Soft Nano Technology

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Lecture – 14
Photo Lithography 3

We continue our discussion, now the third lecture on photolithography.

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Dehydration and Priming

- Before the resist is coated, the wafer must be free of moisture and contaminants, both of which cause a severe problem in resist processing.
- Dehydration baking is performed to eliminate any moisture adsorbed on the wafer surfaces, as hydrated substrates lead to adhesion failures.
- This is usually performed by heating to temperatures between 400 °C to 800 °C.
- After dehydration baking, the wafer is coated with a pre-resist priming layer which enhances the adhesion properties of the wafer.
- One of the most common primers used for this purpose is hexamethyldisilazane (HMDS). Resist coating must follow as soon as possible after priming

We just discussed that after the barrier layer is up there. Now what we are talking about this particular stage where we have started off with a silicon paper, this type is again I am repeating this is just an example that I am giving, it is not mandatory.

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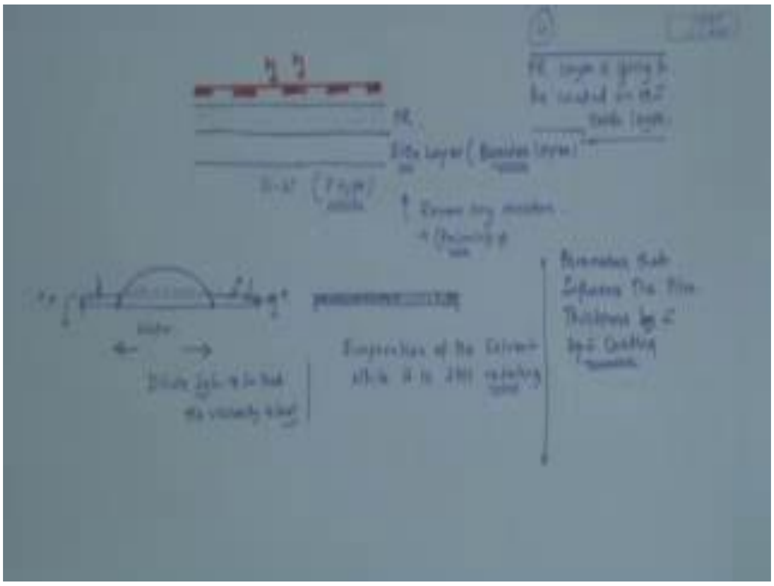

Now you have the oxide layer, the barrier layer, see I am not even giving you numbers like what should be typical thickness of the oxide level things like that because I do not think that these are important details for you to learn. Just check out in the net what are the typical thickness, under what condition you grow what thickness and what is the processing condition just give a brief idea, I mean what is the temperature, how long you grow, what is the oxygen fluoride, please do not worry about these things because these are absolutely trivial thing and you can always checkout manual or in the internet about these matters. It is important to know the process and that is generically the process and that is exactly what we are doing.

After the oxide layer is there what are the mandatory requirements, so what is going to come up is the pr layer, the photolysis layer is going to be coated on this oxide layer and as a run up or as a preparation for that, first thing that you need to do is you need to remove any moisture and then as I mentioned that you can also bit of priming that is to coat the oxide layer with a layer of some material, some chemical that enhances addition between the photolysis system oxide. Once that is done next step is you actually would like to coat the photolysis layer and this is done by a method which is called by a technique that is known as spin coding.

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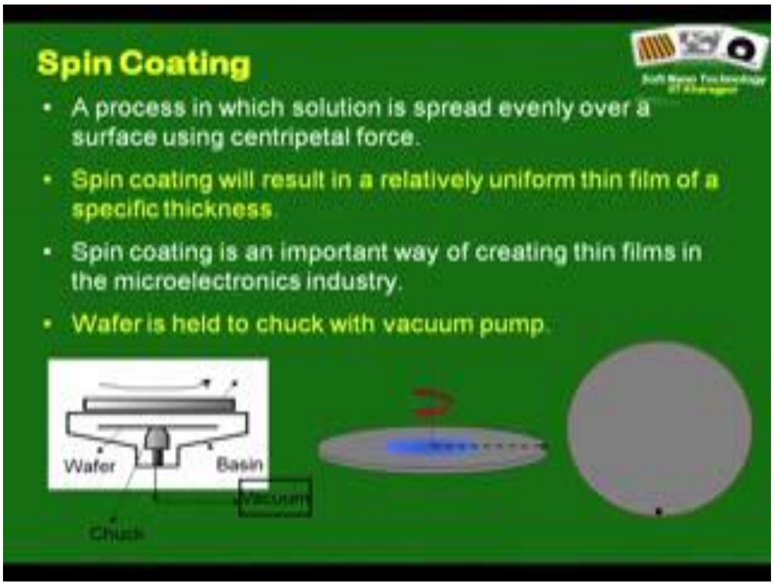

Spin Coating

- A process in which solution is spread evenly over a surface using centripetal force.
- Spin coating will result in a relatively uniform thin film of a specific thickness.
- Spin coating is an important way of creating thin films in the microelectronics industry.
- Wafer is held to chuck with vacuum pump.

What is done it is a very very widely popular technique, now you dilute the photolysis in a solvent and you dispense some amount of this solvent on the wafer of this variorum coating; wafer on which would like to deposit the photolysis layer. You typically have arrangements of holding the whether it is a chuck over which you place the silicon wafer on which would like to dispense the solvent. But these are again unimportant details you are least bothered, you should be worried what happens and then you rotate it at a very high rpl and then as a result of that what happens is that initially dispensed drop might have dispensed it over the entire substrate or you might have dispensed it over the center.

Because of this rotation, there is a centripetal force and the drop many sects starts to spread; why you rotate, you rotate essentially to overcome the limitation of the finite contact angle that might be generated due to Young’s configuration. If you remember I told that these days it is possible to create films on non wettable surface and this is one such example. So, what I mean to say that even suppose this is your wafer and you dispense your solvent solution which lets a makes a finite contact angle and now since you know Young’s equation this you know that this correspond to your partial wetting configuration it is not a fully wetting configuration.

But you would like to have a film that covers the entire wafer surface, so what will you do, you would like to spread this job. How do you do that? You need to apply some force, so that it can overcome the balance in the horizontal components of the surface extension along the contact line and that is very conveniently done by applying this rotation which in the form of centripetal force actually leads to sort of spreading of this liquid drop or the liquid solution, solution drop initially dispense solution drop, but then there are several things, several addition things that happens. There is no guarantee that it will spread only up to the edge and beyond that it will not spread that is exactly the case. So, as you start rotating as the meniscus reaches the outer periphery, a significant amount of the solve solution is actually thrown out, it is wasted.

Second thing is you typically use a solvent that evaporate rather fast so what is the rationale that you spread the solution here over the entire surface and simultaneously while the substrate is still rotating on the spin coater you want your solvent to evaporate away. So, what does it mean, what it will lead to is that eventually as the solvent evaporate away; the solute in this case the photolysis makes a uniform, a very thin layer over the entire surface, this is in a nutshell what is in coating, there are whole lot of issues associated with spin coating.

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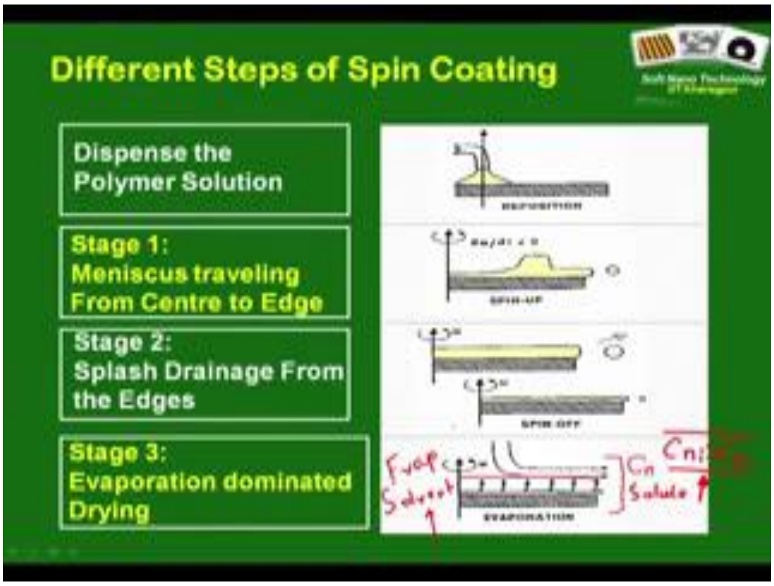

Different Steps of Spin Coating

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- Dispense the Polymer Solution
- Stage 1: Meniscus traveling From Centre to Edge
- Stage 2: Splash Drainage From the Edges
- Stage 3: Evaporation dominated Drying

There can be different stages for example, for example, initial stage is this deposition, then you spin up you can see that the (Refer Time: 06:26) is sort of travelling towards the periphery because of this outwards centripetal force. You can see that some portion of the solution is shown out, often this is referred to as the splash drainage or the splashing phenomena and then towards the later stage of spin coating is entirely nominated by the evaporation of the very important, it is the evaporation of the solvent.

While it is still rotating and as a result, the solvent goes away, so irrespective of the weight ability of the substrate; the solute covers the substrate uniformly. That is one of the real marvelous things of spin coating of course, under appropriate condition you can achieve two more things you can get extraordinary smooth films like smooth coating on a smooth surface. Spin coating on a non-smooth or a rough surface or a non-homogeneous surface or pattern surface itself is a matter of big research and I intend to spend sometimes on that towards the end of this particular course when you are more mature to grasp the advanced issues.

1 of the thing is that you got extraordinary smooth surface and the second thing is that you can also create very very thin films. In fact, by spin coating films with thickness down to 10 nanometers can be routinely achieved to conduct under appropriate conditions. So, for a given substrate size what are the parameters again please do not try to remember what is the concentration is under that is not needed, but what are the parameters that effect, that influence the film thickness by spin coating.

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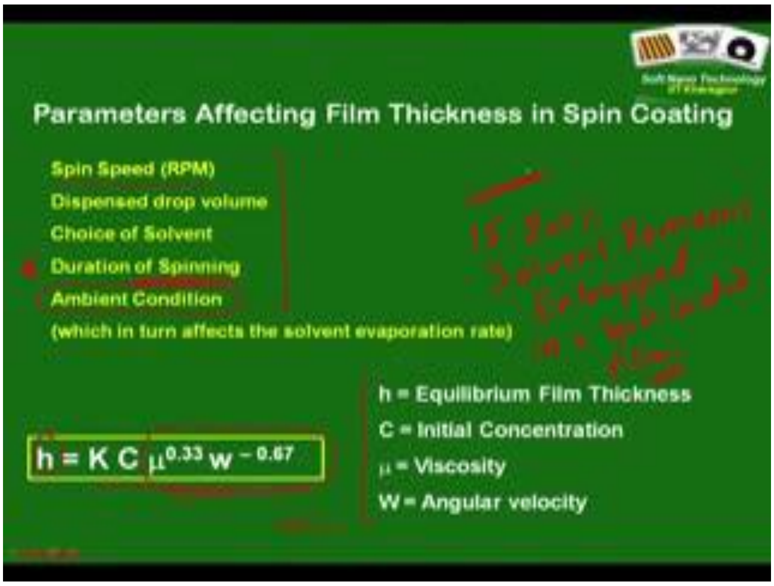

Parameters Affecting Film Thickness in Spin Coating

Spin Speed (RPM)
Dispensed drop volume
Choice of Solvent
Duration of Spinning
Ambient Condition
(which in turn affects the solvent evaporation rate)

15-30% Solvent Remains Entrapped in a Spin coated Film

$$\boxed{h = K\,C\,\mu^{0.33}\,w^{-0.67}}$$

h = Equilibrium Film Thickness
C = Initial Concentration
μ = Viscosity
W = Angular velocity

This is an important issue, there are all some relations like these how thickness varies with this and that. These are mostly extremely empirical data driven relations and they are they are often considered as some sort of steady uniform rate of evaporation which you now know is not the case because spin coating actually has different designs.

I will ask you to stay away from these type of relations of course, they are used and they are act as a good guide at the first instance in certain places. There are certain additional issues which I will patch up on very briefly, but more importantly the typical parameters that influence the thickness in spin coating of course, is the spin speed rpm and you can of course, understand higher is the rpm you are going to get a thinner film because higher is the rpm faster is the meniscus going to reach the outer periphery of the substrate and therefore the proportion of splash drainage of the splashing is going to be higher.

Therefore, higher spin speed leads to lower film thickness, second thing is of course, the dispense drop volume as you increase the dispense drop volume, in fact adding more amount of solvent and more amount of solute and therefore, you are expected to get a thicker film. Again choice of solvent is a very important parameter a more then the film thickness whether the gruffness of the film defense depends a lot on the choice of the solvent because if you take a solvent like t h f which evaporates away very rapidly, you often do not get a very smooth film, you get a bumpy film. But if you take something like Colvin which has much slower rate of evaporation because evaporation pressure is low you often tend to get very very smooth films.

Of course duration of spinning is another important parameter you definitely not like to stop spinning, at a condition when the solvent; when the film is still adequately wet, that is still significant amount of solvent present simply because of the fact that is your substrate is non weighable and you have a adequate amount of solvent that is the viscosity of the film is low, then there is possibility that the solution layer might retract back on the film surface and you may not get a uniform average and of course, the ambient conditions this in fact is often neglected, but is a very important parameter because ultimately obtaining the film in spin coating depends on evaporation because you are going to get the film of the solute and for that while the spinning process is going on, your solvent must evaporates away and the rate of evaporation of solvent depends significant on relativity.

If you have a highly humid situation, the rate of evaporation will reduce and then it is like let me put it like this that if you are not controlling the ambient environment, reproducibility of your film thickness under identical coating conditions is going to be a critical issue which often can hinder your performance. So, these are sort of some of the critical parameters, in fact I would just like to highlight the one very interesting aspect of spin coating, many people tend to confuse that as soon as you start rotating the solute starts to deposit or the film deposition starts.

In fact that is not the case, you typically start off with a very dilute solution, you deliberately take a dilute solution so that the viscosity is low. Because if the viscosity is not low even despite of your applying significant amount of centripetal force, the drop may not spread uniformly, you might have additional roughness and things like that. So, you typically like to start with a very dilution a very very dilute, so one typically spin coats with 1 percent or 5 percent with dilute solution of the solute in a specific solvent and so after this splash drainage and whatever you have a layer.

In fact, the transparency also shows that you have a design when you has a pretty smooth solution layer, but it is still pretty rich in the solution content and what happens is the solution continuously evaporates away therefore, within this regime the concentration of the solvent of the solute progressively goes up and now it is very important to understand that you have actually taken a solvent which dissolves the solute so why should the solvent deposit on the substrate.

Well, the solute will start to deposit on the substrate only when the intrinsic concentration of the solute matches the saturation concentration. So, due to gradually evaporation of the solvent what you need to understand is that the concentrations of the solute is continuously changing and please understand and remember forever that deposition in spin coating starts only when the intrinsic concentration of the solute in this solution layer sort of matches the saturation concentration.

Many people have this confusion that as soon as you star rotating deposition starts to take place, but this is not the case and since this is not the case this is where the duration of spinning becomes very very important. So, you might actually you have to wait for a really few seconds before your deposition starts and you do not want to hasten that you fell good for a very short duration you might not get a uniform film at all you. Please remember that even when you think that your solvent has fully evaporated, often one finds that about 15 to 20 percent solvent remains entrapped in a spin coated film.

This effect is more pronounced in polymers because you have long term molecule and they remain in an entangled state and bit due to capillary effect and capillary additions and things like that, lot of solvent molecules remain entrapped within these stages. So, you essentially and that something that we are going to immediately talk we need to even after your spin coating process is over, you need to worry about this remnant solvent, so and we have been hearing about this particular term when we have been discussing about resist processing and that is exactly what soft baking does.

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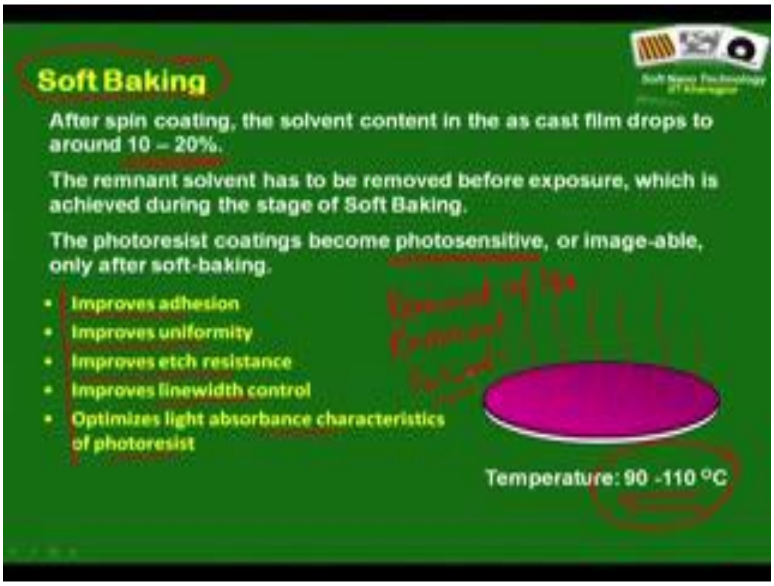

Soft Baking

After spin coating, the solvent content in the as cast film drops to around 10 – 20%.

The remnant solvent has to be removed before exposure, which is achieved during the stage of Soft Baking.

The photoresist coatings become photosensitive, or image-able, only after soft-baking.

- Improves adhesion
- Improves uniformity
- Improves etch resistance
- Improves linewidth control
- Optimizes light absorbance characteristics of photoresist

Temperature: 90 -110 °C

As I just mentioned that even after spin coating about 10 to 20 percent; I just wrote 15 to 25 percent these are all very debatable numbers and there are techniques to measure it, but it is not that easy you need to understand. So, there are about 10 to 20 percent of solvent that remains entrapped within a spin coated film, this remnant solvent needs to be removed, why this needs to be removed? Because your photo resist is going to be subsequently exposed to UV right of course, through a mask and please understand what you expect in the subsequence step to happen, you actually except that the photolysis layer will change its property upon UV exposure.

But please do not forget that only photo resist has the sensitizer and therefore, it will change its property upon UV exposure, but if the photo resist film contains solvent, the solvent does not change property irrespective of whether it is in the zone where it is expose to UV light or not and therefore, if you expose a solvent containing photo resist film, your exposure even after exposure the spearing there will be significant spearing because a solvent does not respond to the UV exposure, only the photo resist responds to.

Therefore what you would like to have, you like to have a complete solvent free sphere photo resist film which will be used for exposure under the mask and that is exactly what is done during the soft baking state, which improves adhesion, uniformity, its resistance line width control and whatever absorbance of the characteristics of photo resist, but primary thing what you does is done at 90 to 110 degree centigrade. Primary thing what it ensures is that it makes the photo resist layer photosensitive that is done by removal of the remnant solvent.

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Photo Mask

A photo-mask is an opaque plate with holes or transparencies that allow light to shine through in a defined pattern

- Lithographic photomasks are typically transparent fused silica blanks covered with a pattern defined with a chrome metal absorbing film.
- Use e-beam or laser or x-ray to strip off chromium
- For Integrated Circuits, multiple masks with multiple pattern are necessary.

Once the photo resist layer is ready now according to the schematic we have used, it is now ready to replaced, under the mask and that is if I; we need to worry a bit about the structure of the mask, I have already told you how mask is made. In fact, a mask contains is a piece of let us say a block of cloth or a block which is partially or at certain locations following the patterns you would like to create on your photo resist layer, it is transparent to UV light and other locations it is opaque.

Here you can see is a mask, so these areas it is opaque to UV light, so no light passes and these areas it allow the light to pass. How do you make a mask? As I already mentioned you typically take a pure cadge glass plate, why do you take a pure cadge glass plate because pure cadge glass plate is transparent to UV light that is a very very important thing, but you actually start off with a chromium coated cadge plate and depending on the patterns you would like to create, you preferentially etch out the chromium layer. So, what has been done here you hade uniform layer of chromium all over this place and this areas, the chromium I am sorry it is not working. So, these areas the chromium layer has been etched out that is how you make a mask and well of course, how do you etch out this chromium you typically using a e-beam or a laser or x-ray strip of chromium.

And we also talked that for making integrated circuits, multiple masks with multiple patterns are necessary and that leads to the requirement of a hardware or very big instrument in fact the mask alignment. I will see if time permits, I will give you some example of how a mask alignment works, but it is a huge hardware instrument and there is no reason why we should bother much about the hardware of an instrument, so you know that can be something called mask alignment enough and that is a whole part of this introductory course on that.

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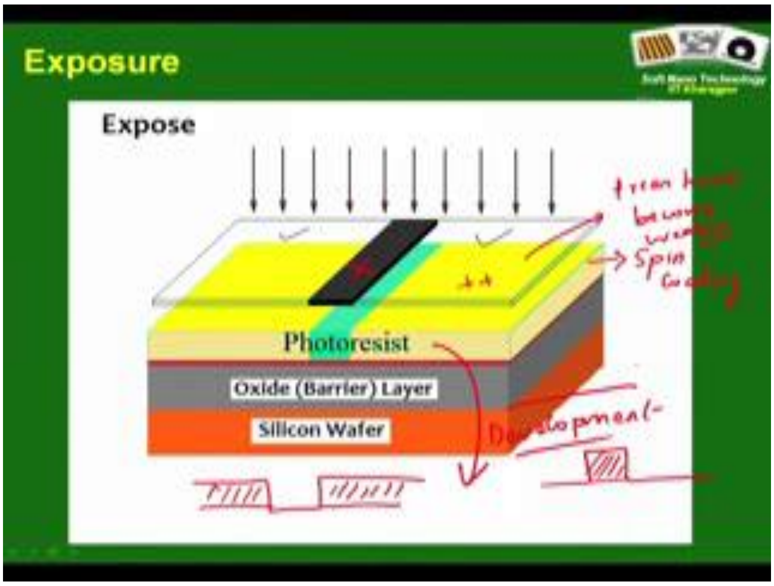

Exposure

Here now this slide should makes sense to all of you, you should know understand the color coding of each of these layers, so this is the silicon wafer you started off with sorry this is the silicon wafer you started off with and then you have deposited the; let us have a relook there is a small problem with the computer sorry about it. So, here you can see started off with the silicon wafer; then you have grown the oxide layer in fact, this tiny thin red layer is the tiny layer now you also understand that, then you have coated the photo resist by spin coating.

What is the next into do? You bring in the photo mask, you now looking at the geometry you also understand that you have started off with a chromium coated glass and over these areas, the chromium layer has been stripped off right and so only this area is going to act; according to this particular figure is going to act as a transparent to; sorry opaque to the UV light and all other areas are going to act as transparent to UV light.

What is the next step to do? Next step to do of course is to replace the photo mask and then you expose and as you expose you can expect the photo resist, you should understand this fully now, you should expect the photo resist to change its property and now you cannot really comment whether from this picture the color coding of course, in a real processing you will be knowing you are using negative photo resister, positive photo resister that is not the issue.

But if I ask you from this particular schematic as to what has happened? All you can say is that upon exposure these yellow areas have changed property, which is expected because looking at the geometry of the mass, you can say those are the areas over which UV light came in contact with the photo resist layer and therefore, it has changed property and now you also know that if you are working with a positive photo resist in fact these areas have strengthened, become stronger.

If it is a positive photo I am sorry, if it is sorry; if I am working with a positive photo resist these areas have become weaker and with a positive photo resist the profile that you will get will be something like this, this is a remaining photo resist layer and if you instead are using a negative photo resist; you will be able to get the profile like this, so these areas are strengthened. Of course this you will get from here to here there will be one more state that will be associated and that will be the state of development.

I think this is a good time to stop, the way I have simplified the picture please understand that though you are learning photo lithography you are a learning a very very simplified picture of photo lithography, it is not a simple process like this, but I have tried to deliberately keep it very very simple so that you understand and have a basic idea. Looking at this particular schematic, let us look at it again, so here we bring in the photo resist layer you subsequently what you do is you bring in the mask sorry it is not working.

You bring in the mask and then you do the exposure, so the way I have explained as if you simply place the mask on the photo resist layer and simply do the UV exposure but that is not often done, there are additional complexities that are there during the exposure process. So, in the next lecture I will start talking about the exposure, different exposure modes and then we will move on to give you a glimpse of certain other very interesting developments in photo lithography that has taken place and subsequently we will also try to find out what are the limitations of photo lithography and then move on to the polymer specific soft lithography techniques.

Thank you.