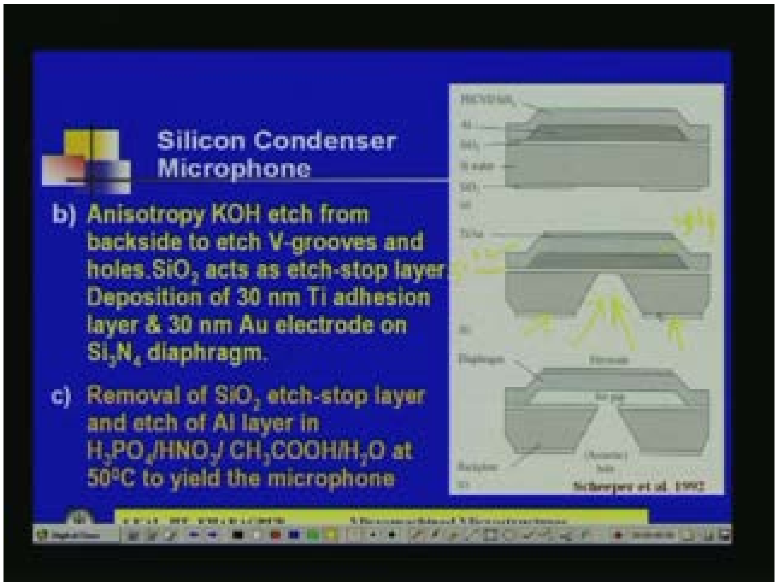

You see the anisotropic KOH etch from the backside has been done after that and you will get this kind of V groove silicon dioxide. In this particular silicon dioxide, in this particular location here and here will act as the etch stop layer here and this silicon dioxide, here is also working at etch stop layer because silicon will be etched from backside here and here and after etching, it will face silicon dioxide. Then it will be stopped there, so that means in the structure you are getting a membrane like this. After that, this silicon dioxide etch stop layer has been removed and then this aluminum is etched. If you etch the aluminum and that aluminum etching solution is the phosphoric H_3PO_4 HNO_3 acidic acid and water at 50 degree centigrade, you will etch the aluminum and before aluminum etching you just get the gold film and before gold, small amount of titanium has been deposited for proper addition of the gold with the PECVD nitride. This is PECVD nitride, this is Si_3N_4 this one. Now there titanium gold layer and then if you etch, this complete aluminum, that is why I told that aluminum will be the sacrificial layer. Then you will get this, the diaphragm and this is the acoustic hole and this is filled with the air.

Now just like a microphone, this is one electrode which is a titanium gold, basically gold electrode. Now depending on your here if you fix something or some acoustic signal is applied in this hole, then accordingly it will vibrate. So this electrode, this electrode will move and below that, this nitride is giving in order to have stability, structural stability. Only this gold film will not be stable at all. Basically is the diaphragm is made of silicon nitride. Silicon nitride is a diaphragm and gold titanium is the electrode. Now here if it vibrates and whole thing you put it in a magnetic field. Automatically the signal will be there. Isn't it? So that is the way how you can make a silicon condenser microphone in a very small area. It is a very miniature form and which can easily be integrated in silicon in just the condition in circuit and this condenser microphone integrated together. Isn't it? So which was not possible in earlier, now this kind of condenser microphone if you can integrate along with the circuit itself. So then it will may very good thing. Now another example I will just give you.

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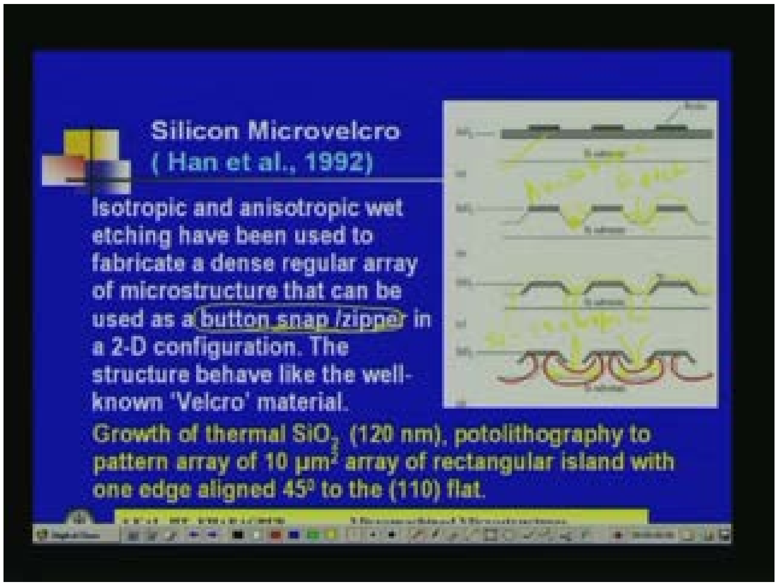

That is silicon microvelcro. How can you made silicon microvelcro using the micromachining technology and in this particular case, we take help of both isotropic etching and anisotropic etching, both are used. Let us see how it is done. Microvelcro is basically one application is button snap or zipper, you see button snap or zipper. That is the application of the microvelcro. So in your zipper the technology is basically is a Velcro. Two microvelcro is in opposite way, there are joined together, that is your zipper. So a regular array of microstructure that can be used as a zipper in 2D configuration. The structures behave like the well-known velcro material. What is the step? You can see the diagram here. So here first silicon substrate, then silicon dioxide is grown. That can be done with the thermal grown, then photoresist coating and patterning the photoresist. So this step A is over.

Now after that you remove the silicon dioxide. Then using the silicon dioxide as a mask material you go for etching of silicon. That silicon etching, that is silicon etch and what is that? That is anisotropic etching, the silicon etching is anisotropic here because your, this direction is 1 0 0 direction is etching. But this surface is not etching which is exposed and may be 1 1 1. Now that means here you are using anisotropic etching. After that you clean whole thing then you again grow for silicon dioxide second time, first time silicon dioxide is grown here with the second silicon dioxide grown. So when you grow silicon dioxide here, so it will be grown over the whole thing here, here, here, here, here, the whole thing. Now you some time you deep it then what will happen? If you etch after growth directly if you go for etching without any masking, etcetera. So in this particular position thickness is small and here it is large and here is also the side relatively large.

So now by suitable technique you just open that silicon dioxide here. That you can do by using masking also. Then you have to need one another mask. So then only this portion, silicon dioxide is etched or if there is a thickness variation of silicon dioxide, where because this is already grouped in a group region if it is a small thickness of side and this portion and this portion thickness is large, because it is exposed more and more oxidant molecules. Then growth rate will be more there. But since narrow groove here growth rate will be less. That also you can use or you can use some mask also, so that later on you remove the oxide here and here, then go for silicon etching. So now, here the silicon etching is done and that silicon etching is isotropic because, etching here, then it is going there. It is etching below, then it is going there, here and is going there, here and then going there. So that means in all direction it is etching that is isotropic.

That means once you use a silicon anisotropic etching, but here you are using silicon isotropic etching. So lateral and vertical in all direction is the etching equal. So because of that, you are getting the structure, you are getting this structure, you are getting this structure, you are getting this structure. Now similar structure to make another, now press it similar structure. Another now you invert it and press it. So then what will you see? It will just push and the whole thing will drop on here. Another will be here, so it will just like a zipper. That is known as the microvelcro.

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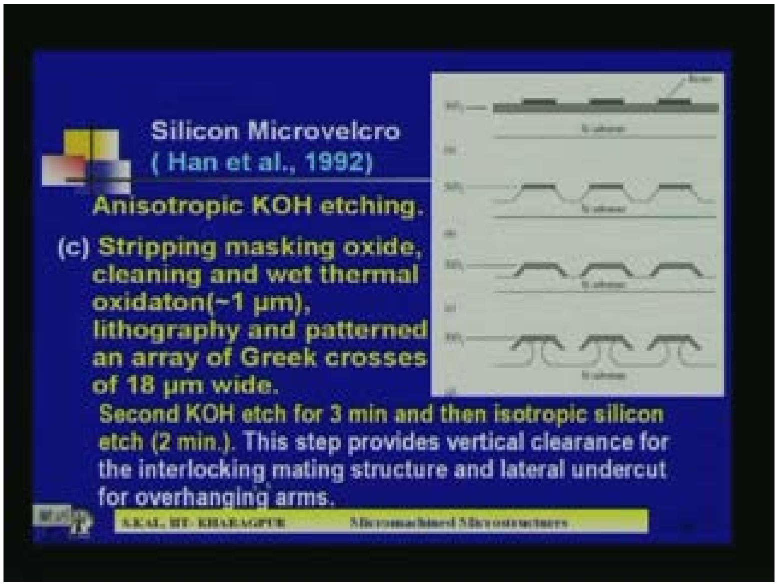

Just like this thing and so get this, then you just you can get for interlocking. Interlocking of second KOH etches for 3 minute and then isotropic silicon etch 2 minute. So first 2 minute for KOH and then isotropic silicon etching for another 2 minute. So then you will get this structure. Then the vertical clearance as well as lateral clearance, so that you can interlock to structure and closely because the lateral undercut there. So they can push it, they can cross, if put it here and they can do like that. So this is one kind of structure with microstructure we can make which can easily be made using the microelcro technique.

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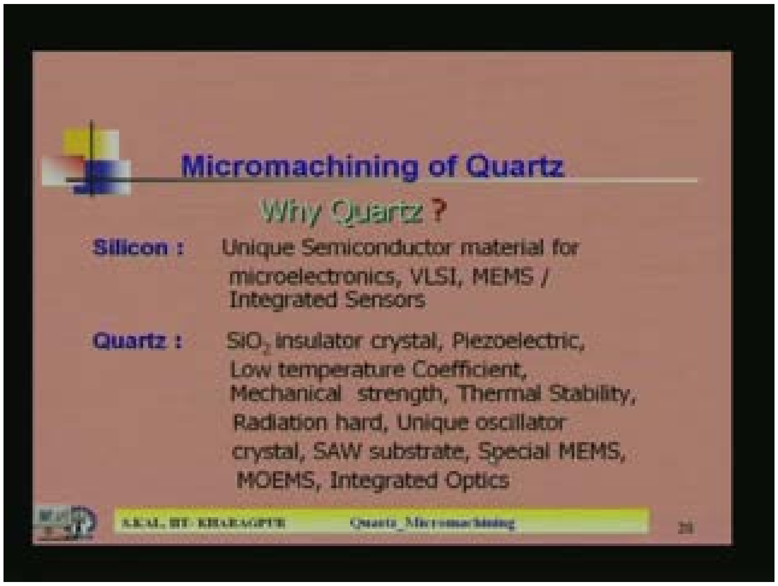

So now, let me now discuss something on the quartz micromachining. Micromachining of quartz. Why quartz? Quartz in a unique semiconductor material for microelectronics VLSI MEMS and integrated sensors. It is basically quartz is a silicon dioxide insulator crystal because in because this is silicon dioxide but in crystallographic form. Silicon oxide quartz is crystallographic form. But normally silicon dioxide which is used for masking that is amorphous in nature. But quartz is a crystal material, it will have piezoelectric property, low temperature coefficient, high mechanical strength, thermal stability is very high. It is radiation hard unique oscillator for crystal and you can make SAW devices also using quartz and special MEMS, MOEMS you can make it micro optical electro mechanical system integrated optics devices you can make.

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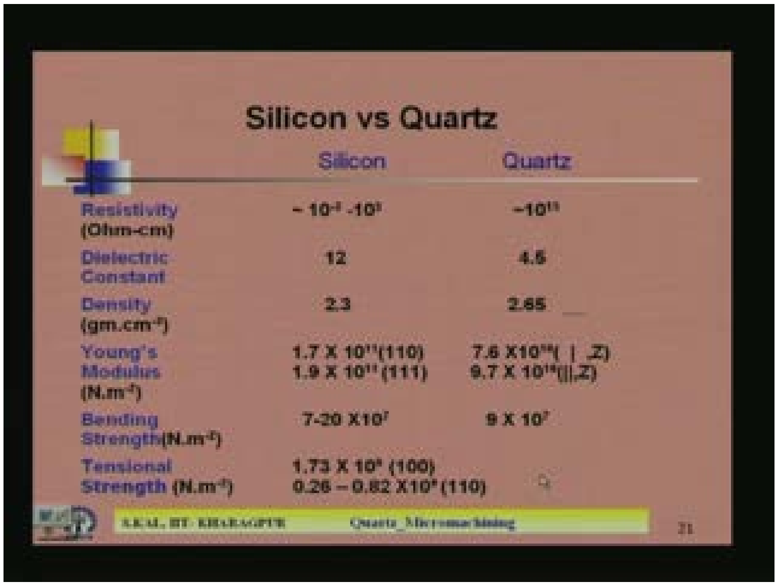

Now if you compare the silicon and quartz, then the properties are like this. Silicon resistivity in that range and quartz is 10 to power 15. That means it is much more insulating material, strong insulating material dielectric constant were 12 here 4.5 densities is almost equal and young's modulus, bending strength and tensional strength are compared in this table. These are the compression of the mechanical properties of silicon and quartz.

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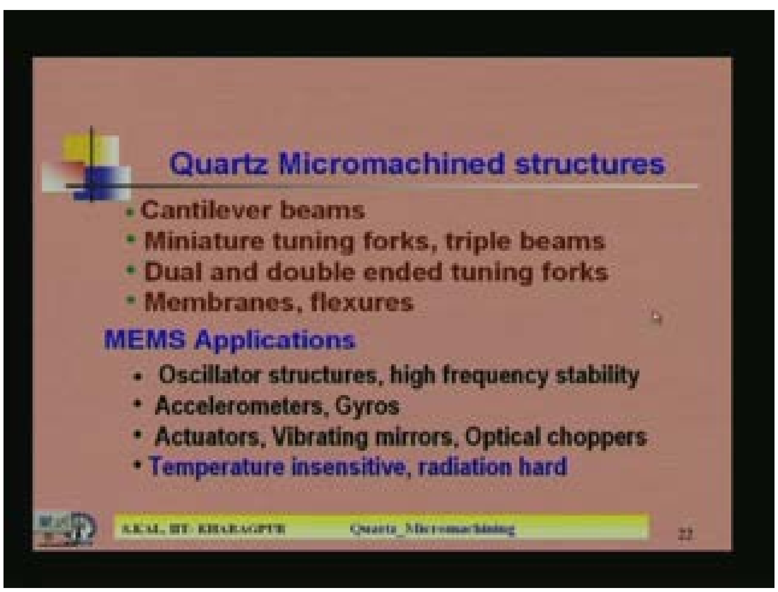

What kind of structure we normally make out of the quartz? We make cantilever beams, miniature tuning forks, triple beams, dual and double ended tuning forks, membranes and flexures. These kinds of structures have lot of application in quartz MEMS or MOEMS. What kind of application? Lot of applications I mentioned. What are the applications? One is known to all that is oscillator structure. Since this is a piezoelectric material you can get very good crystal oscillator and for that if you want to safe, it can be done by micromachining and you know the resonance frequency depend on the structure of the of the piezoelectric material. Dimension structure that will give you the resonance frequency as well as if you make with that some tool circuit, its Q value will depend on how you make this structure. What are the dimensions of the microstructure? So high frequency stability is there. Accelerometer Gyros can be made out of quartz, actuators because it is a piezoelectric material. If you apply electric field, it can vibrate with certain frequency.

So vibrators, vibrating means, if it vibrates if some electric some optical signal is incident on that quartz, vibrating then you can make vibrating mirror also out of that. Optical chopper you can make and most important property of the quartz because of which it is getting much more importance. That is, it is temperature insensitive and radiation hard. These two points are very important because, like piezoresistive sensor, this is highly dependent on temperature quartz sensor is temperature insensitive. Piezoelectric property does not change with temperature is very important and another important point is the radiation hard. Because if you use sensor in space, so you have to look into the matter radiation hardness. Because in space lot of alpha ray, beta ray, gamma rays, are there in addition to the ultraviolet rays. So those rays in case of silicon piezoresistive material can produce lot of carrier electrons and holes or something like that. So they will generate some current, radiation current because of the radiation. But that possibility is not there in case of quartz. That is why it is the radiation hard red hard device can be made using quartz. So these are the advantage and if you go for quartz micromachining, then you have to go for certain steps. What are those?

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Standardization of anisotropic etching of single crystal quartz. Etch standardize you have to do selection of proper masking material that can sustain prolonged etching in fluoride based solution. Because all etching solutions of quartz are fluoride based. So there you have to choose, you have to select certain mask which can withstand long standing exposure of the fluoride based solution. Third point is development and optimization of lithography process for micromachining of quartz which requires double side alignment. Fourth point is the development and optimization of selective deposition of electrode materials at the sidewall of quartz micromachine structures through vacuum masking technique. Because if you make a quartz sensor not only in the top and bottom surface, you materailise and get the electrode. It may require many cases the sidewall electrode sidewall you have to get the metal electrode to improve the Q value of the resonant structure. So that sidewall electrode formation is not easy for that you need a special kind of technique which is known as the vacuum masking technique and that will help you to get sidewall electrode as well as conventional techniques can be used for bottom and top side electrode.

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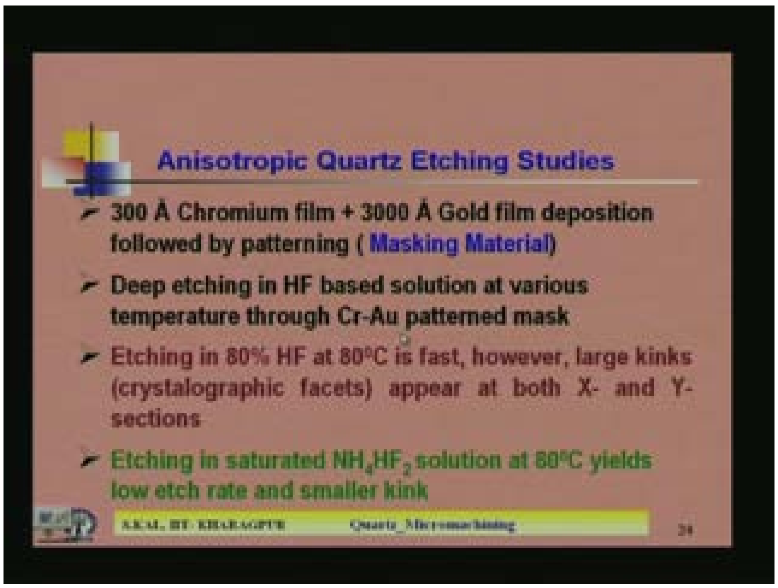

Now is the anisotropic quartz etching. What are the materials we use? Chromium, gold is used as a masking material. 300 angstroms chromium film, 3000 angstroms gold film followed by patterning, it will get the masking material. Deep etching in HF based solution at various temperatures through chromium gold patterned mask. What is then etching solution? Hydrofluoric based solution is the etching solution. 80 percent hydrofluoric acid at 80 degree centigrade is the fast however large kinks crystallographic facets appear at both X and Y sections. So some crystallographic facets will be created and those facets will create some problem in your structure. Etching in saturated ammonium fluoride, HF_2 solution at 80 degree centigrade yields low etch rate and smaller kinks, so this part of the quartz etching and how to get regular structure that I will continue in my next lecture also. Thank you very much.