Soft Nano Technology
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Lecture – 15
Photo Lithography – 4

Welcome back. We will continue our discussion with Photo Lithography, we talked about essentially we talked about.

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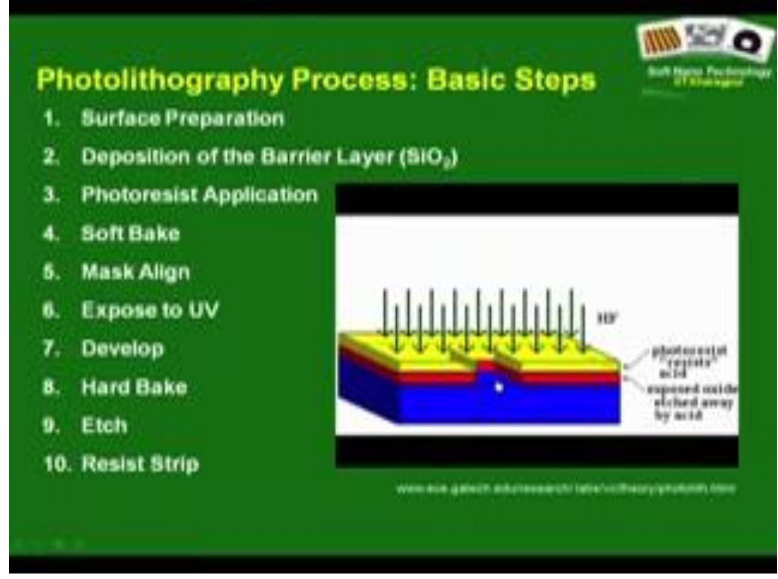

The mask and we will start our discussion today from the different exposure modes, but before that, we have this sought of a cartoon or an animation of the photo lithography process which we will allow us to sought of revise the whole process and also let us track up to what extend we have reached in our discussion.

This is how it goes you see the p type silicon wafer you draw the oxide layer which you all understand now you do draw the photo resist. So, that is by pink coating then, of course, you bring in the mask place the mask do the UV or exposure. So, as you do the UV exposure there is change in property in the photo resist layer this is hardening. So, therefore, it is a negative photo resist. Now you can conclude that then you sought of introduce the developer which is mentioned as thinner in this.

What happens now is the photo resist layer now goes away. So, we have roughly talked about this level not in details, but we will talk and what is the next thing to do next to do would be to. In fact, remove the oxide layer along the contours of the patterned photo resist layer and that is when, you do the etching hydrofluoric acid is the simplest version where which is the ray etching as you will understand.

Essentially what you see now is the pattern on the mask you first transferred on the photo resist layer and subsequently it has been transferred in the oxide layer and that is what you wanted to achieve because, if you remember our initial discussion you eventually wanted to have a patterned oxide layer.

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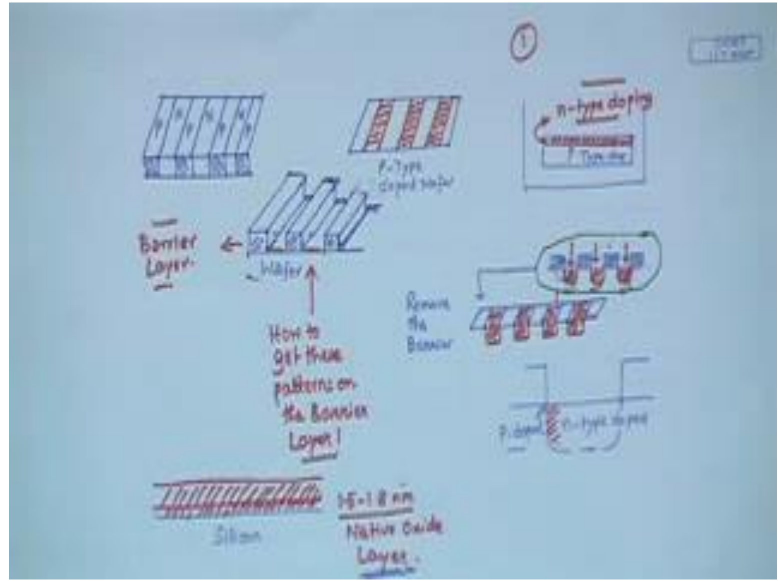

So that now when you place this wafered with this patterned barrier layer you can have space of n type doping. For example, but there is one small issue here it is very likely that the condition in the doping reaction Dopant chamber is going to be a pretty hostile I mean is high temperature high pressure process and the photo resist, even the harden part of the photo resist may not be able to with stand it therefore, before the it is sought of introduce to the Dopant chamber the photo resist layer, the pattern photo resist layer is also remove and this is very important.

You create the photo resist layer by spin coating then you expose it under the photo mask and then what you have is a weaker part. So, called weaker part of the photo resist and the stronger part of the photo resist depending on the nature of the tone of the photo resist, you now know that they are going to be a difference, but the developer. In fact, removes the so, called weaker part of the resist right? But this stronger or the harden part is also removed at a later stage and we will see it is gain some sought of a solution or there can be other processes.

The entire photo resist layer is actually removed, but a different stages and during the in between these two stages you actually have an intermediate stage where, you have pattern photo resist layer and along that at that stage. In fact, you would like to do the etching. So, that you can transfer the pattern in the photo resist layer to the barrier layer. So, you see the pattern actually gets transferred from the mask to the photo resist layer with help of UVO light because that where the terminology photo lithography comes in, but that does not serve your purpose from the stand point from doping which is essential for micro electronics and for that you. In fact, need to do etching of the barrier layer along the contours of the pattern photo resist layer and then you are ready to go ahead once the photo resist layer is removed.

You do the doping. So, you create the p n junctions, but then for your subsequent processing even at the barrier layer is unimportant. So, you finally, need to even remove the barrier layer to get again a flat wafer back, but now the difference between the initial wafer you started off with and the final wafer is the initial wafer was fully p typed dope and the final wafer has domains of p and an regions which act as the p and junctions.

This is in a nut shell the whole process of photo lithography and we have sought of discussed up to this point, you now know what is mask and you are going to expose it to UV or, but there are certain additional issues which we are going to discuss.

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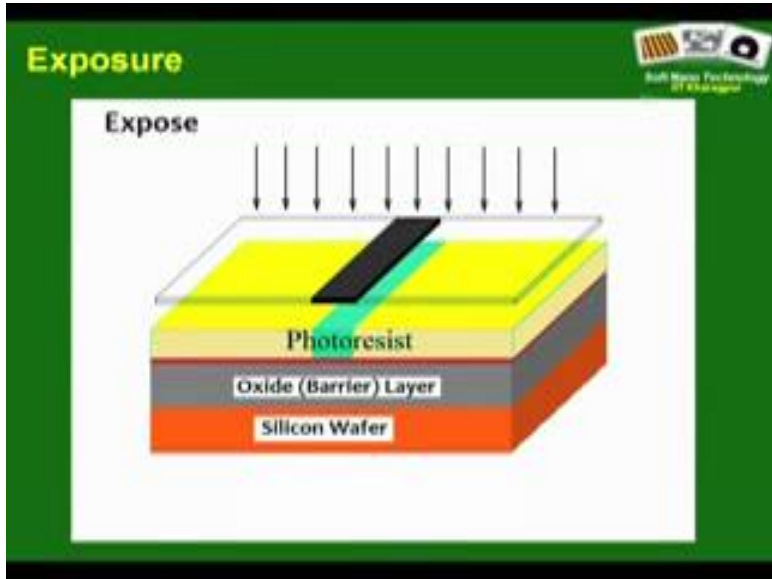

Now, this we discussed in detail in the previous class and I will just repeat it. So, you introduce the mask expose and then you can create the structures.

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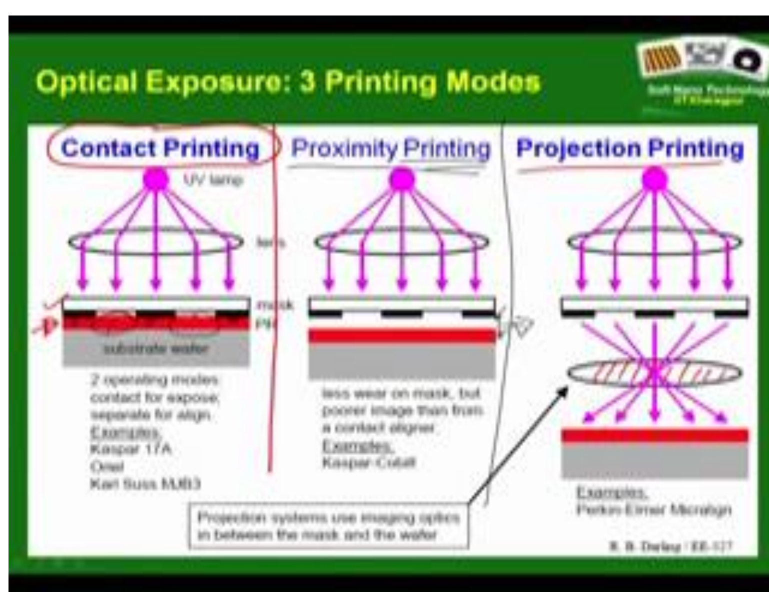

Well the way I have or we have discusses. So, far about the exposure part is apparently gives you a feeling that you bring in the photo mask simply place it on top of the photo

resist film and expose it with the UV lamp. Now that is indeed possible to do and that is how initial the process started and this is what is known as contact printing.

However there are certain problems. Firstly, that when you are placing the photo mask on the photo resist layer there is a possibility that during the UV exposure these portions of the photo resist. When they sought of undergo structural changes or changes in their property there might be some Debri formation and there might be some possibility of some debris sticking to the mask as you can already understand the mask has to be made by some secondary fabrication technique and it is a pretty costly device. So, you do not want your mask to be damaged after every exposure you would like to sort of have the mask to be re used at two for many exposure cycles.

Contact printing though it gives the best resolution and it is easiest to execute, but contact printing has the sever problem of mask damage and therefore, industrially it is not a very well utilized any more of course, in the research level you can always do contact printing what one does is to avoid the possibility of mask damage is bring the mask very close to the photo resist layer, but do not bring it in full contact. So, you have some sought of a placing arrangement and please understand we talked about this mask aligner. So, you typically do not use your hand to keep the mask on the photo resist layer and do the exposure. So, there is a instrumental device the instrumentation is available which is heavily instrumented it is a heavy piece of instrument.

In fact big instrument, so what you do you bring in the mask in very close proximity, but you do not really touch it and this is known as proximity printing there is a little loss of resolution of course, because it is not in perfect contact due to etch diffraction and stuff like that. But it eliminates completely the possibility of your mask damage and things like that once this was developed it was also discover that you can in principle have a situation where the mask is not in full or conformal contact with the photo resist layer and you can still have a develop. And if that is doable then what was immediately thought about why do not why not introduce another lens in this path way. So, increase the gap introduce another lens which can further lead to additional reduction and what will be the advantage. So, you appropriately place the photo resist layer at the focal plane.

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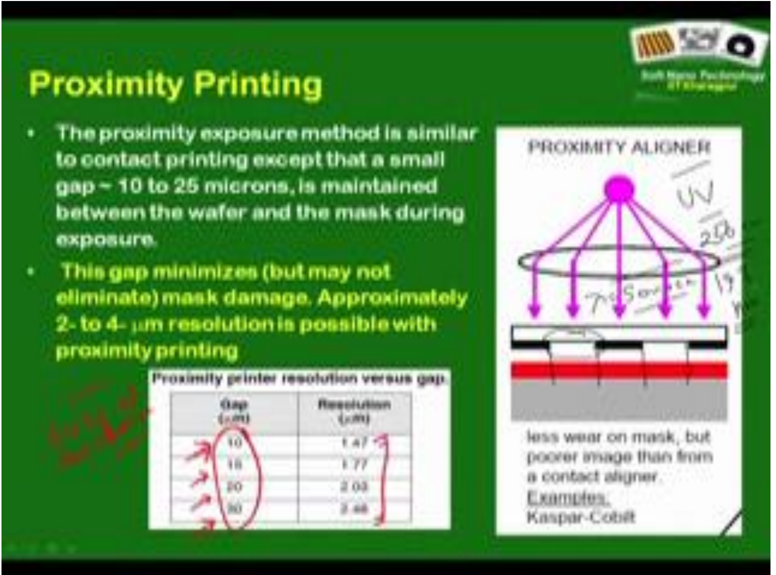

What is the advantage is. So, these are contact printing and proximity printing. So, these are some of the details with how. This particular table again please do not try to remember these numbers these are for your understanding you will have these PPT in your as your resource. So, you see that as the gap increases the resolution the minimum resolution sought of also increases. So, there is a bit of loss of resolution with increase in gap as the gap increases.

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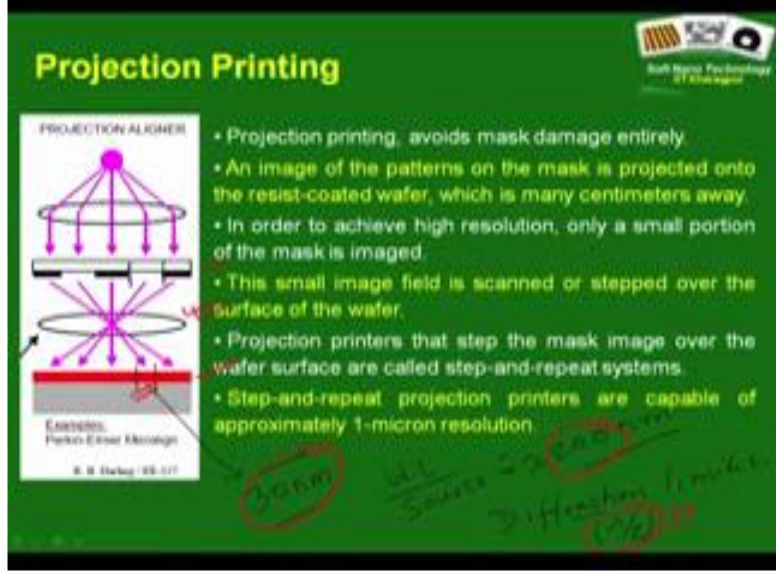

But then, the projection printing as I told that you introduce another extra optical lens which will reduce the dimensions and this is sought of the industry standard.

What is the biggest advantage is that you can in principle create smaller structures with a mask that has larger patterns because.

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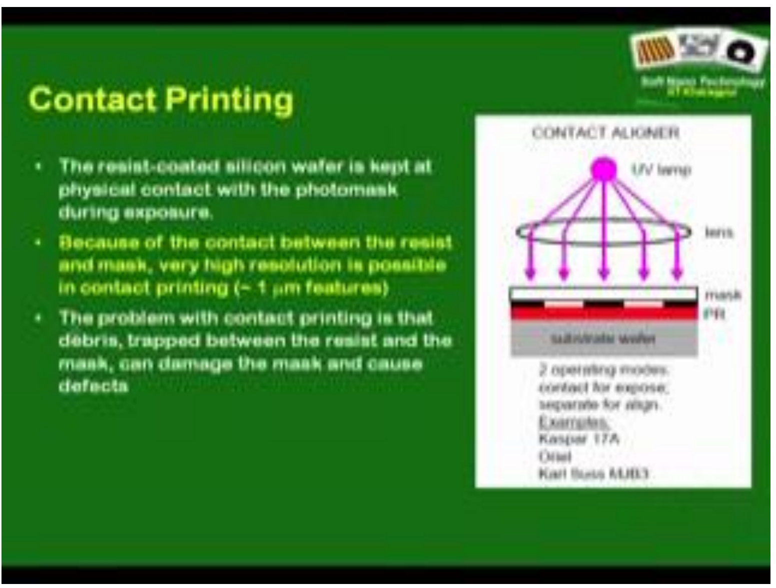

If you look back in your contact aligner or in proximity printing the dimension of your replicated structures is sought of identical to that of the mask. So, if you would like to create two hundred nano meter wide lines or structures, your mask must have two hundred nano meter wide structures of course, there are certain issues with diffraction limitation of the photo lithography that is simply, because of the fact that the minimum wave length of light that will pass to an opening depends on the lambda of the source itself and as I told that you typically use UV for exposure initially one use 246 nano meter wave length, but now it is industry standard is one ninety three nano meter there are issues.

Any way resolution is sought of limited to about hundred nano meter lambda by 2 that is not very good news because and now, you see we have already talked about this I five and I seven coat processers you have line which is down to 20 nano meter. So, question to ask how does people achieve this and we will come up some answer of this these require a pretty detail understanding of optics. And therefore, I will try to avoid did not go to details of that, but here both in proximity printing as well as in contact printing you

understand that the size you get of the features is identical to the size of the mask patterns, but here is an advantage. So, if there is a reduction that is taking place you can have bigger structures on the mask and you can create smaller patterns on the photo resist layer. So, that is one of the advantages.

When I say that you get structures like thirty nano meter and the wave length of the source is of the order of 200 nano meter and you also are aware of diffraction limitation which is sought of the minimum resolution will be limited to lambda by 2 you always tend to worry how is it possible, how is it possible that we have 200 nano meter the lambda by 2 limitation is in place and still you get something like thirty nano meter. So, here is one of the answers what you do is you utilize the possible reduction using another lens between the photo mask and the photo resist layer and that is what is known as projection printing.

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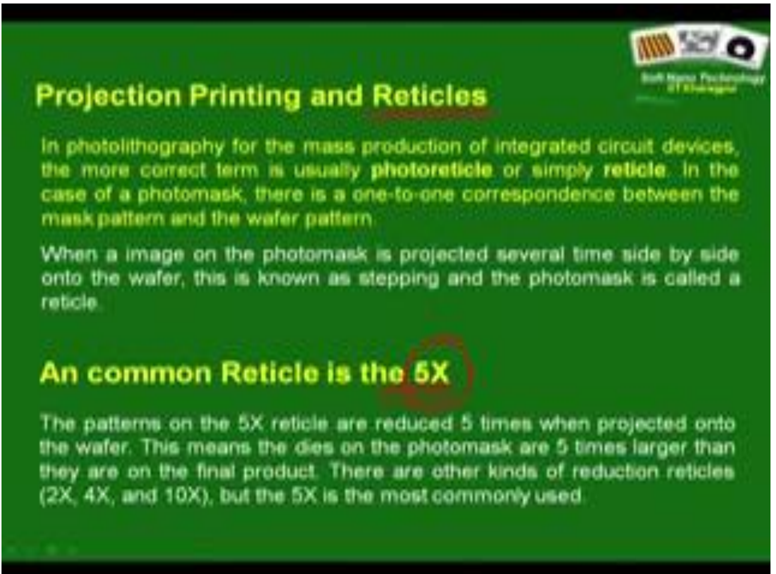

In fact, this is sought of the industry standard with this 5 x reduction lens and there is another term again it term, but it is important at times to know. So, that you sudden somebody talks to you about a Reticle and you feel wow I know about mask and I do not know what is a Reticle, that is not the case typically the masks use in a projection printing mode are call the Reticles.

And typically, if one talks that one is using a 5x Reticle it means that it is a lens you have a lens in the system which is achieving capable of achieving it is features which are 5

times smaller in lateral dimension as compare to the structure on the mask surface that that is what exactly is a Reticle in simple terms.

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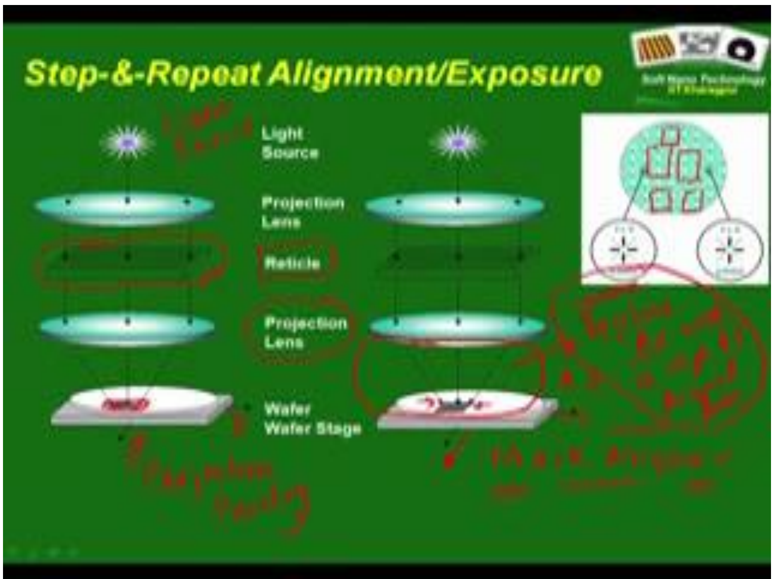

In fact, one of the thing that is important to understand is a wafer is a pretty large. So, you get 4 inch 5, 6 inch or eight inch wafers and you do not print one circuit may be on that you would like to create many circuits or many transistor circuits on them. So, what you do if you look these two figures carefully. So, you have a mask this is the photo mask this is the light source of course, you can now understand here is a lens. So, this is what you can straight away say that the printing mode is projection printing and if it is a projection printing you will not be calling it mask any more you will be calling it a Reticle that exactly what is written you now realize the second advantage. So, what you do is you expose this part. So, so this whole wafer is coated with the photo resist you expose this part other parts are not exposed.

Therefore, there is no proper change in property in the photo resist layer and then, once this part is expose it is now, mounted on a stage in a mask aligner which can be moved in both x and y direction it is a mechanized stage. So, you can sort of shift it right. Once this is this area is a exposed what you do you simply shift it what according to this cartoon what has been done the photo the wafer has been shifted in this particular direction and then again this area just behind the location of the place where the first exposure took place is exposed again following the Reticle following the same exposure

optics what is the advantage here unlike in contact mode or in proximity mode the mask and the photo resist coated wafer, are not in direct contact and therefore, the mask aligner can easily shift it and move it.

You can, sought of use the same mask with the single pattern to sought of expose various areas in multiple number of ways. So, this is one of the utilities I mention that mask aligner is a very, very important piece of device important piece of instrument that is almost mandatory to have because, though the process looks in to you do not take your hand and fingers to place the mask on your thin film and do the exposure that you can do in your laboratory once or twice, but not in the industry.

This is how it this printing modes work the mask aligner you also the other major importance of the mask, aligner apart from printing multiple number of circuits or patterns on the same wafer.

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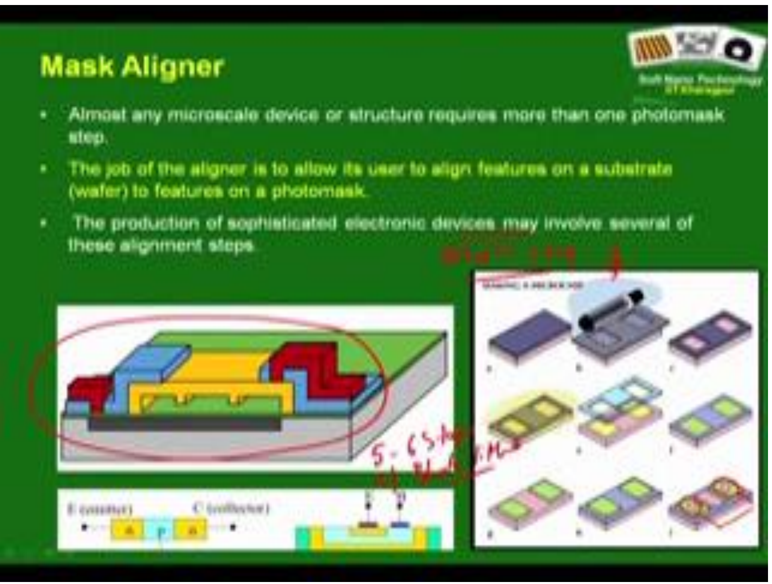

Is that in many actual design of let say transistor or whatever or whatever fabrication you would like to make you might have to do this deposition and patterning at several levels and several layers. So, for example, here you see that, you have one of the preexisting patterns then you would like to place these dots may be for electrical contact or something like that exactly at their middle.

You need to, in fact, know the existence or the location precise location of the patterns that have been created which might have been developed which might not have been developed have been exposed in the previous cycle I mean that is the that is the very, very important thing. So, actual fabrication of a architecture device architecture like this might require five or six steps of photo lithography as you sought of show in this cartoon.

It is a sought of one can argue this is multi step and as you try to do that what is extremely important that the second step onward all your deposition and patterns should be with respect to the pre existing patterns created by the first step or the previous step or the I minus first step and how do we identify that and that is the role of the mask aligner to place the mask for the Ith step accurately with respect to the patterns that has been created in the I minus first step.

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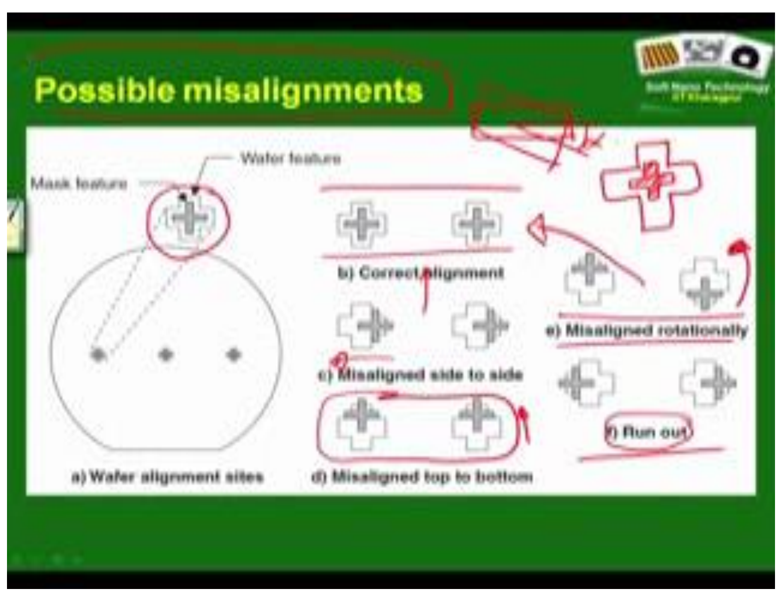

That is the importance of a mask aligner and there are typically these are industrial details. So, there are markers on the mask aligner. So, that you can align it and things like that, suppose this is this is this I just draw it, So, this outer cross is sought of a marker for the mask aligner and the inner one is a mark that has been created in the previous stage. So, you would like to properly align and this is how it should be Align this is the correct alignment. If the alignment is like this do you understand what you understand is the mask you are now placing is actually shifted in the left direction with

respect to the correct the existing pattern. So, you need to you need to adjust the stage of the mask aligner move it in the right direction. So, that it goes back to this arrangement.

If I now tell you now you can understand what is happening. So, if you look at this geometry would immediate this set of pictures you will immediately, now understand well the mask has been place still little lower as compare to the existing structure. So, what you need to do is you need to wind the screws and move the mask in this direction these are interesting case studies. So, this is called run out nothing to do with run out in cricket of course, how is this possible well you are using. In fact, projection mode printing of course, and therefore, this is possible when you have placed your mask or you substitute with respect to the mask at a wrong elevation.

It is not focused it is focusing at a different plane and you do not need to move either the mask aligner stage either in the x and y, but you need to adjust it in the z direction Right? I hope you are getting the point. So, this is like it is not focused and you move it up or down in the z direction and then, you can achieve the alignment rotationally misaligned what has happened is that this was the original pattern and the second mask when, you brought in it is at a angle with respect to the existing pattern.

You need to again not move either in x and y, but you sought of need to orient change the orientation angle. So, that you are back to this configuration. So, this is sought of you it is a very easy way of guiding what are the possible misalignments and what the mask aligner can do.

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Photolithography I will just draw a quick analog photolithography is very similar to classical photography right. Of course, classical photography is now almost did thanks to the advent of the digital camera and why because the photo resist coated wafer is analogous to the film the mask aligner is and the stepper the mask aligner primarily is sought of the camera and the mask or the Reticle is essentially subject of the picture. So, you want to create an image on the film in a classical film based camera and here you want to create an image of your mask on the photo resist layer, but photo. So, that is.

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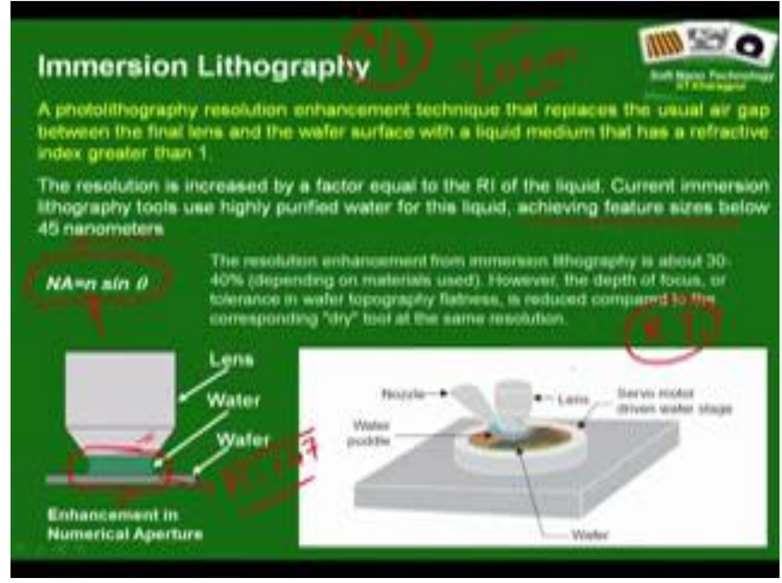

Now, of course, one of the major development that is that is taking place and one of the major issues is how does one sought of try to match with the moves law because, features sizes are going down and down we already know that industrially probably the latest computers that are coming the cheap sought or the processers have line with of around 20 nano meter.

Question to ask is, how does 1 achieve this? Particularly considering this particular number, this lambda by 2 what is that that is the diffraction limit in resolution. So, one of the options of course, is to use a lower wave length exposure light right. So, you do not exactly use a you use something like deep UV and essential you tend towards x ray, but that leads two primary concerns, one of the concern is you need synchronitic light source to generate light which search small wave length that is one of the concern of course, synchronitic light source is a very expensive proposition it is not that easy to get. But there is already huge investment that has taken place worldwide utilizing this UV or based exposure system. So, you have to junk all of them if technology really goes in that direction.

There was a time when people seriously believe that one needs to go for synchronistic light source for achieving high resolution, but it turned out to be very, very almost impossible from the stand point of the capital investment there is another very important second aspect and that is the photo resist chemistry because, what you need to understand that when this particularly the sensitizer part in the photo resist, which is the optically sensitive part of the photo resist is sought of synthesized or tune to change it is property at a particular wave length and presently the wave length is matched with the wave length of the exposure illumination source that is being used. So, if one using UV at one ninety three nano meter all the photo resist are designed. So, that they will change their property when they are expose to hundred ninety three nano meter wave length light as I told you one takes a UV sensitive photo resist to ensure that the photo resist does not change it is property to let say the visible light that is present in the lab during work that is important because you cannot do the coating and all the processing steps in that right.

Now if you hypothetically think that you are going to use light with much reduced wave length you immediately need to understand that the present generation or set of photo resist which again has sought of taken place after huge amount of development and

research in those area are all going to be junked of because, none of them will work suppose you take you start using light at a source of 50 nano meter, wave length the present generation of photo resist will simply not undergo any change in their property at 50 nano meter wave length. So, these are severe concerns and therefore, people are simply trying to stretch photolithography the classical photo lithography in it is present form to the maximum possible extent.

1 of the approaches that is adapted and industrially practiced is of course, the projection lithography which allows you to create structure that are five times smaller than the patterns on the mask. So, even if you have one ninety three nano meter wave length light which sought of gives you a resolution limitation of hundred nano meter you can see that you can still go down to above 20, 25 nano meter that is possible, but people are still working and one of the areas they have sought of realized where they can bring in even further reduction is. In fact, replacing here in this particular area with a high r I liquid which of course, has to be transparent because if it is not transparent if it absorbs all the light then it the wave the light does not reach the photo resist layer that is not good news.

Easiest solution of course, is water you do not want to introduce a solid because why you do not want to introduce solid because then movement of the mask aligner becomes difficult and then will be friction you cannot move it freely. So, to cut it short in fact, what is done is you introduce some water between the projection lens and the photo resist layer what this water does water has an RI of around 1.47 it increases the numerical aperture by you just have a look in to what is numerical aperture n is the refractive index and theta is the angle by which it refracts. So, there is an increase in the numerical aperture and that increases the resolution by somewhat above 30 to 40 percent and even research wise down to 40 nano meters with immersion lithography is pretty easy in fact.

What do you have now, you have the projection printing mechanism and along with that you need to have a nozzle which will dispense water so that there is a continuous water meniscus between the projection lens, and the substrate and you would achieve additional reduction in the feature size due to higher RI of water as compare to here.

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I think, after any way we will just rap it rap up this post exposure bake and then stop this class. Post exposure bake is done at a temperature of 110 to 130 degree cent very short duration it is after you have exposed to the UVO, of course extremely important for immersion lithography because you have a moist photo resist layer coming out, but even otherwise, if there are any debris or something like that any solvent contamination or anything during the exposure this PEB essentially removes that and it also removes the standing wave pattern something that I did not discuss in greater detail, but if you are interested you can just have a look what it is.

1 is to be very careful not to over expose over post bake because, this will lead to polymerization of the photo resist and therefore, removing the photo resist at the latest stage is going to be difficult and it is necessary essential for etching and we will see what way what we discuss about lift off.

What we discussed in this class is about the printing modes and their utilities. And of course, we extended the discussion to immersion lithography and the final stage is a photo lithography we will discuss in the next class.

Thank you.