Instability and Patterning of Thin Polymer Films

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Lecture No. # 10

Photo Lithography - II

Welcome back, we were continuing our discussion on photo lithography, and we will we just got started with the discussions, and we will continue with some more detailed aspect photo lithography in this particular class.

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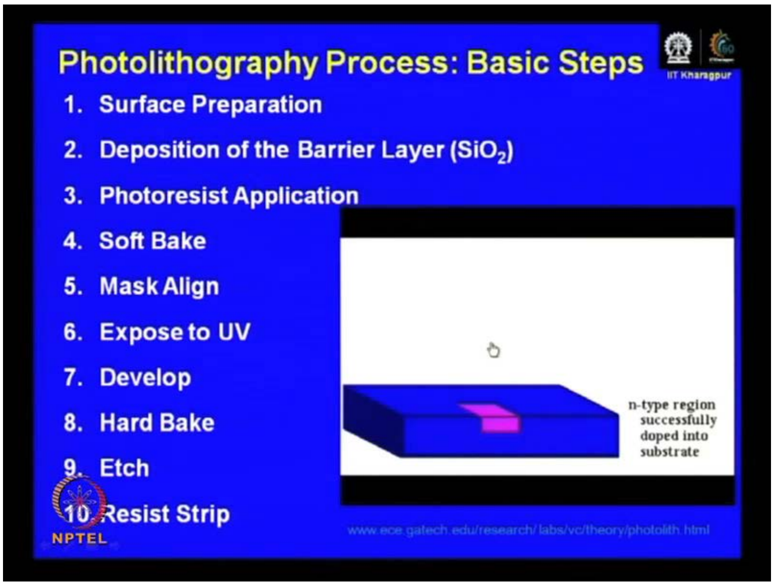

So, probably all of you would now remember that we talked about this particular animation or we showed this animation in some of our at some point in the previous lecture. So, the different steps of photo lithography what we understand so far is, first you take P type or a dope silicon substrate, then the next stage is you sort of grow the silicon oxide layer, which we also refer to as the barrier layer. Then we coat the what is known as photo resist, we just started talking about it, today's discussion we will focus more on the photo resist. We would not go into the too much of photo resist chemistry, but I will still give you an idea about the photo resist stones, and how exactly a photo resist works.

And then, we started talking about a mask which actually contains your original design which you would like to replicate on your photolithography on your photo resist layer or you sort of want to get a copy of that on the photo resist layer. And then, once you place the mask, you do an UV exposure; this is exactly the optical source, we talk about it is essentially, because of this step, the technique derives its name photolithography. Because whatever change in property, you achieve in the photo resist layer is be due to exposure to light, and in most practical cases the lights source used is UV.

The only reason is that the ultraviolet rays have wavelength, which is smaller than visible of light; and smaller the wavelength, it is better for replicating the structures, we will talk about it in some point details. Once UV exposure is done, then of course, there is depending on the tone of the photo resist, there is referential curing or disintegration or degradation. Then the mask is removed and then you apply a different thinners or different chemicals to etch; first of all to resist layer, then you also etch the oxide layer. So that for your diffusion reaction, which is sort of going to create the other type of doping in the wafer; let us say over these areas, if you sort of have a, I have started with a P type refer you would like to dope it with something N type; so that you have P N junctions.

So, first you sort of etch the photo resist layer, then you also etch the oxide layer may be hydrofluoric acid. And then the photo, if you if the photo resist layer remains present during the diffusion reaction this might also get the polymer layer might get contaminated. And some chemicals from the polymer layer or the photo resist layer might also react with the surface, because it is a liquid state reaction of the photo resist layer, as well before your doping reaction starts. So, that is precisely what is done the photo resist layer is also removed and then you do the doping reaction; and finally, you get rid of your oxide layer itself. Of course, in practical, for all practical purpose this is followed by another process of metallization. So we will, as I told you we will sort of talk limit our discussion more into the periphery; and I will sort of highlight you about the major steps, rather than going into too much details.

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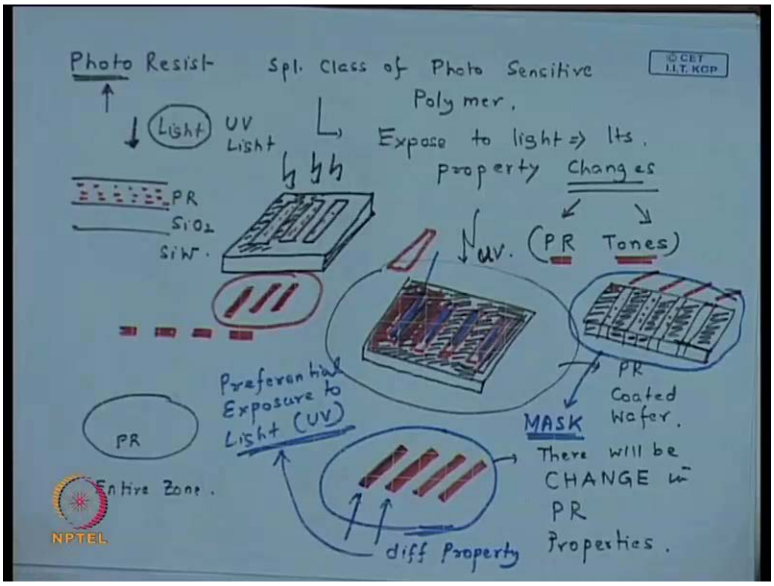

You may recall that we started to talk about what is a mask and how exactly it works. So, you essentially have a piece or a flat object, which has some slits which allows the light to pass, so this is the design. So, first the mask has to be fabricated and then you place this mask on a photo resist coated wafer, you allow the light or shine light over it, all these areas sort of absorb the light, it does not allow the light to pass only these areas basically so called slits, they allow the light to pass. So essentially, based on that the areas which are below these openings, there is a change in the property of the photo resist layer. Due to its interaction with the light, which is shining on it, and therefore, the mask pattern eventually, gets transferred on to the photo resist layer.

So, at this point it is important to understand, it becomes important to understand what photo resist is. I briefly have told you that these are some sort of photo sensitive polymers. Of course, there is a lot of research that goes on into photo resist chemistry with for our discussion, our discussion will be more from the engineering aspect; so, we will skip all the details, but still some of the basic aspects you need to know, particularly the photo resist tools.

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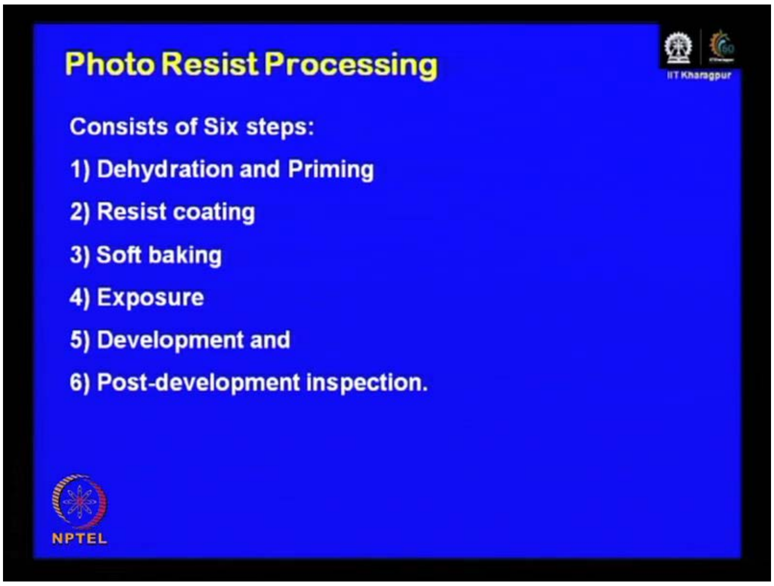

So, as I told you the several steps which are which sort of sub steps of the photo, the entire photo lithography process. For example, dehydration and priming, resist coating, soft baking, exposure, development and post development inspection. So, it is up to essentially, after right after cleaning of the photo resist of the silicon wafer, down to the step, before you sort of dope it or remove or dope with the other type of dopent. All the intermediate steps are part of the photo resist processing.

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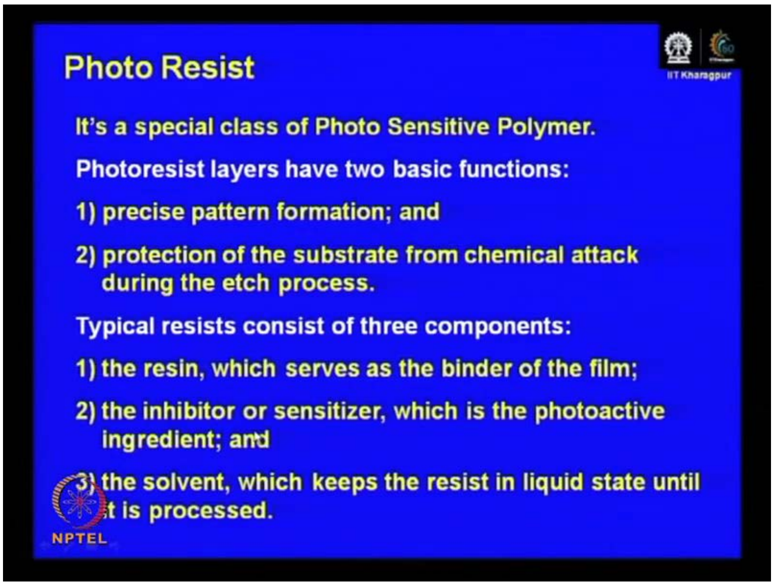

So, let us get started with what are the steps. But before that let's have a look at what exactly a photo resist means. It is a special class of a photo sensitive polymers and photo resist layer a polymer, and a photo resist layer has two basic functions. Firstly, it helps in the precise pattern formation, and secondly, the protection of the substrate from chemical attack during the etching process. Now, what exactly is the etching process and how it works? You have to wait for some more time to get an idea about it. Typically, a photo resist consist of three components. Firstly, the resin, which is a type of a polymer; which serves as the binder of the film.

So, this is the essentially base polymer matrix, the inhibitor or the sensitizer which is the photoactive ingredient. So, it is essentially not the entire part of the polymer sort of reacts in the photo sensitive, I mean photo reaction. You have some inhibitor or sensitizer present within the matrix, which is the photo active ingredient; and the solvent, which gives the resistant liquid state until it's processed.

So, this is another thing, I mean, if you sort of have only the resin and the inhibitor; for example, the resulting material will be very, very high viscosity material, it will be difficult to apply the, you just saw there is a step called photo resist application. So, the photo resist application will be very, very difficult. So typically, what is done for preferential application, essentially application here means that the photo resist layer will be uniformly coated in the form of a film or a thin film on your silicon wafer, on your cleaned primed and dehydrated silicon wafer substrate. Now, this is not done manually or by something like a brush, but this is also done by a technique called spring coating, which we will discuss in somewhat detail. But the issue is that if your, if the viscosity of your polymer or the photo resist is too high, then even spring coating will fail to produce a smooth and uniform layer.

There will special variation of film thickness, which is completely undesirable in the context of the proper pattern transfer. And therefore, you would like to have your film after spring coating as smooth as possible. So, in order to achieve that you essentially need to have some solvent in the system whose prime role is to reduce the viscosity. So, that when there is you want to spread your photo resist on the silicon wafer substrate, to achieve a achieve a film of uniform thickness it can be accomplished.

So, these are the three components of a photo resist, the resin, the inhibitor or the sensitizer, which is the photo active ingredient and the solvent; which is necessary for not only for photo resist, but in almost all polymers wherever people apply takings like spring coating or dip coating.

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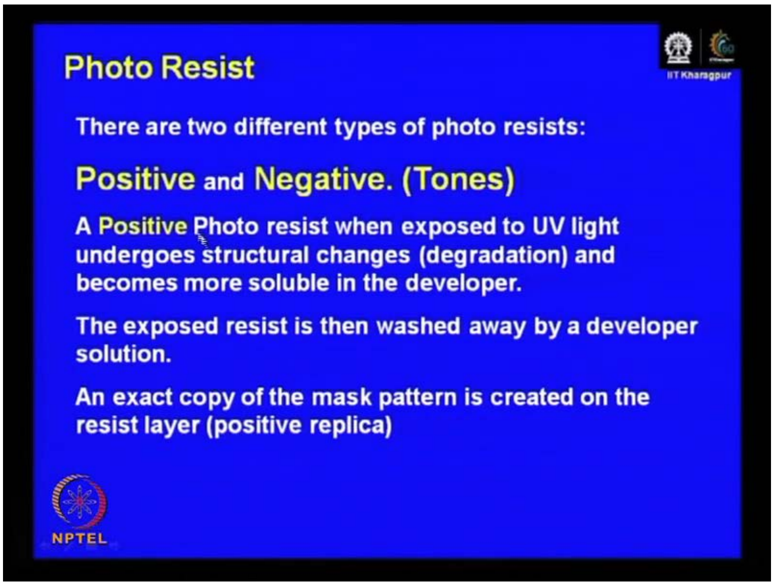

Now there are two, essentially two different types of photo resists or which are also known as the different photo resist stones. The first one is called the positive photo resist, which upon exposure to UV light undergoes structural changes and degrades; and becomes more soluble in the developer. So, essentially a developer is also a another type of a solvent, it is not a solvent that is used for coating of the photo resist layer, but it is used after the photo resist layer has been exposed to UV light.

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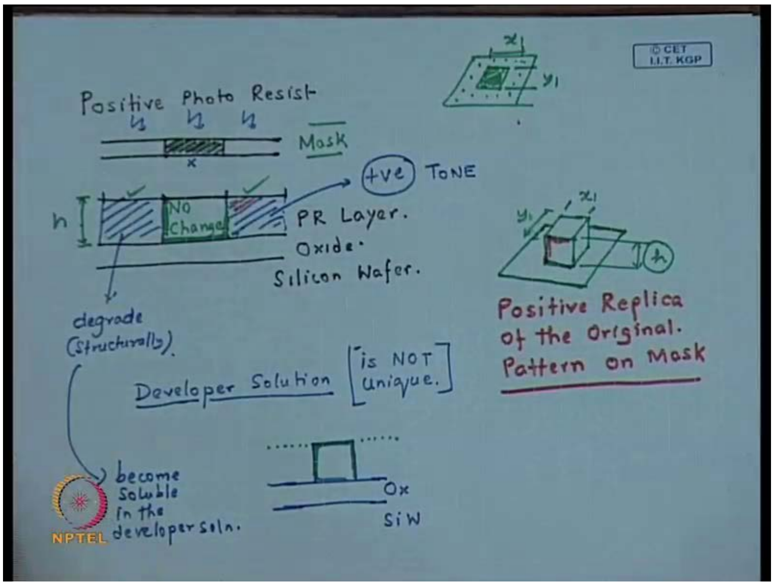

So, a positive photo resist if you look at. So, it is like this you have somehow coated a photo resist layer on your oxide coated silicon wafer; and let us say you place a mask here, where this part is opaque and the other parts are transparent. So, if you now shine UV light from the top, very simply speaking UV light cannot penetrate over these areas; and UV light penetrates over these areas and falls over these zones. For a, if the photo resist here is a positive has a positive tone, then what is going to happen, the resist layer over these zones is going to degrade.

So, they are going to these areas, it is going to degrade structurally, which can be in the form of a chain session that is longer polymer chains are broken down into smaller chains. So, that when you apply the developer it becomes easier for the developer to dissolve polymer preferentially from these areas and there is no structural change to this particular area. So, the here the polymer sort of remains intact or retains its initial properties. So now, what happens? When you now wash or dip this photo resist, which has photo resist layer, which has been UV exposed. To a developer solution, for all our practical purposes, we will just regard our developer for solution to be a special type of solvent. We and please remember that the developer solution is not unique. And typically, every photo resist whether it’s positive or negative has its own developer solution. It is obvious, because the structural changes that are going to happen for every photo resist; for each photo resist or for different photo resist having different tone is different.

So for example, if you are using a positive photo resist, coming back to the example that we were talking about; and now you put it in the developer solution. So, what has happened is over these parts the polymer, the photo resist layer has sort of degraded; and these areas are the photo resist over these areas becomes soluble in the developer solution. While, the photo resist layer over these area remains unsolvable; so, what would be the outcome? The outcome would be, you this is your oxide layer, this is your silicon wafer and you get a structure like this. So, over these areas your corresponds to these zones, where you had a positive photo resist layer, which had been exposed to the UV light. And there the material property there was a degradation of the material property over these zones.

So, when this UV exposed photo resist layer was sort of washed or subject to developer development or was washed in developer solution, what happened is? The polymer from this zone and this zone got preferentially washed away. However, since this part this particular part which was below the sort of obstruction or the opaque zone in the mask or a zone which absorb the UV light, there was no change no structural change and therefore, when it was washed it did not dissolve away. So, it retained it is a structure. So, see what here what has happened here? You had taken a mask like this, in which this particular zone have did not allow the transmission of UV light on to the photo resist coated silicon wafer surface. And consequently, your resultant pattern on the photo resist layer shows becomes something like this.

So, I hope this gives you an idea, roughly about this is the heart of the photo resist process. I mean, while explaining the tone I actually talked about the in nut shell about the actual photo resist process. So, the height of this structure, what you have created, you can probably guess from where you get this height. Well, probably you understand it, this height corresponds to the height of the photo resist layer, you have coated. The dimension of this, the literal dimension, let us say x 1 and y 1 correspond to the dimension of the zone on the mask. So, first thing you can see is that a chemical pattern, which you had on the mask; why I call it a chemical pattern? Because this zone had some different had some distinct chemical properties as compared to this particular zone. And that distinction, in the chemical property was in the form of difference towards absorbing the UV light shined upon it.

So, essentially these parts did not absorb the UV light or did not block the passage of the UV light; while this particular area did absorb the UV light and it did not allow the UV light to penetrate. And consequently, the depending since we had taken a positive photo resist. So, there was degradation of the photo resist which were under the areas or photo resist film, which were under the areas through which the UV light would penetrate. And consequently, a chemical pattern after development what happens is? A chemical pattern, which you had taken on the mask, now gets converted to a topographic structure on the photo resist layer.

Of course, there are several integrity details, for example, whether your exposure sort of has a sharp interface, whether everything is during development, only the entire exposed or photo resist layer is shipped away. One has to also ensure that no polymer from the unexposed area gets stripped away. So, these are some of the critical issues, we might be discussing some of them at subsequent phase. But in a nut shell, this is what is the basic principle of photolithography.

The, you may now want to wonder, why it is called a positive photo resist. And the answer is very, very clear from the figure you see, because this way what you get? You get a positive replica of the original pattern you had on mask. Of course, you now realized that the pattern on a mask need not has a, had a topographic feature, it was more of a chemical pattern. However, the pattern over here you get on the photo resist layer is a physical or a topographic structure. So similarly, the a... So, let us now get back to the definition of a or whatever is written for a positive photo resist. When exposed to UV light, undergoes structural changes and becomes more soluble in the developer. The exposed resist is then washed away by a developer solution, and exact copy of the mask pattern is created on the resist layer. I hope now, based on the discussion we had here, you understand how it works.

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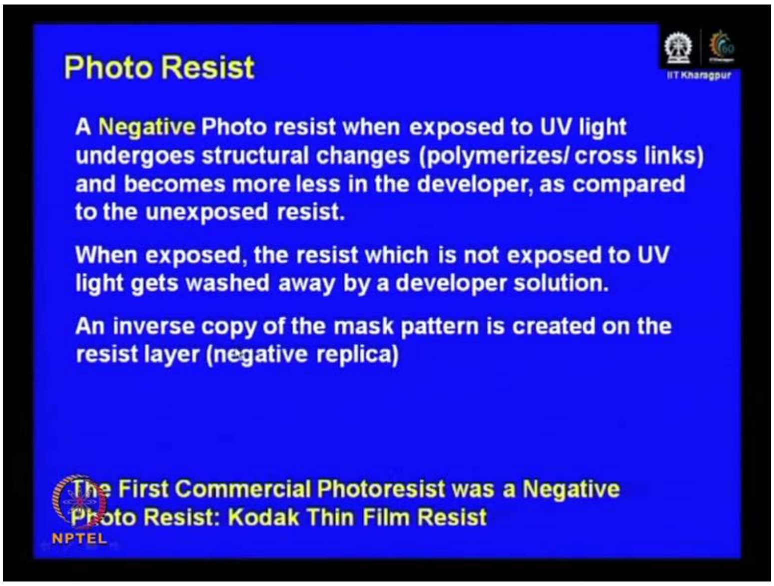

In contrast, probably you now can guess what a negative photo resist will do. A negative photo resist, when exposed to UV light undergoes structural changes, but unlike a positive photo resist, where the structural change was in the form of the degradation; here the changes is in the form of polymerization of further cross linking. So, it becomes more structurally stable; and it sort of can resist dissolution towards the developer. And becomes more less soluble in the developer, I am sorry about this typographic error in the ppt, as compared to the unexposed resist. When exposed the resist, which is not exposed to the UV light gets washed away by the developer solution. And eventually, an inverse copy of the mask pattern is created on the resist layer. So probably, you understand what it means? If you now have a relook at the schematic we sort of used for a, for understanding the positive resist; here what is going to happen?

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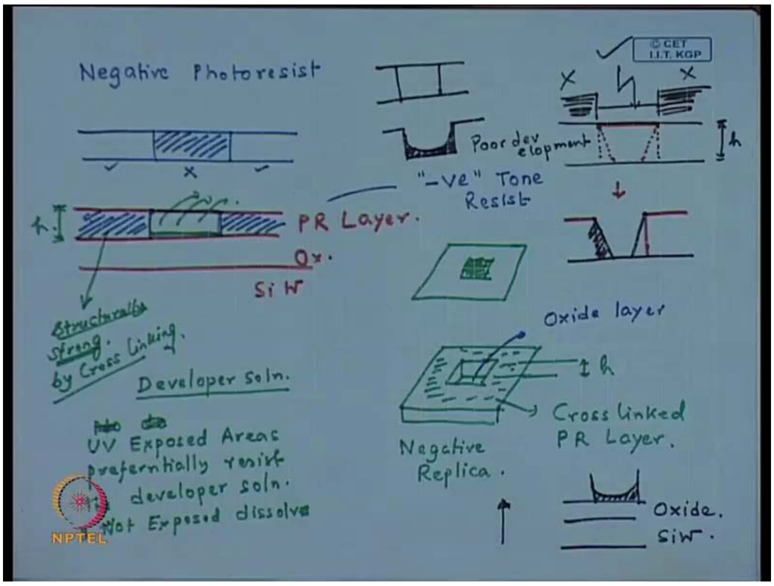

If you have the same configuration, so you have a photo resist layer, this the oxide layer, this is the silicon wafer, and you place a mask, which again has exactly similar property; this part, UV light cannot penetrate; over these areas UV light can penetrate. And this is now what you are using is a negative tone resist. So, what happens is? So, this area on the photo resist layer sort of gets exposed to UV light, this does not gets exposed. So, there is no structural change to this particular zone, it remains intact, as in the previous case, as in the case of a positive photo resist. However, what happens here? In the case in the previous case where we were using a positive photo resist layer, the areas that got exposed to the UV light, they underwent structural degradation.

In contrast, what happens here? Is that these areas sort of becomes structurally strong; which can be in the form of by something called cross linking, what this is we will definitely discuss at some point of the time. Now, what I mean by structurally strong is that, when you used a developer solution and we mentioned a developer is sort of specific to each of the photo resist you are using. So, when you used an appropriate developer solution, the areas which were exposed to UV light, in case of a positive photo resist preferentially got dissolved or gets dissolved. In contrast, here when you use the developer solution causes no damage to the areas which have been expose to UV light. So, no damage or in other words, the UV exposed areas preferentially resist the developer solution. And the area that is not exposed to UV light dissolves.

So, this actually dissolves away. So, you see that if you are using a negative photo resist, you achieve exactly the opposite thing as you had achieved in a positive photo resist. In a positive photo resist, the zones which were exposed to UV light got dissolved in the developer solution. In contrast, in case you use a negative photo resist, the zones which are not exposed to UV light remain becomes structurally weak, as compared to the areas which are exposed to the UV light. And when you subject this UV exposed photo resist layer to the developer solution, this particular area preferentially washes away.

So, now drawing a similarity; so, if this is the mask with which you get started exactly the similar fashion like this. You eventually get to a structure on the film surface like this. But the depth of the structure, each corresponds to the thickness of the photo resist layer; and this is a cross linked photo resist layer. So you see, you again get a copy of the chemical pattern on the mask, but here, the copy is in the form of an in its exactly an inverse copy, what you get on the film surface; that is you get a negative replica. So, in case of a positive photo resist, now again you can compare side by side, you had a mask and what you got is a sort of a self standing pillar of the photo resist layer on the oxide coated silicon wafer. In contrast, if you use a negative photo resist, what you get? You get a hole, in a intact photo resist layer and probably if your development is good, the base of the hole will expose the oxide layer.

Similarly, here if your development is good, the photo resist structure will be standing on the oxide layer. So, this is the key difference, in the patterns that you will obtain that one obtains depending on the tone of the photo resist that one is using. So, if you are using a positive photo resist or a photo resist having a positive tone, you will eventually get to a positive replica. In contrast, if you are using a photo resist, which is a negative photo resist, you will get to a structure which is negative replica. This is what I tried to explain, you in a very, very simple fashion, I hope things are clear to you. So, keep this slide in mind or these images in mind and this is essentially the basic concept of not only photo resist tone, which is of course, a fundamental concept, this is what exactly happens, but this also in a nut shell sort of tells you about pretty much, what you do in photo lithography. Of course, there are lots of complications, because this is a process that is very very well utilized or extremely well utilized in the industry.

So, there are lots of automation, lots of steps, lots of netegrities, but for our understanding from the engineering perspective, from a chemical engineers perspective this is good enough to understand, what exactly photo lithography does or how it works. So, you may be interested to know that the first commercial photo resist was a negative photo resist, which was known as the Kodak thin film resist.

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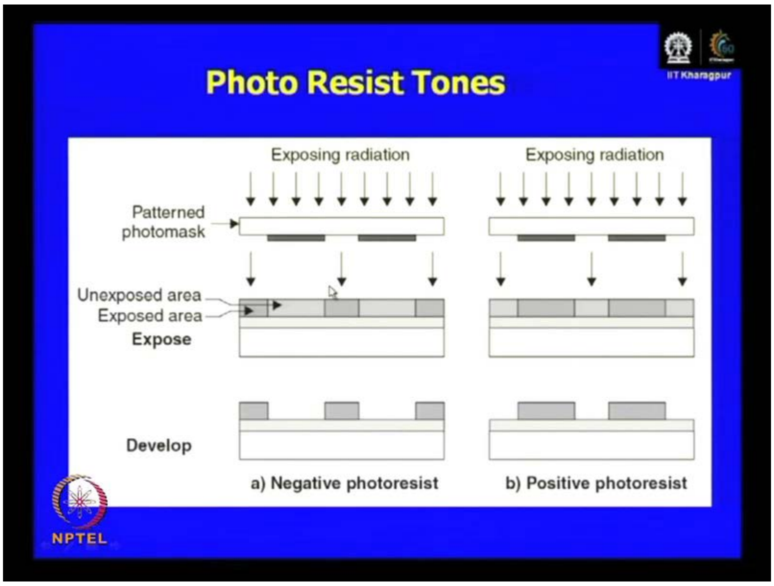

So, this is this slide now sort of shows you what I have discussed so far. So, suppose this you use this as the photo mask, these are the areas over which the light cannot pass or UV light cannot penetrate. So, this is a negative photo resist layer, this is a positive photo resist layer, and here you see upon exposure, so this particular area becomes weaker, a structurally weaker to resist the attack of developer solution, as compared to the ideas which are exposed. Eventually, resulting in a negative replica of the mask pattern, I guess now this figure makes complete sense to you based on the discussion we had.

In contrast, if you use a layer of a positive photo resist and you expose it to UV light. And then what happens is, these areas becomes these areas offer more resistance to the developer solution, as compared to the areas which have been exposed; eventually resulting in a positive replica of the mask pattern on the oxide coated film surface. So, this is the key difference between positive photo resist and negative photo resist.

We will deliberately avoid the chemistry, their lots of chemical chemistry, lots of research in the photo resist chemistry goes on into enhance its photosensitivity, to enhance quality of development. So that there are less residues etcetera etcetera, but we will skip all that for the time being. You can imagine that one of the critical stages in the development or even in the during the exposure stage, would be how do you ensure that your this photo resist layer say over here gets uniformly exposed.

Because as you get deeper into the photo resist layer, suppose this is the photo resist layer, this is the mask you have, let us say these areas like cannot penetrate, but this area it can penetrate, so it gets exposed. But the question is that, as you as the light travels through the thickness of the photo resist layer. How do you ensure that it sort of a uniformly exposes the entire zone of the photo resist layer below this; there is every possibility that the exposure might eventually lead to sort of structural change of a zone like this. So, which is highly undesirable, because then after development, you would not get a structure like this. Whatever photo resist tone you are using, but you will land up getting a structure like this.

So, which from the light way of micro electronics industry is completely unacceptable. The other possibility is that, even if your exposure is proper during the stage of development; suppose, this is a negative resist, so you want this area to strip off; it does not strip off, the entire resist layer, unexposed resist layer does not get washed away, but you get a structure like this. So, there is a remnant photo resist layer that remains, due to poor development. So that is also completely undesirable, because eventually at the end of the day, probably you understand now that you need to have an access to the oxide layer; and we saw in the animation and this is silicon wafer. So, your final objective is to also get rid of the oxide layer. So, that you have access to the silicon wafer, where you can have your doping reaction, but if you, if on top of the oxide layer itself, the photo resist layer is not fully developed, not properly developed and a remnant layer of under exposed or over exposed or unexposed photo resist remains that is going to spoil your entire process. So, there are lot of critical details which one really has to worry about, we will see some form of them without going into too much details of the whole technique.

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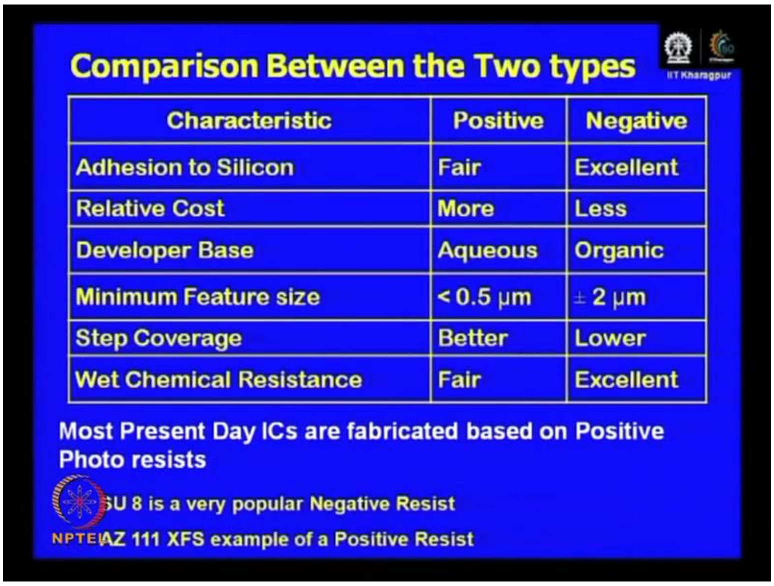

So, here is a quick comparison between the different types of photo resist. There are some several critical properties, one would like to compare. So, adhesion to silicon of course, is a very important or the oxide layer; positive photo resist, it is fair; negative photo resist, it is excellent. Relative cost, for a positive photo resist is slightly more as compared to negative photo resist. The developer base, for a positive photo resist is typically aqueous, the developer base for a negative photo resist is generally organic. The minimum feature size, for a positive photo resist is less than 500 nanometer.

Now, this is important, this is what makes positive photo resist, what is written at the bottom of the table, most present day ICs are fabricated based on positive photo resists. This is where actually negative photo resist has severe issues, because achieving lateral resolution of less than couple of micron is difficult with a negative photo resist. And as we told that for the present day processes of course, one is looking at dimensions of 30 nanometer to 50 nanometer.

So, you need to have feature sizes which are very, very small and its over its due to this particular reason a positive photo resist is well preferred in the industry, as compared to a negative photo resist. The step coverage is better as compared to in a positive photo resist as compared to a negative photo resist. And wet chemical resistance is fair in positive photo resist this is something that is not the best in the positive photo resist.

What exactly is wet chemical resistance, you will soon realize and at what stage it is needed; in contrast, it is excellent for a negative photo resist.

Well, I just already mentioned that most present day commercial techniques preferentially use a positive photo resist, you may want to know the name of some of the commercial photo resist; so, is it 111 X FS and other variance are positive photo resist. lot of, if you read research papers, lot of then you use SU 8 the large scale, this is a very very popular resist, very popular people actually make patterns and SU 8; and then sort of carbonize of them also to create carbon nanostructure or carbon mezzo structure which can be extremely useful in micro batteries, micro capacitors, etcetera. The SU 8 is actually a negative photo resist.

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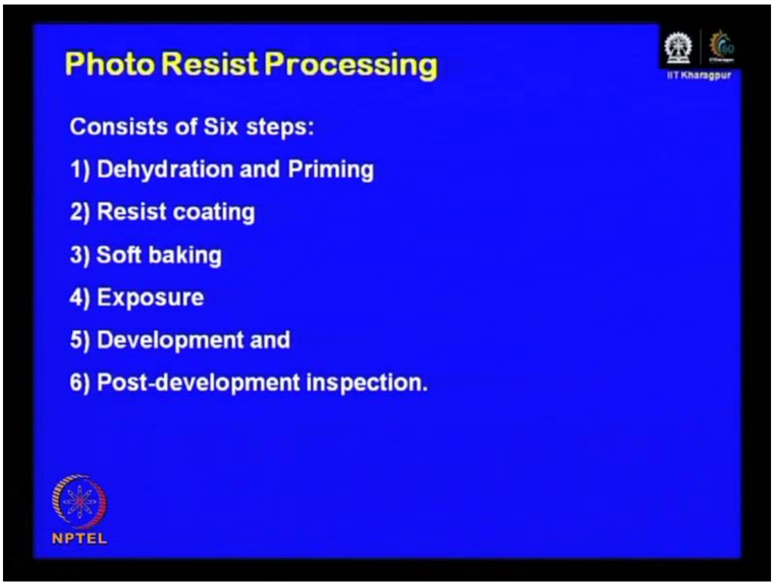

So, now let us get back to the photo resist processing steps. You now understand that the base material, this processing is going to be with photo resist.

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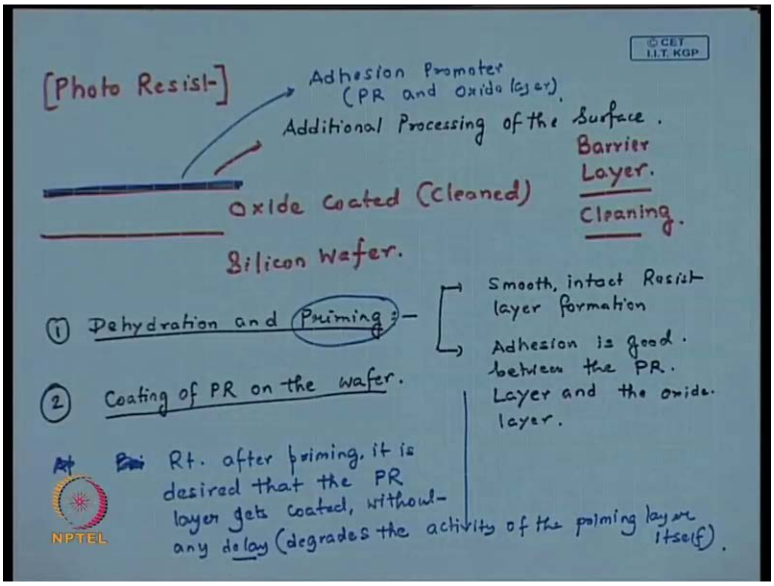

So, here are the things what we understand; so, you understand what is a photo resist now. And the photo resist processing is going to be on an oxide coated cleaned, silicon wafer. We have in our previous discussion or previous classes, in the previous class already discussed about the growth of the barrier layer and about the cleaning. So, first you take the as supplied wafer clean it, then roll the barrier layer. Now, it is ready for photo resist processing. So, you have photo resist, the first thing you need to do is before you coat the photo resist layer, you need to do some additional processing of the surface; which can be you can regard it to be some sort of a cleaning step, but this is a cleaning step not of the silicon wafer, but of the oxide layer. I would not regard it not sort of officially use the word cleaning, but let us put it as some sort of an additional processing of the surface.

And this is the surface of the barrier layer or of the oxide layer, which are known as the dehydration and priming. This is primarily done to ensure that you get a smooth photo resist layer on top of the oxide coated wafer and the adhesion between the photo resist layer and the oxide layer is good. So firstly, to ensure smooth, intact, resist layer formation and also to ensure secondly, the adhesion is good, adhesion between the photo resist layer and the oxide layer. So, this is the key objective of the dehydration and priming process. Now, once your wafer is dehydrated and primed, then it is ready for photo resist coating. So, the next stage that come up, we will again re discuss it is the coating of photo resist on the wafer.

So next few minutes, we will keep our discussion limited to these two critical aspects. Then of course, you can see that photo resist processing comprises of several subsequent steps like soft baking, exposure; we already talked about exposure while discussing photo resist tone. Then development again, this is something we have already talked using the developers solution and then post development inspection.

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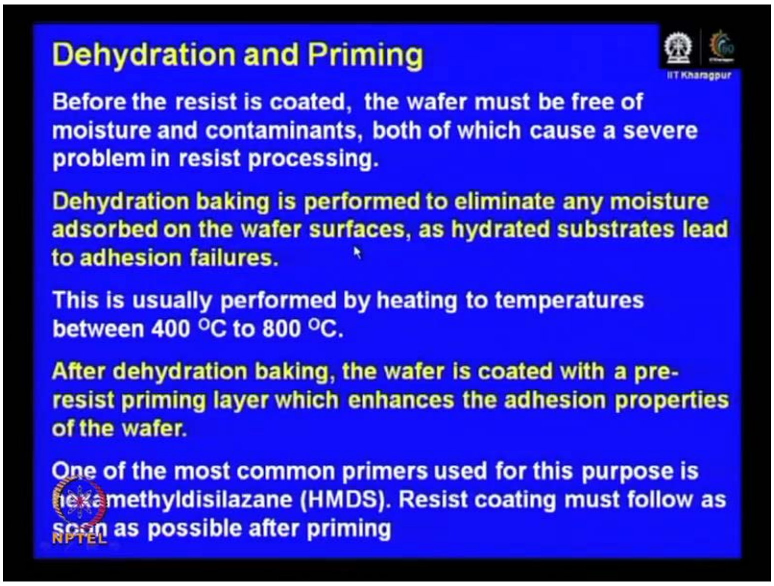

So, let us talk about the first photo resist processing step, as we told that it is dehydration and priming. So before the resist is coated, the wafer must be free from moisture and contaminants; both of which cause a severe problem in resist processing. Contaminants, as well as moisture is there present on the oxide layer, both of them will first try to sort of hinder the formation of a smooth uniform thin film of the photo resist layer on the oxide coated on the various surface. So firstly, there is a possibility that your film quality will not be good and also if you sort of can achieve a or obtain a photo resist layer, moisture severely hinders the adhesion between the photo resist layer and the on the oxide layer on the barrier layer. So, dehydration baking is dehydration; so, you can imagine sort of a high temperature processing or you place your wafer at high temperature; so that any moisture sort of or any organic material sort of preferentially evaporates away. So, dehydration baking is performed to eliminate any moisture absorbed on wafer surface, as hydrated surface leads to addition failure; that means that there is it sort of as you just mentioned that if moisture is present on the wafer surface around the barrier surface, which severally affects the adhesion.

Dehydration is usually performed by hitting the temperature between 400 degree centigrade to 800 degree centigrade; typically some standard over of hardness is used for this purpose. After dehydration baking, the wafer is coated with a pre resist priming layer, it is sort of this can also be done by spring coating at times not exactly the photo resist, but its coated with, its known as a pre resist priming layer that is something is enough if you remember; which enhances the adhesion properties of the wafer. One of the most common primers used for this purpose hexamethyldisilazane HMDS; its goes by the, it is more popular while it is actually HMDS. Resist coating must follow, as soon as possible after the priming layer or application of the priming layer

So, here you see what priming also means. Priming means that you cover your resister, your oxide layer after moisture removal; you cover your oxide layer with another layer or very thin layer of a chemical, which promotes preferential adhesion. So, it can be also regarded to adhesion promoter, it is promotes adhesion between the photo resist layer and the oxide layer. Conventionally, what is necessary to be done? The movement priming is done after all or after right after priming, it is favored or it is desired that the photo resist layer is of gets coated without any delay. Which intern may sort of degrade or which intern degrades, there delay degrades the activity of the priming layer itself.

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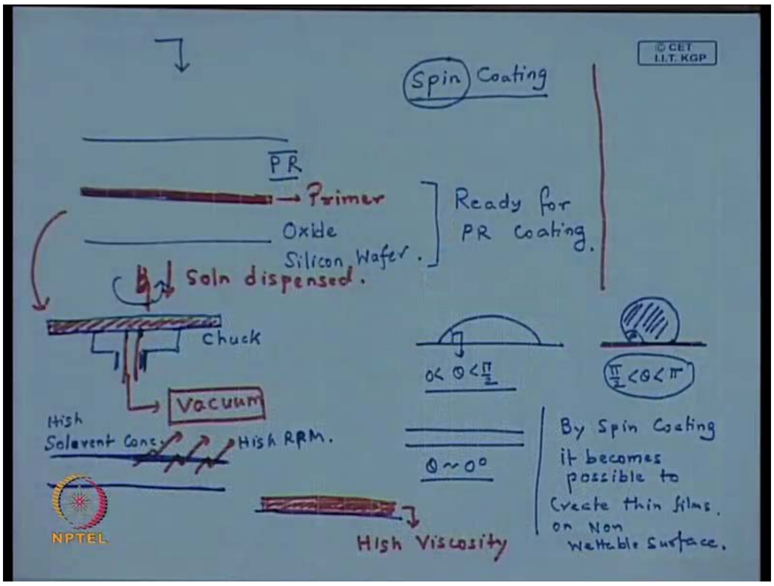

So, now you have an oxide coated, and primed limit, moisture removed, and primed wafer which is now ready for photo resist application. So, this is now ready for PR photo resist coating or photo resist application.

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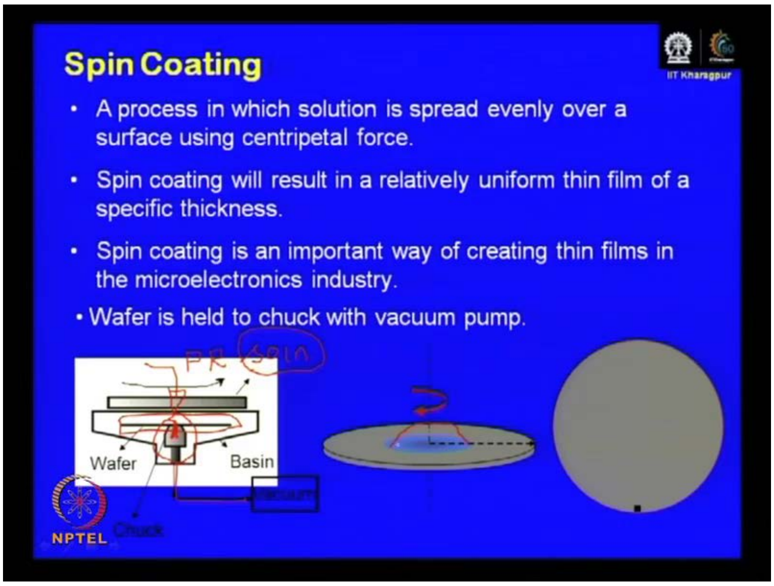

So, the photo resist application is typically or the photo resist coating on the wafer surface is typically done by a technique called spring coating. It is a very popular, very widely used, and very simple technique also. So, all you do is that you use a there instruments are available from lab scale right up to industrial scale. So, what you do you have something called a chuck, on which you can sort of place your wafer and typically during the... So, as you can figure out from the name, it will spin. So, it will rotate at a high RPM, typical RPM vary between 3000 to 6000 or 7000 RPMs; there are spin coaters available which can go all the way up to 10000 RPMs these are pretty well known now. So, one of the...

So, chuck is that hardware element on which you actually place your wafer first, before you dispense the photo resist. Now, one critical issue that is going to come up, what is going to how are you going to ensure that the photo resist that the wafer remains on the chuck, when there is such a high speed rotation. So, that is typically ensured by a vacuum connection. So, you have a small opening on the chart, which is connected to the vacuum light. So, this section provided by the vacuum pump or in the vacuum line sort of holds the chuck, as it rotates.

This is a very standard procedure, very standard technique and almost all the spin coaters are used in this way. The reason that you do not really want to use something like an adhesive tape here, so this is the wafer; so, this is that wafer that primed wafer, which you placed on the chuck and which is now ready for spring coating. And the rotation starts, after you apply a solution of the photo resist layer or dispense the photo resist solution on this wafer. Now, before I was we were just talking about the mechanism by which this substrate or this silicon wafer, in this case the substrate is the wafer is held to the chuck. And typically, that is achieved by a vacuum connection. So, here you can see that also in this transparency. So, this is we call the basin or the sort of area of the spin coater, where all the operation takes place.

So, this is the chuck, if you can see and; so, this is the chuck we were talking about and this chuck is connected to a vacuum line. So, when you place the wafer, this is the wafer here and turn on the vacuum, because of the section triggered at here through the opening, the wafer sort of sticks to the adheres to the chuck even during rotation. So, once the wafer is placed on the chuck, the primed wafer is placed on the chuck and the vacuum line is turned on, it is now ready for rotation; and before that what you now do you can do it manually, but typically, it is done in industry it is also done. So, photo resist solution is dispensed. So, when I say solution, it is actually the photo resist regime and the inhibitors, which are now diluted in the solvent, we talked about and it is dispensed. So, once the solution is dispensed then you start the rotation, so the whole thing starts to rotate.

And what happens is as you rotate it, because of the high speed the; so this is the initially dispensed solution let us say. And as you try to rotate, so this is the initially dispensed drop and as it starts rotating, what happens is this drops starts spreading and covers the entire wafer. So, I will repeat the cartoon again. So, this is the wafer, let us say or the substrate or the wafer sitting on the chuck, on the backside of it the vacuum connection has now been switched on, so that the chuck does not fall of. And then you dispense your photo resist drop, you may dispense it in a fashion that during disposition itself, the photo resist solution covers the entire wafer or you can dispense it at some location centrally, it really does not matter. If you are working with a very small piece, may be you would like to cover the hole substrate during the dispensing step itself.

But anyway, as you dispense and then start the or turn on the rotation, what happens is? Due to the centripetal force, the liquid meniscus starts spreading. And this spreading is irrespective of; I mean this is not exactly what you really worry in a commercial photolithography technique. But may be from stand point of spin coating, it may we may want to point out or I may want to point out here, that we when we were talking about the concept of wetting and hydrophobic surface, hydrophilic surface or a surface with preferential wetting and preferential, non preferential wetting. So, essentially this is a type of a surface which we saw there is partial wetting, but theta lies between 0 and pi by 2; this is a type of a surface where you had complete wetting. So, and this is a type of a surface which is partial wetting, but it does not really prefer the liquid to spread on, because the contact angle is higher than 90 degree.

So, it would really prefer that the liquid dispense remains as isolated drop lets. So, in principle only by spreading you would not be able to even cast a film on such type a of non wettable or preferentially non wettable substrate. You may cast a film, but that film also will sort of have will try to tend to retrieve. Only in this type of cases, you can caste a nice film. But what happens is, in spin coating, since you are going in for a high speed rotation; so, you are supplying a significantly higher amount of centripetal force and which overcomes, the resistance put up by the surface, by the balance of the horizontal component of surface tension forces. So, this is also important and in the context of instability, we will see that this is an extremely important aspect. So by spin coating, it becomes possible to create thin films on non wettable surface. So, here we get back. So, you see that the, you dispense the drop and you start the rotation, so that entire drop spreads covering the whole wafer, but there is something more that happens.

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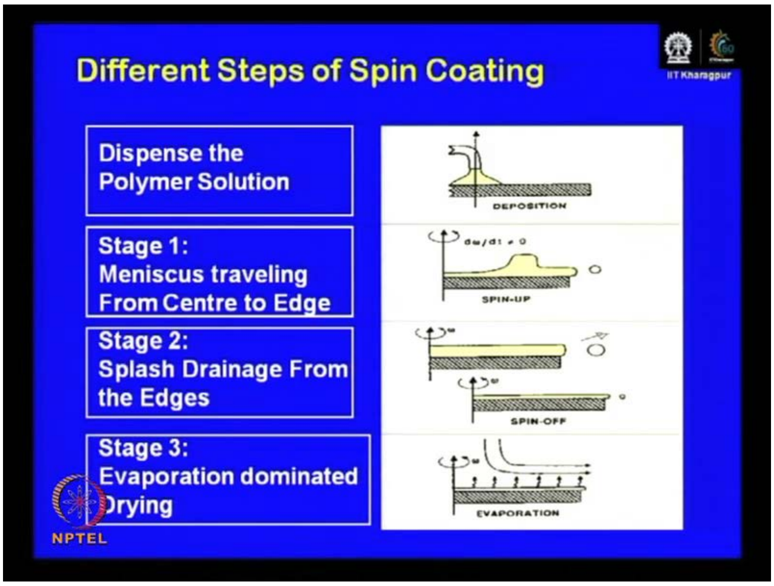

So, these are the different steps or different regimes of spin coating. First operation of course, is that you hold on your substrate to the chuck with a vacuum connection. And then dispense the photo or polymer solution or the photo resist solution. Typically, on uses a pretty dilute solution the reason for which will become clear to you in a minutes time. Then as you turn on the rotation, you can actually see that the meniscus is travelling from the center to the edge. Then, as the meniscus advancing meniscus sort of reaches the etch of the substrate, there is a lot of polymer that is splashed out of the substrate. And in the third stage, what you see that the fully spread solution from the fully spread solution there is evaporation of the solvent. Which so, in the initial stages, if you look at this particular figure, what you have is a as a continuous film, but this is a continuous film of a solvent rich polymer or photo resist in this case.

And eventually, as you continue with your rotation and this rotation can be as low as a minute couple of minute that is it. As you continue with your rotation there is rapid evaporation of the solvent, which results in the polymer, the solvent being sort of completely evaporating away and living behind the polymer in the form of a thin film. So, this is what is this particular aspect makes it possible of obtaining a continuous film even on a non wettable surface. So, what happens is, in the initial stage where you have high solvent concentration. And because of this high RPM, irrespective of the nature of the whether it’s preferentially wetting or not this solvent rich polymer films spreads on the entire solid substrate.

Now, once its spreads the solvent starts evaporating solvent rather rapidly evaporates. and as the solvent evaporates, it leaves behind, however the polymer which is the or the photo resist in this case; which is the solute in this particular case cannot evaporate and it gets gradually sort of a deposited on the film surface on the substrate. Now, once you complete the process of spin coating towards the end of the process, what happens is? Even if you have a non wettable surface, you have a layer of polymer or photo resist which is deposited on to it. In case of photo resist that is typically not the problem, but there can be various other settings or experiments where you may want to sort of have a continuous film on a non wettable surface and spin coating is indeed a preferred technique. Now, this polymer layer though thermodynamically, it is unfavored looking at the spreading coefficient it is unfavored, because the surface does not want to be remain covered with this polymer. But what now happens? These are long chain molecules and there is no solvent.

So, they are they have an extremely high viscosity. So, the molecules do not remain (( )) they cannot move, because they are mobility was essentially due to the presence of the solvent, which so now you realize the importance of the solvent layer which sort of reduces the viscosity allows the spreading of the photo resist or the polymer during the spin coating. If you did, in case you there was no solvent dilution, the meniscus wont travel very fast, because the as dispense polymer will have very high viscosity. And even with rapid rotation, the meniscus will tend to sort of flow or move very, very slowly or it may not move at all; it may actually form some undulations on the surface and can sort of a create a film with non uniform thickness. But this is very, very important.

So this is, these are the critical steps, so you dispense the photo resist dilute photo resist solution or the dilute polymer solution, turn on the rotation, and due to the rotation the meniscus will travels, then you have a continuous film of the solvent rich polymer. The solvent eventually evaporates away living behind a thin polymer layer. And so, this is how in in the context of photolithography, you get a continuous smooth, and pretty thin photo resist layer on top of a primed oxide coated silicon wafer.