Fabrication of Silicon VLSI Circuits
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Lecture No. 17
Lithography.

So let's talk about the lithography, continued what we did last time that is Wednesday, one of the thing which I was talking last time was something about lithography itself and I say firstly we will look into photo-lithography. The simple reason is even for 16 nanometer or 22 nanometer technology nodes photo lithography is still used some different forms but yes. One is expecting may be by 14 or 9 or 11 or 7 nanometer may be we will have extended UVs or extreme UVs. May I will give a reference of extreme UV research from Intel and also from 2 other people. You can have a look at them so that is fine. So let's look for mask we we're telling that we transfer the image and on the silicon.

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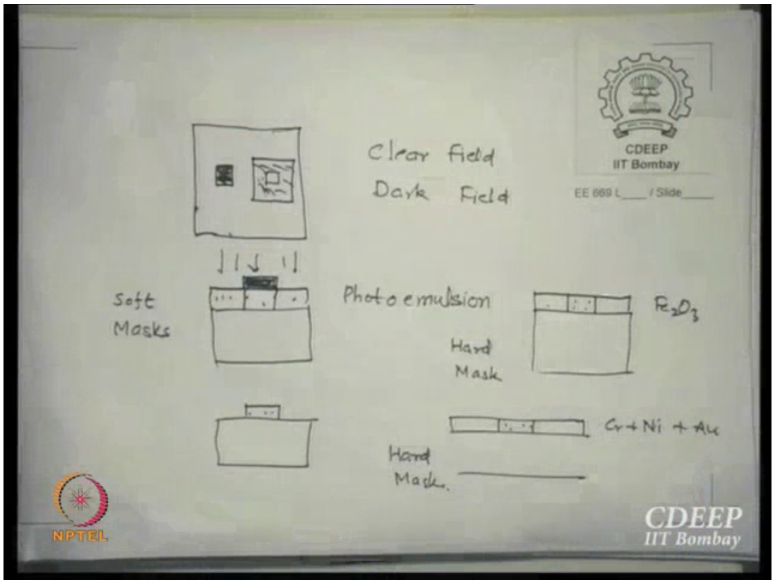

So what is the mask, mask is some kind of a glass plate. Even now it is a glass plate okay. This glass plate is normally quartz glass plate and sometimes it has some impurities added so that its transparency is improves though quartz itself is very good transparent material. Now on this there can be a pattern, there are 2 kinds of pattern possible. One in which this is a dark portion inside the glass which is transparent. Alternatively I may have a dark portion and I may have clear region in that okay. So window could be clear or window could be dark. So either of the way mask can be created. If the total area of larger area on a mask is dark the mask is called dark field. Field is the overall area, so if the overall area is larger area where the patterns are not there that is darker then we say it is dark field.

On the contrary there is a very small dark area, the rest is clear the mask is called clear field. So there are 2 kinds of mask used, Clear field and Dark Field. Now this dark uhh photo plates or the mask plates are created earlier on the even for photography on film polyester films. So could have, the transferred this kind of image one method is that you create a directly from the optical light as other day showed on shine on glass plate which is coated with emulsion. Let's say this is your glass plate and this is your emulsion. Now this emulsion is normally photo emulsion which means, it absorbs light, it absorbs light. Its photo emulsion means, it absorbs light, photo emulsion.

In the olden days for photography the material used was silver halide or silver chlorides or silver bromides and they were actually suspended in a gelatine solution which is called colloidal it's not mixing it's called colloidal. So earlier the films used to be coated by colloidal solution of silver halides in gelatine and that is very interesting thing that when the such films where made earlier some film showed very good resolutions and actual photography and they actually try to find out what gelatine have that they allow better photography. So it happens to be, if they happen to know that this gelatine was had that it allowed better photography. So it happens to be if they happen to know that this gelatine was purchased from Holland where of course probably you may be knowing the dairy products are very popular from Holland. Those cows have eaten mustards, so they thought that if the mustard eating cows give better gelatine so they started adding what is called silver sulphide with some mustard decorations, thinking that it may approve, it did not.

So what kind of science one thinks you know you're very scientific temple we don’t believe no people believe in what they see and start thinking over in a different way. So mustard was ordered just to say it may better have better resolution, it never had… must have nothing to do with it. It incidentally happen those cows ate mustards. So this gelatine is essentially earlier used to be taken from animals. Now gelatine are chemicals which you can create in lab so most gelatine are now available and you can suspend silver halide particles in this. Very fine particles and when you coat on your substrate and you dry it, it sticks to it. So there is a sticking coefficient of gelatine with the glass plate and because of that this is called photo emulsion plates okay. Now this plate this photo emulsion is something in which I can create a pattern. So if I somehow restrict let's say light in this area if I don't allow light, I allow light everywhere but I see I have a darker portion where light cannot go.

Then the property of this gelatine based emulsion is that it receives (())(5:57.0) photons and it actually cyclise itself to a non-etch able emulsions. Or there can be a possible nowadays it can be etchable emulsion the rest place where light doesn't come it remains hard and wherever light goes it becomes soft either way it is possible. Earlier it used to be that emulsions used to be hard and they used to keep, whenever you shine light they used to become soft. So it's positive kind of earlier emulsions where but both are possible. So if you shine light something absorption will not take place in this region and the rest of the region light will be absorbed. Now once the light is absorbed then let's say it will, it will show that initially it was hard and you shine light, so it depolymerises itself or if it is a silver halide solution. Silver halide and silver sulphite reacts with the light and actually silver is left out, either cases could be done.

In that case this will be clear portion and the rest is dark portion is only thing if it is silver emulsion. Photo emulsion otherwise can be organics in which case if this becomes light depended and this doesn't so you've a contrast. So if I remove the plate this dark portion and develop in some time where let say the portion initially was hard which became soft so that gets developed the portion which was did not receive light remained hard. So if I develop this, I may get a pattern which is just like this. This is a cross section so in a plan it will look something like this okay. So you can have patterns, you can actually expose the emulsions and wherever dark or clear areas are there light will do contrast emulsion process and may remain black or white portions across the vapor uhh across the mass plate.

Now the problem with mask plate was that firstly emulsion is some kind of a colloidal solution though dried. But it is still sticky, it's not very sticky but it's still sticky. So if you put and we shall see next time of a wafer then the sticking part may also stick to wafer okay. So there is a issue which is called in contact printing. The emulsion touches the wafer itself. We want to avoid that and as many times you will do this emulsion lithography on different wafers, after a time the emulsion will go away partially or it may pin holes may create there so I will not a good mask so we have to throw that mask and start fresh again. So what we did I mean we means the never generation did that instead of emulsions these are called soft masks. So we have a glass plate on which we actually deposited iron-oxide metal.

And again did the same lithography on this ion-oxide. So let's say I see to it that this portion of iron oxide does not receive light. So that portion is not etchable. This portion is etchable. And you remove this by etching so your iron oxide has the place where you want a window, close window. These FE2 FE2O3 has an advantage is called translucent, what does it mean? Partially transparent so, it has an advantage that in this it's a very dark so for a given wavelength this may be similar for the photoresist below but for seeing through FE2O3 mask may be good and it is little harder than emulsion. So people thought it is better. But iron oxide has its own problems iron oxide gets oxygen from somewhere in the lab and it doesn’t remain FE2O3, it becomes FE2O or FEO2 or FE2O4. And because of that its property is not uniform.

So people love this so called first version of hard mask. Since it was a compound, it was harder than emulsion and could be probably better than soft mask. The next we came with chrome gold or chrome nickel as the metal instate FE2. So I have a glass plate and I have chrome nickel or sometimes even gold also some people did. Some people do not want gold around in the lab so they do not want to have chrome mask which is gold plated now the same procedure use block something in that region, etch out the rest of the pattern chrome nickel and you have chrome nickel dark areas all around. And these are metallic even if you put N times on the wafer they normally do not get disturbed by their thickness these are defects come often. And therefore most cases if you're using hard masks chrome nickel mask are normally used okay. So these are called masks, what is mask? Because wherever those darker portions will be there the light cannot pass through wherever clear portions are there light can pass through.

So this is the simple contrast thinking we're doing. So this pattern or similar other kind of mask other patterns can be transferred on silicon through this mask system is that clear? So this was called masks, stopping something to happen in certain restricted area. Why we're looking for this because let's I want to make a diode very simple and people believe that diodes are very trivial actually they are trivial in fact but to get a diode characteristics uniformly over a million diodes is not easy, it costs you hell and it is very costly process. However all said and done, so in a lab normally if you get 1 diode and IV is okay you are still shouting publish everywhere. But in 999 may not be working, because their the leakage current are very obviously should be less than certain given value, has to be exact, on resistance has to be good, capacitance should be low. All features are circuit performance is required. So when you actually make a diode it will always work like a diode but not to any specification. So in university no one believes that I can a diode means I can diffuse something it's a diode as straight as that.

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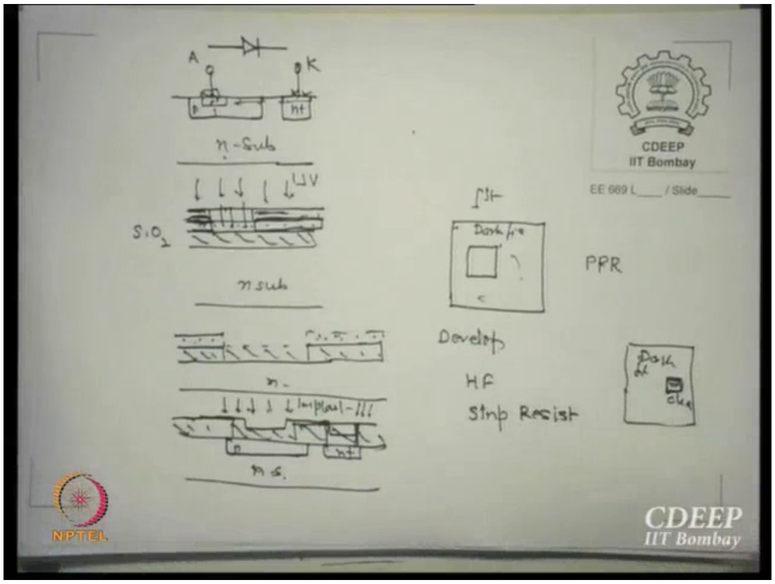

What is a diode? Let's say I start with an n-substrate and I somehow create a selective area p-region okay. And somehow I can make a contact to this P- region and normally I want a plainer diode which means I don't want to take a bottom contact. So I create an N plus region here which is same as contact to N. So this is, you can say this is like anode cathode. So a diode actually requires you can see from it now, how many mask you expect it will require, the first has to be for creation of P-region. Second for N-plus contact region and third for actually creating the metal on the… so a simple diode may require 3 mask okay. However interestingly you could have seen I did not make a P plus diffusion there, this is a technology game, in those days at least. In most cases either you use titanium oxide or aluminium both are type, 3 type, type 3 (()) (14:09.6).

So as soon as I make a contact, part of the aluminium goes down and actually creates a thin P plus region so you don't need any additional contact to P where it self creates okay. So if you have a PN junction diode the way I have shown then I will require 3rd mask but if I have P substrate I may only do N and N plus mask and of course metal so N plus wherever I will make it I will need additional mask is that clear to you. Whenever I will make N plus region in N I will require additional mask because that’s only a contact to that region, is that clear to you. So this 3 mask process is essentially what will make a diode. Similarly for a transistor MOS transistor you may require 4 mask minimum or even 6 mask in many cases. And if it is a CMOS minimum 6 or may be any number as I said 30 odd also.

So this mask making is therefore crucial for us because it will actually us the areas how much the gaps are here, how much is this area because this decides the resistances capacitances so the circuit performance is essentially directly related to the device I make. So anything I do mischief there it's reflected immediately in electrical performance. And since our ultimate aim is not to learn material or may be some material science people are here they may be interested in that itself, that's not a bad issue but for us in VLSI we're interested to see my circuit functions or my chip functions and therefore anything which does not lead to betterment in my chip performance, those technology I will just avoid. Even if they may be fantastic. I will see that my performance of a circuit should not get deteriorated even a percent okay.

And that is where the different start that we keep looking technologies which are cheaper liable and good still gives you a performance of electrical which you're looking for. So no technology is great or something. Technology is as good as the performance you're expecting. So I may reduce my technology content if you're giving me Rs. 5 this is what you're going to get sir. So ohm ka resistor hoga diode ke andar. 1 ohm nahi dikhega apko forward 100 ohms dikhayega. You paid only Rs. 5 no so you have that. So the game is in design a technology is the vendor what I use. He said that this is the jeb me itna he paisa hai, to mere jeb se bhi itna hi kuch milega, this is bargain out. And I want profit out of it, he also wants a profit out of it. So the real cost has to be much lower for both sides. So whole technology details please remember, though we keep thinking of great technologies here because we're trying to learn possibilities but in real life not all possibilities are actually used.

It's only because Intel wanted a process to beat Apple processor tomorrow, or in end of course it's loosing that anyway so they are working for better technology. Then if they don’t do the others will, the worry is not that my processor is best, uski kameez mujhse safed kyu, ye problem hai. So that is where the technology progress starts because I have to beat the system so that I sell my more problem compared to the other competitors. So this is an issue which you should realise that I keep giving options but that doesn’t mean every design house or every system house will actually use all kinds of technology. They may give you cheapest amongst it which gives the performance we're looking of. So one of the best of now implementing a circuit is may be a FEJ which is very cheap so why go on a silicon when a FEJ are available okay but you need a ram there. Now this ram access is bad or ram goes bad then (())(18:21.6) circuit goes away.

So you can't be always reliable on that but you say I don’t want reliability 3 mahine ke liye hi chahiye use it. Use very fast 100K to 1mega gates FEJs are available running at very high speeds of typically now 800 mega-hertz then why go all of it on silicon go buy FEJ, program it and sell. So don’t come to see that apne to itna sab CMOS padhaya, padhaya option dekhne ke liye, samjho koi ne aake bola I want this, then you should know what I should give. So whole course is always focused on this options. In really the system person, I am the person who delivers it has a choice and he decides how much to do okay, there is a standard cell technology there are many methods which can money can be reduced on a chip so look at the performance look at the time frame he wants and then you decide where I will go, technology is only to create something what options I can provide. So please learn technology seriously because these are the options you will have to know what is available in market, of course google gives lot of such information, so you don’t have to follow everything what I say, but all the say it's better if you know. Every time you go on this you're so called mobile it's more like a tablet, you keep actually looking for it and spoiling your eyes it's not fair enough. So better if have a mind keep your brain intact and remember as many smaller things as you can.

So how do I do this, so I first start a wafer which is a N-substrate and then I have the first mask which is shown here. Let us say I have I am going to use PPR. What does PPR means? Positive Photo Resist which is normally hard but when receives light it becomes soft. So since this region I have to open so first thing I do is oxidize this wafer, by the way lithography is always performed in oxide, nitrites or metal prints and never on silicon okay. Silicon is the region which you want to do process on, so that is not actually used for lithography, it is the top layer which allows you windows to create for silicon is what we do lithography. So most cases I will use silicon dioxide layer, this may be typically depends on the windows I opening that thickness is adjusted.

Now if this is oxide I coat this I coat this with a resist okay. If I coated this resist then let's say this is the mask this area. I want to see that this area is open and I am using PPR. Let say resist used is PPR, so what should be this portion, this should be dark or this should be clear? Socho zara mujhe waha window kholna hai. Yes portion jo hai yaha se light jana chahiye aur baki jagah par kaunsa mask hoga. Dark filled mask hoga aur ye sab jagah dark hai except this window is open. So if I put this window mask on the top of resist whereas this is my window and the rest is darker portion okay. So I put the mask plate on the resist and I see to it and this where I have to put is called alignment and we will go through it later. So if I put this and then shine light typically UV light this, depends on which UV we will use this is the other part we will discuss. So what will happen light will go through clear regions okay and will not go through dark portion. So the resist below this portions will what will remain hard because the material used is PPR which is hard. But which resist will become soft? The window part.

So as soon as I have soft this I will develop the next stage after this I will develop so if I develop what will happen I have an oxide I have a resist, this is my oxide this is my oxide and the resist will go away, except for this portion the resist will remain everywhere because light did not pass in those regions. This region the resist could be removed that is called development so I removed resist window. The resist is a very good material and that's why it was not developed that means it is un-etchable. Hard in many of many of the chemicals are used, most of the chemicals. That's why it is very un-etchable in soluble material. Now I put this wafer into a solution which etches silicon dioxide. So what is the etchant I use, hydrochloric acid is the etchant for SIO2. So what we see now that this resist will not allow the oxide below to be etched. And only region where it was otherwise open the oxide goes away.

So the pattern I receive now is something like this and then I will strip resist, what do you mean by strip resist, I don’t want to keep resist for next process. So it must be etched out but where normal etchants do not (())(24:52.0) special etchant which removes resist is called strippers. So you put the resist in strippers so that after the oxide is etched you remove the resist from the all regions where it was otherwise sticky. So I have a window now in silicon in silicon dioxide. And I am now seeing an area there. So I start doing pre-diffusion either by solid state or by implant I am right now showing implant we will see it later. And dry it also in oxygen, so what will happen, it will give a P region and will have pores, oxide region on that. If I drive in an oxygen after implant then I will create oxide on the top and impurities will go down because of the diffusion process and I will create a P-region inside N region.

So in a way diode is now available, diode P and N ho gaya, diode ho gaya. Now the next process what should I do, this is first mask has created PN Junction is that correct. The second mask I need which will open a window for either for N plus diffusion. So again I want a window to be there. I want to etched that area. So what should be the mask again. This is first mask, what should be the second mask should look like, same kind dark field and a smaller window. Which is this n plus area you want okay? So repeat this process again I deposit resist. Now remember oxide has already come, so I don't have to go further anything I have (())(26:50.0) that's why I say every time I will indoor only in oxide nitride or sometimes in metals. These are the only things which I will etch, rest silicon is always where I am actually going to do a process so that is not etched of course in a CMOS what is called as step isolation yes we will do that but some other day.

So if I do this you can see here as if this area will now get protected why because this a dark area. Only the clear region is the small area somewhere here okay, which resist will go away because it will be developed softened. Then I will use oxide, so I will create window again for what this impurities now? N impurities which is either arsenic or phosphorus so I can do either implants of arsenic or phosphorus and I will create heavily doped N plus region below. But during the driving of this again what I will do, I will oxidize it because any driving cycle will be in oxygen and therefore as soon as I finish this oxide is growing on that region, of course the thickness may vary that may now become like this thinner oxide at the N plus region, thicker oxide less portion but that it should be given up for any other things to go through it. So that much (())(28:19.9) you have to do okay. So now I have a P region, N plus region so what next I will do is you have drawn? So I do need a contact, so let's so this is the simplest lithography I will show you and then I will actually look into the details.

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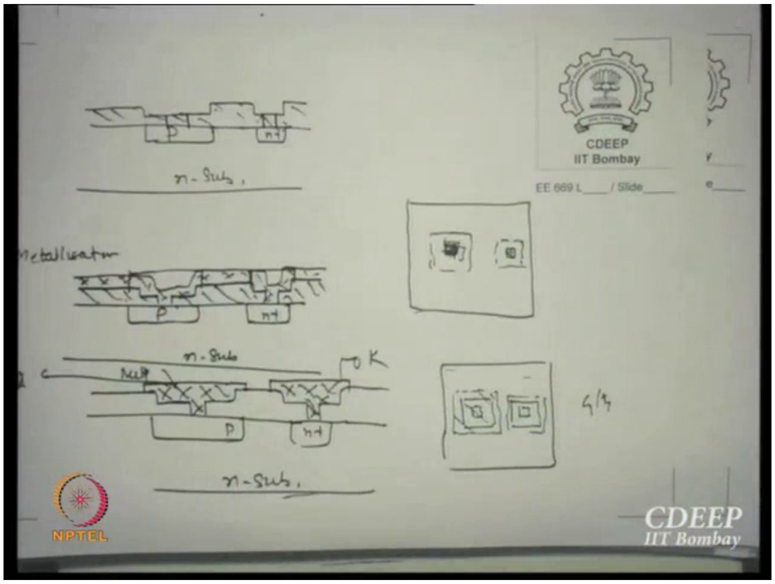

So now I have a situation in which I have a oxide lightly lower oxide for the P plus region then I have a slightly lower N plus region. Everywhere is oxide okay, and here is N plus and here P N substrate. This is what I will get after 2 mask. Now I want to open windows okay, before I put a metal I must open windows for making a…contact is where made to with silicon. So what should be the mask, third mask should be, now you can see, now two mask has opened only make P and N, the third mask so the first pattern which is seen here since there will be thickness change optically through a microscope I will see that image, is that clear because of the thickness variation. The microscope wills actually me the pattern whichever I have printed okay.

Because also their thickness are different and therefore the way optic shows that there will be a change in thickness means change in pattern visibility. So I have this my first pattern. I have this my second pattern, second mask but the third mask which I want to see that I must open a window in the P at the same time I must open a window in N plus. So now again I am opening a window. So this is a clear region mask oh sorry dark is mask where this third mask is only two small dots, 2 small squares the only worry is that this must get aligned in the earlier patterns which I have created, it must go inside one. This is only one diode on a wafer there will be hundreds of them, thousands of them or millions of them. So everywhere similar patterns there will be N such squares will be there for purchase and each of them I must get those new windows getting into old ones. This is called alignment, this is called alignment.

So these windows must get aligned inside the old patterns which are visible through microscope. I know this is one, this is the other one. So I see through put the mask adjust my mask see that the new window actually gets inside this. Safety is I will keep some margin all around. So that I know that I can get easily inside, I may make mistake over the total 3 inch wafer or 10 inch wafer so I have some margin of my error. So this cannot be exactly cannot be exactly of his sense. It should be must taller so that there is always possibility even if this moves up I may have pattern. Here it goes left or slight it's still inside, so any error imprinting as we say it should be taken care you're mask design. This is what we do, so once I print this, by third time I come and do lithography again put a resist put this mask shine like. So I now say I have a window open in the P region and in N region.

So now I have this, I have a oxide we want to etch anything in PPR is only etched if the light does not uhh light passes through that. So if it's a clear area dark field means clear area of the window. Clear field dark windows, I am sorry I am awfully sorry but anyway what can I do then, I will use an NPR okay you're perfect, so I will use the NPR which is opposite that it says that wherever light shines it becomes hard, wherever it doesn't it remains soft. So may be the way I showed the pattern I may using an NPR but you're right I should do, you're very correct. May be I should do again, this is the first window and there should be another window. Okay fair enough, so I have a third mask which allowed me to open windows for contact to N and contact to P. Then I deposit metal, why I show the contours because the process of deposition as we shall see it picks up the contours okay.

So it will go everywhere uniformly, wherever it is dipping the metal will go through that okay; it's a film so it goes through any undulations okay. So if I now put the metallization typically it can be aluminum in olden days. Now it can be copper plus Titanium plus Vanadium plus Tungsten many possible combinations. And once I make this, now I want the contacts, this is now connecting all diodes because metal is everywhere okay. So I want selective diode to be made so I must retain metal for this region one and also for N plus. So what should I do now, another mask? Which kind of mask it should be? No No No, please remember now I want to retain metals in this region. So now it is a clear field mask with dark (())(35:15.0) for PPRs okay. The mask will be should cover more than the this window, is that correct, it should be more than this window even more than sometime this. This is whole is dark which covers that all of it.

Similarly it covers, then there is a separation between the 2 patterns okay. There is no metal should come here. So if I do this the final version I will get so how many mask I went through 4 mask so diode looks so trivial that requires whole mask, each mask cost a hell. Of course these dimensions are big enough so they are not that costly. But even then…so the way I now see it is something like this, this is metal.

Student: (())(36:46.4)

Same same procedure any field will independent of what, the lithography is only by… because we're exposing resist not the metal, etching is going to be permanent. The resist will sit on the metal film okay, so you're actually etching resist so it is safe. So now what I get here, this is my cathode, this is my anode. So in a 4 mask process I could make a diode okay. For an NP diode how many diode I would have required? I would have not required P plus mask so I would have saved a mask out of that. It would require only 3 mask because P doesn't require P plus it builds its N requires always an N plus, is that clear to you. So there is an issue whether to do a PN junction device with NP or PN is decided by of course this is with the goes with other technology part because diode is not singally made it's part of the circuit.

So whatever is a process we will have to keep doing according to that, it can be either N plus P or P plus N. So iske sath karna hai ya P channel ke sath hai ya N channel ke sath karna hai. So depends on what N you have or P you have, you will decide which diode to be used okay. It's not so much in our hand, but if you want independent diode you create another one and create another diode area. Another mask sits, anything additional from process mask it, keep adding additional mask, keep doing additional process okay. So a process of making a diode requires 4 times lithography to come and you will make a simple N plus P or P plus N junction diodes. Now we can see in a CMOS process we will have to do source drains. We will have to do contact to source drains. We will have to do (())(38:58.0) gate, you will require a contact with a gate and you will also require metals.

So at least 6 mass will be required to create either N channel, N channel will require more sometimes or P depends on. Whether I want N plus poly or P plus poly or I want N plus and then P plus additional mask will be required for doing this okay. So process is is there lithography clear…so how close I can bring this is the greatness of my work, because if I am working on 10 nanometers or 22 nanometers the separation has to be such that they should be able to separate by that much amount. Any lithography you do the way it will happen they will overlap. How do you resolve the 2 lines that is all that optics does all that the techniques we use trying to do number of ways we do it also there are possibilities there are problems which we actually run when I print something from the mask on the resist surface something else appears.

Okay this is very interesting and from resist top surface to resist below (())(40:10.3) touches the silicon or silicon dioxide. The pattern is not exactly same, upper portion is called airy patterns. So this error patterns jo hai they do not same as wafer patterns. So firstly from the mask I am creating air patterns and from air I am going to the resist pattern and there an air going on everywhere. So I start with something and I get something else okay. And this I have very small window for adjustments my worry start extremely high and the cost of therefore lithography increases just because you're asking smaller and smaller and smaller dimensions. Is that clear? Lithography is therefore the crux of integrated circuit design uhh integrated circuit realization. And they should be understood well, how fast how another way is how fast it can be done.

See if I take one wafer 2 days then I am broke anyway. So I must doing 250 wafer an hour then only I am surviving. So lithography technology cannot take each wafer require some 3 days to actually expose. That I will not be able to sustain because the cost will be too high for me, so processes we will learn now which essentially optimizes many things at a time and air is trying to minimize as much as we can. We are not saying we will not be able to remove all errors but how minimum errors we can do through some kind of a system is what optics does okay. So of course I am not looking into optics so much but I am now going to show you this is the basic lithography and mask you should know because otherwise you will not be able to realize what is mask essentially okay. So I just thought you should know mask so that when you learn this you also learn. Because we may not do diode we may do CMOS but CMOS require so much but lithography is similar everywhere.

Student: What do we going to require for exposing iron oxide?

Actually iron-oxide film used to be in those days 0.3 micro amps. So typically energy required was 200 milli-joules per centimeter square direct the power density. We're looking for less than 100 now okay. For the case of translucent I mean this chrome this, it is not so much metal it is the resist or emulsion which is going to be put on that which you're going to etch. Okay so that is still I line or g line in those days. So the requirement is not more than 100 milli-joules per centimeter square typically (())(43:04.3). Yes quartz last plate, molygra is not used because moly has a …moly gates are used you're confusing with the mask. They are called super hard mask the problem with moly is it's not translucent you don’t see and image below so there is something called laser imagining. So you need additional mask system to do that, though it is more accurate much harder and remains for long time okay. Moly’s are unless you're rich enough you will not do that. Okay so we are, and today only I was saying if you have extreme UV process the cost of lithography is 55% of the net cost okay. So we have crossed 33% and we're now 55% cost only goes in lithography.

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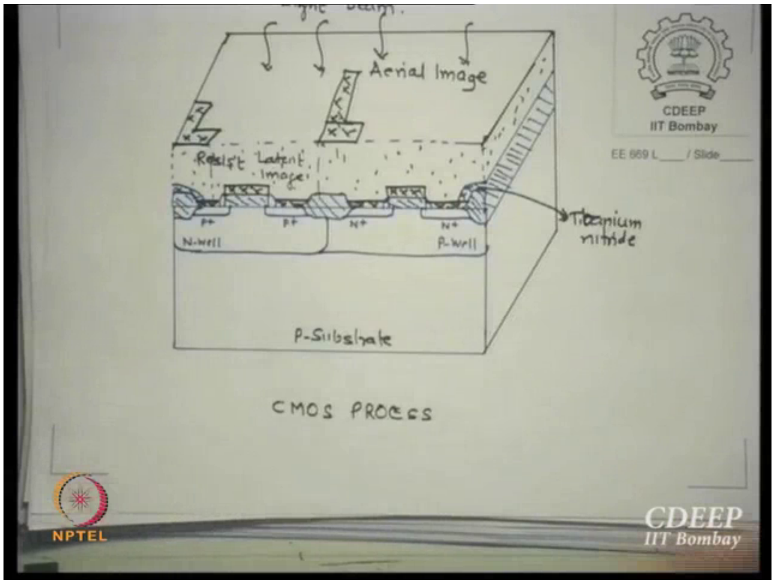

This is what I was saying from the mask on the uhh top of the resist this image is called aerial image. And below this inside this is called latent image which resist image. So how much closer this latent image is to aerial and that is closer to mask is all that lithography is expertise is that clear? So how much thickness I should have so that it goes very good way down but if it is two way what can happen? If too high thickness, thickness is high how much it can happen. So these are the choices one has to make. Our ultimate aim is whatever is in the mask identically come, it should come on silicon okay that’s what we're looking one to one transfer. If how much clever we can get is our tricks of the trade okay. So we have seen some way mask design, mask fabrication, this we did last time. We will look into light sources and then we also started looking at the wavelengths of the light.

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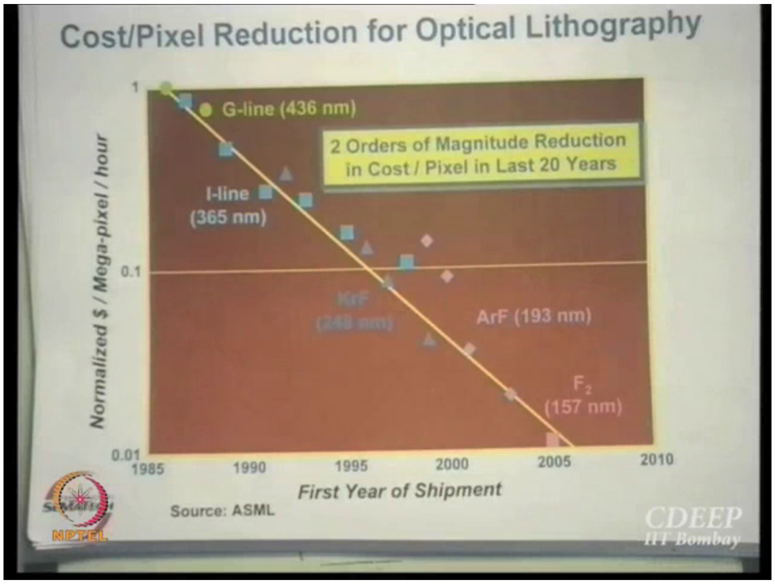

Cost/Pixel Reduction for Optical Lithography

Source: ASML

Many technologies are with F2 now which is 157 nanometers okay. Now we will start looking into resist itself and first we will look into photo resist because it's a photon based lithography. We can also look into electron beam lithography but since electron beam lithography is not directly used and stepper as it's called direct stepping it's very costly process however masks are made using lithography, it's electron beam lithography we're very accurate okay. The resist there may be I will just tell you before I come it's called PMMA, what is it? Poly(methyl methacrylate) okay so this PMMA is the standard resist for electron beam, PMMA we will come to it I just thought I will tell you what it is. So first look into photo resist.

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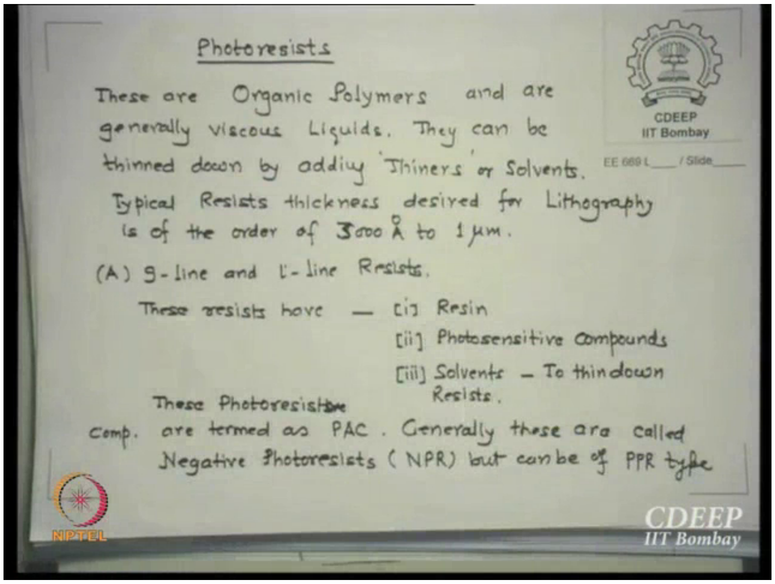

Photoresists

These are Organic Polymers and are generally viscous Liquids. They can be thinned down by adding 'Thiners' or Solvents.

Typical Resists thickness desired for Lithography is of the order of 3000 Å to 1 μm.

(A) g-line and i-line Resists.

These resists have — [i] Resin
[ii] Photosensitive Compounds
[iii] Solvents – To thin down Resists.

These Photoresists comp. are termed as PAC. Generally these are called Negative Photoresists (NPR) but can be of PPR type

Photo-resist are organic polymers and are generally viscous okay. They can be thinned down by adding thinners or solvents. Typical resist thickness desired for lithography is with the order of 3000 angstrom to a microns. These days' people are trying to reduce this to 1000 angstroms but not successfully. There are 2 possible wavelengths of light which have been tried one is called g line resist the other is I line resist. G line is something 460 and the other is whatever it wavelength I said. One is 436 and other is 365 okay. So these are the 2 line resist earlier read so what are the problems with them? All these resist contains 3 things, one is called resins, and the other is photo sensitive compounds and third is, thinning down of that is called solvents, in which actually they dissolve okay. These photo resists compounds are termed as, if you add this some of the resins are built in photo sensitive material inside them, they themselves are photosensitive whereas in most cases it's not so, resins are neutral so you add a compound which is called PAC okay, we will see what is that PAC essentially.

Generally these are negative or positive photo resist depending on whether you've to add a photo PACs or you don't have to add PAC some have built in PACs emulsion itself or resist itself is photo sensitive. So we have to add a photo sensitive materials okay. So generally there is 3 are carbon based or carbon hydrogen based rings of winzing sometimes. Along with CH3 CH1 okay, so these are photo resist as I say what is difference between other resist and photo means they absorb light and change the chemical start the chemical reaction. Whenever you shine light on resist, they do chemical changes in themselves, these are called photo resist. Now if you do a chemical reaction somewhere then you will be able to see, that in a chemical reaction the A plus B equal to C plus D is essentially governed by thermo dynamics okay. So most cases we heat, we increase the temperature that means you're energizing it the process.

Now this energy can also be given by photons and therefore photo-sensitive reactions also do similar or thermal reactions okay. Yes we will come, PS is phot activated some materials which we add okay photo sensitive compounds or photo activating compounds PACs. We will see that that we will pick few short time. So the so far what we have seen is, how to do a lithography and to do this I need a resist. So I start looking into possibility of resist I can have so I said at least for the wavelength earlier we used G line or I line. We have a typical photo resist which contain some resist some photo sensitive or photo activating compounds and solvents. Solvent means it's a viscous material I want to reduce the viscosity I must add little extra solvent is that correct. If I want to thin down that is reduce a viscosity that means I must add solvent to it, thinners is it okay?

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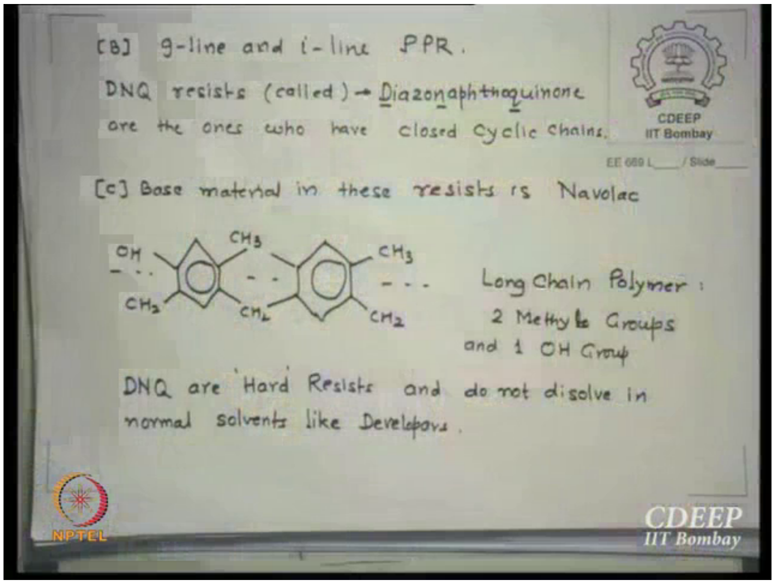

[B] g-line and i-line PPR.

DNQ resists (called) → Diazonaphthoquinone are the ones who have closed cyclic chains.

[C] Base material in these resists is Navolac

Long Chain Polymer:
2 Methyle Groups
and 1 OH Group

DNQ are 'Hard' Resists and do not disolve in normal solvents like Developers.

So let's look at g line I line O ones are generally PPRs and these are called DNQ resist Diazonaphthoquinone Diazonaphthoquinone is DNQ these resist are G line and I line PPRs okay are the ones who are close cyclic chains. You can see from here typical raising chain is shown here, those who are chemist oriented should also should see if this is the orientation here, this will be the orientation here okay. So there is something chemistry involved but anyway we will not go into that detail. These are benzene rings and have OH CH2 CH3 bonds and these are called polymers or polyesters or anything related to resins the material which is base resin is essentially called Novolac. And this is the typical equivalent chain of course this dotted is it's a long chain and at the end they combine itself okay so this for example may actually cycle it out. A typical polymer have 2 methyl groups and one OH groups. CH3 CH2 plus OH okay.

DNQs are hard resist okay and do not dissolve in hard solvent developer or (())(51:48.1) developer. They are hard itself and when they will become soft, when they receive energy okay. Till that time they remain hard. So the cyclic chain is unbroken without light so they remain bonded and unteachable in most solvents including the developers. Is that okay? So these are hard resist because they are unteachable in most cases okay, you can always something but these stripping's but otherwise they are normal etchants they do not get attacked okay. So is that okay? Have you anyone drawn this? This is by the way today now onward the lecture is mostly taken from Plummer's book, so if you don't write or if you wish to write also I will be happy but if you don't everything what I am talking I read recently after many days I read Plummer's book for this, so now I can assure you that most of it what I am telling you is available in Plummer's book. Some terms and somethings which I tell are not written by him because that is my experience but otherwise everything is what I am talking now is available in even more details than what I talk. Because he may give 10 cases I may give you 1 only. So that's the difference.

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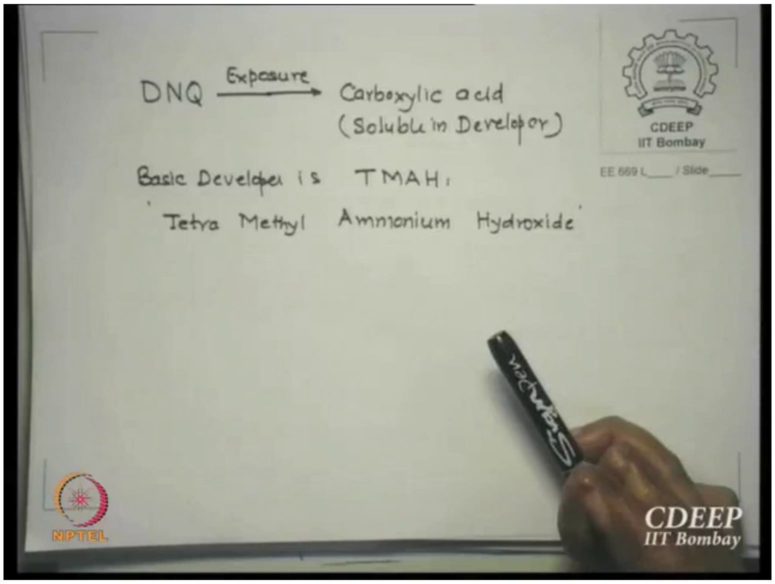

$\text{DNQ} \xrightarrow{\text{Exposure}}$ Carboxylic acid
(Soluble in Developor)

Basic Developer is TMAH :
'Tetra Methyl Ammonium Hydroxide'

Okay so DNQ is the most commonly used this, is it okay. So when I expose this DNQs they they convert itself into a what is called as carboxylic acid that mean chained X and once COOH kind of formation takes place and that is called carboxylic acids. And they are soluble in what is called as developer, etchers for the resist. The basic develop is tetra methyl ammonium hydroxide or called TMAH TMAH I am spending so much time on lithography I keep telling you 55 percent if the amount goes, so let's learn 55 percent nahi to 10 percent to karo. So learn lithography because that is the there are still not good enough models in lithography. Lot of problems in chemistry, there is lot of problem in optics. There is lot of image processing going on, there is lot of electromagnetic radiation based design going on so anyone can touch this area for a novelty any day and come out with something and which will be great. So please think it, this is the area which is extremely fertile as of now. Everyone is trying some funny things, hoping that he may be the one to get a noble price okay. Yeah I mean that's the hope.

The second kind of resist this typical wavelength of the light which we use to work on for the resist exposure is from 2400 angstroms to 2900 angstroms okay. 290 nanometer 240-290 nanometers is typically the wavelength of UV lights which we used to use for or even higher sometimes, but at least this much. However now I want to do deep ultraviolet which includes some of these wavelengths as well okay. So the new technique or new resist which has come is called DUV or Deep Ultraviolet Resist.

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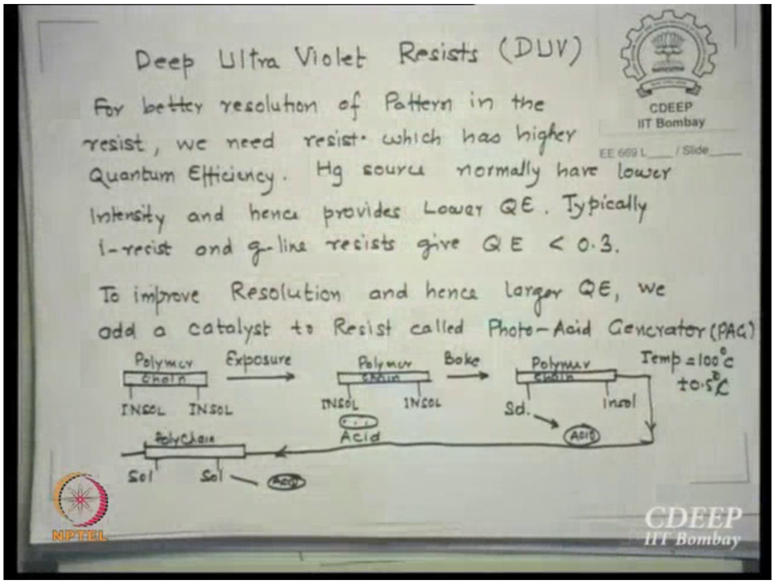

Deep Ultra Violet Resists (DUV)

For better resolution of Pattern in the resist, we need resist which has higher Quantum Efficiency. Hg source normally have lower Intensity and hence provides Lower QE. Typically i-resist and g-line resists give QE < 0.3.

To improve Resolution and hence larger QE, we add a catalyst to Resist called Photo-Acid Generator (PAG)

What is Deep word is, that it has a different wavelengths which is attacked better by the light okay. For better resolution of pattern in the resist we need resist which are Higher Quantum Efficiency. What is Quantum Efficiency?

Student: (())(55:53.9)

So better light absorption so we will model it how much energy is required to actually expose a thickness of resist okay. I is equal to I 0 e to minus alpha X. So we will actually model and see how much absorption in this thickness will be. So what kind of reaction like (())(56:11.9) model we will put a model how much thickness will give how much is the exposure. So we will do that model tomorrow. So for better resolution I say the mercury source normally have lower intensity and hence provide lower quantum efficiency. Typically I resist or G line resist give quantum efficiency less than 3. To improve resolution we need to increase quantum efficiency. And we add therefore some catalyst okay which will absorb more light is that correct? But what is that word catalyst means? It should come back it should not, it start the process but it should not participate in it. Or if it participate should be recovered. So that is the catalyst.

The catalyst used in the case of DUVs, this is called DUV maybe I should write popularly named as DUV the DUVs are essentially, they also have a polymer chain ideally with the what now we call PAG which is Photo Acid Generator which is a catalyst is Photo Acid Generator PAG. This is a catalyst used along with polymers okay. Now if you look at the way sequence have processed is and this is given in Plummer’s book, you have a polymer chain which includes this catalyst you expose so when you expose polymer chain uhh and then you add some kind of a acid here which is the PAG that is continuous process and this acid when it reacts with insoluble photo resist it actually makes it soluble. And when it's soluble it reacts further with polymer and releases this acid, is that point clear I repeat? Acid reacts with or PAG reacts with light and polymer make it soluble and then it reacts further and releases the acid back so this acid catalyst it did not remain with it. It keeps increasing okay. Typical than this process continuous, you can say further you have acid now reacts with the rest of the part and it will now create both soluble and acid will again get (())(58:54.8).

So that is why it is catalyst because acid you have and acid you take out so it is catalyst it did not participate actual reactions. But it added reactions okay, typical temperature of this DUVs where this resist could do exposures is 100 degree centigrade and the accuracy we're asking is plus minus half degree centigrade.

Student: (())(59:24.3)

You can think of it, resist is thick enough so process is going down and down okay, is that clear. So till everything is done, this acid will be released. It will help to make some part of the soluble again acid will come out reacting with polymers again come down, keep doing at the end it will remain acid, as a part of the separate which is soluble anyway okay. So yes…

Student: (())(59:54.4)

So this this is essentially uhh when we use DUV the wafer itself (())(60:05.2) itself with the high temperatures okay. The chuck where the wafers are kept is actually nitrogen embedded at high temperatures okay.

Student: How will I selectively treating that part with acid?

Actually it's not showing properly what I am showing you is the thickness part. So initially light shines, part of the acid reacts and actually makes it soluble. Then acid is again released because it reacts with polymer. That acid keeps going down, till the whole resist is completely soluble. So instead of looking like this you see as if this is the thickness okay. I draw it because this is what the figure was given in Plummer's so I only copied it during arts okay. But essentially saying that as you start it starts reacting reacting reacting is that okay. So the word which we use in lithography before today we have done this there are two things we're worried about, one of course is the word called contrast, I think we will talk about contrast little much more we can but briefly what we like to do is the following.

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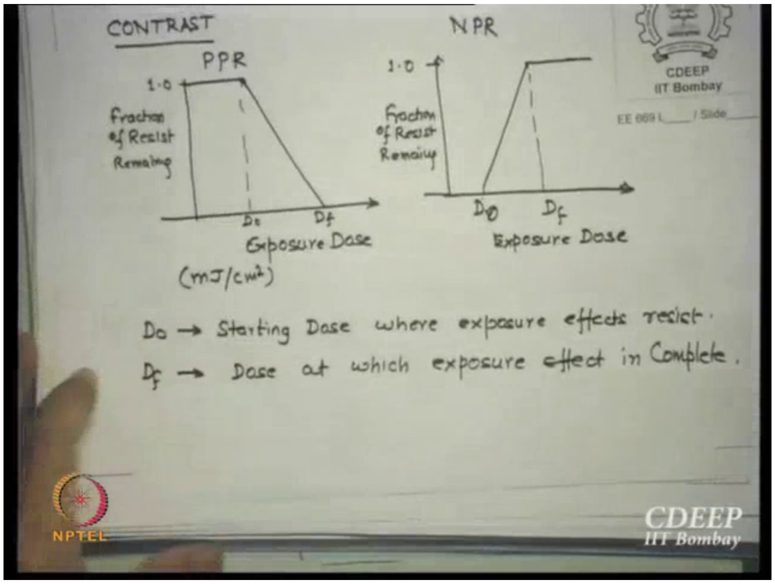

D0 → Starting Dose where exposure effects resist.

Df → Dose at which exposure effect in Complete.

Contrasting between black and white how much separation really you see, is a grey world is grey in fact it's neither white nor black, but we want black and white so how much contrast I create. So typically uhh during the exposure the exposure starts with a, this is called exposure dose, dose means what? The flux permit area or intensity per unit or intensity is essentially per unit area. So if you have a exposure dose which is milli-joule per centimeter square so somewhere let's say initially all of it a resist no exposure and somewhere at D0 it starts reacting, that much minimum energy it should receive so that it starts reactions. And as you increase this the reaction is faster and faster and it reaches where the reaction is complete. So this dose is called DF the start point is called D0. This is a PPR, initially it was already hard and it become softened as it went through light exposure. In the case of negative photo resist it will require some D0 to start the reaction to become hardening and it will keep hardening and somewhere at DF it will become fully hardened.

So what is ideally you will expect D0 be equal to DF that’s what we're expecting step but that we will not give how close we come to the step okay that fraction is called contrast number or gamma is that correct. Ideally I expect hack or attack that doesn’t happen. So how much closer we can get, is all that expertise is all about. So the resist, choice additions, search of catalyst all these games, is that okay everyone? I repeat this is this is everything today has been taken from Plummer’s book, so now worries, people who normally don’t want to see books. At least go an now see the book okay.

Student: What do want this step for (())(63:54.3)

I don't want, the reason is yeah obviously if I had to keep… what I expect is if I shine light or expose it, whole resist should get expose in one, but it doesn't happen, it goes down down down so whenever any process goes slowly down it creates its own problems of non-equivalence what image area I wanted what resist is going to give we will change. Ideally if we transfer whatever in the top will come down. The image under air air image will be transferred immediately the resist down. But if it takes time it has possibility of light getting defractions and that is where the image will get smashed okay. So how much bad image will come will be how much DF you're away from D0. Ideally I want DF to be equal to D0 okay. As soon as I shine light everything should get exposed okay.

Student: (())(64:58.2)

(())(64:59.4) but it doesn't happen it goes through thickness as I showed you chain also it takes time before it is actually exposed. The time taken that means those is not what initially on the top is the…you keep increasing the those only than the lower portions get exposed actually okay. So that essentially changes the pattern down okay.

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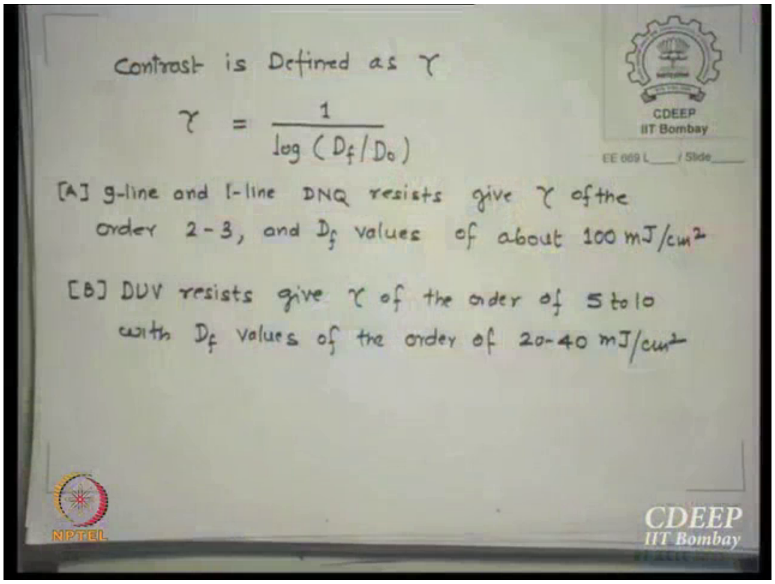

Contrast is Defined as γ

$$\gamma = \frac{1}{\log(D_f/D_0)}$$

[A] g-line and I-line DNQ resists give γ of the order 2-3, and D_f values of about 100 mJ/cm^2

[B] DUV resists give γ of the order of 5 to 10 with D_f values of the order of 20-40 mJ/cm^2

Okay the term which is used to define this accurately is not true, this is some equivalent number they figured out, it is one upon log and whenever at least to me log means to the power to the base 10, ln means to the base E. So if I write log I am always talking of base 10 okay. So log DF by D0 inverse is called Gamma. Typically DF values are of the order of 100 milli-joules per centimeter square for most DNQs for G lines or I lines. However for DUV I want to increase gamma to the order of 5 to 10 with DF values goings down from 100 milli-joules to 20-40 mill-joules. Why this is necessary? Because lower intensity if I have require to expose it, then the defraction of this will be smaller. So I want to reduce intensities as much as possible. Well I don't want because if it doesn't expose then I will give intensity, I will give 100 milli-joules. But if it happens in lower I am happy okay. And (())(66:35.4) so if I gets same contrast I will prefer this and that is why which resist will be more commonly used? DUV's DNQ has a limit what the wavelengths are 465 and this 385 or whatever it is, since those wavelengths cannot resolve the lines much better than their own wavelength okay.

So 0.13 micron lines can be easily resolved through DNQs but below this DNQs will require much higher energy and therefore it will difficult for using what we call finer resolutions using DNQs okay. So we will require DUVs for this and otherwise what we will further do is EUV extreme UVs is what we're now looking for, extremes okay.

Students: (())(67:30.3)

Yes contrast is between the image which you're; okay I will show you a figure. You know there is a image in the air and there is image in the resist which is called latent image. So how much latent image is different from airy image is essentially the contrast okay. So some portion of that is not same, okay I will come to figure. So there is an issue so how much days at what areas do not get exposed okay and therefore there will remain something. I have this but if it happens to be this that means this area additionally either not exposed or exposed over exposed. So I am worried on those terms okay. Okay there is another term which is coming from actually optics. But as of now you take it; it is called minimum optical transfer function called CMTF which is given by DF minus D0 upon DF plus D0 which can also be written as 10 to the power 1 upon gamma minus 1 upon this. The CMTF for G line and I line is 0.4 whereas CMTF for DUV is 0.1 and 0.2, so we want lower and more CMTF as much as possible. We like to see how it is possible.

You can see if DF is closer to D0 what is CMTF 0 so smaller the value of CMTF greater is the resolutions you're going to get okay. This is called minimum optical transfer function. Maybe when I am looking for lens I will show you what is actually transfer functions okay. This results in better resolution of image and top of the resist to the bottom of the resist. Area into lower how much accuracy it goes down. As I say I want this like this, doesn’t happen. If I happens like this means this image, firstly from the mask this image will not be served as mask image. For the mask image to resist image further I have a problem okay. And then finally it goes under wafer, some other things may also happen on oxides okay during etchings. So you have etching problems, you have resist problems and you have mask to these problem. So some problems we will try to solve that whatever mask pattern are created area actually etched in the silicon. That window we designed based on what that window has decided in a diode the area okay. Now if you're window is some area for a given current density or design. That changes something else then the current density has changed for the diode, is that correct? If larger area appears then your current density is smaller. So diode cannot give that much (())(70:29.0) okay.

So this transfer from the mask mask patterns area generated by whom? The designers who think technology people should take care of everything. Hamara kaam ho gaya okay. Now that procedure because those people just give me patterns I will have to worry that what they want, I am transferring to the silicon okay. That is all the lithography problems. From given mask coordinates I generate the patterns on silicon which are exactly same dimension or as close to that as much as okay. This is what effort is all about. That's why lithography is fab, of course I have to tell them that do something there okay, that is why I will show something can be done at the designs this itself okay. Some processing can be done during design which is called DSP methods. So you can do some image processing and do some mischief on the patterns itself okay. What is that can be?

Let’s say X pattern goes to Y okay in whatever lithography I do. But I want X to X so I keep assume that I capture Y image okay. And do lot of processing inverse processing see there at what time I can get X. So that X modified X which is a bad looking X may actually transform into good looking Y okay, this is called image processing, is that clear? I saw a last image I show it’s a source machine kya kare? Isko capture karte hai. Fir reverse processing karke dekhte hai, ke what X I should have which will lead to this Y which is good. I can always make games to realize what I really want. But the cost accuracy of any DSP system processor speeds all these issues come there electronics can do everything in its own time. There is no own time with us, so we will have to worry here okay. Okay so before, I think we have few minutes. So two things I may show you okay.

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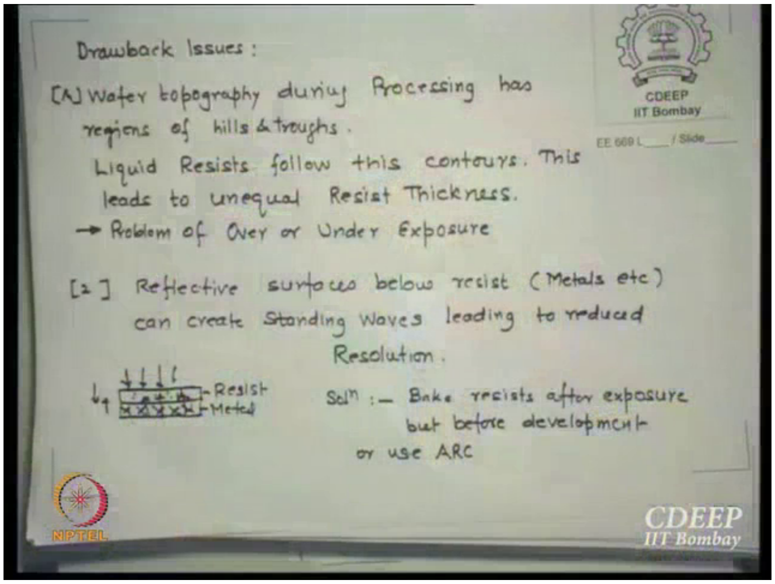

Drawback Issues:

[1] Wafer topography during Processing has regions of hills & troughs.
Liquid Resists follow this contours. This leads to unequal Resist Thickness.
→ Problem of Over or Under Exposure

[2] Reflective surfaces below resist (Metals etc) can create Standing Waves leading to reduced Resolution.

Sol^n :– Bake resists after exposure but before development
or use ARC

There are drawbacks. Wafer topography during processing has regions of hills and troughs. You have seen the wafer during etching there are some areas thicker some areas are thinner, diode also you see undulations. Resists are liquids even if they are viscous they are liquids. So they actually follow these contours. Whatever shape the liquid goes through that shape. But if that happens the thickness of resist from the mask okay, is different from different regions, is that clear? Ye aisa aisa hai mask to flat hoga abhi ye region door hai ye region pass hai. So there is air going on how much undulation you have liquid resist follow this contours. This leads to unequal resist thickness because it will fill try to fill it up. Let's say (())(73:36.3) is there so when the resist fills this thickness will be larger than the other areas. Now what is the problem. You're shining some light okay, the left side of resist which is one the thicker area expose but this lower area where it sent through it did not. Now the problem is I actually decide that wherever the thicker resist I did processing for that, but then what will happen where it happen thin. If that problem then goes into the thinner then I have a problem, is that clear?

One possibility that I only look for thinner resist then I see some areas I don't expose. If I expose the thicker part then what will happen to that thinner part, so I must worry about it. So there is a draw back in any system because resist goes through troughs and hills and therefore thickness of resist is different at different points okay. So it is called problem of over exposure or under exposures okay. There is another problem particularly in metals, which instead of silicon dioxide if you have a metal which is you're etching contacts there will be a metal layer over which there will be a resist and there will light. Now one can see from the way it happens, even other materials can also do the same. There is a refractive index here, there is a refract index here. Depending on N1 N2 N3 the light which is incident on that may actually get reflected. Is that correct? May get reflected, the problem with reflection is not so bad just like that but essentially means photons come back photons went in they do not react they actually came out. Is that clear?

So this is called and if the phase of incident beam to the outgoing beam is 180 degree then it forms what is called as standing wave patterns, then the resist cannot be exposed because standing waves will not allow etching to go through it okay, exposure to go through it. So this problem with metal surfaces or refract index with is higher than N2s creates problem that there is a standing wave patterns okay. What will it happen it will reduce the resolutions okay. So what should we do, easiest solution get the expose wafers as straight. So we will see that how fast. So somehow we change the refract index and thickness of the resist and then we can probably get. Why refract index is different in different temperatures? Because the solvent changes thicker what is called solube percentage changes and that changes the refract index. So some baking may help to reduce, if it is like what is called as total internal refraction so most of the beam may go out but I want most of the beam to get in okay. So I must adjust both D as well as density they have refract index there such that most of the light is absorbed and not reflected, is that clear? This is essentially what is tried in baking system, we will come back to it tomorrow. The last ek figure baki hai aur kuch nahi. Ye ek figure dekho.

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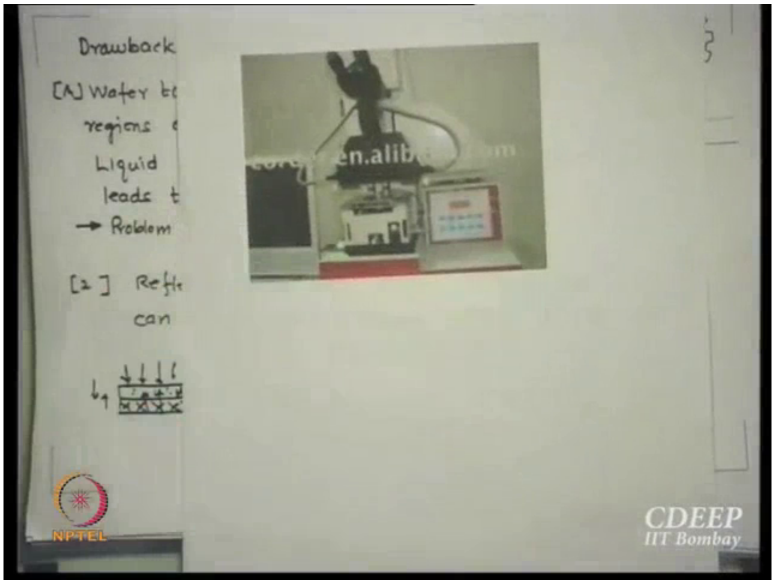

A mask aligner hota kya hai, you can see of course this is the oldest 1965 mask aligner okay. You can see from here there is a chuck here below this on the wafer is kept there. There is a chuck here were wafer is held our vacuum okay. On the top there is a square plate which holds the mask so one side there is a sliding this, you keep the mask and push inside okay. This has xyz motion okay, so this wafer to mask separation can be done or brought down touching itself it can align by x and y I want mask to this to align I will move x and y. Either I can move the wafer or I can move the mask. Generally mask is held constant and wafers moved. The z portion has to be flat because you're separating untouching. So everywhere it should touch okay. So a KAC of Z is more important than even x and y okay. There is a microscope which is not having a wavelength of light which is same as exposure light so you can actually see first the image.

So first separate the mask from wafer closer to it and see the image on the mask, pattern on the mask and the image on the wafer and then adjust x and y so that image of the mask uhh pattern on the mask gets inside the earlier pattern okay. That is called alignment and this all is done under nitrogen environment very. What should be the nitrogen flow if I keep my aligner I am doing it, where from nitrogen should go come and go? It will come from top, so where should it come, it should go here and then it should go out okay why because it should take all particles everything out. So I am not adding my dust to that, everything should come out. So this is called Laminar system so you have to maintain nitrogen laminar fluids okay so it's not trivial it's very important how much accuracy pattern gets because there is a particle sitting on the mask it will not get exposed that region or it will whatever light will not pass through that, that region will go that chip will go. So the (())(79:44.2) are very cost business so maintaining a clean room and super clean in the lithography is a must. So we will come back tomorrow 9.30 and we will continue with lithography hopefully we will complete tomorrow. So we have seen resist tomorrow we will see optics.