Introductory Neuroscience and Neuro-Instrumentation
Indian Institute of Science, Bengaluru
Lecture 39
Introduction to Photolithography (2)

Hi, welcome to this particular module and in this module what we will see, we will continue with a previous module in which we have talked about photoresist and we will continue on lithography and then we will take one example to help you out how to fabricate an EEG electrode or a metal electrode on an oxidized silicon substrate, you can also use instead of oxidized silicon substrate you can use glass, you can use polymer and there different substrates are available on which you can design this particular electrode.

Now, continuing to our last topic I told about the mask and I have shown you a bright field mask and dark field mask.

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So, the one that I am holding right now in my hand is a bright field mask as you cannot see so I will put on my a background as my shirt and you can now see the glass that I am holding which is a 5 inch glass and there is some pattern on the glass. So, this is you see most of the part is transparent and only the pattern which is here in the centre it is dark. So, the field is bright and pattern is dark this is a bright field mask bight field mask this is what we were talking about we have crome glass or crome mask on which there is a pattern and the field is bright field mask.

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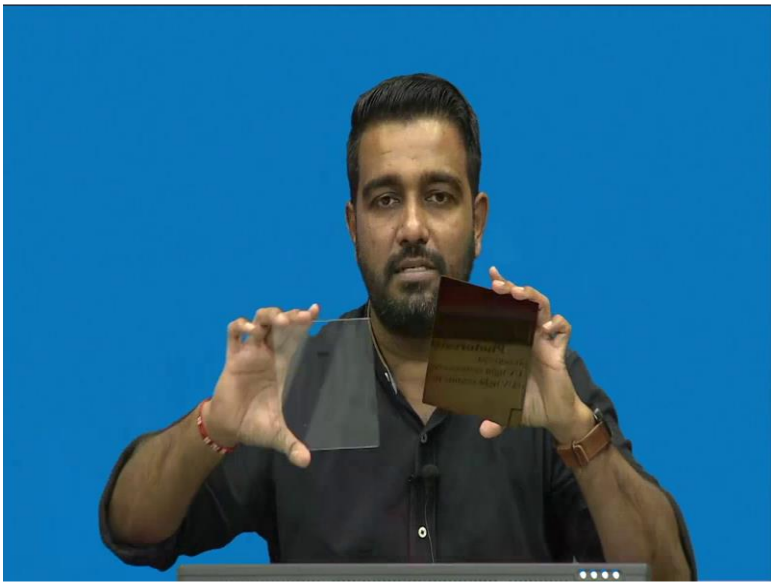

But if you have something like this which I am again holding you can very clearly see that this is a dark field mask and only two places you will be able to that there are two holes here and here, here and here so you can see here there are two transparent areas while the majority of the area majority filed is dark because everywhere there is chrome except this two holes. So, this is your dark field mask, it is very clear to understand and very easy to recognize a bright filed versus dark field mask and importance of bight field versus dark field mask we will discuss when we talk about how to take out the context from the electrodes, I will teach you about that particular part.

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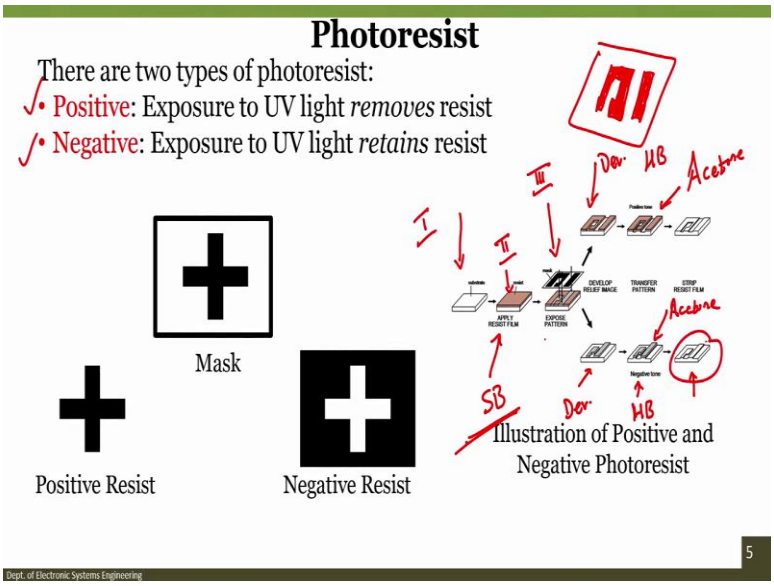

So, coming back to the photoresist if you see the screen, we were talking about positive and negative photoresist and we also discussed that in positive photoresist the explorer or exposed area will become weaker and unexposed area will become stronger, in case of positive photoresist, the unexposed region will become stronger. So, this is an example that if you have a bright field mask which is shown here we the pattern that shows like plus and if you use positive photoresist the unexposed area would be stronger and you can see here that the unexposed area is stronger while the exposed area which is this area gets weaker in case of positive photoresist.

When you use positive photoresist with the bright filed mask, this will what will happen you use positive photoresist bright field or dark field does not matter the concept that you need to remember is that the unexposed region would be stronger. Now, if you take a negative photoresist what will happen the unexposed region is weaker. See, the unexposed region of the mask in case of negative photoresist will be weaker and the exposed region which is this region will be stronger you can see here the photoresist is intact in this region, in this case, the photoresist is edged from the area which is exposed and there photoresist is intact in the area which is not exposed.

The same thing is done in this sentence there exposer to UV light removes resist that is positive photoresist you see exposer of UV light, exposer of UV light will be in this area this area here wherever it is the bright field. So, the exposer of UV light will remove the photo photoresist when we talk about positive and when we talk about negative photoresist then exposer to UV light will retain the photoresist. See it is retaining the photoresist same thing. So, different authors write differently.

Some will write at the unexposed region of the in case a positive photoresist would become stronger in case of negative photoresist unexposed region would become weaker some people will lie that exposed region in case of positive photoresist will become weaker and exposed region in case of negative photoresist will become stronger, some people will like that exposer to UV light removes resist in case of positive exposer to UV light detains photoresist in case of negative at the point remains same.

So, now if you see the illustration of positive and negative photoresist even though this overall the schematic is small still you will be able to understand see you start with a sub striate so this is my first step then off course, you clean the substrate that is but obvious you need to follow it. Second is that you are applying a photoresist, resist film, the third one is you use some mask this is second where the photoresist is applied, third one is using a mask. Now, if it is positive you can see the mask something like this, it comes out like this and then there is a one-line here and this area that we are showing is dark which is some pattern is there, like this. This is our mask pattern which is this one.

Now, if I if the photoresist that you have spin coated which is this one, so what will happen first is your substrate, second is your spin coat photoresist then perform soft lithograph, soft baking which is at 90 degree centigrade 1 minute on hot plate, then you load their mask either mask pattern is as shown in schematic, then if you use positive photoresist you will retain the area which is not exposed and the exposed region will be edged and finally you have to you what you can do you have to hard bake it before you develop the wafer.

So, after you develop the wafer and then you can hard bake it so the point is you go for photoresist coating, then soft bake, expose, then develop and then hard bake. Hard bake is done at 120 degree centigrade for 1 minute on hot plate and then you can eth or strip the photoresist by dipping the wafer in acetone. Now this is case of when the photoresist is positive, but if the photoresist is negative what will happen? Again you have to coat the photoresist, soft bilk, load the mask, expose the wafer then develop the wafer.

In this case, when you develop the wafer you will see that the unexposed region becomes stronger and the unexposed region will become weaker and the exposed region will become stronger. This is what you can see here and then what you have to do? Again you have to perform after developing hard bake after hard bake you have to dip the wafer in acetone so then you dip this wafer in acetone, then you will achieve this pattern. So, this is how positive, negative photoresist works.

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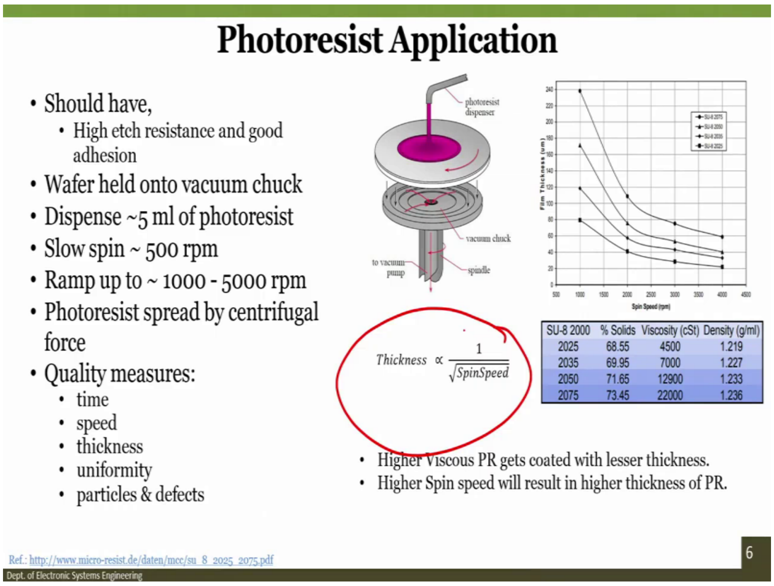

But the point is how you will coat or the photoresist onto the wafer? And you have seen the wafer in the previous modules of silicon wafers and oxidized silicon wafers. So, you have to first take the wafer to clean it or and rinse it which is washing step and then you load the wafer on to the vacuum chuck which is here and then there is a spindle which is connected this whole chuck is connected to vacuum pump and your wafer is loaded on to this vacuum chuck is loaded it makes a hard contact.

So, now the wafers is holded, this is just for you to understand that there is a here there is a gap which is shown there is no gap, it is just to show you that there is a hole which will, through which the vacuum will be generated and are and also these lines are there through which vacuum will be generated, this will help the wafer to stick to the vacuum chuck and then there is a spindle which will rotate. So, when you load the wafer, the photoresist is dispensed and the initially it is a slow RPM to have a uniform deposition, followed by the thickness that you want.

As you can see here that if you increase the spin speed that is rotations per minute of this particular spindle, what will happen? Rotations per minute increase means thickness is decreasing, as you increase the rotation, the thickness will decrease as you decrease the rotation, the thickness would increase. Now here the chart is showing for different material which is SU-8 material SU-8 is another negative photoresist we will discuss about SU-8 at some point of time and then depending on the viscosity we have a different thickness of SU-8 pattern is possible.

So, here let us see that what is the characteristic of photoresist, the properties that it should have a high etch resistance and good addition so you should stick well to the wafer. The second one is the wafer is held onto the vacuum, the photoresist is dispensed on the substrate, it can be silicon, it can be oxidized silicon, it can be glass, it can be polymer. Then there is a slow spin at 500 RPM to have a uniform deposition or uniform spreading, finally, we have to ramp the spin coater from 500 all the way to 5000. It depends on what kind of thickness you desire. Photoresist is spin coated or spreaded by centrifugal force and the quality that we need to measure are time, speed, thickness, uniformity and particles as well as defects.

So, the particle defects would be there if the photoresist is not clean, that is why we require a clean room, we require a particular protocol to follow so that to have a clean photoresist. And you can very clearly see that this spin speed or thickness is inversely proportional to the square root of spin speed. You can also further see that the higher viscous photoresist coated with lesser thickness, while higher spin speed will result in a higher thickness of the photoresist.

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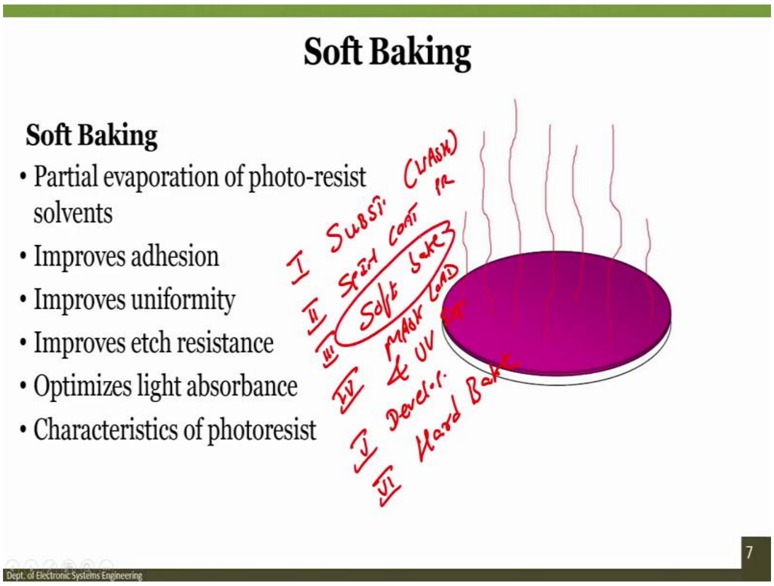

Then we talk about, so if you recall what we said that in photolithography, the first step is you take a substrate and then perform wash, washing of wafer, then second step is spin coat of photoresist, third step is soft bake. So, and then fourth step is the mask loading, mask loading and UV exposure, fifth step would be developer, sixth step would be hard bake, let me write down and finally after you do this step, you have to edge if there is some metal and if you want to remove this or strip the photoresist, you can go for acetone. So, these are the steps.

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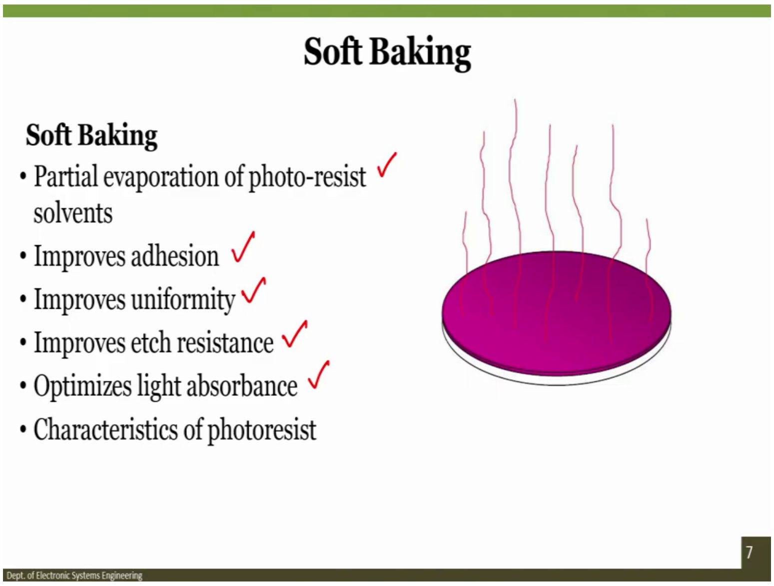

So, why we require soft bake? So, this slide shows the reason of using soft bake. First is that it will help in partial evaporation of the photoresist. You see photoresist comes in a semisolid or in a liquid form and it will get solidified only when you bake it, otherwise, it will stick to the wafer. So, or to the mask, this photoresist is on the substrate, let us say it is on oxidized silicon substrate and for .So, if you load the mass on the substrate, what will happen? It will stick to the mask.

To avoid this thing, what we do, we have to soft bake the photoresist. That is one reason. Second is, it will improve the adhesion, then it will improve the uniformity, it improve etch resistance, finally it helps in optimizing the light absorbance because the photoresist etch is a photo effect, the effects of photons on the photoresist will be tremendous because that is what it is meant for. So, it is if you do not bake it properly, then the absorbance would be different and you will not get the pattern. That is why you need to soft bake the photoresist.

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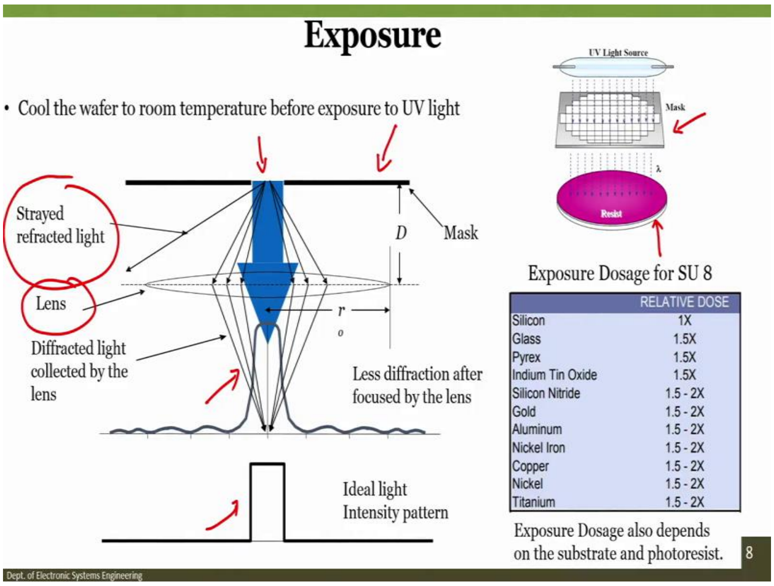

Then if you see the next slide, you do will see on the exposure. So, how exposure occurs? If somebody wants to go in details of optics relate to the exposure, we can go about that, however, my interest of this particular module is not to go in detail on the optics but rather than just to give you the flavour of the lithography and then we will use, we will show you the use cases for using the photolithography in neuroscience or neuro-instrumentation.

So, the exposure is on the photo, on the wafer coated with photoresist is via mask. And there is a UV light source. So, the same thing is shown here, that there is a strayed refracted light and then there is a lens and refracted light is collected by the lens which is finally diffracted and focus by the lens onto the substrate.

So, the when light passes through the mask, this is a dark filed mask and you can see here the light can pass through this region, when it passes through this region, what will happen that depending on the and the distance between the wafer and the mask, the way the refracted light collected by the lens would be different.

And ideal pattern is here, but practically we get something around this way. So, again it depends on what is the dose of the UV exposure onto the photoresist, it depends on what kind of substrate and photoresist you use. For example, if you use silicon, then the relation dose would be 1 times, there is a 1X. in order to increase the dose, while if you use a glass, pyres or ITO, ITO is Indium Tin Oxide, is a semiconducting oxide, then you have to go for 1.5X.

But if you go for silicon nitrate which is an insulator or gold, aluminium which is conductor, in fact, nickel, copper and titanium which are also conducting materials, then you have to increase the dosing by 1.5 or you can keep in 1.5 to 2X. So, that is the requirement for the dosing, dosing is the amount of dosage given to or from the UV source to the wafer.

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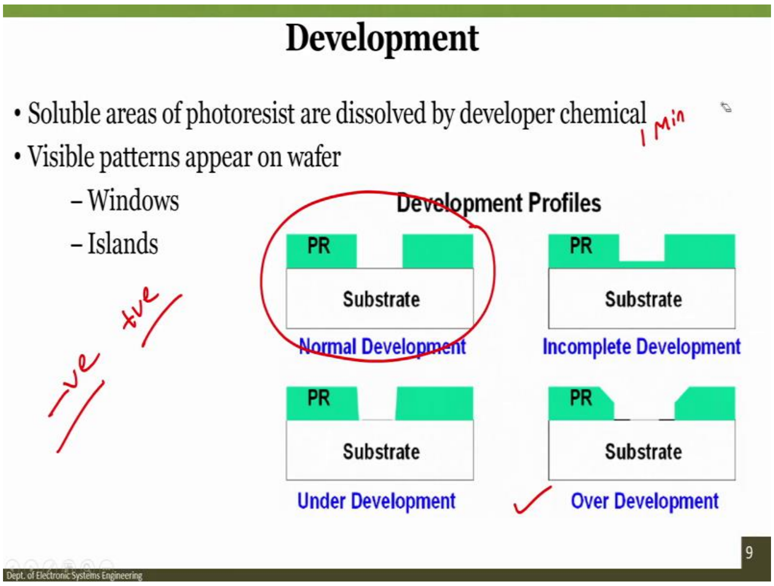

So, when you talk about development, see development there are two ways of developing, one is the using the photoresist. So, the negative photoresist has a different developer, positive photoresist has a different developer. So, what I meant is not two ways of developing, but in fact, we have two different developers, positive for positive photoresist and for negative photoresist. So, the soluble areas of photoresist are dissolved by developer chemical and visible patterns appear on the wafer, either in terms of windows or in terms of island, you can see the schematic here.

When you have overdevelopment, you will see this schematic where instead of, this is an ideal case or normal development. Now, for all the other case you will see if it is incomplete development, when this occurs? When the time for the photoresist etching or developing is let us say 1 minute and somebody or someone in the lab is in impatient and he or she will remove the wafer in 50 seconds, then the photoresist is not completely developed.

Then the second case will be if photoresist time is 1 minute, but someone takes it further like more than 2 minutes or 3 minutes, then there is a over development. And same think will occur that if it is optimization is not taken care of about the dose and exposure, then there can be under development. So, that way under development, incomplete development and overdevelopment in case of the photoresist, we depending a photoresist developer and the exposure time. So, these are all called recipes, recipes so that the time is optimizes, the photoresist quality is optimise, the spin coating speed is optimized and other things.

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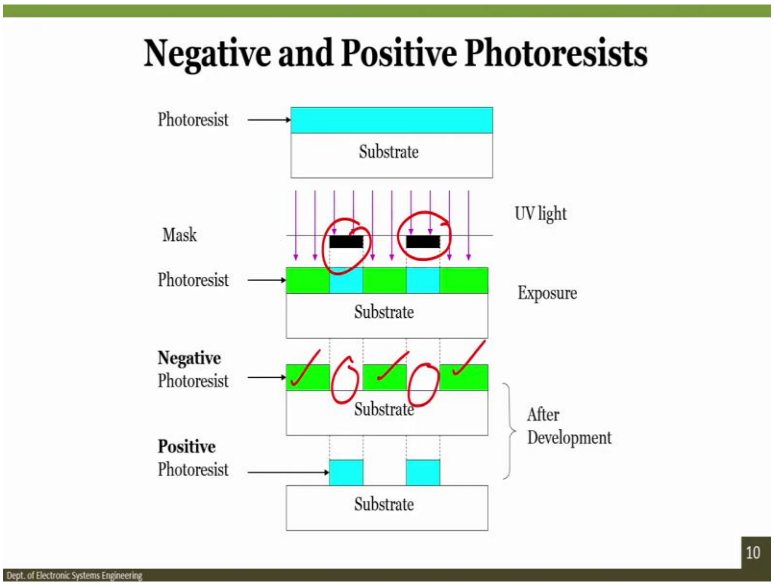

So, again you take an example of a substrate which is coated by photoresist, this is a mask, so what will happen if it is a positive photoresist, the unexposed region will become stronger. You can see here, the unexposed region is becoming stronger. But if is a negative photoresist, then the unexposed region will become weaker and the exposed region will become stronger. Easy? So, you have to understand this particular parameter or properties.

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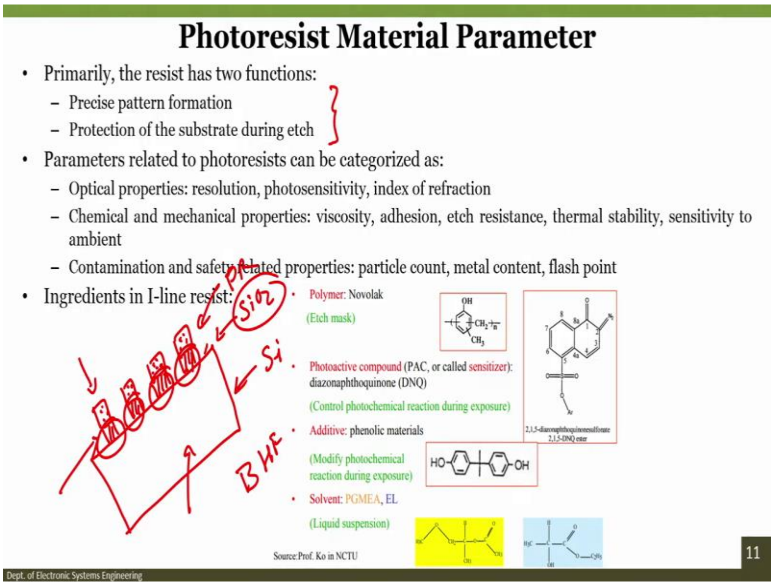

Now, if somebody is interested in the chemistry, we are not right now, so do not worry about this what is polymer and what are the chemicals that are used to develop this polymer or to have the polymer, but our main interest is that the function of the resist primarily is to have a precise pattern formation and protection of substrate during etch. That is our two parameters that photoresist should always adhere to. And then other parameters can be categorize as optimal properties that is resolution should be proper, its photosensitivity should be proper, index of refraction should be there.

And if why talk about from chemical and mechanical properties of the photoresist, then there are several other parameters like etch resistance, it should be thermally conductive, it should not be not too sensitive to ambient and it should have a good adhesion, its viscosity should be uniform and finally, contamination, safety related properties, we can determine which are particle counts, metal content and flash point and the ingredients in I-line photoresist are here, we do not have to worry about it.

So, the point is, if I go far quickly about telling you about the etch resistance, substrate, protection of substrate, these are two important parameters, this is precise pattern formation but it is substrate during etch. So, let me just give a quick example of how you will protect the substrate during etch. So, what it mean by is that if I have a pattern of photoresist and let us say this is silicon dioxide and I have my photoresist patter after doing lithography and this is my photoresist. What is this one? Silicon dioxide, my substrate is silicon and I have some photoresist, positive or negative, it does not matter.

After I perform hard bake, I want to etch silicon dioxide from the area which is not protected by the photoresist, you can see this area which is not protected by photoresist, so I want to etch silicon dioxide. So, let us etch it. So, if I dip this wafer in BHF, Buffer Hydrofluoric Acid, the silicon dioxide from the area which was not protected by the photoresist will get etched. That means, I will have silicon dioxide only in this area which is protected by photoresist.

But that does not mean the protection of substrate, the protection of substrate means that during this thing, the for photoresist, silicon dioxide is now a substrate, silicon is not. Silicon substrate is there for silicon dioxide. So, the one layer below is the silicon dioxide, so photoresist in this case will protect this silicon dioxide from over etching. If your time is maintained, that means recipe is maintained, the photoresist should not affect the substrate below it, that is what it means.

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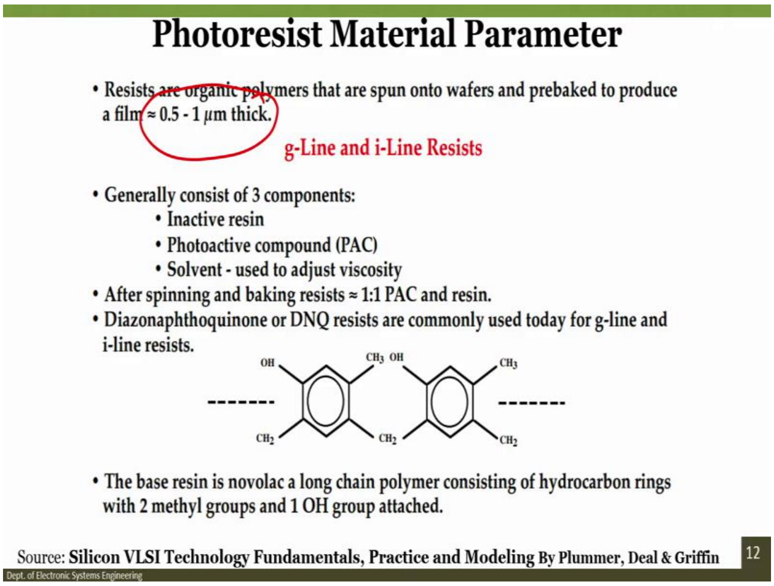

Further you go for g-Line and i-Line resists, then there is further chemistry, let us not worry about this one, but generally, you understand that the organic polymers, it has spun onto the wafers and prebake to produce a film about 0.5 to 1 micrometre thickness. This is the thickness generally we use when we take the photoresist.

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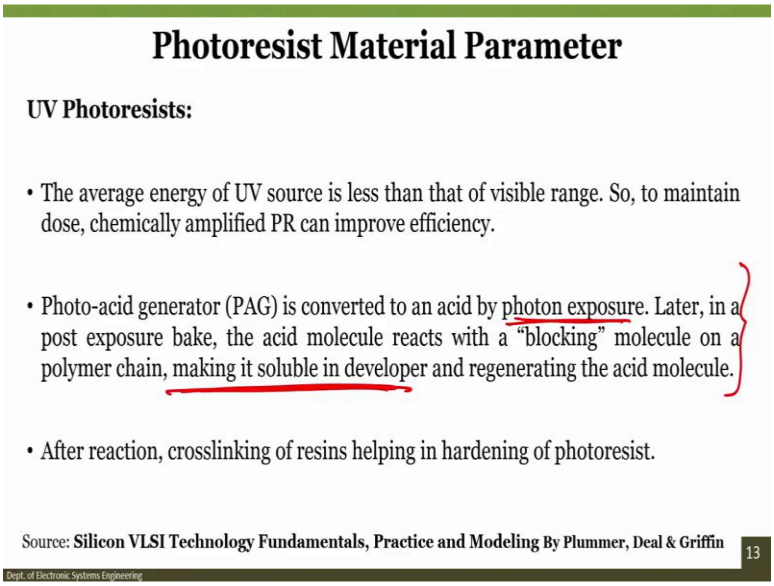

So, about the material parameters, the average energy of UV source is less than that of visible range. So, to maintain dose, chemically amplified photoresist can improve the efficiency. We can also use photo-acid generator, is converted generally to an acid by photon exposure and later in a post exposure bake, the acid molecule reacts with blocking molecule onto polymer chain, making it soluble in developer. So, this is what is the chemistry behind it. That means that when you expose the photoresist, what will happen?

So, initially the photo-acid generator will convert this, is converted to acid by photon exposure which is the UV light exposure and later on this exposure when we do a post exposure bake, then this acid molecule will react with a blocking molecule onto a polymer chain and thus making it a soluble in the developing material. Is, do not have to worry about it. I am just, this is just an concept of how the photoresist changes its properties when it is exposed to UV light.

And finally, if there is a crosslink of resins helps in hardening, that means in case of positive photoresist, the unexposed area, the crosslinking will occur and it will harden the photoresist. In the case of negative photoresist, the unexposed region will be weaker and it will reduce it or soften their photoresist.

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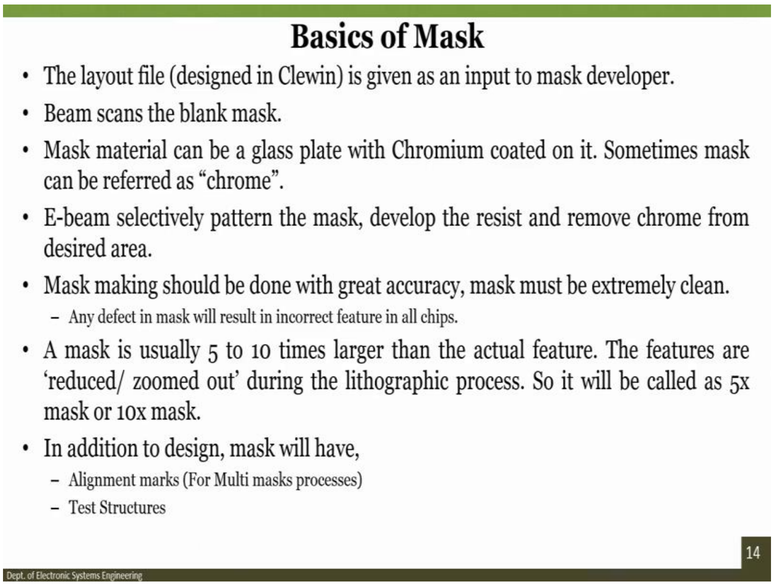

So, if you talk about basics of mask, then you need to understand a few things that the first is that layout file, that is how you design this mask that I was showing you on my in the introduction of this module, is the first you have to design the pattern using Clewin and this is given to a mask developer. Then beam scans and blank mask are used. Actually, the blank mask is a is a mask coated with the photosensitive material and then bean scans are used to expose etch for the better in that we want.

Finally, the mask material can be a glass plate with chromium which I have shown it to you or some time it is also called chrome mask. So, the chromium mask that I was showing it to you, this is a glass plate on which there is a chrome pattern. So, this is also called chrome mask. This is also called chrome because the pattern is with chrome, that is what it is saying. Then if you see that the there is another way E-beam selective pattern the mask, develop the resit and remove chrome from the desired area. So, that is the scanning is done by electron beam and it is selective for the pattern that we require.

Finally, mask making should be done with a great accuracy, mask must be extremely clean because any defect will result in the incorrect feature in all the devices or the chips. Finally, a mask is usually 5 to 10 times larger than actual features size. The features are reduced or zoom out during lithography process, it will called as a 5x or 10x mask. In addition to design, mask will have alignment marks and test structures, we will discuss in one of the module.

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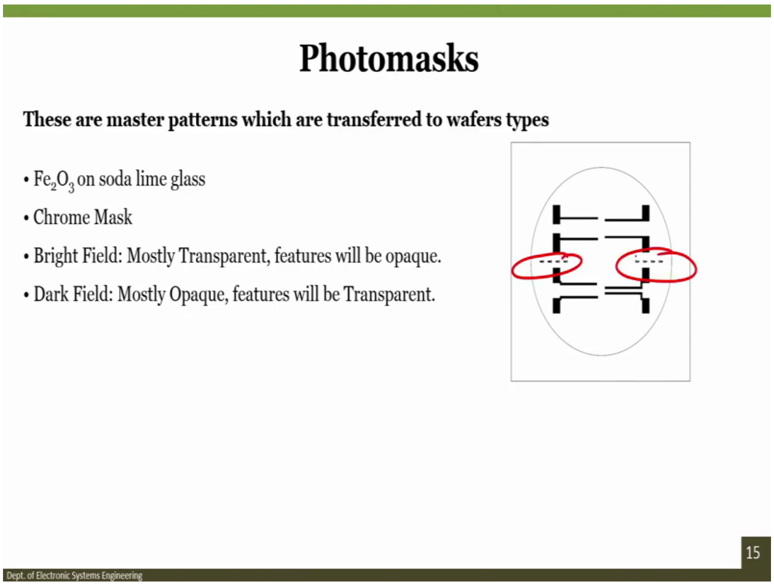

But if you see this particular slide, what you see is that if you take the photomask, then photomask can be developed or the mask can be developed using Fe2O3 and soda lime glass or it can be chrome pattern on glass. There are two types, bright filed which mostly transparent, features will be opaque and dark field, mostly opaque, features will be transparent. These are the patterns which are used for alignment mark, we will talk about the alignment mark when we take a use case.

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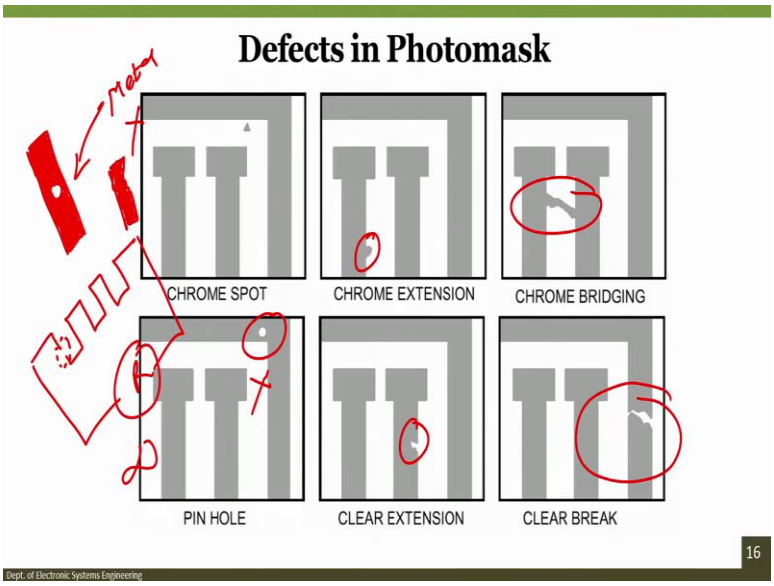

But there are some defects in the photomask. You have to understand firstly chrome defect, you can see here which is called chrome spot, then in some cases there is a extension of the chrome, in some cases there is a bridging, see extension of now how this defect will happen or how this defect will affect what device performance? You see, in this particular area, you can have 1000s of transistors in reality. So, when you talk about transistors and other devices, then this area you are killing that many number of transistor, that is why this chrome spot is not okay.

Same thing goes for chrome extension, let us take not a example of transistor, even we take example of just a heater, then heater, what is heater? It is a let us say there is a, this is a heater, let us say this is a heater pattern and what you see here is a chrome extension. So, for this one, my R equals to rho l by A, that will be my resistance equals to resistance and rho is resistivity, l is length, A is area, but if I have a chrome extension which you can see here like this, then my calculation will not come correctly, it will affect the overall resistance of the heater.

Then if you, the another defect in the photomask is a bridging defect. What is bridging? So, in this case, let us say this is a heater and there is a short between two lines, so it will short the lines, as our resistance at we were calculation will not be accurate because there is a short between the two lines. Then there is a spot that means that if you a spot, how it, I will draw it. it is like this. There is a heater and there is a spot. If this is the spot, let us say this is a spot in the, so let me show you in a different way, so it will help you out.

If I only zoom this area, so if I zoom this area, it will look like this, it is a chrome mask, so everywhere there will be chrome, everywhere there will be chrome and there is a spot, chrome spot, actually it is not called chrome spot, it is called pinhole. So, what will happen? This pinhole will not have any metal, metal is not there in the pinhole. If metal is not there in the pinhole, my resistance value again would be affected. Did you got it? That is why pinhole is or not also okay when you take, talk, when you look at the photomask.

Then there is a clear extension that means that in this case what we will see? We will see that this line is broken to an extent, how I can show it to you? Let me just show it to you here. Let us again zoom this version and what will happen is like this. So, again you see that the resistance of this line would be different because if there is a clear extension, it is a clear breakage, it is a clear breakage of the metal. So, here the resistance would be different. Finally, there is a clear break, clear break is absolutely not allowed because it will just, the will just not help us when you talk about heater.

Clear break means, clear break means like this pattern. So, if I measure resistance of this particular heater, as I connect with a resistance metre, what will be resistance? Resistance would be infinite. Why? Because there is a clear break in this particular pattern. So, these are some of the defects that are occurs in the photomask. So, before you start using the photomask, you should know this defects, namely 6 chrome spot, chrome extension, chrome bridging, pin hole, clear extension and clear break.

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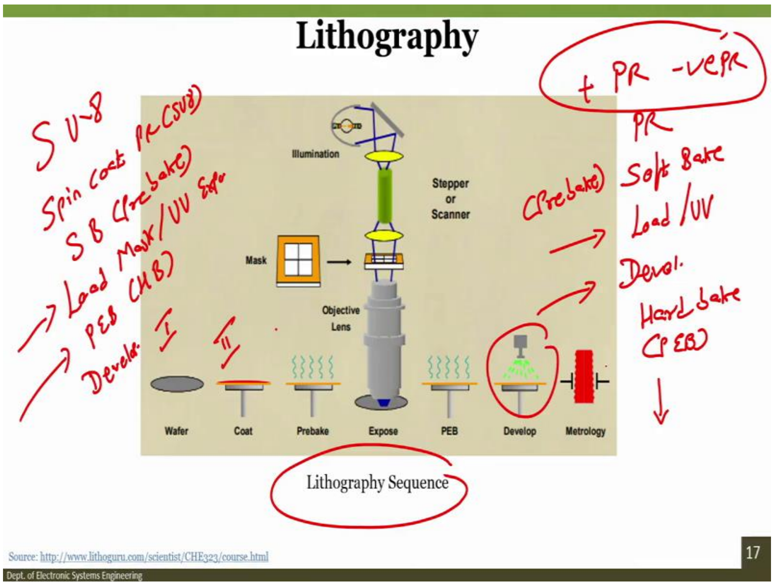

So, lithography sequence is again shown here, you take a wafer, you wash the wafer and then you do the prebaking step, then you coat the photoresist which is your positive or negative photoresist, then you go for soft bake or prebake, both are okay, see, this prebake, some people use prebake, some people use soft bake, some people use post exposure bake, some people hard bake, depends. And which kind of photolithograph, photoresist you are using, that is also another point.

So, if you use SU-8 photoresist, then this is a correct sequence that is showing here. So, in and generally what will happen, in positive and negative photoresist, the sequence is that you coat the photoresist, then go for soft bake, soft bake, then you load the mask and perform UV exposure, then you develop it, then you go for hard bake, hard bake is also called post exposure bake, soft bake is also called pre exposure bake or it is also called prebake. Prebake is short form of pre exposure bake. This is post exposure bake, PEB.

And then finally, after hard bake, developer hard bake and then you go for the next step. This is in case of positive and negative photoresist. But in case of SU-8, what will happen? You spin coat, spin coat photoresist which is your SU-8 in this case, then you perform soft bake or pre exposure bake, prebake, then you load the mask, perform UV exposure, then you perform post exposure bake or hard bake, post exposure bake or hard bake, then you perform developing step.

You see what is the difference? Here, first after the exposure, you have to develop and in this case after exposure, you have to go for post exposure bake, fine and then develop. S, only one step is interchanged. So, this case, this sequence of soft lithography of the lithography is for SU-8 as you can see here that after coating there is a prebake, then there is a exposure of UV light via mask and then there is a post exposure bake. After post exposure bake, you have to develop the wafer, after developing the wafer, you can check it about the structure or the pattern that you get on the wafer.