Microscale Transport Processes

Prof. S. Ganguly
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture No. #06
Photolithography

I welcome you once again to this course on microscale transport process.What we were discussing is various manufacturing methods to form a micro microscaledevice,and I mentioned thatthetraditional micromachining process that is typically employed in mechanical fabrication that can always be employed here as well.However, there are alternative routes people are looking for.

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Photolithography mask

- Protects certain part of a resist from illumination (spectral band 300 nm to 450 nm).
- Plates of quartz on which deposits of chrome forms a pattern.
- Deposition is made using electron beams.
- A less-precise one can be just a print-out on plastic transparency sheet.

Andthesephotolithography techniquethat is one such method,which has been borrowed fromsemiconductorfabrication processes;that the method has been tuned, method has beentailored forfabrication of microscale devices. So, the essence of this technique has been taken form semiconductor manufacturing; however, the technique has been tailored forthesefabrications of microscale devices.Now, we need to discuss first how this photolithography works?Basically, you have to create a channel on a micro,you have to create a channel on a silicon plate, that channel will act as a microchannel.

Now, when it comes to making a channel of aperture or of width one millimeter, you can always do it in a conventional, in a traditionalmachining process, using something called lathe machine.However, when it comes to making a channel which has width of one micrometer orsomewhatwidth of the order of one micrometer, it is difficult;I mean one micro meteris avery small dimension.

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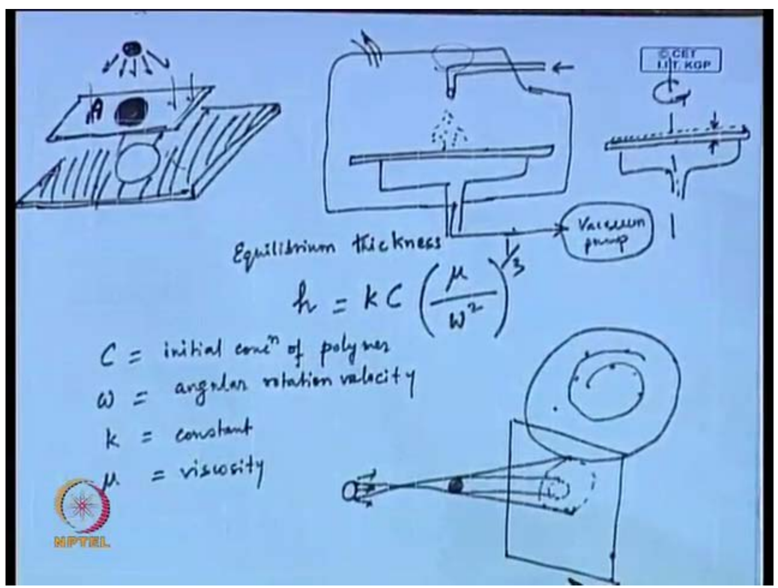

Sothe method that iscommonly employed to make a channel of one micrometer on a silicon substrate is that a light source is therein the top; then there is a,so light emanates from there.Light of certain wavelength emanates from there, and then you have ainstrument called a mask aligner thatpositions a mask here.So this is a mask,this is basically a plate on which certain pattern is there.Let us say a circle is there and then you havethe actual siliconsubstrate, which comes below the mask.So, this is the actual silicon substrate, that is there.

Now,these silicon substrate is coated with a photo resist material; that means, these silicon substrate is coated with a polymer, that polymer has some photo solubility; that means, it isthis polymer, if it is exposed to light of certain wavelength, this polymer becomes soluble to certain solvent or it could otherwise.If it is exposed to light, then it was originally, it was otherwise soluble to a solvent, but nowafter the exposure, this solubility is lost. So, it could be either way; that means, these polymer is sensitive to

light.And if this polymer is exposed to light of certain wavelength of course, then these solubility patterns of this polymer, solubility property of this polymer gets altered.

Now, you are exposing this polymer,you are coating this polymer on the substrate. So, this substrate is coated with this polymer and then, you have a mask, a portion of it which is dark.How do you make it dark?ThatI am coming to it.Now as the light comes there, light cango through this part of the mask, but not through this circular portion. So, you will see a pattern on the plate on the substrate; that meansthese portions would be exposed to light; however, these portion will remain unexposed because of thispattern. So now, if you go back anddissolve this polymer to another solution, then what you see is depending on what type of polymer you have chosen,either this part of the polymer will completely dissolve, leaving a layer here or it could be the this part of the polymer gets completely dissolved, leaving the layer elsewhere.

Now, what you do is you dip this substrate; it is exposed preferentially to some places and not exposed in other places.You have coating of polymer in some places and you do not have coating of polymer in other places. Sonow you dip this into an etching fluid,the idea of etching fluid is,these etching fluids will have a chemical reaction with silicon and dissolve this and product goes back to the solution. So, if you leave it for some time this chemical will attack the silicon substrate, whereverthe silicon is exposed and eat away the silicon. So, it forms a grove on the silicon, wherever it is exposed, wherever thewherever the coating is not there;soit isit will form a grove there.

And then as, soit will form a grove on the silicon layer.Now depending on how long you dip, how long you keep it in the itching solution it could beforming a grove ofsay depth soand somicrometer.If you dip it for doubled the time, you expect that there will be more itching happening.So, these this is a technique. So, once you are done with that, then you can remove thepolymer that is left out. So, this is a technique which is considered very accurate and it can givechannel ofdimension of the order of micrometer. So, let menow readthesewhat I have on the slide,this isphotolithography mask.

First is photolithography mask, the mask is the one thatI have at the in the middle of this figure.In this figure,I have the middleone that is the mask; that is what we are talking about.What we are talking about here is the mask and the bottom one is the substrate, silicon substrate, on which you want to make the channel and the top one, this is basically the light source.Now, photolithography mask protects certain part of a resist from illumination.The spectral band of the illumination is 300 nanometer to 450 nanometer.A plate of quartz on which deposits of chrome forms a pattern; sobasically this mask is a plate of quartz, on which deposits of chrome forms a pattern. So, the pattern that circle that, that is the pattern there.

That could be just a line, which will form a channel. So that pattern is formed by chrome deposit.Deposition is made using electron beams;this deposition is done on this plate, on this quartz plate by electron beams.A less precise one of less precise photolithography mask not a good mask, but something which you isstudents who aredabbling on this, who are just trying to understand the process, a less precise one can be just a print out on plastic transparency sheet.So, there are plastic transparency sheets available, on which you can take using a special printer, you can print the diagram; for example, here it is a circle, soyou can print the circle,make the inner portion dark and print on a plastic transparency and thatmay act as a less precisemask.

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Photosensitive resist

- Mask is placed on top of a substrate, covered by photosensitive polymer.
- Substrate is put under uniform beam.
- The regions appear on the polymer as lit or dark as per the pattern that had been designed on the mask (pattern transfer step).
- Light sets changes in photosensitive polymer and make the polymer soluble to certain solvent. Upon dipping in the solvent, the polymer in the lit portion is dissolved.
- The exposed portions of the substrate undergo chemical attack from the etching fluid.
- Depending on the time over which the substrate is kept in etching fluid, the exposed portions are etched to a depth.

Now, the photosensitive resist,I said that there would be a coating of polymer on the substrate.There would be a coatingof the polymer on the substrate and that polymer should have certain property,in terms ofphoto solubility; that means, when it is exposed to light, it solubility property it changes.Nowphotosensitive resist,I see what,what I see here is mask is placed on top of a substrate covered by photosensitive polymer. So, this polymer comes as a,thissubstrate is covered by the photosensitive polymer.How we cover it?There is a special technique to it;I will discuss this in a moment.

Next, what you do is substrate is put under uniform beam, after the uniform coating of substrate with photosensitive polymer, the substrate is put under uniform beam,that is what we discussed photolithography.Theresins appear on the polymer as lit or dark, as per the pattern thathad been designed on the mask;this is referred as pattern transfer step.Instead of a circle, say instead of a circle if we would have hada symbol A here;if we would have had a symbol A here,we would have seen a replica; wewould have seen the pattern transfer happening to thesilicon substrate by this method. So, that is what we are talking about is,what we are referring as pattern transfer step. So, resins appear on the polymer as lit or dark, as far the pattern that has been that had been designed on the mask.

Soyou must understand that pattern is not transparent, pattern you are making it by a dark ink.You are taking a print out, pattern is not allowing light to pass through it;the rest of it, anything other than the pattern that is allowing light to pass through it. So that is how the pattern is created and pattern is transferred to the substrate.Light sets changes in photosensitivepolymer and make the polymer soluble to certain solvent.Upon dipping in the solvent, the polymer in the lit portion is dissolved. The exposed portions of the substrate undergo chemical attack from etching fluid. Soyou dipafter the exposure by light, then you go to,then you dip thissubstrate coated with polymer, you dip this substrate into certain solvent.

So, upon dipping in the solvent, the polymer in the lit portion is dissolved; that is one type resist, where the lit,polymer in the lit portion is dissolved.Theplaces where light has hit the polymer,in those places the solubility that property has changed and so;that portion is getting dissolved.Now, once it gets dissolved means those portions are getting exposed,so that surface is getting exposed.The exposed portions of the substrate undergo chemical attack from the etching fluid. So, when you dip this substrate, after the

dissolution of the polymer, when you dip this substrate into the etching fluid, then the etching starts, but the etching happens only in the places where the substrate is exposed.

Next is, depending on the time over which the substrate is kept in the etching fluid the exposed portions are etched to a depth. So, how long you keep it in the etching fluid,so gradually you see the etching taking place and the depth develops in thatchannel.Now, how do you coat the polymer?How do you coat the substrate with the polymer?There is a special technique, which is used the methodgoes by the name spin coating.This spin coating is the method that is employed to coat the polymer on the substrate material, because these coating has to be very, very uniform.It is absolutely necessary that the coating is very uniformand certain properties of the polymer are also required.

What type of property?For example, this polymer itself has to be transparent to light,if there is a thickness and the upper portion of the light is, upper portion of the polymer is the change, the property of the upper portion of the polymer gets changed, because of light, but light cannot penetrate all the way into the depth of the polymer. Sothen the lower portion will not change, the property will not change there. So, you want the property to change everywhereover the entire depth.Sothat,for that to happen this polymer has to behas toallow light to pass through it. So, there are certain properties of polymer.

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Spin Coating

- Photosensitive polymer is deposited in a thin layer on a solid substrate of silicon or glass.
- Three stages of the coating process are Distribution, Spreading, Evaporation, Solidification.
- Use of vacuum to hold the wafer.
- Equilibrium thickness: The thickness achieved after spinning for few minutes. With evaporation of solvent, viscosity increases. With decrease in radial velocity, viscosity increases for shear-thinning fluid. The fluid stops moving beyond a distance.
- Heating of resist at 70°C for few minutes to evaporate 15% of solvent remaining to avoid formation of cracks.

In fact, these polymers aremade bylargebusiness houses and they havedone, they spendgood amount of researchdeveloping this polymers and they found the best polymerthat is,I mean that is their objective to find the best polymer that suits the purpose.Now, photosensitive polymeris deposited in a thin layer on a solid substrate of silicon or glass. Sosubstrate is either silicon or glass, when it comes to photolithography.Silicon is a crystal line material;I mean we will discuss briefly, what a silicon?Andwhat is a difference between silicon and glass? Silicon is the crystalline material and glass is an amorphous material.

Crystalline means there is an arrangement, when it comes to the atoms, but amorphous means they are all tangled up.I mean there are certainand these properties willcome into picture, because you are creating a microchannel on this material, soall these properties are important.So, you havephotosensitive polymer deposited in a thin layer on a solid substrate of silicon or glass.Three stages of the coating process are distribution, spreading, evaporation, solidification, evaporation and solidification.What is this spin coating process?What you have here is you have the wafer, this is called the wafer; wafer means it is a thin silicon substrate, the width of it is500 micrometer andit comes in saythe other dimension is typically 4 inches.

So this is a silicon substrate, it is obtained fromsiliconmonocrystal. So,you can expect acrystalline arraignment of siliconmaintained their.Silicon has a particular crystal line arrangement,I willin a moment we will discuss this, what is the crystal line arrangement, because this crystal line arrangement comes into play, when you make this when you start the etching process.Sothese, sofor the time being you take it that it is a wafer. Sowafer means it is a thin plate,the sizethe other size is four inches, the other dimension is four inches and the thickness is500micrometer. So, you have this silicon wafer and this silicon wafer, on this you want to coat this silicon wafer by the photoresist material, which is a polymer.

So, what you do here is you have a resin feeder; this is the feeder through which you inject the polymer. So, this is the place where the polymer is put on the silicon.And then, what you do is you rotate this wafer, rotate at a really high RPM;initially maybe 1000 and then going all the way to 8000.You rotate this waferat a high RPM,moment you rotate what will happen to this rigid material, because of centrifugal force, it will start

spreading out. So, next time when you see when you start rotating,suppose this is the wafer and this is the chalk, this is called chock to hold the wafer.

Now, you when you start rotating, when this starts rotating, you see that there would be a thin layer being deposited, thin layer forming on this substrate, because by centrifugal action there would be a radially this resin material will start flowing. However, their exists something called an equilibrium thickness. What could be this equilibrium thickness?And more important,equilibrium thickness is if you rotate this material for asometime;in fact, I have defined on the slide this equilibrium thickness.

The thickness achieved after spinning for few minutes, with evaporation the thickness achieved after spinning for few minutes, so that means, you spin thiswafer with the resist material on itand thenyouspin it and you see there is a coating developing. So, this thickness here this thickness is developedthis thickness is referred as equilibrium thickness.So, with evaporation of solvent, viscosity increases; with decrease in radial velocity, viscosity increases, for shear thinning fluid; the fluid stops moving beyond a distance. So, you understand why you havean equilibrium thickness, because if it is just water, you think of putting water on arotatingsubstrate and a spinning substrate like this; and you have a centrifugal force, you expect thatyou have created a driving force and water would be simply thrown out.

Buthere what is happening is, the moment you are putting a spinningaction, the radial velocity at the center it is highest and the radial velocity decreases, as you as this material moves out. So, if it is a shear thinning fluid, then in that case, if the velocity decreases; that means, if thedel u, del y, the velocity gradient del u, del y, if that decreases, then you have higher viscosity. So, it becomes more difficult to flow and also the evaporation is constantly taking place, because this entire material that when it is deposited, this entire material was in one place a blob.But now you are spreading it, you are creating such a high areaover which the evaporation can take place. So, because of this evaporation you will,what will result is that this material will become moremalice of a liquid;soautomatically viscosity increases.

So, what do you find is that after you spin for some time, you develop a equilibrium thickness and you find that the liquid is not moving anymore beyond a distance; sothat is the, that is referred as equilibrium thickness. In fact, there is a formula for equilibrium thickness, equilibrium thicknessI mean an empirical formula, but at least this gives you an ideaas to what kind of dependence you have,thishow this equilibrium thickness depends on thespinning rate, etcetera.This is the formula that is used for equilibriumthickness, where h is the thickness,C is the initial concentration,C is equal to initial concentration of polymer; omega is equal to angular rotation velocity and K is some constant and obviouslymu is the viscosity. So, if somebody tells you that,you are getting equilibrium thickness say after running it at says5000RPM,you are getting certain equilibrium thickness.

If somebody tells you,if instead of 5000RPM, if you would have done it at 9000RPM,what would have been the thickness? So, using this formulayou can calculate what would be the thickness.Can you tell me it will be higher or lower?It would be if the omega increases, then h would be automatically decreasing; sothe thickness would be lower.And obviously, if you have a Newtonian fluid, you expect that entire fluid to be just thrown out of the centre. So, you cannot have the concept of equilibrium thickness.This can exist only for a non Newtonian fluid and where the viscosity changes with evaporation of solvent.Once you are done with this, now I have another point to make here;thissilicon material that has to beheld in place.Now, if something you have to rotate something, say in a lathe machine, you have something called a chalk, mechanical chalk, in which you fit that plate and then you rotate,then you do the necessary operation on this.

Now, here in spin coating, here the rotation speed is pretty high, rotation speed is very high; and more over the vapour that you are working with is really thin. So, holding this vapour by a mechanical chalk is not very easy. So, there is analternative method people have come up with, which is the use of vacuum. So, what they are doing is, thisis basically this part is connected to a vacuum pump. So, vacuumso this place is under vacuum. So, outside it is atmospheric pressure;so, if you create vacuum, you can hold this vapour in place. So, this part is connected to a vacuum pumpsothat this wafer is held over this chalkover by means a vacuum and not byany mechanical clip or anything, because this vapor as such is very thin and it has to rotate at a very high speed.Now, once

you are done with this coating,this heating ofresist, this is typically followed heating of resist at 70 degree centigrade for few minutes, to evaporate 15 percent of solvent remaining to avoid formation of cracks.What does that mean?Thisyou have achieved an equilibrium thickness; you have achieved an equilibrium thickness on the substrate material, but still 15 percent of solvent is still there.85 percent got evaporated and that is why this material became immobile, but still 15 percent of solvent is there; and that solvent has to be removed in a précised manner, because otherwise that solvent can come out at some other odd moment and at that time it will form crack, because that solvent has to come out at some point. So, it has to be heatedin a controlled manner and that is done by heating the resist at 70 degree centigrade for few minutes, to evaporate this 15 percent of the solvent.

Now, there are variousreasonsbecause of which the spinning processcan get into trouble.One is that these air bubbles in dispensed regime can come, air bubbles can come in dispensed regime if dispense steep is cut unevenly or has defects.And air bubble means, if this is the wafer and you are expecting a coating of this wafer, uniform coating everywhere and what you end up with is having small bubbles here and there inside the coating.

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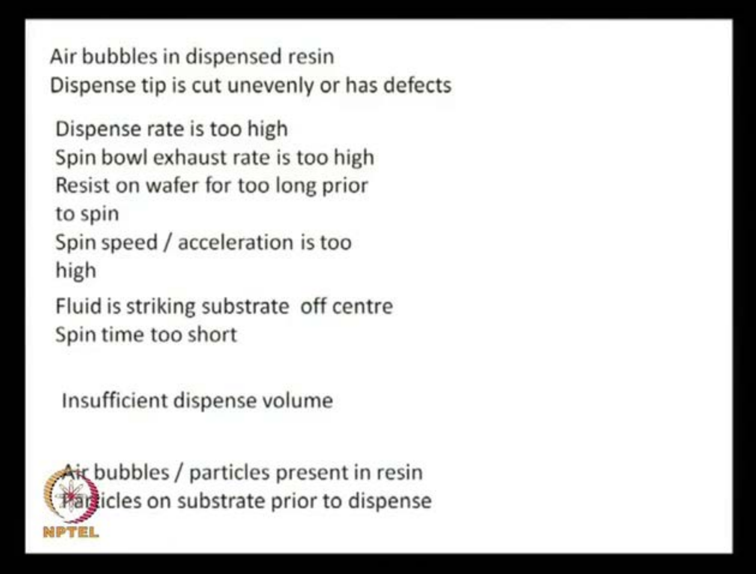

So, this has this;sothe person who is running this he has to be careful.The next point is if dispense rate is too highor spin bowl exhaust rate is too high or resist on wafer for too long prior to spin or spin speed or acceleration is too high.So, if these are high, then in that case, you will see some amount of an even distribution of this resist material on the substrate. So, there are these parameters need to betaken care of.Spin bowl exhaust rate is I mean this is the newterm I see here, spin bowl exhaust rate is this entire material entire assembly is put inside a spin bowland then exhaust is collected.This there would be, it could be possible thatin fact, some people to ensure there isnot any bubble formation and this liquid penetrates all over the surface, everywhere, uniformly.

They put a little bit of vacuum as well,if a vacuum here as well.So, spin putting under vacuum that is a that is also another possibility. So, this is over they are referring asspin bowl exhaust rate.There could be another problem, which is fluid is striking substrate off center; fluid has to fluid has to strike at the center.If the fluid strikes off center say here, this is rotating around this access, but the fluid is striking here. So, what will happen? Then you will see a pattern forming within the fluid, a spiral instead of a uniform coating, you will find a spiral; fluid has to be dispensed at the center,because the rotationthat the flow of this regime over the substrate is accounted that way.

Then insufficient dispense volume, if the volume that is dispensed at the center is insufficient,you are expecting a coating of certain thickness.Now, you havegiven the resin, which isyou have already decided an equilibrium thickness, you know that this is the speed and at that speed, at this viscosity,I can expect this to be the equilibrium thickness.And if this is the equilibrium thickness, what should be the volume of resin?You must have that you need to calculate.Then if you give less than that volume, then automatically what you will see is places of this substrate exposed; places of the substrate not covered by the polymer.And that we will have an in a very erratic manner, because the entire materialsee the way it is done.

Soif the, ifin some places resin is,if resin is insufficient, in that case, that coating is will also be insufficient and soin places, we see thesubstrate exposed, not properly covered by the polymer.The last point here is that air bubbles or particles there may be present in resin or particles on substrate prior to dispense. So, you have to be careful that these air bubblesor particles they are not present in the resin, because if they are present then, they willdisturb this whole process of spin coating.

And moreover, there could be particle sitting on the substrate itself, the substrate itself may have particle sitting on it and that can altered the flow process completely.Sothat can createaproblem in spin coating.This,so that is why the substrate prior to spin coating this substrate needs to be clean, then there is certain protocol that has to be followed for cleaning the substrate, prior to going for spin coating.

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Exposure

- Substrate, coated with photosensitive polymer is placed in an aligner.
- Luminous flux crosses the mask and hits the coating on the substrate.
- Light of wavelength 300 – 450 nm is used.
- Luminous flux initiates reactions in the polymer.
- Positive Resist (PMMA): After exposure, the polymer becomes soluble in a solvent as the light weakens the internal bonds→ Exposed part is eliminated.
- Negative resist (KTFR from Kodak, SU8 from IBM): After exposure, the polymer becomes insoluble in a solvent, as light induces covalent bonds between chains → The unexposed part is eliminated.

NPTEL

Sothis entire idea of spin coating is to make sure that there is a coverage of polymer over the entire substrate.And then, it would betaken to the exposure step, where a part of this polymer will be removed, a part of the polymer will be expose to light. So, one portion would be light portion or other portion would be dark;one portion would be light portion, other would be dark portion.And then, depending on where it is light or where it is dark that polymer will be dissolved, will be taken away from the substrate.Nowthe exposure step, substrate coated with photo sensitive polymer is placed in an aligner.Aligner is the mask aligner; that means this mask has to be made parallel to this substrate.

So, you have to make sure that there is a precise aligner that does this job.Luminous flux crosses the mask and hits the coating on the substrate; that is exactly what I said.Light of wave length 300 to 450 nanometer is used; luminous flux initiates reactions in the polymer that is it has to alter the solubility pattern. So luminous flux initiates reactions in the polymer.Now, there are two types of resists I said at the very outset;that the there are two types of resist; one becomes more soluble, once it is expose to light and other

becomes less soluble. So, depending on whether it is more soluble or less soluble,differentiate this resist by calling it positive resist or negative resist.

And example of positive resist is PMMA poly methyl methacrylate;and example of negative resist is there isthis istrade name KTFR from this company or SU8, that is also another well knownname from anotherbusiness house.Nowpositive resist, the definition of positive resist is after exposure the polymer becomes soluble in a solvent, as the light weakens the internal bonds. So, the exposed part is eliminated. And for negative resist, after exposure the polymer becomes insoluble in a solvent,as light induces covalent bonds between chains.So, in one resist light breaking down the chains and in other resist, light is creating the chains. Sothat is allthat is how nature works. So in case of negative resist, the unexposed part is eliminated and in case of positive resist, the exposed part is eliminated.I hope this clear to everybody.

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Other issues

Half-light effect during exposure

- Opaque object produces shadow as well as penumbra.
- Diffraction.
- These effects should be as small as possible.

Transparency of the resist

- Light has to penetrate and modify the resist over the entire thickness of resist layer

Choice between positive and negative resist

- Negative resists adhere better to the substrate.
- Negative resists are more chemically resistant.
- Positive resists show better contrast in photosolubility.

Now, there are otherissues to this photolithography process, this you should havepointed out at a very outset.The other issue is that the half life effect, during exposure.The half life effect is that the opaque object produces shadow as well as penumbra, what is that?You have I said that there would be a source of light and then there would be a mask and there is pattern transfer happening.Now, think of a light, source, and anobject, hereand that is forming a shadow;so there would be a shadow here that is what you are

expecting; that is called shadow.If this is the object and this is the light source;sothere would be shadow forming.

I am sure you have studied something called penumbra.There would be a reduced light around object, because after all what you are doing here in thismask and this pattern transfer step is you are creating a shadow; you are creating a shadow of the mask that you put.So, once you while talkingabout this shadow under light source, you will have this problem. So, you what you are ending up with is basically half light around the object.You have define the object very well, but around the object you will not have,soyou will have something called a half light. So, this is called half light effect during exposure.You can refer thispenumbraand how this opaque object produce a shadow; you can read this in,this is the very preliminary course on optics, the firstlecture probably this would be in a initial lectures it would be covered.

So, this iswhatthis half life effect is.Also there could be diffraction happening; light is passing by a mask. So, there could be diffraction happening and that can causethe reduced light or scattered light, when it comes to the pattern transfer. So, these effects should be as small aspossible that is one,the one point that you need to understand.The other point that you have is transparency of the resist, light has to penetrate and modify the resist over the entire thickness of resist layer.So, light has to penetrate the entire thickness of the resist.If it just, if it hits the upper portion of the resist and modifies the solubilityforms covalent bond or breaks covalent bond, only at the upper part, but this resist itself does not transmit light, it does not allow the waterallow the light to pass through it.

Then the lower part of the resist will not beexpose to light.So, this change this photo solubility, thiseffect will not be uniform over the entire thickness of the resist. You will say what this thickness would be very small,I understand, because that is what that is why you are using spin coating; this thickness would be very small; however, whatever the thickness it is, this property of this resist material you have to ensure.Light has to penetrate and modify the resist over the entire thickness of resist layer.Then there is this choice between positive and negative resist.You may ask that I have a choice, now which one to take.Now, the practicalsuggestion would be negative resists adhere better to the substrate, negative resists are more chemically resistant.

On the other hand, positive resist show better contrast in photo solubility. Sothese are frozen cones of these two resists andpeoplewhen they develop protocols, they develop based on these understanding.

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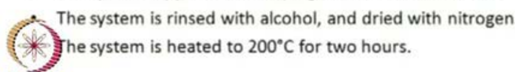

So, this is a typical protocol that is followed.I mention that first you have to put a mask aligner,and take the exposureprior to that you have to have spincoating done, but I said that particles are not allowed on the substrate surface.Because if particles are sitting there on the substrate that can disturb this spin coating process and the coating will not uniform and there would be all kinds of problems coming up.So, a typical protocol would be immerse the wafer in acetone in an ultrasonic bath to dissolve organic residue and then drying. So, take the wafer first, the silicon wafer that you have gotten 500 micrometer thick, and diameteror the otherdimension is 4 inch; and immerse the wafer in acetone in an ultrasonic bath.

Ultrasonic bath is it is the ultrasonic bath the purpose is that it is, it ensures that any dirt, any particle which is adhering to thissubstrate that, because of that vibration it gets dislodged.So, you put it an acetone and ultrasonic bath, and make sure that organic residues are dissolved and thendry it.Then repeat the previous step with alcohol, so that means, instead of acetone, you do it with alcohol.Some residues which would be going away with acetone, but some will remain,soyou ensure that you do it with alcohol

itself.Now, then next it is you have dehydrate on a hot plate at 120 degree centigrade for 5 minutes; dehydrate on a hot plate at 120 degree centigrade for 5 minutes.

The first three steps, the objective of first three steps that I mentioned, that means, once in acetone then with alcohol and then dehydrate,the objective is to ensure removal of contaminant from the wafer. Sothat wafer does not have any extraneous material, which can cause trouble later.Next the wafer is coated with photoresist in spin coater and that process I have already descried, how this spin coating works. So, once the spin coating is done the system is heated to 65 degree centigrade for one minute and 95 centigradefor three minutes to ensure hardening of photoresist.Photoresist, it formed an equilibrium thickness, because it cannot flow anymore; that does not means that it has a hardened.And you may say thatif I leave iton that table, it will harden; however, there would be always some harden may be it has hardened to the extent you want for the purpose you have, but it has not the property is still continue to change.

Soonce you put it in this 65 degree centigrade per one minute and 95 degree centigrade;soyou will ensure that the hardening is complete.Theybecause otherwise there would be some changes going on inside thatresist which you do not want.You want that process completed, when you go to the next step.So, system is heated to 65 degree centigrade for one minute and 95 degree centigrade for three minutes to ensure hardening of photoresist.Next step is exposure;and what is that exposure?I have already mentioned, you have the light and then you have the mask, put by mask aligner and then the exposure takes place.

Next step is that the wafer is post baked to 65 degree centigrade for one minute and 95 degree centigrade for two minutes, to ensure progressive rearrangement of material during thermal deformation.There would be progressive rearrangement of material andonce again I,as I told you want to ensure that all the rearrangements that are taking place.Becauseit is a chemical physical chemical process that is happening within this resist.And whateverrearrangement is taking place, let us have this completed and frozen, because if, because the otherwise you know a reaction will continue till in an asymptotic manner for a long time.So, you do not want that to happen, you want towrap it up, freeze it and go to the next step.

Next is the systemdipped in developing solution for three minutes.What is this developing solution?Developing solution is that solution in which polymer is soluble. Many a times it ispotassium hydroxide,I think.The system dipped in developing solution for three minutes; system is rinsed with alcohol and dried with nitrogen.The system is heated to 200 degree centigrade for two hours.Again this process this 200 degree centigrade for two hours ensures that all the rearrangements are done completed frozen.

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Silicon

- Delivered in the form of wafer that constitute a monocrystal.
- Produced by well-controlled crystalline growth process in clean-room (Class 1-10), by slowly pulling a crystal from an ultrapure bath of silicon.
- Slices are cut from a cylinder, followed by atomic polishing phase.
- Typical thickness of wafer ≈ 500 μm.
- The other dimensions ≈ 4 inches.
- Two inter penetrating face-centred cubic lattice network.
- Side of one cubic face is 5.43 A°.
- Highest density planes <1 1 1> form an angle of 54.74° to <1 0 0> plane.

Now comes to the silicon,I mentioned that is it is a silicon wafer.You can work with either a silicon or glass, when it comes to photolithography.Now,what is the silicon I said, at the very outsetit is a crystalline material; that means, it has an arrangement it has these atoms arearranged in a particular lattice structure.Where as glass is a amorphous, so that means, one is dangling with the other, there isnot a veryorganized align structure.So, silicon that you get in wafer is delivered in the form of wafer that constitute a mono crystal.Mono crystal means it is a single silicon crystal,I think I must point out what a silicon crystallooks like.

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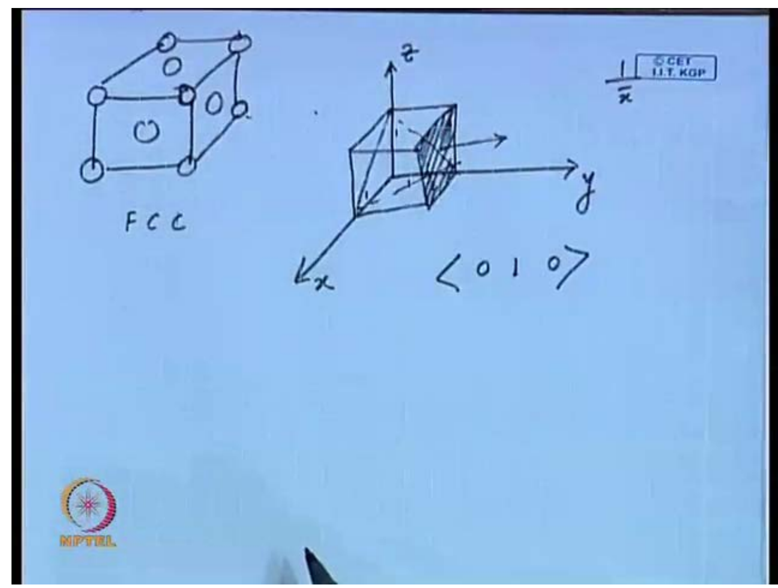

The silicon crystal, it is basicallyyou understand what a cubic lattice is.Cubic lattice means a cubewith one atom at each corner; this is not silicon, but this is this is called a cubic lattice.Then there is something called a face centered cubic lattice; that means, one atom at the center of each face as well; so, this is called a face centered cubic lattice FCC.Silicon is basically an inter penetrating network of face centered cubic lattice.Now it is not,that is not end of it.It is basically think of two lattices placed one over the other, think of two lattices placed two cubes placed one over the other.Then you shift one cube from the other by one fourth distances.If one is the distance between the two atoms here, you go by one fourth distance; shift one fourth on x axis, shift one fourth to y axis, shift one fourth to z axis.

So, this is basically an inter penetrating network of cubic lattice, where two face centered cubic latticecubic structures, they are shifted by one fourth, one fourth, one fourth.And the structure that you get, now it is extended to infinity in all directions; then that is the structure of a silicon. So, it has a very organizedalignment and that, now when we talk about a silicon mono crystal, we are talking about that material.So, mono crystal means, it is a single crystal. Sothis crystal is produced by well controlled crystalline growth process in clean room, class one to ten; by slowly pulling a crystal from an ultra pure bath of silicon. So, from an ultra pure bath of silicon, this baththat material rotates and you get this silicon out from there.

And this is the single mono crystal that is a mono crystal; that means, this lattice structure face centered cubic, inter penetrating face centered cubic lattice, where two cubes are shifted by one forth, one forth, one four, that structure is retained everywhere.And then, you cut it into slices, slices are cut from a cylinder followed by atomic polishing face.So, you get the silicon out from awell controlled crystal line growth process and then cut slices.And thenthat one slice, we are referring as silicon wafer. So, this is a single mono crystal of silicon. So, you expect that thisface centered cubic lattice structure that I said that extensive infinity; that meansthere would be one, then there would be another one on top, then another in their right side, bottom;so, this is extending everywhere.

Extending and these basically the wafer that you get is basically fallhaving this crystal line an arrangement.SoI read it once again,delivered in the form of wafer that constitute a mono crystal produced by bulk controlled crystal line, growth process in clean room by slowly pulling a crystal from an ultra pure bath of silicon.Slices have cut from a cylinder followed by atomic polishing phase.Typical thickness of wafer is 500 micro meters the other dimension is 4 inches.Two inter penetrating face centered cubic lattice network, you understand what that is,I just now mentioned.Side of one cubic face is 5.43 angstrom and highest density planes,1 1 1 form angle of 54.74 degree to 1 0 0 plane; this 1 1 1 and 1 0 0, these are called miller indices.Now, what is a miller, what is this miller index?What is that?If you havea cube, supposeand you form a cube here.

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Now, suppose thiswe focus on this planeand if we look at, where this plane cutsthe x, y, and z axis.Suppose it cut at say x bar location, then we write one by x bar as the x component this miller index; that means, what would be this plane?Typically, when it comes to a plane we generally it, if we assign a vector it, we write it perpendicular to this plane that we refer as that that particular, we refer the direction as far as this plane concerned.So, this plane cuts the y axis, suppose this dimension is 1, this dimension is 1 and this dimension is 1; this plane cuts the y axis at a distance 1.And at what distance does it cut the z axisor at what distance it cuts the x axis?This never cuts the x axis, because this is parallel to the x axis.This never cuts the z axis; because it is parallel, so that meansyou can say it cuts at infinity, as far as intercepting the z axis or x axis is concerned.

So this, soif I take the one upon the reciprocal of this intercept,I see that only I have y present there x is 0, y is there as 1 and z is 0;these are theso these particular one 0 1 0 defines this plane.So, you find out at what intercept it cuts the x axis, y axis, z axis; take reciprocal of it andyou see the reciprocal of infinity is 0,so you write this as 0 1 0,this plane. So, this way you can define 1 0 0 plane, this way you can define,how can you define 1 1 1 plane?What would be that?It is cutting the y axis at 1, cutting the x axis at 1, cutting the z axis at 1, so that we. WhatI can think of a something like this;so, it is cutting all the planes. So, you have 1 1 1 plane. So, what you have in silicon is thathighest density planes are 1 1 1. So, the way when you have this two face centered, when you have this face centered cubic lattice, inter penetrating network of its center cubic lattice, and when they arewhen there are these two inter penetratingcubesseparated by this by one forth unique distance away fromin each axis.

In that case, you have highest density plane as 1 1 1; that means, 1 1 1 plane in this crystal line structure is packed with atoms; that is the most packed with atoms and these forms this angle 54.74 degree to 1 0 0plane.So, this is a particular feature which you would be very important, because the way the atoms are packed, when you take this silicon substrate for etching.After all what is happening in etching?In itching, this silicon atom is reacting and the product is getting into the solution. So, if that plane is more packed with atoms, soit would be more difficult to each that plane;whereas, if some other plane is less packed with atoms that plane would be easily itched.

So, when it comes to the itching ofsilicon substrate,there would be an isotropic developing within the silicon substrate. I willtake this up in the next class,this is an interesting exercise thisphotolithography.And we aretaking the essence of these methods and we are we will(( ))this method for the micro scalefabrication, that thefor making the micro scale devices. Soin the next class,I will continue further with these itching processes and how these crystalline arrangements affects the itching process.Thank you very much.