

Electronic Materials, Devices and Fabrication
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Lecture - 25
Lithography

We have been looking in detail at the various processes or steps that are involved in your integrated circuit fabrication last class we looked at doping. So, we show the two main kinds of doping so, we can dope by thermal diffusion which is normally used for doping larger areas. The other technique is ion implantation this is especially used if you want to dope smaller region.

Because, your substrate is held at room temperature we also show that ion implantation is comparable with conventional lithography techniques because of the fact that the implantation is done at near room temperature.

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Today, we are going to look at lithography, in other terms for this is called Patterning. So, this is one of the most important steps in IC fabrication. So, the ability to pattern smaller and smaller regions is what drives the miniaturization of circuits. So, when we started in the 1960's typical circuits were few micrometers long so pattern sizes were few orders of micrometers.

But these stays pattern sizes or of the order of the nanometers and this is possible because, we now have newer technologies and newer methods to patterns smaller and smaller regions. So, we can define lithography as a series of steps that establishes the shapes, dimensions and placement of the various components of the chip. So, the important thing is it controls the shape of the various components.

So, whether you want to pattern a linear component or if you have some sort of structure to it. The dimension so that goes which scaling so, originally in the 1960s the typical dimensions were of the order the micro meters. Now, the dimension year of the order of nanometers and placement because, we have different components that have part of given chip; all these components have to be aligned with respect to 1 and other so the placement is also important there.

There are certain process goes which we can define for lithography, the similar way to what we defined for doping. So, if you look at process goals: one is to create a pattern with specified dimensions, usually the dimension are specified by the circuit design. So, you and the pattern is also specified by circuit design so this pattern has to be now created on to the wafer.

In other thing is, the correct placement of the pattern with respect to the based crystal orientation. So this is because, typically we will have multiple layers or multiple patterns for a given chip. So there all of this multiple patterns have to be alien to each other and they also have to be aliened to the base wafer. So, both creating the pattern and placing of the pattern or important goals in the case of lithography.

So, usually in lithography we expose a certain portion of the wafer we will see examples of this soon and this certain portion is either removed or may some material is added to it. Similarly, we can also you do doping of the certain portion. So, lithography is always combined with some of the other steps that a part of the IC fabrication so you could have lithography followed by layering, lithography followed by etching.

So in layering you add material, in etching you remove material or lithography if followed by doping where you add selective impurities which provides some sort of electrical functionality we that portion of the chip. As we mentioned earlier, alignment is very critical in these steps especially because, you have multiple patterns that are there as part of single wafer.

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So let us, look at a brief over view of the lithography process. So, the first thing that you need for lithography is something called a Reticle or mask. We will see later how a Reticle or a mask is made, but this contains the hard copy of the design. So, this is the copy that has to be transfer to the wafer so usually if you have multiple layers. Each layer has its own Reticle.

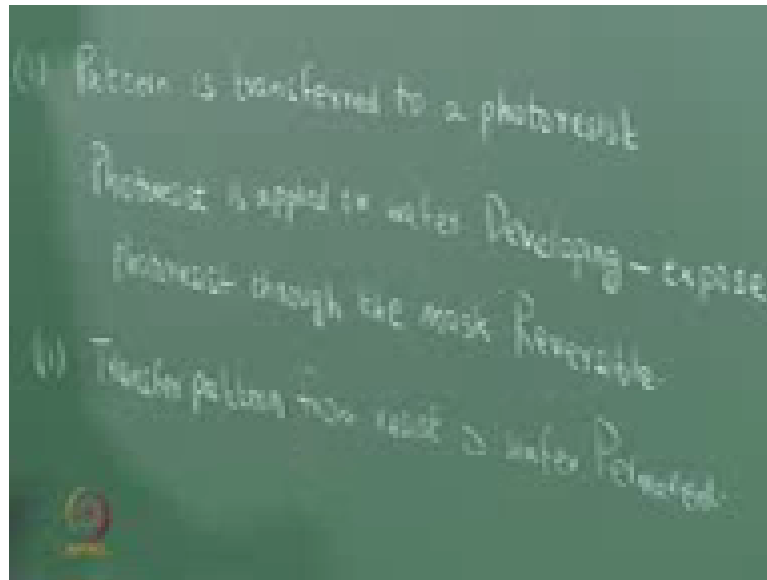
So, in the case of IC fabrication process they may be as highest 40 Reticle or 40 masks depending upon the complexity of the circuit that all need to be transferred on to the wafer. This is way alignment becomes so critical because, you have all of these multiple masks and all these masks have to be aligned to each other and also with the wafer. So, the pattern is first transferred from the Reticle to a photo resist.

So a photo resists is nothing, but a light sensitive material which is deposited on top of sample we again see examples, photo resist and how they are actually applied to the sample. So, the photo resist is applied on to the sample of the wafer and the pattern first transfer to the photo resist. As a mention before, a photo resist is light sensitive material so by using light selective portions of the photo resist are exposed and this changes which properties.

So, this process is called the Developing so you expose the photo resist through the mask. At this point the pattern is still short of temporary, so if there is some issue will how the pattern has been form it is possible to remove the photo resist from the wafer. And then,

the clean the wafer applying the new layers of the photo resist and then, the start the process all over again. So this write now is a reversible process and which only temporary because, the pattern is only on the photo resist.

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The next step, is to transfer the pattern from the resist to the wafer so, this is actually your permanent process. So this involve as a mentioned earlier, either removing material from the wafer or are ding material to the wafer or doping certain amount of impurities at the specific points. So, this becomes a permanent process so later we will look at a various waves of measuring the wafers during the IC patterning process.

So looking at, the pattern when the photo resists on their so critical step because of the pattern is misaligned or is not correct then it is easy to remove the photo resist and start this process over again. So, we look at the over view of the process so let us look briefly at photo resists.

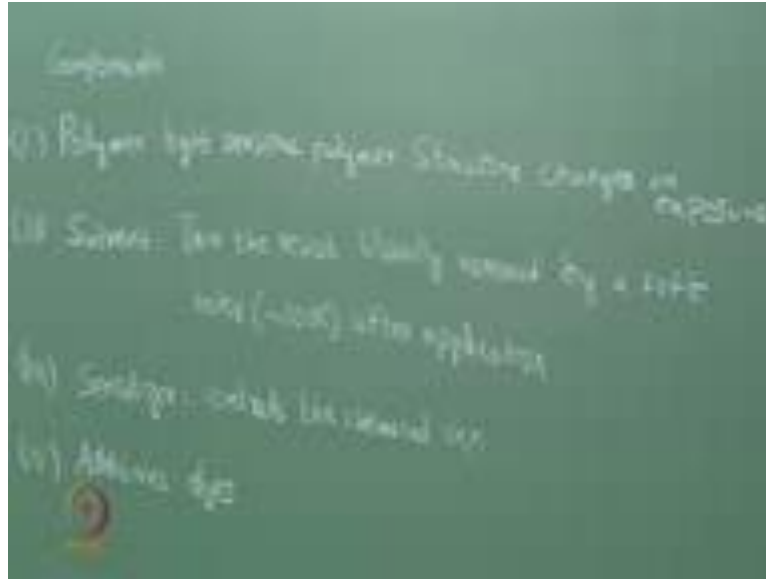
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So, the photo resist was adopted by the wafer fabrication industry, somewhere in the late 1950s so this is a concept that is someone taken from the world photography. So, were we know we always have film that is exposed and developed and then printed. So, photo resist can either be general photo resist or they can also be used formally specific applications.

The case of the research lab usually general photo resists are use, but in the case of manufacturing there may be specific photo resist available for specific application. So, these are usually tuned to a specific wave length.

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So let us, look at the various components of a photo resist: so the first component is your light sensitive polymer. So, this is the material whose structure will change on exposure to light so where you have the term photo resist. Then, you have a solvent so let me say structure changes on exposure. Then, you have solvent which is used to thin the resist so, solvent is used to enable the photo resist to be applied on to the wafer.

Usually, a process called spin on is used for applying the photo resist will see that later how that works. But solvent is used to thin the resist, after applying the photo resist usually it is baked somewhere on 100 degrees c for a few minutes to remove the solvent. So, is usually removed by a soft bake process after application. In other component is called a sensitizer, which controls the chemical reaction during the exposure.

And in also had some additives usually in the form of dyes so, different photo resist have different parts or different components and these could change depending upon the wavelength at which it is being exposed. And the conditions in which spin on takes place and the conditions is the photo resist supposed to be exposed to during the further processing. Photo resist is normally divided into 2 major categories: we call positive photo resist and negative photo resist.

So, we said that the photo resist is something that is sensitive to light right so it reacts upon exposure to light.

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Usually the light that is used can be u v or the visible rain you will also fine that there photo resist there are sensitive says x rays or electrons. But we deal with persists that are react with light, these are essentially called optical resists. Usually the light changes the way the resist is dissolved in a particular solvent based upon that, you can divide your photo resist in to 2 types: 1 is called positive resist and the other is called negative resist.

In the case of a positive resist, expose to that light whether it is u v or visible makes the resist most soluble. So, exposure makes it soluble and negative resist on the other hand, exposure makes it insoluble. So, the type of photo resist that you choose for a particular application depends upon the nature of the mask you have. The pattern that, you want to transfer and also the base wafer. So let us look at the difference between the positive and the negative small example.

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So considered a wafer, which say an oxide layer on path so it's could be a simple silicon wafer in oxide layer. We now apply the photo resist and for the first time and going to choose a positive resist. We then have a mask with a specific pattern so, the dark portion is the pattern and usually mask all made separately we look at mask later. But the dark portion is your pattern and we now want to transfer this pattern on to a wafer.

So, we have a positive photo resist and we expose the photo resist through the mask, so we have a specific u v light or a visible light some wave length. We also have to choose the intensity of the light, which again depends upon the type of photo resist you have. The exposure time will also change depending upon the type of photo resist, but the photo resist is expose through the mask and then we had 2 different regions.

So, where ever we have the pattern the resist is cover and where ever there is no pattern it is exposed. So, we have 1 region of the resist there is covered and 2 regions that are exposed. After the exposure if you now use a suitable solvent we said that in the case of positive photo resist, the expose regions are more soluble. So, we are left with a wafer with the oxide layer and then the layer or persists which is covered the rest of the resist is removed.

So this process is after developing, there is also the oxide layer the remaining regions so let me try that. So, we have expose the resist and then develop it so that where ever its expose the resist is remove and where ever it is not exposed the resist is still there. If you

now etch this wafer in order to remove the oxide layer. The resist will protect the oxide layer that is directly below it, while in the rest of the portions we oxide layer can be removed.

This gives a wafer with an oxide layer, which is being protected by the resist above it. So, this is after etching we could now remove the remaining resist by again using some sort of solvent so that, you're left with a wafer and the oxide layer. So, the pattern of the oxide layer is the same pattern that is present in the mask. So, a positive photo resist will transfer the pattern directly from the mask on to the wafer.

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so we can do the same thing with a negative photo resist so once again I have my wafer there is an oxide layer on top we apply a resist, but now we have a negative resist. We will use the same mask and again expose the wafer so this is expose, this is expose and the center region is covered. In the case of a negative photo resist the exposure next the region is insoluble.

So that, these 2 regions are now hard to remove while the region that is covered can be easily removed. So, after developing what we are left with is the oxide layer and 2 regions of resist. Once again we can etch the oxide layer away, whatever the region that is written below the photo resist is protected. So, we can etch the oxide and create the hole we can then remove the photo resist that is remaining.

So, that you are left with a wafer within oxide layer and the hole where the pattern was there in the mask. So, in the case if the negative photo resist we are transferring a negative of the pattern on to the wafer. So, it depending upon the kind of the application on the kind of mask you have can either have a positive photo resist or negative photo resist.

So, usually in the case of IC fabrication, you would a end up having both kind of photo resist for different processes is again depends upon what process you have and what mask material you have. So let us now look at how this mask is actually made. So when we look at lithography we said that the first thing is to have a hard copy of the design, which you want to transfer on wafer.

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So this hard copy is called your mask or Reticle in this is the first thing that has to be need. So, the pattern the glitch to be transfer is usually develop by the circuit designers and this pattern is then broken in to a series of mask. So, mask is the hard copy of the pattern so this pattern is usually made and decides, by the circuit engineers these are then converted to either 1 mask or a series of mask with required dimensions.

Usually a mask is made out of some short of glass Borosilicate or Quartz. So, this base material is glass that be a Borosilicate glass or Quartz a layer of Chromium is spatter deposited on top of this class with Chromium this typically a 100 nanometer stick and then a layer of photo resist is applied. So, in some waves a mask making is similar to the

process we just show when we transferring the pattern on to the wafer.

So, these are usually supplied so for example, you are trying to make your own mask use possible for to you by this blank mask, which has which is made of glass having a chrome layer and the photo resist layer. Then, the pattern is return on to the mask using a laser writer. So there is usually a digital copy of the design and the laser writer exposes specific areas of the photo resist on the glass, by using a depending upon the pattern.

So, the laser light can work a different wave lengths some typical wave length used are 365 nanometers 248 or 193 the first 2 are in the visible region, the last 1 is the u v region. The wave length defines the resolution of the features on the masks, so if you want to write finer and final features then you go for a smaller wave length. So, the laser writer is used to write the pattern on to the mask and this is a process you can typically take hours.

So, again it defines depends upon how intricate the patterns is and what resolution is required. So, after writing the pattern once again the photo resist is developed so that wherever you have a pattern being return those regions are remove and the chromium is exposed. This is then etched in order to remove the chromium and after some final photo resist removal we have the hard copy of the pattern. So, after writing the pattern it is developed and then chromium is etched and the remaining photo resist is removed.

So, mask making is actually very tedious process because, intact typically hours to make a single mask. And depending upon the complexity of the pattern you may have, to make have more than 1 mask. But once a mask is made, it has as a hard copy so that it can be used to take multiple copies on to the wafers. So, the next thing we look at this how we use the photo resist on to the wafer.

So, we will look at process over view after making the mask, the first thing we said first that the pattern have to be transferred on to the photo resist. And this photo resist layer has to be applied on to the wafer.

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So, the photo resist application is usually done by a process of spinning. Demand so before application of the resist, the wafer surface is clean in order to remove any defects or any other contamination. Typically it is cleaned in the iron ice water and then, a bowed right along with Nitrogen. So, the wafer has to be cleaned a process that is usually calls spin drying, which involves the washing the wafer with water.

Then, blowing nitrogen to remove the x as the water and then doing at de hide ration bake in order to remove any of the excess moisture there is on top of the wafer. The wafer is then loaded on to a vacuum check so you have a vacuum check. This aces as a wafer holder and there a different checks depending upon the dimensions of the wafer; this is the wafer.

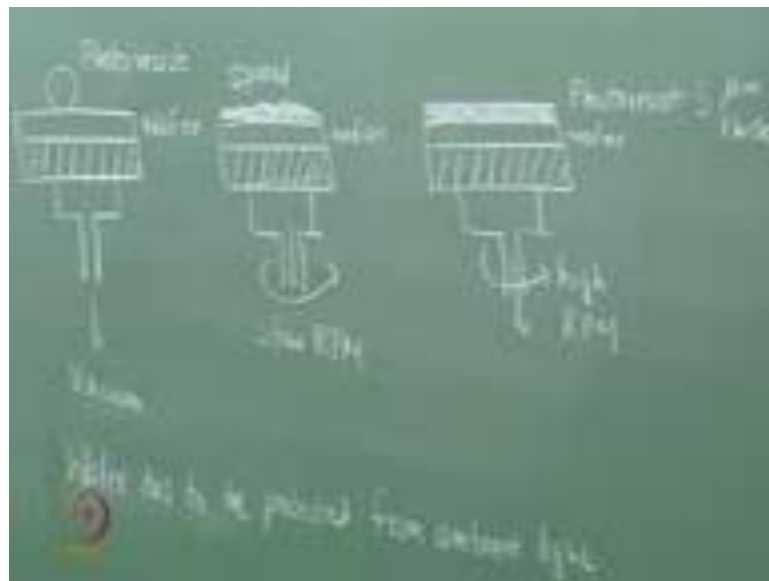
So, when we apply the photo resist on the wafer the important thing is that it should form a uniform continues layer and thickness should not change from 1 point to another This is because, when later we will expose the photo resist through the mask. If you have a very thin layer in exposure will not be correct and you will not be able to transfer the pattern correctly.

In order to built a thin layer the photo resist is first, drop on your wafer the wafer is done rotated so wafer is rotated slowly. So, that the photo resist pledge on to the surface by still not a uniform layer, after some time usually few tense of second. The wafer is fun at high RPM when you do this all the excess photo resist that is there on the surface is

removed, when you now have a uniform layer of photo resist on the surface.

This photo resist is usually a few micrometers thick may be a 1 or 2 micrometers but it is uniformly present on the surface. In all of these cases, the wafer is still held by vacuum using the vacuum chuck. So once the photo resist is spun on to the wafer this is now taken and then exposed using mask.

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At this point the wafer is sensitive so it has to be protected from ambient light. So, usually spin on and developing takes place under special lighting conditions. So, that the light is chosen in such a way that the wave length does not match that the wave length at which the photo resist become can become active due to the instruction with light. So, those ways the wafers are protected are the photo resist is protected before the expose a process.

The next thing we look at is how the expose the process works so we have the photo resist there is to the wafer the next step is to expose the wafers to the light through the mask.

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So, this process is done a something called an Alignment and exposure; alignment because, the mask has to be aligned to the wafer either to the wafer surface or to any existing pattern that is there on the wafer. So, the first step is mask alignment and this is usually done, by using something called an alignment marker or alignment marks. So, these are use to align the different pattern they are not part of circuit design.

But they are usually written in part of the design in order to help the alignment. For the first step is, the alignment process this is usually done by using the machine called the stepper. Now, alignment can be done both on the front side and on the back side of the wafers again this depends upon the complexity of the stepper that is there. After alignment, the wafers are then exposed to the light in order to develop.

The exposure time and exposure light intensity are the variables here. So these can be calculated depending upon the type of photo resist and also upon the wave length that is being used. There usually, standard tables that available the tell you how long to expose a particular photo resist and at what intensity this has to be done. So, we align and then do the exposure after the exposure process is done, the whole thing can take place in less in few minutes which is while lithography is such a fast process.

So, can go on making multiple patterns or multiple copies of a masks, so even though the original hard mask can take hours to make once that is done the pattern can quickly and effectively transferred to different wafers. So, after alignment and exposure the wafers

are developed; so developing process removes the excess photo resist. So, that the pattern is now transfer to the photo resist.

So, this again as we show earlier depends upon whether you have appositive resist or a negative resist. The most steppers are essentially 1 is to 1 so that if you have a mask of a certain area then, that area is directly copied on to the wafer. It is also possible to have the steppers, where you reduce the size of the features and copy them on to the wafer. So, these are called production steppers.

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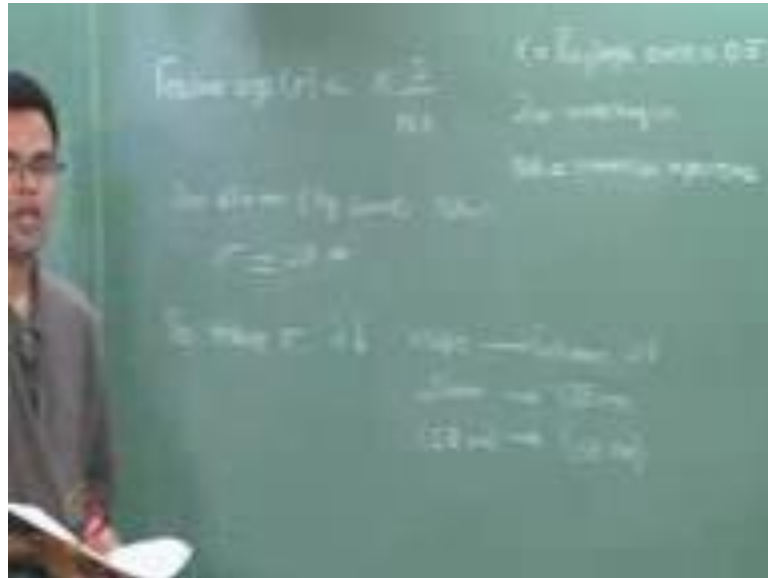
So, steppers are usually 1 is to 1 so you have a direct transfer of the pattern, we also have something called a reduction stepper; where you can have a 5 to 10 time reduction in the size. So, after we develop the pattern usually the resist is then bated in order to harden the photo resist then the wafer is taken for any of the other operations; whether you want to do layering or etching or doping.

And after that is done the remaining photo resist is removed usually again, using some hard acid in there is a process as a sort of wet etching or doing something called plasma etching using oxygen. That way the hard copy of the pattern is transferred on to the wafer. So, this process can be repeated multiple times in order to transfer different patterns on to the wafer.

In if you doing this multiple times the important steps make sure that the different

patterns are aligning to each other. So, 1 of the important things that lithography it has to do is that with a reduction in feature sizes we need to be able to pattern in smaller and smaller regions. So, the smaller features size that is possible depends upon the wave length and the numerical aperture of a system.

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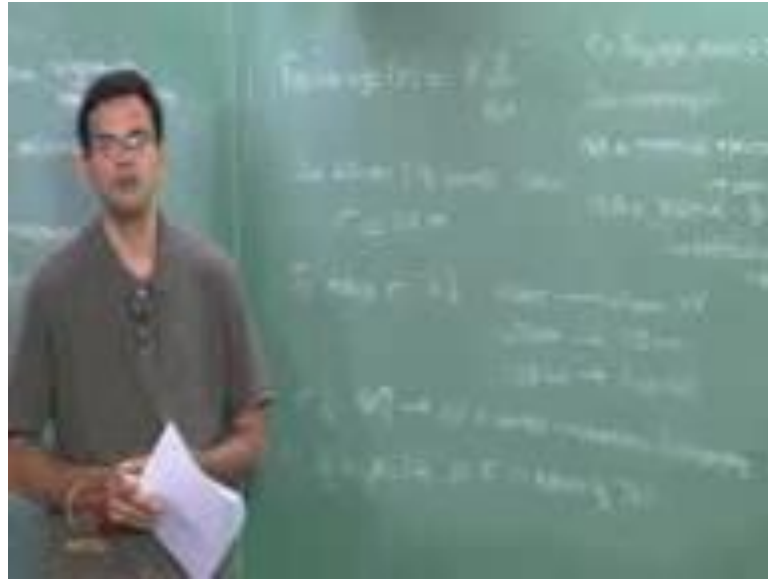


So that, the feature size which is a smallest features that can be pattern let me call this sigma is related to the wave length and the numerical aperture. So k is the constant which is called the Rayleigh constant typically it has a value of 0.5, λ is the wave length NA is called a Numerical Aperture. This again depends upon the length system, to give you some typical numbers if λ is 436 nanometers is it is for a typical mercury source and the numerical aperture is 1, the feature size sigma is 280 nanometers.

So this refers to the smaller size that can be pattern on to the wafer. But we know the typical wafers now have dimension of the order of tens of nanometers. So, 1 way to achieve that is to reduce the wave length of the light that is being used. So, to reduce sigma 1 option is to reduce the wave length so we can go from visible to extreme u v. So, if you have visible which is 436 nanometers and you go to 135 nanometer.

Then, the feature size goes from 280 nanometers to around 68 nanometers. And other way to reduce the feature size is to increase the numerical aperture increase NA.

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So usually water or oil is used as the medium instead of air this is because, water or oil as a higher refractive index NA is related to the refractive index by the formula $NA = \mu \sin \alpha$, when μ is the refractive index and α is the semi angle of the lens. So, the using oil or water you can have a higher refractive index and which will have a higher NA and a smaller sigma.

So, this process is called an inversion lithography system, again for example if you use water has a μ a 1.44 so, sigma is reduced by 70 percent. So, if you have 68 nanometers to be the feature size by using water you can reduce the feature size to somewhere around a 50 nanometers. There other various tricks that are used for example, double pattern in is a process that is used in order to get again feature sizes much smaller than what the lithography system can give you.

So, various tricks are used in order to pattern smaller a smaller regions 1 option is to replace light with some short of x rays source. So, we have a extras lithography in electron beam can also be used he is called EBM lithography; EBM lithography is very slow process because, it is a mask less process. The pattern is directly written on to the wafer it can pattern really small features.

But because, there is a direct process its time consuming and like the regular lithography process which takes place only a few minutes. So 1 of the challenges as we go to smaller in smaller devices is always be able to pattern these on to the sub stretch so, the different

strategies that a employee. That way lithography forms one of the most important steps in the IC patterning industry. It is that step that define the critical dimensions of the devices that are possible.