Introductory Neuroscience & Neuro-Instrumentation
Lecture 35
Introduction to Photolithography

Hi, welcome to this module. In the last module, we already have discussed ~~about~~ silicon dioxide, silicon wafer and as I promised, let us see in this module photolithography.

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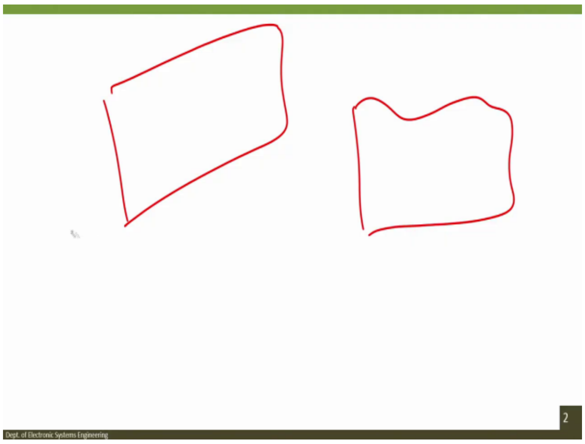

So, if you see the screen lithography, lithography ~~actually~~ means to carve from a single stone. You have a single stone and if you make something out of single stone, it is called lithography. ‘litho’ and ‘graphic’. So, litho means single stone, graphic means to carve, it is a Greek word called lithography.

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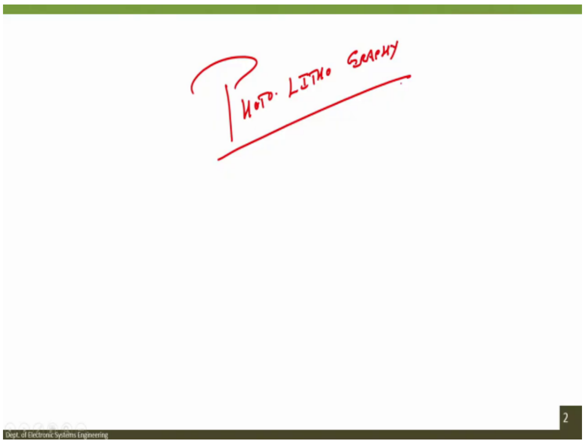

Now, if we use photons, it becomes photolithography, photo litho and graphy. So, it is a single word, photolithography.

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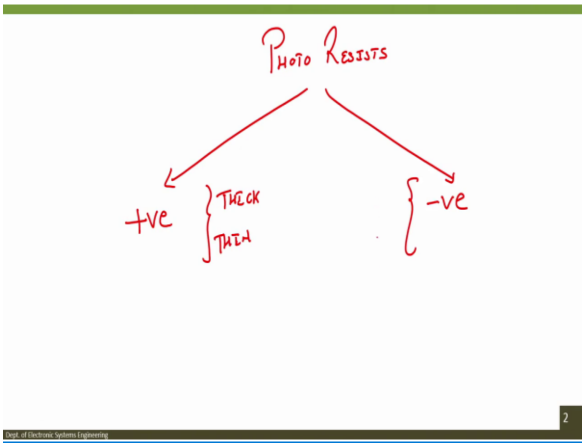

So, let us understand what is the importance or how we can design or pattern different materials on a substrate using a photolithography technique. So, a very important part in photolithography is your photoresist, photoresists. There are two types of photoresists. One is called positive photoresist, second is called negative photoresist and positive photoresist again depending on the viscosity, there ~~are~~ is a different kind, thick photoresist, thin photoresist. ~~Same~~ The same thing holds ~~true~~ for negative photoresist as well, thick and thin.

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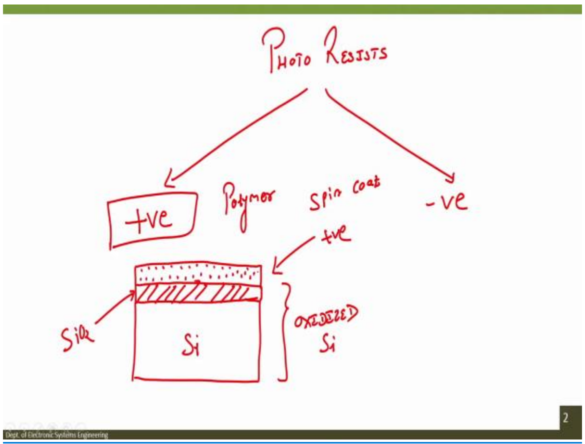

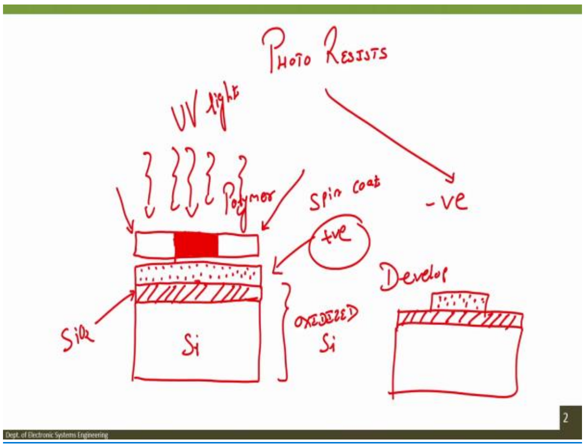

Now let us see what is positive photoresist?~~.~~

If I expose only some of the area of photoresist let us say, I am exposing only the region which is not shaded by red colour, which is this particular box, so this box and this box, it is transparent and the one in the centre is ~~a~~ opaque. So, if I expose this particular photoresist which is my positive photoresist with UV light, UV light, what is it? UV light~~. A~~ and I developed this photoresist, develop, what will happen? I will have ~~a~~ silicon or oxidized silicon wafer with photoresist only in the centre region.

So, what will happen here? What happened is, the region which is not exposed to the photoresist, which was not exposed became stronger. You see here~~. W~~, while the photoresist that got exposed through this transparent layer got weaker. So, you can see here there is no photoresist. So, what is ~~the~~ a characteristics of a positive photoresist, that the area which is not exposed to UV light will become stronger.~~.~~

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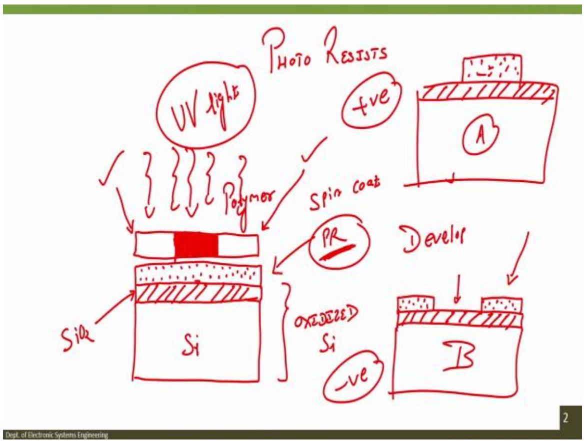

So, on an oxidized silicon wafer, if we spin coat negative photoresist and we expose this oxidized silicon wafer with negative photoresist using UV light. After exposing if I take the wafer and develop it, that means we will develop the photoresist, what will happen? The area which was not exposed got weaker and the area which was exposed got stronger, you can see here. That means when we use positive photoresist, then we had a pattern like this which is shown in this figure A and when we use, this is when we use positive and when we use negative photoresist, then we got pattern which is shown in B.

So, depending on the photoresist, positive or negative, we will have different pattern either A or B. A, we will get if the photoresist is positive and what we said? The area which is not exposed got stronger. If the photoresist is negative, then the area which is not exposed gets weaker. So, a very important point when you understand photolithography is your photoresist.

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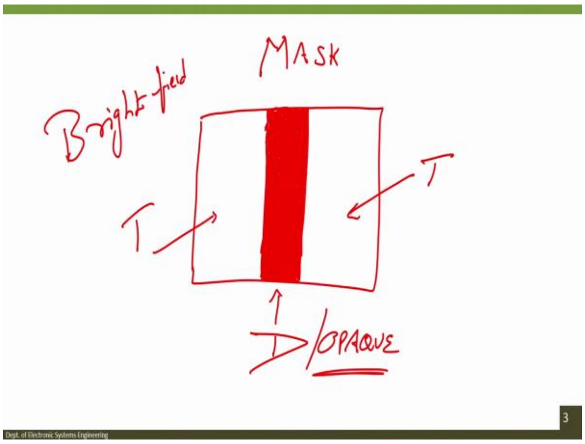

So now, let us understand one more thing and that is called the mask. So, let me give you a very simple example, you will understand. Assume this is completely shaded, is red, complete red like this. This box is dark. A and this pattern is on a glass substrate, glass. It can be Fe2O3, glass and what we see here is that the centre portion is opaque to light while the portion on the sides are transparent.

What we see here is that the side portions are transparent and the one in the middle is opaque. Now, why I am drawing this, there is a reason. You see the maximum area in this mask, maximum area in this mask, is it dark or transparent? This is transparent, this one is transparent, this one is dark or opaque. That means light cannot pass through this, light cannot pass through the opaque region. Since the maximum of the field of this mask is bright, we call this as a bright field mask, bright field mask.

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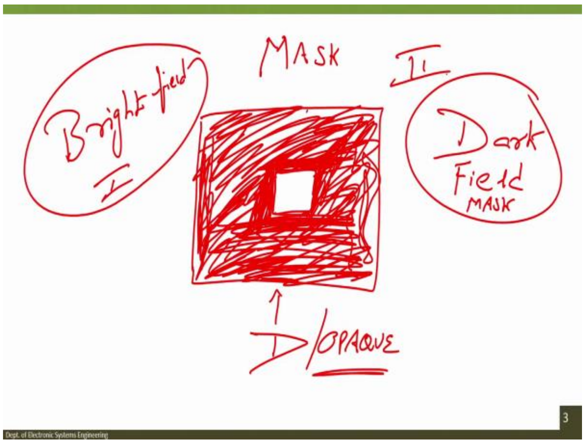

However, if I have a mask where except this area everything else is dark, everything else is opaque. Assume that everything else is opaque, except the one in the central region. So, if everything else is ~~(okay)~~ opaque that means that maximum region of this mask is opaque, this is called ~~dark~~ dark-field ~~make~~mask, it is dark, opaque ~~. Opaque~~ means light cannot pass through it, is dark. ~~-~~Only the region in the centre is, the region in the centre is transparent. Which region? This region.

~~Region~~ The region which is in the centre is transparent remaining everything is opaque. Assume that everything is opaque. This is your dark field mask, dark field mask. So, you have seen two types of mask, one is a bright field, another one is the dark field. ~~Alright s~~So, photoresist two type, positive, negative. Mask two type, bright field and dark filed. Now let us understand how can we use a photoresist and what are the steps for lithography.

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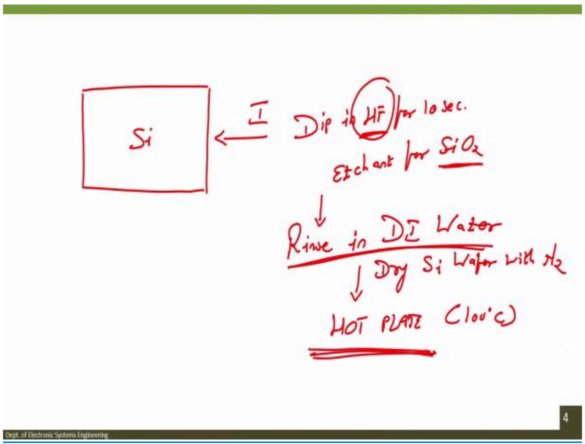

So, let us assume that we have a silicon substrate. I will draw it on the screen you can see silicon wafer. This is our first step. If you can see the screen please.

Now, form where silicon dioxide came, because this wafer is exposed to air, it may be possible that there is a very thin layer of silicon dioxide present on the silicon wafer.

What will happen? This that water will, before you put on the hotbed after rinsing with DI, you have to dry the wafer, dry silicon wafer with nitrogen gas. First step is to take silicon wafer, dip in HF, then you rinse in DI water, dry it with silicon, a dry silicon wafer with nitrogen and then place the silicon wafer on the hot plate. Why hot plate? To remove any moisture present on the silicon wafer. Ones you perform this step, then let us grow silicon dioxide using wet etching and for growing silicon dioxide and wet etching you will use a horizontal tube furnace.

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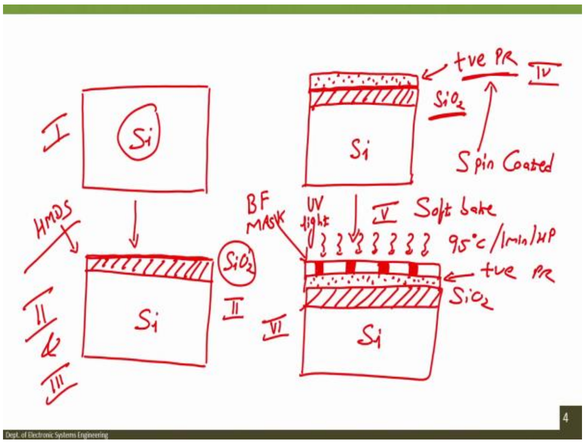

And we have a silicon dioxide which is about 1 micron grown on the silicon wafer, this is my silicon dioxide, this is a silicon wafer, this is my step number 2. Silicon, silicon dioxide. Next step is I will use a photoresist. Now, let us take the example of positive photoresist. So, how can we have a layer of photoresist on oxidized silicon wafer? We can have a layer of photoresist on oxidized silicon wafer by spin coating the photoresist.

So, this is your spin coated photoresist. What kind of photoresist we are using? Positive photoresist. ~~Easy?~~ Now, in certain cases you will see that the positive or negative photoresist does not adhere to silicon dioxide surface. That means, it will not stick to silicon dioxide surface and that is why in some sometimes what we do is after silicon, after ~~sf~~ oxidized silicon wafer is there~~-~~by growing silicon dioxide in using thermal oxidation technique, we ~~scot~~ ~~(())(16:05)~~ a thin layer of HMDS, HMDS.

This HMDS will create a site of adhering or improving the addition of positive photoresist or negative photoresist with silicon dioxide or purge in an other words, it creates a, it improves the addition of the photoresist on any surface or most of the surface. Do you got it? So, silicon wafer, we clean the silicon wafer, then we perform the HF, then we rinse it and do the drying, then hot plate, then we can grow silicon dioxide.

Of course, there are RCA1 and RCA2 cleaning if you want to perform RCA1 as it to cleaning it, you have a new silicon wafer, you may not like to go for RCA1, RCA2. So, you have first step, then you grow silicon dioxide, after that you coat a thin layer of HMDS. HMDS thin layer which will create a site for improving the addition of photoresist. After that you have your photoresist. So, this layer is very thin in particular maybe I have drawn a too thick layer here.

So, if in reality, this layer is very-very thin layer like this. This is HMDS. So, and then you have a positive photoresist, so after positive photoresist, ~~just for~~ this positive photoresist is ~~spin coated,~~ spin coated. So, spin coating of positive photoresist we perform, so that we have the photoresist on silicon dioxide wafer. Now next step would be you load the mask on this positive photoresist. Load a mask, but before we load a mask, there is one more step. So, let us understand again.

You have your silicon wafer, then you perform your cleaning steps, so this is step 1, then in step 2 you grow silicon dioxide and step 3 you spin coat HMDS, then step 4 is you have your positive photoresist. After HMDS you can again heat the wafer at ~~95~~ 95-degree centigrade for 1 minute and then you take the wafer, spin coat positive photoresist. After that, the next step which is step number 5 would be soft bake.

The soft bake is done at ~~95~~ 95-degree centigrade for 1 minute on hot plate. So, after soft bake the next step would be you load the mask, load the mask on an oxidized silicon wafer, where you have positive photoresist~~. A~~ and let us say my mask looks like this. Now what you can say, the maximum field is bright, field is bright and that is why this would be a bright field mask, bright field mask. This will be my sixth step.

Let us quickly recall. ~~First~~ The first step is silicon, second step is to grow silicon dioxide, now I am skipping the washing step which is already known that you dip the wafer in HF and remove silicon dioxide and then rinse it with DI, then dry with nitrogen, then you put on the hot plate, then take the wafer, grow silicon dioxide, then after silicon dioxide you have HMDS layer, after HMDS you have~~r~~ positive photoresist, after positive photoresist you have soft bake at 95 degree centigrade for 1 minute on hot plate, then you load the mask~~. A~~ and in this case it is a bright field mask.

After loading a bright field mask, we can expose this wafer with UV light, expose this wafer with UV light. When you expose this wafer with UV light, the next step would be to develop the wafer. So, what I will do if I say this wafer which is exposed by UV light is called A.

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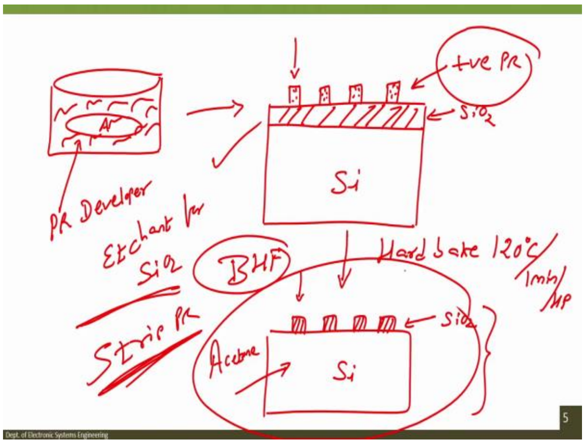

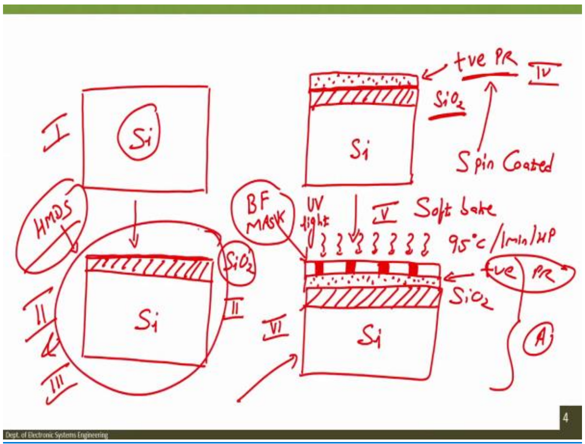

~~So, what I will do if I say this wafer which is exposed by UV light is called A~~ T~~t~~hen I had to dip this A in a beaker which has a photoresist developer~~. A~~, so I am ~~nd~~ dipping the wafer which is exposed with UV light, of course, I will remove the mask and then I will take the wafer and dip the wafer in PR developer. When I do this step, what I will have is, I will have my oxidized silicon wafer and photoresist pattern as shown in this figure. You see what happened? From here since this is a positive photoresist, it is a positive photoresist, what happens? The area which were not exposed got stronger.

See the opaque area, the area of S of the photoresist that was not exposed by UV light got stronger, you see here. Next step is that I want to now dip this wafer in silicon dioxide. After you develop it, the next step would be, after you develop this wafer, the next step would be hard bake, hard bake. Hard bake is done at ~~120~~ 120 degree centigrade for 1 minute on a hot plate, hard bake is done at 120 degree centigrade for 1 minute on a hot plate. So, once I perform hard bake, the next step would be I will dip this wafer in BHF.

If I dip this wafer in BHF, BHF is the etchant for silicon dioxide. So, what will happen? We will have a wafer which looks like the figure that is shown here and if you have carefully observed what happened is, that wherever the photoresist was there, the silicon dioxide below the photoresist is protected. Why the silicon dioxide which was not protected by photoresist got etched. So, we have patterned silicon dioxide on the silicon wafer. But do we require positive photoresist? We do not require positive photoresist.

So, next step would be you dip this wafer in acetone. Now acetone is called photoresist stripper. To strip photoresist, you have to dip the wafer in acetone. See if I dip the wafer in acetone, what would I have? I would have my photoresist stripped off ~~be~~ and I would be felt with wafer as shown in the schematic. So, this is why silicon dioxide pattern on the silicon wafer. ~~Easy?~~ This is how the photolithography would work. So, this is how the photolithography would work.

So, let us again quickly see. First step would be silicon wafer, second step would be oxidized silicon or silicon dioxide grown on silicon wafer with the help of thermal oxidation, next step would be to spin coat HMDS on this followed by placing the wafer on a hot plate at 100 degree centigrade for 1 minute, then you have spin coat of photoresist followed by soft bake, 95 degree centigrade 1 minute hot plate.

Next step would be to load the mask, in this case it is bright field mask. Next step is exposed with UV light, so UV light exposure. Next step would be unload the mask and develop this wafer. So, when you develop the wafer in photoresist developer, what you will have? You will have this particular pattern where the unexposed area, see the unexposed area, will become stronger, because it is a positive photoresist.

Next step would be you dip this hard bake, hard bake is at 120 degree centigrade, 1 minute hot plate and then you can dip the wafer in BHF. If you dip the wafer in BHF, then the area which is protected by the photoresist will be stronger, the area which is not protected by photoresist will be weaker and finally you dip the wafer in acetone, which is a stripper for photoresist, you will have a pattern shown here. So, right from wafer which looks like this to the wafer which looks like this, we can pattern different kind of materials using a photolithography technique.

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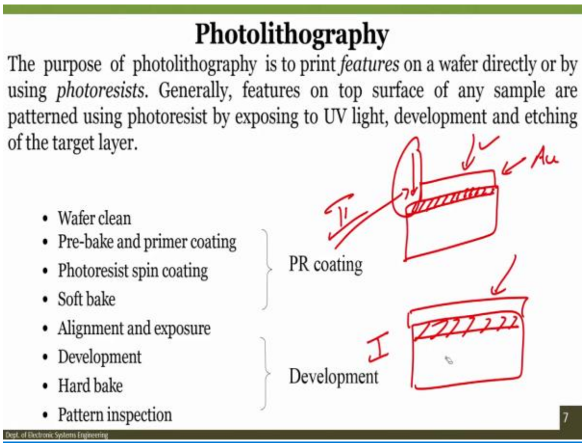

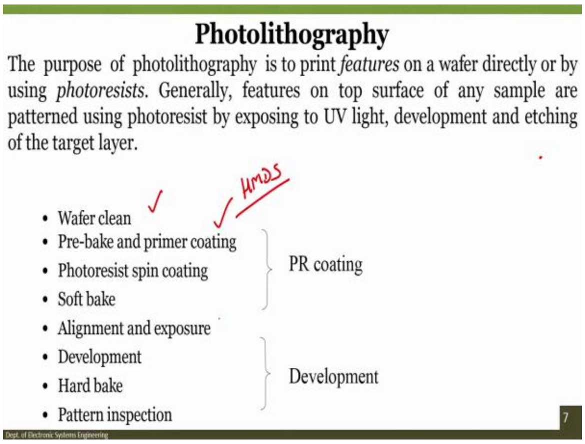

So, if you see the photolithography process, a photolithography process is to print features on a wafer directly or by using photoresist. Generally, features on top surface of any sample are patterned using photoresist by exposing to UV light development, etching of the targeted layer. So, what is the reason of running photolithography, so that we can know that if there is an oxidized silicon wafer and you want to have a gold patch on this particular wafer, everything I want is a gold.

Maybe I do not want gold everywhere except in this area. So, how can I get this kind of pattern? I can obtain this kind of pattern from this oxidized silicon wafer where you have coated gold or like this and you perform lithography, so to reach step number 2. Because only this area does not have gold, in this area everywhere there is a gold, so I want to protect this particular area and I want to remove the gold from the area which is not required to be protected with gold. If I want to do this step that can be used for measuring EEG, it can be an EEG electrode after some modification, then I need to use the lithography system.

So, as we have discussed if you see the steps, the first step is always wafer cleaning followed by pre-bake and primer coating, see wafer cleaning and then I said that we place the wafer on a hot plate to remove the water vapour that is your prebake and primer coating, primer coating I said HMDS. So, this is a primer that will help to improve the addition of the photoresist onto the wafer.

Then we have photoresist spin coating, either positive or negative, followed by soft bake, soft bake is at 95 degree centigrade 1 minute hot plate. Then alignment and exposure that means loading the mask and then next step would be UV exposure. So, alignment is loading the mask, exposure is UV exposure followed by developer.

So, ~~developer or~~ development of what? Development of photoresist. After develop of photoresist you have to go for hard bake, hard bake is done at 120 degree centigrade for 1 minute on hot plate, followed by pattern inspection. That means how the pattern has come after you have performed the photolithography.

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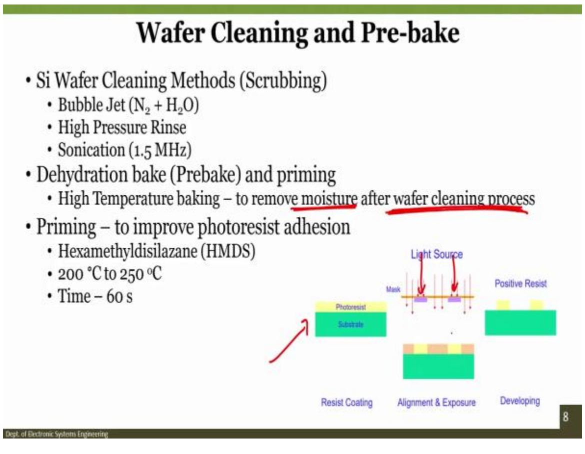

So, when you talk about the first step which is wafer cleaning and pre-bake, it consists of Bubble Jet, High Pressure Rinse followed by Sonication. So, bubble jet is using N2 plus H2O and sonication is done at 1120. 5 megahertz frequency. Followed by prebake which is a high temperature baking to remove moisture as we have already discussed after water cleaning process. ~~(())(30:22)~~ A~~a~~fter wafer cleaning what you do? You rinse the wafer in DI water and then you dry the wafer using nitrogen and then you prebake it at high temperature to remove any moisture content.

Now primer, ~~is~~ as we already discussed is to improve the photoresist addition and in this case we are using HMDS which stands for Hexamethyldisilazane. So, after the primer, we can use 100 degree centigrade, we can also sometime use a high temperature like 200 degree centigrade, time would be 1 minute.

In this case, you can see here resist coating, so this is the step resist coating, soft bake, then expose, after expose you have a developer. So, if it is a positive photoresist, you can see that the unexposed area which is this area got stronger and the exposed area got weaker when you develop the wafer.

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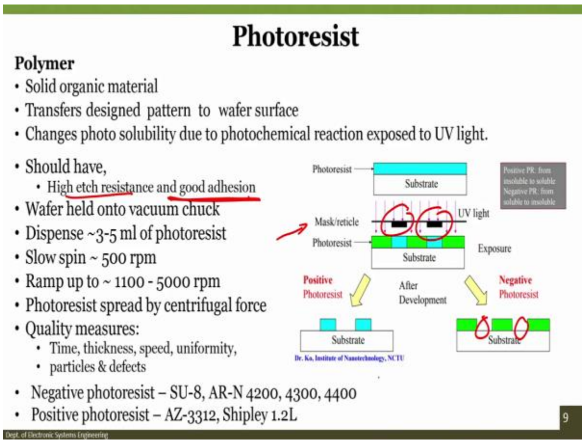

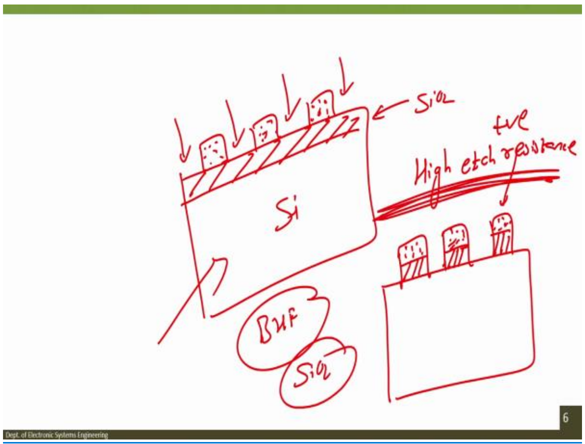

So, this is the same thing that the photoresist is nothing but a polymer solid organic material that can be used for transferring the design to the wafer surface. It changes its photo solubility due to photochemical reaction to expose UV light. You can see here, if you have a positive photoresist coated on a substrate and you use a bright field mask, what will happen that, if it is a positive photoresist, then the unexposed region would be stronger. Where, if it is a negative photoresist, then the unexposed region will be weaker.

So, this is after development we have seen that. So, what are the other parameters of a photoresist or characteristics of photoresist? It should have a high etch rate. Actually, photoresist should not be having high etch, it should have a high etch resistance and absolutely good adhesion. Etch resistance means if you dip the wafer in let us say BHF, this silicon, the photoresist should not get affected. What I mean by this is.

Let us see this case. You have a wafer which after you perform the photolithography and hard bake you have photoresist in this area for example. This is your photoresist. Then you perform hard bake, hard bake. Now, I want to etch silicon dioxide from this area. What I will do? I will dip this wafer in BHF. If I dip the wafer in BHF, what will happen? If I dip this wafer in BHF, what I am expecting that I would have silicon dioxide etch from this area while the silicon dioxide which was protected by the photoresist would not get etch.

Also, simultaneously, I am expecting that my photoresist should show a high etch resistance. What does it mean that this photoresist should not get etch in BHF when I am dipping the wafer in BHF, which is meant to a silicon dioxide and photoresist should not get affected. That is your high etch resistance. So, when you discuss about the photoresist in high etch resistance that is what it means. You can see here high etch resistance, and good adhesion.

Wafer held onto the vacuum and then there is a dispenser which will dispense about 3 to 5 millilitre photoresist. Initially we do slow spin, then we ramp up the system at a high rotations per minute which is rpm to have uniform coating. Higher the rpm, thinner the photoresist; closer the rpm, thicker the photoresist coating on the wafer. Photoresist is spread by ~~(centri)~~ centrifugal force and the quality measures are time, thickness, speed, uniformity, particle defects. There are several kind of photoresist right from SU-8, to AR-N 4200, ~~4~~, 4300, 4400, while positive photoresist are either Shipley or AZ-2212.

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In this module what we have covered, we have covered silicon dioxide. But in actual world, you may want to have a conductive electrode pattern onto the oxidised silicon wafer which you can use as a patch electrode. We can put on the scalp and you can measure EEG signal because that is what we are interested in, in this particular course which is on the neuroscience introduction. A and particularly, when you talk about neuro instrumentation that depends on the how good your electrode is, so to capture the signal from your scalp.

So, we will talk about further details on the photolithography in the next class. Till then you just look at this class ones again, understand the points that I have been teaching you and if you have any question, do feel free to ask us and we will able to help you out by using the forum, which is there for all of you to ask questions. Till then you take care. I will see you in next class, bye.