Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology- Part- 2

Module- 04
Micro Fabrication Technology

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Hello and welcome to this manufacturing process technology part 2 module 4. We were discussing about the etching process.

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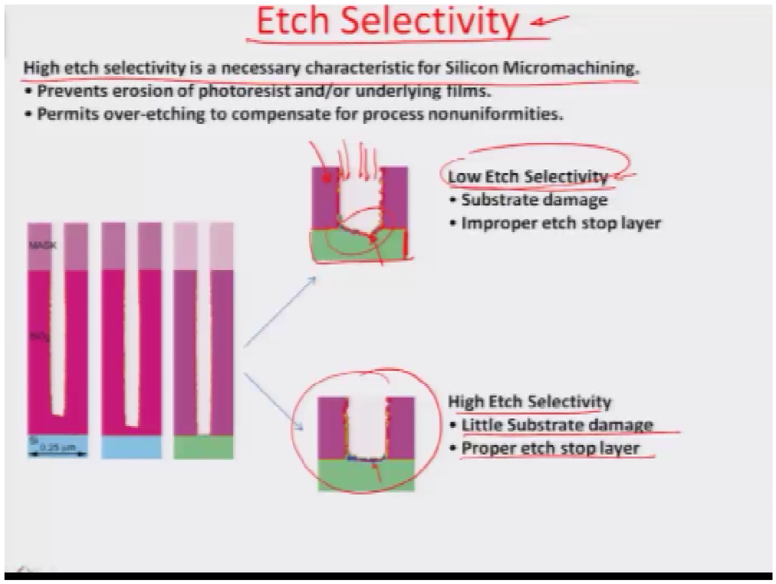

And in context of that we had mentioned the last module not about this etch selectivity factor which was about your material which would be highly selective or low selective to an etchant. For example, if supposing there is a low etch selectivity of an etchant, it typically means that the material itself will be jupatized and it will be eaten away and the etch will not stop up to the layer that is intended to stop okay.

So in this case for example we showed that this green layer is suppose to be an etch stop layer. But because of the low selectivity of this green material towards the etching that is being used, the layer as you can see gets, you know sort of jupatized and cut off, and there is no flat surface which otherwise was the purpose of putting this layer with that should typically stop.

On the other hand if supposing there is a high etch selectivity the etch would continue to have a flatter surface and basically the boundary which is formulated is almost the boundary of the green material meaning thereby the material itself is not jupatized much.

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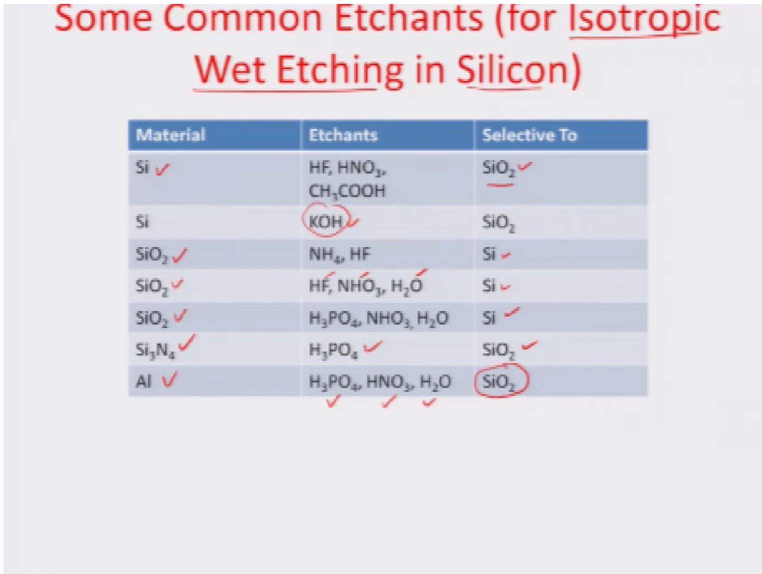

So let us look at some of the different etchants which are used and what it is selective too. So for example, if you know, we consider all this different materials silicon for example, silicon dioxide, silicon nitride aluminum, there is a combination of etchants which are working well in case of silicon. And when I mean to say, when I say selective to it means this is the etch stop layer.

So combination or for example, hydrofluoric acid HNO_3, CH_3COOH is basically a good etchant for the materials. Silicon, but as soon as it faces the SiO_2 layer there it should stop or it will slow down. Similarly, for, you know KOH it will be etching silicon and SiO_2 is the stop layer in that case. SiO_2 has several such etchants for example, NH4 and HF together or HF, HNO_3, H_2O, you know these are all sort of materials designed or etchants designed for the material SiO_2.

But as soon as they face the silicon layer they would do not stop, for a nitride you have phosphoric acid etch and there the etch stop is about, is an oxide or aluminum for example, you have a combination of phosphoric acid, nitric acid and H_2O. There also if you had SiO_2, the etch would stop. So that is how sort of wet etching is done in silicon, and this process of etching for at least some of these etchants except this KOH is also known as isotropic wet etching.

Meaning thereby, that when the etching starts it is like same in all directions and there is no preferential etching direction over the other. Let us look at these concepts in a little more details. So let us take a closer look at this etching process here right here.

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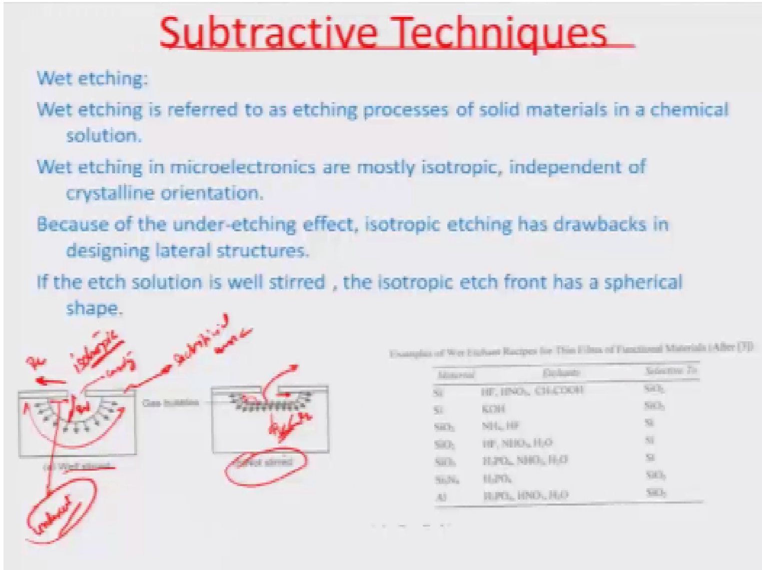

This shows the wet etching process, you know the subtracted technique as I had already described earlier and as you can see here the etch is similar in all directions which makes this process isotropic in nature. So there is no preferential direction with the etch, there will be a vertical etch which is in this direction and a lateral etch as well which are almost at equal rates, because the etchant that we are talking about is homogenously able to etch similar kind of materials from all the directions.

And for this particular isotropic process the main issue which comes here is designing of this cavity, so basically when we are talking about this cavity it means that you know the lateral etch for example, RL would actually make an undercut happens. So this region for example, here is also known as an undercut okay which means that you know whatever is the planed region of the particular mask that we are talking about this is the sacrificial mask this layer on the top is the sacrificial mask okay so this provides some kind of undercut because of the isotropicity of the etching processing.

Now if supposing you had stirred it well this is what it would result in but if you do not stirred it obviously there is going to be a preferential etch direction because do to graffiti whatever is going to be etched out from these regions are going to fall and collect in this pit and so there is going to be a lesser concentration of the etched available on the vertical side there why the RV that is the vertical etch rate would be Jupatized in comparison to the horizontal etch rate RL, so

RL is always or lateral etch rate is always greater than the vertical etch rate in this particular case.

So you can think of it that even with stirring or not stirring a satiation can be raised at where in one case you know the etch etching is completely isotropic in other case the etching may not be that isotropic and it may be having some directional properties.

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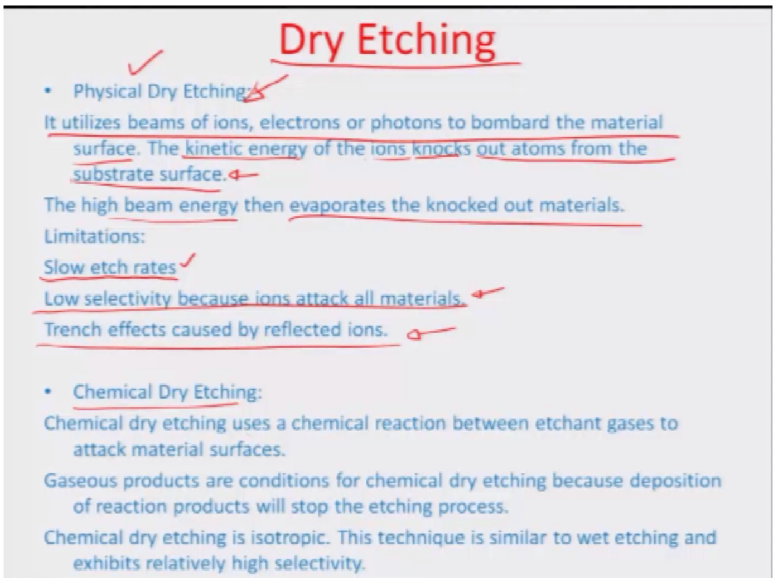

So let us look at some of the other subtractive processes which are available which the first process which comes to mind is dry etching and in the dry etching you can have either physical dry etching meaning there by bit utilizes beams of ions electrons or photons to bombard the material surface and so typically ion beam machining or electron being machining or even laser machining falls in this category this physical dry etching category and essentially in this whole you know recipe the kinetic energy of the ions or the photon or the electrons.

Whatever is an etching source knocks out the atom from the substrate surface so basically there is some kind of transmission of the energy of the particle that is being sent to the surface into in terms of lattice variations and there is an increase in the local temperature which leads to some kind of a knock out the atoms bound within otherwise bound within the lattice and the high energy of the beam then sort of evaporates the knocked out materials away.

Now there many limitations of these dry etching process for example the major limitation is a very slow etch rate so this cannot be avoided if you look at comparisons between a wet etching or dry etching you will always find that there are orders of magnitude difference with the wet etching process much faster in comparison to the dry etching process also there is a low selectivity because of ions which attack all most all materials there is no choosing between two materials in which an ion would be bombard you may perhaps be able to control the etch rate a little bit by changing the energy or trekking the energy of the material.

That is in question but you cannot really all together stop a material from getting etched away so there is nothing called a etch stop layer when we talk about these kind dry etching techniques but in the wet etching as I showed you clearly there is going to be an etch stop layer which stops the etching and then there are trench effects which are created by the reflected ions.

So ions almost always which are able to take of the material and are able to transfer only partial energy bound of the surface where they are striking and these kind of go and create some kind of trenches you know trench effects which are basically destock on the sides and this results in a rough overall surface roughness or surface finish of the trench that is being etched by the physical try etching process there is a chemical dry etching technique which uses a chemical reaction between extent to gases to attack material surfaces.

And I will show you variety of such recopies which are used for the different materials again you know the advantage because of this chemistry being involved here that is you can actually make it the selective process, so you can select it to certain material and make it selective to a certain material and you can use that material is in stop just in the case of wet just as in the case of wet itching process.

That I had shown earlier so the gaseous products are conditions for chemical dry etching because deposition of the reaction products will stop the, the etching process so typically you know whatever comes out of the material should be carried away, carried away as gaseous state from the chamber were this etching is going on and the chemical dry etching is completely isotropic in nature, so basically there is a homogeneity of attack you know and there is no directionality which is imposed.

Because now there is no question of the material falling under need but the material going away as gaseous state so there is absolutely situation where homogenous attack is possible, by the chemical gases of this sub straight which is in, in concern so this technique is similar to the wet itching and exhibits relatively high selectivity like looks at some of the recopies which are.

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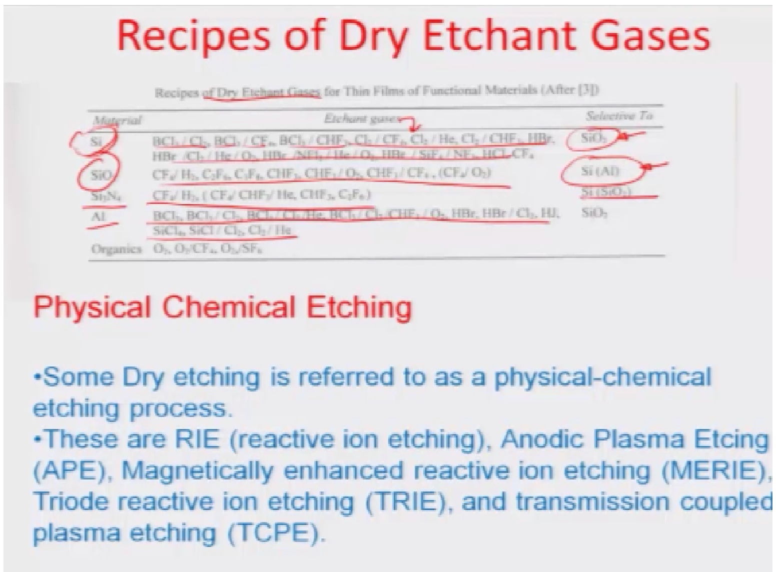

Available for dry itching gases where chemical reactions would pose etching for example these different H1 gases which have been shown here, combination of boron dry chloride chlorine or boron dry chloride carbon tetrachloride or boron dry chloride CH of 3 and all these different combinations of gases as listed here are etching or rr etchants for the materials silicon and whenever the phase a silicon oxide silicon dioxide.

Is SIO2 they are selective to this materials so they will typically stop the etching process similarly if we looked at SiO2 there is a quite a bit of some recopies of gases which are listed here again selective to silicon so on one side you are making this as a selective layer one side you are making this as a selective layer so there is kind of a parity and you know you can even manipulate, these process so that you can have alternate layers of a Si, SiO2 you have various H depths of certain regions of the vapor.

Then you have the silicon nitrite Si3 and 4 which is again taken off by a few H1 gases here and one second selective to again silicon and silicon dioxide both similarly in case of aluminum you have another set of recepies of gases or mixture of gases which would be able to H of the aluminum but again they are selective to SiO2 and for all the different organics typically these are the applications which are used today, in flexible electronics or organic thing forms you know which shows electronic properties and there you have all these different recepies which have selective or which are actually good etching recepies for the organic material there is also another process called physical chemical dry etching or physical chemical etching.

Where you know there is not only a chemical process which is happening because of which there is a dislodgement of the material but again you know you can actually have a directed chemical process by making the gases go into the state of plasma and plasmas assume no or irons or combination of irons and electrons I mean in fact go into take some modules on details aspects of a how plasma are formulated or how they can be manipulated, over the surfaces but the plasmas are typically gas molecules.

Which have their dislodgement of electrons from the normal atoms, so you have moving irons free irons and you also have free electrons in a chamber of plasma and so in this plasma can be actually converted or made to fall on a sub straight at a certain momentum which can be again changed or altered by means of a biasing voltage and then there is a chemical reaction of the constituent of the plasma with respect to the surfaces so there are certain free radicals which are ready to almost react the moment they find out a surface side which is having a tangling possibility or tangling bond possibility they go attach they cleave that I mean they coming to the gaseous state.

So in a same manner you can do the etching process but much more directed and much more high momentum transfer is can be involved okay and so therefore you have typically high aspect ratios structures within the meme, so these are called reactive ion etching processes okay.

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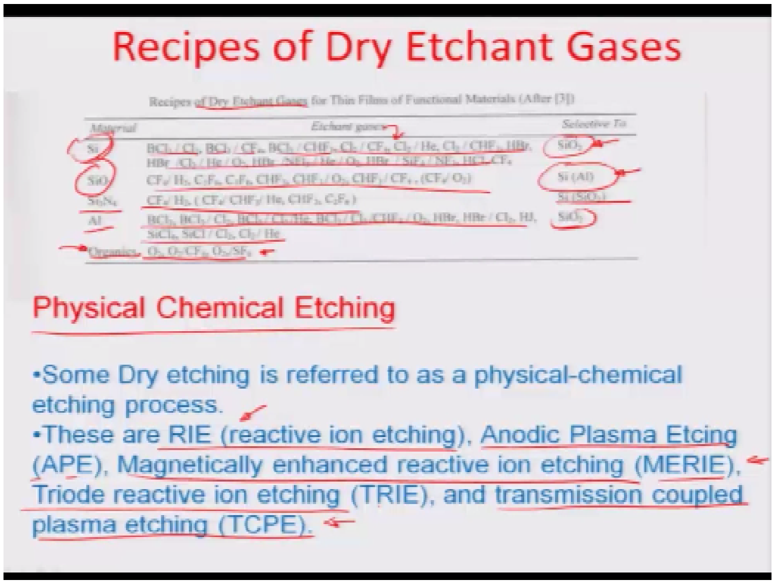

And then you have different other forms of these physiochemical dry etching processes like anodic plasma etching process magnetically enhanced reactive ion etching process and I will actually show how these magnetically enhanced plasmas are created or even the normal DC's plasma or the RF plasma are created, you also have try out reaction reactive ion etching process or transmission coupled plasma etching process. These are some of the processes which are actually falling within the category of the physiochemical etching.

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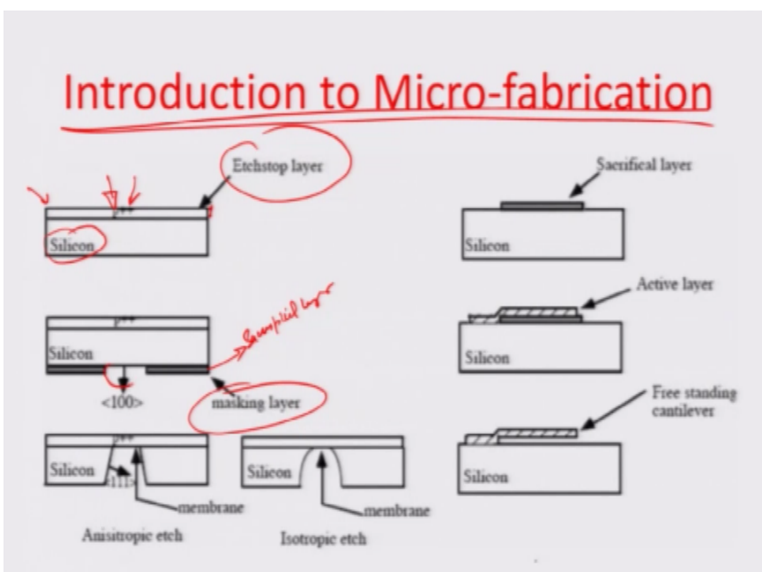

So typically you know when we talk about micro fabrication techniques I had earlier illustrated the concepts of bulk and surface micro machining so you have a Each stop layer as you can see right here so there is a silicon wafer over which you have doped this with a positive you know impurity which makes this speed double plus okay so this layer is really highly positive doped impurity on the silicon for a few microns within the silicon.

And let us say we have a sacrificial layer or a masking layer that we have formulated on the back side okay and we are actually able to pull out a portion of this sacrificial layer to subject the wafer which is having a 100 direction.

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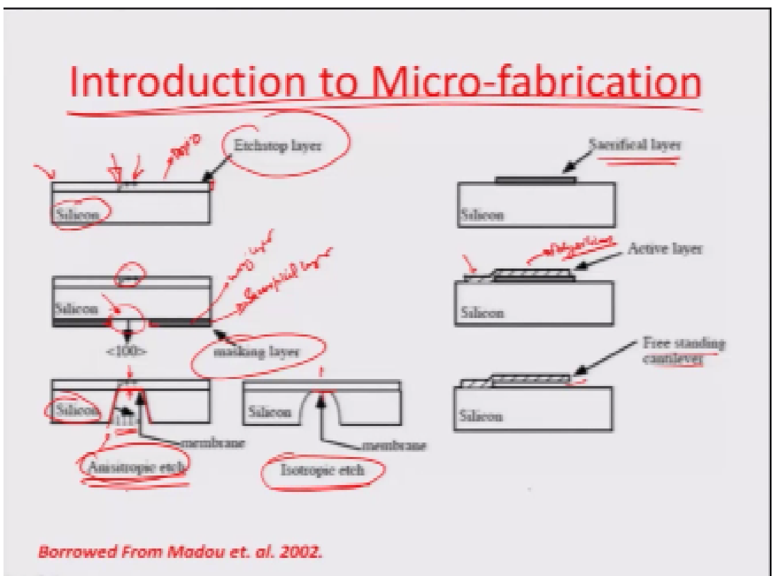

To the agent that is being concerned okay so the agent is such or is selected in such a manner that violate such as a basic materials silicon it has this P++ layer as a Etch stop so the etch will stop here so you can think of it that because of this agent going into and if supposing it where an isotropic etch mechanism which are more look cover in a few minutes the agent would typically go inside and it will go all the way up to the etch stop layer okay this P ++ layer.

But what is interesting is that this line membrane of a few microns comes out is a free standing membrane and you can use this for a variety of applications like pressure monitoring pressure sensing so on and so forth so similarly you have isotropic etch also possible this is an isotropic which is having a preferential direction of 111.

I am going to illustrate this process in great details later with some numerical as well but in the isotropic etch process again you have a homogenous etch and but again the same mechanism that as soon as the etch and phases the layer that is selective to its stops the etching process and again creates a free membrane you can actually develop cantilevers as well as you can see here this is a again a sacrificial material a deposited material on the top of the sacrificial material this could be something like poly silicon.

Which is otherwise having good mechanical properties good mechanical stability and then you can actually remove this sacrificial material here so that you can have a free standing cantilever, so this is how typically all this micro fabrication is carried out and what it would essentially need is a set of mask which would open these kind of small windows as and when it is needed and also sort of you know battery of processes.

Like in this case how many processes are involved there is a doping process which is there, there is this formation of the masking layer which could be something like a car bite or a night ride and it could be you know lay out through chemical means on the top of silicon then you have a masking strategy so you have a masking process you have a etching of this sacrificial layer which would be Y some gases for example you know in the dry etching system and then once this is etched you can further use some wet etched again to etch of this silicon so there about 5 or 6 processes which are coming in order to make something this is small.

But the advantages that the process of micro fabrication is such that it can give you a high yelled because these are small devices and you can lame many devices on one wafer and subjected to the same processing around assuming that all the devices in the wafer would actually be processed in a similar manner so all you need to do is six steps where are you getting back about 40 devices which are laid in a very nice manner on the, on one single silicon substrates, so that is the advantage of this kind of processing.

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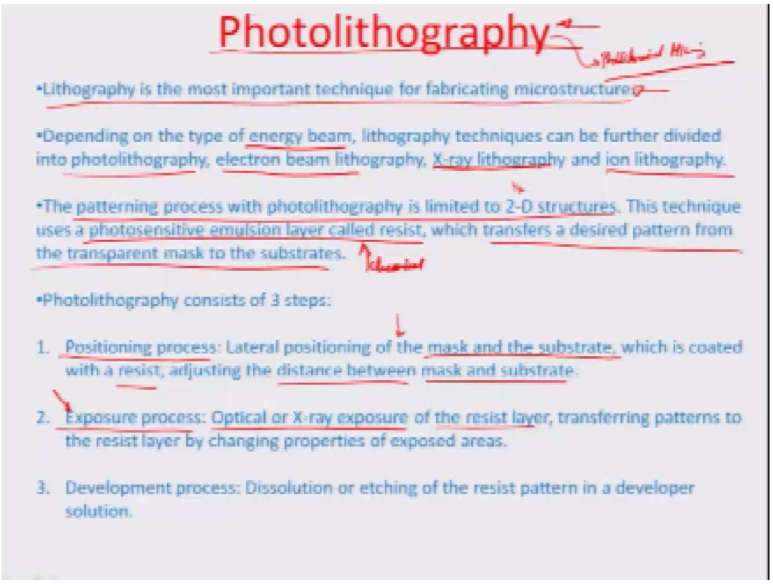

So let us now look at very important aspect of micro fabrication or you know even advanced machining which is called photolithography okay, so the photolithography as we are maybe some of us are aware is a very basic process which is also can be correlated to photochemical machining okay. So what is the process of photolithography and how it is accomplished I am going to over step by step probably if time super midst will also show I share with you a video at later point of time when we actually describe about the photolithography process in details.

But this would be of the number of forwards that I am going to teaching, so just for reference say, so lithography is the most important technique for fabricating micro structures and basically as I think we all understand that using the power of light to sort of transmit at a very high resolution so features by looking at their shadows you know so depending on the type of the beam which is used whether it is you know electron beam or whether it is you know bunch of different photons or even X-rays.

The lithography or ion lithography can be divided into various different types like one of them is obviously photolithography and other is electron beam lithography, X-ray lithography, ion lithography and as the energy source is going more towards to high frequency high energy regime the resolution of the process also keeps on changing. For example, probably photolithography may not be that resolvable at as an electron beam lithography when we are talking about nanostructures and how we laid it out electron beam lithography would be more helpful in comparison in comparison to photolithography and so would be X-ray lithography.

Because they are in the high energy regime and basically low wavelength meaning there by that the ability to resolve the light is much, much higher in a high energy system okay. So in the photolithography process however, is typically drive by UV light or UV energy and it is a two dimensional process we call actually a two and a half dimensional process, because of the fact that you are always limited to a plane where you are trying to sort of structure or micro structure and you know the only possibility to go up is by a few microns few hundreds of microns which you would typically obtain by processes like double layering, okay.

I will just verify to what the process is, so that you would be able to understand what is, what I mean by double layering process so the pattering process with lithography is limited to 2-D structures typically but you can go in the third dimension over a very small extend of few 100 microns that is why it is called 2 and a half D process and this technique uses a photo sensitive emulsion layer called resist.

So this is that chemical layer that we are talking about when we mentioned about photo chemical machine. So photo resist is something which may have constituents which are photo sensitive or sensitive to a certain frequency of light and so when typically light of that frequency would fall on the this chemical layer resist layer it would change the constituent of the layer in terms of either cross bonding.

The resist are enabling the de bonding between the molecules of the resist so there is some kind of a electronic transition made by the photo sensitive by virtue of getting exposed to light which would change the chemical constitution of the film or the layer that we are talking about. So it is typically what you experience in common day you know life when we talk about just photo graphic development well there is a film again exposed to light through step arrangement and through the film which actually changes its properties on development.

Because again the selective exposure of that photo paper to light a beam of light of a certain energies able to initiate some photo chemical changes on the chemical layer which is there on the photo paper. And the similar manner we are talking about much smaller scale which is do able by

UV radiation or UV EV light and the obviously the emulsion layer is completely different chemical in this particular case.

Although they desire properties of that layer is that it should change chemically with the respect to the exposure to the light, so it transfer z desire pattern from a transparent mass to the substrate and it consist of three different steps one is the positioning process so it is the lateral positioning of the mask and the substrate so typically why I am saying mask is because it something which shells of the light in certain areas and let the light come out in certain area.

So if I had some feature late out over this mask typically it would be a black and white kind of lay out were wherever there is aback region the light will not go through the mask or wherever the transmitting region or transparent region the light would go through the mask, so the typically those regions which are open to light or allow the light to go through would be the regions which would get imprinted on the resist or this photo chemical layer or the emulsion layer.

Which is placed just below the mask okay so you have this layer you have the mask and then you are ascending the light selectively in to those windows which are opened in terms of features, so those features get transmitted directly on to the photo chemical layer okay or photo emulsion layer. And the regions which are not transparent would typically you know transmit or typically enable shadows to fall on the layer below and these are the regions which are not affected by the light, because light is blocked okay.

So that is how you do the selective planning or selective feature imprinting from the whatever is designed in the mask to the surface of the photo emulsion layer. So then are you are having an exposure process so the mask has been position with respect to that resist film okay and there is a either certain distance which is kept between the mask and the substrate or there almost a contact maintain between eh mask.

And substrate and this again a different forms of lithography one is called the contact lithography and other is called proximately lithography or even sort of non contact lithography and if there is difference between the mars needs to be careful about the di fraction, effects which would happen if the size of the features are very small and there will be some kind of small bending of the beam of which the features would change.

Although what we are talking about it is really very cross features and probably the micro range or micro domain and they might not get so much affected by this defections process. So you have the next step which is the exposure process, once the mask is position you are optical and x- ray exposure of the resist layer, transferring patterns to the resist layer by changing properties of exposed region.

I have been talking about the details and the last few sentences about this process and then obviously once the features as been transferred in terms form either cross bonding or t bonding, you do a chemical change on the cross by the process called development process where you are dissolving or etching, resist pattern in a developer and in one case in the de bonding. The regions which are re bonding them of another case, cross bonding the regions which are not cross bonded are not exposed to light come up.

Typically there are two calls based on you know features coming out, in the exposed zone or unexposed zone they have got positive and negative resist. So typically the photolithography will start with the catch system.

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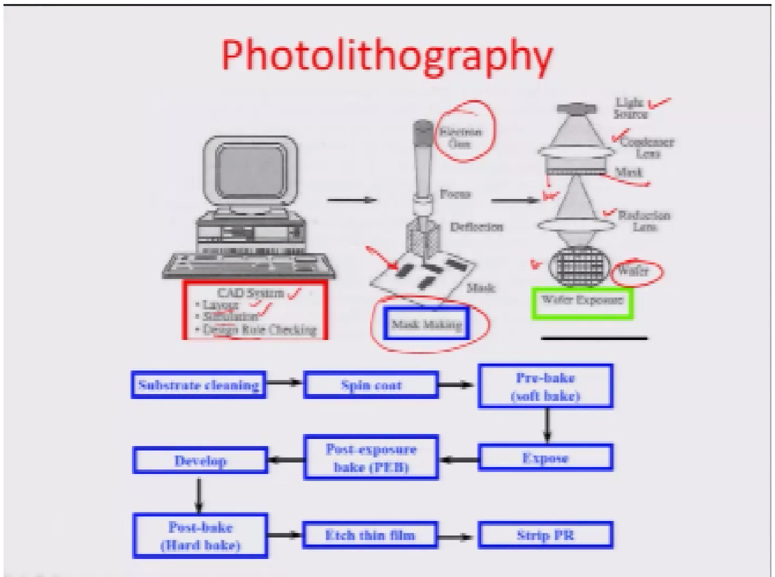

The layout the design that they are going to transmit and this CAD system is enabled to make a mask so you have a, some kind of design rule checking, some layout planning and this layout is basically done by may be an electron gun or laser machines and there is mask which is created and this mask needed for the lithography, so you have the vapor placed here. There is a mask that is somewhere particular region. Set of condenser lenses and reduction lenses as you can see and there is a light source.

If you have the mask placed in between the condenser lenses and the reduction lenses it basically leads to some kind of a feature reduction. So if this was 100 microns arrangement of condenser lenses and the reduction lenses reduces al this to 10 microns so, or even slightly lower. So this is kind of non lithography we are talking about, and contact lithography this mask happens to be very close to the sub strain or vapor. So here all the following steps that you have sustained cleaning first.

So you clean whatever you want to expose on, and you sprint the coat the emission layer at the top of this subs train leaning. Pre bake the emission layer which is also, enabling the layer to be harder, so that it does not come off when it is in the contact with mask. You expose the layer when you do a post exposure bake. You would do a development here, needed for sort of catalyzing the process of formulation as define by the type of resist.

Develop it and the region are unbounded typically they come off and they close to bake again after development, so you can try of that over, you know the this particular sacrificial layer pattern could be used. For etching the thin firms or doing various amount of micron manipulation on the surface. And then finally you can step of photo resist, it is the sacrificial layer which will enable you do a process and sacrificed the process has be done, so that is how you define photo lithography. I am going to cover little more the lithography probably in the next lecture and I am going to close this module thank you so much.

<u>Acknowledgement</u>

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