MEMS & Microsystems
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Lecture No. # 11
Micromachining Process

So we will continue our discussion on micromachining of silicon. In my last lecture I told you there are two micromachining processes. One is bulk micromachining, other is surface micromachining. So out of those two processes, today I will discuss in detail bulk micromachining process for silicon. So this particular technology there are various chemical etchants we use for bulk micromachining. So one of such chemical used or etchant used for bulk micromachining is ethylenediamine pyrocatechol or in short EDP etching. So here we use three chemicals; one is ethylene diamine, another is pyrocatechol and the third is water. So they are mixed in a certain stoichiometric ratio and then we go for etching silicon at a particular temperature.

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Ethylenediamine Pyrocatechol (EDP) Etching

Advantages

- Highly selective over materials like SiO_2, Si_3N_4, Cr and Au
- Etch stop technique is very simple

This particularly technology has got certain advantage. One is it is highly selective over materials like silicon dioxide, silicon nitrite, chromium and gold. So all these three materials can be used for masking purpose that means it can be protected. This particular layer can be used for protection of silicon where you do not want to etch that material, means silicon material. So it is very good masking material and in this particular technique EDP etching etch stop technique is very simple; it is not that much complicated. So these are the two basic advantages for EDP etching. So now some other features are there for EDP etching. Those features are mentioned here one by one.

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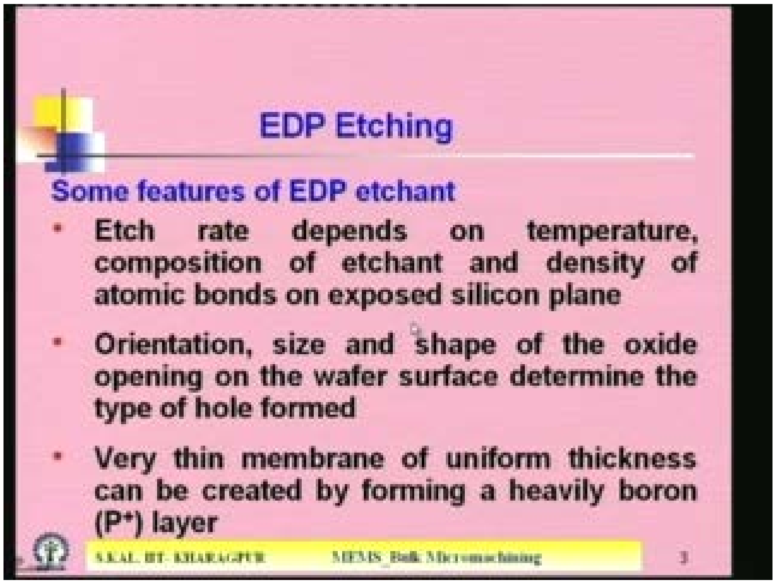

EDP Etching

Some features of EDP etchant

- **Etch rate depends on temperature, composition of etchant and density of atomic bonds on exposed silicon plane**
- **Orientation, size and shape of the oxide opening on the wafer surface determine the type of hole formed**
- **Very thin membrane of uniform thickness can be created by forming a heavily boron (P^+) layer**

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Etch rate of the silicon material depends on temperature composition of etchant and density of atomic bonds on exposed silicon plane. What does it mean by that? Density of atomic bonds on exposed silicon plane means it will depend on crystallographic orientation because in different crystallographic plane the atomic density the silicons are different. That means the etch rate will be different for 1 0 0 oriented plane crystal plane in silicon 1 1 1 and 1 1 0 the etch rate of these three planes will be different for getting different structure and shape of silicon microstructure. Now orientation size and shape of the oxide opening on the wafer surface determine the type of hole formed that I have explained. I think in my earlier one video graph that complete structures etch structure will depend on the shape of the opening on silicon dioxide mask. If you want to membrane or if you want to have the v group or want to have the micro nozzle.

So accordingly you have to shape the masking oxide material and silicon will referential etch in different crystallographic direction. So as a results of which you will get different kind of shape in the etch group. So that means your design or mask should be such that at the end of etch process you will get your desired structure out of the silicon. Now third one is very thin membrane of uniform thickness can be created by forming heavily boron P plus layer. That means here the P plus boron layer will act as an etch stop layer. I will discuss in detail the etch stop mechanism and etch stop process, what are the various etch stop techniques used in micromachining in my next lecture. Now let us discuss on the the setup, EDP etching setup.

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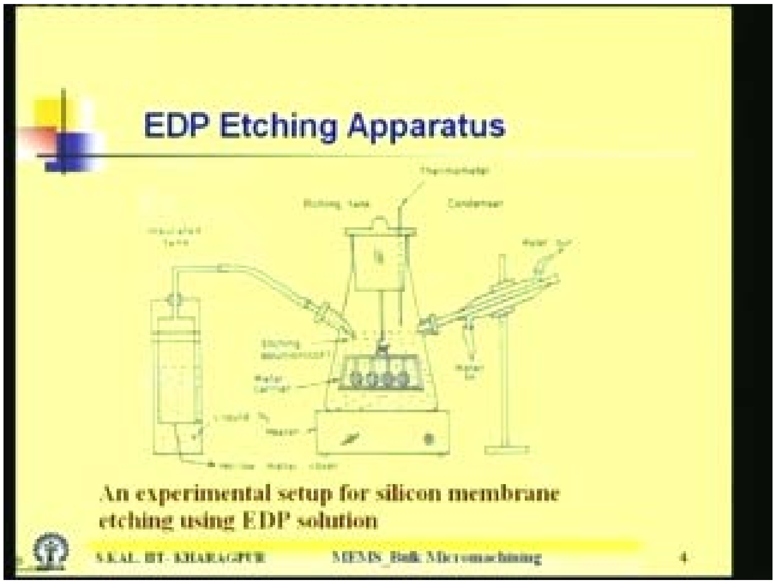

EDP Etching Apparatus

An experimental setup for silicon membrane etching using EDP solution

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So in this diagram you can see the laboratory level EDP etching apparatus. It is not commercial. What we use here, you can see your conical flask is here. So there we put the etching solution and there is a wafer carrier which is held in a hook here and which is basically the insulating rubber or some polypropylene or some other hard ceramic material, then some cork is here. Now inside that the thermometer is there which can measure the temperature inside the chamber. Now the wafers are like this in this figure, it is just vertically you can dip the area of wafers into to the solution. Now there are two other things here you can see, in the right side there is an arrangement which is the condenser arrangement and the left is another arrangement which can give you the liquid nitrogen will be generated here and those nitrogen will be flown into the etching chamber.

Now as I mentioned that the etching of silicon in EDP is dependent on the temperature. That means ion concentration of the etching solution. So to ensure that we have to have a heating arrangement, so the heating arrangement is here in the heater and thermometer can measure the temperature, so that you can adjust the temperature by controlling the heater and you can measure the temperature with the thermometer. Now other thing as I told you just concentration of etching is also important. That means you have to ensure that concentration of the etching solution will remain constant throughout your etching process. That means once you make the solution during etching the concentration may degrade of various reason. Because of the reactions and at the same time since you are doing this etching at a high temperat0ure in the range of that temperature is nearly 100 degrees centigrade, 100 to 110 degree centigrade.

So there some of the etching solution will evaporate and if the etching solution evaporates, then automatically concentration will increase. So the evaporation has to be stopped. So for that reason in condensational, arrangement has been made here. So whatever the etching solution will evaporate, it will because this side is closed top and the only path is through this and when you will, the vapour of EDP solution, when you will passes through that, is cold water circulation around that tube. So again it will condense and it will come back to its original conical container.

So the evaporated EDP solution it goes through there again it condensed and it will come back to its original location. So that, in that way we can prevent these going out of the EDP etching solution and after evaporation at higher temperature and so that the concentration of the etching solution will remain constant and another arrangement here, this liquid nitrogen evaporator has been used here.

The reason is that, this particular etching is highly sensitive to the environment. That means, environment means, if the etching the solution is done in open atmosphere, so there, it will have lot of oxygen also along the hydrogen. So if oxygen is there, so this oxygen gas will oxidize the etching solution, as a result of which the etch rate will vary in order to prevent the oxidation. What we have to do? The complete etching process should be done; etching should be done in nitrogen environment. So above the etching solution the space has to be filled by nitrogen for that the easiest two techniques, either you connect a gas cylinder, nitrogen gas cylinder and you can pass nitrogen through that. So that may be little bit expensive. So on easier technique we adopted in our laboratory. That is a liquid nitrogen bath. So liquid nitrogen is very cheap and easily available in our institute is no problem.

So here what we have done, you allow the insulated thermocol chamber. There we put liquid nitrogen and then what has been done? A metal cover, this is basically cylindrical funnel so cylindrical funnel is inserted and this portion is metallic. So what will happen at room temperature? So this, it is a metallic, means highly conducting. So that means a room temperature a liquid nitrogen temperature is very low, you know. So in outside, is a room temperature. So you because of the temperature difference, the heat will be conducted from through the hollow metallic cylinder into the liquid nitrogen. As a result of which the liquid nitrogen will evaporate. So that liquid nitrogen through this cylindrical space it will flow into that, to this path into these etching chamber. We do not need the high pressure nitrogen inside the chamber just the environment inside the etching chamber should be nitrogen.

So that is why this is the very simple technique and using that if you do go for etching for long time the consumption of the liquid nitrogen is not that much. So the nitrogen will flow slowly into the chamber. So as a result of which inside the chamber it will be in nitrogen ambient and temperature is controlled here, condensation you are preventing here, so this is the complete the setup it is a laboratory scale setup and you can for EDP etching.

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EDP Etchant Composition

Composition of EDP solution:

50 mole percent water (112cc)
40 mole percent ethylene diamine (387cc)
4 mole percent pyrocatechol (55gm)

Etching temperature - 100°C

Etch Environment – N_2

Etch rate of <100> silicon plane – 25μm/hr

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Now what are the compositions of EDP etching? So the composition of the EDP solution is given here, 50 mole percent water, 40 mole percent ethylene diamine and 4 mole percent pyrocatechol. So if you calculate from their formulae, then you will get the 387 cc of the the ethylene diamine which is liquid, 55 gram of pyrocatechol which is solid and 112 cc of water is mixed and this pyrocatechol is dissolved into the solution and that is the EDP etching solution and etch temperature we used normally used here in 100 degree centigrade, etch environment is nitrogen etch rate of 1 0 0 silicon plane is found to be 25 micrometer per hour. That is the etch rate there.

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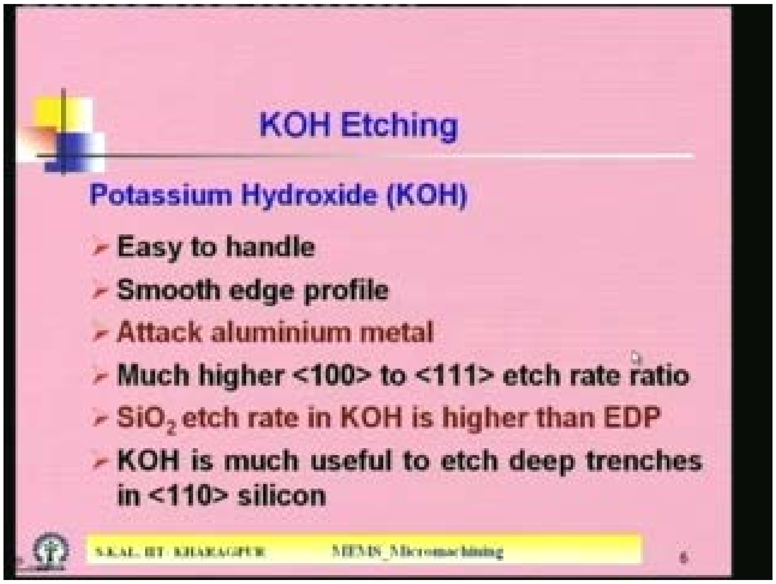

KOH Etching

Potassium Hydroxide (KOH)

- Easy to handle
- Smooth edge profile
- Attack aluminium metal
- Much higher <100> to <111> etch rate ratio
- SiO_2 etch rate in KOH is higher than EDP
- KOH is much useful to etch deep trenches in <110> silicon

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Now another technique is KOH potassium hydroxide silicon etchant. But EDP although it is a very simple process, although is a masking of silicon is very simple in EDP etching, but there are certain problems. What are those problems? Problem is this etching solution is highly toxic. So you have to have very good exhaust system into the etching room as well as the complete etching apparatus. What are the vapour come it has to be exhausted properly otherwise it will be health hazardous. That means this particular solution you have to have certain specific arrangement for etching for prevention of your health, protection of your health. That is why many laboratories they do not EDP etching. They go for very simple user friendly etching solution which is KOH potassium hydroxide is a very well known solution and is not expensive also and potassium hydroxide is a highly popular as silicon anisotropic etchant in micromachining of silicon. So here the advantage of KOH is easy to handle. With KOH you can get a smooth edge profile, but it attack aluminum metal. So aluminum metal or in some cases gold metal also cannot be used for passivation.

In EDP you can use chromium, gold but not aluminum. Aluminum passivation is not allowed either EDP or KOH. Next is much higher 1 0 0 to 1 1 1 etch rate ratio. That means anisotropic is very high 1 0 0 to 1 1 1, the etch rate ratio is large compared to EDP, Silicon dioxide etch rate in KOH is higher than EDP. That is one advantage. KOH is much useful to etch deep trenches in 1 1 0 silicon. If you want to have deep trench, so to you need etching solution whose etch rate is relatively high. So that advantage is than KOH. Now normally the KOH concentration is used 10 to 50 percent of KOH solution is used for the micromachining of silicon. In KOH we sometimes add some organic chemical which is isopropyl alcohol and that isopropyl alcohol will help you getting more selectivity. This particular solution will improve selectivity, means selectivity with respect to what, with respect to passivation layer will masking layer and silicon and at the same time selectivity is, that is you can say anisotropic between different crystallographic planes. So particularly for that reason a small amount of isopropyl alcohol is sometimes added into the KOH solution.

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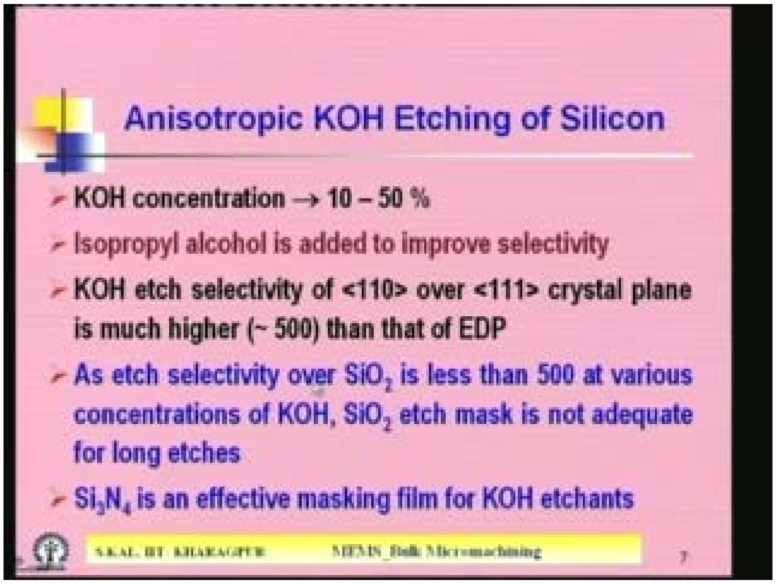

Anisotropic KOH Etching of Silicon

- KOH concentration → 10 – 50 %
- Isopropyl alcohol is added to improve selectivity
- KOH etch selectivity of <110> over <111> crystal plane is much higher (~ 500) than that of EDP
- As etch selectivity over SiO_2 is less than 500 at various concentrations of KOH, SiO_2 etch mask is not adequate for long etches
- Si_3N_4 is an effective masking film for KOH etchants

KOH etch selectivity of 1 1 0 over 1 1 1 crystal plane is much higher of the order of 500 than that of EDP. As etch selectivity over silicon dioxide is less than 500 at various concentrations of KOH silicon dioxide etch mask is not adequate for long etching. Here the silicon dioxide if we will not protect the layer ideally, if you go for long etching. For example if you, for 4 inch wafer, complete etching whose thickness is nearly 400, 500 micrometer then silicon dioxide will be attacked by the KOH also. But for say 1 micron, 2 micron or even say 10 micron, 15 micron, 20 micron etching, it will not create any problem. In that case, another passivation layer is prescribed for KOH micromachining that is silicon nitride. Silicon nitride is an effective masking film for KOH etching.

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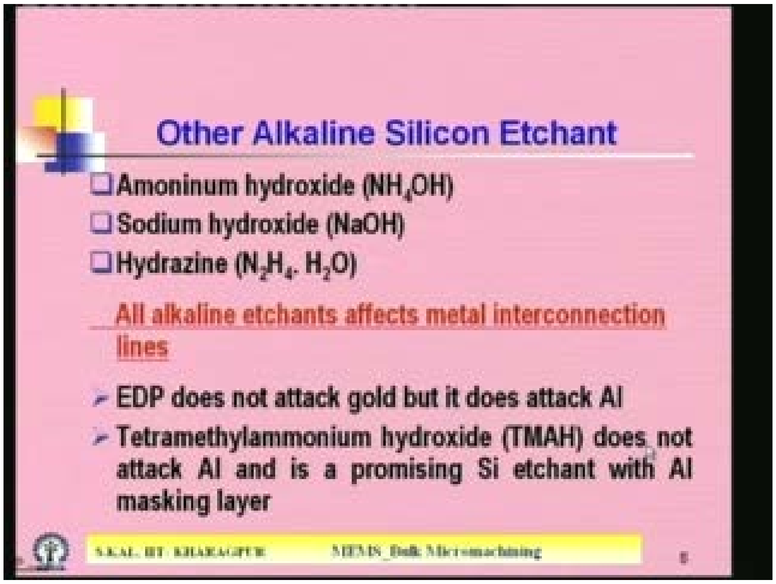

Other Alkaline Silicon Etchant

- ☐ Amoninum hydroxide (NH_4OH)
- ☐ Sodium hydroxide ($NaOH$)
- ☐ Hydrazine ($N_2H_4 . H_2O$)

All alkaline etchants affects metal interconnection lines

- EDP does not attack gold but it does attack Al
- Tetramethylammonium hydroxide (TMAH) does not attack Al and is a promising Si etchant with Al masking layer

Now other than those KOH and EDP, some other alkaline solutions may be used for silicon. They are namely sodium hydroxide NH_4OH sodium hydroxide NaOH, ammonium hydroxide is NH_4OH, hydrazine $N_2H_4H_2O$. But, these alkaline solutions are not very much popular because these alkaline etchants affects metal interconnection lines. Not only than out of these, the hydrazine is extremely health hazardous chemical. So that is people try to avoid these chemical, that is why these ammonia is also not user friendly chemical. So because of the hazardous nature of these chemicals people do not use these chemicals for silicon etching. EDP does not attack gold, but it does attack aluminum as I mentioned. So gold or chromium gold can be used as masking layer in case of EDP. So another promising silicon micromachining etching solution is TMAH tetramethyl ammonium hydroxide. It does not attack aluminum and is a promising silicon etchant with aluminum masking layer.

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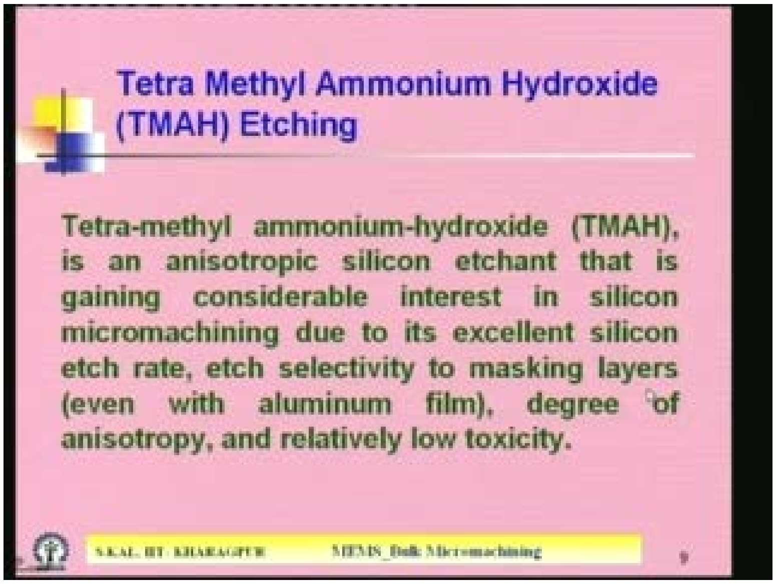

Tetra Methyl Ammonium Hydroxide (TMAH) Etching

Tetra-methyl ammonium-hydroxide (TMAH), is an anisotropic silicon etchant that is gaining considerable interest in silicon micromachining due to its excellent silicon etch rate, etch selectivity to masking layers (even with aluminum film), degree of anisotropy, and relatively low toxicity.

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So we will discuss little bit on TMAH solution now. So TMAH has come into the micromachining process late than KOH and EDP. The TMAH basically is a organic etching solution and this particular etchant has one biggest advantage is that, it does not attack aluminum. That means after complete metallization of the silicon wafer, that means interconnect lines has been pattern then you go for micromachining. So the aluminum fine lines which are used for interconnection will never be attacked or never be disturbed. Because of that reason, we say the TMAH is CMOS compatible micromachining etchant solution. Many cases now days as I mentioned earlier also that the sensor and the signal conditioning circuits are fabricated side by side and they are integrated together. In that case you can fabricate the CMOS signal conditioning circuit.

Then sensor definition and then at the end you can go for the micromachining or etching of silicon. In that case you have to protect the CMOS chip interconnect metallization lines. So people who are looking for a long time, for a particular etching solution which can be used in presence of aluminum, which will not attack aluminum. Ultimately we found that TMAH is a very good etchant alternative which is highly CMOS compatible and this is gaining considerable interest because of its excellent silicon etch rate. Etch selectivity to masking layers even with aluminum film degree of anisotropy and relatively low toxicity. Because it is an organic chemical etchant, so it is not toxic also, that is another advantage. So we always try to avoid the toxic etchant because of the health point of view.

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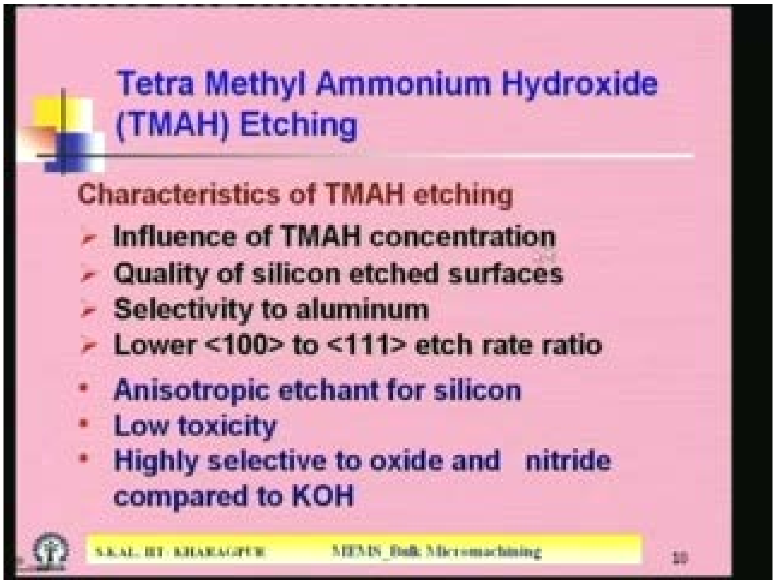

Tetra Methyl Ammonium Hydroxide (TMAH) Etching

Characteristics of TMAH etching
- Influence of TMAH concentration
- Quality of silicon etched surfaces
- Selectivity to aluminum
- Lower <100> to <111> etch rate ratio

- Anisotropic etchant for silicon
- Low toxicity
- Highly selective to oxide and nitride compared to KOH

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Now the characteristics of TMAH etching are as follows. Influence of TMAH concentration is there on etching process. Quality of silicon etched surface has to be studied. Because if you go for the VLSI realization along with the sensor realization. So silicon etch surface quality should be extremely good. Smooth surface you have to get for various reasons selectivity to aluminum lower 1 0 0 to 1 1 1 etch rate ratio. Anisotropic etchant for silicon, anisotropic etchant means it is like selectivity over the different crystallographic plane, low toxicity, highly selective to oxide and nitride compared to KOH. The selectivity to oxide and nitride is more in TMAH compared to KOH. So that means you can go for either oxide masking or nitride masking or aluminum masking or gold masking. You have lot of freedom if you use TMAH. But the total standardization technique of the TMAH etching in silicon is not very simple is not that much easy.

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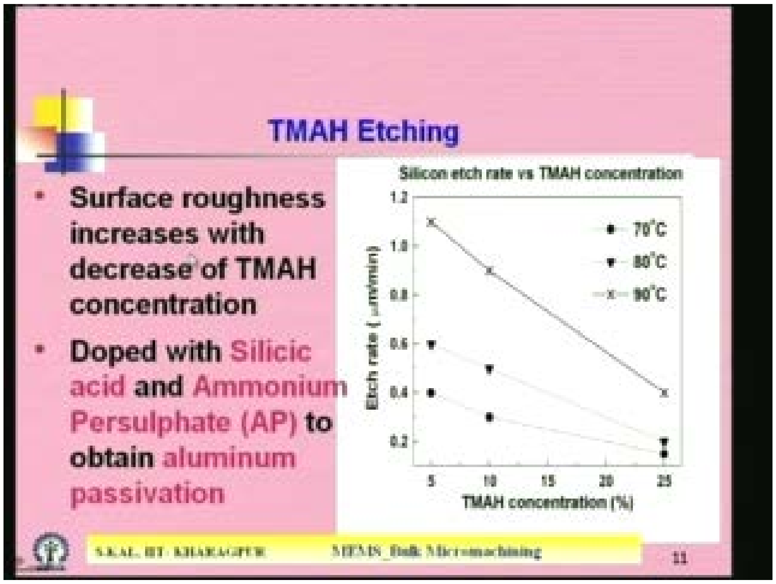

TMAH Etching

- **Surface roughness increases with decrease of TMAH concentration**
- **Doped with Silicic acid and Ammonium Persulphate (AP) to obtain aluminum passivation**

Now there are some features of TMAH you have to do in the lab. Some experiment to improve the selectivity as well as more etch rate as well as surface finish of the etch surface should be very good. For that we did lot of experiment in our laboratory and some of the results will be shown now. We have seen the surface roughness increases with the decrease of TMAH concentration. Here is a plot of etch rate versus TMAH concentration. You can see one typical thing over different temperature we did it 70 degrees, 80 degree and 90 degree Celsius. We found the TMAH concentration increases the etch rate falls. That means at low concentration TMAH the etch rate is higher which is normally not true in many of the etchant solution. But at the same time if you decrease the the TMAH concentration surface roughness increases. So if we need high etch rate ratio as well as good surface then we have to go for certain extra technique. We have to adapt extra technique, extra mechanism. What is that? We use here silicic acid and ammonium persulphate as a dopant into the TMAH solution. Basically silicic acid, ammonium persulphate has got different purpose or different action on total TMAH etching process. What are those?

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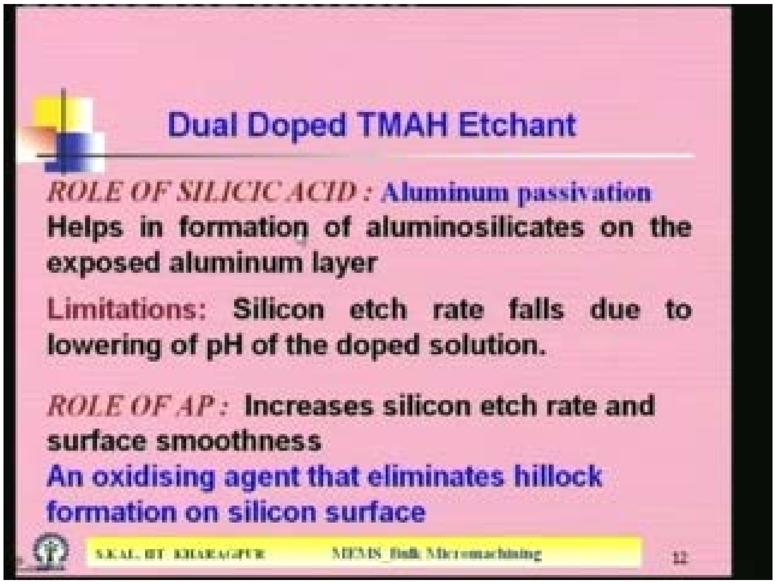

Dual Doped TMAH Etchant

ROLE OF SILICIC ACID : **Aluminum passivation**
Helps in formation of aluminosilicates on the exposed aluminum layer

Limitations: Silicon etch rate falls due to lowering of pH of the doped solution.

ROLE OF AP : Increases silicon etch rate and surface smoothness
An oxidising agent that eliminates hillock formation on silicon surface

First let us talk about silicic acid. Silicic acid material is a highly helpful for aluminum passivation. It helps in formation of aluminosilicate on the exposed aluminum layer. Although TMAH has got the property of not attacking aluminum, but even then if you want ideal masking property, the aluminum should not attack at all. Then you add little bit silicic acid, so that silicic acid with that TMAH it will form aluminosilicate and a thin layer of aluminosilicate over the exposed aluminum layer will help further passivation or masking properties of this particular layer. But it has got certain limitation. Silicon etch rate falls due to lowering of pH of the doped solution. If you add silicic acid, then etch rate will be little bit at a downward trend because, the adding silicic acid will lower the pH value of the TMAH solution. That is one of the thing we have to adjust by proper mixing of silicic acid.

You cannot use silicic acid as much as possible for get 100 percent selectivity over aluminum. Some compromise you have to do. Now, the role of ammonium persulphate. That a particular chemical increases silicon etches rate and surface smoothness. If you add silicic acid it decreases the etch rate. But in addition if you add the ammonium persulphate, it will improve again etch rate. At the same time surface smoothness. Etch surface smoothness is also an important criteria I told you. So that we will get it by adding small amount of ammonium persulphate and this ammonium persulphate is basically an oxidizing agent that eliminates hillock formation on silicon surface. Because surface smoothness will be disturbed if there are certain hillocks on the surface of the silicon and that hillock formation will be prevented by ammonium persulphate because it is you know oxidising agent.

That means we found in TMAH if we add judiciously, silicic acid and ammonium persulphate with proper stoichiometric ratio, then at the same time we can achieve different objectives. Number one etch rate will be increased number two the surface smoothness will be improved and number three what we can get that etch rate surface smoothness and aluminum passivation. All the three things can be achieved by judicious solution of the silicic acid and the ammonium persulphate.

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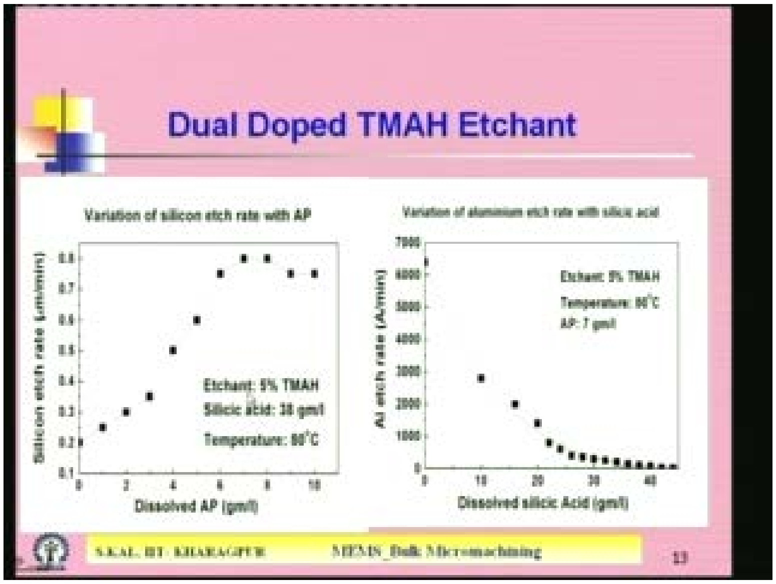

Dual Doped TMAH Etchant

Some of the experimental studies we shown here in this plot we can see here. The dissolved ammonium persulphate silicon etch rate. Here the micron per minute. So ammonium persulphate gram per liter with 5 percent TMAH because as I shown you the TMAH concentration increase the etch rate also falls. So that is why we confined 5 percent TMAH etching solution silicic acid we added 38 gram per liter at 80 degree Celsius. Then if we go on adding ammonium persulphate in this ratio 2 gram per liter, 4, 6, 8 like that silicon etch rate is like that. So that means here with addition of more AP the silicon etch rate also increases. On the other hand the aluminum etch rate you can see dissolved silicic acid. As I told you the silicic acid will formed an aluminosilicate film on the bare aluminum and it will prevent etching of aluminum into the TMAH solution.

So how much silicic acid is to be added that will depend from this characterization curve. You see aluminum etch rate goes down drastically if you go on dissolving silicic acid. So here also 5 percent TMAH etching is solution is used and AP is used 7 nearly here in this region middle of that some 7 gram per liter ammonium persulphate. Then the silicic acid, addition of silicic acid you go on changing accordingly the aluminum etch rate will fall. Aluminum etch rate will fall is desire thing, that means it is not attacking aluminum at all we will get perfect passivation layer.

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Photomicrographs of Silicon Surface after TMAH etching

- Surface roughness increases with decrease of TMAH concentration

5wt% TMAH solution

10wt% TMAH solution

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So now some picture is same photomicrographs are shown is here. The surface roughness increases with decrease of TMAH concentration in a, you see here again as I told you the etching of etch rate will be higher at lower TMAH concentration, that we have seen in the curve. So when the etch rate will be higher, then the problem will be the surface roughness also appear. Because etch rate is very fast and this picture shows 5 percent TMAH and you can see lot of the hillocks and these black portion are basically the groups that is why it is a black. So these are the island so the silicone at silicon atoms are disperse into in different direction and these are the blank portion and as a result which surface roughness will deteriorate. But other in all other case you can see here 10 percent TMAH solution those the black regions are missing here. That means here surface smoothness is good in this particular picture.

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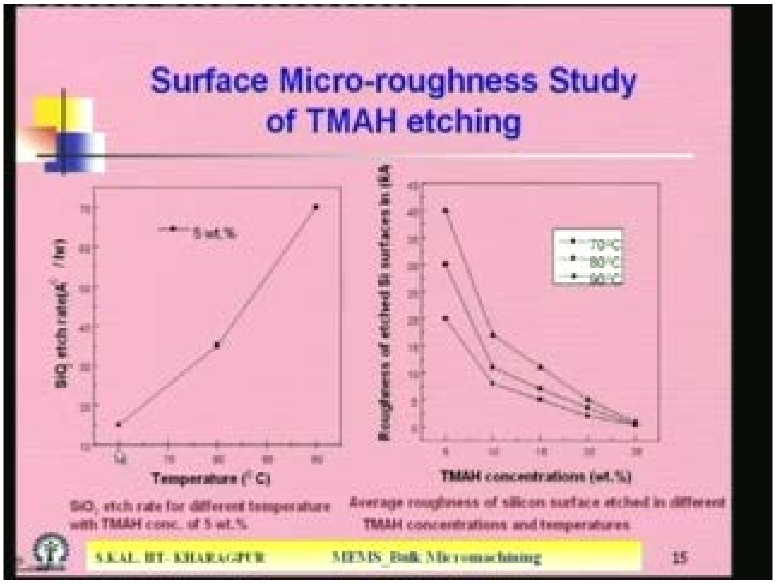

Surface Micro-roughness Study of TMAH etching

SiO_2 etch rate for different temperature with TMAH conc. of 5 wt.%

Average roughness of silicon surface etched in different TMAH concentrations and temperatures

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Now here is again the silicon micro roughness study has been made in this diagram as well as the masking property of silicon dioxide is also shown in this diagram. You can see if you go higher and higher temperature etching then silicon dioxide etch rate will be more and more. That means silicon dioxide etch rate more and more means, the silicon will not be a good masking layer. It should not etch at all. So high temperature etching may create problem if you go for silicon dioxide masking layer. But here although that is micron per hour unit it is angstrom per hour. So although the silicon dioxide etch rate increases with temperature, but at a small rate. Now in this diagram you see roughness of the etch silicon surface in kilo angstrom and here is TMAH concentration.

So here you see lower concentration of TMAH the higher etch rate and surface roughness also is higher. Because roughness of the etch silicone kilo angstrom, means the tops option bottoms are there inside roughness. So that is in this range, so in kilo angstrom unit. So that is very large at lower TMAH concentration and low at higher TMAH concentration. That means using those characteristics curves with temperature, with TMAH concentration, with silicic acid and with ammonium persulphate a good study has to be made in any lab to get a perfect etching solution which will satisfy all the criteria.

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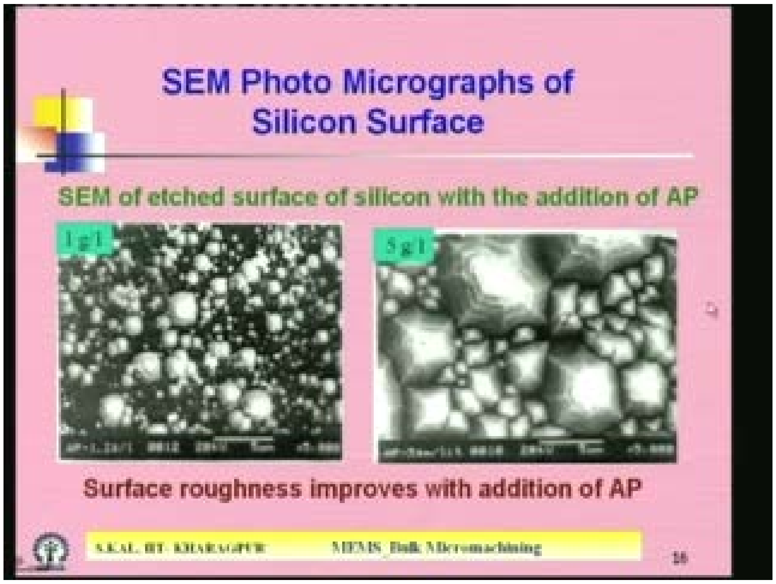

SEM Photo Micrographs of Silicon Surface

SEM of etched surface of silicon with the addition of AP

Surface roughness improves with addition of AP

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Now here is again some photomicrograph study. You can see SEM of etched surface of silicon with the addition of ammonium persulphate. One is 1 gram per liter is a 5 gram per liter, 1 gram per liter surface roughness is more because you can see here the lot black spaces, means lot of holes are created. But here it is not that much because you see the holes are less in this particular picture black regions are less.

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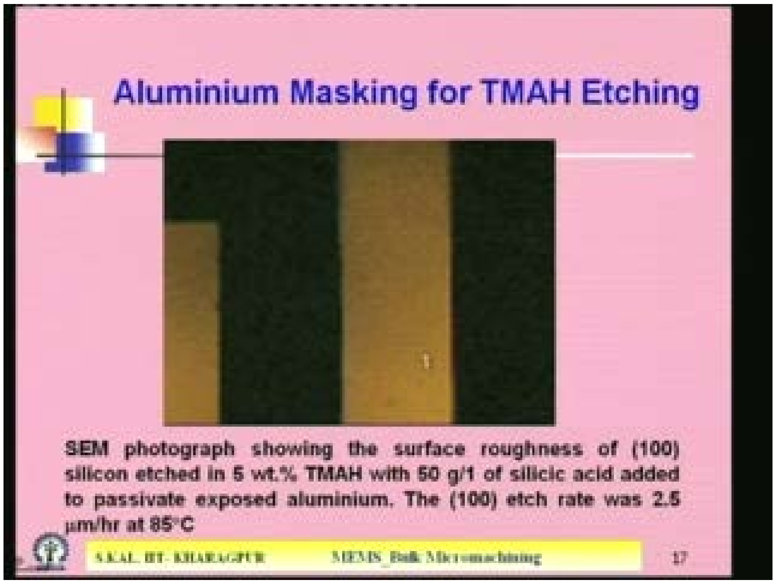

Aluminium Masking for TMAH Etching

SEM photograph showing the surface roughness of (100) silicon etched in 5 wt.% TMAH with 50 g/1 of silicic acid added to passivate exposed aluminium. The (100) etch rate was 2.5 μm/hr at 85°C

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Now the aluminum masking property one photograph as we will take using the scanning electron microscopy and here you can see the aluminum line in this particular picture has not affected at all and the black region is a silicon and the colored, these line say aluminum line. Say this shows that this particular etching has been done with 5 weight percent TMAH 50 gram per liter of silicic acid to passivate exposed aluminum and 1 0 0 etch rate was 2.5 micron per hour at 85 degrees centigrade. That is one photograph taken in our laboratory after etching silicon using aluminum as a masking layer.

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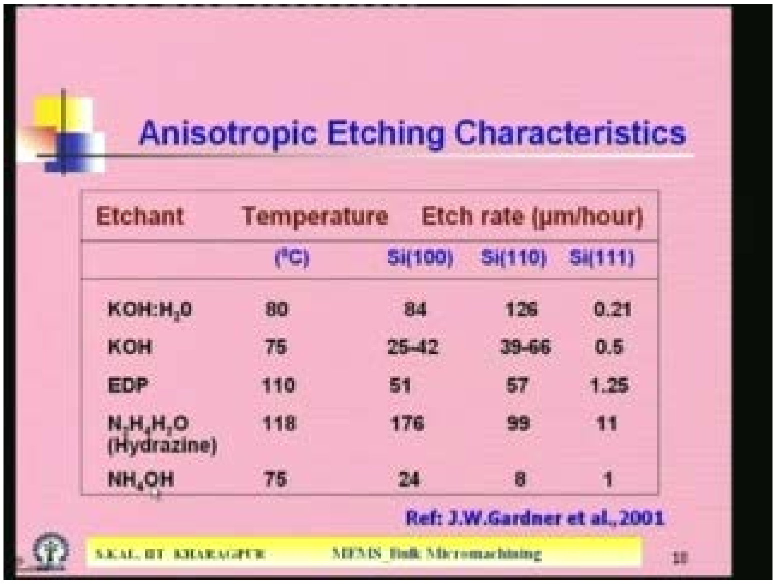

Anisotropic Etching Characteristics

Etchant	Temperature	Etch rate (μm/hour)		
	(°C)	Si(100)	Si(110)	Si(111)
$KOH:H_2O$	80	84	126	0.21
KOH	75	25-42	39-66	0.5
EDP	110	51	57	1.25
$N_2H_4H_2O$ (Hydrazine)	118	176	99	11
NH_4OH	75	24	8	1

Ref: J.W.Gardner et al., 2001

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Now this particular table shows the anisotropic etching characteristics. Here we discussed on KOH, H_2O, KOH, EDP hydrazine and ammonium hydroxide. The temperature used is here 80 degree, 75, 110 degree, 118 degree and 75 degree Celsius and 1 0 0, 1 1 0 and 1 1 1, these three surface etch rates are very important and the etch rate in micron per hour is mentioned here. You can see 1 0 0 silicon in KOH water 84 micron per hour. Only KOH if you use 25 to 42 EDP is 51 and hydrazine is highest even then it is not used because as I told you is a not user friendly chemical is extremely health hazardous chemical. Now you can see here the EDP is 1 0 0 to 1 1 0 the etch are almost similar so that 1 1 0 and 1 0 0, that selectivity is not there in case of EDP. But 1 1 1 and 1 0 0 you can see the high selectivity. 51 micron per hour here is 1.25 micron per hour. On the other hand here in KOH also it is in the range of 25 to 42 and 1 1 1 is 0.5 micron per hour. But if you go for the high selectivity of 1 0 0 and 1 1 0 then you to have dilute KOH solution. KOH plus H_2O which will give you 84 and 126, 1 0 0 and 1 1 0. Depending on your application, depending on the etching structure you have to choose which solution you are going to use for your desired microstructure.

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LIGA Micromachining Technique

LIGA is a German Acronym

- LI → Lithographie → Lithography
- G → Galvanoformung → Electroplating
- A → Abformung → Molding

Now another technology I will discuss today that is a LIGA micromachining technique. LIGA is again bulk micromachining it is not conventional etching technique which is used in EDP. KOH or TMAH is a altogether complete different technique for making microstructure. In this particular LIGA process you can get very high aspect ratio 3 dimensional structures. Basically many of thus mechanical structure which is used in watch are now being made with the help of LIGA micromachining process. The complete name of the LIGA is lithographie galvanoformung and abformung. These are German words and it English equivalent is “lithographie” is lithography. Galvanoformung is “electroplating” and “abformung” is a molding. So LIGA basically lithography, electroplating and molding. Let us discuss now how this particular in this particular technique we get the exact 3D structure with high aspect ratio.

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LIGA Micromachining Technique

Advantages :

- The ability to create 3-D structures as thick as bulk micromachined devices, while remaining the same degree of design freedom as surface micromachining.
- Microstructures with feature sizes of several microns have been made with a thickness in excess of 300 micron with the LIGA process.

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Now it has got certain advantage over other techniques. What are those? Ability to create 3D structures as thick as bulk micromachine devices while remaining the same degree of design freedom as surface micromachining. Design freedom of surface micromachining and etch depth is similar to bulk micromachining you get it. Microstructures with feature sizes of several microns have been made with a thickness in excess of 300 micron with the LIGA process. More than 3 micron thickness is easily obtained by the LIGA technique.

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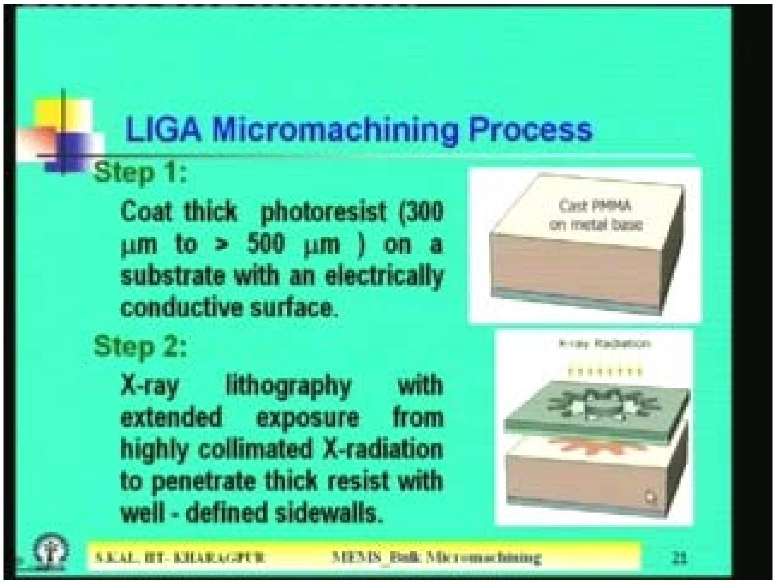

LIGA Micromachining Process

Step 1:

Coat thick photoresist (300 μm to > 500 μm) on a substrate with an electrically conductive surface.

Step 2:

X-ray lithography with extended exposure from highly collimated X-radiation to penetrate thick resist with well - defined sidewalls.

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Now let us see the process steps of LIGA micromachining technique. First we take a substrate is a bottom. One is a substrate and on the substrate you put a conductive, electrically conductive layer. That means some metal plating has to be done at bottom. After that you coat photoresist and that photoresist thickness is 300 to 500 micrometer. That means one important point I would again mention they are not on bare silicon, not on bare ceramic insulator material. You cannot coat these PMMA photoresist and it first your substrate has to be coated with conductive layer because in the next stage you are going to form an electroplating. So electroplating means some cathode anode will be there. So until unless you coat on conducting layer you cannot use as either cathode or anode. So whatever the substrate is used either silicon or ceramic or other material first you coat with some conducting electrically conducting layer then you deposit the thick photoresist.

Normal photoresist which we use for VLSI process, those photoresist cannot be used in LIGA process. Here you will need photoresist thickness of the order of 300 to 500 micrometer. So that means you need a very high viscous photoresist and PMMA polymethyl methacrylate is one such resist, SU8 is another resist which is used for LIGA process. So that a photoresist will give you a thick layer of the film after spinning and drying. So now the PMMA of thickness greater than sometimes 500 hundred micrometer on this may conductive layer coated substrate is made. Then the step two. What is the step two? This is the mask you can see the green color is the mask and then you have to expose. Through the mask you have to radiate the PMMA with x-ray radiation. Normally UV lithography cannot be done here. You need here x-ray lithography. So x-rays are collimated and it will penetrate to the thick resist in well-defined sidewall.

This is the mask, so through that mask x-ray passes. Because here the thickness of the photoresist is 500 micrometer. So here this 500 micrometer thick photoresist should be reacted with the radiation. So for that you need x-radiation. So that x-radiation will penetrate through that thick layer and complete reaction will take place that is polymerization will take place. So that is the X-radiation you expose it, then here there is a much contrast red color means through that X-ray penetrates into the layer and then it reacted here and as a result of which it will be polymerized.

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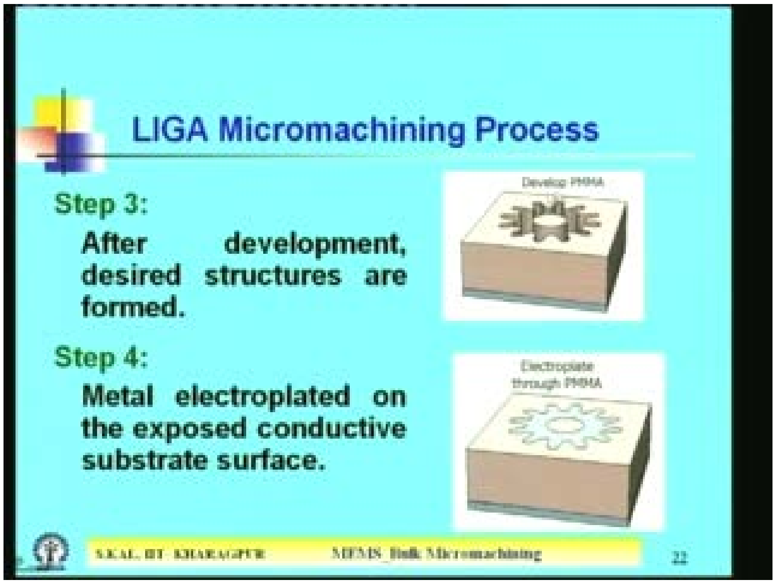

LIGA Micromachining Process

Step 3:

After development, desired structures are formed.

Step 4:

Metal electroplated on the exposed conductive substrate surface.

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Now step three. Here you have to develop, after exposing next step is developed. So you develop the desire develop the photoresist after exposing. Then during development as you have seen in case of negative photoresist, so our positive photoresist is there, whatever you it is some kind of positive photoresist in nature. So where you expose, those such portion will dissolve. So here also this portion where exposed by x-ray radiation has been dissolved by developer solution of the PMMA. So then here hole has been formed. Step four. Step four is what? Metal electroplated on the exposed conductive substrate surface. So metal is electroplating. So after that the bottom is a conductive layer, you for electroplating.

What electroplating, which metal you want to fill this group, this thick developed structure. So go for electroplating. So electroplating will help you depositing that particular metallic film into the groups as higher thickness as you wish. So long time electroplating you do it so there you can increase the etch rate, you can adjust the electroplating process by the what are their variants. One is the concentration of these electroplating solution, another is the temperature and another is a current. The current through that electroplating is basically electrolysis process. So if you change the current, so the rate of deposition will also change. So by adjusting those parameters you can get the thick layer.

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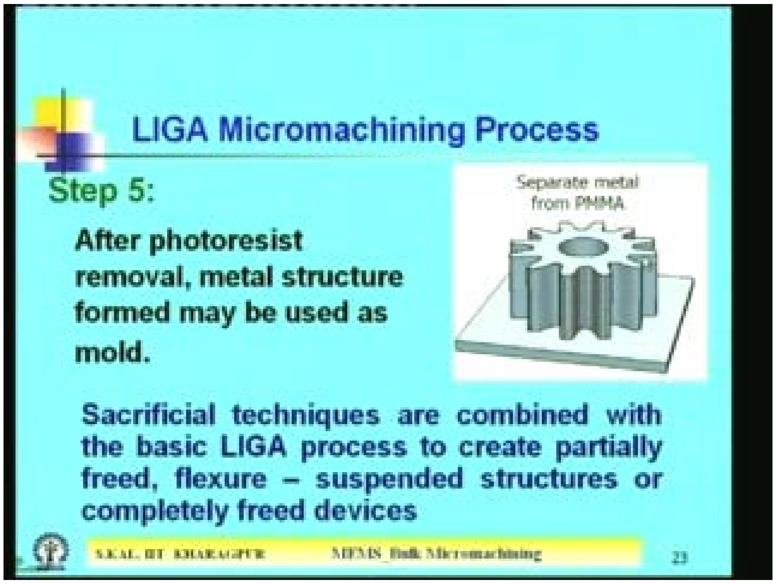

LIGA Micromachining Process

Step 5:

After photoresist removal, metal structure formed may be used as mold.

Sacrificial techniques are combined with the basic LIGA process to create partially freed, flexure – suspended structures or completely freed devices

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So after that, then step five. So in step five what you are doing? So the photoresist is removed. You see photoresist has been removed and then only the metallic structures is there which is which is basically fixed on this bottom metal plate. So now here the sacrificial techniques are combined with the basic LIGA process to create partially freed flexure suspended structures or completely freed devices. Now this can be used as a mold. This is one mechanical structure that easily can be made. You see here thickness is a large and this hinges can be very small then the aspect ratio is very large so that can be made using the LIGA process. Here you do not need that mask aligning you do not need the conventional machine which is used is normally lithography process. But here some important feature which are different from normal lithography techniques are first is a x-radiation you need it, second is electroplating you need it, third is a different kind photoresist you need it. Those are the different form the normal the lithography and etching process.

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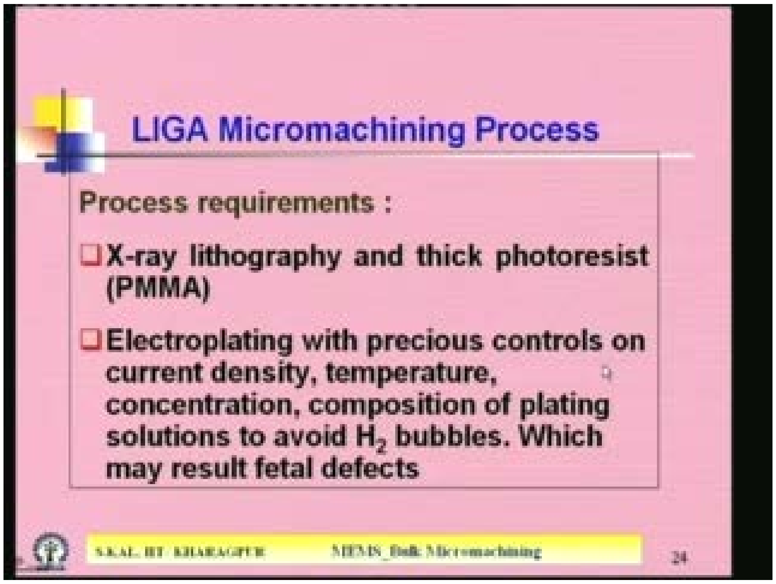

LIGA Micromachining Process

Process requirements :

- ❑ X-ray lithography and thick photoresist (PMMA)
- ❑ Electroplating with precious controls on current density, temperature, concentration, composition of plating solutions to avoid H_2 bubbles. Which may result fetal defects

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Now as I mentioned process requirements are x-ray lithography and thick photoresist PMMA or SU8, that is one of the requirements. Second is electroplating with precious controls on current density. Because the deposition on the metal, on the base plate depends on the current density, temperature, concentration of the electrolyte solution, composition of the plating solution to avoid hydrogen bubbles which may result fetal defects. So here all the temperature concentration composition will decide whether hydrogen bubbles are coming from the deposition process. If hydrogen bubbles are coming more, then automatically they will create some holes and that will form a defect into the mold. So the rigidity of the mold will be less and it will be porous, the total mold which you got it. Isn’t it? So that is why you have to control or standardize the complete electroplating process by adjusting temperature, by adjusting current density, concentration and composition of the plating solution.

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LIGA Micromachining Process

Lithographie Galvanoformung Adformung

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Now just in a cyclic way, how do you proceed that is shown again. The lithography galvanoformung and abformung. So is cast PMMA on metal base then coming here x-radiation then after that develop the PMMA solution. After developing you get the holes then you come here. Then is electroplate through PMMA and after electroplating you this photoresist is completely removed, dissolved then you will get this structure separate metal from PMMA. This is the LIGA micromachining process which is used now days for making mechanical structure, mostly metallic structure. You cannot get ceramic structure out of that because you see electroplating only for metal deposition. If you want to have, then you have to go for this LIGA process. Now another technique I will discuss today, so that is the laser micromachining. So we initially discussed on the conventional chemical etching process, silicon etching process that is KOH or TMAH or EDP or some other solution hydrazine or other materials. Then you went for different in total different technique, that is the LIGA method and now I will discuss on laser micromachining. Now days people are in some cases they are using the laser micromachining.

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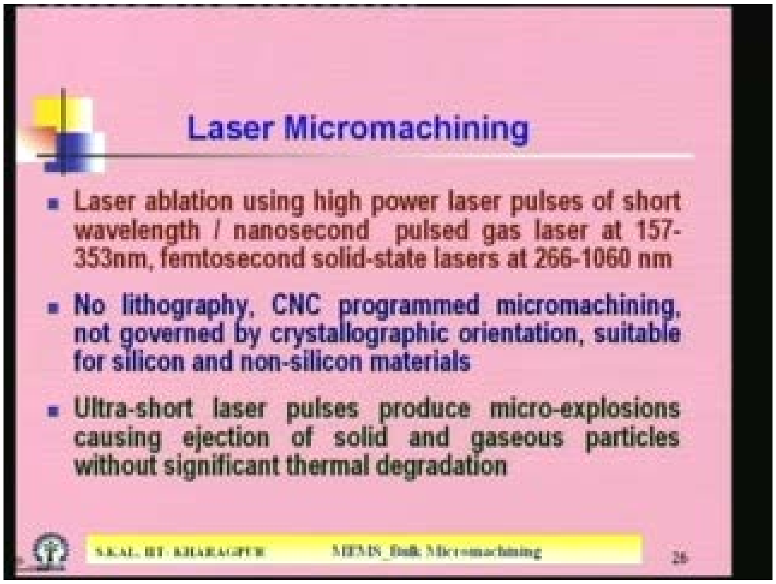

Laser Micromachining

- Laser ablation using high power laser pulses of short wavelength / nanosecond pulsed gas laser at 157-353nm, femtosecond solid-state lasers at 266-1060 nm
- No lithography, CNC programmed micromachining, not governed by crystallographic orientation, suitable for silicon and non-silicon materials
- Ultra-short laser pulses produce micro-explosions causing ejection of solid and gaseous particles without significant thermal degradation

So laser micromachining means here you have to have high concentrated high power laser and laser basically the laser ray if is incident on some structure, some micro explosion will take place and a result of which that will evaporate or that will be ejected from the basic material. So laser drill is available and that laser can be used for getting a mechanical structure. Here one of advantage of the laser micromachining obviously, this particular micromachining will not. I should say etch simple class a single class a metal like it earlier we see silicon in KOH or TMAH. Only silicone, ceramic cannot be done for example electroplating will micromachining structure can only metal ceramic or semiconductor cannot be done. But if you use laser there semiconductor can be done, metal can be done, ceramic can be done, irrespective of the material because it is a mechanical process, mechanical machining process.

It will not obviously just the etching rate or removal rate of the material will be different for ceramic or metal or the semiconductor. But any kind of those materials you can easily make using the laser micromachining process. But here another point you cannot get the etch selectivity kind of thing. You do not need any masking layer also. Because the laser material when it a hitting a material that will be removed. So that means there is no questing of masking. There is no question of the mask aligner. There is no question of developing. So all these things are not there. So basically this is useful only for materials which cannot be micromachining. Using the conventional techniques, popular technique the laser micromachining. Obviously here one disadvantage is there. Very small microstructure of say small dimension cannot be made using laser micromachining. Why because, there you need the laser beams to be focus to a singular point of diameter. May be sometimes less than of the order of micrometer. If you cannot focus there, so automatically you cannot there you cannot get very fine line. So those problems are there even now days in some cases people are people use these laser micromachining technique.

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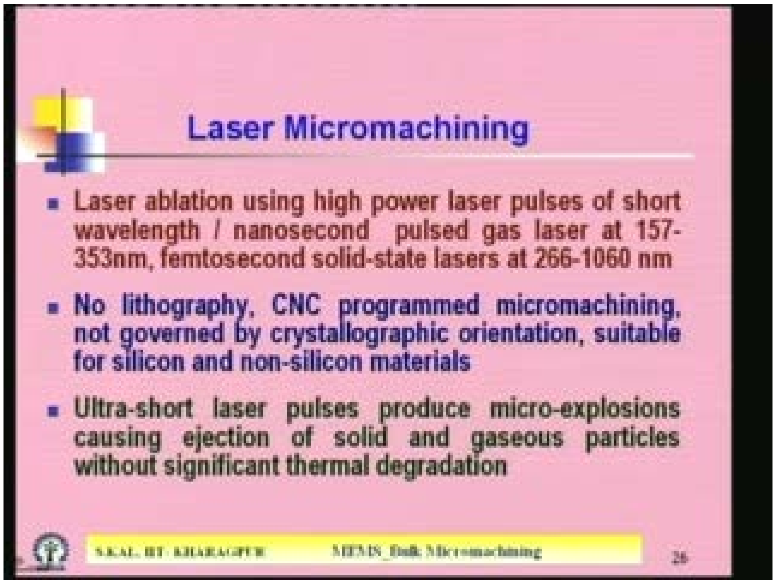

Laser Micromachining

- Laser ablation using high power laser pulses of short wavelength / nanosecond pulsed gas laser at 157-353nm, femtosecond solid-state lasers at 266-1060 nm
- No lithography, CNC programmed micromachining, not governed by crystallographic orientation, suitable for silicon and non-silicon materials
- Ultra-short laser pulses produce micro-explosions causing ejection of solid and gaseous particles without significant thermal degradation

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Here basically the process is laser ablation using high power laser pulses of short wavelength or nanosecond pulsed gas laser at 157 to 353 nanometer or femtosecond solid state laser at 266 to 1060 nanometer. That is the wavelength of the laser normally used in case of laser micromachining technique. No lithography CNC programmed micromachining that is basically the structure is CNC programmed machine is available in mechanical laboratory. Mechanical machining laboratory the CNC machines are available all. Though is a computer programmed control the CNC machine which is used for cut a metal cutting and structure making the same machine is used for micromachining for guiding the laser beam. Not governed by crystallographic orientation, I discuss it is not governed by crystallographic orientation. Suitable for silicon and non-silicon materials. Another point to note it is suitable for silicon and non-silicon. Both materials, ultra short laser pulses produce micro explosions which causes ejection of solid and gaseous particles without significant thermal degradation. So that is the basic principle or basic thing based on which the materials are ejected.

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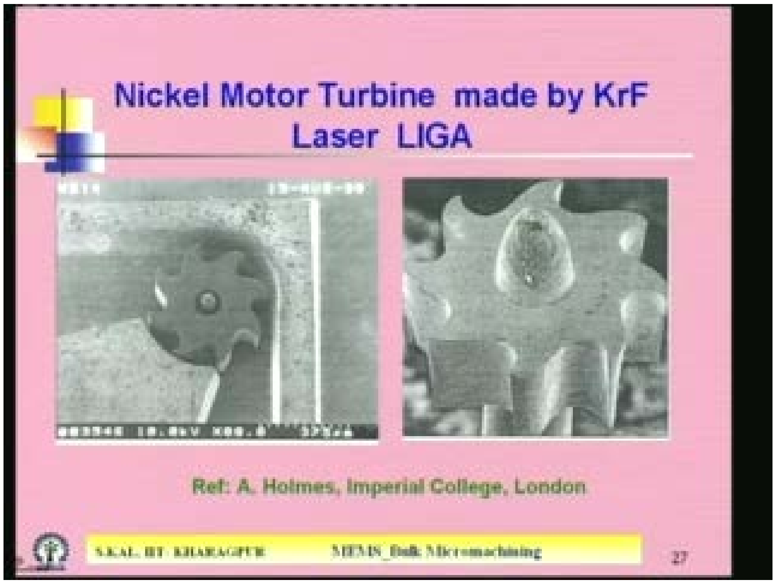

Nickel Motor Turbine made by KrF Laser LIGA

Ref: A. Holmes, Imperial College, London

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So this video graph I am showing you some of the structure which has been made using the laser micromachining, they call it as laser LIGA. So KrF laser has been used here and this structure is nickel motor turbine. So miniature micro motor and which is structured from nickel, that has been made using these laser micromachining techniques and this picture has been taken from this particular paper reference and you can see here the structure is not extremely small, here the size of this 375 micrometer may be the group. But total structure in the range of a few 100 micrometer to millimeter range. So that is made using the laser LIGA process. So now the basic bulk micromachining processes I discussed now today. Those are normal chemical anisotropic etchant solutions and then LIGA and then laser micromachining. So we compare the advantage, disadvantage of the various anisotropic silicon etchants and as well as now you can just differentiate the LIGA process as well as the laser micromachining process.

What to be used to what? That you have to select depending on your requirement. Out of all these techniques I should now conclude with that TMAH is the best choice of laser best choice of micromachining technique. So for as the integrated microsensor fabrication is concerned and it is the basically the organic etching solution which will not at all toxic, which is not health hazardous and biggest advantage is that. It is done in laboratory in normal environment and biggest advantage is aluminum passivation. So with this I will just stop today. In the next class we will continue on micromachining. Particularly the surface micromachining technique, we will discuss and then we will go for the etch stop techniques which is also another important aspect for micromachining to get different structure. So thank you very much.

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Preview of Next Lecture

Preview of Next Lecture

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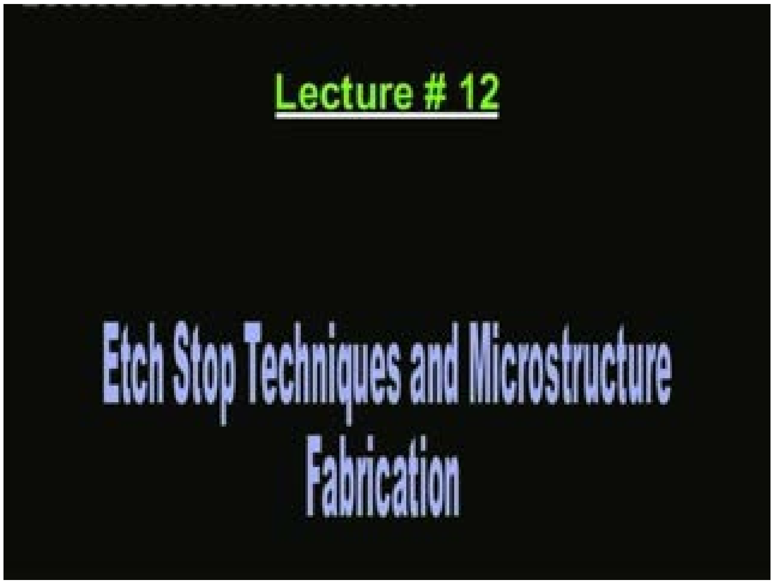

Lecture # 12

Etch Stop Techniques and Microstructure Fabrication

Etch Stop Techniques and Microstructure Fabrication.

Today we will discuss on etch stop techniques and microstructure fabrication. Etch stop is an very important aspect in making microstructure. I have told you earlier that in MEMS in many cases we need membranes and flexures or cantilevers of certain thickness and that thickness varies in case of surface micromachining may be 2 micron, 3 micron in case of bulk micromachining. Sometimes we need membrane of 10 micron, 20 micron or 30 micron and thus those 10, 20 or 30 micron is coming from the bulk thickness of the wafer which is nearly 300 to 500 micrometer depending on the wafer size. If it is a 2 inch diameter wafer the thickness is nearly 280 to 300 micrometer. If it is a 4 inch diameter wafer, the thickness of the wafer is nearly 500 micrometer.

If it is 6 inch or 8 inch, then it is further you you will get more thickness of the silicon wafer. So from that thickness it has to come down to 10, 20, or 30 micrometer. So somewhere you have to stop the etching process. Then there are two ways; one is a mechanical process, that means you observe the time if you know the etch rate of that film basically silicon. Here if you now the etch rate of silicon in that particular etching solution then you can note down the time, how much time you etch then after that you take out the wafer and then you measure the thickness you can get it. The other way is automatic stopping. So you see automatic means it will continue etching. But after certain point, that point has to be decided by electronically or electrically.

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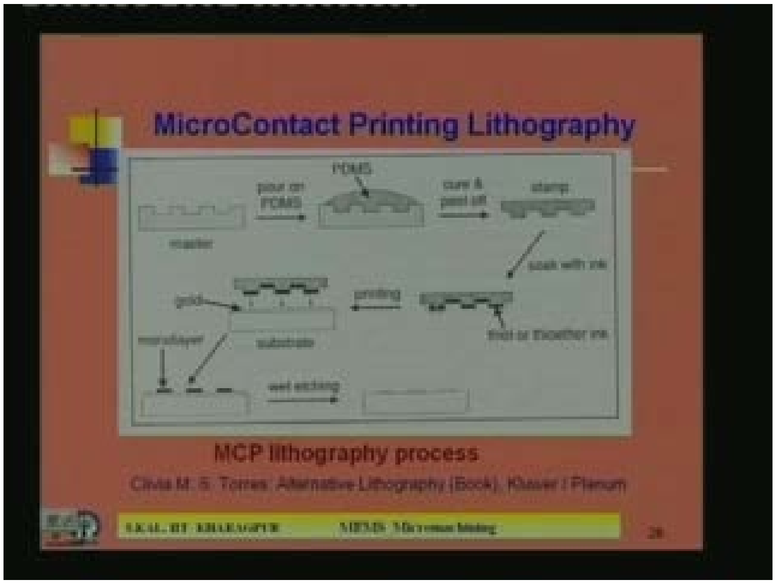

MicroContact Printing Lithography

MCP lithography process

Clivia M. S. Torres: Alternative Lithography (Book), Kluwer / Plenum

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So now you go for printing just like your stamp you use it. You printing here and this is the gold coated this is substrate is a gold coated. Now if you print here that thiol or thioether ink will make some passivation layer, monolayer and after that go for wet etching. This particular portion will be stopped and here etching will be done. That is basically micro contact printing no lithography no exposure no machine nothing all required very simple technique. Isn’t it? Is a not at all the high expenditure equipment required nothing required. So next is some issue.

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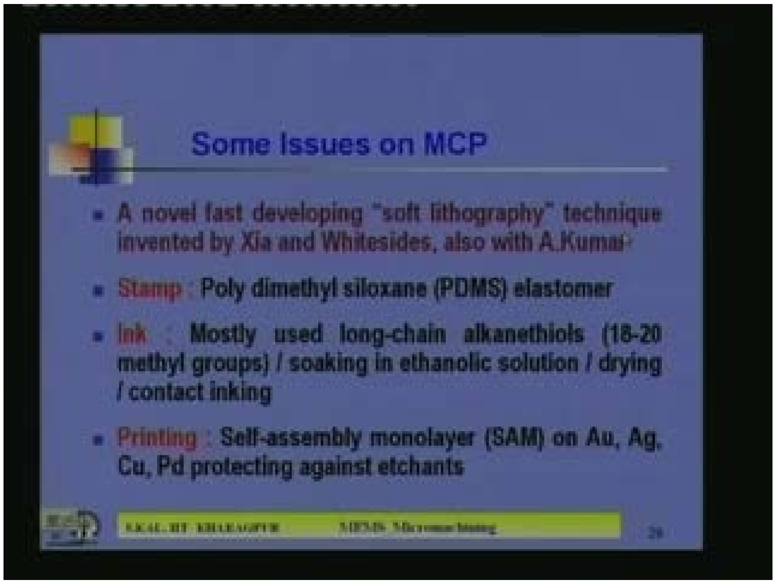

Some Issues on MCP

- A novel fast developing "soft lithography" technique invented by Xia and Whitesides, also with A.Kuma
- Stamp : Poly dimethyl siloxane (PDMS) elastomer
- Ink : Mostly used long-chain alkanethiols (18-20 methyl groups) / soaking in ethanolic solution / drying / contact inking
- Printing : Self-assembly monolayer (SAM) on Au, Ag, Cu, Pd protecting against etchants

I will just these are known as soft lithography. The novel fast developing soft lithography technique invented by this people. This is mpl or stamp and lithography process. Stamp poly dimethyl siloxane PDMS elastomer that is the stamp material. Fast stamp material has been found then you are going to use a ink mostly use long chain alkanethiols 18 to 20 methyl group soaking in ethanolic solution drying and contact inking, that is the ink. Printing self assembly monolayer SAM on gold, silver, copper, palladium protecting against etchants what I just showed you. So that technique is is getting importance now a days that does not have lot of money. Lot of capital equipment is not required, so easy technique you can get some micro fabrication using these two methods. So let we stop here today. We will continue in the next class on the micromachining surface micromachining basically. Thank you very much.