**Electronic Materials, Devices and Fabrication**
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**Module - 01**
**Etching and deposition (growth)**
**Lecture - 26**

Last class we looked at the process of lithography. So, lithography is a process where we transfer a pattern from a mask onto your wafers. So, the pattern is generator by the IC circuit you are trying to design and for a given circuit there could be multiple patterns or multiple masks. We saw that in lithography it is essentially two step process, in the first step, the pattern is transferred on to a photo resist layer that is applied on top of a wafer.

So, this is a temporary process, photo resist is a photo sensitive material that can either dissolve when exposed to light making it more soluble. That is called you positive photo resists are you can also have a negative photo resists were the photo resists become less soluble when expose to light. The first type of course is transferring the pattern on to the photo resists, and then the pattern has to be transferred on to the wafer. So, this usually involves removing some material from the wafer. A process called etching or adding new material to the wafer again at specific locations determined by the pattern in this process is called growth. Last class, we looked at lithography which is the first step and today, we are going to look at the etching and the deposition or growth process.

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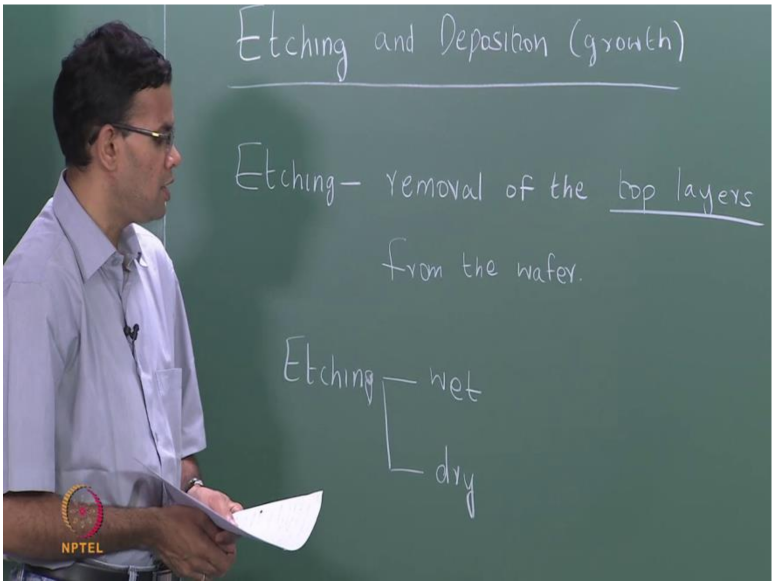


We will first look at etching and then move on to growth. So, etching can be defined as the removal of the material from top of the wafer in other way of writing at is that it is removal of the top layers from the wafer again as a mentioned earlier etching is usually combined with lithography. So, that lithography is used to expose certain portion of the wafer, which are then removed. Similarly, you also can use lithography to expose certain portion of the wafer, where you add material and that will be the deposition or the growth process. So, there essentially to main types etching, etching can be wet process is called wet etching the other process is called dry etching, so we will first look at wet etching.

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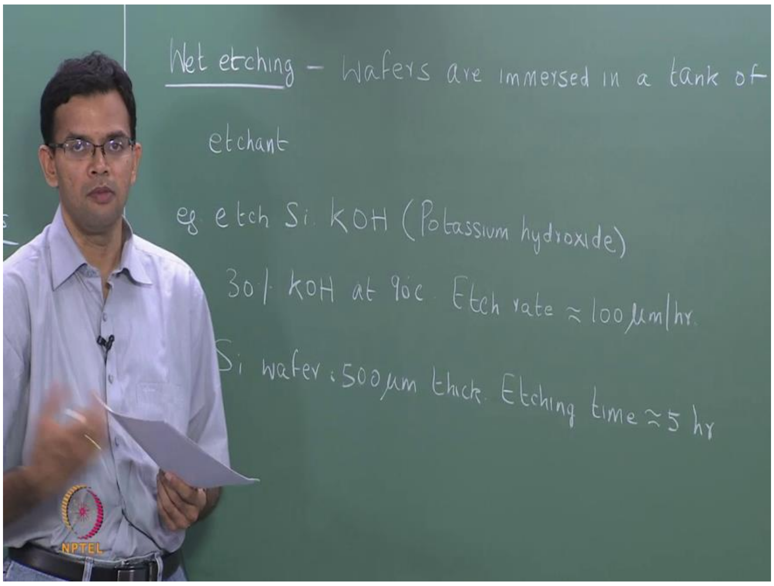


In the case of wet etching as the name implies usually some solve wet chemicals are used to remove the material from the wafer. So, the wafer is usually immersed in a tank of etchant and this is usually done and the certain condition, so is specific concentration of the etchant specific time? Sometime, this can be run done at room temperature would most of in etching is also carried out at elevated temperature to speeds up the process. So, if given example is considered, you need to x silicon a number of different etchants are used, but the most common one is potassium hydroxide.

So, for etching silicon, usually 30 percent KOH is used at a temperature of 90 degrees. So, you chemical is taken in bath which is heater to 90 degrees and then they wafer first are we must and a used in order to remove the silicon and these condition, the etch rate is approximately 100 micro meters per hour. So, if you think about a silicon wafer at typical thickness of silicon wafer is around 500 micrometers are approximately 0.5 millimeter, so silicon wafer there is 500 micrometers thick.

You can etch through the entered wafer in approximately 5 hours. So, usually after wet etch, the wafer are removed from the etchant, then they are cleaned again with distilled water in order to remove any of the aces etchant material usually some sort of chemical, then the wafers are dried an then used for further processing.

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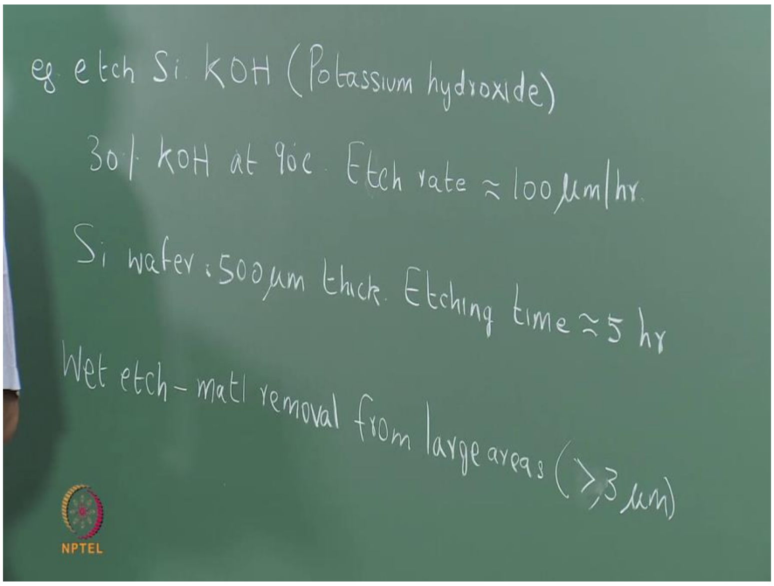


So, wet etch is used for removal of material from large areas of your sample when we can give a typical number say few micrometers. So, let me say at 3 micrometers for smaller precise etching. So, for etching from smaller pattern regions usually dry etch is prepared. So, whenever we think about etching, etching uniformity is really important and these again depend upon the process conditions.

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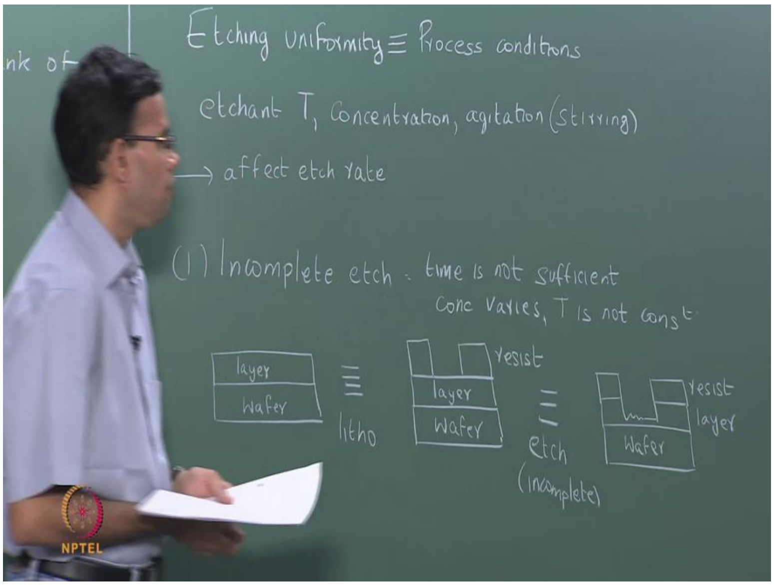


Etching uniformity maters and this depends upon the process conditions the typical process conditions are the etchant temperature concentration. You can also have some sort of external agitation this could be a simple magnetic stirrer that is used stir the liquid so that they have greater fluid flow. So, some sort of stirring and all of these affect etch rate. So, is usually very important the keep all of these numbers constant. So, you have constant etch rate for example, if you material is being consumed during etching then the concentration will change a changing concentration can again lead to a decrease or an increased in etch rate. Similarly, if for some reason the etchant temperature is not constant, but keep fluctuating that will again affect the etch rate.

So, usually some sort of initial experiments are done for different values of these numbers in order to fix are etch rate for the material before the actual wafers are used and again these depend a lot upon the process conditions. So, let us look at some of the various issues there are present in etching. So, this is through for both wet etch and dry etch. So, let us, so for dry etch then wet etch for we can used it is to illustrate some of the important process issues associated with etching the first of course is at you have an incomplete etch.

To give you a first example, consider wafer with some layer on top. So, we want to remove a certain portion of this layer in order to expose to the underline wafer. So, we can do some sort of patterning, let us say we do lithography using you standard photo resists. So, I would say litho here and we do this in such way that we open a window on this to layer.

So, we use a resists. So, that we open a layer the open a window on to this layer we saw this how do this in last class. So, we take either positive or negative photo resists we use a corresponding mask we spin on the photo resists layer expose through the mask develop an then remove this resists. So, that we get the window we can now etch through this layer in order to expose the wafer, but, if you etching time is not sufficient. So, you have in incomplete etch instead of removing the material completely you let be left which some of the layer still in that.

This is the resist is the layer. So, this is an example of an incomplete etch were the etching as not gone all the way to the wafer, but it stop somewhere here. Now, an incomplete etch could be because time is not sufficient most of in that is the case for example, if you estimate an etch rate of say 100 micrometer is in are, but your actual etch rate is lower say on 60 or 70 micrometers is in the time.

You have given would not be sufficient for the layer to the removed completely, there could be other reason as well, for example your concentration might not be correct concentration varies temperature is not constant. So, all of these which are essentially you a process parameters, you can affect your etching process giving you an incomplete etch. So, when essentially have an IC fabrication process some sort of experiment was we done before you actually use you given material to determine the etch rate. So, one process issue with etching is the fact that you can have incomplete etch another one is where you go the other way and have something called an over etch with under cutting, so your first process issue is an incomplete etch.

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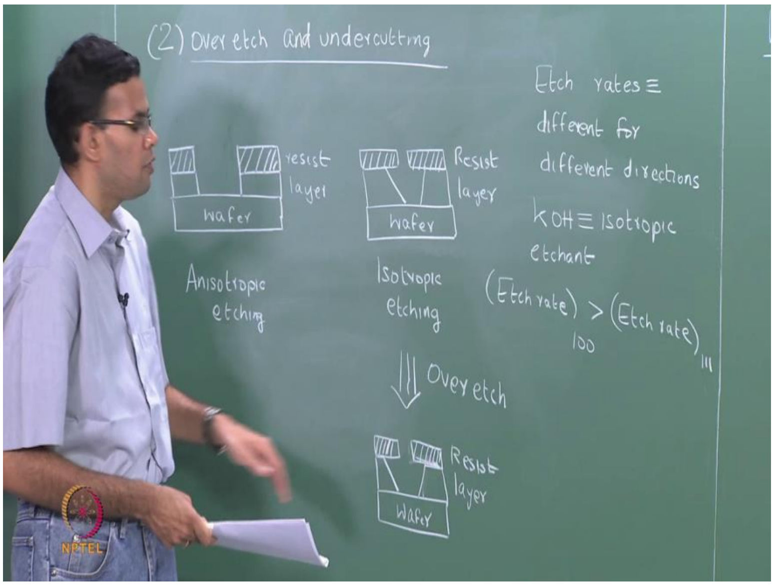


The other one could be an over etch, usually a companies with something called and undercut. So, it gives you one example again, let us go back to the wafer. So, this is the wafer this is the layer were you want to create window and again you have some sort of resists that you used to open the way windows this is your layer this is the resists, so let me just shade the resists. So, in differentiated from the layer an ideal etchant if you think about it essentially give you this really strait side walls.

In order to do this, your etching must be anisotropic when we say anisotropic, we mean the etching should take place only in the vertical direction and they should be no laterals spread. Usually, that is not through in the case of wet etchant you have etching that is essentially anisotropic though in have different rates going in different direction.

So, instead of pure anisotropic etch you might have an isotropic etch. So, instead of having strait side wall you might end of the with the side wall with a certain amount of taper, so this is your layer. So, this is the wafer, this is the layer in that is the resist. So, right instead of having a side wall that goes right you have material removal in the lateral direction is well giving your sort of a taper. So, this is the case when you have isotropic etching and again etch rates would be different for different direction.

For example, we looked at KOH, which is used for etching silicon, we could find the KOH will not only etch the 1 0 0 surface. So, let us say you have a silicon wafer that is 1 0 0, the 1 0 0 direction is perpendicular to the plane of the wafer. So, KOH will not only etch 1 0 0, but will also etch the 1 1 1 direction. So, KOH is an example of a isotropic etchant. So, the etch rates are different, but it still etch the other direction is well. So, the etch rate for you 1 0 0 direction is greater than the etch rate.

For 1 1 1 and in fact there is specific angler differences which will develop in the case of wafer when you are trying to etch 1 0 0 because also etching along the other directions. So, when we have an isotropic etch, so we solve that we not we do not have straits side walls, but we also have some etching along we lateral direction give in you a side wall that is loped. If you go for etching longer than the time that is required, you have more material being removed from the sides leading to something call and undercut.

So, we want a pattern that is being defined by a photo resists, but because also removing material from the sides you actually end up having a wider pattern. So, this is the case of an isotropic etch if you go for over etch of this again to give in one example, let us say you have you have determined an etching rate of 100 micrometers an hour. So, you plan for a one hour etch, but your actual etch rate because of you process conditions is faster. Let us say it is 100 on 20 or 100 on 30, there in the same 5 hours you are going to remove more material not only in the vertical direction, but also in the horizontal direction, so over etch here can lead to away.

So, again this is the wafer this is the layer that is resist. So, comparing these two, we have more material being removed from the sides. Ultimately, if you over etch a lot, you can even have the resist layer completely lifting of because there is insufficient material below it. So, one problem is in incomplete etch when you etch for shorter time on the other hand for an isotropic etching you can end of having n over etch. Now, in other problem, we looked at wet etch is the selectivity of the etch an material that you used.

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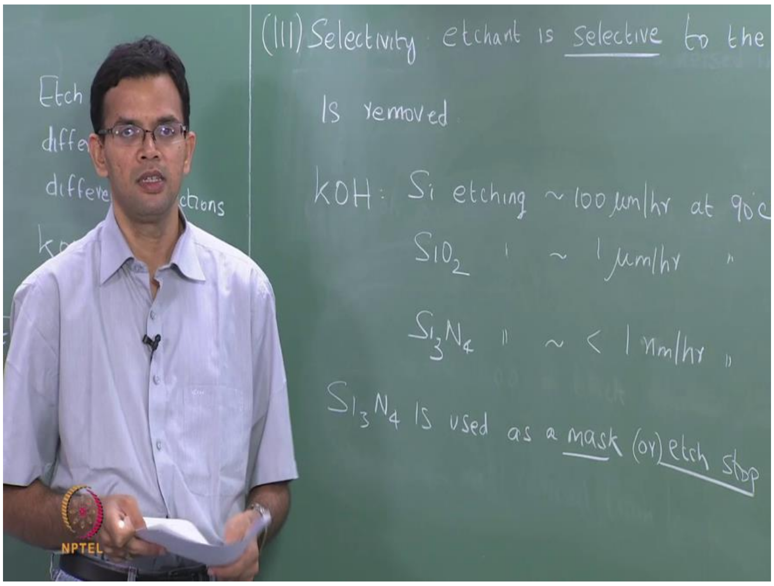


At third issue is the selectivity, you have to choose the etchant material corrective correctly. So, that it is selective to the layer you want to remove. So, this is very important because you need to be able to protect the material that is below it in you also want to be able to provide stop for the etching process to happen. So, usually that is not the case. So, sometimes you have etchants that are not completely selective, but if they have were different in etching rates between two different materials that should also be fine.

To give you an example, let us go back to KOH, we solve the KOH can be used to remove silicon and the etching rate is approximately 100 micrometers in hour at 90 degrees. So, it is used for silicon etching, but same KOH instead of having silicon if have silicon dioxide $SiO_2$, the etching rate is usually 1 micrometers an hour again at the same 90 degrees. So, you can see that KOH more selective to silicon, then silicon dioxide though the rates are just 100 times of instead of silicon dioxide.

If you have silicon nitride, $Si_3N_4$, the etching rate actually way lower with is 1 nanometer an hour. So, we can say that KOH is highly selective to silicon etching less selective $SiO_2$ and really stops etching when we have silicon nitride. So, if we look at silicon etching, usually silicon nitride is used as the mask layer for the silicon can either the used as a mask or an etch stop for silicon. Similarly, for other layers you have specific etchants that I used which are selective that particular layer and will not affect the other layers. So, let us look at some examples of some etchant materials that I used for the various silicon layers, so some examples of etchant materials.

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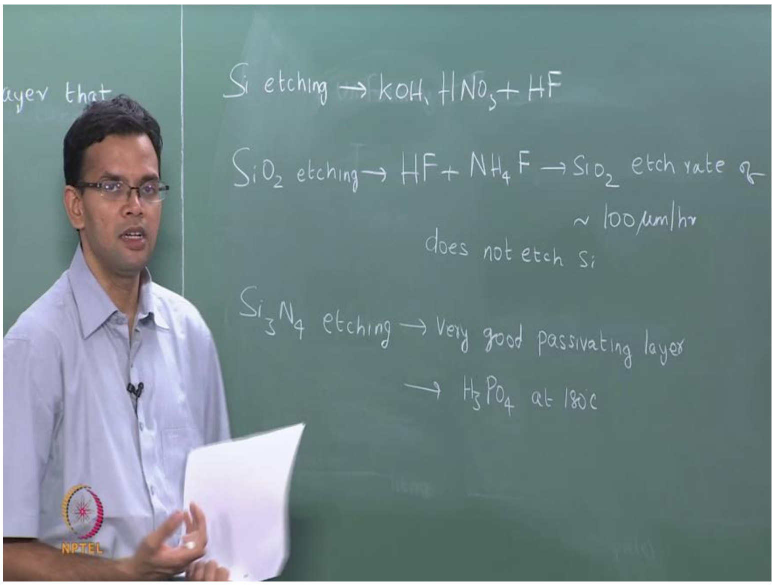


So, for silicon etching you already seen KOH as 1 material can also use a mixer of nitric acid plus hydrofluoric acid for SiO2 etching. Typically, hydrofluoric acid plus ammonium fluoride is used NH4F. So, this gives in SiO2 etching rate proximately 100 microns an hour, but it is very selective to SiO2, it does not etch silicon for silicon nitride silicon nitride is usually in pervious to lot of etching materials it forms a very good passivating layer. So, hot phosphoric acid is used, so H3PO4 at 180 degrees is used to silicon nitride usually for MEMS device fabrication.

There are some devices were a silicon bridge or a silicon membrane needs to be found by being supported by a silicon frame. In those cases, the entered wafer has to be etched in order to create the silicon membrane for such applications silicon nitride reduced as a sort of etch stop layer so that once the KOH each through the entire silicon. It sees the layer of silicon nitride and then stop etching silicon the silicon nitride used the very good passivating layer not only for silicon for also for silicon dioxide. So far, we are look at wet etch, let us now look at dry etch.

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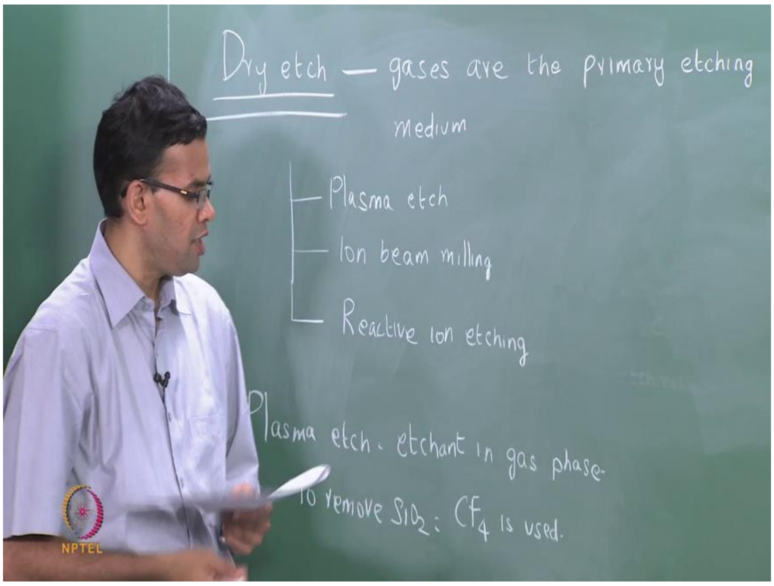


So, if you look at wet etch, one of the limitations that we said are we can only be used for etching large areas. So, if you micrometers long of this is really not possible when we have to pattern smaller and smaller features. So, we need to etch from really small areas wet etch also uses a lot of harmful chemicals. So, it is environmentally not very sound. So, for this, one of the new techniques, it is come of its use a process of a dry etchant.

In order to remove materials, so dry etch gases are the primary etching medium there are essentially three kinds of dry etch one is called your plasma etch. Other process is called ion beam, ion beam milling is more of a physical material removal process than a chemical etching process. There is ion beam milling and the combination those to which is call reactive ion etching.

So, if we look at the plasma etch, the chemical etchant is introduce in the gas phase and electrodes use in order to generate a plasma. So, this plasma then attacks wafer surface and then remove the material. So, again you have the etchant in gas phase for example, to remove SiO2 some sort of fluoride gas has to be used. So, usually c f 4 is used, let me just draw brief schematic of the plasma etch, so you have chamber.

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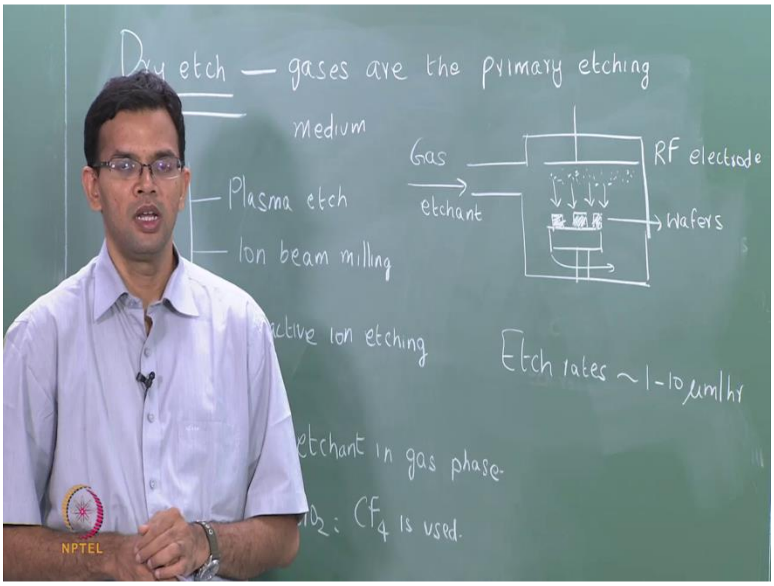


The chamber is usually evacuated, so we know the wafer is taken on some substrate holder usually multiple wafer can be etch for the same time. So, these are you wafers an electrode is brought close to the surface of wafers connected to a radio frequency source this is RF electrode, the etchant gas is then introduced in to the chamber, some sort of carrier gas also used. So, this reacts with the electrode in basically there is the plasma that is generator this then attacks the wafers an then reacts with the silicon dioxide and removes the material, we can protect the surface of the wafer usually by using of photo resists.

So, that once again you can have a window when where ever the layer is expose it is removed a, where ever it is protected by the photo resists the material is still that. So, in the case of dry etching the etch rate are usually much solver the etch rates are typically 1 to 10 micrometers per hour. So, the etching is usually carry doubt with the sample at room temperature like the case of wet etching were the chemical a usually at higher temperature, so the etch rates are lower.

So, if you want to etch a really thick full then the wet etching would be the wet go to because dry etching we can take long time, but it is highly selective process. All should be used for really small areas; the other kind of dry etching is the ion beam etching.

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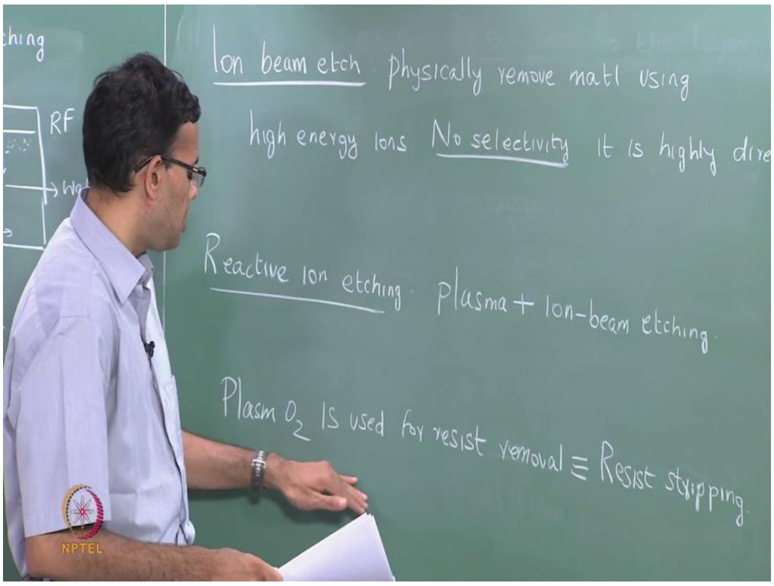


So, the ion beam etching the chamber arrangement is similar, but instead of a chemical reaction, you have physical removal of a material, but it with high energy ions. So, physically remove material using high energy ions, so in the wafer, this similar to the ion beam milling process that take place in them. So, this has no selectivity because it is only a physical process, but the advantage is it is highly directional. So, if you want define really vertical side walls it highly directional we can also changes the direction of the beam. So, that it is not inspiring the surface vertically, but inspiring the surface at some angle.

So, if could get different etching profiles using ion beam milling reactive ion etching is third kind of etching. So, this combines both the process both plasma and ion beam etching. So, you not only have physical removal of material, but you also choose your etching gas in such a way that there is some chemical reaction. So, it is mixture of both plasma and ion beam etching. So, dry etching is also used to remove the photo, the photo resists after the etching growth process.

So, again we saw in last class in lithography, we span a layer of photo resists on the surface open some windows were you can do some work or some chemistry on the wafer an. After the process is removed, we completely remove the photo resists from the entire material. So, usually dry etching with oxygen reduces in order to remove for photo resists.

So, usually plasma oxygen this process usually calls resist stripping similarly, where is some mistake when the pattern transferred to the photo resists. For example, if there is in alignment issue and then pattern is not transfer to the photo resists completely. You can strip the photo resists again using a plasma oxygen clean and the reapply the photo resists an then do the entire masking and design transfer process. So, dry etch again is used for that, so we are looked at some of etching process. So, in the case of etching, we are removing material, now you are going to look and some of the growth process.

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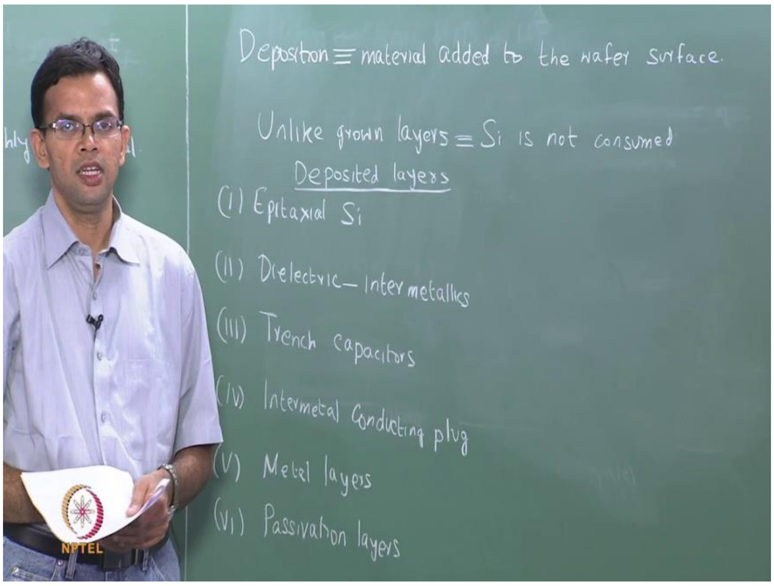


So, etching is removal of material deposition is addition of material. So, you have material that is added to the wafers of surface. We have seen grown layer before, for example we of seen oxide layers or nitride layers before in those cases we are consuming this silicon in the wafer in order to form the silicon dioxide at the silicon nitride. In case of deposited layers, we are not consuming any of the underlines silicon. So, unlike to grown layers silicon is not consumed. So, some of the areas wet deposited layers are used usually you had epitaxial silicon or epi silicon that is grown.

So, here are growing a new layer of silicon and top of you silicon wafer detect materials are in other example of deposited layers. So, usually they are made of some sort of metals could be inter metallic. So, our high trench capacitors again a trench is formed in the silicon and dialect material is used to fill the trench inter metal conducting plug. This is used for making electrical contacts the metal layers themselves, surface passivation layer all of these are different examples of deposited layers.

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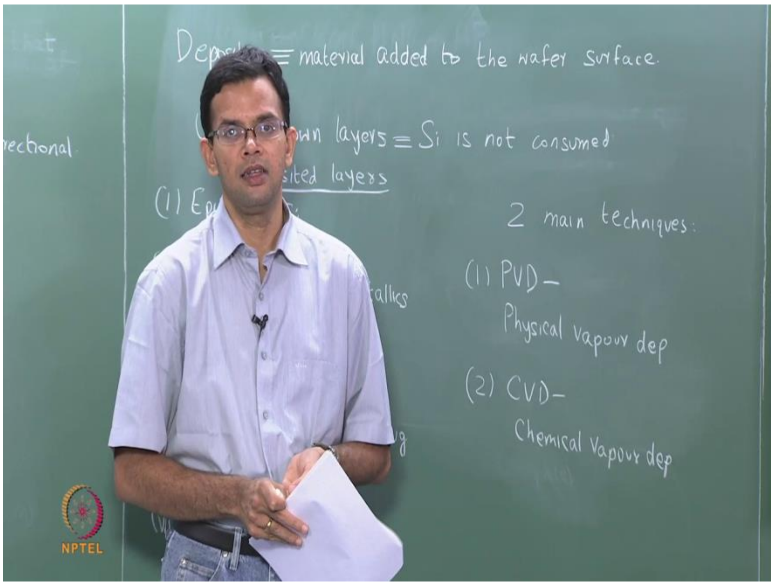


So, that two main techniques for growing deposited layers, one is a physical wafer deposition techniques or PVD and the other one is the chemical wafer deposition, so CVD. So, physical wafer deposition is usually used in order to grow metallic layers will see more about it next class. So, CVD is usually used for growing layers next silicon or epitaxial silicon directly, next silicon dioxide or silicon nitride some sort of silicate gallium arsenide an, so what?

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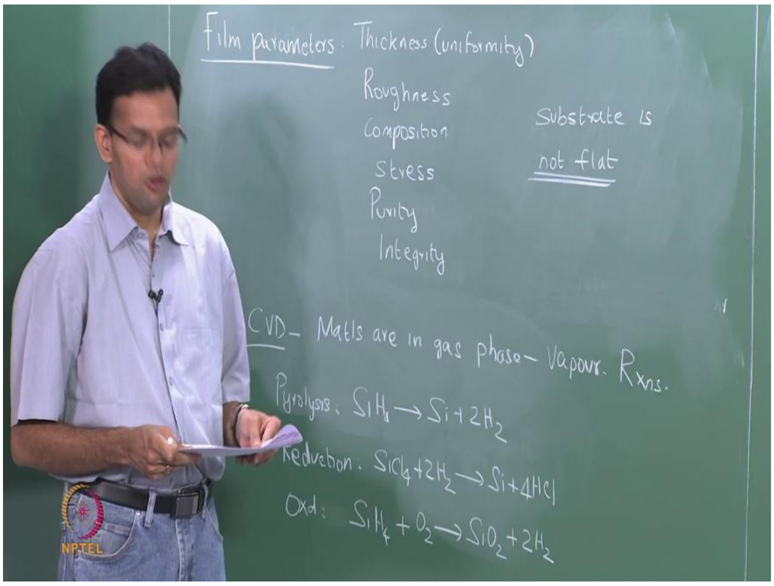

So, when we look at deposited layers, some of the important film parameters that we should keep in mind one of course is thickness, how thick these layers are along with thickness an important parameter is uniformity. So, we want uniform thickness through the entire wafer and this becomes is more important because is now migrating to larger and larger wafers. The current IC fabrication involves 300 millimeter wafers or 12 inch wafers and now you a moving two 450 millimeters or 18 inch. If you are trying to grow a layer, not only one the desire thickness put, also one the thickness to be same over the entire 18 inches surface roughness or the roughness of these layers.

Usually, some sort of polishing you can also be used composition stress stresses important because this can to lead to delaminating later on and you will use the film integrity purity and fill integrity. So, these are some of the important film parameters are important to note, but your substrate need not be flat. So, substrate could have other features that are on there, so let us not essentially growing on a flat substrate.

So, this becomes a especially important for surfaces that have say a deep trench or a deep well and you need to grow with in that well in such cases the thickness and also the accept ratio this layers become important. So, in the case of CVD, which is chemical wafer deposition your materials are introduced in the gas phase in these then react to from the film that you 1 which then gets dispositive. So, the materials are in the gas phase. So, they form vapor which is why called vapor deposition is.

These then react in the chemical reaction to give you the final film. So, some reactions there are typically possible for example, you can have pyrolysis. So, this is a simple silicon hydride we in you silicon plus $2H_2$. So, this silicon layer will then the deposited film you can have a simple reduction reaction again we can have silicon tetrachloride. We are acting with hydrogen to forms silicon plus HCL can also have an oxidation reaction $SiH_4$ reacting with oxygen to form $SiO_2$ plus $2H_2$ you can a right similar reaction for metrication and. So, in all of these, the material that is form is deposited on to the wafer, so the many variations to the PVD process.

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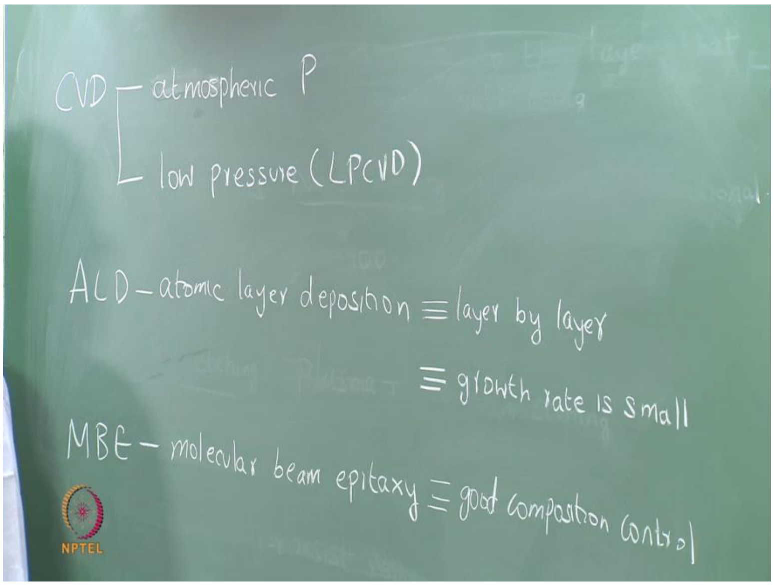


We own going them in detail in most common method is doing CVD under atmospheric pressure we can. Also do c v d under low pressure the growth rate is lower this process is called l p c v d a l d is an other process is called atomic layer deposition. So, here you are again growing material layer by layer. So, the growth rate is very small, but we can have very precise atomic growth. So, this actually just a variation of the CVD process where instead of introducing the two gas together, one gas is introduced which forms a monolayer.

It is removed from the system this again gas is introduced that reacts with the first monolayer in order to form material. So, you essentially growing material monolayer by monolayer another technique is called m b c or molecular beam epitaxy.

So, in this case molecular beams of the onsite of the final film you want is used in order to grow a materials MBE can be used for draw again thin epitaxial layer with very good composition control. For example, to growth gallium arsenide you can have molecular beam is of gallium and molecular beams of arsenic both of which impinge on to your surface in order to from gallium arsenide. You can also introduce your dopants along with it if you want to form N type or P type gallium arsenide.

So, these are some of the examples of c v d growth process usually some sort of hard marks is used along with these growth process. So, that the rest of the wafer is protector and the growth takes place at the region way you want. So, in next class, were going to look at some of the physical wafer representation process especially those that I used form metals. So, this is called metallization and will also look at polishing the wafer in next class.