Soft Nano Technology
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Lecture - 16
Photo Lithography – 5

Welcome back. Continuing our discussion on photolithography, so let us see how far we have now understood.

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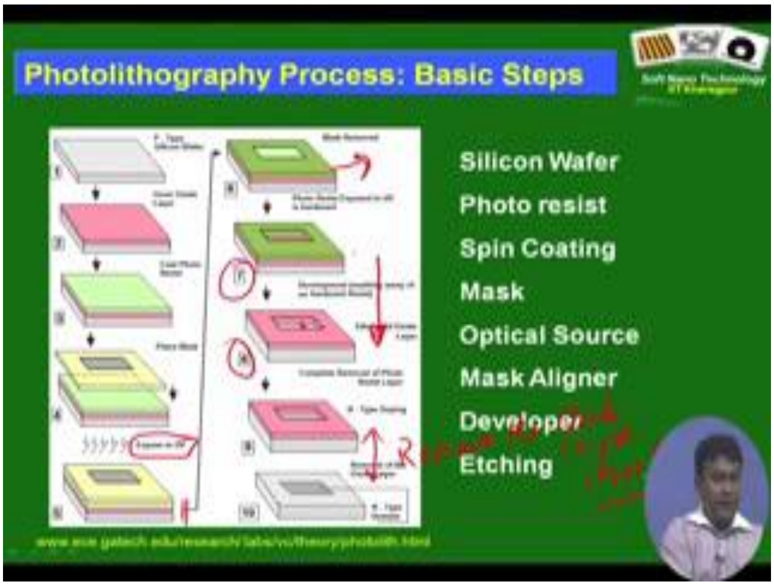

Photolithography Process: Basic Steps

- Silicon Wafer
- Photo resist
- Spin Coating
- Mask
- Optical Source
- Mask Aligner
- Developer
- Etching

Now see you understand the all these stages and in the previous class, in fact we had a pretty detailed discussion around this particular step and now you also understand that though in this schematic or the cartoon movie we showed, you tend to believe that the mask is always placed in conformer contact with the photo resist layer, that is not exactly the case. So, you can have an additional reducer, reduction lens between these 2, they may not be in contact you can have proximate contact of the proximity printing mode etcetera, etcetera.

But anyway, the basic function after the UV exposure is this and that is where the photo resist undergoes this change. Now you are all set after your photo resist have been exposed to develop and to transfer the mask pattern on to the photo resist layer to start with, so let us see what we need to do.

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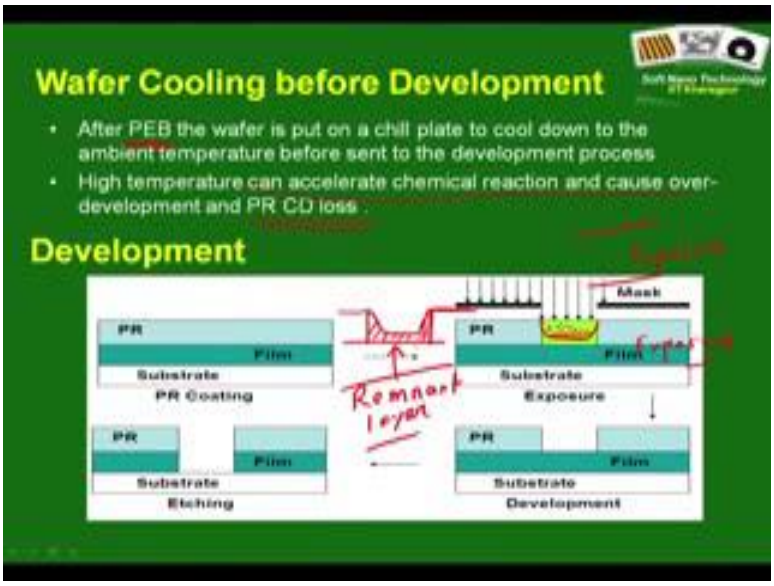

Wafer Cooling before Development

- After PEB the wafer is put on a chill plate to cool down to the ambient temperature before sent to the development process
- High temperature can accelerate chemical reaction and cause over-development and PR CD loss .

Development

We first nothing we need to do is we need to do wafer cooling before development because you if you remember, I mentioned that right after exposure you do a post exposure bake at about temperature 90 or 110 to 130 degree centigrade. So, the wafer is still hot and you need to cool it down because high temperature. If you expose, if you develop at high temperature it might in fact lead to loss of photo resist from areas where you do not want to get it removed.

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Development

- Developer solvent dissolves the softened part of photoresist
- Transfer the pattern from mask or reticle to photoresist
- Three basic steps:
  - Development
  - Rinse
  - Dry

This the development process which is in fact very simple and if you look into the schematic for a second you will understand it yourself, so this the top layer shows the location of the mask and these are the areas were the mask was apex, so no light passed. This is the slit through which the lights passed and you had a uniform photo resist layer, so now you yourself understand that the areas where, so this has led to a negative replica. So, what it means that the areas where the light has shined on the photo resist layer, those areas are strengthened right and in contrast this is positive photo resist layer, so the areas over which the light has shined it has in fact weakened.

We now know that the developer in fact removes the relatively weak zone and that is precisely what is done. Very important to understand is that you are let us say I am drawing this picture again, so this is a positive photo resist and this part is the so called weaker part but please do know so your developer is a solvent for this particular polymer or photo resist. Please do not forget that after all it is the same material, only some part may be the chains are smaller here as compared to this area or something like that.

If you keep it immersed in the developer solution for very long time everything going to go away. So, your time for development is extremely important because if you keep it for longer duration, it might; everything might get dissolved. If you keep it for shorter duration, even the layer that you want to dislodge might not get removed fully, so you can easily end up getting something like this.

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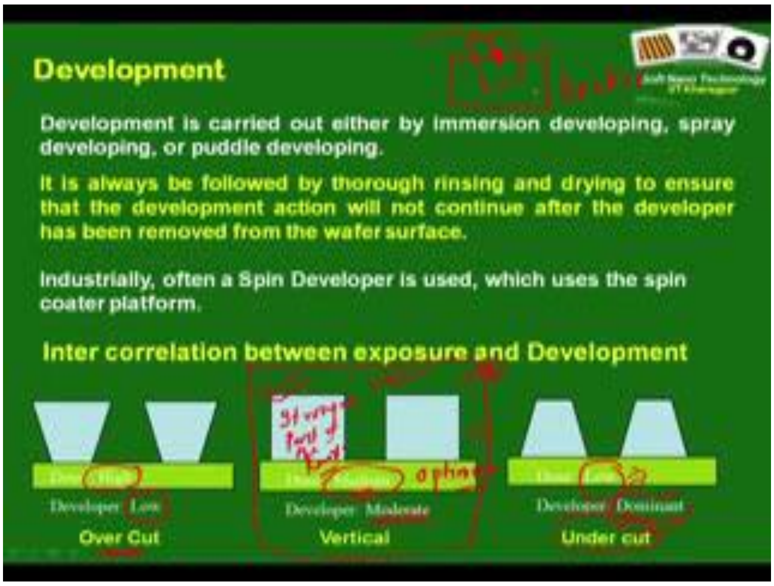

Development

Development is carried out either by immersion developing, spray developing, or puddle developing.

It is always be followed by thorough rinsing and drying to ensure that the development action will not continue after the developer has been removed from the wafer surface.

Industrially, often a Spin Developer is used, which uses the spin coater platform.

Inter correlation between exposure and Development

This is sort of under developed and so this sort of gives you a very comprehensive idea. So, this is the ideal development profile right, so what is this; this is the stringent part or the stronger part of the resist and you typically you would like a vertical profile, so those are the exposure in fact and this is a developer. So in particular geometry, please remember that the going too much detail this is what you expect to have. So, the same problem will happen if you exposure timing is also not appropriate if you under expose then across the whole layer where below the mask, the material will not change property.

Let us say it will change property of this point similarly if you over expose then in fact, the material turn to change property along or even the neighboring area sort of tend to get effected by the presence of u v radiation because it is not a question of the direct shining of the light, it is in fact the question. So, light comes from here it bring in certain amount of energy and that energy in fact causes the structural changes in the zone. So, if you have excess amount of energy what will happen the, it is the transfer problem, the energy will start percolating in this direction and the zone over whose structural change in the photo resist layer takes place will increase.

Similarly, so this is over expose this is the problem of over exposure and in the process what you do? You actually get wider structures on the photo resist layer as compared to your mask and that is something you do not want to have because at least for the microelectronics industry you need to achieve as small structures as possible, so this spoils your performance on the other hand. So, this is a problem that can happen during over exposure as well as now we that understand that after exposure it has to be developed. So, this problem can again happen, if you over develop, so it is very very important that timing not only development for exposure as well as development is suitably optimized that is extremely important.

Exactly similar will be the case where if your development is if you are sorry if your exposure is inadequate again the same problem happens you actually have less amount of energy coming in through the u v radiation that is necessary to make structural changes to this amount of photo resist done. What will happen is; if you under expose of course the layer goes to the top, the photo resist close to the top layer they receive adequate amount of energy but due to resistance against heat transfer.

These layers towards the bottom part they get lesser amount of energy and they do not undergo appropriate changes in structure and so when you try to develop and under expose photo resist layer, you are very likely to get structures like this, so what is that the exposed part of the photo resist did not dislodge fully. So, it is some sort of a remnant layer that remains and you know very well this not going to help your cause; why because finally, patterning the photo resist is not your objective.

You actually want to transfer the patterns on the photo resist layer to the barrier layer below and this if the remnant photo resist layer is present barrier layer is not exposed. So, your whole functionality is lost therefore, it is extremely important to suitably optimize both the exposure and the development stages, this cartoon also sort of gives you a quick idea about that. So, this is aprocradiates it is medium and moderate, but this the optimum cases this is optimum optimally developed and optimally exposed. So, this seems to have high exposure, may be associated with low development.

There are cases where this over cut structures are required there is a methodology that we will discussed in leaftop, where this type of structure are desirable, you may from some other application not exactly for microelectronic you may want to have these type of trapezoidal structure. So now, you know what to do, you sort of do a bit of low exposure and you can do some bit of stronger development and you get what is known as the undercut structure, but I mean these are details and you may want to tell at the geometry and the sharpness of the line with all this can be doable the take home message is this can all be done, but ideally from the plane vanilla photolithography stand point this is what you like to have.

I mean just a minute; I will spend on that development methodology, so typically it gives us a feeling that if you want to develop you take a beaker which contains the developer solution, you take the exposed photo resist coated wafer and simply rinse it there and you achieve the development which indeed is doable, it is absolutely doable in a large scale, but industrially wherever with a high throughput system it is difficult to do, so how do we do it and industry has very cleverly utilized again the spin coating platform for development.

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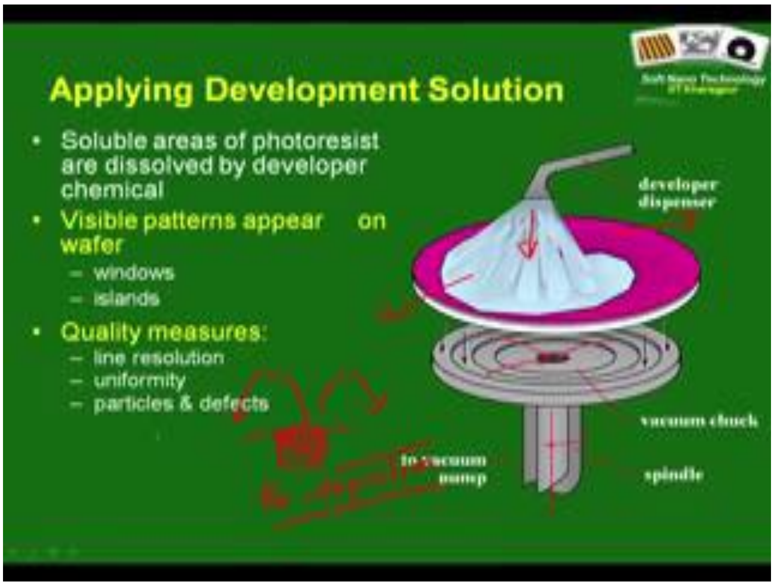

Applying Development Solution

- Soluble areas of photoresist are dissolved by developer chemical
- Visible patterns appear on wafer
  - windows
  - islands
- Quality measures:
  - line resolution
  - uniformity
  - particles & defects

What you simply do is just the way you obtain your photo resist layer, you simply put the exposed substrate, exposed wafer again back to the spin coating platform. You now instead of dispensing the solution; simply dispense the development, developer solution and rinse it for a final duration. So, it is all optimized and as you rinse it the 2 advantages take place in fact it rinses, it washes away and simultaneously since there is lot of flashing in spin coating, so this washed photo resist or the dissolved photo resist.

Please understand this can also be a nuisance because this may want to redeposit on your other intact parts and that again sort of spoils your functionality. So, development on a spin coating platform eliminates re-deposition completely, so this is sort of industrially accepted now and it is routinely done.

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Hard Bake

Hard bake is performed after exposure, at temperatures slightly higher than Post Exposure bake.

Typical temp ~ 130 °C and Time 1 – 3 minutes

Key Features of this step

Evaporating all solvents in PR

Improving etch and implantation resistance

Improve PR adhesion with surface

Polymerize and stabilize photoresist

PR flow to fill pinhole

Once it is developed do not forget that during development, so this is what you have started off with and then you developed and then you get to this and now you know what you have is the barrier layer which is fine, but either you use the spin coating platform or you use the simply rinsing technique, one thing is obvious that the whole photo resist layer has again come in contact with the solvent, which is the developer solution itself and please do not forget that this solvent or the developer solution is indeed a good solvent for this photo resist material.

May be this part of material is not dislodged because it has higher strength, higher molecular weight, higher viscosity, higher resistance toward dissolution, higher resistance again dissolution and therefore it stays there, but what is unavoidable from a fundamental stand point is there will be some uptake of the solvent by this photo resist or the so called stronger part of the photo resist matrix. So, the essentially this photo resist layer, this remaining photo resist layer after development is in fact wet and this is not wet with moisture that it is wet with the solvent and this solvent is nothing but the developer itself.

Again next stage is; you would like to what is the next stage you all know once you have the pattern photo resist layer you are now going to do the etching. So, that you can transfer the patterns on the photo resist to the barrier layer and the presence of the solvent within the photo resist is going to definitely interfere with the etching step the chemicals that you are going to use for etching, it is going to create some problem.

It is important now to eliminate the solvent again and so how do you do that, you do that by hard baking. This is a very interesting I mean you have different baking stages in photolithography, so roles are roughly the same soft breaking removes the solvent after spin coating; initial spin coating so that the solvent is not exposed during the solvent is not present during the UV exposure, exactly same way after you have developed again the photo resist contains come solvent and that solvent needs to be removed and so it is done by the process called hard baking and there is an intermediate baking stage and that is the post exposure baking stage.

This is some important that you have to bake it in different level to eliminate all possible contaminants that might be present in a polymeric matrix and see when I talk about this solvent uptake by a polymer, by this photo resist in fact, we are talking about some physics which we discussed while we were discussing about the surface tension. We did not go into the detail and that is the static interdiction, see the photo resist after all is s crosslink polymer chain. So, you have a ne2rk like structure and between these ne2rk there are lot of space for the solvent to actually go and remain entrapped which you will even not only realize that it is stuck up and dislodging this type of interact solvent is pretty difficult and therefore, the only way you can do that is to do some baking where you increase the temperature so that the rate of evaporation increases, what is in fact rate of evaporation.

In fact, that kinetic energy on the molecules increases the rate prefers to change phase and go to preferred phase and therefore, they leave, they overcome the capillary addition and sort of leave the polymer matrix. So, these are very very interrelated connected things and if you look at the fundamental level everything has a reason, nothing is done for without a reason and I hope if you are enjoying this course, following this course you should be able to connect it within by your own understanding by now.

Typical temperature again do not try to remember this temperature nobody is going to ask you what is the temperature and hard bake and this and that. So, evaporating all the solvent of photo resist, so this is important. What the hard baking does? It removes all the solvent and then the second stage to understand or second step to remember is what we discussed where does the solvent come, the solvent comes from the development stage itself and of course, it improves the etch resistance. These are terms if one say while it is improves the etch resistance you will learn, it does enhance the etch resistance, but what it is? It is that you are going to do some processing for the etching simplest form is the hydro hydrochloric acid wash which is known as weight etching and you do not want some organic solvent to be present and contaminate this acid because then the functionality of the acid, what is the functionality of the acid? The functionality of the acid is to etch of the barrier layer will be reduced, so you want stay clear of that and do the hard baking step.

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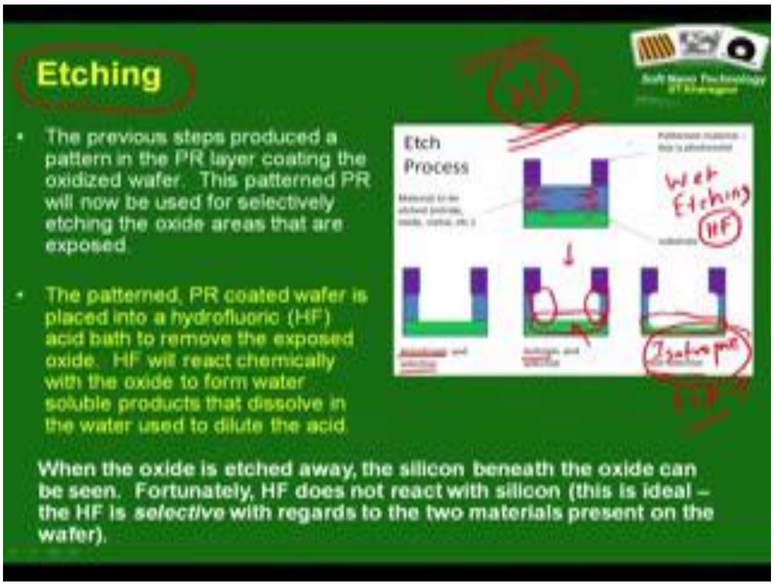

Etching

- The previous steps produced a pattern in the PR layer coating the oxidized wafer. This patterned PR will now be used for selectively etching the oxide areas that are exposed.
- The patterned, PR coated wafer is placed into a hydrofluoric (HF) acid bath to remove the exposed oxide. HF will react chemically with the oxide to form water soluble products that dissolve in the water used to dilute the acid.

When the oxide is etched away, the silicon beneath the oxide can be seen. Fortunately, HF does not react with silicon (this is ideal – the HF is *selective* with regards to the two materials present on the wafer).

Then there are additional steps, but we will not talk about all those things. Then comes the etching step and again so if we quickly have a look at this particular figure what are we doing. In fact, we are doing something that is missing in this schematic; that you want to transfer because if you compare figure 7 and figure 8. These in fact represent 2 steps. If you look very carefully see here you have a pattern photo resist layer and here you see that you have a patterned barrier layer.

In fact 2 processing steps have taken place. One is etching of the barrier layer that is something I have missed out while I was preparing the schematic sorry for that. I should have probably drawn but then I do not know how exactly to show it, may be the video will give you a slightly better idea.

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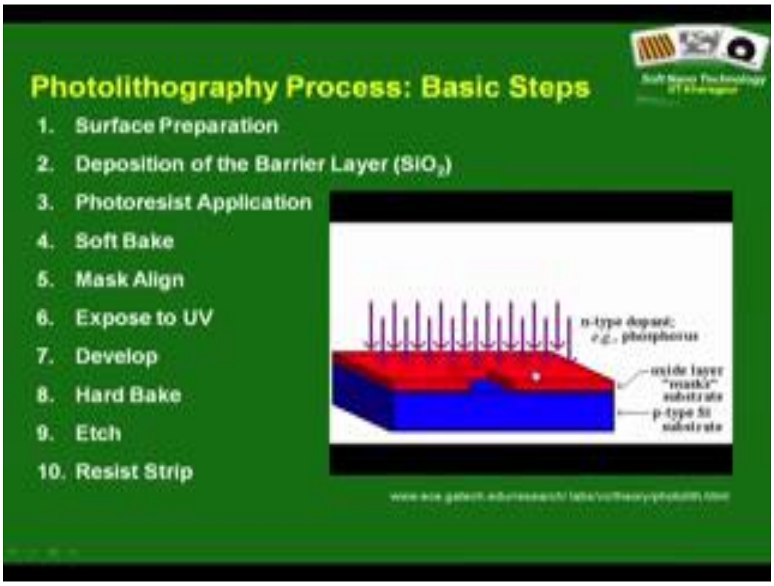

Photolithography Process: Basic Steps

1. Surface Preparation
2. Deposition of the Barrier Layer (SiO_2)
3. Photoresist Application
4. Soft Bake
5. Mask Align
6. Expose to UV
7. Develop
8. Hard Bake
9. Etch
10. Resist Strip

Let us look into that, so these steps you know as it is a good revision and when I take this course in my class in IIT, Kharagpur, I always show it. So, say once you place the photo mask and then you do the exposure, so this is where after you remove your mask you would like do the p e b. So, this is where you do your p e b and then you do the development. So, after you do the development your weakened part of the photo resist layer goes away, but at the cost of there are some solvent uptake by the hardened part of the photo resist layer and therefore, what you do is you do a hard bake and once it is hard baked, now it is ready for etching.

This is the step which will correspond to etching, so you see first what you do is you do the etching so that the pattern along the cantos of photo resist layer is transferred into the barrier layer as one stage and once the barrier layer has been gagged, you next need to remove the so called hardened part of the photo resist right, so this is the steps and if you noticed carefully these 2 steps have been sort of combined between these 2. So, first you do an etching and then you do a photo resist removal to achieve this structure and then you place this for doping, so there doping take place only over this zone and what is here is that you remove the oxide layer or the barrier layer itself.

Talk about etching shortly briefly, so this is sort of etching and the schematic itself tells you everything. So, let us say this is your pattern photo resist layer; this is the layer that you would like to etch and as we talk and this is the desired profile, but there are issues, I will not doing to too much amount of details because this is bit heavy and we have many thing to consider but etching can be what you for the context of this course what we can claim that etching can be of primarily 2 types; one is wet etching which is like using hydrogen fluoride. Logic is that, hydrogen fluoride will dissolves the oxide layer but the reality is that so etch or wet etching often hydrogen fluoride is used; is selective.

You would like your etching to only remove what is desirable, so if this is the geometry of your pattern photo resist layer; you would actually like your etchant to remove only this much amount of material. What you do not like is, you do not like your etchant to heat up material from here and you also do not like your etchant to heat up your material form here and that is exactly what is shown here that is may be here. In fact, that is the problem if you apply wet etching, it indeed dissolves the barrier layer or the oxide over here, but then it is sort of it starts to diffuse in this direction also because you cannot stop that it is seen that monadic material and as a consequence, it often results in a shape like this, it typically does not attack silicon, so that is not a problem, but there can be other layers where etching can heat up at the bottom layer and this is something you do not want to have, so this is an example of a nonselective and isotropic etching.

This is isotropic because it is heating up here, but it selective it does not affect the substrate material, it is even better but what you would like to achieve is an isotropic and selective etching and I am sorry to say wet etching is very simple you can do in your lab, but be very careful because hf is a deadly material. So, please be very careful if any one of you using hf or Phirana solution and things like that they appear to be very simple liquids, but be very careful with them, otherwise you can really land up in disaster. So, I know; I mean for research many people tryout but be very careful with hydrogen fluoride. So, most cases though this is the easiest etching you can really think of but it does not; the wet etching does not have; does not provide proper selectivity or an isotropic.

There are different methodologies for achieving this type of etching and one of them is to go for this reactive anode etching where you in fact utilize a plasma to sort of create some ions and the ion sort of attack the layer, the barrier layer in one particular duration and it can lead to some sort of an isotropic and selective because this photo resist layer; existing photo resist layer sort of acts as a barrier since it an isotropic so the ions only charge in this particular direction and as a result you get a very sharp edges of the boundary. This requires additionally instrumentation typically reactive and etching and stuffs like that reactive and etching etcetera are already there and so those things might be necessary, just we need to; see we have sort of reached almost all the points, we are now in a position where you have achieved this.

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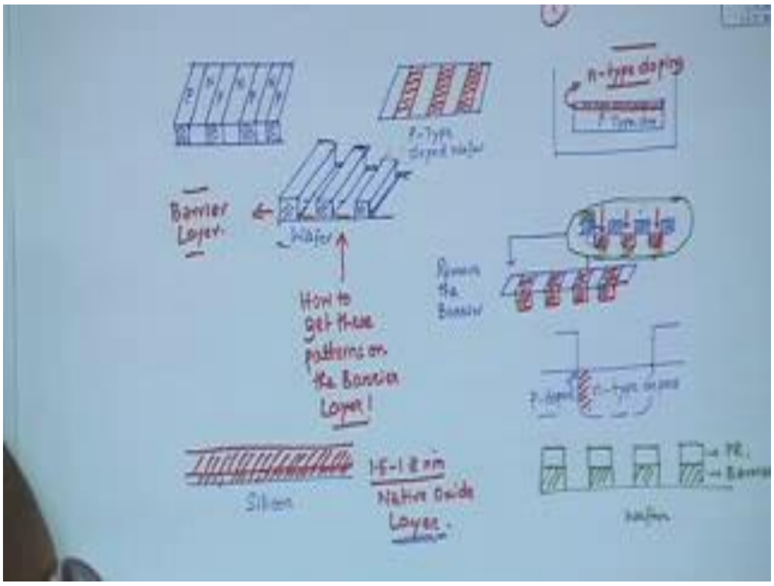

You have a patterned barrier layer and how you have done, so the next step of course, is that you initially had some where this structure also. So, I will just quickly re draw, so this is the wafer and the discussion up to which we have reached, we have created this structure that is now you have patterns in the barrier layer as well as in the photo resist layer.

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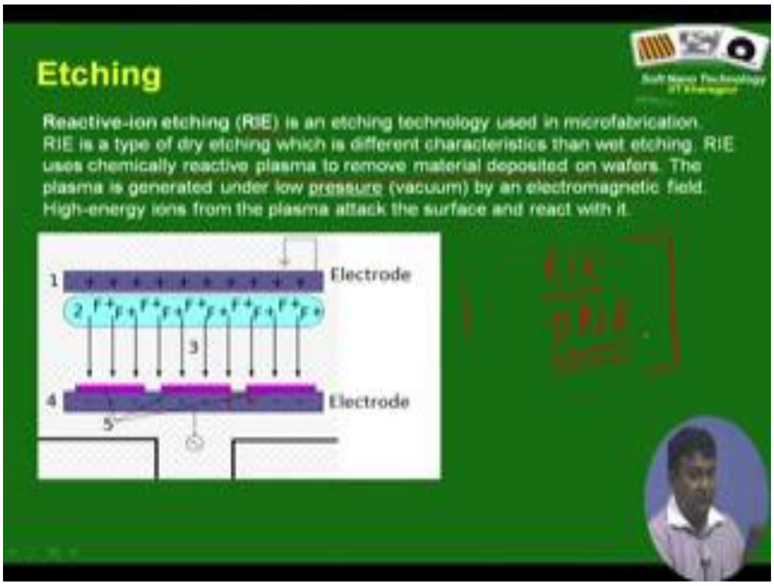

Etching

Reactive-ion etching (RIE) is an etching technology used in microfabrication. RIE is a type of dry etching which is different characteristics than wet etching. RIE uses chemically reactive plasma to remove material deposited on wafers. The plasma is generated under low pressure (vacuum) by an electromagnetic field. High-energy ions from the plasma attack the surface and react with it.

Before I end here is a quick schematic of reactive ion etching, which you create it is different from wet etching and it is chemically reactive plasma to remove material deposited on the wafer. So, you require 2 electrodes in fact and then you use plasma where your photo resist layer, the patterned photo resist layer in fact, acts as a guide and you expected heat of material from here. You typically need a vaccum, you can check out with terms like r i e and d r i e these are these again require huge instruments and these are sort of industries standard to achieve good quality etching with high quality lines etcetera, etcetera.

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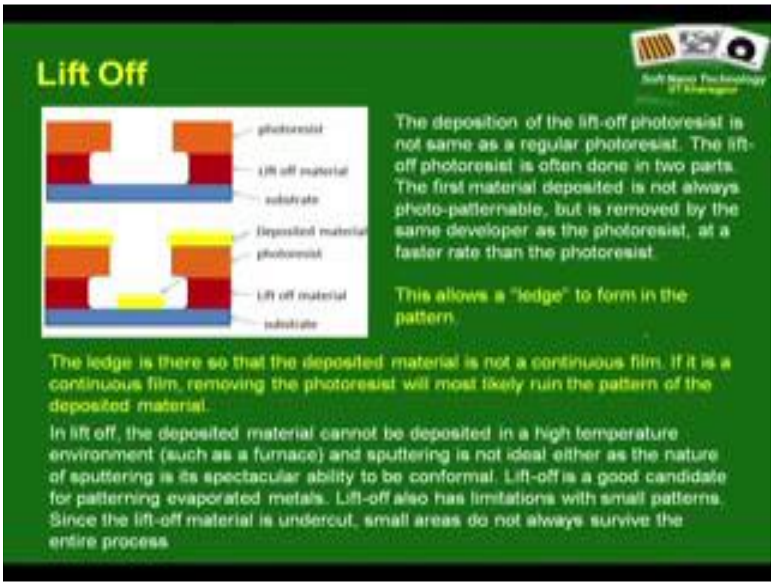

Lift Off

The deposition of the lift-off photoresist is not same as a regular photoresist. The lift-off photoresist is often done in two parts. The first material deposited is not always photo-patternable, but is removed by the same developer as the photoresist, at a faster rate than the photoresist.

This allows a "ledge" to form in the pattern.

The ledge is there so that the deposited material is not a continuous film. If it is a continuous film, removing the photoresist will most likely ruin the pattern of the deposited material.

In lift off, the deposited material cannot be deposited in a high temperature environment (such as a furnace) and sputtering is not ideal either as the nature of sputtering is its spectacular ability to be conformal. Lift-off is a good candidate for patterning evaporated metals. Lift-off also has limitations with small patterns. Since the lift-off material is undercut, small areas do not always survive the entire process.

The next of course, at this point I think I will stop here in this particular class and I will continue my discussion on this.

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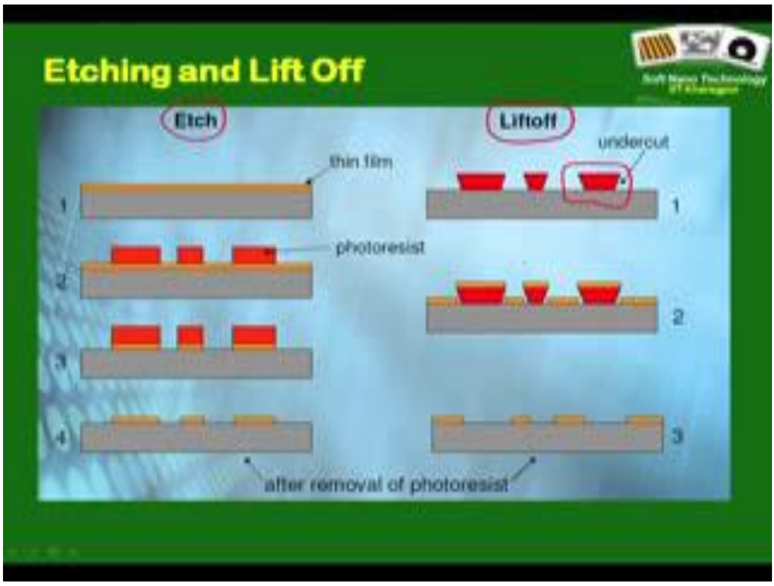

Etching and Lift Off

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We have been discussing the approach based on etching, but there is another approach that is lift off the that is not exactly for the chip fabrication, but particularly if you would like to make metallic nano structures one, always uses the liftoff and I mentioned this when I was talking about this undercut; undercut thing, optimization of exposure and baking.

So that is another quick methodology that I will discuss. And then I will give you some very novel sort of research level almost fun type developments that have taken place in photolithography. In our next class we will wrap our discussion on photolithography.

Thank you.