Design Practice - 2
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Lecture - 17
Etching Processes

Hello and welcome to this Design Practice 2 module 17. We were talking about the various micro fabrication techniques particularly related to silicon where we were discussing the etching processes. It is important from a standpoint of sensors because the person who want to design sensors and actuators and MEMS systems should have some knowledge of all the fabrication modalities which are available for one to have good designs, good sensor designs.

So we were talking about etching processes and we had in detail talked about homogenous or isotropic etching processes.

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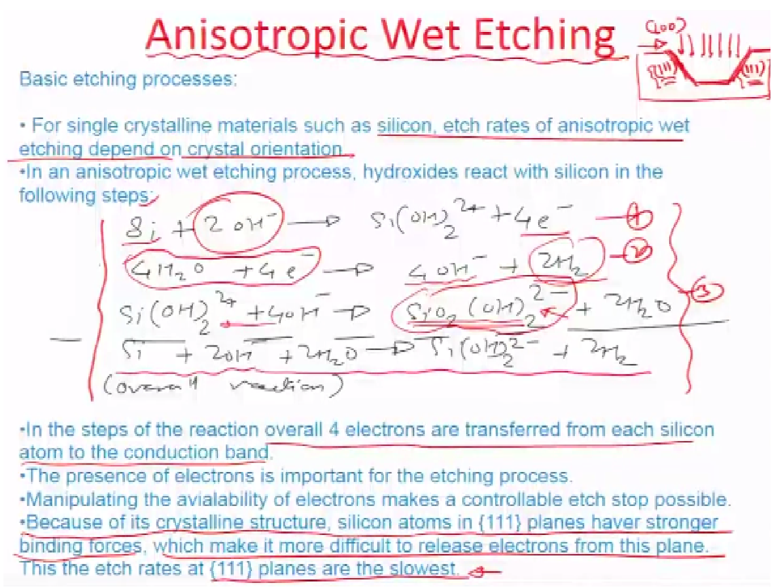

Today I am going to just visit another very important process for MEMS which is known as anisotropic wet etching process. So related to etching what we deciphered in the last lecture is that etching can be carried out through liquid medium as well as gases. There can be also a physical etching through particles particularly ions and electrons which are accelerated to a high velocity thereby imparting a kinetic energy and knocking off material from the sources. and also the same can be performed through photons or beam of laser, lasing light.

So these are the different techniques which we covered in the last section. So when we revisit wet etching and we study about this anisotropic wet etching process, this process is different than the isotropic wet etching in the sense that here the etching is a function of the direction. And when we talk about directions and particularly related to silicon crystal we know that there are principally 100 direction or 010 direction, 001 direction or then directions related to 111 or 110, 101, 011 so on so forth.

So these are the principle plains in such a cubic lattice structure of the silicon and so when we talk about directional etching we talk about the inhomogeneous rates in different directions. For example in the anisotropic etching process which is typically carried out through hydroxides, hydroxides like potassium hydroxide or sodium hydroxide it is basically an electron release phenomena which leads to eventually the dissolution of the silicon material or single crystalline material such as silicon. You know the etch rate really depends on the crystalline orientation.

So when we are talking about electron release obviously the electron release would also depend on the atomic density in the plane which is perpendicular to the direction that we are talking about. So therefore if we looked at a silicon cubic lattice structure and looked at the atomic density along each and every direction for example the plane perpendicular to 100 or the plane perpendicular to 110 or the plane perpendicular to 111.

Obviously, there are going to be different atomic densities in those planes and you know if we looked at the 111 plane that is the plane where there will be maximum atomic density. So the electron release process of an atom which is there inside a group of atoms okay which are bonded to each other obviously depends on the surroundings or the family in which it is in. how closely it is bound is a function of how many atoms or what is the atomic density okay on the particular plane which we are talking about.

So when we refer to the direction as a direction in which etching would take place the 111 planes having maximum atomic density would have the slowest electron release and because of which the reaction which leads to eventually the dissolution of silicon which is given here in a bunch of different you know processes which are going on for example hydroxide having the OH- reacting to the silicon atom giving 4 electrons.

And then again the water which is in the medium in which the hydroxides are dissolved again gets electrolyzed and converts into more OH- ions and hydrogen and this OH- ions again participate in the process making finally SiO2 OH 2 2- and 2H2O and this is which comes out into the solution as (()) (04:46) and it can be taken off. So basically an atom which was otherwise present in a crystal lattice now has come out as this particular ion which is dissolvable in water solution.

So if we wrote the overall reaction you know from steps 1, 2 and 3 together we find out that the overall reaction is about a 4 electron transfer process. And then I am saying that the electron releases slower in different planes. So obviously in 111 plane where the electron releases the slowest the etch rate will also be the slowest.

So eventually when we are talking about etching silicon in different directions, the 111 plane would be the last plane which will come off or etching will happen along this plane at the very last because it takes the maximum time, the rate being the minimum in that particular direction.
So whenever we are performing wet etching using hydroxide chemistry there is a possibility of eventually the 111 plane to evolve.

So let us say if I started in a certain direction, let us say this direction right here is 100 direction and the plane perpendicular it is again given by the circular bracket 100. So eventually the array of planes which would be formulated because of the etching action of the etchant, the hydroxide etchant which is there in the solution facing the silicon, the plane which eventually would emerge is going to be.

So therefore eventually it is going to be the 111 plane which is going to emerge in both the directions and that is going to result in the stoppage of the etching action. So that is how the angular profile in case of the anisotropic wet etching comes out. Because of the crystalline structure silicon atoms in 111 planes would have stronger binding forces which make it more difficult to release the electrons and because of this the etch rates at the 111 planes are the slowest and eventually the 111 plane or set of planes let us say which emerges in the process of this kind of anisotropic wet etching. So let us do a little bit of problem example.

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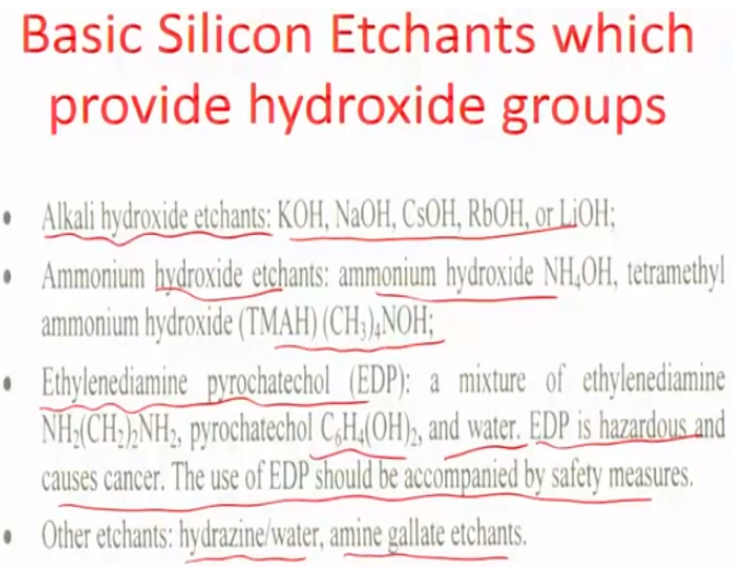

And before doing it even I mean let us actually look into what are the etchants which are available. So there are many hydroxide etchants which are available for example alkali hydroxide etchants KOH, NaOH, cesium hydroxide, rubidium hydroxide, lithium hydroxide so on so forth. There are also very specific hydroxide for example ammonium hydroxide or TMAH as we call tetramethylammonium hydroxide.

Or there can also be other you know generatives for hydroxide ions for example this chemical right here ethylenediamine pyrochatechol EDP which is a mixture of ethylenediamine pyrochatechol is C 6 H 4(OH) 2 and water. So this also is used although it is very hazardous and carcinogenic but sometimes it is used for you know doing silicon etching. Obviously, one has to handle it with utmost care and then you can also other etchants like hydrazine water or amine gallate etchants so on so forth.

So these are all group of etchants which would provide the hydroxide, hydroxyl ion and you will generate hydroxyl ion to do etching on planar surfaces or silicon.

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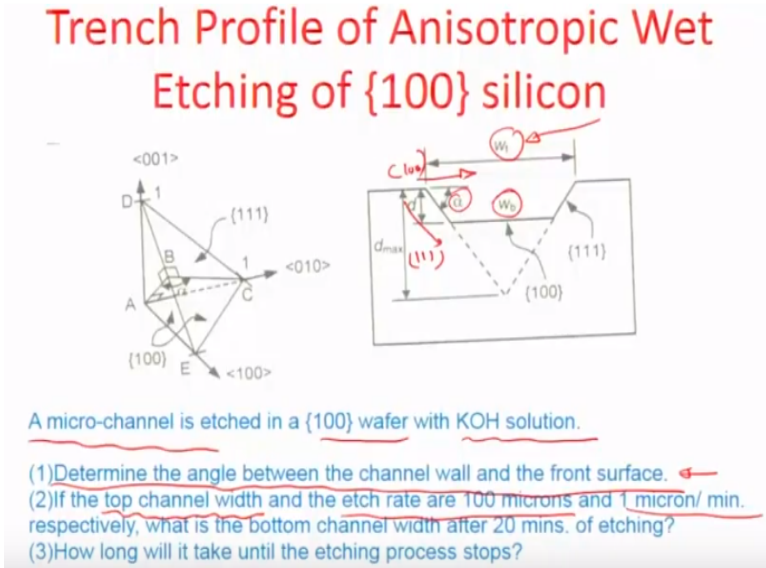

Will try to do a problem example of finding out what is going to be the angle particularly of the 111 plane in relation to the 100 plane. So here in this example problem we are trying to etch using an isotropic etching process or microchannel in the 100 wafer and we are etching with a KOH solution and we want to determine what is the angle which will be formulated between the front surface that is the 100 direction and the 111 direction okay.

Front surface of the principally grown direction of the wafer and the channel wall direction. So obviously the two vectors which are representing these two directions are discrete and so we can somehow have a dot product of these vectors and try to see what is the angle between them. So also we try to find out the overall times, time scales which should be involved in this etching process.

The top channel width is given here which is defined again by the mask you know the sacrificial material. I think I had mentioned about this in the last class and the etch rate which is also defined so top channel width in this case is 100 microns and the etch rate is 1 micron per minute and this etch rate is a vertical etch rate and the idea is that we would like to first evaluate what is going to be the bottom channel width given the top channel width and the etch rate.

So the angle alpha here is very critical. The angle between the 2 directions that is 100 direction and 111 direction and then we can also keep talking about how long this etch process will continue when it will stop so on so forth.

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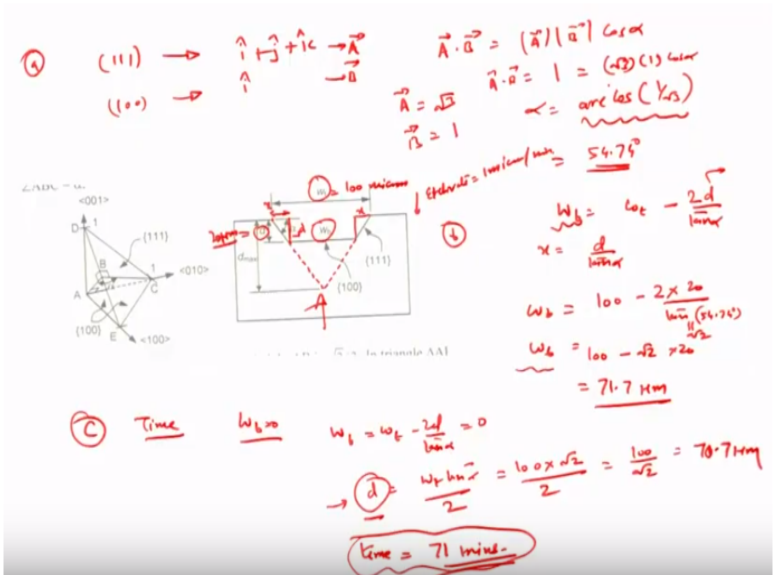

So let us actually look at this problem from an aspect of first finding out the angle. So in the 111 direction if we wanted to have a vector notation it would be simply given by I, j and k one units in each direction and in the 100 direction the same would be available through i plus you know just the i vector and then 0 along the j and k directions respectively.

So when we talk about a dark product between these you know so basically let us say this is vector A and this is vector B and we have A dot B provided through modulus of A, modulus of B, cos of the angle between them, in this case the angle being alpha between the 100 direction and 111 direction and modulus of A vector in this case comes out to be equal to root of 3 and that of B vector in this case comes out to be 1.

So we are left with A dot B which is actually equal to i dot i 1 and 0 dot j and o dot k which are all eliminated being equal to the mod of A which is root 3 times the mod of B times the cos of alpha. So alpha really is the arc cos of 1 over root 3 and this happens to be around 54.74 degrees if we wanted cos inverse or arc cos of 1 over root 3 calculated. So that is what the value of the angle is between the two directions that is 111 and 100 direction.

Let us now further go ahead and look into the calculations associated with part B of the problem, this is part A. Part B of the problem mentions about a total channel width to start with of 100 microns and a vertical etch rate of about 1 micron a minute that is called this etch rate 1 micron per minute. So if we figure out the relationship between W b and W t so obviously W b would be represented as W t minus of twice whatever distance b is covered within the number of minutes that the etch is allowed to continue.

In part B it clearly mentions that the etch is allowed to continue for a total duration of 20 minutes okay. So there are about 20 microns which would be covered and d becomes equal to 20 microns in this particular case because of the etch rate being 1 micron per minute. So with d on board here we know that this particular distance which is from one end really to all the way to the projection of the lower surface on to the top surface.

So this x right here okay is represented as d divided by tan alpha and so you have such x in both the directions, x here as well as x here and geometrically we can say that W b which comes out is equal to W t minus twice d by tan alpha okay. And that is how you look at W b. So in this particular case W b would be equal to 100 minus twice 20 which is the amount of etching which has happened.

The vertical etching at time duration 20 minutes divided by tan of 54.74 degrees and therefore this particular number W b comes out to be in this case equal to so this being equal to root of 2 it comes out to be 100 minus root of 2 into 20. That is approximately 71.7 microns. So that is about the size of the lower window W b when time equal to about 20 minutes has been given for the vertical etch to continue.

The other part of the problem statement wants to find out what is going to be the total time for which the etch would proceed uninterruptedly beyond which the etch will stop. So obviously that is an instance when W b is 0 because now there are only 111 planes. So I have you know projected this 111 array of walls all the way to the bottom where they meet each other.

And so assuming that these are the planes which are corresponding to the slowest or almost negligible etches when they meet together there is no further etching because there is no material which is available in the non 111 plane direction okay. So we can assume that once it closes or W b becomes 0 the etch would typically stop because 111 again is a slowest etch rate in terms of different planes and different orientations that the silicon might have.

So corresponding to W b equal to 0 again if we use the same equation as above we have you know a d value which emerges which is actually equal to W t tan alpha divided by 2 and this being 100 microns already we know that times of root 2 by 2 so this becomes 100 by root 2 okay. So and this is close to so this is close to again 71.7 microns and we know that the etch rate which is provided with 1 micron per minute.

So the amount of time which will take to etch out depth of 71.7 microns is typically going to be about 71 minutes okay. So that is what the total etching time would be for the etch to not proceed anymore and 211 planes to meet together as shown in this illustration right here. So that is how you would look at this problem. So therefore this value becomes equal to 70.7 and the amount of time which is needed to etch off the depth d is approximately 70.7 minutes or 71 minutes.

That is how the etch kind of closes because the 211 planes start facing each other. So that is about anisotropic wet etching. We have more or less covered all the subtractive machining techniques.

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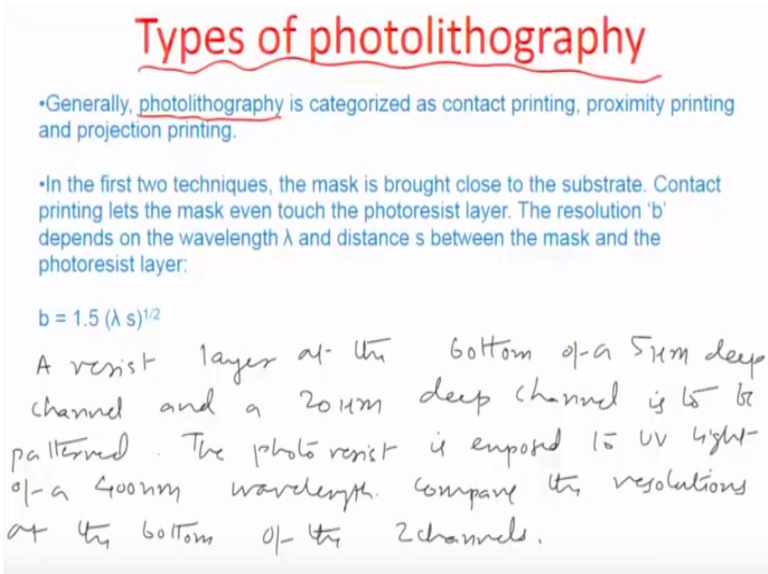

The other important aspect which I would like to now deal with is the photolithography aspect which is actually the way in which patterning is you know pattering is provided on to any surface and then this can be coupled with a variety of processes like etching and deposition to make metal patterns, make you know small etches within the surfaces. Generally if I looked at various classes of photolithography and even before looking at it let us actually look at what is this process all about.

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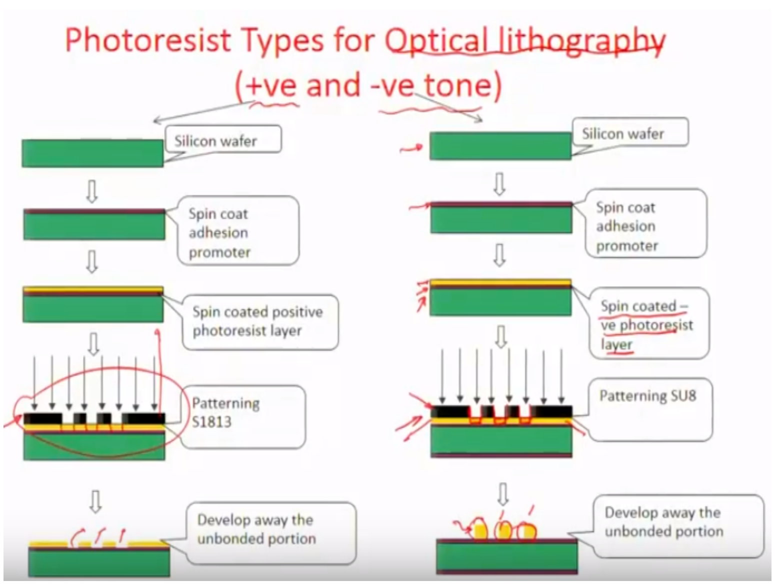

So let us say when we are talking about photolithography it is a process of selective exposure like photography through a black and white transparency or mask of otherwise photo activating or photo activated chemical which is known as photoresist. So the advantage that photoresist have is that they would have chemical transitions being exposed to certain wavelengths of light.

So those transitions could be debonding effects or they could be bonding effects and there can be various photoresist based on whether they debond or whether they cross bond on exposure to light of certain frequency. So when we talk about optical lithography, largely we are basing ourselves on these resists because these are what causes chemical transitions to happen and these chemical transitions can be again utilized in order to pattern surfaces through very small features which would then be extended to the surface over which these patterns outlay.

And the extension can be in terms of either etching of the surface or depositing something on the surface meaning thereby that we can do bulk and surface micromachining as we had showed in the earlier lectures. So here for example there are 2 different kind of photoresist shown. One is a negative tone where there is cross bonding which would happen and positive tone where there is debonding and so it start with the silicon wafer.

This is the silicon wafer and we spin coat in adhesion promoter layer which is actually something which holds on the resist layer which will come over it and it is like a cross linker which can cross link the resist to the particular surface of the silicon. That there is a spin coated negative photoresist layer which comes on the top of it. You can see this particular layer. So you have a green silicon layer.

You have a yellow resist layer on the top of it and then again a intermediate adhesion promoter layer which is purple. You are patterning this layer with selective exposure to light of a certain frequency. The selectivity is carried out through this mask which is you can see here the black layer where there are white openings in between and dark regions where light would not go through.

So typically when we use this as a mask on the surface that we are trying to pattern, light would only go through those areas which are actually having this open vials and it would fall on the resist and wherever the light falls on a negative tone resist it cross bonds okay so you can remaining. So basically the cross bonding effect starts only in those vials which are just allowing the light passage to go through and these are the regions which would firmly get attached to the wafer surface and we can easily dissolve away the remaining region.

So after a process of dissolution these are the features which are retained on the surface where there is crosslinking which is happening okay. So this is how optical lithography is carried out for negative tone resist. Similarly, a same scheme can be employed for a positive tone. The only difference that the positive tone makes is that wherever there is exposure for example these are the regions which are exposed that is going to be debonding and there is going to be material which comes off thus resulting in vials and crevices okay on the photoresist film.

So that is how you do optical lithography in the positive tone photoresist. Let us now go back to our problem of how you know different kind of lithography can be carried out. So it is all about how you are placing this mask. So this mask can either be placed on the surface in close proximity with the surface.

But the disadvantage that such an orientation would have is that when you want to do photolithography between alternate wafers and alternate trans you need to tear off the mask which may, and pull out the mask, which may damage the surface which you are actually working on. So that is one of the fallouts of this particular process. And then there can also be another instance when this mask is taken away from the surface of the resist.

So in that case we call the particular lithography proximity lithography. Now this cannot be going for a long distance because the optics is not able to cater to the defraction and other you know in principle light deviational means and there may be spreading of the shadow or the image I can say of the light which emanates from the mask. So the proximity lithography can be only done with a few microns gap between the mask layer and the resist layer as you can see here in this particular region.

But again it has its own advantages that it does not directly contact with the resist. However, the disadvantage is the preciseness of the few micron separation which may or may not be straight or parallel, completely parallel and it may result in some kind of a resolution loss on the wafer surface. Then there is yet another kind of lithography which is done by this mask going away quite a bit of distance and being projected through a properly guided optical system.

So that one ensures that there is no resolution loss or there is no change in the overall sizes and dimensions of the projections and so there can be lensing systems through which guide the light from a longer distance and so if the mask gets far away the advantage is that every time you know you have a wafer you can without removing the mask do exposure and go for the next wafer. So these are high yield processor used by the industry and we call them projection lithography.

So we can categorize this whole lithography process into the contact lithography which is shown here, proximity lithography which is about a 1 micron to 2 micron separation between the sorry tens of micron separation between the mask and the resist surface and then there is projection lithography which can be far away you know from the surface of the resist. So I would like to close this particular module now.

But in the next module we will investigate a little more of optical lithography, how it is carried out and try to end with all the MEMS processes. Thank you very much.