Microscale Transport Processes

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

Lecture No. #08
Deposition

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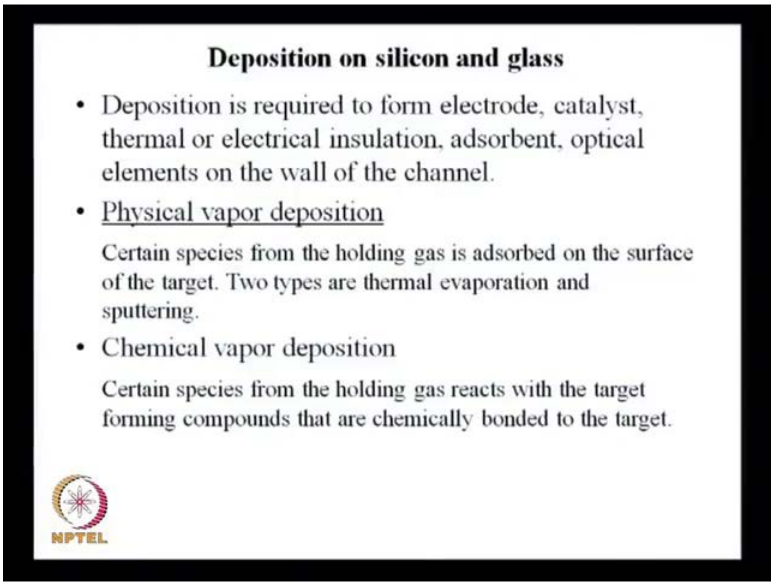

Deposition on silicon and glass

- Deposition is required to form electrode, catalyst, thermal or electrical insulation, adsorbent, optical elements on the wall of the channel.
- Physical vapor deposition

  Certain species from the holding gas is adsorbed on the surface of the target. Two types are thermal evaporation and sputtering.
- Chemical vapor deposition

  Certain species from the holding gas reacts with the target forming compounds that are chemically bonded to the target.

I welcome you once again to this course on Microscale transport process. In the last class, we were discussing about deposition on silicon and glass.What we hadso far covered is, a technique called photolithography by whichsilicon substrate can be etched in selected locations; and that process is utilized to make channels of certain depth on the substrate.WhatI pointed out is that next thing you need to do to this substrate isyou need to make deposits on the channel wall,which will constitute electrode,catalyst, thermal or electrical insulation, adsorbent, optical elements on the wall of the channel. Sofar various reasons, you need to put the put some you need to make some deposition on the channel wall.And once that is done,thenyou are suppose to close the channel by putting another lid on top of it,and seal the channel.

And once you make some interconnects, that means once you makes some pores through which you canconnect a pump or you can connect a some other external source,then this microstructure device is all done.So, deposition on silicon and glass, here I already mentioned what all reasons for which deposition needs to be done.There are two types of depositions possible; one is physical vapor deposition, where certain species from the holding gas is adsorbed on the surface of the target.And there are two types -one is thermal evaporation and other is sputtering.And in chemical deposition, certain species from the holding gas reacts with the target forming compounds that are chemically bonded to the target.

So, these are the two forms of deposition that is commonly pursued. And in last class,I pointed out there are certain benefits to give this deposition done from the gas phase;that is why we are talking about to vapor deposition process.And we are not going through the route of precipitation from a liquidphase, though that is a very viable technique to make a deposition on the channel wall.Precipitation of certainmaterial on the channel wall; however, since a gas phase diffusivity is much higher, you can expect a bettercrystalline structure, when you deposit it from the vapor phase.

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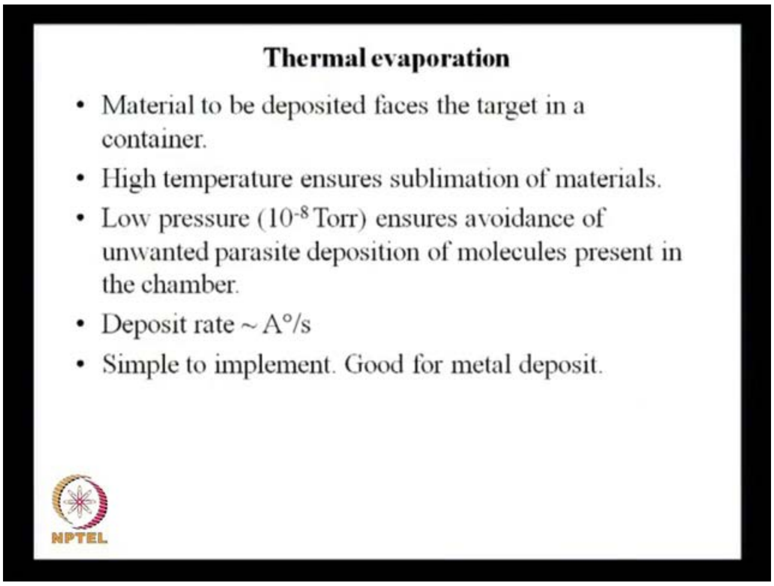

Thermal evaporation

- Material to be deposited faces the target in a container.
- High temperature ensures sublimation of materials.
- Low pressure (10^{-8} Torr) ensures avoidance of unwanted parasite deposition of molecules present in the chamber.
- Deposit rate ~ A°/s
- Simple to implement. Good for metal deposit.

Nowthere is this,I said there are physical vapor deposition is of two types, one is thermal evaporation and the other is sputtering.Inthermalevaporation, what you do is?First, material to be deposited faces the target in a container.

Then the high temperature ensures sublimation of material and then low pressure ensures avoidance of unwanted parasite deposition of molecules present in the chamber; and then deposit rate is given here, it is simple to implement and good for metal deposit.

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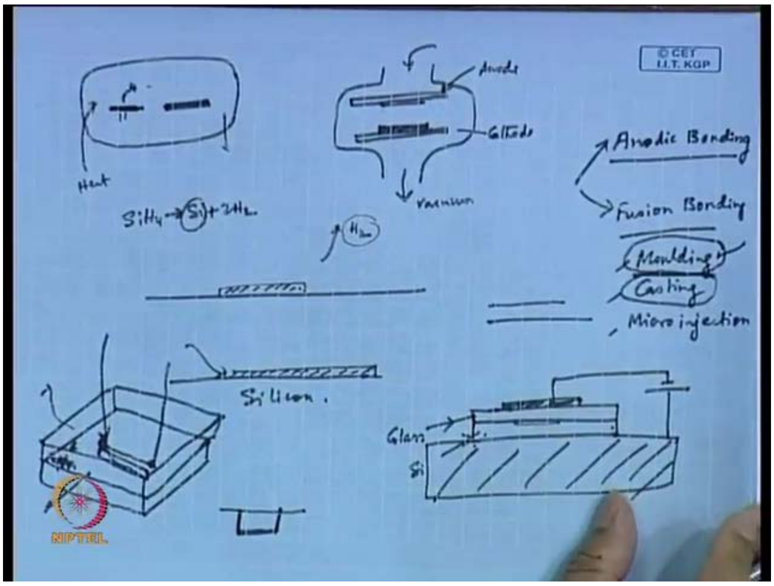

What you do in this thermal evaporation process is, that you take a chamberyou have some heating arrangement,so this is practically, this is a furnace,you have the heating arrangement.And you have, suppose this is the substrate, which needs to be,this is the substrate and a part of this substrate needs to be deposited;so, you leave this part exposed and other partunexposed.And then you keep this solid material that you need to deposit, you keep this solid material next door; may be at an angle and then you heap this,heap this solid material.So, this solid material undergoes sublimation, soit goes to the gas phase and there is a gradient in temperature; may be the heating is done on this side,soheat is supplied here.

And this part is cooled,sothere is a gradient in temperature. So, as this sublimatedwhich is basically a gas. So, this is basically a solid, which you need to deposit.And this is the substrate, on which you want to make the deposit and it has certain exposed part, where this deposit will be made. So, this gas as it travels it encounters a temperature gradient;so, this gas gets again deposited itgoes back to the solid phase on the substrate in the locations that you want. So, this is commonly the thermal evaporation.

So, if I repeat it, once again the material to be deposited faces the target in a container material, hereif I see on this figure, material to be deposited faces the target in the container; target is the substrate on which you want to make the deposit.High temperature ensures sublimation of material,soby heating, you ensured the sublimation of materials.Sublimation means going from solid phase to gas phase.Low pressure 10 to the power minus 8torr and I have already mentioned, what one torr is, it is basically one millimeter of mercurypressure.

So, 10 to the power minus 8torr ensures avoidance of unwanted parasite deposition of molecules; that means, if in the gas phase,there is unwanted material already presentthat material also may get deposited on thesubstrate. Soby creating vacuum, you ensure thatonly the sublimated material is present and only the sublimated material deposits, if there is no other parasite deposition.That means, sublimated material is getting deposited by the on the side of it, some other material is also getting deposited, sothat you are trying to avoid. So, you are putting this whole system under vacuum.Deposit rate is typically angstrom per second; it is simple to implement and good for metal deposits.

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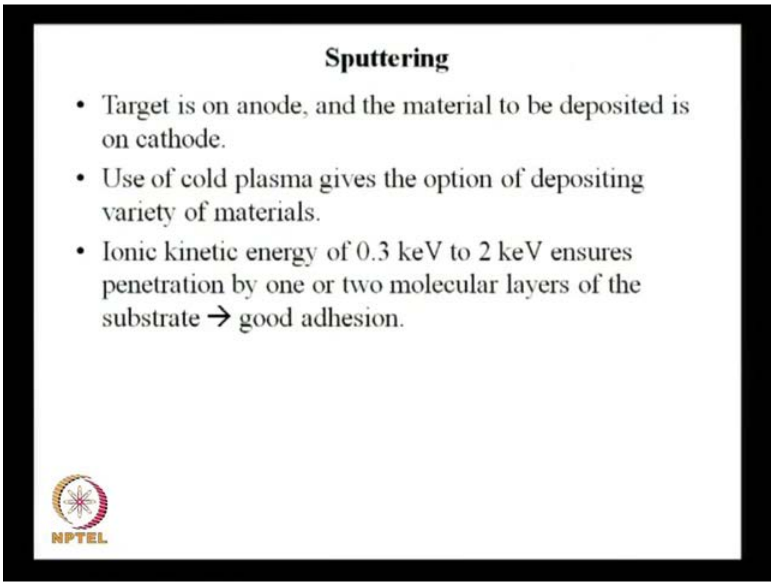

Sputtering

- Target is on anode, and the material to be deposited is on cathode.
- Use of cold plasma gives the option of depositing variety of materials.
- Ionic kinetic energy of 0.3 keV to 2 keV ensures penetration by one or two molecular layers of the substrate → good adhesion.

The other method that is there iscalled sputtering.Sputtering involves a use of voltage and not heat. So, if a material which is heat sensitive, which you where you cannot apply lot of heat, sothere this sort of this technique is very useful.Here the target is on anode and the material to be deposited is on cathode.

You rememberwhat we saw last time, we had this physical vapor deposition and how was it?We had an anode, we had a cathode and we had placed substrate on cathode; that was what the physical deposition that is how the physical deposition works. So, you had anode andhere you applied vacuum and then you introduce a gas, which get ionized here in the between these two electrodes and then it was bombarded the substrate to create the physically etching; sothat is what we have already studied.Here in this case, you are keeping the target.Target is on anode and the material to be deposited is on cathode;so, your target is on anode this is the anodeand this is the cathode. So, target is the substrate on which you want to makethe deposit, target is on anode and the material to be deposited that is on cathode.

Use of cold plasma gives the option of depositing variety of material. So, youare creating a plasma inside, soyou do not need to rely on that temperature toget these deposition done. So, this allows deposition of variety of materials, ionic kinetic energy of 0.3kilo electron volt to 2KeV,this ensures the penetration by one or two molecular layers of the substrates. So, this is not justthe other layer is sitting on the substrate, it is penetrating, because you are applying a voltage you are adding some amount of ballistic effects goes one or two molecular layer into the substrate;so, this is good for the adhesion. Sothis is, sothese are the two methods you have for physical vapor deposition.

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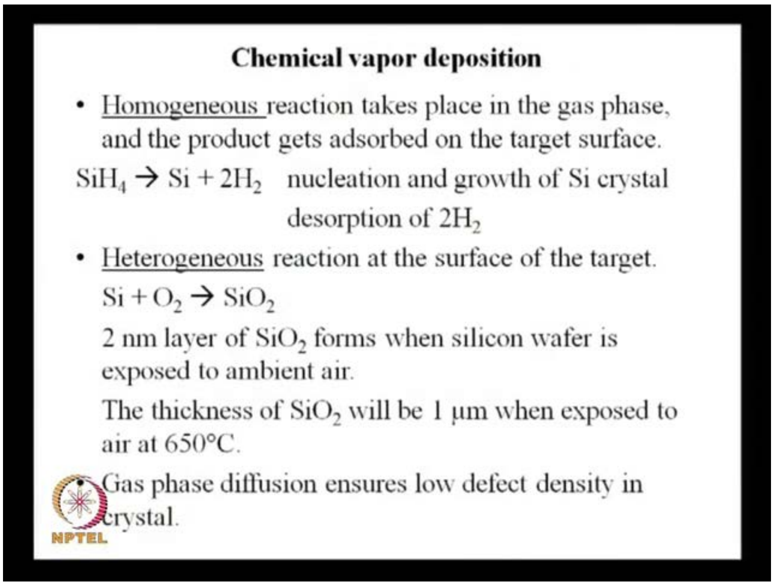

Chemical vapor deposition

- Homogeneous reaction takes place in the gas phase, and the product gets adsorbed on the target surface.

$SiH_4 \rightarrow Si + 2H_2$ nucleation and growth of Si crystal
desorption of $2H_2$

- Heterogeneous reaction at the surface of the target.

$Si + O_2 \rightarrow SiO_2$

2 nm layer of SiO_2 forms when silicon wafer is exposed to ambient air.

The thickness of SiO_2 will be 1 µm when exposed to air at 650°C.

- Gas phase diffusion ensures low defect density in crystal.

The next technique that I have here is chemical vapor deposition, this is a very popular technique, you might haveheard of this technique.Here, there could be either a homogenous reaction taking place in that gas phase or a heterogeneous reaction that can take place at the surface of the target.Here, you see the homogeneous reaction takes place in the gas phase and the product gets adsorbed on the target surface.What you what I have written here is SiH 4; thisis breaking down to silicon and hydrogen. So, this silicon issoif this is the substrate and you supply SiH 4, which breaks down to Si plus 2H 2. So, this Si gets deposited on the substrate and a hydrogen goes away;so, hydrogen goes away and silicon gets deposited on the substrate.

So, SiH 4giving rise to Si plus 2H 2,it gives rise to nucleation and growth of silicon crystal and adsorption of 2H 2. So, you do not have you do not have hydrogen, hydrogen is going to the going back and the silicon that is being deposited. So, after doingafter preparing the substrate, if you need to make a deposition of silicon at some place; that can be done by this technique,sothis is basically one form of chemical vapor deposition.Similarly, it could be heterogeneous reaction at the surface of the target.There the substrate itself contains the silicon,there the substrate itself contains the silicon and oxygen comes there andreacts with this silicon to form silicon dioxide.

Two nanometer layer of SiO 2 forms, when silicon vapor is exposed to ambient air anyway and the thickness of SiO 2 will be one micrometer, when exposed to air at 650 centigrade,so that is the way it works.This is an example of chemical vapor deposition,which is heterogeneous type.You are depositing SiO 2 on the layer of silicon, on the silicon substrate you want to cover one particular portion with SiO 2. So, for that what you do is you encourage this, you ensured that you have these heterogeneous reaction takes place at the surface of the target at those selected positions.

On the other hand, it could be that you want to deposit simply the silicon, in that case you have SiH 4supplied there and this SiH 4, in the bulkphase it reacts with silicon,it reacts to forms or it dissociates into silicon and hydrogen; and this silicon is deposited on the substrate. So, this is an example of homogeneous reaction.Now, gas phase diffusion ensures low defect density in crystal.ThatI already pointed out, the gas phase hasgas phase diffusivity is much higher,soit helps you in reaching all the places.

Andso, mass transfer limitation;for example, a crystal is a crystal formation requires that atom be supplied at the right time, at the right place, then only a crystal line arrangement can grow; in the form we said, two face centered cubic lattice separated by etcetera, etcetera.So, if we need to do that we have to ensure that the silicon atom that we are talking about that silicon atom is there, when you want it in the right quantity.If you have a mass transfer limitation, one siliconcould diffuse, but there was a concentration gradients,so silicon could not reach there.If such situation comes up, then it will not bestraightforward. Soin that case, the crystal line arrangement will be imperfect; you will not have exactly that face centered two face centered at cubic lattice interpenetrated in the way it is suppose to. Sothese,sogas phase diffusion helps you inso,I mean you can do it otherwise, but there could be some defects you are introducing,here the defect density would be less.

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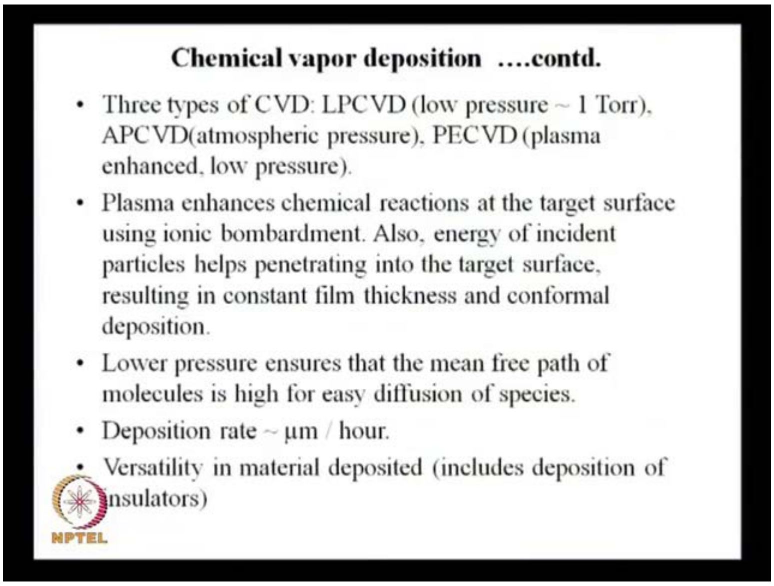

Chemical vapor deposition ….contd.

- Three types of CVD: LPCVD (low pressure ~ 1 Torr), APCVD(atmospheric pressure), PECVD (plasma enhanced, low pressure).
- Plasma enhances chemical reactions at the target surface using ionic bombardment. Also, energy of incident particles helps penetrating into the target surface, resulting in constant film thickness and conformal deposition.
- Lower pressure ensures that the mean free path of molecules is high for easy diffusion of species.
- Deposition rate ~ µm / hour.
- Versatility in material deposited (includes deposition of insulators)

Now, chemical vapor deposition is of three types, one islow pressure chemical vapor deposition, other is atmospheric pressure and other is PECVD,plasma enhancedchemical vapor deposition.plasma enhances chemicalreactions at the target surface using ionic bombardment plasma enhances chemical reactions at the target surface using ionicbombardment,also energy of incident particles helps penetrating into the target surface, resulting in constant film thickness and conformal deposition.

What is means is ifbasically what you need to is you need to have a reaction,SiH 4dissociating into silicon and hydrogen, but you can provide energy through plasma, soplasma this plasma is enhancing the chemical reaction at the target surface; and also, it is ensuring that the film thickness is constant and there is conformal deposition.Conformal deposition means there is no (( )),the deposition isuniform; there is no ups and downs in the deposition. So that conformal deposition can be ensured, if you have this plasma deposition. So, reaction is conducted,the chemical reaction is conducted within the plasma chamber here.Low pressure ensures that the mean free part of molecules is high for easy diffusion of species.

Sothat is whythis plasma enhance that is also at low pressure and there is LPCVD technique, which is at low pressure.Deposition rate is of the order of micrometer per hour and versatility in material depositedis there.Thisversatility in material to be deposited that is there in this includes deposition of insulators as well. So, I mean unlike physical vapor,unlike this thermal deposition,for example, here this chemical vapor deposition, here you can havethis versatility and if you are using plasma enhancedplasma,thisplasma enhanced CVD,in that case, you are ensuring that you have a conformal deposition.That means, deposition that you make is uniform it does not have (( ))on the substrate.

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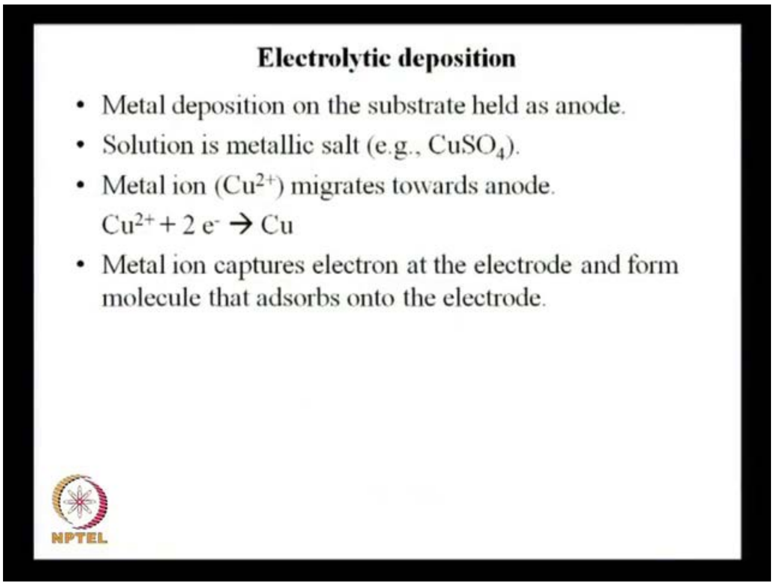

Electrolytic deposition

- Metal deposition on the substrate held as anode.
- Solution is metallic salt (e.g., $CuSO_4$).
- Metal ion (Cu^{2+}) migrates towards anode.
  $Cu^{2+} + 2\ e^- \rightarrow Cu$
- Metal ion captures electron at the electrode and form molecule that adsorbs onto the electrode.

Now, I put it as if these are the two methods of deposition, this chemical vapor deposition and physical vapor deposition.Butthere is a third type of deposition which has already been there for some time and which you already know, which is called electrolytic deposition.Here, the metal deposition on the substrate, which is held as anode.Solution is metallic salt such as copper sulphate.Metal ion that is copper ion migrates towards the anode,so copper sulphate breaks down into Cu 2 plus and SO 4 double minus.

And then,Cu 2 plus is attracted towards anode; anode means it because Cu 2 plus is positive it migrates towards anode,where it gets two electrons and formthe elemental copper and these copper gets deposited on the electrode. So, metal ion captures electron at the electrode and form molecule that absorbs on to the electrode. So, this isthis isa verytraditional method of making deposition or making a coating, electroplating you might have already seen. So, this kind of deposition you are already aware of.It is just that I mention it for,I meanthis should be a part of this exercise, this since we are talking about deposition,electrolytic deposition isvery much there.

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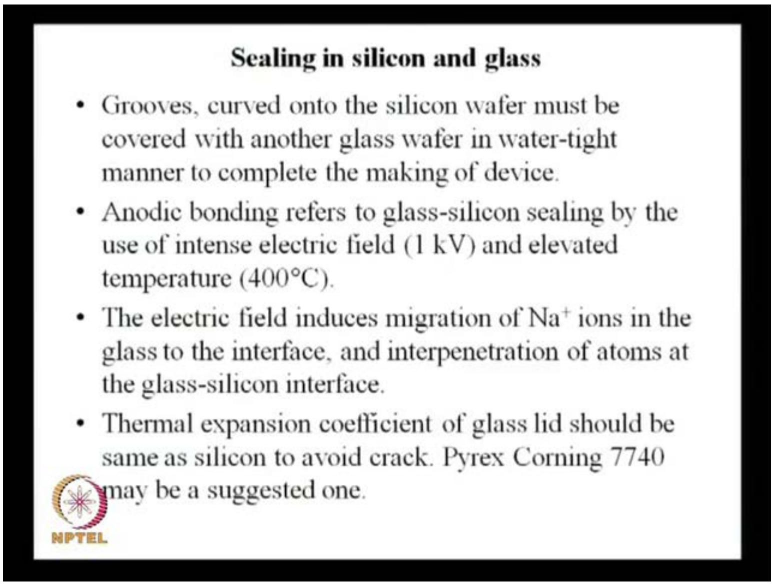

Sealing in silicon and glass

- Grooves, curved onto the silicon wafer must be covered with another glass wafer in water-tight manner to complete the making of device.
- Anodic bonding refers to glass-silicon sealing by the use of intense electric field (1 kV) and elevated temperature (400°C).
- The electric field induces migration of Na^+ ions in the glass to the interface, and interpenetration of atoms at the glass-silicon interface.
- Thermal expansion coefficient of glass lid should be same as silicon to avoid crack. Pyrex Corning 7740 may be a suggested one.

Now, once you make I mean as I said that you have taken a substrate, you made channels whether it is circular orin a in a zigzag manner or a straight line, you made a channel of certain depth.The depth, what depth you want you can make it.

Whether you want the vertical wall to be vertical or whether you want wall to be inclined,I mean that you have various choices.You can have you can go for wet deposition;you can fordry etching processes. So, you have made a channel,you have curved channel on the substrate the way you want.Then on the channel wall, you may be that requirement is that you to put someelectrode material at selected places or some catalyst material in selected places or some thermal insulation in some places; sothat deposition can be done using these methods that I discussed. So, once that is done, what you need to do is you need to put a lid on top of this substrate.

You have met the surface, met the channel, inside the channel wall you met the deposition, then you put a lid on the substrate and make it water tight, soit can hold some pressure.Then you considered this microstructure to be ready and then you have to make some interconnects at selected places through which the sample can be introducedandso these microstructure should be ready. So, how to put the lid on thatsubstrate that is what we are concerned here.And what the title says is sealing in silicon and glass.WhatI write here is grooves curved,this should be I think c a r v e d, grooves carved this is curved. So, c a r v e dgrooves curved on to the silicon wafer must be covered with another glass wafer in water-tight manner to complete the making of device.

Now, anodic bonding there are ways to do this, one is called anodic bonding.There are methods to do it, one is called anodic bondingand the other is called fusion bonding.By these methods, you can bondsilicon substrate; you can put a lid on top of this.Now, anodic bonding, anodic bonding refers to glass silicon sealing by the use of intense electric field one kilovolt and elevated temperature 400 degree centigrade.The way it works here is that suppose this is the silicon wafer,the silicon substrate, on which you are putting another lid,sothis is made of silicon andthis is made of glass. So, you are applying a voltage across this. So, how do youapplying a voltage?Youand you put this;you apply voltage across these two. So, this is one is glass and the other is silicon.

Why are we sealing it?Let me put it this way.Suppose, this is the substrate, this is the silicon substrate,on which you have curved a channel, you have curved a channel here on this you curved a channel.So, how does the channel looks like? So, you have curved a channel here, you understand.And on top of that, you are putting another lidthis is a solid one. So, this is the second one you are putting it on top, sothat you this channel was otherwise when you have done the etching, you have done this part either this or at an angle.

Now, you have to cover this right then only the channel will be complete, sothat is exactly what you are doing here that is exactly what you are doing here.The bottomone is silicon that has some channels at some place;and on top of that, you are putting another glass slide of similar dimension.And then, you have to bond.Bond means these portions this glass and silicon,these has to be water tight; sothat if you make a port here and through this you introduce the sample or apply some pressureand you have another port for some other reason.

So, when you put some liquid there, liquid will flow through the channel, this becomes watertight, this should not come out and start leaking from hereor start leaking from there, got my point. Sothat is the purpose of putting the cover. So, when you put the cover, you have this silicon on top of that you have this glass layer and you are applying a voltage; that is what we are talking about here.Anodic bonding refers to glass silicon sealing by use of intense electric field;one kilovolt an elevated temperature of 400 degree centigrade. So, not only you are applying a voltage, you are applying heat as well, the value is 400 degree centigrade.

The electric field induces migration of sodium ion in a plus ion, in the glass to the interface and interpenetration of atoms at the glass silicon interface.You understand what a glass is, you understand a composition of glass; you might have already seen, it has sodium ion.And other than that, you have orthoborosilicate,heard of thisortho borosilicate and. So, you have a sodium ion and you havesodium as a positive ion in that glass. So, when you apply thisintense electric field, this sodium ion goes to the interface.And it goes for,so there is you are ensuring interpenetration of atoms at the glass silicon interface.

Sothat interpenetration is an,at the same time you are applying a temperature of 400 degree centigrade. So that interpenetration is basically creating the addition that you require here and these are very perfect addition.Now, one issue here is that since you are having silicon and glass,these thermal expansion coefficient of silicon and glass could be different.And when you take this to 400 degree centigrade, if the thermal expansion coefficients they are not similar,not of similar order, you would expect crack, bending and all these things.

Becauseon one hand, it tries to expand to the, to one silicon substrate and a glass lid,they try to expand by different magnitude,that is one issue and at the same time you are trying to bond them;so, youwill develop crack. So, you have to ensure that the glass lid that you choose that has thermal expansion coefficient similar to silicon that is the fourth point that I have on the slide.Thermal expansion coefficient of glass lid should be same as silicon two avoid crack.Andthis ispyrex corning 7740 this isone basically a commercially product, which issuggested for this purpose that for the, this is the type of the glass as of the glass can be of various types and this is the type of glass that they have chosen. That can be suggested,that has been suggested in literature.

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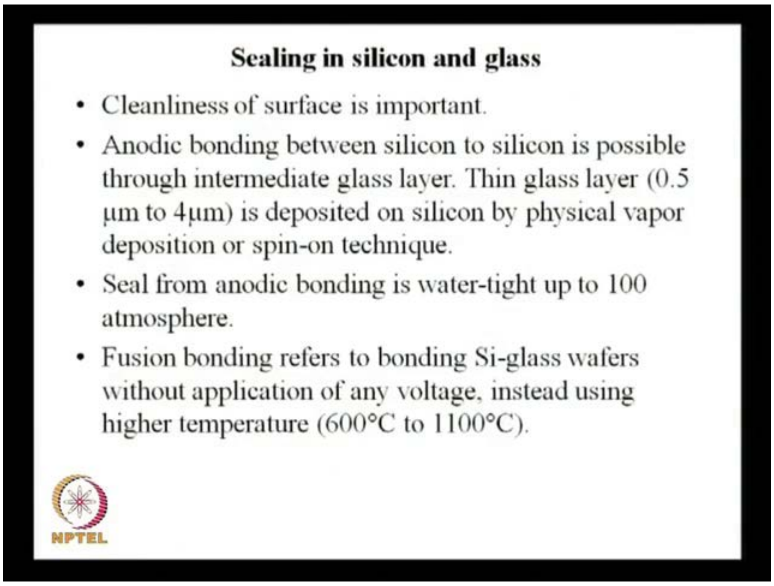

Sealing in silicon and glass

- Cleanliness of surface is important.
- Anodic bonding between silicon to silicon is possible through intermediate glass layer. Thin glass layer (0.5 μm to 4μm) is deposited on silicon by physical vapor deposition or spin-on technique.
- Seal from anodic bonding is water-tight up to 100 atmosphere.
- Fusion bonding refers to bonding Si-glass wafers without application of any voltage, instead using higher temperature (600°C to 1100°C).

Now, thisanodic bonding, this cleanliness of surface is extremely important.If the surface, if thein between silicon and glass layer, if there isdust particle that can go against this sealing process. So, cleanliness of surface is important and for that, probablyyou have to clean it.We have already discussed about some protocol,you dip it in acetone and dip it in alcohol and dehydrate and all these. So, for the purpose here is that there isnot any such substance and the operations are to be done ensuring that the ppm level of particles of certain diameter isless than limiting value.

So, these are few things which you ensure to,these are the few things which youlook into for ensuring this cleanliness of surface.Now, anodic bonding between silicon to silicon is possible.We talked about a silicon substrate and on whichyou are putting a glass lid.Now, you may say, if I want to put the silicon lid itself instead of glass,that is highly possible;only thing is then there would be an intermediate glass layer, because this aspect of sodium ion dangling and going into the silicon phase and forming an interpenetrating network, that is possible between silicon and glass.

So, you to utilize this, what you are doing is you are putting a very thin layer of glass between two silicon. So, one half of the glass connects with the upper silicon lid and the other part of the glass connects to the lowerone the silicon substrate and that is how you can have a bonding done. So, what you do here is anodic bonding between silicon to silicon is possible through intermediate glass layer. So, you put an intermediate glass layer just for the bonding purpose and nothing else.

Thin glass layer of 0.5 micrometer to 4 micrometer, a thin glass layer can be deposited on silicon.Now, thequestion is how will you deposit this?On the silicon I have suppose silicon substrate is there, plain substrate I want to make a coating of 0.5 micrometer to 4 micrometer.Again this deposition can be done on silicon by physical deposit silicon that we discussed just now or spin-on technique. So, you haveglass melt put there and you spin it and you form a layer. So, there are methods do this.You already you should appreciate, because you have already you have been introduced to this ideas.

Now, seal from anodic bonding is water-tight up to hundred atmospherethat is a very high valueit looks like.Now, fusion bonding which is the other type bonding, you remember at the very outside,I said that there are two types of bonding possible; one is anodic bonding,another is fusion bonding.Now, fusion bonding refers to bondingbetween silicon and glass as before.Only thing is that entire penetration of Na plus,etcetera, these are probably cause by application not by application of any voltage, instead the temperature or the heat takes care of it completely. So, the heatingis instead of applying any voltage, the heating is to be done and heating has to be to a very high temperature,600 degree centigrade to 1100 degree centigrade.

So, if you can take this silicon and glasssilicon substrate with the glass lid and if you take this to that temperature, you can expect a fusion bonding to take place.However, anodic bonding is more popular, anodic bonder is device which is availablefor people who are working with these microstructure fabrication.

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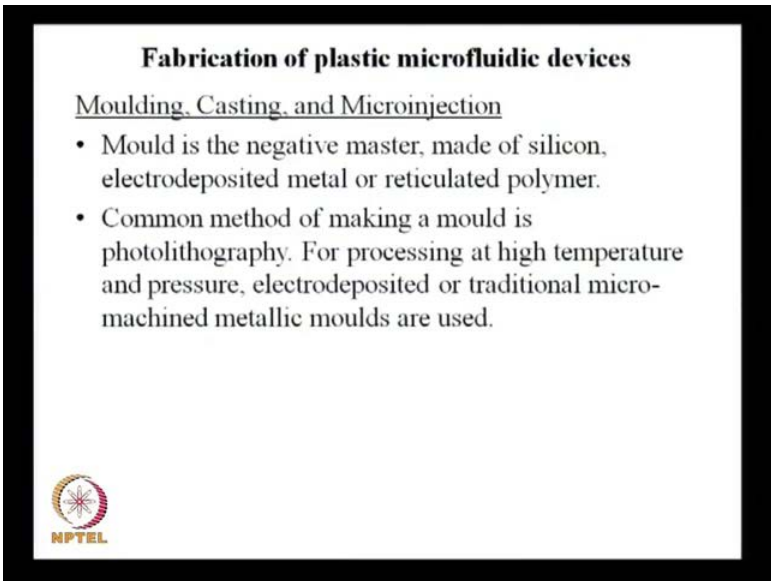

Fabrication of plastic microfluidic devices

Moulding, Casting, and Microinjection

- Mould is the negative master, made of silicon, electrodeposited metal or reticulated polymer.
- Common method of making a mould is photolithography. For processing at high temperature and pressure, electrodeposited or traditional micro-machined metallic moulds are used.

Now,so far what we discussed is thatI said at the veryoutside this photolithography;photolithography, etching and all these things, these are concerning only the silicon substrate, silicon or glass.I said you will have when it comes to wet etching,we discussed about anisotropic etching,and then we said that the same thing will have isotropic etching glass, but we restricted our discussion to silicon and glass.Butthere is a huge,there is a major part of work, which is there not with silicon and glass, but with plastic material.And at the very beginning, we discussed about this, we mentioned that plastic materials.

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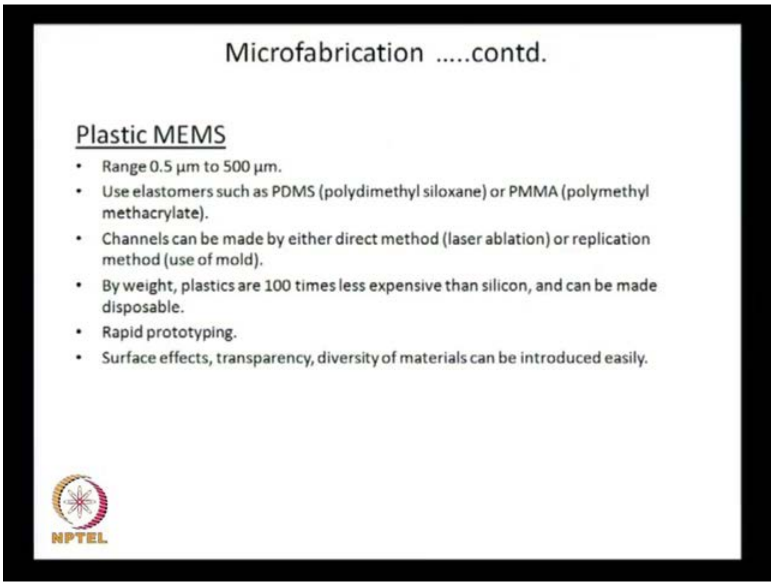

Microfabrication .....contd.

Plastic MEMS

- Range 0.5 μm to 500 μm.
- Use elastomers such as PDMS (polydimethyl siloxane) or PMMA (polymethyl methacrylate).
- Channels can be made by either direct method (laser ablation) or replication method (use of mold).
- By weight, plastics are 100 times less expensive than silicon, and can be made disposable.
- Rapid prototyping.
- Surface effects, transparency, diversity of materials can be introduced easily.

In fact, if we go back to theprevious slide,what we see here isthatthere is plasticMEMS.And there,what we mentioned at that time, therange is 0.5 micrometer to 500 micrometer elastomer such as PDMS or PMMA,these are used.Channel can be made by either direct method by laser ablation or replication method by use of mold.Now, mold is basicallya negative replica, you understand what a negative replica is that the negative, suppose you want to make a channel, soin the mold, you will see a raised portion there.And then when you poured a liquid, pore polymeric liquid on this and let the polymeric to solidify, then when you peel it off, you see the positive one the channel engraved in that. Sothat is use of mold and the laser ablation is that you take the plastic material and selectively remove some material by application of laser.

Or there are other methodsthere is there are other direct methods also available,we will discuss this briefly later.By weight, plastics are hundred times less expensive than silicon,soand can be made disposable. So, this is thebenefit ofplastics, use a plastics and rapid prototyping is possible, because you are, if you are using replication method, then you need only one master; and on that master, you put something and peel it off, put another use the same master; So, you can do the replication over and over. So, these are some of the benefits you have, also the other benefits are surface effects.You can induce surface effects on polymeric material very easily.

You can make surface hydrophilic,you can make surface hydrophobic, you can make that surfaceattracting to some other material, which is flowing. So, you can make it you can introduce this surface effectsand transferences, if this plastic material can be verymuch transparent. So, you can seefrom outsidethrough which the liquid is flowing, or more importantly, if the optical element, if a part of the optical element you want to keep it outside.If it is optically transparent, then still you can expect the lightto of certain wavelength can pass through this material;and diversity of materials can be introducedeasily,sothese are some of the benefits you have.

Of course,there are some strong disadvantage, one is say aging,because plastic material if you live it for some time.It may the properties may change and it may buckle,I mean if you have a channel of high aspect ratio, you remember in the last class we discussing about deep reactive ion etching,where you can make a channel or make a make hole which has high aspect ratio diameter is of the order of 10 micron and the depth is 500 micron.They if you make a channel of such dimension in plastic material,these materials can bend can buckle. So, channel may not retain its dimensions uniform. So, these are some of the benefits we had at that time.

So, this is a plastic MEMS device, which is another branch ofmaterial,I mean which we did not discussed; we have been focusing so far on silicon and glass.Now,there is a reason for doing this exercise, for this plastic formaking this plastic MEMSas well, because to make that master,I said you have to create the negative of it and use that to replicate, the positive once.Now, how will you make that negative one? So, it could be that the silicon substrate that you make that itselfacts as the mold, got my point.The photolithography technique is used to make the mold.The mold is not made of metal,I mean which commonly we thought the mold will be a metal, on which we pore the polymer, but mold could be silicon itself.And you can makethe negative make that mold using photolithography technique.

Sothat is the soyou cannot;so, if somebody says thatI am only interested in plastic MEMS and I do not care what happens in photolithography or what happens insilicon and glass and how you bond anodic bonding or fusion bonding.Because after all plastic, when you have a plastic device and on top of that you put another plasticlid;and then when you tried to bond them, definitely anodic bonding will not work, fusion bonding will not work, sowhy we are getting into this;ifI am only concern with plastic devices.First of all there are disadvantages for which you need to resort to this silicon device.Andsecondly, the mold has to be made first and that mold, for making the mold photolithography technique is used.So, if I go back to my new slide now. So, we are talking about fabrication of plastic microfluidicdevices.Now there are three common methods,there are other nontraditional methods also available, but when it comes to traditional ormethods that are commonly used is moulding, casting, and microinjection.Now,I am spelling it out as m o u l d, but that it that is a perfectly,the rather that is that is the old traditional spelling.

Now,mould is the negative master,made of silicon electrodeposited metal or reticulated polymer. So, this is a mould;so, mould is basically the negative master.The master is that one which remains there and using the master, you create thousands of replica. So, here that negative master is can be made of silicon itselfor it could be electrodeposited metal or it could bereticulated polymer.Now,common method of making a mould is photolithography.If it is silicon, then you will you will use photolithography to create,of course not to create a channel,you have to create a channel,you have to create a raised face.

So, probably you have to go for a vapor deposition to create that raised face.Mass the rest of the material, rest of the part out and go for vapor deposition.Or if you want to eataway or if you want to do the etching, you have to do the etching for the rest of the part.Channel means,if you etch out a portion other than that slit, then you getraised face, sothere various ways you can do it.For processing at high temperature and pressure, electrodeposited or traditional micromachinedmetallic moulds are used.If the processing requires high temperature and pressure, andtheon an industrial scale over and over again,then probably one would go for a metallic mould.And how would you make a, suppose an extra layer, then you have to go for an electrodeposition.

We have already talked about that three methods have deposition, physical vapor deposition, chemical vapor deposition, and electrolytic deposition. So, electrodeposited or traditionally micromachined metallic moulds are, moulds can be used when the processing is done at high temperature orpressure.Now this process, first of all I said there are three methods. So, we mentioned in the previous slide, we mentioned three methods, one is moulding,the other is moulding, casting and the third one is microinjection; so, these are the three methods we are talking about.Now, if you focus on this first one, the moulding that is what we have in thenext slide.

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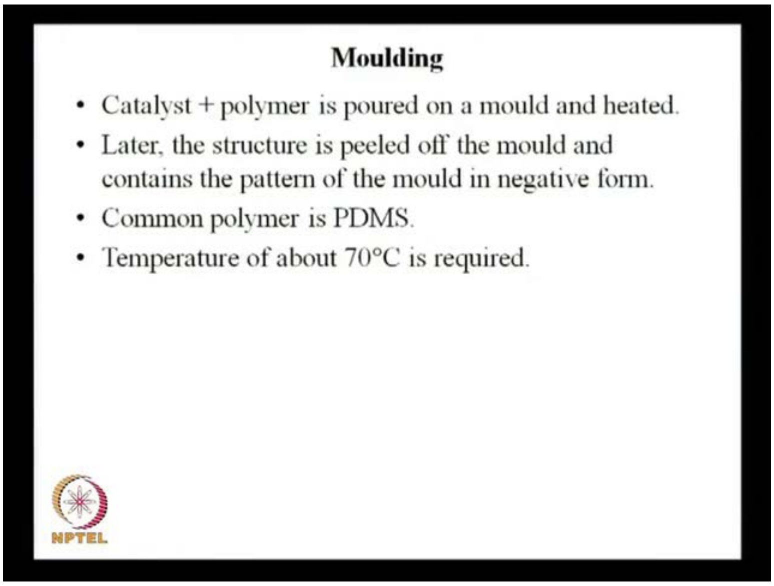

Moulding

- Catalyst + polymer is poured on a mould and heated.
- Later, the structure is peeled off the mould and contains the pattern of the mould in negative form.
- Common polymer is PDMS.
- Temperature of about 70°C is required.

Catalyst plus polymer is poured on a mould and heated,catalyst plus polymer is poured on a mould and heated. So, you first of all you take this polymer to molten state,soit is like a liquid.

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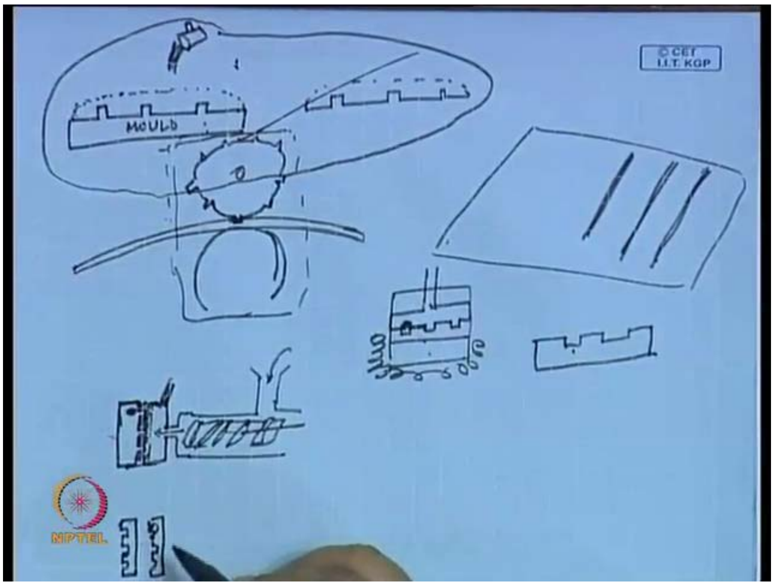

It is like a liquid and you take it,suppose this is the mould.Now,you take this supposeyou take this molten polymer and pour iton this mould, sothis is basically the mould, on this is this molten polymer is poured. So, what will happen is you will form a layer like this;you heat the mould as well, sothat if there is tendency tofor the polymer to solidify here in the corners, you will ensure that the polymer flows everywhere to all the cornersand it forms a layer.Then you later the structure is peeled off the mould and the contains the pattern of the mould in negative forms.

So, when you peel it off, how will it look?The upper portion if you peel it off,this would be the upper portion that you peel off,when you peel off.Andthe mould is ready to be used again and again you put next lot and again peel off,soyou will be creating this structures that is what moulding is about.Now, the common polymer is PDMS.I said at the very outside there are two polymers, one is PDMS,other is PMMA. PDMS hasthis can bethis will melt at a temperature of about 70degree centigrade;it isyou can see that temperature of about 70 degree centigrade is required. So, you have to heat this polymer to 70degree centigradeso that itmelts.

Now, the other polymer which is PMMA,you will find that the temperature at whichyou will operate that PMMA material is used for casting, there even it is 120 degree PMMA will not melt. So, PDMS will melt at 70 degree centigrade and this PDMS material is used for moulding.Butthis PMMA material polymethyl methacrylate that is not used for moulding, as such that PMMA materialwill not melt even at 120 degree centigrade;sothatyou have to make note of the type of polymer used here as well.

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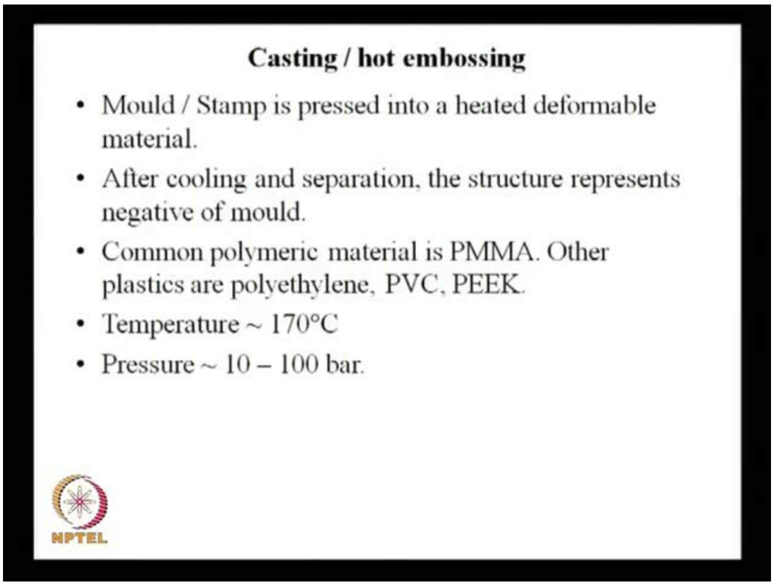

Casting / hot embossing

- Mould / Stamp is pressed into a heated deformable material.
- After cooling and separation, the structure represents negative of mould.
- Common polymeric material is PMMA. Other plastics are polyethylene, PVC, PEEK.
- Temperature ~ 170°C
- Pressure ~ 10 – 100 bar.

The other method, the second method, we had three methods we talked about. One was moulding, we just now we statedand we said this PDMS is a common polymeric material, which melts,which is liquid at 70 degree centigrade, which can be used for moulding.The other method is casting, casting is basically,this is done with PMMA. And you can see the fifth point here in this slide, temperature is about 170 degree centigrade and pressure 10 to 100bar. So, what you do here is here you do not getmelt and you are not going to pore this on the surface; rather what you do is you will put a stamp,I mean it would bein a common casting method,I mean if you look at the just conventional casting not a microscale casting it is like this.

You havea sheet,I am talking about conventional casting notmicroscale casting, you have a roller here, which has teeth like thisand this roller rotates; here, you have a another roller,this roller also rotates. So, this plastic material goes out and this whole assembly is heated, this whole assembly is this material, this place is heated. So, what you are doing is basicallyby application of heat the polymer, this is basically a plastic layer, this remain solid, this is not this not like it is it is being poured from a jug; it is it remains solid and this, but this becomes deformable by application of heat.

Otherwise it was a solid and you cannot create a dent on it, but by application of 170degree centigrade you are ensuring that the material is deformable,it becomes soft.And now, you put this stamp, this is calledthis;I mean here we have just a tooth here, which is creating a channel on this layer. So, you will be having when you get this, suppose this is a roller which has a dimension hereand this also has a dimension here, sothe plate that you will get,so you would be you would generating something out from here.And after,you will be getting channels like this, because of thisheating deformation and at the same time applying a stamp, applying a mould. So, here the mould or stamp is pressed into a heated deformable material.

After cooling and separation, the structure represents negative of mould.ThisI what I am discussing is a very traditional casting process and this is on continuous basis.Butwhat I am talking about in the slide there, here it is more of a batch process, there probably you put, you take the entire thing in a chamber, put the polymer layer then you heat it;so, you apply heating layer outside; so that this is heated to 170 degree centigrade, bring in the stamp.Stamp means you have this; no it should be other way;bring in the stamp and then you put push it hard.

So, once you push it hard this is molten,soyou will be creating a dent. So, what would be what you would be producing is like this. So, this layer will take this kind of shape after it is done. So, the one that I am talking about in this slide, it is basically a batch process,after cooling and separation. So, when you take this off mould, then you get the layer in which you have the impression,sothe structure represents negative of mould.Common polymeric material is PMMA,the other plastics PVC,PEEK;these are allthis could be common polymeric materials.

This also goes by the name hot embossing. Sobasically you are heating the layers,so that it did becomes soften and then you have a stamp which you are putting; sothat you form an impression and that becomes the channel, sothat becomes a channel here, this becomes the channel.The next topic that I have here, which is which goes by the name microinjection and this is meant for serial production on industrial scale.Here the, it is basically a moulding process, but not like this, because this is not this method that we discussed here this method that we discussed here, this is not a good practice, when it comes to serial production on industrial scale.

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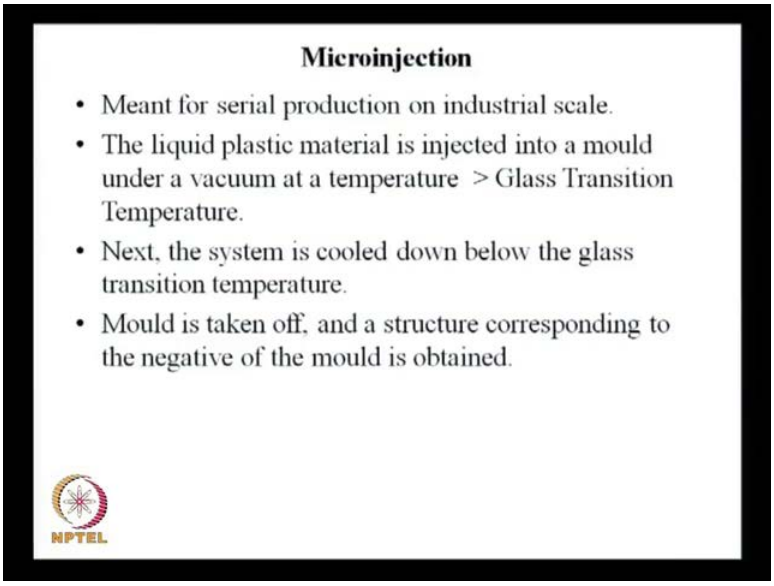

Microinjection

- Meant for serial production on industrial scale.
- The liquid plastic material is injected into a mould under a vacuum at a temperature > Glass Transition Temperature.
- Next, the system is cooled down below the glass transition temperature.
- Mould is taken off, and a structure corresponding to the negative of the mould is obtained.

So,on industrial scale, the injection moulding that is commonly used for polymeric materials that method isborrowed to generate on a continuous basis on serial production ofmicroscale device.What you do in this case is you have an, you have a hopperand you have a screw, by which you pushing this polymeric material and you have heating arrangement; and by which you pushing the polymeric liquid into this.And now, here you have this polymer comes out like this and here you have the other part.Now, suppose you have thislike this. So, this is a jig, which is sitting there and you are pushing the molten polymer through this. So, molten polymer is put through this hopper and using this screw conveyor, you are pushing the molten polymer through this port.And this jig, it comes here once get fit it to this and then it moves out, it you gets fit it to this and moves out, it has a movement like this.

On top of this one, one possibility could be that you can have some vacuum management, which would be possible.This vacuum will ensure that liquid reaches all the corners, all the nook and cranny of thismould. So, what you have here is suppose it comes there and sills to this.Suppose, there is arrangement which pushes this pushes this one and it sills. So, you have a layer being formed; you will form a polymer layer like this.Next moment, this whole assembly goes out, moves out and this layer comes here.This layer, just a thin layer with the appropriate channels in place that comes down, that simply fall,that is just a fall that simply comes out it peels offand it is falling down.

Again this one, this block goes back fits to this jig, the next layer is form and then you collect another one then you collect another one. So, this would be a serial production. So, basically what you are having is you are having this jig, which is moving back and forth back and forth.And continuously, polymer is supplied through this hopper. So, continuously your are supplying the polymer, continuously this isI mean of course, it is adding that way the time it takes to come back, time it stays there and time it goes back that is sufficient for this polymer to spread through the places andthis you get you get prefect device.

So, this is ideally suited,I mean instead of going for a mould, where you take it injag and pour it on the mould and then wait for this remove it, this is more often automated system by which you can create hundreds of them in a very short time. So, this is the commonthis is replication method which can be used on industrial scale, this can be used this moulding method that I am taking about this can be used on a lab scale oron a small scale;this is good for serial production on industrial scale.

Now, injection moulding I suggest if you want into look, because this picture may not be as perfect, youthere are variouspicture that should be available of injection moulding, not microinjection moulding.Basically, injection moulding is the idea that is taken and injection moulding is very similar.Butinjection moulding is definitely not onnot in microscale, but here the idea is taken from there. So, if you want to knowfurther about this process, you can you should read about injection moulding; there is there should be very established literature available.And this injection moulding, this idea is taken.

Now you have tell this time,I mean I am just introducing this techniquesto you; this moulding and casting these are very traditional method used for polymer used with polymer sheets. So, these are anybody who is working with polymer composite they should be aware of these techniques.Only thing is, since people are making plastic MEMS device,sothey saidthese techniques, we should borrow them, but they have to be tailored to. Sothat it suits the purpose of making microscale devices.So, if I quickly go through slide, what it says it's meant for serial production on industrial scale,the liquid plastic material is injected into a mould under a vacuum at a temperature greater than glass transition temperature.

Under a vacuum means, you apply put a line of vacuum and it connect through to a vacuum pump.The idea of vacuum is that,so that, becauseif air remains trapped,I mean think of it that liquid is flowing and in certain portion, the air remains trapped. So, if air remains trapped, then the material that you get here, it here, here a bubble of air setting there. Sothat will not have the purpose. So, you have to a vacuum line, so that air will be sucked out. So, you will get liquid,you will get melt polymeric melt that moving that goes to the, to every corner of that mould that is very important. So that is greater than and it has to be greater than the glass transition temperature.

Next, the system is cooled down below the glass transition temperature and the mould is taken off and a structure corresponding to the negative of the mould is obtained; that is exactly what you are doing. So, this whole process taking, it just above glass transition temperature and bring cooling it down and then removing the mould, the entire process is automatic. So, this is good forserial production.So, this is what we have as far as plastic MEMS device is concerned; and other methods,I will discuss them briefly.And then we talked about the plastic device, how it isthese plastic devices, they also have to be bonded.

If you have plastic substrate and on top of that you have to put another plastic substrate bond it and finally, once we have done with this, then we will discuss about the interconnects.How you make a port and how you can put a tube through that.And that part,I have not discussed for silicon substrate.

So, we will that part is left out. So that would be a general discussion,we discussed about how to put a tube in a silicon micro device or how to put a tube in a plastic device. So, once we do that I think our microfabrication the discussion microfabrication will be over; and then,we will go into the theoretical aspects of microfluidic device. So, I will take probably anothertwo classes orso to wrap up this microfabrication; two or three classes may be to wrap up of the microfabrication.And then, we will go to the actual, how the transport, how the various aspects of transport phenomena getting affected, because of this microscaleaffects andwe will go from there.That is all I had for today’s class.