Microscale Transport Processes

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Lecture No. #09

Plastic Microfluidic Devices

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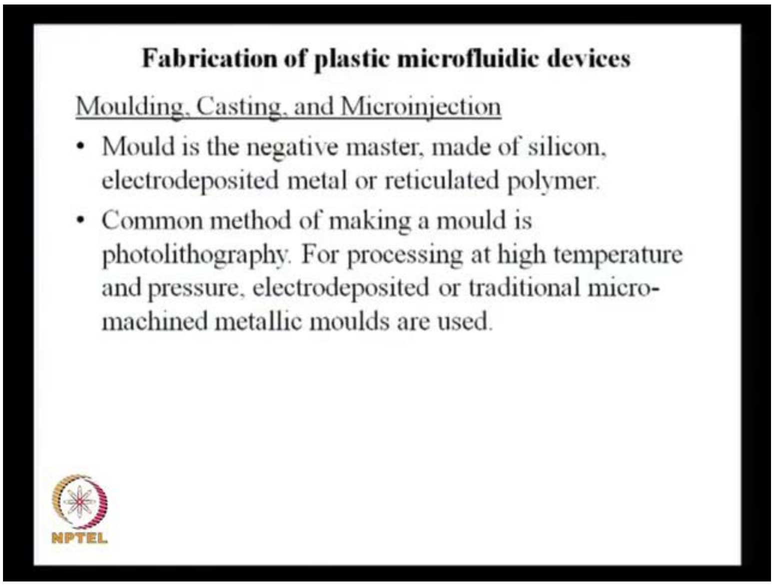

I welcome you all to this course on Microscale transport process;to this lecture of microscale transport process. We have been discussing plastic microfluidic devices.We started with microfluidic devices, manufacturing of microstructure devices and what we have considered sofar is silicon and glass, and we have discussed various techniques to etch a channel on thatsubstrate, and how to bond anothersilicon or glass structure,glass wafer on top,sothatwater-tight microstructure device can be fabricated.These we all these we have already discussed, nextwe are what we are considering is plastic microfluidic devices,and we have discussed various advantages and disadvantages of these plastic devices.

In the last class, wetalked aboutvarious techniques that are employed to make microfluidicplastic microstructuremicrofluidic devices.And we pointedout,I pointed out that there areprimarily three techniques; one is moulding, the other is casting, and the third one ismicroinjection.In case of a mould, moulding process mould is a negativemaster made of silicon that is a definition of mould; mould is a negative master made of silicon and or electro deposited metal or reticulated polymer.The common method of making a mould isphotolithography,and processing at high temperature and pressure, there are other techniques which are employed.

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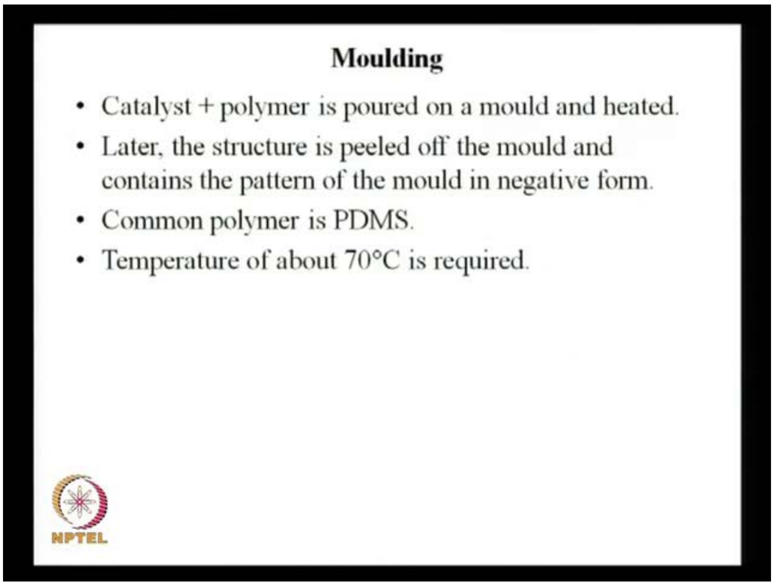

Now, moulding process means that it is done with a polymer,which has a lower melting point typically the temperature is about 70 degree centigrade and PDMSis the common polymer.Now, catalyst plus polymer is poured on a mould and heated.Later, the structure is peeled off the mould, sothat the pattern forms.Now,thisprocess here thepolymer is polymer in itsmolten state that ispoured on themould that is the idea.

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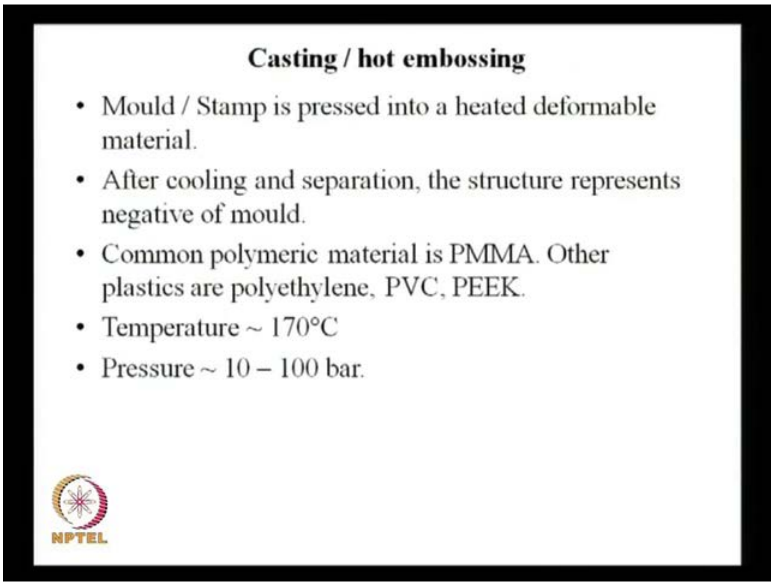

Whereas in case of casting, which I discussed in last class, a mould or a stamp is pressed into a heated deformable material; that means, here as I said the common material is PMMA,polymethyl methacrylate and other plastics are also indicated there; temperature is close to 170 degree centigrade and pressure is 10 to 100 bar. So, here the temperature is much higher, pressure is much higher and the polymer does not go to its liquid state,rather polymer is just softened by application of heat and pressure; polymer is simply softened.And on top on this polymera stamp or a mould that is pressed,sothat anegative and the,I meanafter cooling and separation, the structure represents negative of mould,sothat you can generate.

So, here the polymer is not taken all the way to its molten state rather polymer is simply softened,sothat it can deform at the places, where thestamp or the press is put.Theother technique that we discussed in the last class is micro injection.Micro injection is meant for serial production on industrial scale.Here,the technique is very similar to moulding; that meansyou are forming a liquid which flows whichyou areforming the molten polymer, which flows into the mould.In the last class, we discussed this technique.Here also,it happens in the similar way.However, this is not done on a bad scale, this is done on a serial production; that means, you can produce thousands of them at a time.

So, the entire arrangement is more formore intended towards making it in a bulk scaleand for large scale production.AndI have discussed this with picture in the last class, how this is accomplished.Now quickly summarise,I would like to quickly summarise the advantages of plastic microfluidic devices.Here, the precision is surprisingly high sub micrometric precision.See, the way we are talking about as if we are borrowing a technique, which has beenthere for ages that you havenegativereplica and then you are pouring it or putting; the way,I mean I am presenting it as, if it is I mean we are making an idol out of clay,I meanit that way it is that simple.

So, the immediate question that comes to our mind iswhat would be the precision of this kind ofmethods,I mean we were talking about a microscale device and you are using a technique,which has been which we know already for ages. So, with it is surprisingly high that is why the word surprising is there,I mean the what scientists have found out that this precision is very high that is one particular aspect here.The other advantage of plastic device is PDMS is transparent. So, I told you what the advantage of transparency is that you can see what is inside, if you want to make an optical interrogation, that means, if you want to put an put a light source and try to find out how much light is absorbed, how much light istransmitted.

So, you can do that, because this structureyou can put the deceiver or you can put the light source outside the structure; and still you can expect light to pass through the solution that is flowing through the micro channel, sothat is one advantage.The third point is elastomeric quality,I am extremely sorry; this word should be elastomeric quality.Elastomericquality helpswater tightness by holding on tightly to the lid or interconnect.See theplastic material has some elastomeric quality,I mean it is, it has some amount of elasticity that we already seen; we have seen in plastic devices that it can,if you pull an it stretches a little bit, which is not possible with glass possibly.

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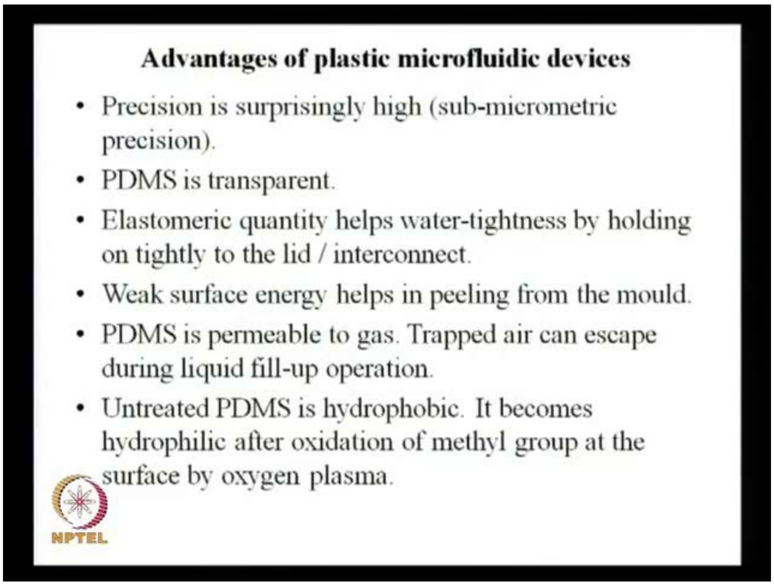

So, these gives you some amount of water tightness by holding on tightly to the lid or interconnect.That means, suppose you want to put a tube into this device, which is made of plastic. So, when you insert it,plastic stretches a little bit and make a space for this device to go in. and when you will really,whenafter it goes inside the plastic materialthat hugs the tubing, such that it becomes somewhat water-tight.Theidea here is thatthese,theelastomeric this elastomeric quality helps in water tightness by holdingon tightly to the lid or interconnect.You might have already seen, there arethese inwhile we assemble toys,there is something called a press fit connection.

You press it shrinks a little bit and it goes in and then fits there,this is called press fit connection.And this press connection is possible, because of this elastomeric quality of thematerial. Sothat is that can be utilised here to put some interconnects, put some tubes on this.Weak surface energy helps in peelingof peeling from the mould.If the surface energy would have been stronger, then the material, after you put it on a on the mould, then that would have stuck to the mould; you could never,you could have gotten it peeled off. So that is possible, because of these weak surface. So, this is a favourableproperty of a polymer,I mean this is a property which is favours your application,so that is what you have tokeep in mind.

The next point is PDMS is permeable to gas. So, trapped air can escape during liquid fill up operation.ThisPDMS materialcan permeate a gas,so if you create a pressure inside a channel, thensee when you start your developwhenyou start working with your device, suppose you fill the channel with a liquid and the channel is already the channel is occupyingsome air. So, what you have to do is either you have to apply vacuum, sothat air comes out and liquid gets in. So, you have to make some arrangement the how the liquid penetrate into the channel.Now, this PDMS I mean what I learnt inplaces that PDMS is permeable to gas and so,if there is any trapped air inside the channel, when you fill the channel with a liquid for the first time, then this air canpermeate out of thisPDMS layer and so,liquid fill up operation would bewill have less hindrances.

The other point is untreated PDMS is hydrophobic. So, PDMS as it is, it is hydrophobic. Hydrophobic means, if you want to flow water through a PDMS channel, you will find resistance.If you would have taken an inert channel of that similar size, then in that case, you had a,you find that that would be easier for theliquid to flow through that channel.Butsince it is hydrophobic,soif you want to flow water through that channel, you have to overcome a higher pressure drop. So thatmay not be good for your application or it may be good for your application, you never know it depends on what application you choose.However, itthis PDMS can be made hydrophilic, after oxidation of methyl group at the surface by oxygen plasma.

So, common method is that you take the PDMS material andput this to a plasma asherput this in aplasma chamber and use oxygen plasma to treat the surface;so, the oxidation takes place with the methyl group at the surface and PDMS becomes hydrophilic. So, this kind of changes in property, this kind of property change that cannot be implemented in,it may not very easy for silicon and othermaterials, but plastic has this property.You can change theproperty of a plastic material very easily by such surface treatment;sothat is one major advantage of plastic devices. So, these are some of the advantages that I have listed here.

Of course, nothing comes free, there are disadvantages of plastic devices, one major thing is aging; plastic devices that will not remain that will not retain the propertiesfor a long time.So, it has a shelf life,I mean you make a microstructure device and keep it in shelf. So, just like,when we purchase a medicine,it saysthree years from manufacturing,there is shelf life given; similarly for plastic devices, it will notbe there for ages, it will not be there foryears. Soit will,there is shelf life, sothat has to betagged.

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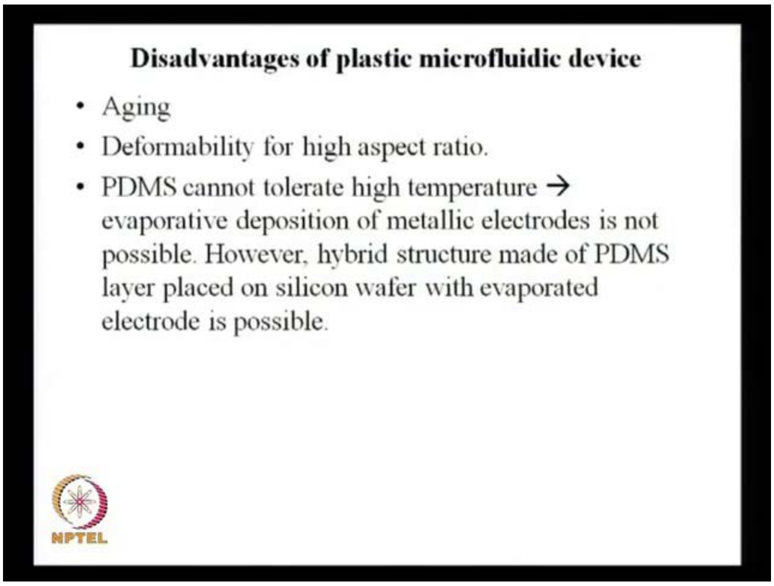

Andthe other issue is deformability for high aspect ratio, these I said I mean, one advantage you get is elastomeric quality that it can stretch, it can bend.Butthe same thing would be a disadvantage, when you are working with high aspect ratio.High aspect ratio means you have a,suppose you have a hole in a micro channel, the hole is, or suppose you have a channel in a way in a plasticdevice;so, in a in basically in a plastic plate, you have a channel, the dimensions of the channel are such that the aperture there is of the order of micro meter; whereas the depth of that channel is very high. Sothat the aspect ratio is almost thirty is to one; if the thirty is depth,one is the aperture.

Soin that case, there is a possibility thatthis may bend,when it is under pressure. Sothis, soyou cannot retain the structure as it is.If you want to, if you call it a rectangular sleet, if this rectangular sleet will not remain rectangular everywhere that problem was not there with silicon. So, this deformability is one concern for high aspect ratio of course, but if you are working with a normal channel dimensions that is not a problem.The other point is PDMS cannot tolerate high temperature.I said at the very outset PDMS was used for moulding and moulding was done at 70 degree centigrade; so, at 70 degree centigrade PDMS is all liquid and you are pouring it on the mould.

So, at 70 degree centigrade the PDMS is all liquid. So, if you have a PDMS microfluidic device, you raise the temperature to 70 degree centigrade, you find it is allliquid; it is not no longer a structure.So, if you want to have evaporativedeposition of metallic electrodes.We have discussed about this thermal evaporation, you remember what we had in the last class.

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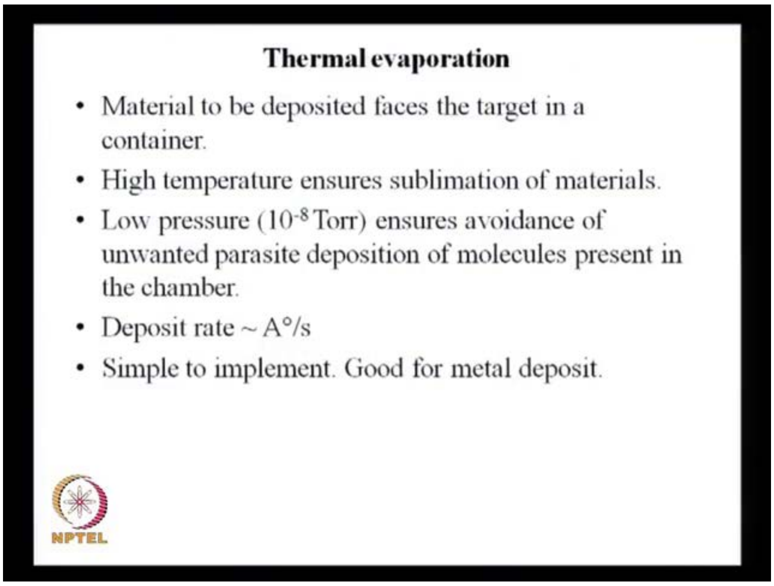

We have discussed about that deposition,we have talked about thermal evaporationin a previous class.Thermal evaporation, where material to be deposited faces the target in a container, this comes under physical wafer deposition.We discussed about two type of deposition, physical wafer deposition and chemical wafer deposition.And under physical wafer deposition, we said we can have thermal evaporation or we can have sputtering.In case of thermal evaporation, you apply heat and sublimate the entire,sublimate the solid material and against the solid material, you hold the substrate orhold the substrate, portions of the substrate, which isto bewhere the deposition has to be made. So, other portions are masked, other portionsdeposition will not take place.

Only the portion,where you want it to be, you are holding that substratefacing to the solid material.And you are applying heat, sothat the solid material sublimes.With sublimation, the wafergets generated and you have a thermal environment which has a gradient; that meansit is hot on this side,sosolid is forming gas.Butas it travels, as the gas travels downstream over the substrate material, there is a thermal gradient and the gas cools down; and the movement gas cools down, it forms a deposition.

So, if you want,if somebody wants to make a deposition to make an electrode, at one particular portion on the channel wall, sohe has to resort to either thermal evaporation or the other technique is sputtering.Sputtering means instead of heat, you would be using plasma; that meansyou are providing the energy in the form of electron bolt. Sothis,these are the techniques that we depositedthat at we, that we talked about regarding deposition.Now, when we want to do this on PDMS,this evaporative deposition ofmetallic electrodes is not possible.It is very simple,70degree; below 70 degree centigrade nothing will sublimate.If that would have sublimated,then that would havethat metal does not have any purpose to me.

However, hybrid structure made of PDMS layer placed on silicon wafer with evaporatedelectrode is possible.That means, you can have a hybrid structure; that means, this structure is comprising of both silicon and PDMS, sothat you can take the benefit of both technique both the substrates.Silicon gives you the robustness, silicon gives youthesilicon helps you indoing the deposition of electrode material or whatever you want.On the other hand, you need some plastic device; you need the properties of a plastic device.For example, surfaceproperty, hydrophilic, hydrophobic that orientation and say etcetera. So, that can be arranged by using the,that can be arranged using thePDMS layer.

So, first you take the silicon wafer, change it to change this,first you take the silicon wafer, put theevaporated electrode and then,you go to thefirst you put the siliconwafertake this to the evaporative electrode, the electrode and put it there.And then,you go forthis application of this PDMS layer on silicon wafer, such that you havetheright evaporate.So,such that you have thebenefit of both of the structures.That means,you havethe evaporativedeposition of the electrode taking place,at the same timeyou have thestructure, the robustness of the silicon wafer.

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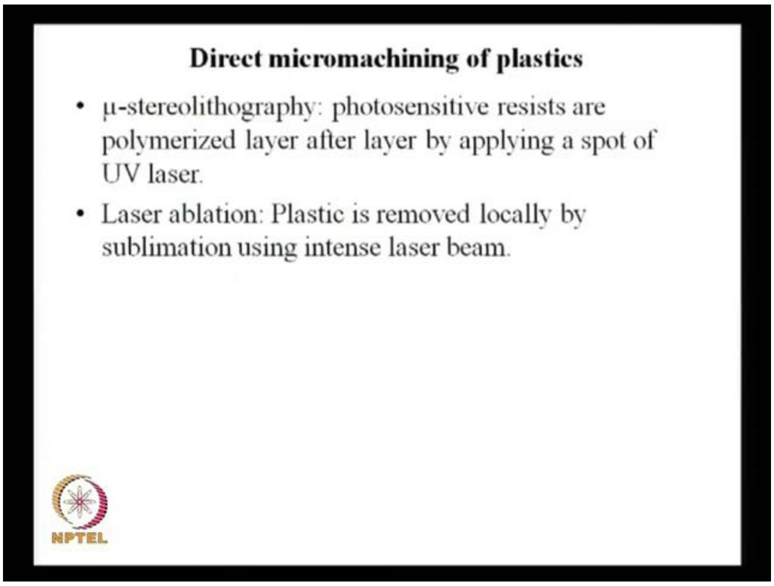

The next technique isdirect micromachining of plastics.Here, what you have is that you have a technique called micro stereolithography and the other technique is laser ablation. So, instead of applying the mould,instead of using the, using a mould that is a negative replica,you can do it directly.What you do here is you are using a photosensitiveresist.This photosensitive resist are that is polymerized layer after layer, by applying a spot of UV laser.What this technique is you have a photosensitive resist, then you build the structure from bottom to top.That means, you take a photosensitive resist then you have to create a channel.Channel means a portion that does not have any solid and around that portion, you have a build up of solid;that is how you can create a channel.

Suppose, you think of makinga channel in sand or in clay.So, you apply you put clay layer one after the other.Now, if we go back to the slide,what we see is that there could be photosensitive resist that can be polymerized by using a spot of laser.That means, you have a polymer,we you have the resist, which will form a solidstructure, if you apply a laser light. So, if apply the laser light only on those portions, where you want that buildup to take place. So, basically you have first you have this polymer layer and you are putting the laser light in selected places, where you want the solid to buildup. So, you have a mask on top,sothat light will go only through the portions, where you want it to be. Andso, those portions this polymer is getting solidified. So, one layer develops,then anotherlayer, then another layer and it continues to grow.

And when it is all grown up, then you see then in between two layers there is the channel that you want. So, it is a completely different type of approach, it is different from the casting ormouldingthat we have talked about.It does not have any replica, it will have a mask and it will have a laser light, which will ensure that polymer material solidifies. So, micro stereolithography, here photosensitive resists are polymerized layer after layerby applying a spot of UV laser.The other technique is laser ablation.Instead of building the plastic layer by layer,you can destroy the plastic layer by layer in selected portions using the laser beams.

So, plastic is removed locally bysublimation of intense laser beam; that means you are applying the laser beam, which is cutting the portions of a solid polymer structure such that a channel forms. So, it is just opposite of micro stereolithography.In one case, the sides of the channelsides of the channel is built layer by layer and here the structuresolid structure is already there and you are cutting channels using laser. So, these are these are some direct micro machining techniques that are available.However, these techniques are not thatwidely used,I mean the techniques that are most widely used ishot embossing or casting or moulding or microinjection; these are the techniques, which are morepopular.However, thesemicro stereolithography or laser ablation, these are some of the techniques that are available.

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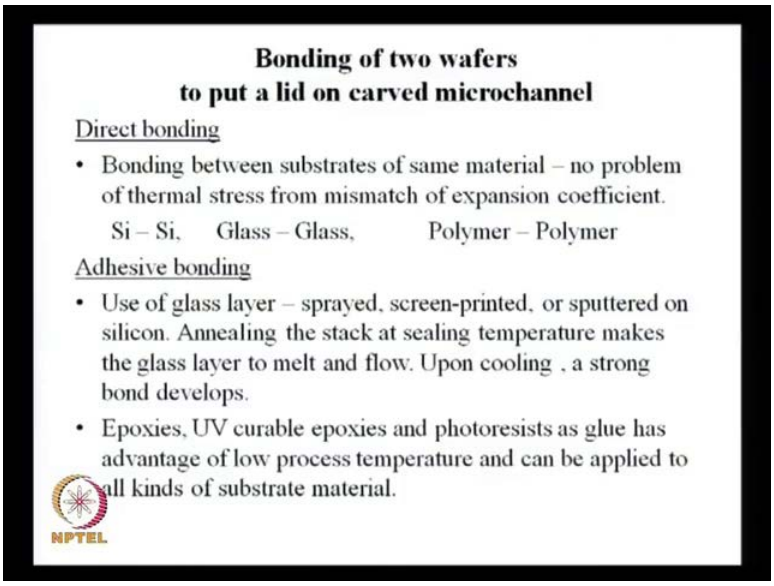

Once you have done the, you once you have made the channel, the way you want; it could a circular channel or it could be a rectangular channel.Once you have the channel, the way you want it, then you have to put a lid on top and then go for a direct bondingthen and go for a bonding. Sothat is exactly what we have done, previously with silicon.You remember and then we talked, there we talked about two types of bonding, one is anodic bonding and the other is fusion bonding.So here in this case, what we have is, we have a bonding of two wafers,there are two types of bonding we discuss here, one is direct bonding and the other is adhesive bonding.

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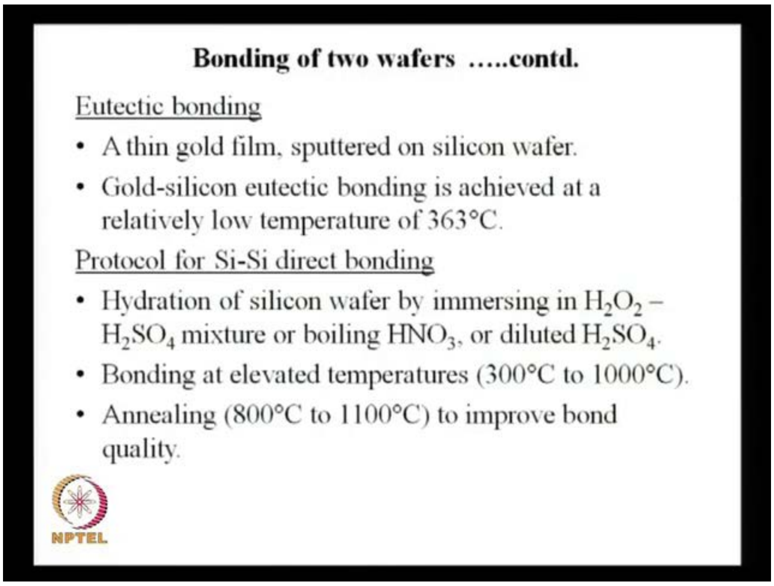

There are of course, the some other types of bondings available, one is eutectic bonding andthis is the eutectic bonding. So, there are practically three types of bonding, one is direct bonding,the other is adhesive bonding and the third one is eutectic bonding.Direct,the adhesive bonding is very popular and direct bonding is alsoused.Now, direct bonding refers to bonding between substrate of same material, sothat no problem of thermal stress from mismatch of expansion coefficienthappens.Here the bonding is done between silicon and silicon, or glass to glass,or polymer to polymer. That is theearlier we talked about silicon to glass, you remember we werewe said that glass has,when you apply a voltage between a glass and a silicon, this sodium ions they penetrate into the silicon layer and it hasverywater tightbonding;it develops a very water tight bonding.

Now, herethere when we talked about is glass and silicon bonding,this thermal stress came into picture, because atfor anodic bonding, we had a temperature of 400 degree centigrade.I mean even if you apply a voltage, still you have to take the system to a temperature of 400 degree centigrade.There this question of thermal stresses came into,we discussed about this thermal stress.We talked about the differing expansion coefficient.One the expansion coefficient of silicon and the other is the expansion coefficient of glass.Andif the expansion coefficients are widely different and when you are rising the temperature to 400 degree centigrade, it is likely that thesematerials will tend to bend, because thermal stresses will develop.

One tries to,you are trying to bond two layers,now one layer tends to expand more,the other layer tends to expand less,so the entire there would be a mismatch.Now,when you are going for a direct bonding that problem does not exist, because here the bonding is between substrates ofsame material;silicon to silicon, glass to glass or polymer to polymer, that is what we are referring to;sono problem of thermal stress from mismatch of expansion coefficient.The other typeI mean,how we get into this direct bonding,I am I will discuss this in a moment.Next is adhesive bonding; adhesive bonding, here you can use a glass layer spread, screen printed or sputtered on silicon.

Annealing the stack at sealing temperature makes the glass layer to melt and flow, upon cooling astrong bond develops.So that means, you have two layers in between youput some glass, how do you do that?A glass thin glass layer either you screen print it.That means, you put just like we have an inkjet printer you know; it is similar way, because it you need a very thin layer, because that glass will melt and justcreate the bond.Or it could be spread or sputtered; sputtered means you can you will go we are going for a physical wafer deposition. So, either way it can be done and it can be put on the silicon waferand then, you are putting one against the other and you are going for a fusion bonding practically.

You are tracing the temperature, sothat the glass melts and it flows,upon cooling a strong bond develops.The other type of adhesive bonding is use of epoxies or UV curable epoxies and photo resists as glue; these has advantage of low process temperature and can be applied to all kinds of substrate material.These epoxies are very popular,if you need to bondtwo layers, these epoxies can hold a significant amount of pressure; and these are cheap and its readily available, epoxies are commonmaterial that we use toputfixtures,I mean the kids use tomake thosework education typedrawings and all structures.

So, you can use this epoxies they those areverypopular. So, epoxies UV curable epoxies and photo resist as glue, has advantage of low process temperature and can be applied to all kinds of substrate material.Let me point outthat there exists another technique, which goes by the name eutectic bonding.Not that it is a very general one, but just look at the technique here.A thin gold film is sputtered on silicon wafer; gold silicon eutectic bonding is achieved at arelatively low temperature of 360 degrees centigrade.Do you know what a eutectic mixture is?Ityou got to go andread this it is eutecticwhat eutectic mixture is.

Gold and silicon it forms a eutectic mixture; that means, it does not, so when it comes melting of this material, it follows a different temperature;so, you got to.

It becomes a single phase.

It becomes a single phase. Soit is, so this eutectic mixture it has its unique properties. So, gold silicon it forms a eutectic mixture.And thatso, if it becomes a single phase, then that is basically the bonding isthe it is practically it is the single, soitis like any direct bonding, if it forms a single phase.So now, you remember when we talked about this anodic bonding with glass silicon, thereeven the temperature was 400 degree centigrade.If somebody wants to make a silicon-silicon direct bonding, the temperature should be around 100 degree centigrade. So, these temperature levels are pretty higher,pretty high.

That way, if you use the gold siliconeutectic,if you apply a gold layer between two silicon layer, this since gold forms a eutectic mixture with silicon.And it will follow a different temperature, it will not follow it will not melt atthe temperature silicon dictates, it is not that way. So, you can take advantage of that and get this done get this bonding done at relatively low temperature 360 degree centigrade.Protocol forsilicon-silicon direct bonding; now, we have talked aboutthree types of bonding, one isdirect bonding, the second one isadhesive bonding and the third one iseutectic bonding.

Now,direct bonding I said at the very outset that direct bonding can be done between silicon to silicon, glass to glass or polymer to polymer.Now,silicon-silicon direct bonding thatthere you have to follow certain protocol.Protocol is something which I tried to summarize here, hydration of silicon wafer by immersing in hydrogen peroxide,H 2 SO 4 mixture or boiling HNO 3 or diluted H 2 SO 4.So, it hassome,you have to treat this silicon material firstby dipping it into certain liquid and then the bonding between a silicon and a silicon layer takes place at elevated temperature of 300 degree centigrade to 1000 degree centigrade.

Next the annealing is done at 800 degree centigrade to 1100 degree centigrade to improve bond quality.That means, first the bonding takes place at a temperature between 300 to 1000 degree centigrade.And then after that, you go for another step which is annealing, that is done at a little higher temperature,so that the bond quality is improved.It isit that the hold that the technique is nothing the technique is basically you take the two layers heat them, sothat the silicon meltsat the interface and it bonds, but before that, you have to treat the surfacedip it in certain liquid. So, there are certain protocol you have to follow.Temperature also first you initiate the bonding and then you anneal it,sothat the bonding that you have develop it gets finalized.I mean that should the you have to go through certain steps that is all, but it is nothing just heating the two layers,so thattheat the interface the solid melts and forms asingle phase.

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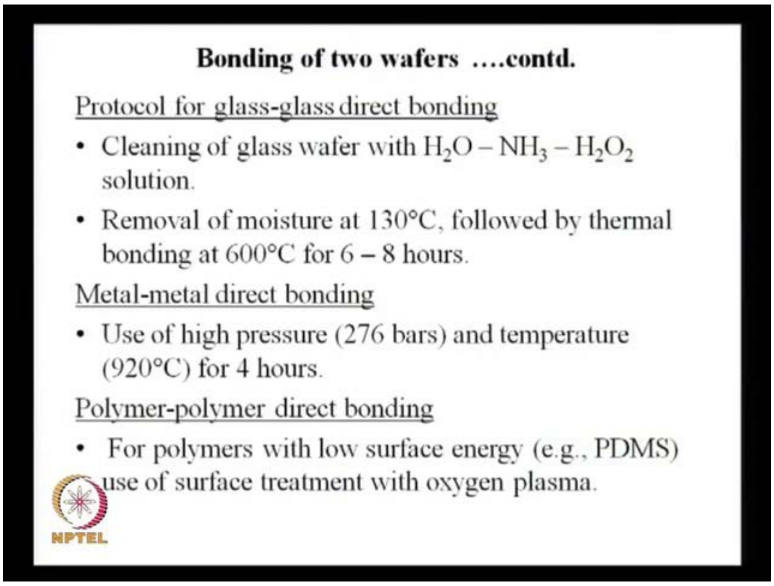

Similarly, for glass-glass direct bonding,we discussed about silicon-silicon direct bonding, for glass-glass direct bonding, cleaning of glass wafer with a solution,I mentioned H 2 ammonia,H 2 O 2. And then removal of moisture at 130 degree centigrade, first that has to be put in an oven, sothat the moisture gets,sothat you get rid of the moisture; and thenthe thermalbonding takes place by putting this two layers two glass layers;one against the other at 600 degree centigrade for 6 to 8 hours.So, it is a very straight forward protocol, take the two layers first make sure that the surface is properly treated with by dipping it in certain liquids, and then put it into the oven furnace,at certain temperature you have to hold it for certain amount of time, the bonding will be over.

Now, if we go for a metal-metaldirect bonding, we talked about silicon-silicon direct bonding, we had certain temperature.Here for glass,I see the temperature is less 600 degree centigrade. If you go for a metal-metal direct bonding,use of high pressure and temperaturefor four hours;of course, it depends on what type of metal you use.I think it isthis temperature that they are referring here possibly, it isiron or steel orsome material is there,sofor from material to material it will differ.Butit would be at a higher temperature than glass that is for sure and you have to apply pressure.Similarly, there could be polymer-polymer direct bonding.

For polymers, with low surface energy, such as PDMS,use of surface treatment with oxygen plasma is necessary. So, for polymer-polymer direct bonding, if you put the two polymer layers and heat it, definitely there would be if the polymer at the interface will melt; and you have polymer-polymer direct bonding.However, because of this low surface energy of PDMS that we discussed before, that because of this low surface energy thetake this advantage by pealing this PDMS layer from the mould. So, that sameproblem this low surface energy that can be improved by treating thisPDMS layer in oxygen plasma; putting in plasma asher and use oxygen plasma,so that the surface is treated and then you put them together.

In fact, after you treat the surface, if you just put one layer against the other you can expect some amount of bonding to take place. So, if one layer is to be bonded against the other, typically you go take the layer andtake thatsubstrate put it in plasma asherin oxygen plasma,you treat the surface; and then put it on this layerput the two together and automatically that will be bonded,because you have giventhe surface energy now that will take care of it.

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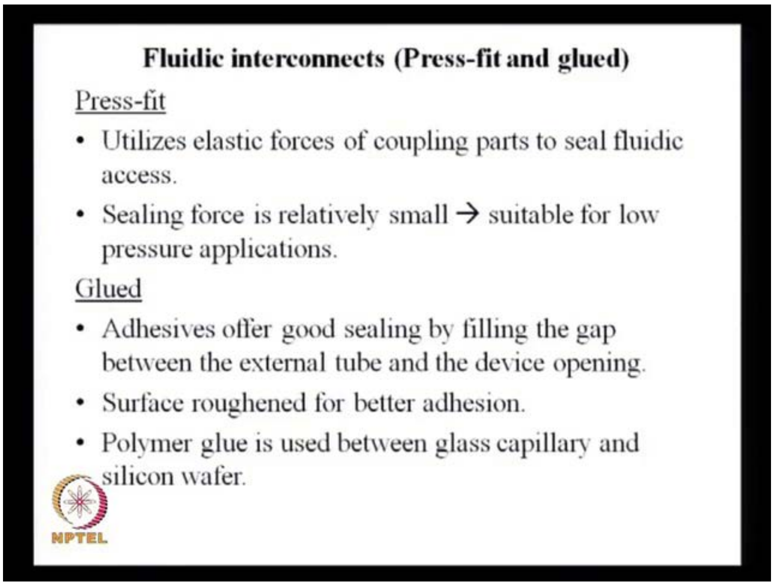

Fluidic interconnects, it could befirst of all why we need fluidic interconnects?You have the silicon or glass or plastic structure on which the channels are embedded,on top of that you put a lid and bonded.Using somany bonding techniques, we have anodic bonding,direct bonding, using glue adhesives,sowe have discussedof several methods. So, you have already bonded the other layer, one layer on top of the other. Sonow, the microstructure device is ready, now you can put interconnects; that means, the liquid that will flow into this microstructure that has to have some port through which it will flow. So, you have to have some connection some union,sothat it can be there should be somethread arrangement.

Sothat it can go in and the outside wall can communicate to this microstructure device,this will you have to ensure that this fluidic interconnects areat least the provisions are there.Now, there are two types of fluidic interconnects possible, one is press fit.Press fit we have already discussed, you have this hole through which this interconnects has to be placed.Andwhile putting it you apply certain force,sothat theplastic material around that hole that allows this tube to go in there; and once it goes in, it hugs the tube, because of thiselastomeric quality. So, that is typicallywhat we mean by a press fit arrangement. So, press fit utilizes elastic force of coupling parts to seal fluidic access.

And the sealing force is relativelysmall suitable for low pressure applications. So, you can arrange asealing by depending on this elastic force; however, the force is relatively small.So, if you have a high pressure generated within this microstructure automatically it will start, you will see that there is leakage taking place, through that port, got my point. So that is that problem is there. So, this press fit,at a press fitarrangements these are very popular as long as you are working with a low pressure a system. Because this is more of a just take this and press this in,put little bit of pressure, little bit of force and the interconnect will go in and seal; however, thatit can seal only up to certain pressure.The other method is what do you call glued.

Glued means,adhesivesoffer good sealing by filling the gap between external tube and the device opening. So, you have an external tube and you have a device opening; that means, you have this device, on top of that you put a lid,then you etched a hole; if it is a silicon, then you etch using this deep reactive ion etching technique, because that techniquewill give a hole of high aspect ratio, the other techniques there are problems. So, we discuss this you make the hole there.Now in that hole, the capillary has to get in. So, and around the capillary, you have to apply something, such that it becomesthere should not be any leakage taking place, when you have pressure inside the microstructure device.

Sofor that, wetalked this press fit and we said that the limitation is that moment you have higher pressure inside this microstructureinside this device, then automatically liquid will start leaking from that port.In case of glued, you apply adhesives.These adhesives offer good sealing by filling the gap between external tube and the device opening. surface is rough end for better adhesion. So, on the surface you roughen it.This is, this we have we have seen,I mean if you bond a sole on the shoe, that person the cobbler he first roughens, he has a typical device by which he roughens the sole and then he applies the adhesive. So, surface roughened for better adhesion that is understandable.Polymer glue is used between glass capillary and silicon wafer.

So, you have a silicon wafer, you have a glass capillary which goes in there,still you can use polymer glue.At the very outside,I said these epoxies and these UV curable these glues, these are very effective; if somebodyis using itfor a small scale,I mean if he if it is a moderate pressure and if he is not fussy aboutkeeping things very pure, this polymerglues areperfectforthese applications.So, a press fit and glued, these are the two types of interconnects that you understand,I mean what the objective here.There is a glass sealing on metal tube which is possible. So, when it comes to silicon and glass, you can use polymer glue that is the last plan.You have a silicon wafer and a glass capillary goes it there, glass capillary is, it is easy to make glass capillaries.So, glass capillary is going in there and you can apply the glue around.

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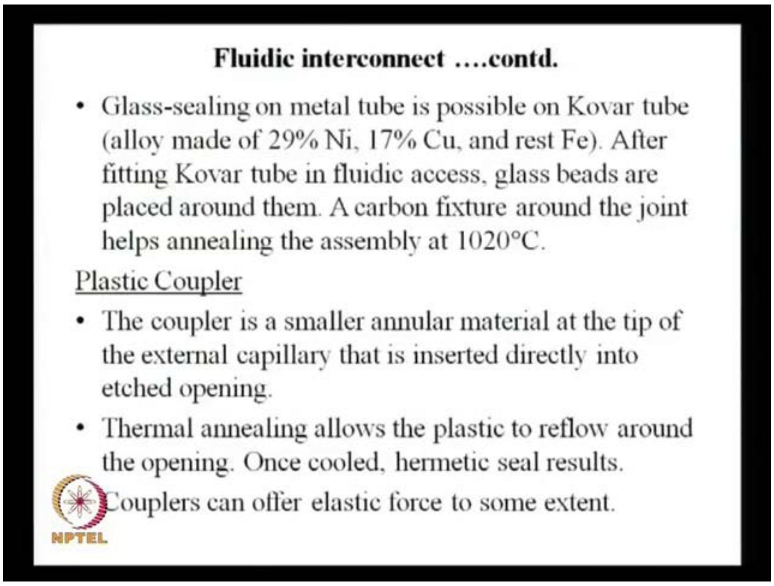

However, when you have a metal tube, that means, here we are working at a higher pressure or here, we are working withcertain materials for or certain temperatures for which a metal tube would be necessary. So, if you have to use a metal tube, then a common material that is used is calledkovar tube,it is an alloy of nickel copper and iron.

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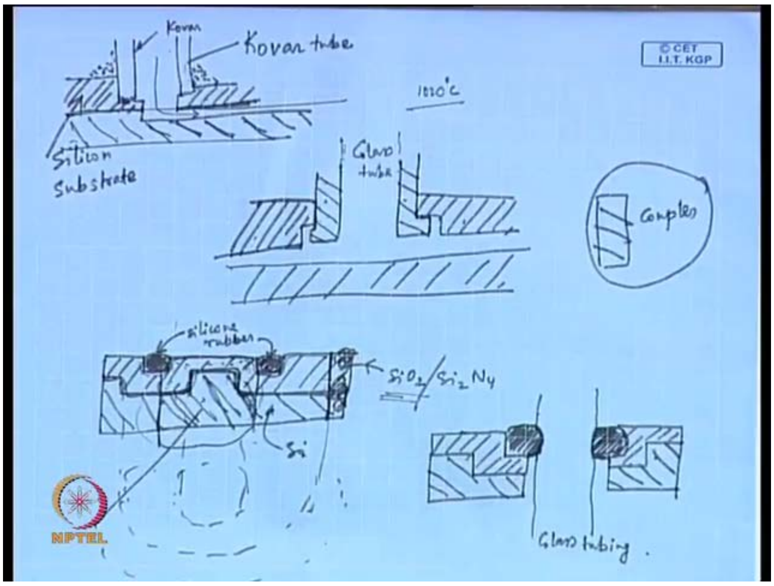

And this tube, basically what you do here is you take the tube, suppose this is the kovar material, this is the kovar tube, and this then, on thisbasically this is the place, where you havethis is the rough end portion.

(No audio from 41:40 to 42:05)

So, this is the fluidic access,this is kovar tube;this tube is basically kovar tube,this is siliconsubstrateand this is the, so youhave suppose nowand then there is another layer here I am sorry.So, this is the bottom plate, this hatching represents the bottom plate,thesehatching represents the top plate, and suppose this is the channel we are referring to;so, the fluidwill come through this and will go through will pass through this channel. Sothat is the idea.Now, you have to mix, sothis portion is rough end etcetera and they go in there,now you have to do this bounding and since this is a metal.So, the common method of doing the bonding is you put small glass beadsaround this corner,you put glass beads.

And then, you place this place a carbon fixture around a joint and anneal the whole thing, anneal the assembly at 1020 degree centigrade. So, you take this entire joint, you put it in a carbon fixture, then you put it in a enclosure and heat isthe heat whatever is inside upto a temperature of 1020 degree centigrade.What happens is thisglass melts?Andthese glass helps bonding between these two materials.

So, glass sealing on metal tube is possible. So, if somebody has to use a metal tubethat to be connected to the silicon wafer,what you will do is you will use small glass beads and those glass beadsare to beheated in a carbon fixture;so that that glass melts, it flows through the nook and cranny of thiscorner and ensure that thebonding takes place sothat is the way.There is another popularitem that we have here, which goes by the name plastic coupler.Let me draw how this plastic couplerlooks

(No audio from 44:52 to 46:03)

Here, the tube is inserted through this portion.So, these hatchingthese hatching these hatching refer to thecouplersothese hatching refer to the coupler. So, this is the coupler. So, coupler is basically an annular material,sothese annular material is this one.And the glass tube is inserted.So, this is the glass tube, so this is the glass tube glass tube is inserted to this; this is the silicon wafer that you have.Now, the idea here is that this coupler material, you apply some heat this coupler material is made of plastic; this plastic material melts,may not beperfectly melt andleaking from everywhere;it justgets softened it melts to some extent.

And this plastic material flows and this when it flows through various gaps, the places where the leakage can take place, it will flow through those places and it will make a permanentsealing.So, once you take this onceyou put,so youapply the coupler.You apply the coupler,it would be it would be a similar to, when you purchase a new pen, we see aon the tip of therefill, there is something;it would be a very similar one you put inside the. So, you put inside the hole and then you apply heat, the coupler material melts, it flows through the nook and cranny of that inter section and ensures that this becomes water-tight.Butonce it melts is this coupler material is gone.

So, once you take out,then you have to remove that coupler material and you have to put another coupler, when you canuse it. So, plastic coupler if I write it, if I see what we have written here, it is basically the coupler is a smaller annular material at the tip of the external capillary that is inserted directly into itched opening.Thermal annealing allows the plastic to reflow around the opening, once cooled hermetic seal results.Coupler can offer elastic force to some extent;so, you understand how a coupler works here. So, this is the glass tube and just a, at the tip of the tube, you put a small annularplastic material andinsert it; and then apply heat locally, sothat material melts.

Butit melts means itif, it liquefies and it leaves the place it is not that way, it softens it melts somewhat flows through the nook and cranny of that interface and ensure that this whole thing is.There is a possibility of integrated O ringthat is also people havelooked into.The picture would be something like this, you have

(No audio from 49:12 to 51:59)

What you have isan annular area will be etched fast by one of the techniques,DRIE say.Deposit an oxide or a nitridelayer,deposit an oxide or a nitride layer.

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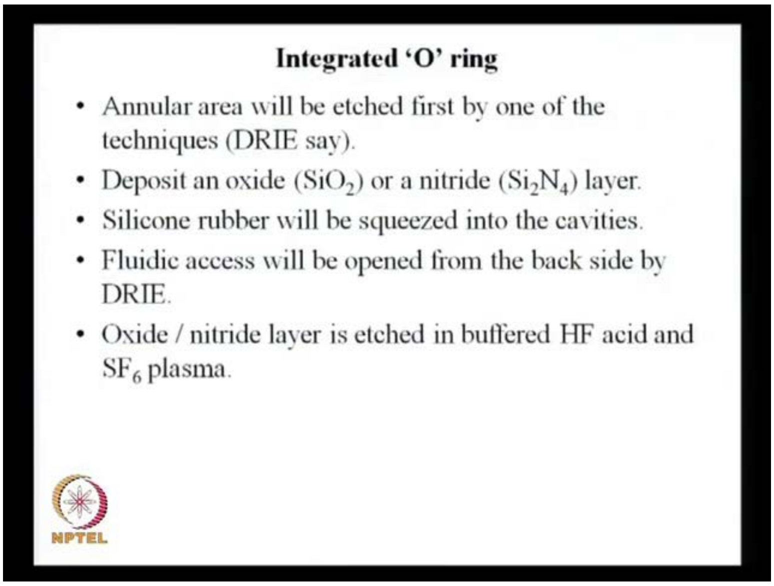

Silicon rubber will be squeezed into the cavities, fluidic access will be opened from the back side by DRIE and next oxide and nitride layer is etched in buffered HF acid and SF 6plasma.What this means is,first what you do is you etch and annular area. So, this is the annular area, what is this annular area?Youhada silicon wafer,this is the silicon wafer; you etch and annular area, this is that annular area.I should havemade it uniform,this looks a little bigger.So, you etch this annular area. So think of it, this is basically an annular area. This dipthis is the onesee,if you look at the top view,this portion refers to a, this portion refers toan annular area. So, this dip I mean,I just mind it I mean it should have been closed here,then it would have been uniform. So, this portion refers to an annular area. So, this you ensure by doing an etching,you form an annular area.

Then on thatannular area, you deposit an oxide or nitride layer,SiO 2 or Si 2 N 4, you deposit. You know how to do this deposition.Youtreat this,say for example, when it comes to deposition by SiO 2, you keep it in oxygen at a temperature of 600 degree centigrade orso;automatically SiO 2 layer of micrometertype thickness, sothat you can achieve; soyou if, soyou form a SiO 2 layer.On top of that,you silicon rubber will be squeezed into the cavities.Here you make a cavity, in which you.See,since you form this annular layer, when you make this, when you make acoating of SiO 2 or Si 2 N 4, automatically this portion will also be dipped like this.

So, when you make this coating of SiO 2, Si 2 N 4, thenautomatically these portions will be dipped. So, you have a cavity hereand that cavity will befilled by silicone rubber.So, silicone rubber will be squeezed into this cavity; that meansyou make it you hit it,get in a molten state,so that you can squeeze it inside that cavity.Silicone,it remind it is not silicon, it is silicone, c o n e silicone rubber,soit is it a completelydifferent material. Sothat is squeezed into these cavities.After you do that, then youopen a fluidic access from the backside; that means, from this side, from the backside, backside means this side. whatever you are doing is on the top silicon outside layer, thensilicone rubberput in there, then you open a fluidic access from the backside; that means, you by DRIE deep reactive ion etching;so that means, you cut off this portion.

You remove this portion all together,you etch it out,I meanyou are basically you are using a dry etching technique to take out this material.So, once you take out this material the,what you end up with is,onceso you etch this material and then oxide or nitride layer is etched in buffered etch of acid and SF 6 plasma; that means, you firstthis etching this layer would be easier, because this portion is silicon mind it; this portion was silicon, soetching this part would be easier. So, this part would be etchedquickly.And then, when you try to etch this layer, it would be difficult to etch this layer, this we pointed out, because silicon andSiO 2 acts as a mask, it is much difficult to etch the siliconSiO 2layer.So, for this you have to bring in plasma. So, you get this part also etched out. So, once you take this whole layer out,then what you end up is a structure somethingsimilar to this; where the glass tubing runs like this and this silicone rubber that you put there, that is acting as theseal, that is acting as the seal you see.

So, this is the silicone rubber. So, you put first, you take the silicon wafer put a layer on top,so that you form a cavity in these placesand pour it pour the silicone rubber, which is different squeeze into this, which is going to act as a gas kit. So, youput it there, then you go from the backside, first remove the silicon layer; silicon removing silicon is very easy it is not at all a problem, but SiO 2is difficult to remove.For that you have to go for dry etching andwhichyou need to go for a stronger etching technique and that you do.And then, after that we once you remove this whole material, then what you have is you have thisfluidic access made.And this silicone rubber is acting as aO ring.

You know what aO ring is,you need a O ring, which practically acts as a gas kit;sothat o ring would be in o ring would be there. Sothis is,this would be acting as aO ring.So, this you have integrated;so, what you have is this structure with integrated O ring; that means, you are not having a separate O ring, which you put and then you put the tube it is not that way.Instead, what you have is you haveanyou have the O ring which is already inbuildinside the structure that is what we are referring to integrated O ring.

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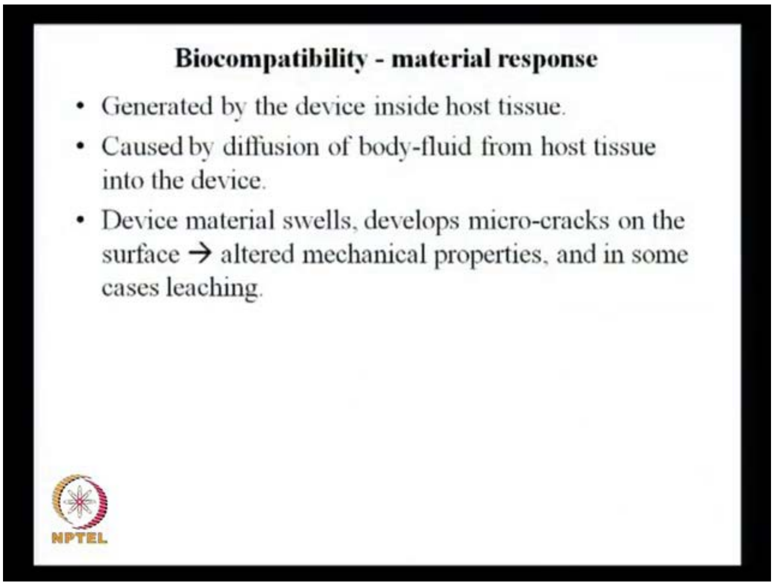

In the next class, we will discuss about the biocompatibility issues, probably very briefly; what are this biocompatibility issuesinmicrostructure.And then we get into the theories of microfluidics.We will probably start withmixing betweentwo streams.That will that is a first topic that we take up as far as a theories of microfluidics is concerned. So next class, verybriefly I touch upon thebiocompatibility issue and then we get into the theories.Wetreat that thediscussion that we hadso far on microfabrication that is over.