Fabrication of Silicon VLSI Circuits
Professor. A N Chandorkar
Department of Electrical Engineering
Indian Institute of Technology Bombay
Lecture No. 18
Lithography.

Okay so we will start we will just go back to slides, we were to keep yesterday's start with some contrasts and then went over but then there were few things which I forgot to mention.

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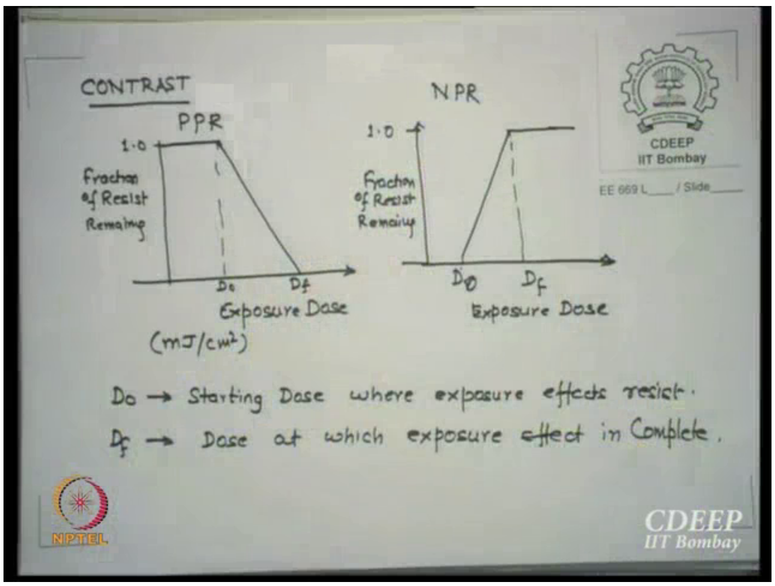

We did say that for PPR and NPR the fraction of resist after exposure, it may start at initial dose of D0 and may end at Df when all of PPR is exposed. Or we start from D0 to start exposing and finish at Df. And we define a term gamma which is called the contrast factor.

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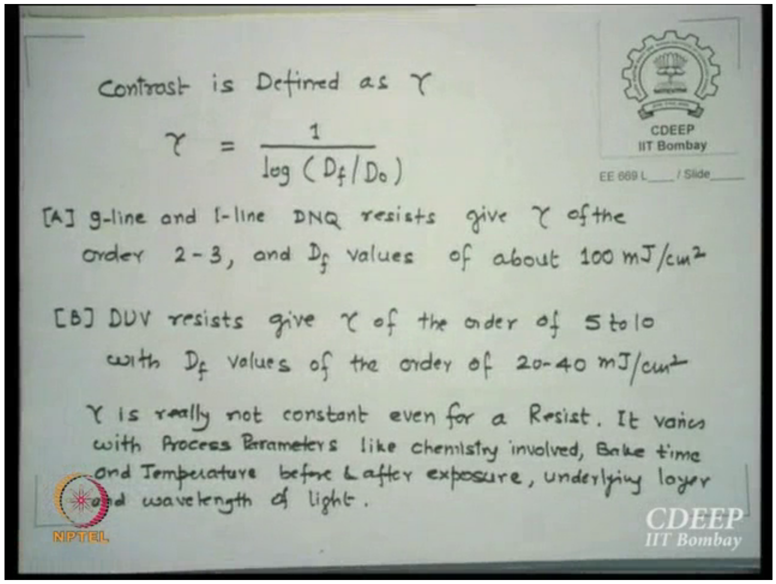

And we say it is 1 upon log of this. However one fact I forgot to tell, it seems as if Df and D0s are constant for a resist it's not really and that’s why I thought I should rewrite, I wrote this line afterwards after I saw in the book. Gamma is really not constant even for a resist; it varies with process parameters like chemistry involved, baking times, baking temperatures, before and after exposures, underlined layers and wavelengths. So it's not that for a given resist Df by D0 rati is fixed it can vary with so many of them. And we're expecting gamma to be higher enough such that the required Df values are not very high and still it's able to expose all the resists okay.

This is what I wrote yesterday and I thought that I should show you okay. There is also a interesting feature which is related to contrast which we will see now. I keep repeating my problem is essentially the sufficient intensity of light should get inside and get inside as early as possible so that full resist is exposed okay. And the amount of those required this should be smaller, that is what I am really looking for in lithography. How good I do it is what my expertise is. Okay so this is of course I read yesterday book again and I realized that these are issues which you should know that gamma is not really a constant. Though to a great extent for given all these parameters gamma will be a constant, is that if you're time lithography is fixed so okay gamma will be fixed but otherwise gamma is a function. If I change the previous temperature (())(2:56.0) as we shall see. This gamma may vary.

So there is a possibility of improving gamma by this is what I wanted to stress. So it's not just that I chose one kind of resist and I am through. I can't then help the case. So I have a first possibility of playing with gamma values as well. Is that point clear to you so why suddenly I said 5 to 10 so you may ask is so if this is fixed what is 5 to 10 yes I can do some mischief and I can get little higher gammas if I need okay, so that I have better resolution or better contrast. This is something which last I forgot.

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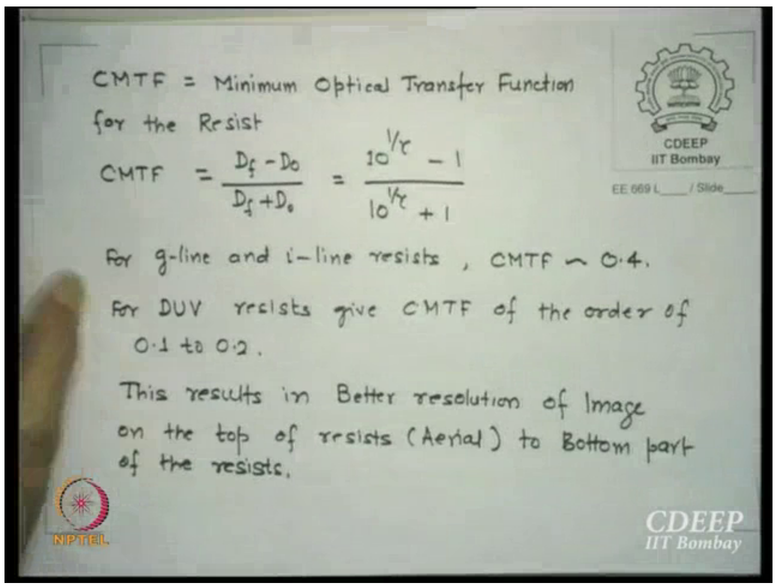

This of course we did.

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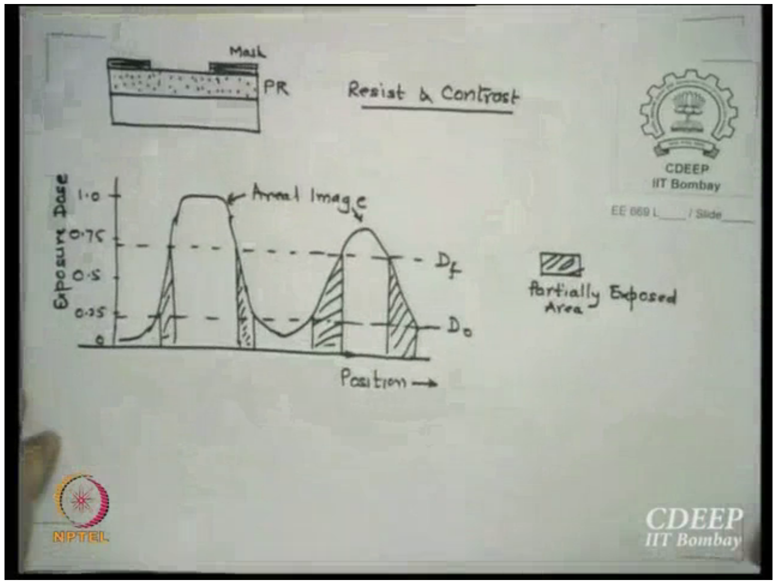

But what we did not show I think that slide was double, it just go mixed up there so that slide was there. This slide was showing that there is a mask good mask. I have put it on a resist. And depends on the exposure dose and position position along with X axis from here to here. I figured it out that depending on the thickness of resist all other parameters this upper portion you know you can see this of course other portion is not shown here, this is the second metal line or second mask area. So let us say if this is where corresponding to this, this is your aerial image pattern for a given exposure and this is your Df D0 this is D0 this is Df okay and if you have a another area which is under mask and it is so that the aerial image has a lower intensity and this can happen because of thickness of resist not being constant.

In that case one can see it may be little flattening up and this hatched area are essentially called partially exposed resist areas okay. You're going from D0 to Df or Df to D0 or this. In one case you can see the partially exposed areas are larger. Ideally it should be 0 I want sharp this and that may not happen I may have some grey areas as shown here and this happens reality why because of the wafer the thickness of resist is not uniform throughout the wafer okay. So there is a possibility that you may actually get gamma differently at different positions because Df D0 to shaded areas may be different at different points okay. And this means some contrast will be lost even if you have everything good but there is a possibility the mask may be not be the culprit. The culprit may be the resist thickness okay.

But these your all issues because at the end of the day I can't blame anyone, if it doesn't work someone else will blame me. So obviously I must (())(5:59.3) know what could could be done so that this is minimized, is that clear. Please remember every time I am looking for a smaller dose however at the same time I want full exposure to the resist thickness, is that clear? So of course there are tricks and trade of how to get rid of even if I made mistake I can slightly correct it and that can be shown little later okay. We've already looked into the drawbacks of yesterday this was shown and also we showed the actual alignment system okay. So now we finally show you the actual lithography sequence. Yesterday we did show you a diode being made but here is exact process which is given in a book given in many journal papers and it is available everywhere wherever you wish and maybe I see this lady wearing a INUP so must have heard in INUP n times okay.

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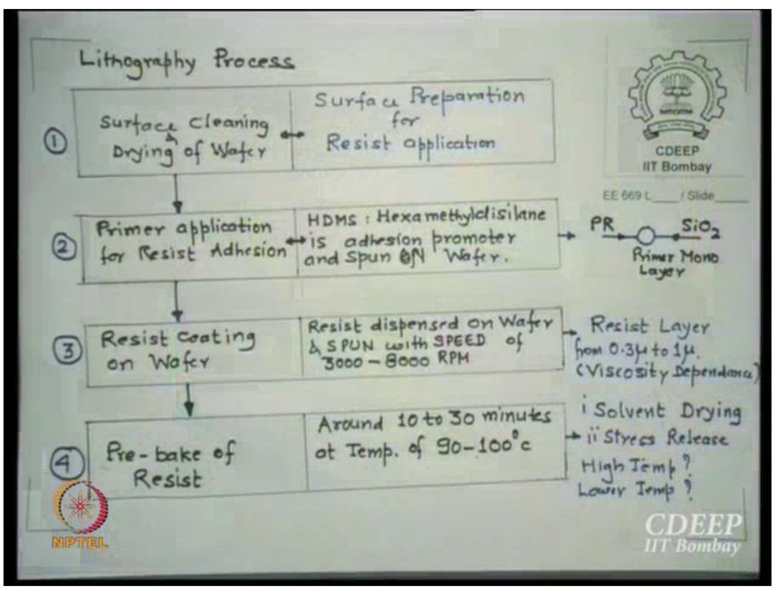

The lithography process uhh I now create a some kind of sequence of process which leads to a good lithography okay. The first thing in the process of doing lithography is cleaning the wafer its most important, there must be some oxide or some other material which you want to in which you want to create windows but the surface of whatever you have has to be very good clean okay. So you may actually go through a RCA clean and dry it very heavily. This drying process is also very very important okay. Because this is called surface preparation prior to coating of the resist. If there is a moisture resist may actually crumble or sometimes doesn't stick okay. So because of that the drying process is very crucial. Normally run in a little higher temperature ovens and oven is running with a huge amount of nitrogen flow inside okay.

Typical flow in normal ovens is around few liters per minute but we need roughly at least 30 liters per minute flow inside the oven chambers so that there is no oxidation of wafers and there is no dust going on it okay. Once the wafer sometimes even the furnace you may put and take it out but if there is a metal don't put it into a furnace. If it is oxide or nitrite or anything yes you can push after for drying itself in a heated furnace at the edge. And nitrogen is anyways passing in that so you can put it there for a while and then take it for masking okay. Then we apply a what is called is primer. Primer is a sticking material, I hope many of you have heard about this some home I don't know many of you have seen how the paints are put on the walls or on furniture's. They always coat with a primer okay. The primer is essentially the creator of a bond between the resist and layer which you want to like SIO2 and nitrite.

So if I put some primer layer it will allow resist to stick and it will also allow SIO2 to stick with the primer. So of course a mono layer is put so it is also applied by putting into a chuck and rotating it or spinning it. The primer generally used is Hexa Methyl Disilazane HDMS very famously known HDMS. And layer typically reaction. The kind of thing which I am looking for this is SIO2 this is photo-resist and there is a primer in between which bonds okay. Now this primer application is only for resist region because otherwise resist will ruin. We have not seen it but resist film is coated and after a while it actually rolls. So everything that you did is lost half way okay. So we normally wish to see that it sticks well okay. Then of course we after the primer we coat the wafer with resist and normally there is a different dispensation.

Earlier we used to put through a syringe sub drops, now there are former diffusing dispensers which actually puts sufficient small drops around all the wafers and there is a chuck which is rotating bowl and the dispenser is on the top. So few fixed amount of resist is dispensed on the wafer and then we give it uhh spin which may be of the order of 3000 to 8000 rotations per minute okay. No No No No when you go to remove the resist primer will (())(11:01.9). Then RC and all you will have every time you will go for cleaning so that everything will get cleaned away. In RCA everything where HCL and H2SO4 everything will be coming out. Every process the wafer should be fresh. The last process you finish you go to cleaning, then you will actually remove everything. When you strip your resist you will strip everything.

So of course this depending on the viscosity of the resist used and the thickness you're trying to build this thickness is decided by feature sizes and thickness is also decided by viscosity and as well as kind of source you're going to use expose okay and kind of lithography, three of them will show you. So this laser resist layer could be please remember what resist layer is important because resist even if it is hardened somewhere after exposure it should not get etched out when the other part is non-resist soft part is been etched that resist should not actually itself come out. So it should stop etchants actually attacking the surface below. So you need to have some times thicker resist so that it doesn't attack layers below but to a thick uhh too thicker resist actually rolls, it doesn't remain enough sticking coefficient for it so it rolls.

So one has to worry how much thickness for a given kind of films by experience. Typical thickness could be 3000 angstroms to a 10000 angstroms. Then the most important step in the case of resist before the exposure is given is pre-bake, this is very very important because many things are happening one is of course since resist has a solvent and we want a film which is solvent free only resist part. So I want to remove that solvent. So I heat the wafers or either give what called pre-baking our pre in the sense pre to the exposure okay. So I actually bake it around 90 degree to 100 degree allow for 10 to 30 minute depending on the resist and depending on the thickness is you've deposited this time may vary. The first advantage is it remove solvents and it also has an advantage of releasing stress any thermal this is called (())(13:33.2) and it releases stress in the material okay. So it is stress release so the film is more uniform it doesn't crumble so it needs to have some pre-baked.

Now just think of it, I just put a question mark, what if I do it at 120 or what if I do at 60 degree? What if I do at higher times and what if I do at lower times? Possible 4 combinations, why do I choose some combination which suits me okay. Think of it, one example I can give you. If I actually bake at higher temperatures the upper surface will get hardened first okay because it will dry faster but lower one will not so there will be some kind of gel below the hard surface which will not get exposed okay. So one example I gave you. Now think of it similar things 4 possible combination higher temperature higher times, higher temperatures lower times, lower temperatures higher and lower times. Think of it why only some selective combinations work because there is a possibility of resist not getting properly exposed. So one I answered the other 3 you look for it okay. Think of it there is nothing great. And why I am leaving it may be ask them so.

Of course these are all experiences you do and you realize arre not happening well. So think over it why it has happened you create some solution for yourself and then you find ya it works okay. So this is not something which is popularly given in books but these are something experience we know how much I do. So for example these temperatures are also not very (())(15:20.9) for all resist okay. Some may do a ready (())(15:23.6) but some other time, some may do 9 to 5 some other time. So there is combination but there is a maximum (())(15:31.9) which you have to follow in either case. The next step of course is the alignment which is the most important part, the pre-baked wafer is then put on a chuck which is the mask alignment chuck yesterday I showed you and over which the mask plate is actually sitting okay.

And there is a gap between the mask plate and the wafer, there is a gap between this may be a 50 microns or even lower but those are not touching is that point clear? They are not touching okay. What is that why they are not touching because when I move one of them related to each other they should not scratch each other so there is a gap between them so that I can move wafer with reference to mask or mask (())(16:23.8) for alignment of patterns. Now many a times there are alignment patterns we create and these are created by designers they have been paid to do this which I will show you quickly, just a minute I will come back to that. What we do is, there are alignment mask the first alignment mask may be something like this.

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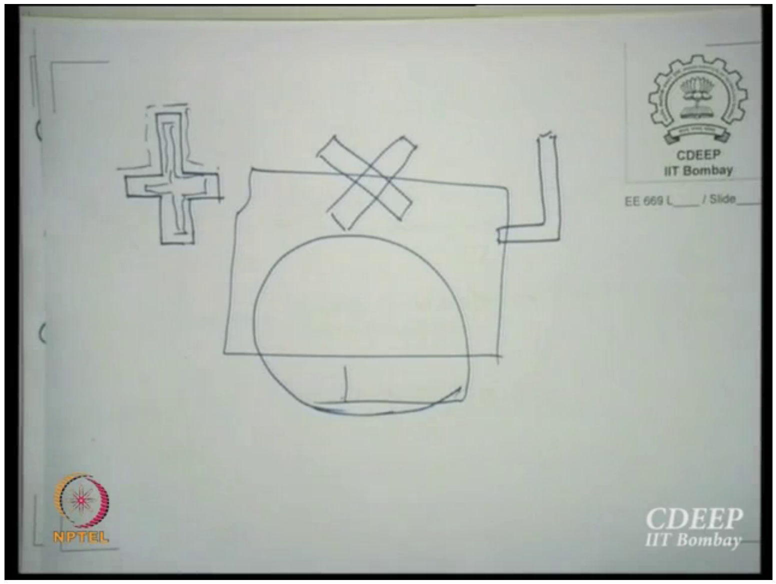

This is blown up version not necessarily that big. This is put on 4 corners sometimes in the edges of this is one pattern we create. Sometimes the pattern could be like this, sometimes the pattern could be like this. These are called alignment mask okay. Okay so these are called what is called as Global aligning. Since each mask corners will have these some kind of alignment mask and in the last mask there will be similar this, so if I am for the second mask it must be either if you want to cover it it should be either this or it may be for depends on what being etched and what being retained the other pattern may be inside or outside depends on whether you're covering something or you're etching something. So the next alignment mark on the second mask will be correspondingly same position either slightly lower or slightly higher depending on what patterning you're doing and these alignment marks are created by designer during their layouts. They provide you everywhere this.

Because layout I am not creating layout must come from design side. So these are the patterns which they create and these are major corners and sometimes in the inside edges as well. So when I align the first time I align is these alignment mask which is called coarse alignment. I don’t see patterns. I only see these two corners and 4 corner or 6 corners 6 areas I line. So major wafer may get align but the problem is if you have a wafer, let us say like this your mask may be like this, this area still may not get aligned. You may have on some chips you saw the alignment went and some area may not be so one has to guarantee that full wafer corners so not only on chip you align but also align on edges of the wafer both chips so that roughly you know your mask and your wafer which has earlier some prints is actually now just below that.

This can be done by this stage or it can also be done optically by mirrors but that we shall see later. Now this alignment once done then individual wafers some X and some Y are actually chosen and there final alignments are done from corner to corner. We believe that if 2 diagonals are matching then most of the time wafers will match okay. The diagonals has matched so wafers must have got aligned now the problem starts in most cases the kind of lithography I do is called contact printing, I have after this alignment is done which may be 25 micron mask away. I bring it down and allow the mask to touch to the wafer. The emulsion portion is below that means there is no gap between the mask and the initial pattern between the resist. Now there is a problem there itself because in any XYZ system it is mechanical there is always backlashes okay or there is what is called inertial motions.

So if I have if I have a wafer and I am putting this on top of it I thought I go like this but actually I may go like this okay. So there is error and in general this error is many a times systematic errors unless you every time change the direction of X and Y. This you know roughly which side it goes okay, so (())(20:56.6) your initial miss alignment itself is to be such that when I stick it will get aligned. If it doesn't you come back in the line keep doing after a while you will realize how to align okay. It takes months sometimes years to learn exact alignments for a smaller patterns. Every time you do you scratch something you out of it some chips get aligned some chips don't but that's only experience and you know how to align large number of chips in one wafer and number of such wafers. And therefore these are tricks which I say I cannot just say do it, try it yourself and learn it.

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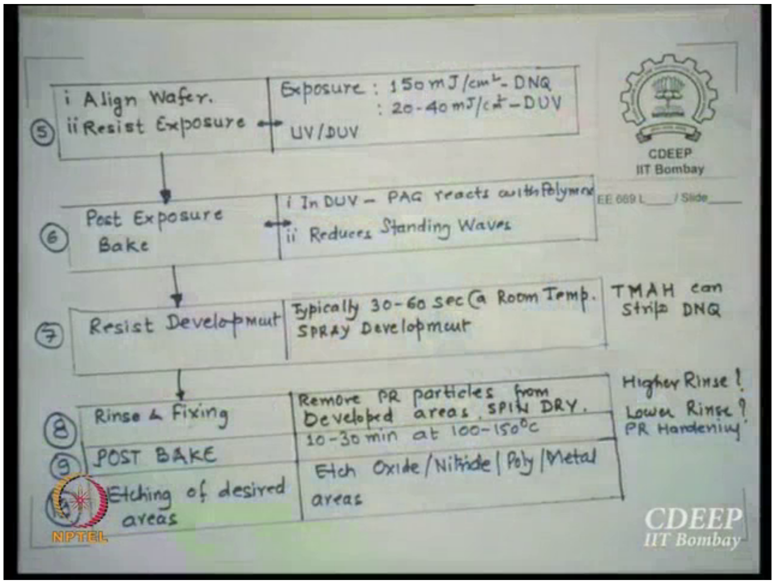

Okay so this is called alignment typically the ultraviolet light source energy or source intensity is 150 milli-joules per centimeter square DNQs and 20-40 milli-joules per centimeter square for DUVs so this then we expose once we align we expose so wherever dark portions are there on the mask light will not pass through wherever clear portion light will pass through depending on the resist, either it will get hardened clear areas or it will become softened if it is PPR it is softens, if it is NPR it is hardened okay. So this is important step this is essentially what the major step is in all the business. How to put patterns and this how many times I may have to do in a diode 4 times and for a CMOS it may be as I say 16 into 24 mask or even higher.

(())(22:34.4) CMOS process may require 32 mask and current Intel processor is requiring 38 mask. So it's some kind of FinFET based extreme controls side walls. So many things we're trying there so it require 36 mask or 38 mask. If you have wireless shape you may have further 4 mask may be because of the lengths you have to adjust for the RF lines. So you have even 14 process for a wire (())(23:06.7) receiver chip using a even standard inter-process. So these are all you must understand every masking step will create some error, is that clear? So the next masking should take care of that error itself otherwise error may start building and finally it may not get aligned anywhere is that clear. So there is a trick of so please remember this the way we do it is something like this to avoid some errors first time I create some patterns next time these two may be aligned and I may create new pattern on the next mask and to this when the fourth mask comes I will align first with them. And then align with the earlier ones so I keep creating a new pattern and old ones I keep aligning and that is how I can minimize my errors if possible.

And that's the trick which and so therefore you must remember every mask where to create the new pattern and where to keep the whole patterns matched. So this is all this is called test area designs and oh sorry frame designs and frame designs are very crucial at the end in chips okay. Designer may look into only circuit layout but if this is not there things may never work for him okay. So some experience of knowing technology problem is essential for designers. Of course which you're anyways experts the game in integrated circuit is something like this is wo bhed chaal hai, if this works so it was copied kisi aur ka kaam kiya hai mera bhi karega aisa karke copy karo okay. That's why all of us used to do it but sometimes you have to do novelty as well okay.

After the exposure is done the resist has to be, please remember you're shining light and your assumption was that light did not pass through the dark regions. Yes it may not pass through dark regions that’s true okay but if this is your window let's say you thought light did not go I mean did not pass through this but light can pass through edges this is diffractions and this is major worry in our case okay. So the actual pattern to patter which you are doing are not necessarily same, this is isotropic, it's a diffraction area and we will see that that is how the different alignment system do. How to minimize diffraction problems okay? So please remember that masking is not a very trivial issue it's a very important issue and the proof that your masking was good at the end chip works and if doesn’t work there is some way your masking has a problem or may be patterns created by circuit people may be a problem.

Now the purpose of this post exposure bake is typically this is also around 90 degree to 100 degree sometimes 120 degrees depending on the kind of resist you have if it is DUV then it is this yesterday say acid generator photo acid generator it reacts with polymer because you have released you have just bonded it, it reacted in polymer but it has to come back. So this catalytic reaction can now take place during this post bake system so acid is reused again. It also allows you to some to some kind of reducing the standing wave patterns because the reflection have because the density of resist becomes higher so reflections are minimal relatively smaller and therefore one says that post bake reduces standing waves and post bake also reduces release acids.

This is very important step if if this not properly baked when you develop resist from everywhere resist will go away okay. So this post bake for 30 minutes 100 to 120 degree some may require some resist may require 150 will be hard baked okay. So it depends different resist people, then after resist post bake is given we actually put the wafers either by spray development there is a gun which sprays the developer or in earlier times we used to actually dip the wafer itself in the bath. So you're number of racks wafers on a rack and the is a bath you just dip there okay either way. But nowadays it's mostly spray developments. It takes roughly 30-60 seconds uhh at room temperature for resist to develop. What do you mean by resist to develop? The soft portion of resist is solved dissolved and hard portion is not attacked. So here again if I do too long what can happen I will just show you I will come back to it. This is my resist area which is hard okay.

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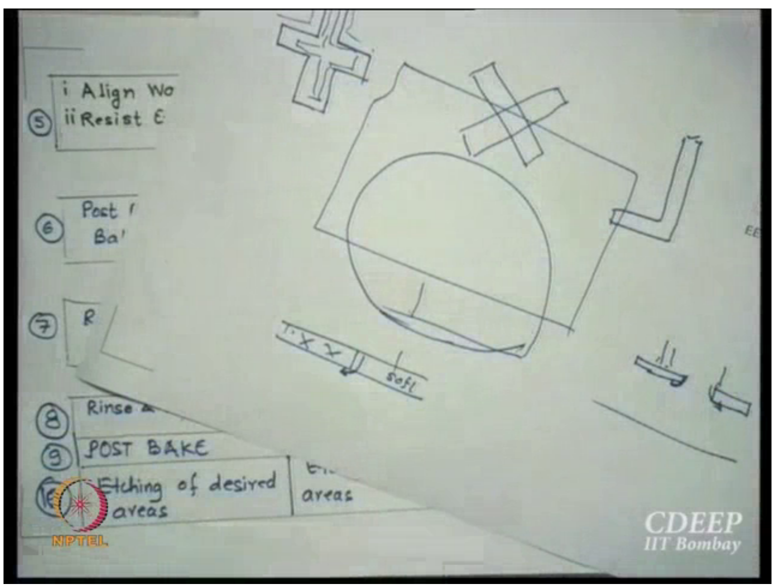

This is my soft, so this was getting etched or developed but part of the developer can get inside and actually lift the hardened resist. So it's too long development can also actually pull the actually hardened resist areas. And therefore 30 second is not that. So we figured out it enough that the hard portion remains there itself otherwise when below is something like this. The developer goes through below and it just takes away so in the plane wafer will come there is no resist anywhere okay so this tricks of time and temperature is very crucial and thickness how much you've put that decides the time and temperatures. Normally room temperature is good enough and therefore the lifts process is smaller. If it is higher temperature it will lift definitely if this technique is used in what we call shadow lithography but some other day. Lift if something going wrong I use it for my advantage.

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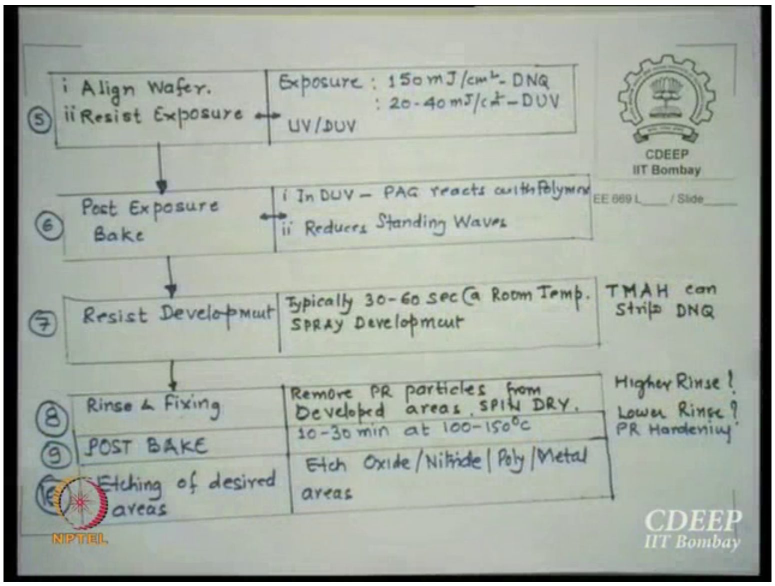

Then I rinse because there is a particles of resist sitting in the clear areas so I want to remove all because that's the clear area where everything has to be etched later. So I want to remove any resist particle sitting on the portion from where resist has been taken away or develop out. So this has to be rinsed. And also there is many a times it's not necessarily in water there are fixers like in the case of photography we used to put fixing in hypo. What is Hypo, have you heard of the work Hypo? You're right but why it was called Hypo?

Student: Rough and Tough?

Nahi Nahi aisa nahi hai, because initially people thought it is sodium hypo Sulphite so it was given a name hypo. But later on we figured out it's (())(30:33.3) Sulphide. The H it's more acidic actually then they figured out it's not hypo but that name stuck. So history hai, thodi photography suno padho kabhi time mile to. So anyways this and done after the PR resist particles are removed you clean it and then you develop the areas, spin dry it completely. Then actually you post bake it because I just now said there is possibility of edges slightly getting lifted okay so you want to stick them back okay. So that actual etching of oxide or nitride during that time HF may go in. HF is a very strong etchant and it just gets in.

It's as soon as it sees SIO2 below it will just walk-in so there the edge has to be very strict the edge is very important than the rest okay. If you see here the resist may actually enter faster here okay because there is a oxide below, here you only want this oxide to go but actually it will lift this. So all all that pattern you were trying will go away after development. Resist because you're in a solution which is dissolving resist. So it may also attach the etched part easily. The edge has maximum stressed areas. So the resist can penetrate in the particles there. So there you must harden it again so that resist is not that strong etchant there because they harden resist but HF or any other etchant for the the other surface may actually enter, because this… it not only remove this SIO2 it will also remove sideways also. So you're creating windows in nothing because there is no oxide anywhere so you find there is no pattern.

Nahi then stripping will be a problem nothing great otherwise happens. So it is typically the bakes are given for 10-30 minutes 100-150 degree centigrade, here also the earlier version I have put a question mark. If you rinse it for too long or if you rinse it for short time what happens, these are all issues you answer. So after the photo resist is hardened from the edges once again. Then you etch put this wafers into etching solutions for the layer which you want to etch like SIO2, nitride, metal whatever you are (())(33:09.9) which is your patterning that region should be now, that etchant should be put in the material.

So for example nitride essentially goes normally not in the normal Hf but you have to need sodium not sodium ammonium fluoride mixed with HF probably can etch with some drop of nitric acid probably can etch nitrides so there are different etchants for different materials at different concentrations. So one has to look at it which is relatively strong but not very strong that’s the way. So once the etching of areas desired which can be oxide nitride poly metal whatever it is and that area is then etched out and once you put everything in this all it has become messy so you must rinse and clean the wafer once again is that madam clear? Every time you go you rinse the wafer completely again go through a RCA clean okay.

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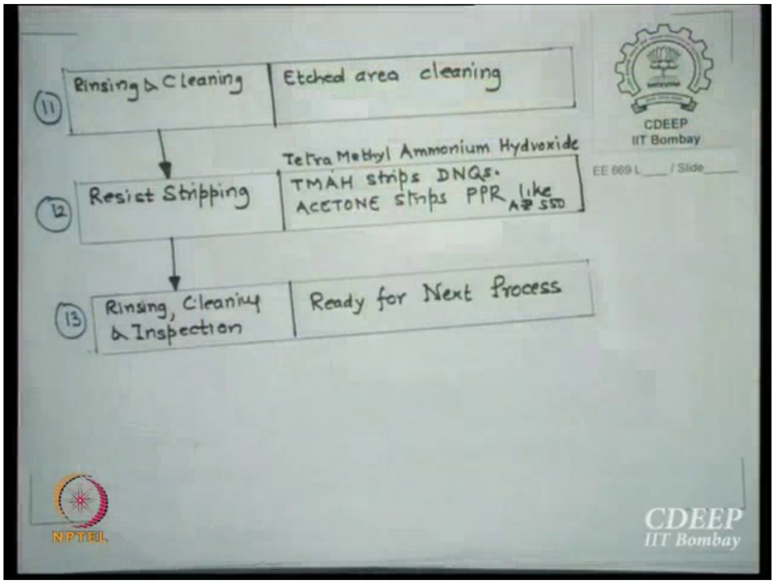

But before going to RCA right now you only rinse in water or xylene many times use this. And then remove the resist, how to remove the resist you have already said TMH at higher temperature itself can act like a stripper the best stripper is nitric acid. What is the nitric acid we do there is something called fuming nitric acid. What is fuming nitric acid? Anyone heard of this chemistry? Fuming Nitric Acid. Fuming so if you've seen the nitric acid constantly brown vapors keeps coming so why all others are not called fuming when some this. So if there is a copious fumes coming they can only occur if the concentration of etchant uhh nitric acid is 48 percent which is maximum possible. So if it is one 1M solution then the fumes coming from nitric which is the most concentrated nitric acid normally we 10 percent we use nitric acid.

Diluted by 10 percent 10 times water. But here we use 100 percent nitric acid which is actually 48 percent which is called maximum possible nitric acid concentration, you actually keep your wafers on the wafers itself, it keeps fumes. So wafers are held in the fumes. Resist is attacked very fast. However many people don’t like acids so they have some organics uhh which are called snoopies okay. They are also alkaline material and they also can strip the resist okay. So some acetone can be used for a PPR also okay. So once so earlier I during the etching or SIO2 nitride or any other I did not want resist to be removed I want that to stick because area wise I was etching.

But once I am over I want resist to go away because resist is a carbon which I don’t want to be around okay. So I must remove all of it. As much as possible and then give full RCA clean to the wafer except if it is metal don’t go through (())(36:25.3) okay otherwise metal will also go. But otherwise for oxides and nitrides go through full RCA clean once again and wafers are ready for next process, next diffusion next implant next whatever you're doing you do that and come back for the next lithography. Keep this keeps doing every time you do a process selective and lithography does process keep doing till all of the masks are consumed and the circuit is completely available on silicon dioxide. That's what lithography is all about.

Okay so we are now seeing the procedure of doing actual lithography. Yesterday I showed you diode also I showed you (())(37:07.9) as well and why I am doing it. Because at the end I am at least the Plummer’s 16 mask standard CMOS process I want to explain you later. So there at times you shouldn’t ask I will only say lithography done okay, you don’t say how. Abhi how dikha diya okay. So that is why I keep saying this you learn because there we will only use all the processes which we learn we know how they are done what is the physics behind what is the chemistry behind and one I know what is happening then I will say okay do this do this do this. Use this mask only I will show you mask.

Use this mask I get this pattern I etch this I get this 16 times I go through such lithography and I realize standard CMOS okay. That is what we have 16 mask process. So if I do FinFET it may be 26 24 26 mask uhh if you have only double gate may require 21 or 22 mask so different kind of structures if surround FinFET you're working it may be 30 odd mask. So there are structures which are different and require different masking’s. Now we come to so far we looked into resist and we looked into mass. Now we look into the exposure systems.

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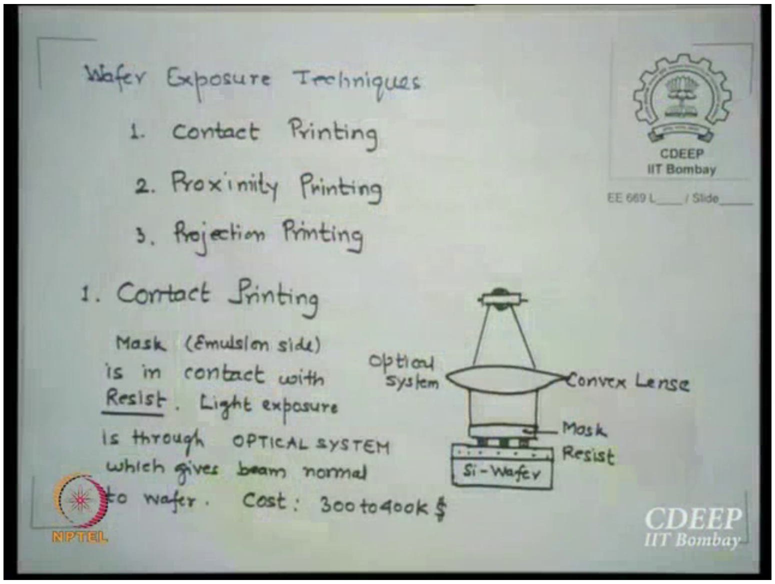

There are 3 exposures possibilities one of course is very popular just now I showed told you all the time was contact printing. Essentially contact printing means this is my optical system which focusses the source which is a point source shown here, ultra violet source which is a point source shown here ultra violet source and this comes in in such and angle that this becomes parallel the distance is adjusted so that if this is kept at the focal point the beams comes out in parallel. So I put it into beams are coming parallel to the direction and they pass through mask patterns the light passes through mask patterns and then attacks resist. What is the difference between other thing and this? Here the mask and wafers are touching, contact. This is contact printing, this is like photography. In photography so far negatives are actually connect touched with photo-paper and actually exposed so wherever black it becomes white and wherever white it becomes black that's the photograph.

So this is essentially contact printing, the word has taken from photography contact prints. You go ask na iske char contact print chahiye exactly. So the emulsion side is on the side of this resist so it touches and that is one problem I last time said that if every now and then if you touch the mask to a resist to a different wafers because the mask is costly so you keep doing and after some time the resist I mean the resist may attach to the mask or the mask emulsion may go. And therefore it cannot be used after few numbers of lithography's which cost goes to you. Then why this is so important yes it is. It's still used once a while since this does not have any great attachments actually you have a optical system which is sometimes multiple convex or convex lens for focusing properly or concave convex lens or planoconvex there are different kind of lenses which focuses the beams or by focus beams comes to the parallel okay. So adjust focal lens.

This is relatively cheaper, 300-400 thousand dollars which people think cheap okay. Total salary meri 30 saal me nahi hue hogi. Whenever I listen 1.76 lakh crore loss I just count the number I can't count, kya hota hai yeh number. Is that okay? So what is contact print, the mask is touching the wafer or your resist okay. Then you shine the light it will give you very good result we will show you later because whatever edge you're saying light possibly can go there easily okay. So it may be one of the best lithography possible but it has its own problems. Is it okay?

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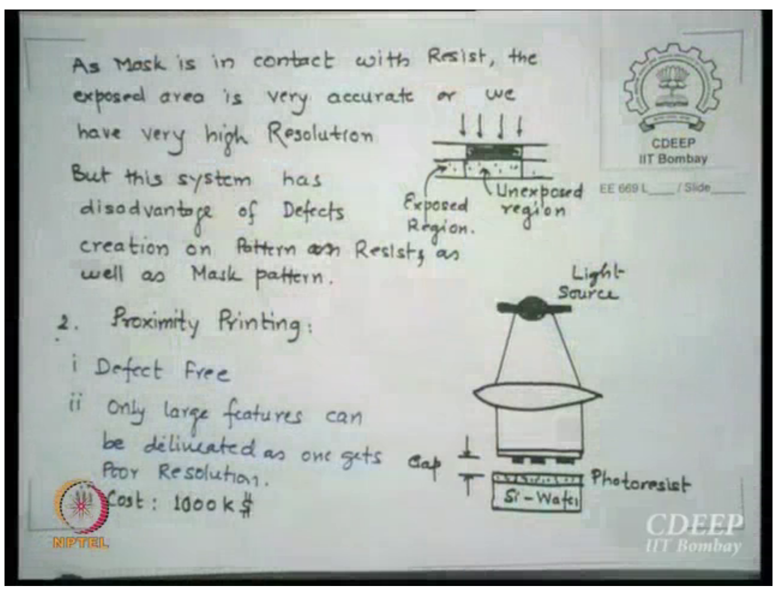

As mask is contact the resist is called you know you can see since this edges it very sharp image can be transferred. However the it's a very higher resolution resist I have processed actually. Sharp mostly sharp, however as I keep touching the mask will goes bad as well as wafer may go bad okay. Resist may be not straight all the time every area. In some areas resist thickness and mask thickness may not be touching so it may have another problem there. So contact printing is better only when the patterns are large then it is 100 percent transfers no errors. Smaller pattern don’t try contacts we will show you what we will do then. Second possibility is uhh separate the mask from wafer or resist by some small amount this is called gap distance, it may be 50 micron, it can be 25 microns it can be even 100 microns in some proximity aligners okay.

But 100 is normally not favored typically it is 25 to 50 microns separation between a mask plate and resist pair so this is gap between resist and mask plate. Again it only can do large features can be done through this kind of this. We will show you what numbers one get actual values. I have a relatively poor resolutions okay. And the cost is slightly more it is 1000 kilo 400 se ab 1000 ho gaya. That is 1 million dollars ka hai ek normal proximity printer. In our lab if you have MJB some old SUS kind of companies aligner, in those days it used to cost 4 lakh rupees now such mask aligners are not even available okay. But that time my patterns were 5 microns so it was perfect everything went well okay.

Student: (())(44:07.0)

Both places some resist may stick to the mask since its densities are different the refract index are different so the next time when you use it will create a problem. Secondly if I remove the resist for some part the exposure thickness will be varied. So it may spoil the image the present one and it will spoil the image for the second one okay. Is that clear? So avoid it if possible. Touching be avoided. The problem is if it exactly sits like this it doesn’t happens so much both are dried and everything but as I told you what will happen? It slides on that, that may be 2 micron slide but it will remove that much area from there at times okay. And that is where the problem starts.

But one can see if it is a large area thik hai yaar sab kuch uska wo bhi thik rehta hai, everything is fair so all are fine. Okay so this is called proximity aligners and these are very of course very few places we still use like you're using HEMT’s here you're number of transistors are 10 and 20 waha thik hai ye sab acha hai. We're looking for an IC which has million or billion transistors such processes will never be used okay. So why are there no, there are certain people who are working on different things and buying a huge cost of projection printer which we will show you which may be around 10 million to 20 million is worthless because you're not even doing 10 wafers in next one year. So putting so much money is waste.

So buy a cheaper one play some games look for results and then you're publishing so ye one bhi thik hai but in industry it's numbers. So there you need to have a proximity awareness. Okay so the last and the not the one which is mostly used uhh actually the proximity printers can do as much as 1 micron 1- 5 micron. But below 1 micron certainly is not possible accurately I mean you put it something will happen and there are games of retrieving it as well may be some other day. Then you know something called necessity is mother of inventions, in my time many things were not available but we still did it.

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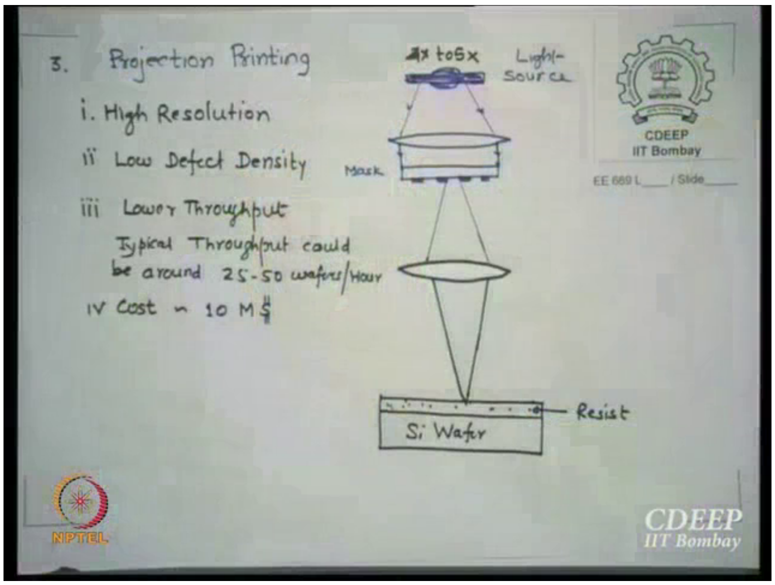

Like when I first time did my Ph.D. during that time there was no matrix inversion problem in any of the libraries of computers which we had. We have 16 21st IBM computers. So I wrote my matrix inversion myself okay. I learnt a lot how to write a program for such a large arrays. The problem came that the memories of those used to be 32 K usable memories. 32K sun ke kitna bura lagta hai Mega Giga aur ye K. So no arrays can be put there. So you think ek scan karo usko release kardo. Jab phirse use karna hai phirse uski value lelo. So you keep doing that job N times but don’t store ab fir bhi hum ne kiya na solve kiya na. So it is not that we couldn’t solve a matrix the system didn’t allowed us. So when you think that can't be done probably your engine fails. So don’t think that earlier times we could never do anything we still could do better as good in those days possible.

The cost money was very crucial for us, uhh a proximity aligners has a uhh typically image reduction system which is 4-5X initial pattern which can be reduced to 1X it has 2 optical areas one is essentially the collimator and then there is a mask and then through another optical collimating system it is focused on the silicon wafer okay. So mask is far away from the wafe actually. Mask is far away from the wafer it's a very fantastic okay. Seems to be otherwise but it is very high resolution process and creates very very low density because it doesn't touch anything anywhere okay. The only problem it gives is it's number of wafers per hour are fewer contact prints are fastest. The process is in line, if you see a conveyer belt there are exposure systems the wafer contact, the wafer next and it keeps moving okay. This is not possible in this project aligners actually they do some 4 or 5 at a time but that's there so this is throughput could be as low as 25 wafers in an hour whereas contact printers can give you 2000 wafers in a day. So that's the cost, but at the cost is resolutions.

This machine is typically 10 million and this price is of 2002 so now with all inflation and everything the why the cost will not be lower because not that many foundries are buying them very few people are buying it. So even more cost becomes more and more is the (())(50:01.7) the next person has to pay more money because he has invested so he will charge second banda even more. So that's the game, so actually prices never go down in case of any of this semi-conductor system, because more and more companies are folding so those who are sticking has to pay more. I have invested okay so this is a interesting projection printing now all is fine if the dimensions of the mask patterns which you're looking is small uhh larger up to 0.13 microns all everything looks so fine. One can say something which is now I will come back to and which is most important part for our lithography. Uhh some optics because everywhere we're showing you optics so what is the optics playing part in this whole game okay. This figure is available in this. These are the features, high resolutions, low defect density low throughput higher cost okay.

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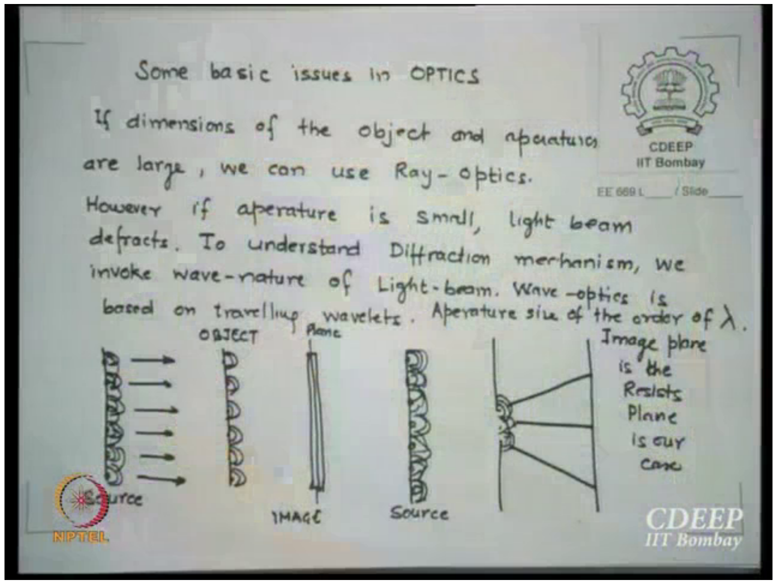

Uhh now these issues are very crucial for us if the dimensions of the object and apertures are large we can always use what is called as geometric optics or the ray nature of light it's a ray travels okay. However if the aperture is small and the light then at the edges of the apertures light being diffracts and this diffraction mechanism can be explained by saying that light beam has wave nature okay. It is not the photon beam but it is, it has a wave kind of structure. What is this law called, De Broglie's Law? Every matter can be thought up as waves okay. So what is the why de Broglie’s was famous. Firstly he was crown that means he was one of the kings family in France those days. Actually there were 7 de Broglie’s 3 won the noble price okay. Of course since they were crowns so no one could refuse them, of course they did great the de Broglie’s PHD thesis that the waves are matter can be explained as waves. Actually has only one line in his PHD thesis and he was awarded doctorate. Abhi aisa nahi ho sakta hai, abhi hum bolenge 130 panne chahiye, literature survey 30 panna chahiye, conclusion chahiye. Ek line me usko PHD mil gayi.

Okay so we need we have to leave geometry optics and we actually go to wave optics just for those of course this is also give in the book just for that, all the point sources actually emnets the EM waves and this is the direction of propagation. So it's electric vector and this vector is normal to the propagation. EH and then third sides is the propagation. So thoda EM waves padho theory is same wave theory. So if if the propagation is this these overlapping waves around are called wavelets or final wavelets okay. These trial and actually hit the object okay and depending if they are also small objects there if they also form similar wavelets around those object points. And this is my image and since if they are very close to each other there is a overlapping wavelets patterns so you actually see a full pattern.

So whole of the object is seen as one unit if this point are very close to each other and there is overlapping again functions okay. This is wave theory. So if that happens you see this image, however if this object is not the kind shown here but has a slit which has an aperture so this is small aperture. Then when the wavelets travel here as in this the center ones of course may straight because they are unhindered but the edges do get some kind of age effects okay and that essentially word used is diffraction okay. So now the wavelets travel upward. This wavelet travels downwards so the image has right now because of the aperture this object is only now restricted to this and is not same as what you thought okay.

So diffraction pattern actually modifies your object image of the object and that happens because of the wavelets going from aperture to the image plane. What is image plane in our case in this resist there the light is actually coming so that's the resist plane okay what is object the mask the mask which you have dark and white portion is the plane these are slits for us. 2 separated dark portion by a clear portion acts like a apertures so light is passing through a mask through the apertures if they are close, why will they close because as your nodes going to 10 nanometers down you are looking for smaller and smaller gaps, therefore smaller apertures and smaller apertures will lead to diffractions okay and this is provable by (())(56:03.4) laws okay yes.

Student: (())(56:06.8)

Oh yeah the typical source if it is distributed if it is a point source I may show you something but okay I will show you point source system. This is only a source which is like a UV light I have a lamp which shines everywhere okay. So wherever I shine, but in real life I may focus that okay and here is what you've asked okay. That was only to show you diffract why it diffracts okay that is the wave theory okay. This is our system this is our projection printing or projection mask aligner.

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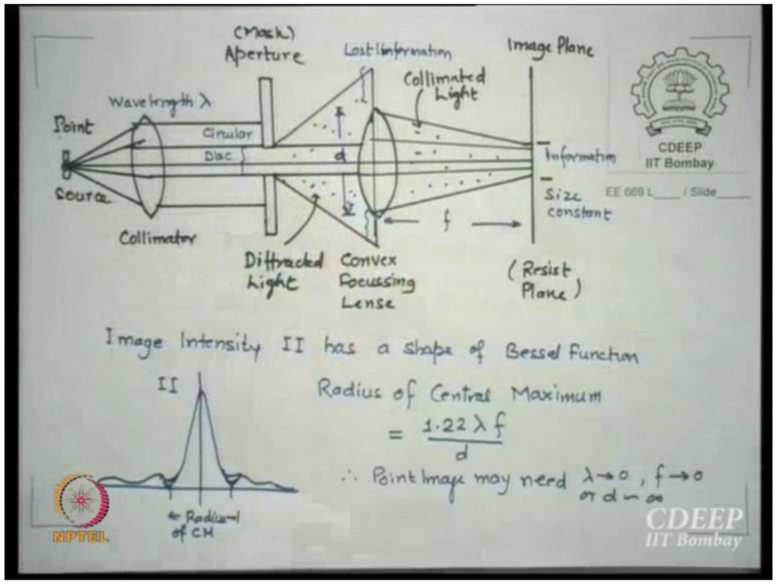

You have a point source and the first thing it passes through is collimator okay, which is essentially a convex lens. The distance is so adjusted focal lengths so that it becomes parallel beams. Here is your mask which is having a slots which is apertures is that okay that portion and clear portion again black portion so open space in between clear areas these are like a disk circular disk okay. Now this aperture as I just now said whenever the beams come here the center ones may straight go but the edge ones may diffract. Now the problem is I may refocus them for the image okay the problem starts something like this depending on the actual apertures part of the beam may actually be outside the next focusing system. So this essentially is the last information, information was coming from the source to this but it has gone outside the range of the next focusing system.

So this much information typically one can say it's a high frequency information is lost and only what is the information available? Which is impinging on the lens okay? So now this of course I should have shown this also, so once you see a lens system it focuses down again okay. Now this lens has a what is we call has diameter how the lenses are made. Lenses are made out of a sphere of any material, glass or anything and then they are cut into some shapes okay so curves are created out of that because you know it's spherical it gives you some kind of convex or concave shapes okay. So whatever is the this ball you use and you cut that diameter of that sphere is essentially the diameter of the lens okay. So this is a dia of the lens okay. Now this is the distance F focal points and you see because of the diffraction all of them are not focusing at the midpoint okay and there is an information which is slightly in a spaced area and of course you can now see it roughly reflects whatever is your aperture it comes down by adjusting F and D while you may get almost similar pattern aperture pattern seen at the image plate. Is that clear?

Whatever gain we are looking for I want an airy image should be same as mask image. So I can create by choice of proper lens system which will create this size is roughly same as this size and that is what and the mask are this is mask so mask is not touching to the wafer or resist and still able to project the image which you actually wants to okay. So this is essentially called projection alignment system okay.

Student: (())(60:39.1)

That's last what is last cannot be gate. Yeah there is a lack of some information but as I said normally you can see from here this intensity pattern at higher frequency it's much lower intensity. So it's not that you really lose all of it. It's 90 percent is covered through lenses. If you really want increase the dia and (())(61:06.2) the diameter you have okay. Itna bada lens lagaoge to sab kuch milega but then there is a money involved. It has been found that the image intensity II at this plane is essentially forms the solution of wave equation is in vessel form vessel function form and this is how the vessel function looks. These are called first minimums. This is the maximum, these are called first minimums here and here this is the intensity patter along X axis. So one can see this first minimum or this is called center of maximum.
By wavelets theory one can see that this essentially is 1.22 lambda f by The this is derived from vessel function through relays formula okay. So if you see the radius that is the maximum available intensity only at the maximum uhh at this point then this radius is essentially this minima to minima how sharp it is, what are we really looking for all intensity sharply available maximum intensity. So if this is small it is even better okay so we find the radius of center maximum is 1.22 lambda f by d where d is the diameter of the lens F is the focal length, lambda is the wavelength of the light used and okay. Now if you really want the image to be point image very sharp point image to be created that means this should be 0 you know smaller the radius sharper the image so if I want a very sharp image what should I do? Lambda bhi 0 focal length bhi 0 and the diameter of the length is infinity.

Yeah it's the ideal system which never can be done so obviously the radius cannot be point image it will always be slightly larger than that because lambda is finite, focal length is finite and the dia is also finite, beam which actually I can create okay. This is image available to you energy available to you for exposures. So II essentially is decided by how much is F how much is D and what is the wavelength of the light used and it gives a bezel functions okay. I read it further if not I will give you a paper where more details are available. Now this idea point image cannot be created so how best is what I have shown you keep finite every and image will be slightly diffracted all that I am now seeing if this can be almost equal to the aperture I have solved my problems okay.

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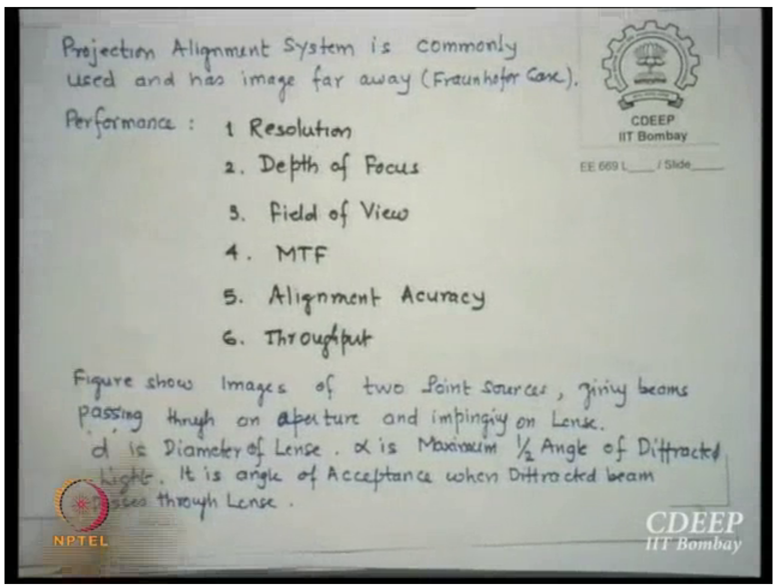

What are the advantages acha there are also two uhh diffraction patterns or diffraction law one is called Fresnel Law. If the image plane is very close to the lens system that it is follows what is called Fresnel laws and if it is a far field you are far away your image plane is of infinite or very far then the image transfers are essentially due to the effect Fraunhofer images okay. Optics padhna hai to kisi aur ek din pura optics okay. So since in projection alignment the distance of image to this is little larger than proximity is the minimum contact is 0 okay, here the image plane is away so we say is Fraunhofer case, it has a resolution performance as following thigs we look for any mask printing. How good is the resolution? Then the word that we want to explain quickly is Depth of Focus.

Iska example batayenge. Field of U MTF alignment accuracy and throughput these are the features we're looking for lithography expertise okay. Of course this image now I will show you what is each term I am talking about. The word Depth of focus is something like this, why we're interested in the word depth of focus anyone?

Student: (())(65:33.0)

No it's not true I mean you're saying is not wrong but the problem is essentially this, the resist on a wafer does not have uniform thickness is that correct so some image is away from the resist some image is closer to the resist but at the image plane both should come same place okay. Let's look for something more about quickly.

We have an image we have a figure which I am going to show you uhh there are two problem one is of course the depth of focus other is two point sources, how do they transform there, on to lens system. Ek object ka point uske neeche hai to ye example hai uska thoda definition ke liye wo chahiye mujhe. I repeat this is given in Plummer's book okay. Not exactly in the order not exactly the way I explained and not exactly the way I write but in general whatever I am teaching for last 2-3 days is somewhere or the other or may be identical in some cases because I have read it. Since I have read it some of my words may be coming from them okay. Okay so just to just you D is the diameter of the lens and we're interested to see uhh what is word we're going to see now is the work numerical aperture. Ek lens ke system ke sath ye bohut common word ata hai.

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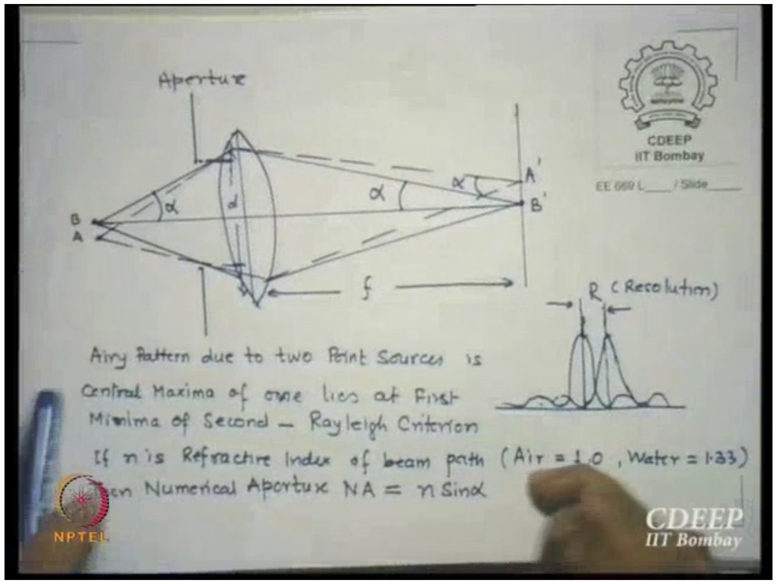

So let's say you have two point sources at A and B, passing through a lens system and they're said this is the focal length so we what we see is let's say you start with B and it appears are B dash here, so it goes through a angle alpha then it focuses down to B. The maximum angle up to which the point source can be accepted by the lens is called numerical aperture is that clear. The maximum angle or maximum this hypotenuse value to this value ratio. Distance to this, this is sin theta okay how much is the sin alpha essentially gives you numerical aperture. Kitna zyada ho sakta hai zyada se zyada 90 karenge to without bohut bada ho jayenga, lens itna bada ho jayenga. 60 degree, 45 degree is what possibly is easily to attend the alpha angles and this alpha is also half so actually it is half alpha in fact I should I have shown you alpha but many books you actually this as total alpha okay. This and this because this is D but I have done slightly different as he uses d by 2. If you use D then the alpha should because used as 2 alpha but since he uses uhh d by 2 so it's only this defined as alpha so some books if you see old ones or some paper they show you this alpha, this is exactly what is really aperture.

How much is the total beam edges to edges lens can see if that angle is called numerical aperture. But definition mean there we say okay use instead of d use d by 2 so it is similar and therefore needed not worry the number may come same okay. So this if you have two such point sources (())(69:31.4) refracted this it has some small triangles, though both will pass through and angle alpha even this angle is also alpha okay. I should have shown you the center line also so this also is alpha. So now what we're seeing that two resolve what is our object there are 2 point that is 2 areas of the mask I want separate how 2 lines I can separate? That is my resolution okay that is my resolution. So these are the 2 such point sources and I say I want to see how whether they resolve at the other end.

Now for each of them what is the pattern, intensity pattern would be Bessel function. So this is one Bessel function for A and this is another Bessel function for B. What Reyleigh say is and that's most important it's called Reyliegh's criteria, the resolution between these 2 maxima which is the R value it gives will be such that the center maxima is separated by R if the first minima of the one matches with maxima of the second, if that happens you have the resolutions. If anything otherwise they will come closer and then you will not be able to resolve. So one of the minimas so match with the maxima minima of first maxima should match with uhh minima should match with the maxima of the first, is that clear, this is Reylieghs criteria okay.

We also should realize that this right now we assume beams are in air. Air has a refract index of 1 let us say I put this system in water. Water has a refract index of 1.3 and let's put some emersion oil is which is what the new technology is, it has a 1.4-1.5 refract indexes okay. 1.4 is most likely but there are more oils have come which has 1.48 or 1.5 kind of refract index. So the numerical aperture is defined as the refract index multiplied by sign alpha and sin alpha is defined as in physics what we're saying the maximum amount of angle through which the lens can receive from any source is this numerical aperture is that clear? Kitna aa sakta hai that's it's aperture okay. So is that clear definition and this R you want to find R now. Why all this math's? That I want to relate numerical aperture with the D as well as R, R is my ultimate I want to separate two line. How closer I can come? What is lithography expertise? Can I separate 10 nanometer lines? Can I separate 50 nanometer lines? So I want to see what is resolution I get from this so called projection alignment system okay. And no better system you know so this is the system you will use okay?

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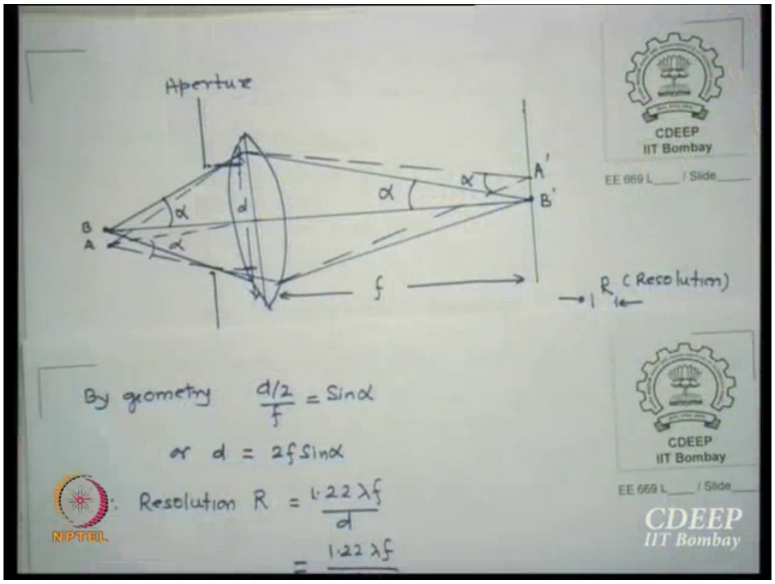

Now if you look at the geometry may be is okay, this is sin alpha. So d by 2 by f you look at this side, this is f this is d by 2 this is alpha. So d by 2 by f is sin alpha. Is that okay, perpendicular divided by this is sin. So d by 2 divided by f is sin alpha. So d is 2 sin alpha, however in this assumption was the air was the where wavelets were going in the air if you now substitute r what was r we figured out from the airy pattern, 1.22 lambda f by d. That's the function we go, is that okay. If we got this function replace d here by 2f sin lambda and if you improve the refract index with this then it will be uhh instead of f it will be nf sin alpha so 0.61 lambda n sin alpha. But n sin alpha is numerical aperture so its 0.61 lambda by numerical aperture that's the resolution is that clear? So how to improve the resolution? Resolution means r should be smaller I want to resolve as close as possible okay so what should I increase? Ne so I must somehow increase the NE so I must increase refract index, so that is why immersion word has come, I can change the refract index okay.

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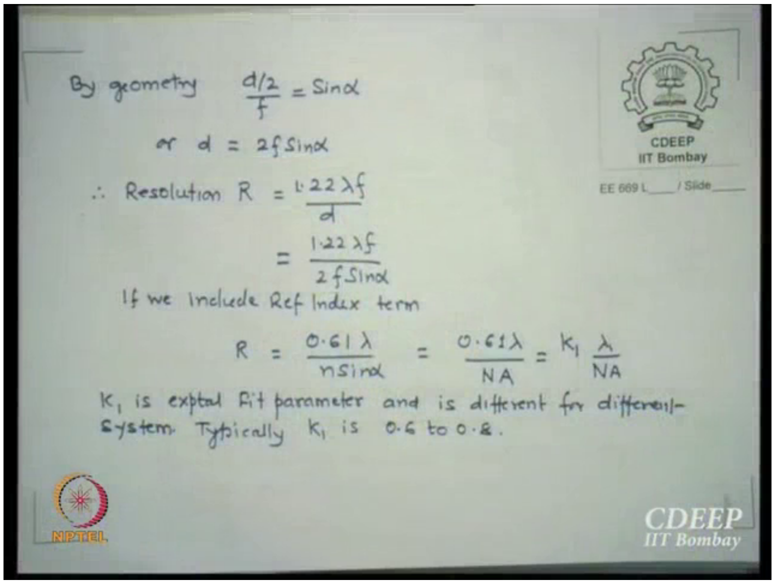

If I change your alpha which is possible but then the lens dia will correspondingly increase, so I can't increase alpha too much okay. The other possibility is lambda be smaller that's what we're trying we're actually reducing the wavelength of the light from g line to I line to 193 okay. 465 to 268 to 193 and fluoride is calcium fluoride is 157 okay. So one of the why we reducing is this now clear why wavelengths were going down because I want to improve r so if I improve r improve means smaller immersions lithography. This 0.61 is true for certain values so we normally name it as K1 it has also depending on the machine used and typical value is around 0.6 to 0.8. Now another term simultaneously appears okay. So what I am now, what is the second parameter, first I said how much you can separate, the second one what I was saying (()) (76:19.0) depth of focus because you know my resist is no uniform thickness everywhere so I want to see a depth of focus. Is that okay, this is also given in Plummer's book. Wo ek pura paragraph likhne ke baad ek expression likhta hai me direct apko mooh se bol raha hai aur expression likh raha hai, itna hi farak hai.

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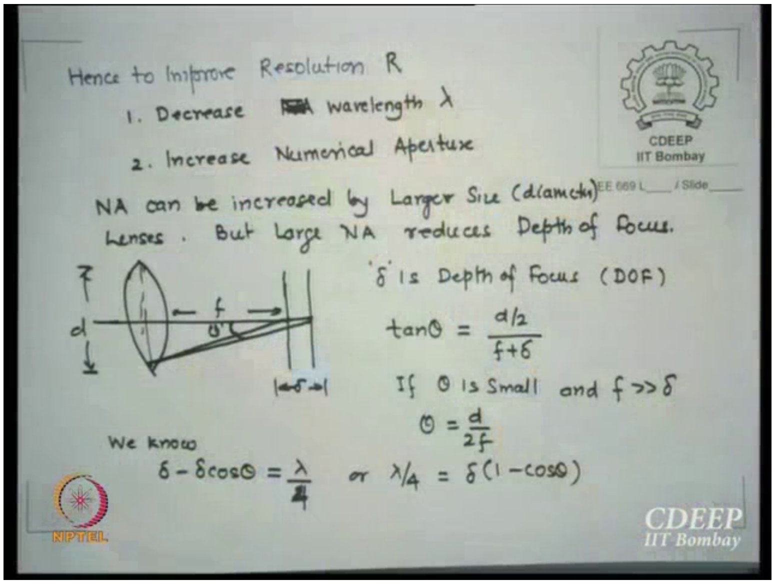

Okay this is what I earlier said. Now if increase na and my worries are now I am proving that the depth of focus will go down, let's see what happens. Uhh depth of focus is you had a lens system and this is the delta is called depth of focus. Two planes up to which image should be possible okay. Why it should be like this because I want to see if the thickness of resist is here or here image should be at same point okay. So I call that as depth of focus for the lens okay. So if I this angle is cheta let's say I am sorry this is the external line not this. Don't use this, so this goes to this. This is delta, this is the focal length. So we see tan theta and this is d by 2, d by 2 by f plus lambda is tan theta is that okay. This is geometry, d by 2 by f is f plus delta is tan theta and if theta is smaller that is f is long enough then f is much larger than delta which it will be. Depth of focus is much smaller compared to focal lengths okay.

Student: (())(78:07.3)

Same method, microscope actually it goes on same principle, depth of focus. You adjust it okay. So theta tan theta is theta, therefore theta is d upon 2f if f is much larger than delta. Then theta is roughly d upon 2f okay, is that point clear. I did tan theta is this upon perpendicular (())(78:36.4) divided by base. Base if f plus delta sorry f plus delta. d by 2 upon f plus delta is d by 2, now divide this is tan theta if theta is smaller tan theta is theta essentially how it is written, tan theta is equal to sin theta if theta is smaller and sin theta is theta if theta is smaller. You can keep series of expansions. So now what is the difference between delta minus delta cos theta. What is delta cos theta? Remember this is delta so I am looking for this okay. So delta minus delta cos theta by optics law it must be proportional to lambda by 4 okay. Please remember what I am talking, this is my delta and this is delta, yeah this is delta divided by minus delta cos theta.

Student: (())(79:41.6)

Arre baba ye jo theta hai wo yaha par hi hai ye theta hi hai.

Student: (())(79:49.4)

Ye delta hai, aur ye kitna hoga.

Student: (())(79:55.6)

Ha ha sorry sorry I am sorry I am only saying this. So the separation between these two delta cost theta minus delta is essentially always lambda by 4 by optics okay. So lambda (())(80:09.7) is delta minus 1 cos theta and if I expand everything again this you can this value in the way I have done but may be given.

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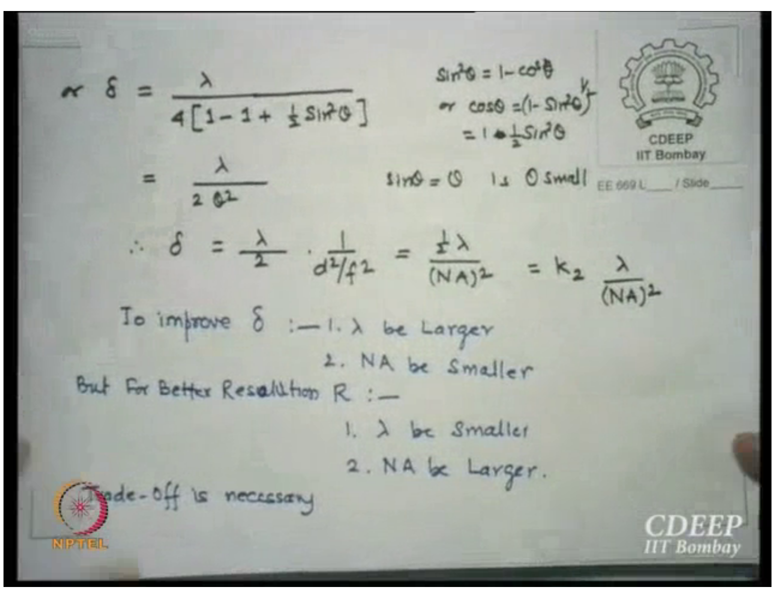

So I can prove that I can write sin square theta is 1 minus cos square theta cos theta is under-root of 1 minus sin square theta. By (())(80:27.7) expansion is sin theta is smaller so it is half sin square theta. After all this delta is lambda upon 2 theta square okay, simple math's. Or delta is lambda by 2 and theta square is 1 upon d square by f square theta just now I found. So theta is d by f so d square by fs square. So this half lambda but d by f is also numerical apertures fine d by f so it is numerical aperture square and this half is normally is a machine dependent many times so it is given a name K2 which is 0.5 or close to that. So if I want larger depth of focus what should I do from this expression? I want even if there is a variation in the resist thickness I want focusing be done so I want depth of focus be larger what should I do from the expression? Lambda be larger and Na be smaller what was the condition for resolution?

Lambda be smaller and NA be larger and now were asking just the opposite okay. So which means some trade-off is essential. Either you will get greater resolutions or greater depth of focus both cannot be simultaneously achieved is that clear? So you cannot say I will have a variation in resist of 0.5 microns and will also have a resolution of say 0.10 nanometers that's not possible in any case, is that clear to you? So either you can adjust higher depth of focus systems if you're lithography is so bad you look for delta larger you will have a worst resolution is that clear or vice-versa this is what our ultimate is.

Student: (())(82:39.1)

Yeah but that is pixel based if it is CCD based otherwise okay last few just a minute I know you're tired. The problem there are few more problem which you can read in this, one of them is called MTF. I will very quickly pick 2 slides may be enough for you.

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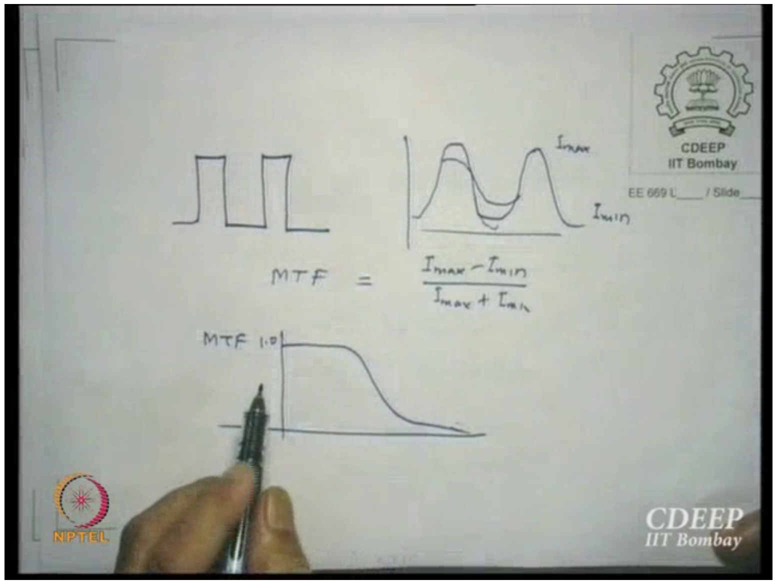

Typical intensity pattern for the 2 areas may be like this. But in real life when it goes through a mask in this projection printing actually you get, something like this. This is called I minimum and this is called I maximum. And we define it on modulation transfer function as I max. minus I min. divided by I max. minus I min. and if I plot MTF vs dimensions this is 1.0.

Student: (())(83:54.5)

Oh sorry, 1 ho jayega fir always one ho jayega. What is it trying to show you? That if you're dimensions are larger this is I max. to I min. This is one can see what I am plotting, for a larger dimensions separations that is larger dimensions of the patterns MTF can always be achieved 1, I min. can go as low as 0 okay. Image can all the way down I mean light can go all the way down. However if it is very close and there is diffraction going on this I min. may not be 0 but I minimum will be higher. Since the thickness of resist is higher, I max. may not be this so it may be something like this, in which case MTF will become smaller okay. Which means that means the actual intensities are not passing as I reduce dimensions is that clear. So as I scale down from the technology one of the problem I see is that the actual available intensity for exposure starts reducing is that clear? Because of MTF factors the last but not the least some figures I may show you, the rest you can read from the book.

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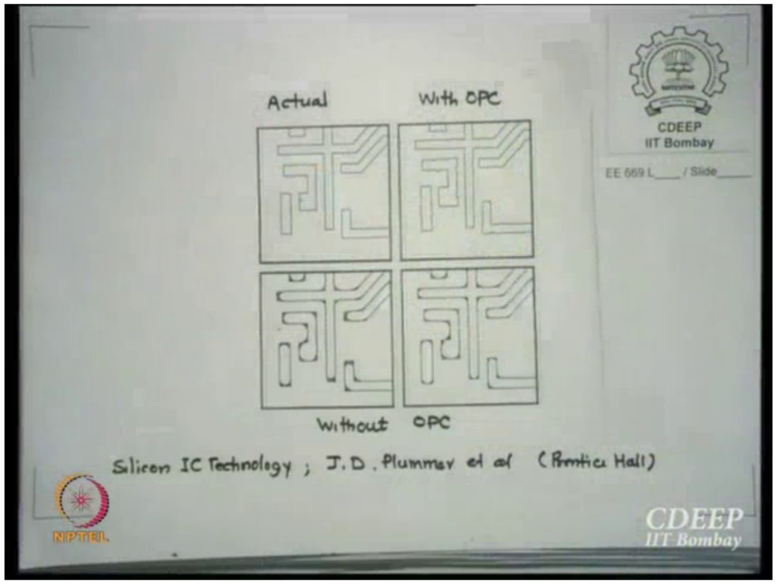

Yesterday I did say uhh there is something called optical proximity corrections, let's say this is my actually image and I do optical proximity corrections and I get this image. But when I print if use this without OPC I get this mashed up image and if I use OPC corrected mask then I get little better than this, what is OPC? It's a software program which actually do image processing. It's is a software program which does image processing, it sees that given at this if I transfer the image on a resist what do I get? If I modify that initial image itself mask image then I may get little different outputs, this is called optical proximity corrections these are possible okay. Is that clear? So via lithography prior to exposures prior to mask you have to actually do some kind of proximity corrections.

So you create the actual mask the mask which you really want from the layout designer you actually modify it okay. This only can be done if you roughly know from image processing how does it transfer in real life and then start correcting so that better image is then transferred on the resist, this is called OPC techniques.

Student: (())(87:03.9)

Yes it's preparation on mask.

Student: (())(87:08.7)

If you have a laser you can remove some part of the resist, it's called strolls. But that is not, it's very costly system okay. Last sheet on this.

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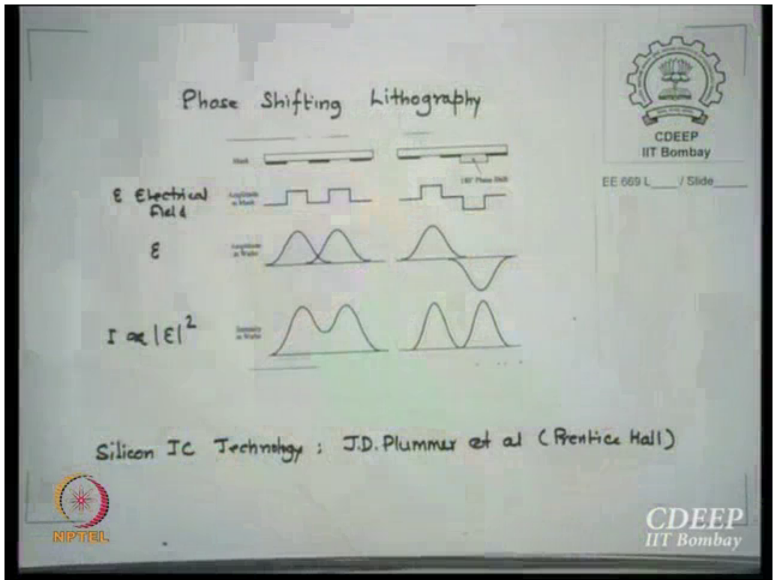

There is something very interesting happen since it's a wavelet on a smaller dimension this is your mask and this is the electric field or amplitude of the light as per the mask okay. This electric field at the mask and electric field at the wafers and wafers will be airy patterns so this some kind of this pattern I get and I know the intensity is proportion to electric field square so actually I get this. So what is the resolution between these two, the merging has happened okay. So while I do it when I reduce dimension, the second part of this I have some material I put which gives 180 degree out of phase this is called waiting optics se liya gaya hai. We actually core some material on the other side which gives you 180 degree out of phase so the electric field at the mask is something like this, electric field at the mask is something like this, electric field means electric field vector for EM waves. Don’t think I have biased it okay.

So the E for this and this is this. But since it is a square 2 separated intensity patterns can be get. This is called phase shifting lithography. So if a smaller dimension comes do phase shifting do OPC, do projection alignments, adjust numerical apertures, use immersion lithography and you will be able to get far better patterns on wafer, is that clear? Ek photo dikhata hu aap padho mat. Just a minute, ye miller book me hai.

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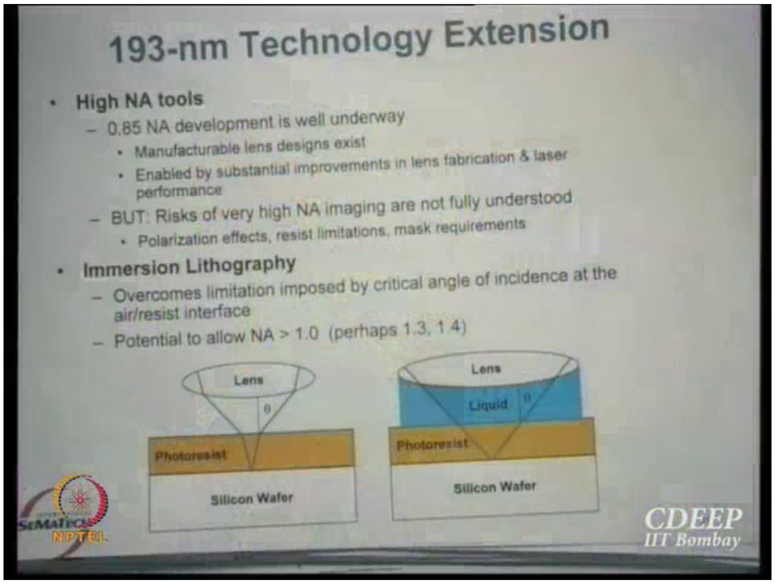

How to improve numerical aperture, that's what I have said. This angle was the limiting factor, so I have put a liquid somewhere here okay. This is called immersion phase okay. And generally best liquid is what? Water, so most immersion technologies use water as their liquids okay. Iske karan theta badaya ja sakta hai and therefore numerical aperture badaya ja sakta hai. So this is one technology of improving numerical aperture. Before we quit this is the last item of this show.

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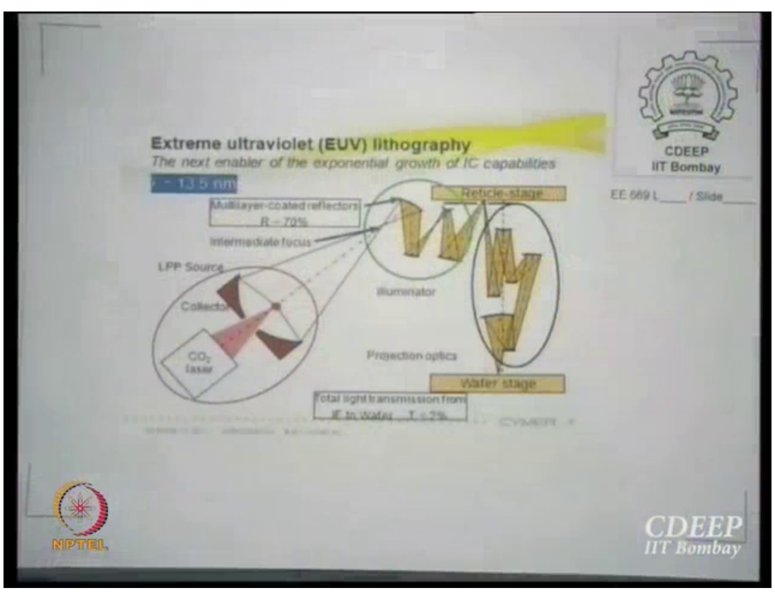

This is what we're looking for now this is called extreme ultra violet lithography technique. You have a carbon-dioxide laser through a lot of collecting system and focusing system. We pass the beam this is a plasma chamber so we actually convert this gas laser beam and put it into plasma. And this plasma beams actually are observed even here but we want larger intensity so I don’t want any observation but 30 percent will still absorb here then I have mirrors, I don’t use lenses lenses will absorb much more so I use number of mirrors. Even mirrors absorb some energies and you deflect the beam and put it on the wafer okay. This deflecting system using mirrors which are controlled by motors are very costly and very accurate, you want a order of nanometers movements it's very difficult.

The lambda which you get from this is 13.5 nanometers. Please remember the numbers, if I use extreme lithograph the lambda which I can get is 193, 158 and what number now I am talking 13 nanometers so 5 nanometer technology is doable if I can achieve extreme UV system okay, it's very expensive right now it's in billion dollar system going on and no one has full success. However this is what the ultimate will be in the lithography. You will have a deep extreme UV system very costly system may have a smaller throughputs but may give you features of as low as less than 5 nanometers because it's wavelength is just 13 nanometers. This is something what ultimately what every company is dreaming. So that 0 dimension FETs could be created okay at the end of the day. Thank you for today for patience. So next Wednesday we will start with implants okay.