Advanced Neural Science for Engineers

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Lecture 16
Photolithography -III

Hi everyone, so we will continue the third session for the photolithography. We have seen in the last session - what are the process flow for fabricating a micro heater and we took an example of nickel as a material. We started with silicon wafer, we oxidized the silicon wafer using thermal oxidation technique and then there are steps to achieve the certain patterns. Now just to quickly recall what were those steps let us see the slide and we take it from there.

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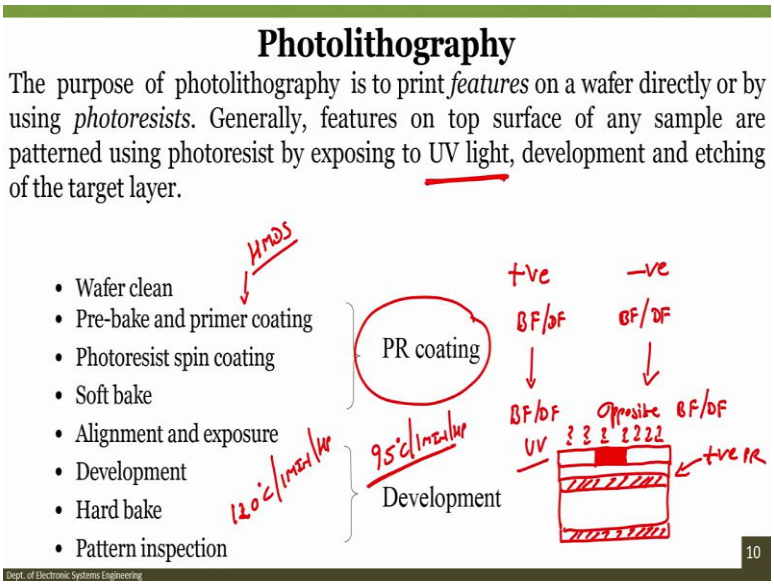

Photolithography

The purpose of photolithography is to print *features* on a wafer directly or by using *photoresists*. Generally, features on top surface of any sample are patterned using photoresist by exposing to UV light, development and etching of the target layer.

- Wafer clean
- Pre-bake and primer coating
- Photoresist spin coating
- Soft bake
- Alignment and exposure
- Development
- Hard bake
- Pattern inspection

PR coating

Development

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So as I have discussed earlier the purpose of photolithography is to print features on a wafer directly or by using photoresist, there is a direct lithography also but we will focus on the one that uses the photoresist so generally the features on the top surface of any samples are pattern using photoresist by exposing to UV light we have taken an example and I have shown it to you what happens whether if it is positive photoresist, if it is negative photoresist, if it is bright field mask or dark field mask.

In both the cases whenever we use positive photoresist we can replicate the same patent on the bright field mask and dark field mask, if you use negative photoresist we get opposite to what is there on the bright field mask or dark field mask this much we know, correct, so but the idea is that you have to as if this is a silicon wafer, oxidized silicon wafer and then you have let us say photoresist on this silicon wafer, spin coated on silicon wafer and then we have pre-baked it at 90 degree centigrade, 90 - 95 degree centigrade for 1 minute on hot plate.

After that what happens, we have to load the mask and then once you have mask let us say the mask is like this when you load the mask and align the wafer you need to expose the photoresist with UV rays UV light so that is what is written here, UV light, development and etching of the target layer, so the photolithography processes are as follows.

First is PR coating within that PR coating this kind of repeat but just to recall the photolithography itself is divided into two parts, one is the PR coating and second part is in development but the process is same you see the first step is wafer cleaning then you have pre bake or primer coating I told you about HMDS so HMDS.

Then photoresist spin coating, it can be positive or negative then you have soft bake at 95 degree centigrade for 1 minute on hot plate but if it is oven the time changes temperature remains same, alignment and exposure with the help of mask then you have to unload the mask and develop the photoresist using the photoresist developer followed by hard bake, hard bake is done at 120 degree centigrade for 1 minute on hot plate correct.

This is hard bake and finally you have to inspect the photoresist that is pattern on the substrate. So that is how the lithography is steps are defined and in a easier definition what we called as a technique for printing features, fine features on a wafer so and the steps are UV light, development and etching of the target layer.

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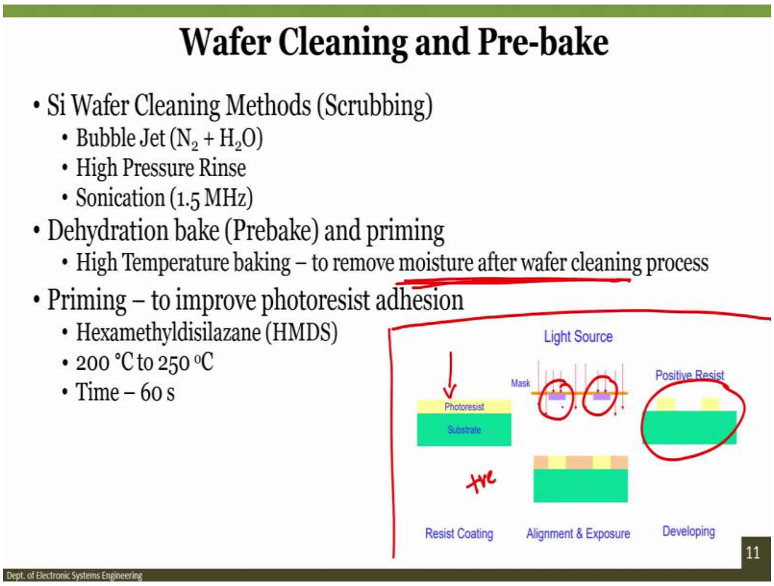

Wafer Cleaning and Pre-bake

- Si Wafer Cleaning Methods (Scrubbing)
  - Bubble Jet ($N_2 + H_2O$)
  - High Pressure Rinse
  - Sonication (1.5 MHz)
- Dehydration bake (Prebake) and priming
  - High Temperature baking – to remove moisture after wafer cleaning process
- Priming – to improve photoresist adhesion
  - Hexamethyldisilazane (HMDS)
  - 200 °C to 250 °C
  - Time – 60 s

So wafer cleaning and pre-bake we know that the wafer cleaning consists of RCA 1 cleaning and RCA 2 cleaning once it is done you can also use alternative like scrubbing which is bubble jet N_2 plus H_2O or high pressure rinse, sonication followed by the pre-bake and priming pre bake is high temperature baking to remove the moisture after wafer cleaning process, pre-bake.

But soft bake is 195 degree centigrade 1 minute on hot plate, pre-bake is at a higher temperature to remove the moisture followed by priming to improve photoresist addition, this primer is nothing but your HMDS it is hexamethyldisilazane this is called HMDS and then you have to bake it at 200 degree centigrade to 250 degrees centigrade for 60 seconds followed by coating the photoresist.

So if you see this process, this one in this box the once you have the photoresist spin coated on substrate and you expose these photoresist with help of the mask. If it is a positive photoresist, if it is a positive photoresist then the area which is not exposed, area which is not exposed will gets stronger and you can see that the area which is not exposed is stronger or the, we had a similar pattern.

Whatever the pattern is there on the mask on to the final wafer you see only those area which were not exposed got stronger, these were positive photoresist if negative photoresist it will be opposite.

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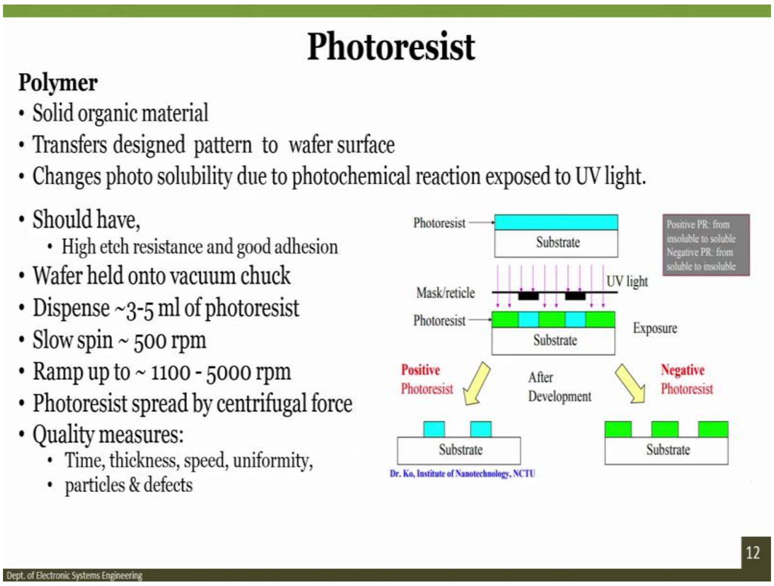

Photoresist

Polymer

- Solid organic material
- Transfers designed pattern to wafer surface
- Changes photo solubility due to photochemical reaction exposed to UV light.

- Should have,
  - High etch resistance and good adhesion
- Wafer held onto vacuum chuck
- Dispense ~3-5 ml of photoresist
- Slow spin ~ 500 rpm
- Ramp up to ~ 1100 - 5000 rpm
- Photoresist spread by centrifugal force
- Quality measures:
  - Time, thickness, speed, uniformity,
  - particles & defects

Positive PR: from insoluble to soluble
Negative PR: from soluble to insoluble

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So what is photoresist and if you and this is a very nice example where you can see that if I use a mask with certain pattern which is shown here and if I use UV as a light source to expose the photoresist, if it is positive photoresist the same pattern is replicated if it is negative photoresist you can see that the area which is black color it is developed, correct, so it is opposite of whatever the mask pattern is there.

So in another way the area which is not exposed gets stronger in for positive photoresist, the area which is not exposed gets weaker in the negative photoresist, correct, so but what is photoresist, photoresist is nothing but a polymer and a solid organic material the transport designs to wafer surface and changes the photo solubility due to the photochemical reaction exposed to UV light.

And what should the photoresist consist of, what are the parameters or properties of the photoresist, property is the right term, high etching resistance and good addition, what does that mean, let us take an example so we know, what do you mean by high etching resistance, okay.

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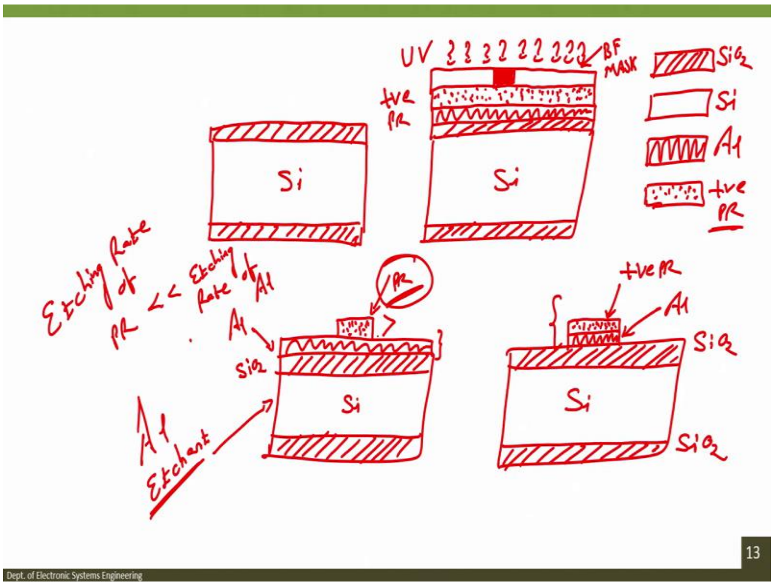

So I will just have, I will just put one slide in between so let us take example of what is high etch resistance so I am just drawing I hope that you can see in this form also or let me just draw straights, it is easier okay, so I have a silicon wafer and I have oxide layer, several oxide layer what we are looking at here is the high etch resistance of what, of the photoresist, so this is silicon and so this silicon dioxide on that I have a metal let us say aluminium.

Now on this metal I am spin coating a positive photoresist so this is a positive photoresist, these dots represent the positive photoresist now if I have a mask where the pattern is as follows, so what is this mask, bright field mask, after pre-bake after we have positive photoresist we pre-bake it then load mask and then expose the wafer with UV light, UV light, unload the mask, develop the photoresist.

What we will have? We will have aluminium end photoresist, aluminium end photoresist because this is a positive photoresist and it will replicate whatever the pattern is there on the mask or in other way the unexposed region will be stronger, so this is your photoresist. Now you see if I have this is your SiO2 as we know, this is your aluminium as we know and this is your photoresist that also we know, correct.

So I should have drawn like this because photoresist is denoted by this pattern okay now what will happen we have to go for the hard bake, hard bake is done it 120 degree centigrade 1 minute on the hot plate if I dip this wafer next this wafer in aluminium etchant, what will happen aluminium will get etched.

But while the aluminium is getting etched the photoresist to sustain, the photoresist should not get etched or the etching rate of photoresist should be way lower than etching rate of the material that we are etching, in this case it is aluminium, in what, in aluminium etchant in the aluminium etchant. So if I have etching rate extremely low then what will I have, got it, but if the etching rate is very poor then what will happen?

That by the time this aluminium layer gets etched the photoresist will get H and we may not get the, we may not be able to save the aluminium below the photoresist, so this is an example of how the etch resistance the photoresist should be resistance against the etching, against the chemical that is used for etching the material below it, in this case this is aluminium, in a other case it can be any other material as well, so that is a etch resistance of the photoresist.

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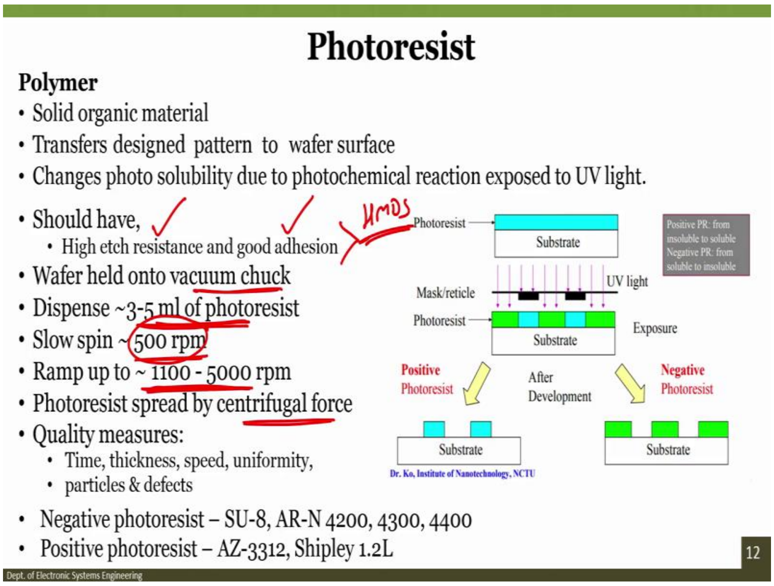

Photoresist

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Positive PR: from insoluble to soluble
Negative PR: from soluble to insoluble

Dr. Ko, Institute of Nanotechnology, NCTU

- Negative photoresist – SU-8, AR-N 4200, 4300, 4400
- Positive photoresist – AZ-3312, Shipley 1.2L

So the high etch resistance is what we have seen, second point is good adhesion, if it should stick well on the wafer, wafer surface or any other material we can use HMDS to improve the adhesion to improve the adhesion, now the next thing that we need to look into is that the wafer held so how it how it is spin coated, how the photoresist spin coated onto a wafer so first wafer is held on the vacuum chuck.

And then we have to dispense 3 to 5 ml of photoresist we have a slow spin at 500 RPM on the wafer when you dispense the photoresist like this then what you should do, you slowly spin code this water resist so that there forms a very thin uniform layer of the photoresist onto the wafer, this is a let us say 3 to 5 ml of photoresist that we have dispense on the substrate, 3 to 5 ml of photoresist onto the substrate.

So once you do that and you slowly spin at 500 RPM you have the uniform coating followed by ramping up at 1100 to 5000 RPM okay so photoresist spreads by centrifugal force and quality measures are time, thickness, speed and uniformity, the thickness should be in the range that we want, if you increase the speed of the rotation the thickness would be lower.

If you decrease the speed, the thickness would be higher if you increase the time the thickness will be lower, if you decrease the time the thickness of the photo resists on the substrate would be higher. And we need to see whether the photoresist is free of any particles and defects, so negative photoresist some of those are SU 8, AR N 4200 4300 4400 while positive photoresist can be AZ 3312 or Shipley 1.2 L.

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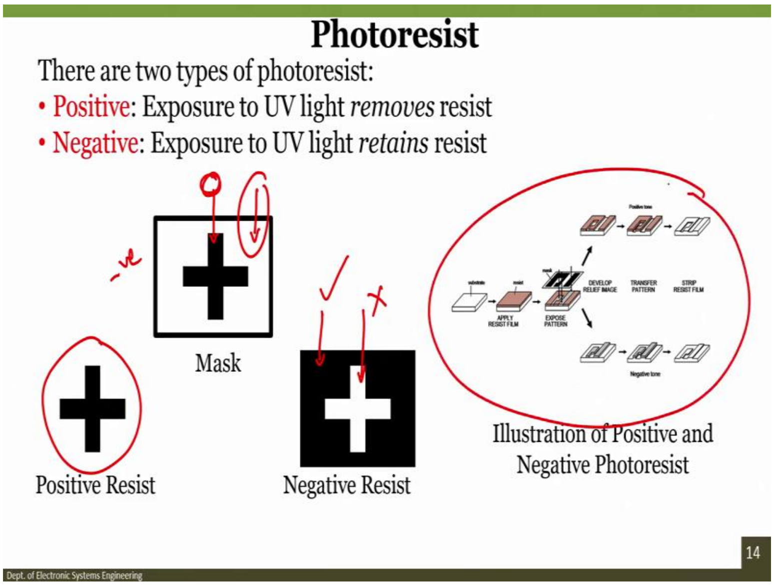
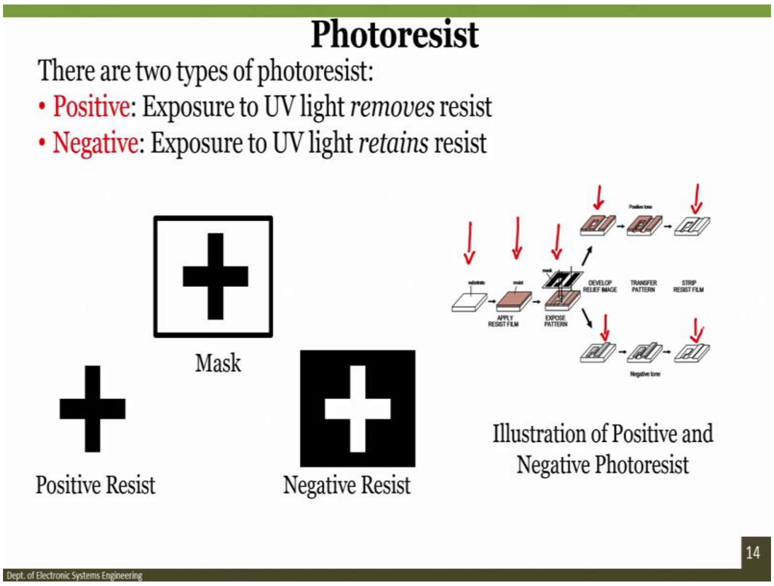


Photoresist

There are two types of photoresist:

- Positive: Exposure to UV light *removes* resist
- Negative: Exposure to UV light *retains* resist

Illustration of Positive and Negative Photoresist



Photoresist

There are two types of photoresist:

- Positive: Exposure to UV light *removes* resist
- Negative: Exposure to UV light *retains* resist

Illustration of Positive and Negative Photoresist

So this also we have discussed, a photoresist are of two types positive and negative, what I told about positive photoresist, do you recall, what we have discussed about for positive photoresist that the exposure to UV light removes the resist that is exposure to the UV light removes the resist or the unexposed region in the photoresist will get stronger if it is positive photoresist.

In negative photoresist exposure to UV light retains the resist that means in if it is negative photoresist then wherever this exposure is there this will get, resist will be retained but where there is no exposure like this case then the photoresist is gone, easy, this is an illustration of the same we have Illustrated in in earlier cases I am not going into detail about this schematic, you can look into that when you have time and you should have time but sometimes we over commit things so we may not find time.

But the point is very simple that you start with the substrate then you coat the photoresist, pre-bake it or soft bake it at 90 degree or 95 degree 1 minute hot plate then you expose the photoresist by loading the mask and taking help of UV then if it is positive photoresist the pattern that is on the mask will be retained as you can see here finally while in case of negative photoresist the opposite of whatever the pattern is there in the mask will be there on the final wafer.

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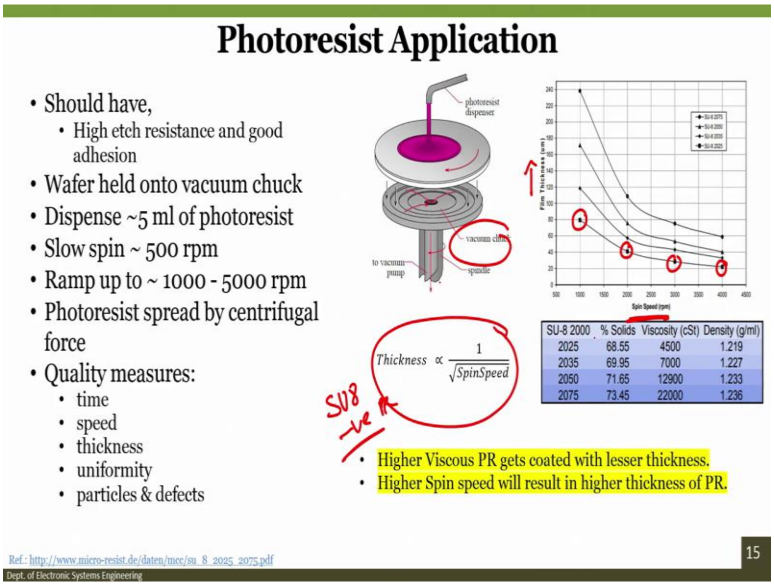


Photoresist Application

- Should have,
  - High etch resistance and good adhesion
- Wafer held onto vacuum chuck
- Dispense ~5 ml of photoresist
- Slow spin ~ 500 rpm
- Ramp up to ~ 1000 - 5000 rpm
- Photoresist spread by centrifugal force
- Quality measures:
  - time
  - speed
  - thickness
  - uniformity
  - particles & defects

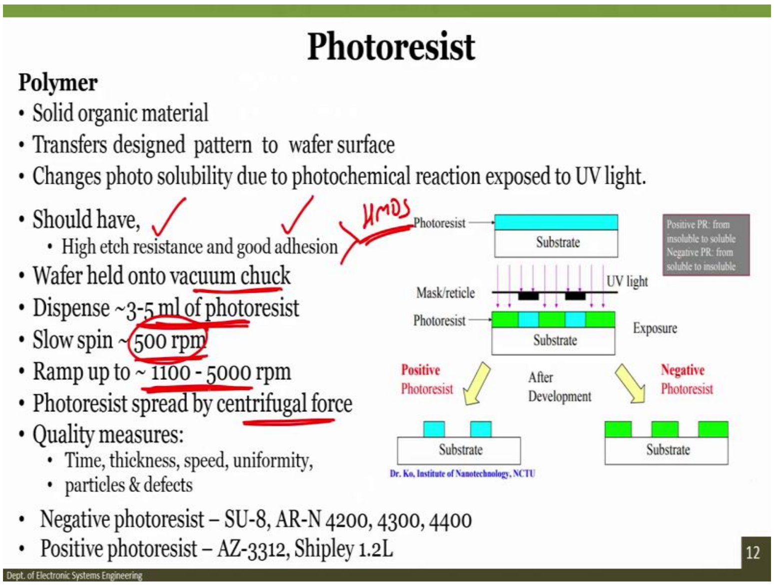
$$Thickness \propto \frac{1}{\sqrt{SpinSpeed}}$$

SU8
-ve PR

SU-8 2000	% Solids	Viscosity (cSt)	Density (g/ml)
2025	68.55	4500	1.219
2035	69.95	7000	1.227
2050	71.65	12900	1.233
2075	73.45	22000	1.236

- Higher Viscous PR gets coated with lesser thickness.
- Higher Spin speed will result in higher thickness of PR.

Ref.: http://www.micro-resist.de/daten/mcc/su_8_2025_2075.pdf



Photoresist

Polymer

- Solid organic material
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- Should have, ✓
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Positive PR: from insoluble to soluble
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Dr. Ko, Institute of Nanotechnology, NCTU

- Negative photoresist – SU-8, AR-N 4200, 4300, 4400
- Positive photoresist – AZ-3312, Shipley 1.2L

So earlier like we have seen this is the photo dispenser, we have discussed about the timings 500 RPM, 1100 to 5000 RPM and 3 to 5 ml of photoresist, here you can see that there is a photoresist dispenser then there is a vacuum chuck onto which the wafer is holded, there is a spindle and there is a vacuum pump so these are, this once again in a different format that what are the photoresist application and what are the properties of photoresist.

So if you reiterate there it is highest resistance and good addition wafer is holded onto the vacuum chuck as you can see on this one slow speed followed by ramping up for and this the quality measures are time, speed, thickness, uniformity and particle size and defects. Here you can see that if you use photoresist which is called SU 8, SU 8 is a negative photoresist.

There is some, so there are some properties of SU 8 which is similar to the negative photoresist however the process steps are little bit different okay they are little bit different and the thickness is inversely proportional to the under root of for spin speed, in this case if the spin speed is in RPM and the thickness is in micrometer you can see that as you increase the thickness, as you increase the speed the thickness would also would decrease correspondingly.

And the equation is given here, so if you are still interested look into that for us to understand is that there is a photoresist called SU 8 which in this process flow is little bit different.

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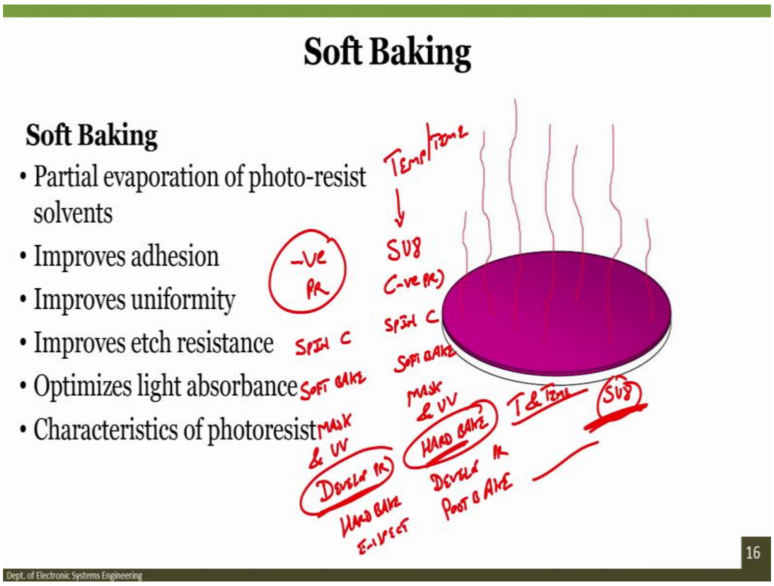

Soft Baking

Soft Baking

- Partial evaporation of photo-resist solvents
- Improves adhesion
- Improves uniformity
- Improves etch resistance
- Optimizes light absorbance
- Characteristics of photoresist

So what is difference, so let us see here, you have negative photoresist and you have SU 8 okay both are negative photoresist both are negative this also works as a negative photoresist. Now in the negative photoresist we, the first step is let us say cleaning the wafer is same then pre-bake and then you have spin coating of the photoresist.

So this spin coat, spin coat, spin coat one step is same second step is you soft bake here also you soft bake, the baking temperature is different 65 degree and timing is different okay so in SU 8 the soft bake temperature and time is different than the regular negative photoresist. After that what we do soft bake then we put the mask and expose with UV, here also you do the same thing mask and expose with UV.

Next step we develop the photoresist in this one you had to form hard bake again temperature and time depends on the type of SU 8 you use, see the difference here after developing photoresist here after UV exposure you have to do hard bake, after this you perform the hard bake, is not it, after this you develop the photoresist.

And then you inspect here in this case you further post bake it, post back it at very high temperature, at very high temperature, post bake it at extremely high temperature not really extremely high is higher than the hard baking temperature so that the SU 8 becomes SU 8 becomes stronger. So in a way what I wanted to show it to you is that the, here the step changes and this is already when you when you open a PDF the data sheet for SU 8 these steps are given of how to develop the SU 8 material.

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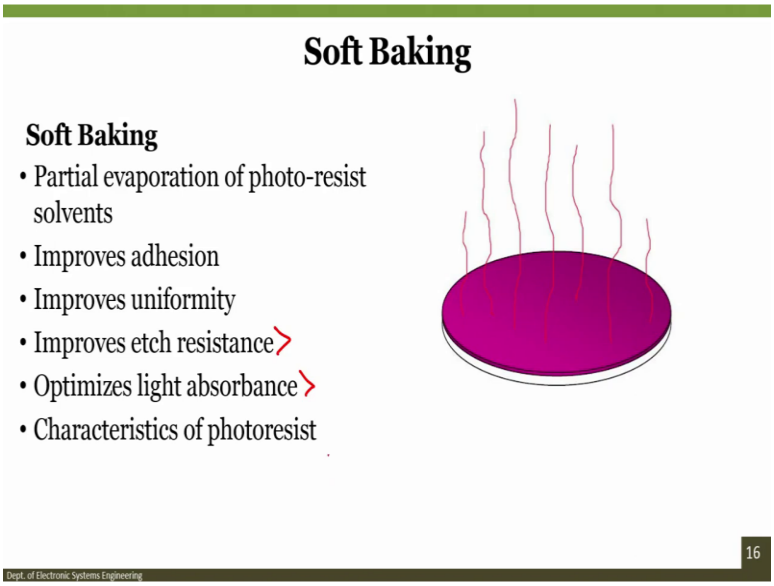

Soft Baking

Soft Baking

- Partial evaporation of photo-resist solvents
- Improves adhesion
- Improves uniformity
- Improves etch resistance >
- Optimizes light absorbance >
- Characteristics of photoresist

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Now the question is why we need to do the soft baking, why we need to do the soft baking, so let us see the soft baking is for partial evaporation of photoresist solvents it improves the adhesion, improves uniformity, improves etch resistance, optimize the light absorbance and it is a characteristics of a photoresist, so that is the reason of using soft bake.

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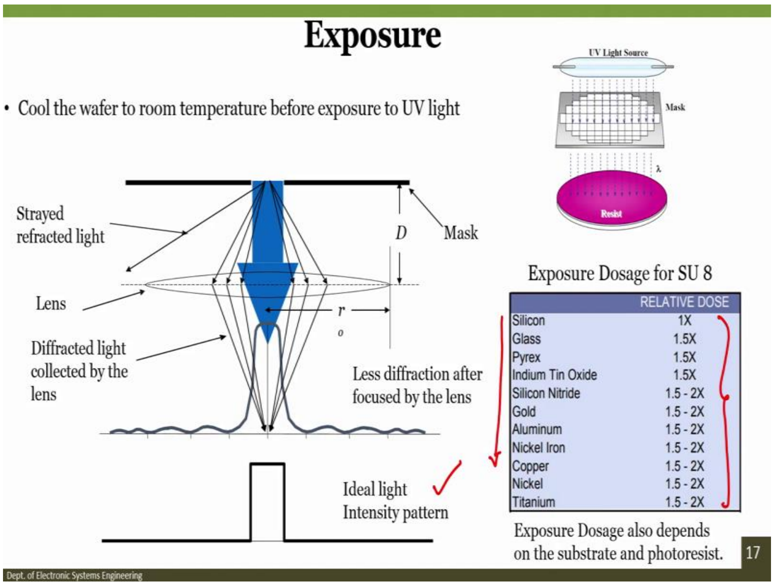

Exposure

- Cool the wafer to room temperature before exposure to UV light

Exposure Dosage for SU 8

	RELATIVE DOSE
Silicon	1X
Glass	1.5X
Pyrex	1.5X
Indium Tin Oxide	1.5X
Silicon Nitride	1.5 - 2X
Gold	1.5 - 2X
Aluminum	1.5 - 2X
Nickel Iron	1.5 - 2X
Copper	1.5 - 2X
Nickel	1.5 - 2X
Titanium	1.5 - 2X

Exposure Dosage also depends on the substrate and photoresist.

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If you want to go for exposure, we will take a detailed TA class on why and how this UV exposure works and in this case you can see the schematic that the ideal light intensity pattern should be in this way. However, when we actually get the diffracted light collector by the lens and the less diffraction after focused by the lens, the ideal versus this is an actual one, practical one.

And the you can see the light passing through the mask and it passes through the lens and the refracted light collected by lens how it looks like and in this case you, if you use SU 8 then the exposure dosage would be different depending on the type of the material that you use, so like a type of substrate you use. So if you use SU 8 on silicon the related dose is 1X but if it is glass then you have to increase the relative dose pyrex, ITO, silicon nitride, gold, aluminium so and so forth.

So you can see that the relative dose for the exposure would change and rather increase from silicon all the way to the titanium, so you need to also understand what kind of substrate you are using on which you have the SU 8 material. Now always understand that you need to cool the wafer to room temperature before exposing to the UV light.

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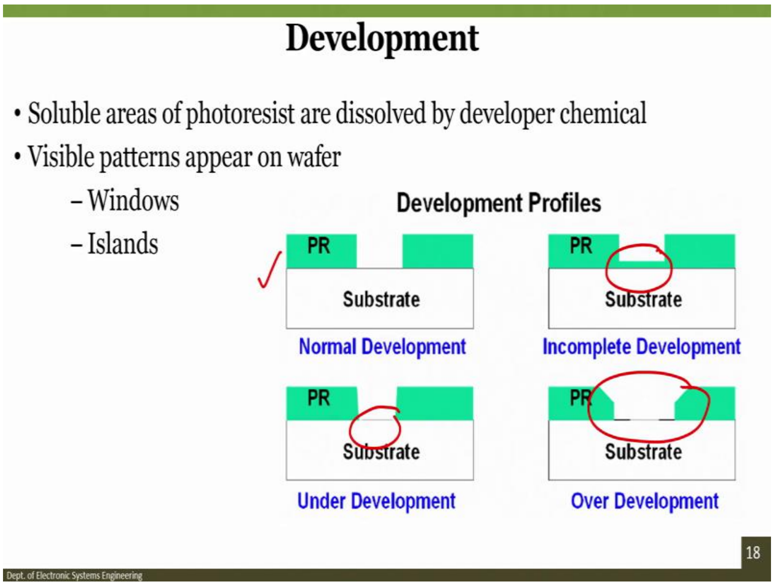

Development

- Soluble areas of photoresist are dissolved by developer chemical
- Visible patterns appear on wafer
  - Windows
  - Islands

Development Profiles

Normal Development

Incomplete Development

Under Development

Over Development

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When you have developer you need to also understand it is like a recipe, the one is recipe and one is process flow so it is important that what kind of chemicals you use to etch different materials also the time, if the time is more or the time is less than the process will not be successful, for example, in this case you can see the development profile of the photoresist when the time is optimized, normal development you have beautiful photoresist pattern on the substrate.

But if you are impatient and you stop before the actual time you can see that incomplete development, you if it is or it can be also under development as you can see here. But if you are too patient instead of one may let the wafer sit in the developer for 1.5 minutes, 1 minute 30 seconds then you will have the over development so it is very important to optimize the parameter and stick to the timings, so visible patterns appear on the wafer windows and islands.

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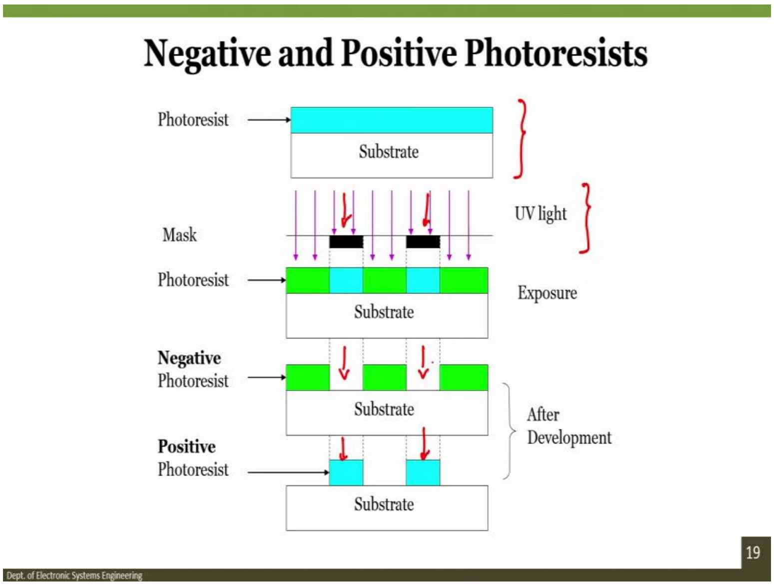

Negative and Positive Photoresists

Now if you coat the photoresist onto a substrate and you expose the UV light so depending on the type of the photoresist, if it is positive photoresist you will have the same pattern as you can see here and in this case while in case of negative photoresist the area which is not exposed will get weaker and you can get the opposite pattern.

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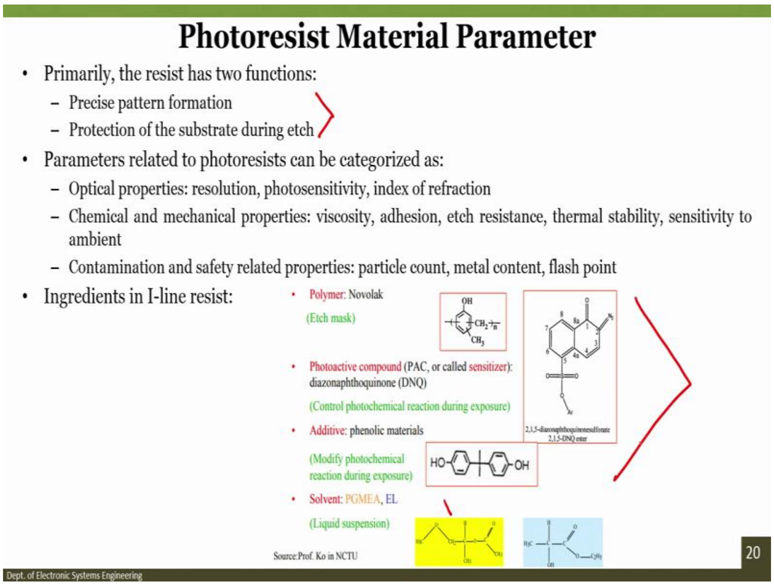

Photoresist Material Parameter

- Primarily, the resist has two functions:
  - Precise pattern formation
  - Protection of the substrate during etch
- Parameters related to photoresists can be categorized as:
  - Optical properties: resolution, photosensitivity, index of refraction
  - Chemical and mechanical properties: viscosity, adhesion, etch resistance, thermal stability, sensitivity to ambient
  - Contamination and safety related properties: particle count, metal content, flash point
- Ingredients in I-line resist:
  - Polymer: Novolak
    (Etch mask)
  - Photoactive compound (PAC, or called sensitizer): diazonaphthoquinone (DNQ)
    (Control photochemical reaction during exposure)
  - Additive: phenolic materials
    (Modify photochemical reaction during exposure)
  - Solvent: PGMEA, EL
    (Liquid suspension)

Source:Prof. Ko in NCTU

Now let us see the material parameter although this is not too important for this particular course this is just for our understanding okay, so the primarily the resist has two functions the main functions are the precise pattern formation and protection of the substrate during the etching these are the two main functions of the photoresist, the parameters related to photoresist can be categorized as follows one is the optical parameter, second is the chemical and mechanical properties of the tissue.

The first optical properties includes the resolution, photosensitivity, index of refraction while the second one which is chemical and mechanical properties include viscosity, adhesion, etch resistance, thermal stability, sensitivity to ambient and so on, so the contamination and safety related properties which is particle counts, metal content and flash point, ingredients in the I-line resist are this many let us not really go into details of the ingredients because it is way off then what we are looking at right, so let us not worry about it.

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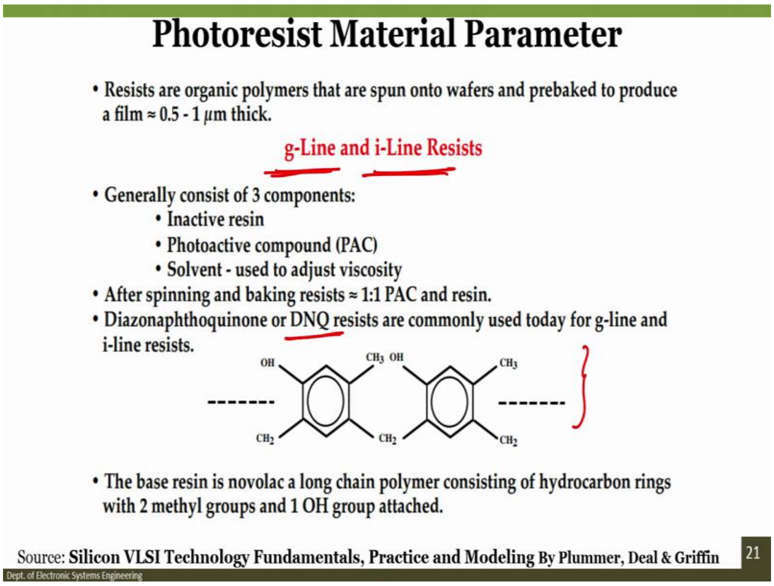

Photoresist Material Parameter

- Resists are organic polymers that are spun onto wafers and prebaked to produce a film ≈ 0.5 - 1 μm thick.

g-Line and i-Line Resists

- Generally consist of 3 components:
  - Inactive resin
  - Photoactive compound (PAC)
  - Solvent - used to adjust viscosity
- After spinning and baking resists ≈ 1:1 PAC and resin.
- Diazonaphthoquinone or DNQ resists are commonly used today for g-line and i-line resists.

- The base resin is novolac a long chain polymer consisting of hydrocarbon rings with 2 methyl groups and 1 OH group attached.

Source: **Silicon VLSI Technology Fundamentals, Practice and Modeling** By Plummer, Deal & Griffin

These for people who are, who was interested in understanding that how the resist commonly used for g-line and i-line resist or DNQ resist are commonly used for the i-line or g-line for you, you do not have to worry about how this is formed but for some of the applications it is very important to understand what is g-line and i-line resist, the thickness of this resist is generally between 0.5 micron to 1 micron.

And it consists of three different components inactive resin, photoactive compound and solvent and the after you spin and bake you have 1 is to 1 PAC and resin which is photoactive compound and the resin and like I told earlier that for g-line and i-line DNQ resist are generally used and the base resin is Novolac a long chain of polymer consisting of hydrocarbon rings with 2 methyl groups and 1 OH group attached, as you can see in this figure but let us not worry about it at all.

I will not ask you question, no assignment, no homework, no questions in exam from this particular slide okay let us not worry about it.

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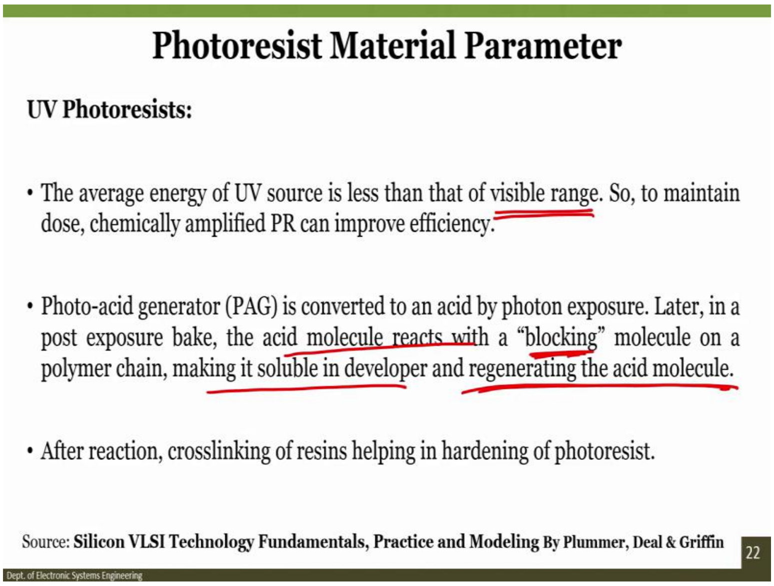

Photoresist Material Parameter

UV Photoresists:

- The average energy of UV source is less than that of visible range. So, to maintain dose, chemically amplified PR can improve efficiency.
- Photo-acid generator (PAG) is converted to an acid by photon exposure. Later, in a post exposure bake, the acid molecule reacts with a "blocking" molecule on a polymer chain, making it soluble in developer and regenerating the acid molecule.
- After reaction, crosslinking of resins helping in hardening of photoresist.

Source: **Silicon VLSI Technology Fundamentals, Practice and Modeling By Plummer, Deal & Griffin**

Dept. of Electronic Systems Engineering

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So but you need to also understand a little bit on what should be the material parameter for photoresist okay so the average energy of UV source is less than that of visible range so to maintain those chemically amplified photoresist can improve the efficiency, that is the reason why we have photoresist which can be chemically amplified.

Photo acid generator is converted to an acid by photon exposure, later in a post exposure bake the acid molecule reacts with a blocking molecule on a polymer chain making it soluble in developer and regenerating the acid molecule, so that is how the photoresists are developed and if after reaction cross linking of resins helps in the hardening of the photoresist, so once you expose it and once you develop it then when you do the hard baking this cross linking of resins will help it to form harder, help would, help who, help the photoresist.

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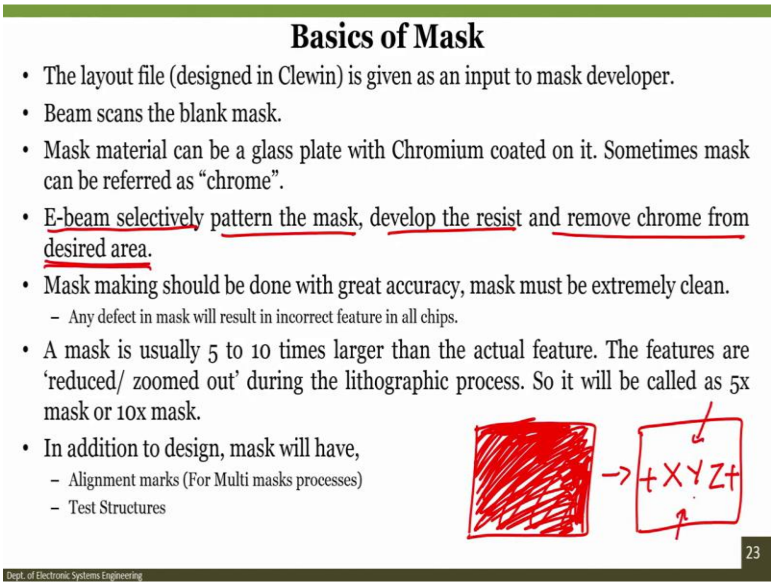
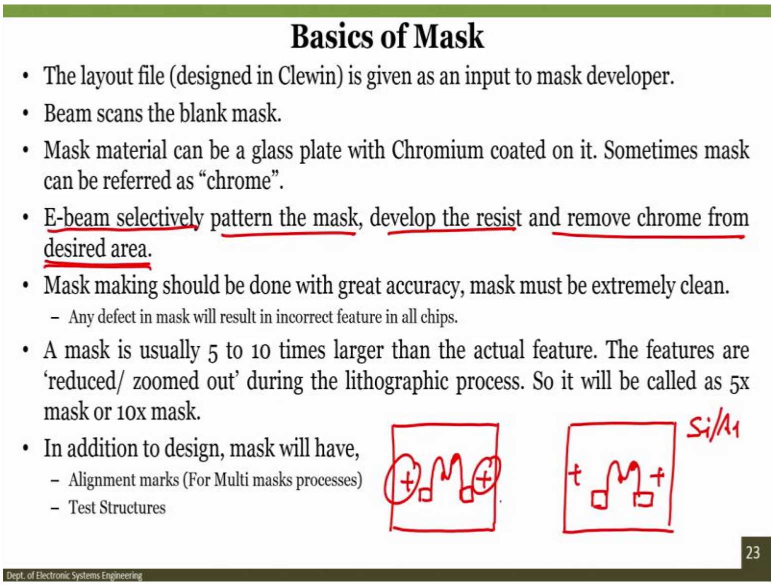


Basics of Mask

- The layout file (designed in Clewin) is given as an input to mask developer.
- Beam scans the blank mask.
- Mask material can be a glass plate with Chromium coated on it. Sometimes mask can be referred as "chrome".
- E-beam selectively pattern the mask, develop the resist and remove chrome from desired area.
- Mask making should be done with great accuracy, mask must be extremely clean.
  - Any defect in mask will result in incorrect feature in all chips.
- A mask is usually 5 to 10 times larger than the actual feature. The features are 'reduced/ zoomed out' during the lithographic process. So it will be called as 5x mask or 10x mask.
- In addition to design, mask will have,
  - Alignment marks (For Multi masks processes)
  - Test Structures



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Now from photoresist let us go to the next part which is the basic of mask we have seen that there are two masks bright field mask and the dark field mask, is not it, so let us see what are the basics of mask. So for the mask the layout file is generally drawn using the Clewin software and it is given as a input to the mask developer, beam scans the blank mask the and then mask material can be a glass plate with chromium coated on it sometime mask can be referred as the chrome mask okay.

So because there is a chromium coated and you pattern the chrome that is why it is called a chrome mask, e-beam selectively pattern the mass develop the resist and remove the chrome from the desired area thus a initially if the mask has chrome everywhere, everywhere there is a chrome you assume that this is fully dark block and when you have this e beam scanning through this one and when you develop it finally you can get the pattern which you want it can be let us say like this.

So e beam selectively patterns the mask develops the resist and remove the chrome from the desired area so all the area which accept that X Y Z and plus we do not want chrome so this is called the chrome mask and masking should be done with the great accuracy, a mask should be always extremely clean because any defect in the mass could result in incorrect features in all the chips.

Now when we say chips because they are microchips generally we talk about the electronics where you talk about transistors so there are many transistor in one single dye, what does it mean, suppose this is on silicon wafer and you have let us say aluminium on the silicon wafer so if you have a mask then if the mask says that you have this particular pattern like this if there are, so let me just draw this pattern once again what I wanted to show is let us say this only m okay.

Now if there is a defect in the mask what will happen if the defect in the mask then defect in the wafer would be further carried out, suppose there is a extra dot here then you will have this with extra dot, metal will not get etched the aluminium will stay there or if this line is shorted like this then here also you can replicate the same thing, so the defects should not be there because any defect in the mask will come on the silicon wafer.

Next what we see a mask is usually 5 to 10 times larger than actual feature, the features are reduced or zoom out during the lithographic process it will be called as a 5X or 10X mask in addition to design mask will have the alignment marks which is here and for multiple mask process and text structures we will see the role of the alignment mark in the next class but you do remember that the mask has the alignment marks okay.

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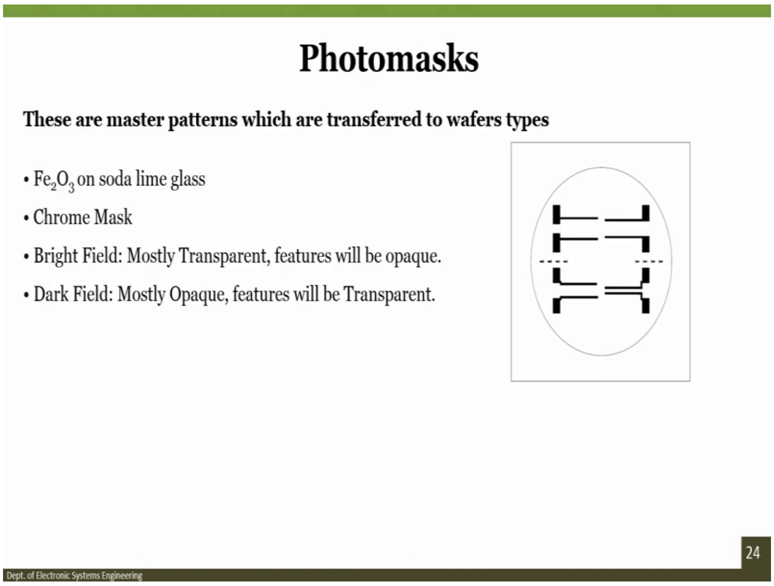

Photomasks

These are master patterns which are transferred to wafers types

- Fe_2O_3 on soda lime glass
- Chrome Mask
- Bright Field: Mostly Transparent, features will be opaque.
- Dark Field: Mostly Opaque, features will be Transparent.

So if you see further on the slide you have photo mask and the photo mask are of several types but basically we divide into two, one is Fe_2O_3 on soda lime glass and second one is a chrome mask then there is a bright field mask and there is a dark field mask and we have discussed this thing earlier I have shown the mask to you as well, so in the bright field mask the field is mostly transparent and features are opaque, in the dark field mask mostly the field is dark and a features will be transparent.

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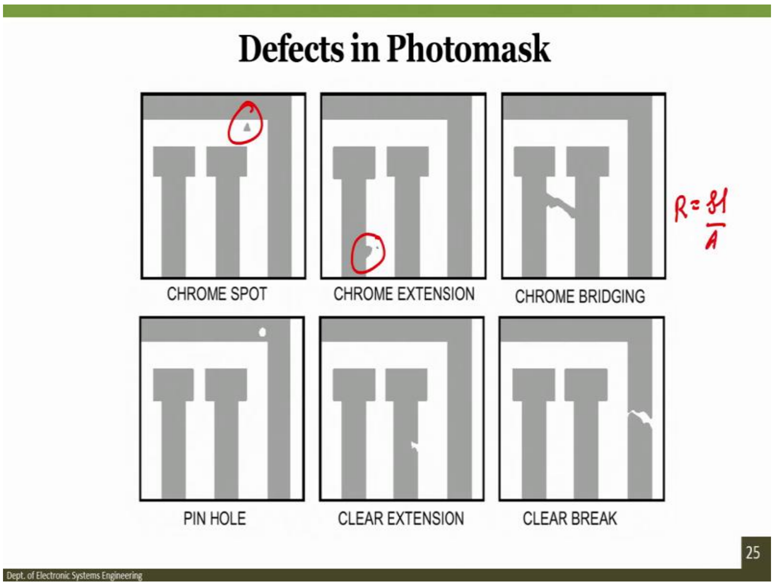
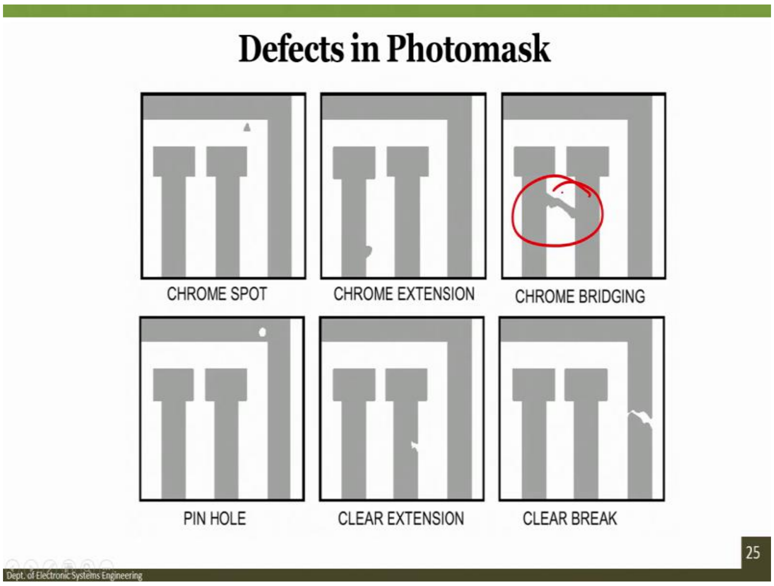
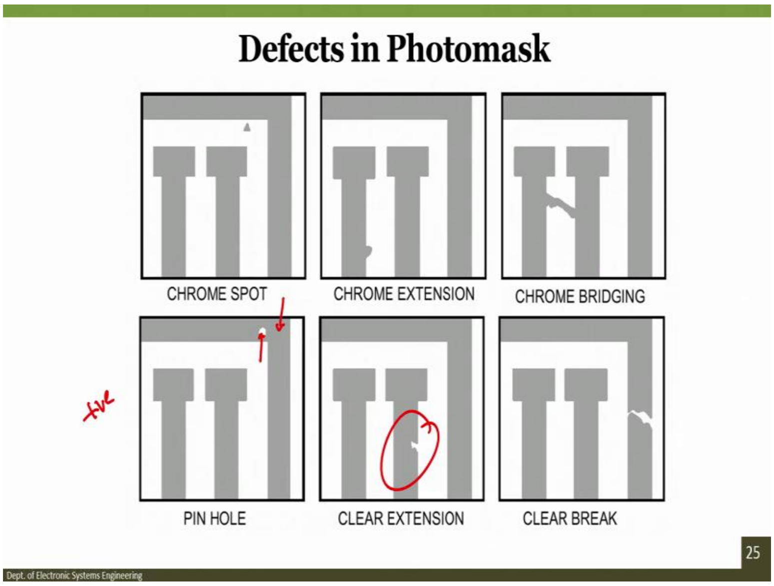


Defects in Photomask

$R = \frac{\rho l}{A}$



Defects in Photomask



Defects in Photomask

So these are some of the defects in the photo mask as you can see there is a chrome spot right here, if it is outside the feature area we do not care but if it is within that region it is extremely harmful because lot of components will get killed because of that particular small chrome spot then we have chrome extension.

If you talk about a heater the resistance value that we calculate rho l by A in this case the l will change because here and so is the area so then the whole resistance value that you have used during simulation will not match the experimental values. If there is a chrome bridging then for sure there is a short and we cannot use it, if there is a hole that means that instead of this region which should be dark there is a transparent region.

So the photoresist in this region would get etched and in this region not get etched if it is a positive photoresist, so it is negative then opposite will happen if there is a clear extension that means that again the value would not be correct and finally if you have crack then the current will not flow or the resistance would be infinite because there is a crack in the mask so these are some of the defects that you can find in the photo mask.

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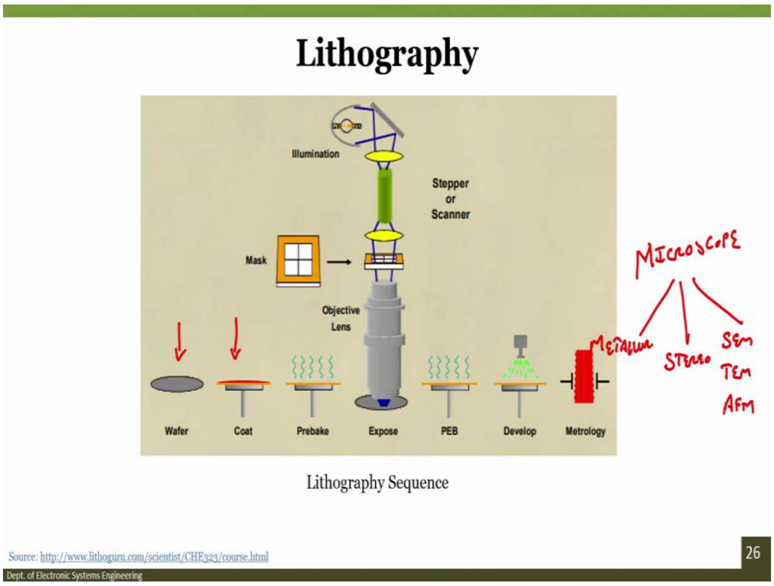


Lithography

Lithography Sequence

MICROSCOPE

METALLUR

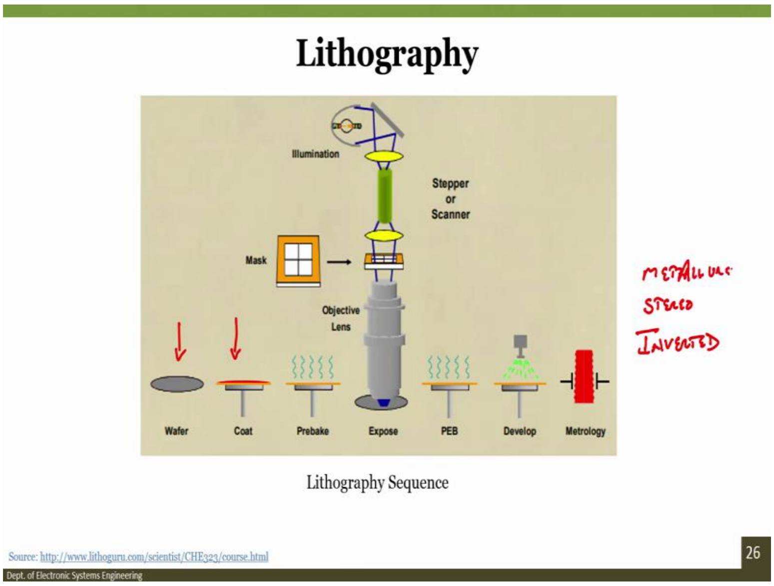
STEREO

SEM

TEM

AFM

Source: http://www.lithoguru.com/scientist/CHE323/course.html



Lithography

Lithography Sequence

METALLURG

STEREO

INVERTED

Source: http://www.lithoguru.com/scientist/CHE323/course.html

Now the lithography sequence if you understand then you have a wafer, then you coat the wafer, pre-bake it then or soft bake it and then you prebake some books they write pre-bake expose and pre-bake exposure develop and then look at the inspection in some of the books you will find that it is called soft bake and hard bake.

So in this thing which is on the lithoguru scientist CHE323 course the way they have illustrated is that you take a wafer you coat the wafer with the photoresist, you pre-bake it at 95 degrees centigrade 1 minute on hot plate then you have you expose it by using the mask then you do the post exposure bake or a hard bake and followed by develop it with the photoresist developer and then finally inspect it with the several meteorological tools.

So the easy one is the microscope, microscope, but in microscope also there are several kinds of microscope, one is the metallurgical microscope, second one is the stereo, third one is SEM, fourth one is TEM, so then fifth one is AFM, so SEM is, metallurgical microscope, stereo microscope we will show it to you, SEM stands for scanning electron microscopy, TEM stands for transmission electron microscopy and AFM stands for the atomic force microscopy.

So we can generally it is divided into two paths, the metallurgical microscope, stereo microscope and third part is inverted microscope, inverted, stereo and metallurgical, metallurgical so you have three kinds of microscopes, so that is how the lithography sequence is defined.

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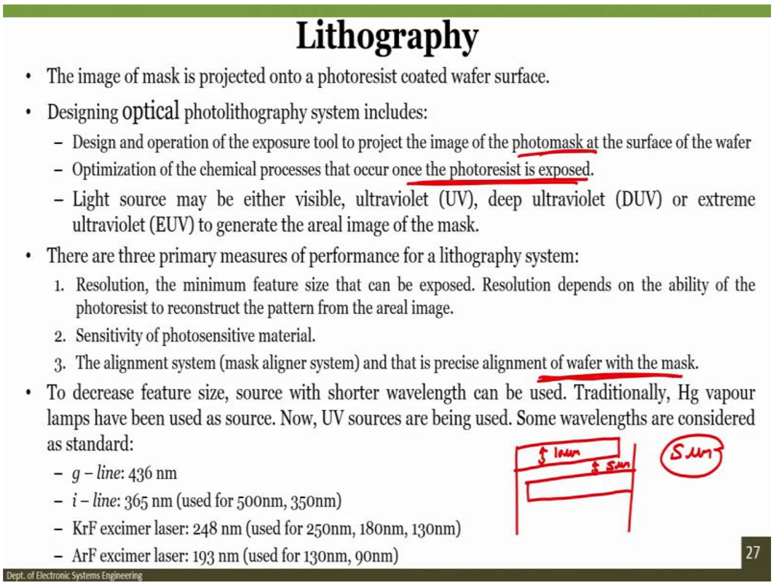

Lithography

- The image of mask is projected onto a photoresist coated wafer surface.
- Designing optical photolithography system includes:
  - Design and operation of the exposure tool to project the image of the photomask at the surface of the wafer
  - Optimization of the chemical processes that occur once the photoresist is exposed.
  - Light source may be either visible, ultraviolet (UV), deep ultraviolet (DUV) or extreme ultraviolet (EUV) to generate the areal image of the mask.
- There are three primary measures of performance for a lithography system:
  1. Resolution, the minimum feature size that can be exposed. Resolution depends on the ability of the photoresist to reconstruct the pattern from the areal image.
  2. Sensitivity of photosensitive material.
  3. The alignment system (mask aligner system) and that is precise alignment of wafer with the mask.
- To decrease feature size, source with shorter wavelength can be used. Traditionally, Hg vapour lamps have been used as source. Now, UV sources are being used. Some wavelengths are considered as standard:
  - *g – line*: 436 nm
  - *i – line*: 365 nm (used for 500nm, 350nm)
  - KrF excimer laser: 248 nm (used for 250nm, 180nm, 130nm)
  - ArF excimer laser: 193 nm (used for 130nm, 90nm)

Now further the explanation of the lithography is this that the image of the mask is projected onto photoresist coated with the wafer surface and during the optical photolithography the system includes what, system will include, the system includes design and operation of the exposure tool to the project the image of the photomask at the surface of the wafer, second is optimization of the chemical processes that occur once the photoresist is exposed, next one is light source may be either visible, ultraviolet, deep ultraviolet or extreme ultraviolet.

It is like you, visible, UV, DUV or EUV to generate the aerial image of the mask then the three types of measurement performance of the lithography system, now from if you use a photo lithography what is, how you will understand the performance, so first one is the resolution that is the minimum feature size that you need to understand then for example if what is the minimum feature size you can get?

So let me take an example of an interdigitated electrode, interdigitated electrode, so if I say that I can successfully fabricate each finger for 10 micrometer and a spacing between the finger can be 5 micrometer I can say that the resolution or the minimum feature size that my lithography tool can provide is 5 micrometer, what is the minimum?

The smallest feature size, the resolution depends on the ability of the photoresist is to reconstruct a pattern from the aerial image that we know, sensitivity of the photosensitive material and finally the alignment mask system and that is precise alignment of the wafer within the mask. So these are some of the primary measures of the performance of the lithography system and further if you want to decrease the feature size.

For example, from 5 micron to 1 micron and below the way to do that is source with a shorter wavelength can be used so traditionally mercury vapor lamps have been used as source, now UV source are being used, some wavelengths are considered as standard for example for g-line or i-line which is 436 nanometer or 365 nanometer or if it is a KrF excimer laser which falls into 48 nanometer or ArF excimer laser which is then 193 nanometer. So the point is with the shorter wavelength the feature size can further be reduced.

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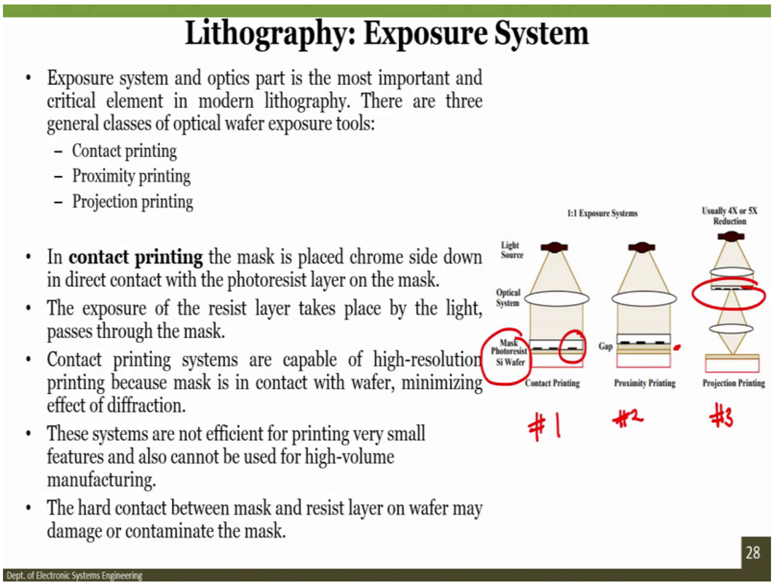

Lithography: Exposure System

- Exposure system and optics part is the most important and critical element in modern lithography. There are three general classes of optical wafer exposure tools:
  - Contact printing
  - Proximity printing
  - Projection printing
- In **contact printing** the mask is placed chrome side down in direct contact with the photoresist layer on the mask.
- The exposure of the resist layer takes place by the light, passes through the mask.
- Contact printing systems are capable of high-resolution printing because mask is in contact with wafer, minimizing effect of diffraction.
- These systems are not efficient for printing very small features and also cannot be used for high-volume manufacturing.
- The hard contact between mask and resist layer on wafer may damage or contaminate the mask.

We called something called e-beam lithography that is used to fabricate several transistors but we in this topic or in this course we will stick to the photolithography so when you talk about lithograph or exposure system further there are three classes of optical wafer exposure tools one is called contact printing which you can see here, the second one.

So let me say 1 2 3, first is a contact printing where the mask is in contact with the wafer, the mask is in contact the mask is in contact with the silicon wafer. Then second is the proximity printing whether there is a slight difference the gap that is there between the mask and the wafer, while the third one is the projection printing where the patterns are projected onto the mask so in contact printing the mask is placed chrome side down in a direction contact with the photoresist layer on the mask.

The exposure of the resist layer takes place by the light passing through the mask and contact printing systems are capable of high resolution printing because mask is in contact with the wafer minimizing the effect of the diffraction. Finally, these systems are not efficient for printing very small features and also cannot be used for high volume manufacturing, the last one is the hard contact between mask and resist on the wafer may damage or contaminate the mask.

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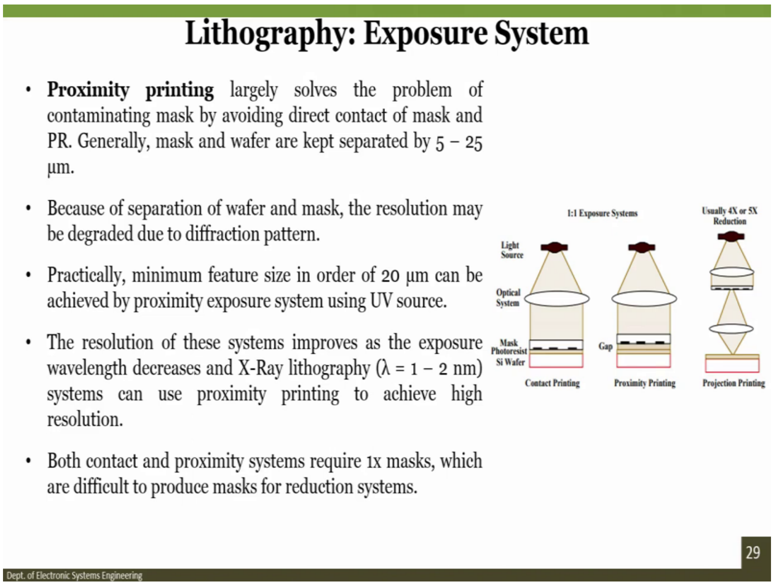

Lithography: Exposure System

- **Proximity printing** largely solves the problem of contaminating mask by avoiding direct contact of mask and PR. Generally, mask and wafer are kept separated by 5 – 25 µm.
- Because of separation of wafer and mask, the resolution may be degraded due to diffraction pattern.
- Practically, minimum feature size in order of 20 µm can be achieved by proximity exposure system using UV source.
- The resolution of these systems improves as the exposure wavelength decreases and X-Ray lithography (λ = 1 – 2 nm) systems can use proximity printing to achieve high resolution.
- Both contact and proximity systems require 1x masks, which are difficult to produce masks for reduction systems.

But if we talk about proximity printing then in proximity printing the solution will help to solve the problem of contamination because of the mask because even though the mask is very close to the wafer it is not in contact with the wafer and generally the distance that is kept between wafer and the mask is about 5 to 25 micrometer.

Now because of the separation of the wafer and the mask what we find I say the resolution may be degraded but due to the diffraction pattern but the minimum feature size in order of

20 micron can be achieved by proximity exposure system using UV source and the resolution of the system improves the exposure and wavelength decreases.

So if you decrease the wavelength then the resolution will increase and x-ray lithography which is about 1 to 2 nanometer wavelength system can be used proximity, can use proximity printing to achieve higher resolution, finally both contact and proximity systems require 1X mask which are difficult to produce mask for reduction systems.

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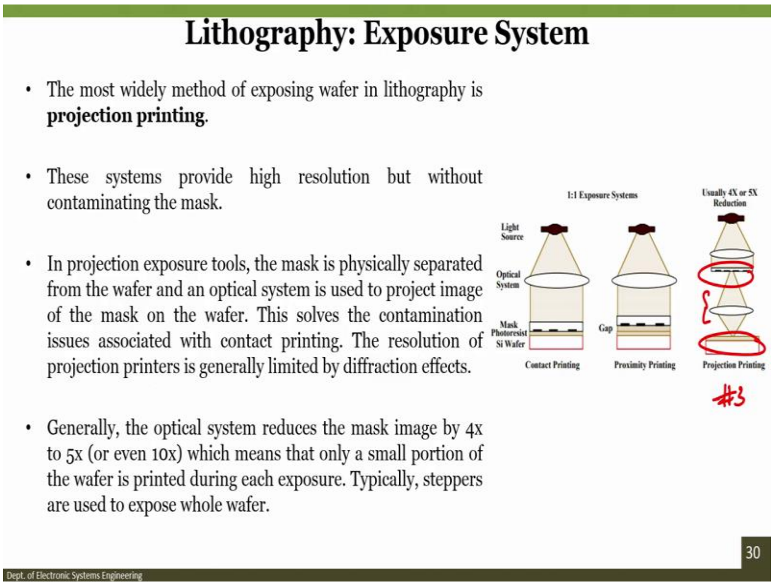

Lithography: Exposure System

- The most widely method of exposing wafer in lithography is **projection printing**.
- These systems provide high resolution but without contaminating the mask.
- In projection exposure tools, the mask is physically separated from the wafer and an optical system is used to project image of the mask on the wafer. This solves the contamination issues associated with contact printing. The resolution of projection printers is generally limited by diffraction effects.
- Generally, the optical system reduces the mask image by 4x to 5x (or even 10x) which means that only a small portion of the wafer is printed during each exposure. Typically, steppers are used to expose whole wafer.

So what is the advantage of projection printing, number 3 projection printing, the most widely method of exposing wafer, wafer in lithograph is using the projection printing, this systems provide high resolution without contaminating the mass the most important advantage, second is in projection exposure tools the mask is physically separated from the wafer and an optical system is used to project.

You can see here the mask is right here the wafer is here but in between there is a optical system that is used to project the image of the mask on the wafer and this solves the contamination issues and the resolution of projection printer is generally limited by the diffraction effects. The optical system that is used in the projection printing reduces the mask image by 4X or 5x or even 10x which means that only a small portion of the wafer is printed during each exposure, typically steppers are used to expose the entire wafer.

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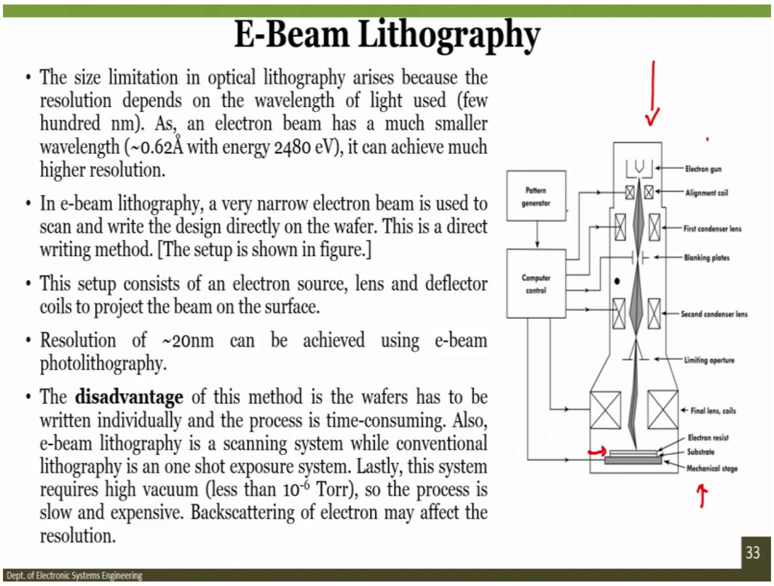

E-Beam Lithography

- The size limitation in optical lithography arises because the resolution depends on the wavelength of light used (few hundred nm). As, an electron beam has a much smaller wavelength (~0.62Å with energy 2480 eV), it can achieve much higher resolution.
- In e-beam lithography, a very narrow electron beam is used to scan and write the design directly on the wafer. This is a direct writing method. [The setup is shown in figure.]
- This setup consists of an electron source, lens and deflector coils to project the beam on the surface.
- Resolution of ~20nm can be achieved using e-beam photolithography.
- The **disadvantage** of this method is the wafers has to be written individually and the process is time-consuming. Also, e-beam lithography is a scanning system while conventional lithography is an one shot exposure system. Lastly, this system requires high vacuum (less than 10^{-6} Torr), so the process is slow and expensive. Backscattering of electron may affect the resolution.

If we see the slide what we see here is a e beam lithography, please look into the each section from electron gun all the way to mechanical stage, just read one by one, so what you find, what you find is from electron beam gun or electron gun to alignment coil, first condenser lens, blanking plates, second condenser lens, limiting aperture, final lens, electron resist, substrate and mechanical stage.

That is how the things are there and the beam will scan across this particular resist and the pattern generator and the computer control are attached along with e beam lithography. The size limitation in optical lithography arises because of the resolution depends on the wavelength of the light we already know that and that is why because the electron beam has much smaller wavelength, it can achieve much higher resolution.

Typically in the photo lithography we will have the minimum feature size no lesser than 2 microns, in e beam lithography a very narrow electron beam is used to scan and write the design directly on the wafer, this is the direct writing method. And most of these things we use this direct writing method very often when we want feature size below 2 microns, the setup consists of an electron source, lens and deflector coil so project the beam on the surface, the resolution of 20 nanometer can be achieved by using the e beam lithography.

The disadvantage now every system has advantage and disadvantage or limitation, the limitation of this one or the disadvantage of this method is the wafers has to be written individually and the process is time consuming, so also e beam lithography is a scanning system while conventional lithography is one shot exposure.

You see you have to scan the entire wafer and it takes longer time compared to the normal conventional lithography system with the UV source. Lastly the system requires high vacuum so the process is slow and expensive, back scattering of electron may affect the resolution.

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Commercially Available Mask Aligners

https://www.youtube.com/watch?v=_nmlxEhBDWU

https://www.youtube.com/watch?v=BwODuUo-kMA

https://www.youtube.com/watch?v=zLvz4COyqoo

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So as I told you that there are certain aligners, mask liners I will not give you this mask aligners because you can easily find those on the YouTube you can write down the mask aligners in YouTube and you can find those things so the videos that I will be sharing with you will not be something that falls in the YouTuber or has a copyright but I will try to get you some open access videos which will help which is there for a general public okay.

So but in any case what I want is just go through some of these videos that I am showing it on this slide you can copy the text and paste it on your system and look into that okay so I am not going to play it here.

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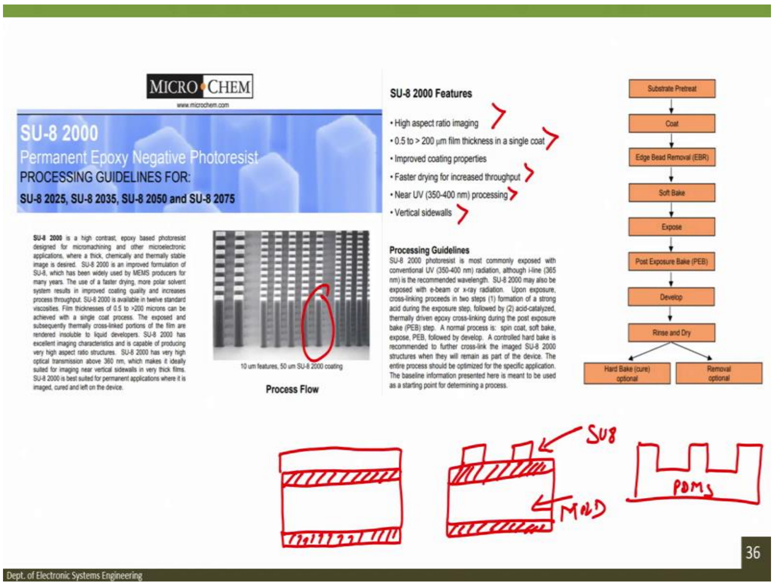

MICRO CHEM

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SU-8 2000

Permanent Epoxy Negative Photoresist

PROCESSING GUIDELINES FOR:

SU-8 2025, SU-8 2035, SU-8 2050 and SU-8 2075

SU-8 2000 is a high contrast, epoxy based photoresist designed for micromachining and other microelectronic applications, where a thick, chemically and thermally stable image is desired. SU-8 2000 is an improved formulation of SU-8, which has been widely used by MEMS producers for many years. The use of a faster drying, more polar solvent system results in improved coating quality and increases process throughput. SU-8 2000 is available in twelve standard viscosities. Film thicknesses of 0.5 to >200 microns can be achieved with a single coat process. The exposed and subsequently thermally cross-linked portions of the film are rendered insoluble to liquid developers. SU-8 2000 has excellent imaging characteristics and is capable of producing very high aspect ratio structures. SU-8 2000 has very high optical transmission above 360 nm, which makes it ideally suited for imaging near vertical sidewalls in very thick films. SU-8 2000 is best suited for permanent applications where it is imaged, cured and left on the device.

10 um features, 50 um SU-8 2000 coating

Process Flow

SU-8 2000 Features

- High aspect ratio imaging
- 0.5 to > 200 μm film thickness in a single coat
- Improved coating properties
- Faster drying for increased throughput
- Near UV (350-400 nm) processing
- Vertical sidewalls

Processing Guidelines

SU-8 2000 photoresist is most commonly exposed with conventional UV (350-400 nm) radiation, although i-line (365 nm) is the recommended wavelength. SU-8 2000 may also be exposed with e-beam or x-ray radiation. Upon exposure, cross-linking proceeds in two steps (1) formation of a strong acid during the exposure step, followed by (2) acid-catalyzed, thermally driven epoxy cross-linking during the post exposure bake (PEB) step. A normal process is: spin coat, soft bake, expose, PEB, followed by develop. A controlled hard bake is recommended to further cross-link the imaged SU-8 2000 structures when they will remain as part of the device. The entire process should be optimized for the specific application. The baseline information presented here is meant to be used as a starting point for determining a process.

Substrate Pretreat

Coat

Edge Bead Removal (EBR)

Soft Bake

Expose

Post Exposure Bake (PEB)

Develop

Rinse and Dry

Hard Bake (cure) optional

Removal optional

I am just going to the next slide and that is your SU 8 200 permanent epoxy negative photoresist, I had told you that the way this resist is used is to create mold, what is mold we will talk about in the next lecture for now you just understand that if you have an oxidized silicon wafer and you want to have some features that can permanently stay on the oxidized silicon wafer, one way is to by etching the wafer itself facing the silicon.

The second way is that if you have SU 8 and you can pattern this SU 8 in the form that we want and that can stay for longer time this is hard material then you can use SU 8 as a mold. So for example I will pattern SU 8 like this and this SU 8 will stay there forever until unless I want to etch it using oxygen plasma.

So now on this one if I pour anything, let us say I pour some material like PDMS and cure it and remove it then I will have feature size which will look like this in PDMS and I can retain once I have this PDMS peeled off from this wafer, then I can retain my SU 8 again, so this wafer can act as a mold, m-o-l-d or m-o-u-l-d both terms are correct.

The advantage of this SU 8 is that it has a high aspect ratio imaging 0.5 to 200 micron thickness we can get in a single quote, it has improved coating properties, faster drying for increase throughput, near UV processing and vertical side walls, you can see very beautiful pillars here with 10 Micron features, 50 micrometer SU 8 2000 coating and all these things you can find from the micro cam website about how to use the suite materials whether it is SU 8 2025 2035 2050 or 2075.

We will talk about the soft lithography in the next class till then what I feel is let us stop here and then we can go and understand more about how to utilize soft lithography and also some more videos for you to grasp the different photolithography unit, different mask aligners, so along with soft lithography we will now go little bit deep into understanding how to use multiple mask process.

Right now we have used only one mask, there is a plus and then there is a wafer and you align it and that is it but what happens if there are multiple masks and how to use a multiple mask using the single on the same wafer, so how to align it that is a part of the next session.

Till then if you have any questions feel free to send email if it is really a tricky question that you do not get solution from the NPTEL portal otherwise please use the NPTEL portal for your queries and as I promised earlier we will try to solve the queries if we know or we will try to find it out the solution for your queries and get back to you on the portal, till then you take care I will see you in the next session. Cheers.