Microscale Transport Processes

Prof. S. Ganguly

Department of Chemical Engineering

Indian Institute of Technology, Kharagpur

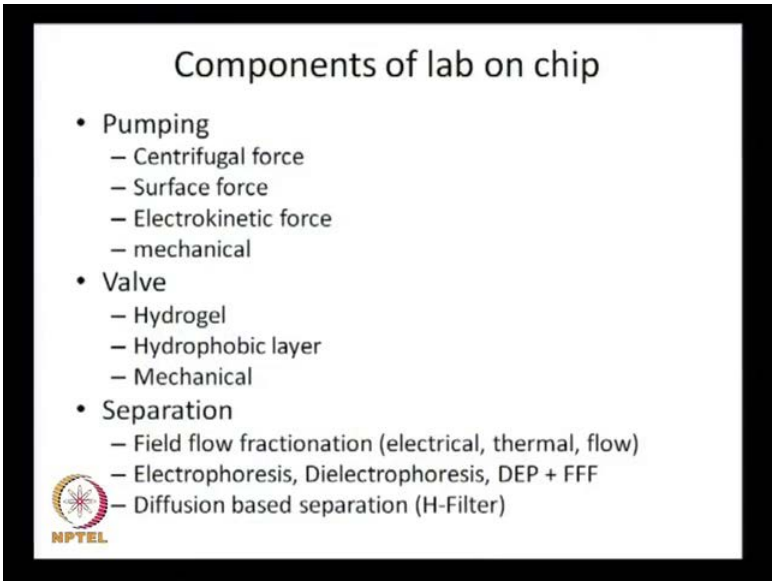
Module No. # 01

Lecture No. # 04

Lab on Chip (Contd.)

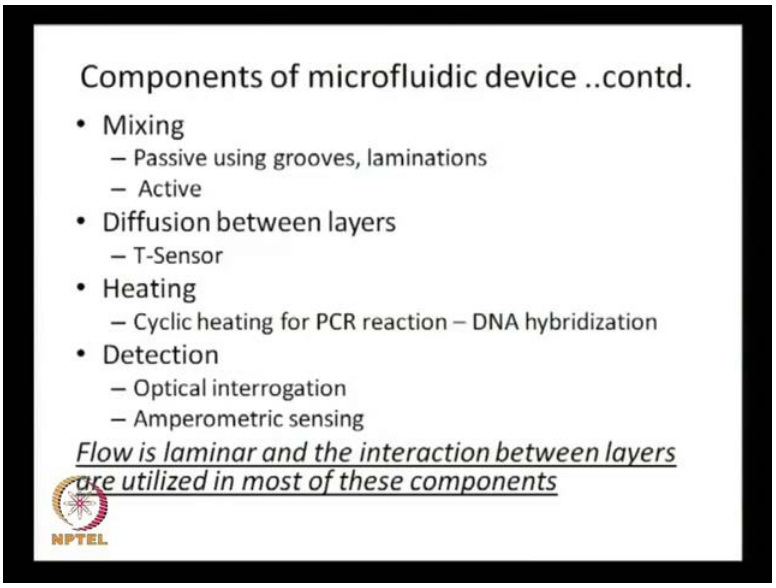
I welcome you once again to this class of micro scale transport process.What we have been discussing is various components of lab on chip.

(Refer Slide Time: 00:25)



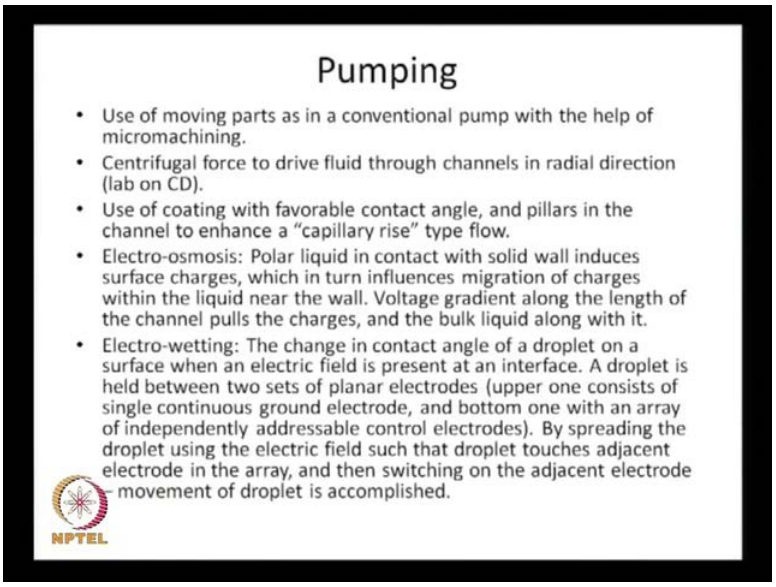
We mentioned in the last class that you need to have a pumping action, a valve action, a separation process going on, mixing, heating, detection all these happening inside the chip.

(Refer Slide Time: 00:35)



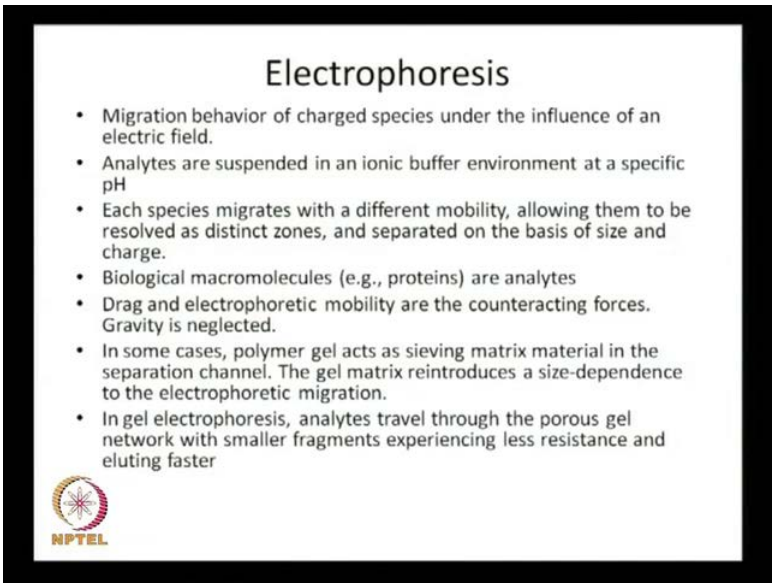
And there are some unique ways to do to.To accomplish these operations particularly in micro scale.What we have discussed in the last class is pumping.

(Refer Slide Time: 00:52)



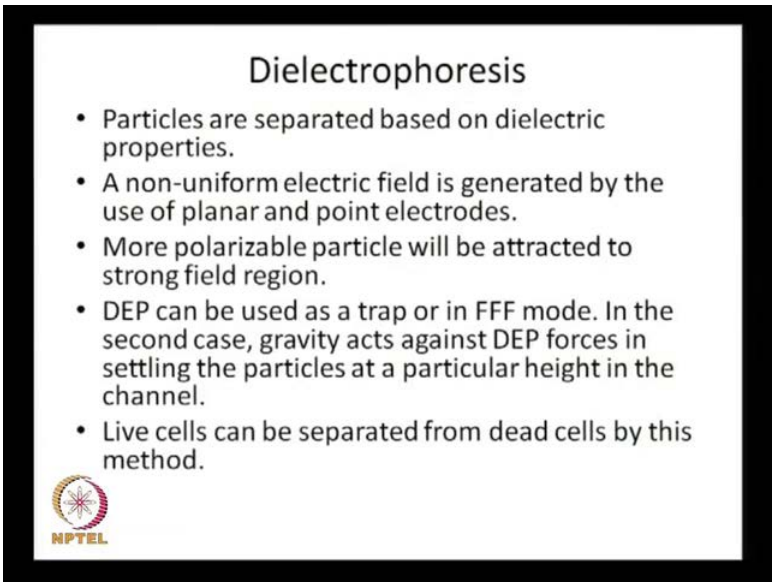
And then t sensor, then H filter, then detection methods and then electrophoresis.This is one method which goes with electrical field flow fractionation.

(Refer Slide Time: 00:58)



This basically separates a mixture of particles based on their size and charge they ban them in in layers and then these layers can be eluted in the way you want.

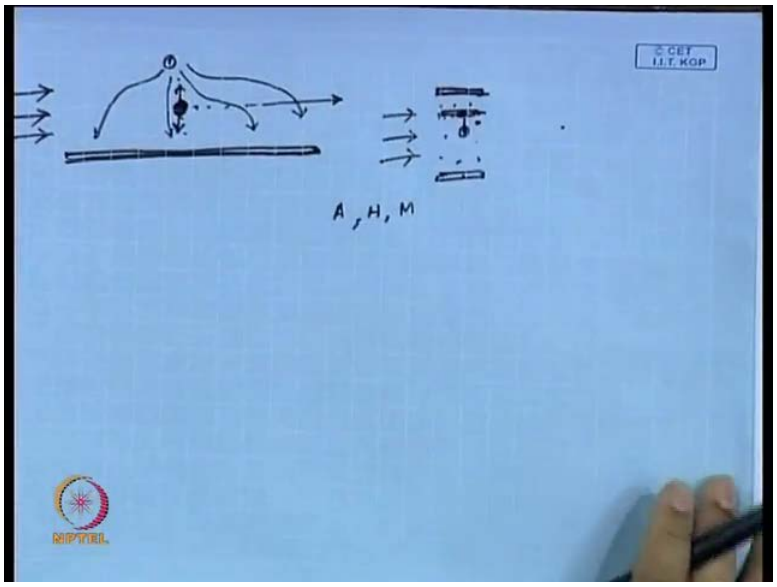
(Refer Slide Time: 01:19)



The next item that I want to discuss today is known as Dielectrophoresis.This is little different from electrophoresis.Here, particles are separated based on dielectric properties not their size and charge.Particles are separated in electrophoresis particles are separated based on their size and charge.Here, in dielectrophoresis the the whole idea is

different.Here, the particles are separated based on dielectric properties. For these a non uniform electric field is to be generated by the use ofplaner and point electrode.

(Refer Slide Time: 02:12)



What that means is, you need to have a non uniform electric field and that can be generated by point and a planner electrode.

So that means,one electrode is a point electrode and the other electrode is a planer electrode and the electric field that is generated here, if we look at these electrical lines of force that is non uniform and when you are subjecting particles to these non uniform electric field more polarizable particles will be attracted to strong field region.See, there is a there is a stronger field and there is a weaker field, there is a non uniformity in the electric field.So more polarizable particle will be attracted to strong field region.We will discuss the essential theories of this I mean how how what would be the what would be the force acting on the particle if we apply certain voltage that we will discuss the theories of it but, for the time being you, I want you to appreciate the fact that there are various methods existing by which you can separate particles based on their properties.Earlier we mentioned about electrophoresis and I said that this electrophoresis can be turned ninety degree and can be used in conjunction with field flow fractionation.

Here, we have another technique which is known as dielectrophoresis where the more polarizable particles will be attracted to strong field region.So, DEP can be used as a trap or in field flow fractionation mode. DEP can be used as a trap depending on properties,

dielectric properties of the particles.Some particles can be held between the two electrodes while others are will be allowed to pass through that place.

This is called a DEP trap or it can be you can somebody can walk on a field flow fractionation mode where you have the upper electrode,where you have the upper electrode and the lower electrode.And then you have laminar flow parabolic velocity profile going in this direction.In that case if the particles are oriented, if the particles are settling depending on the force balance at various locations, they will eluting at different time at the outlet.So it can work as a trap.That means particle is held within this electric field or it can be working on an FFF mode.That means particle is settling at a particular layer and would be eluting along with the velocity profile.

So in the second case in the second case gravity acts against DEP forces in settling the particles at a particular height in the channel.In the second case means in the case with FFF mode that means in the case of field flow fractionation mode the particle will be if if this is the particle if this is the particle there would be a DEP force and then there would be gravity force acting.

So there would be a balance between them and wherever this balance is satisfied, the particle will be settling at that layer and so when you have these elution taking place, you would these these particular layer whenever it is eluting, which is governed by the parabolic velocity profile so, whenever this particle is eluting that you know I mean that that will come at the outlet.So, here it would be a balance between the between the gravity force and the DEP force.So, in FFF mode the gravity acts against DEP forces in this in settling the particles at a particular height in the channel. Live cells can be separated from dead cells by this method.That means if you if ifififif some analysis is to be done where some what type of cells are that it has to be analyzed.

Now, if the cells are dead or cells are live that is important because dead cells may not contribute to the decease when it comes to the, I mean that is that is already that is that problem already that is that problem always there people boil water to to make sure that the cells are dead.So, these thesethese DEP in the, in this by this method live cells can be separated from dead cells.So, you know exactly what you are measuring that you are measuring only the live cells.So, this DEP DEP is also another dielectrophoresis and

DEP coupled with FFF, that is also one important operation that can that can be harnessed to accomplish a separation in in micro micro devices.

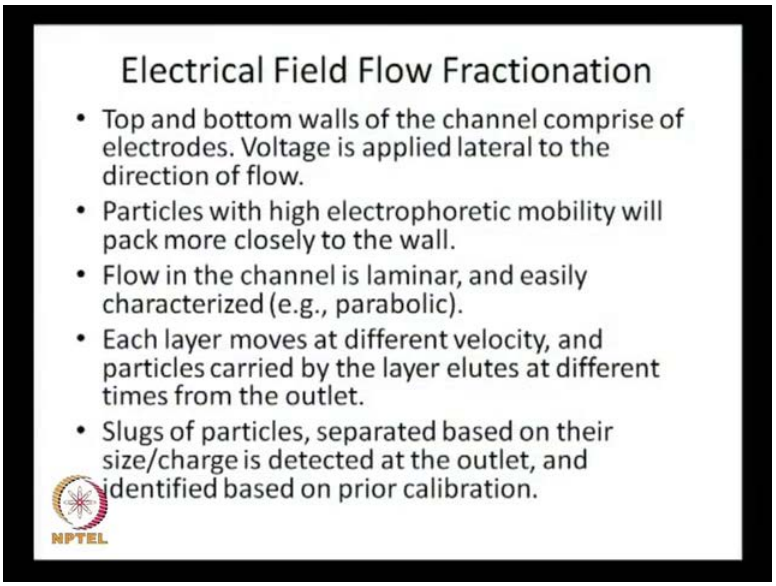
The next topic is electrical field flow fractionation I said it is nothing but, the electrophoresis only it is only it is turned by ninety degree so what I say here is top and bottom walls of the channel comprise of electrodes voltage is applied lateral to the direction of flow.Voltage is applied lateral to the direction of flow.Remember what the drawing that we have in earlier class; we turned it ninety degree.So, you have one electrode here, another electrode there based on the size and charge the particles will be will be will be forming a band.Particles will be say for example, if these they the the system that is there you have a b a H and M components; these components are these a H and M components, these components are they belong to one particular band because they by virtue of their size and charge.

So they will be settling in one layer why? Because they if if this is a particle; these particle would be experiencing some electrophoretic mobility right.The electrode is pulling.So what are what are the forces you have?One force that electrodes are imparting on this particle and at the same time for this particle to move they would be a drag force which is opposing it.So, if you if you if you put these electrodes for a particular time, this particle will start moving and if you freeze, if you switch it off, if you do not, I mean you apply the voltage and then you switch it off; so by that time these particles will travel up to certain distance.Particle of similar size and shape they will travel up to certain distance.Particles of different size and shape they would be travelling probably a lesser distance or a bigger distance.So, these particles will be forming a band.One band represents particle of similar size and shape.

So this, if you on the on top of it if you can apply laminar velocity laminar velocity a parabolic velocity profile through this so at the outlet you will be eluting 1 layer at a time; first the central layer then the other layers.So, if you have a pre calibration you can using that calibration.That means if you had a known sample going into it and if you know when the components are eluting; so by looking at that calibration plot you can you can you can compare with a real life sample and then say this real life sample must be having these thesethese components.

So what I write here is top and bottom walls of the channel comprise of electrodes voltage is applied lateral to the direction of flow.You understand that that flow is moving.Flow is flow is going in this direction flow is going in this direction and voltage is applied lateral to it voltage is applied lateral to it.

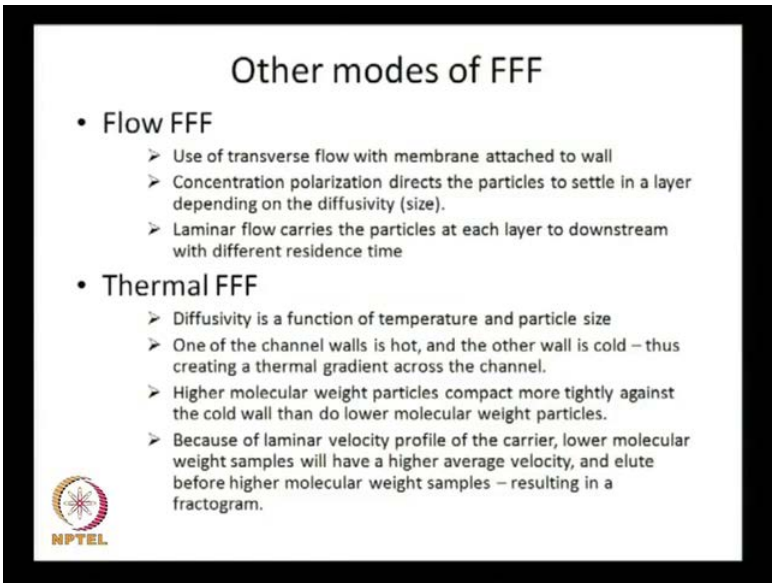
(Refer Slide Time: 10:05)



Now, flow inparticles with high electrophoretic mobility will pack more closely to the wall.That we understand if if the electrophoretic mobility is higher that will go close to the wall.Flow in the channel is laminar and easily characterized such as parabolic each layer moves at different velocity and particles carried by the layer elutes at different times from the outlet.We discussed this already slugs of particles separated based on their size or charge is detected at the outlet and identified based on prior calibration.

So this is exactly what I said.For the time being you just I mean I want you to appreciate that these methods can be very handy when it comes to accomplishing a separation in micro devices.Now, essentially I mean, if you if you are interested in the theories I mean what what force we are talking about what would be the drag force, we will we will come to that very soon.

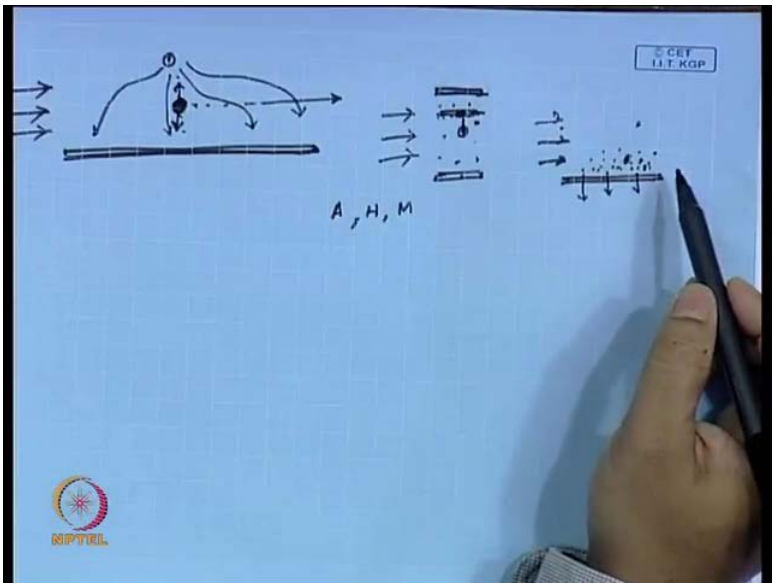
(Refer Slide Time: 10:59)



Now, I said that is this field flow fractionation.This is very unique treatment that layers are moving, sliding one against the other and we are relying on it.We are assuming there if if there is a cross flow, if there is some Eddie's forming then, this whole idea is you should throw in the dust bin.It is absolutely of no use but, you are practically you are relying in a in a very significant way the flow of two layers parallel to each other and only diffusion can take place between the two layers and 1 layer is sliding against the other.

Now there are other modes of field flow fractionation we discussed; 1 is flow FFF flow field flow fractionation.Here, we have use of transverse flow with membrane attached to wall right.What we had there is a transverse flow with membrane attached to wall, concentration polarization directs the particles to settle in a layer depending on the diffusivity.In turn the size right this this we this we briefly discussed in the in the last class.

(Refer Slide Time: 12:06)

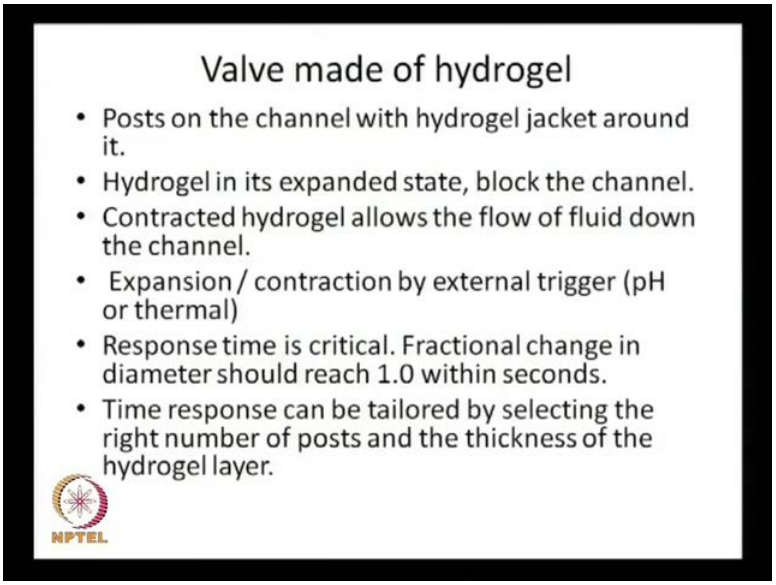


That you have the bottom say bottom mall is the membrane.So, in that case the you have particles plus some liquid some somesome say water and some other particles in water.So, water would be flowing through the membrane and the particles will be held next to the membrane.Now, the bigger particles it would be difficult for the bigger particles to diffuse back to the bulk whereas, for smaller particles it is easier to go back to the bulk.So, there is something called a polarization happening and so the particles will be forming bands depending on their size.And then if you impose a velocity, if you impose a parallel, if you impose a parabolic velocity profile what you find at the outlet?Yes that each layer will be having, each layer would be representing diameters or or particles of certain size.So, against some pre calibration you can always check you can always confirm what all particles were present in the system.

Similarly you can have a thermal FFF there the bottom wall and the top wall they are at different temperatures so diffusivity is a function of temperature and particle size.So if 1 of the channel walls is hot and the other wall cold thus creating a thermal gradient across the channel then, you can accomplish this thermal FFF.Now, here higher molecular weight particles compact more tightly against the cold wall than do lower molecule weight particles and again because of laminar velocity profile of the carrier, lower molecular weight samples will have higher average velocity and elute before high higher molecular weight sample resulting in a fractogram.Just exactly same method.You are playing with velocity parabolic velocity profile 1 layer moving against the other and 1

one layer is moving at a higher velocity or a lower velocity compared to the next layer.At at the same time you are creating a gradient in lateral direction.You you are you are putting the particles of different sizes different charges at different layers and so you are eluting at different time and against a pre calibration against I mean, you run in own sample see when when you when you see those particles coming out of certain sizes and then compare that with a real life sample and put 1 against the other and compare and see which what you have.

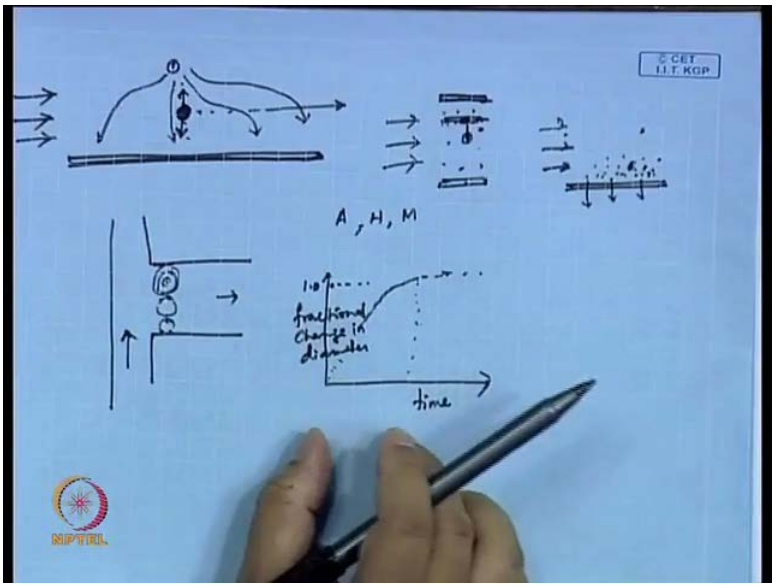
(Refer Slide Time: 14:40)



We discussed this valve action and we said that there is there are certain ways to accomplish a valve action.One could valve made of hydro gel and another is valve made of hydrophobic layer.Of course, there could be there could be valve using usingusing a mechanicalusing a system similar to mechanical valve.That means there is valve seat and there would be a there would be a piston which would went it when it hits the valve seat then you consider valve to be closed or it can move allowing the flow to take place.

So these are some of the things that you can accomplish in micro scale but, it may not be be very easy to accomplish and we should we should be looking out for other alternatives that are available in micro scale and that alternative is this valve made of hydro gel.

(Refer Slide Time: 15:35)



What you have here is, suppose you have a channel like this you have a channel like this and you have pillars placed here you have pillars placed heresothese or these are called posts posts on the channel with hydro gel jacket around it.So, you have a post with hydro gel jacket around it.You are having a flow taking place and you want to when you want youyouyouwant to see that when you desired to have a flow to this channel that should happen. So what happens here is hydro gel in its expanded state block the channel.

So these hydro gel layer can contract or expand that means it can it can it can shrink or it can grow.When it grows it blocks the channel and when it shrinks it opens a part of the channel.So, contracted hydro gel allows the flow of fluid down the channel.Now, how will you accomplish this contraction and expansion that can be done by an external trigger because hydro gel has unique properties.It responds to external triggers such as (( )) or thermal environment.

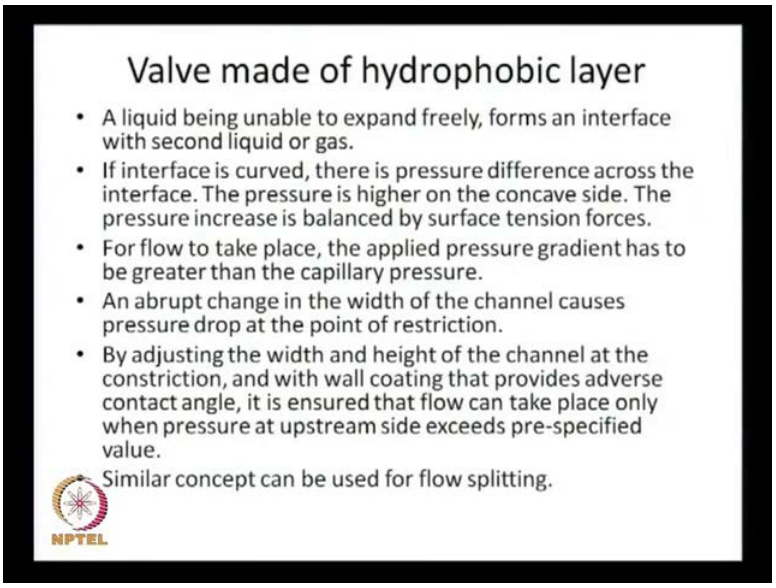
So that means if you increase the temperature around it itit shrinks or swells.thethis is This is a unique property of a hydro gel.So this this is this this property can be utilized when you are working with a micro scale geometry now here the response time of course, is very critical.How quickly to respond because fractional change in diameter should reach 1 point zero within seconds.That means if you plot fractional change in diameter with time, fractional change in diameter.So, the final diameter is say 1.0 that is when you considered this to be closed.

So that is the place, that is the point when you consider this to be closed.So with time with time you will find that the diameter will change.Suppose it was it was in a contracted state and then you certainly you you put the trigger so the moment you put the trigger you start measuring what is the fractional change in diameter and you would like to reach 1.0 because when you reach 1.0 that that is the point when the valve would be completely closed.So, these these should be you should accomplish this within seconds then you considered this response time to be good right because you put the trigger and immediately you should see the change because if because this this is a chemical physical chemical property you are utilizing.So if the if you put the trigger and the response it it takes place for half an hour then of course, it is not going to work.

So it has to it has to act within seconds then only you can consider this to be good.Now there is an there is an article in in nature in fact people have worked with different materials where you can accomplish, you can you can reduce this response time.And and another another important point is time response time can be tailored by selecting the right number of posts and the thickness of the hydro gel layer.See you you have a choice of number of posts and what thickness of the hydrogen layer you want to pick up.Now, you should choose it such that it matches the response time so that the valve gets closed within seconds all right.suppose I mean you got my point what I am, what what I am trying to say is the number of posts that you have the thickness of the gel layer all these things are in your hands.

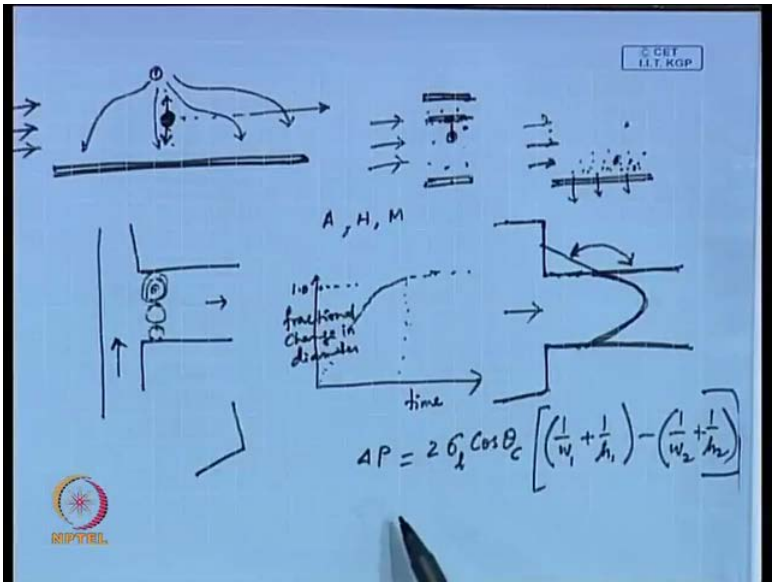
So, you would be playing with them as well and and see the fractional change in diameter and then you then you come up with a best design.

(Refer Slide Time: 19:49)



Then, this other idea that is there wall made of hydrophobic layer.It is basically something like this, a liquid being unable to expand freely forms an interface with second liquid or gas that that is basically the essence of surface tension.If interface is curved there is pressure difference across the interface the pressure is higher on the concave side and the pressure increase is balanced by surface tension forces.How would I put it here?

(Refer Slide Time: 20:24)



If I have a hydrophobic layer if I have a hydrophobic layer and if I have say flow of water taking place how would the meniscus look like?The meniscus will look like this.the meniscus will look like this rightIf it would have been hydrophilic then it would have been advancing but, since its hydrophobic its its in other direction right.So, the interface is curved and there is a pressure difference across the interface.So, this unless this threshold pressure is applied on this side you may not see this fluid entering into this hydrophobic into this capillary with hydrophobic wall.also

So, a flow for a flow to take place the applied pressure gradient has to greater than the capillary pressure.Also an abrupt change in the width of the channel causes pressure drop at the point of restriction.So, by adjusting the width and height of the channel at the constriction and with wall coating that provides adverse contact angle, it is ensured that flow can take place only when pressure at upstream side exceeds pre specified value.What is the what is the formula you have their if this is the angle it makes?Suppose this is the angle it makes; then in that case and and if you have if you have if you have an abrupt change in the width of the channel that means abrupt change in the width of the channel means you have, suppose you have the channel which is having an abrupt change in the width.

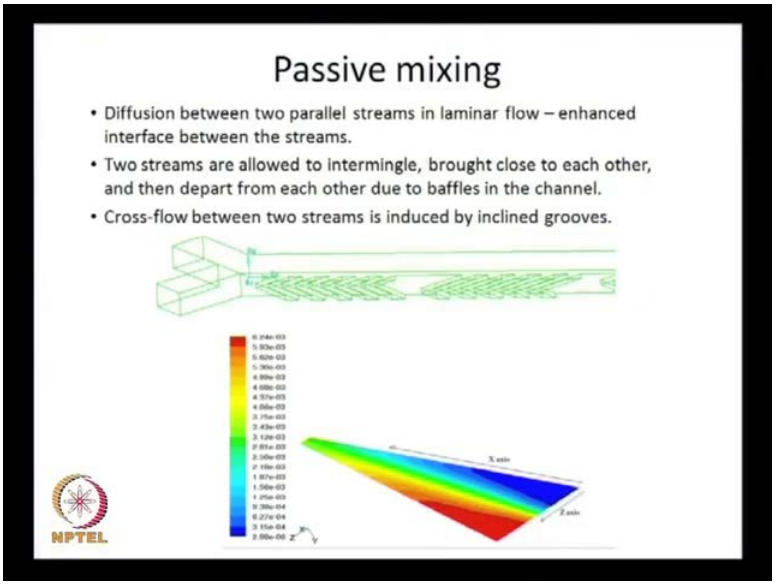
So this was the original channel, this was the channel rightso this was the channel and you are pushing the liquid through this channel.So, in that case that delta p, the pressure difference that you have to provide is given as 2 sigma l co theta c into 1 by w 1 plus 1 by H 1 minus 1 by 1 by w 2 plus 1 by H two.

So this is this is the this is the pressure drop that you have.This is the pressure difference between the liquid menisci so these pressure and of course, you will ask what is w 1 and H 1 these channel is considered having a width w and height H.So, this channel is not exactly a circular channel this channel has width w and height H and other channel is 1 is w 1 H 1 and the other channel has w 2 H 2.So, these are the dimensions of the channel.Theta c contact angle and sigma l is the interfacial tension.So this is the formula.This formula is very similar to the one you have seen you remember for a capillary rise.You had this what was the formula pi d n sigma where d n is the diameter or if d is the diameter of the capillary it is pi d c sigma pi d sigma cos theta.

So,it is it is a very similar formula.It is a very similar formula.Only thing is here you have change in abrupt change in width of the channel and that is reflected here.So here this is the pressure drop and these pressure drop you have to overcome if you want to have flow through this through this channel all right.So you can you can set your system in such a way I mean you youyou have what w and what H you choose that is in your hand.What material what theta c you choose that is in your hand.

So you choose this materials in such a way so that these acts as a valve.When the pressure exceeds this delta p then only there would be a flow and if it is not there will be no flow.So, if you want this branch if you want this branch to have flow you have to go to that delta p otherwise thereotherwise the flow will take place if you if you have a parallel branch it will go their but, it will never enter through this one.Similar concept can be used for flow splitting.So,the thisthis is one way you can play with the hydrophobic layer to accomplish the valve action.

(Refer Slide Time: 25:18)



Then this we wewe discussed about mixing you remember that mixing would be an essential part because you are introducing a sample and very importantly that sample has to mix with the reagents that sample has to mix with the reagents.So and then how it responds to certain reagent that you are checking in the detector.

So that is how a sensor will work.Now, mixing is a very integral part of this micro systems and and not only not only for lab on a chip mixing would be a very integral part

for any any micro scale micro micro scale operations.Now, this you can you can always have.Active mixing you can always have.A moving component with just like the impeller in a pump.However you should be looking for alternative rounds and people have already looked into these they have come up with something what is referred here as passive mixing.What you have you you look at this channel you look at this channel here.At the bottom wall this channel has grooves this channel has grooves in the bottom of wall.So,the when the flow takes place suppose the two streams are coming from two sides and you expect the two stream to mix.So, as the two streams enter into the channel these grooves at the bottom at the at the at the at the floor of the channel.These grooves will ensure that some fluid flows through this groove.Some fluids flows through these some somesome portion of the fluid flows through this groove and when it flows through this groove, what it will do is on the way it will drag the fluid which is above it right.If one layer is moving then by viscous action the next layer will move may not be at the same velocity but, at a lower velocity than the next layer would be moving also.

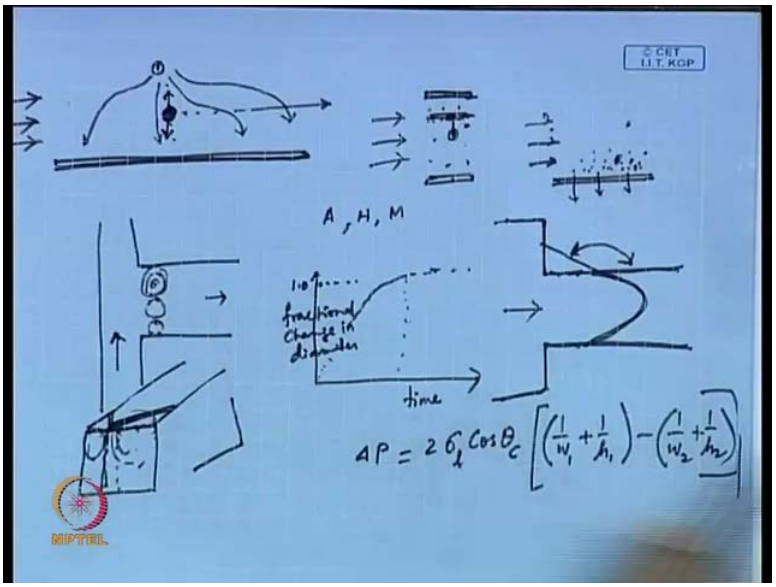
So, when a fluid moves, when a fluid goes through this channel it will it will pull some of the fluid above it as well.So you will be inducing cross flow to this channel.That is the idea that you have these channel.You have these grooves placed in the floor.So, you are intentionally inducing a cross flow.Why do you need such cross flow? I mean after all a diffusion we will ensure that there is if two layers are flowing side by side, you know that there would be diffusion and the diffusion may ensure that there is mixing taking place and if they are, then they will mix.So, what is the what is the purpose of having this?Having having this cross flow?The idea here is that when two layers are flowing side by side when 2 layers are side by side there would be diffusion but, the diffusion will take place only through certain contact area.That is the contact area between the two layers right.So, that is that contact area through which the diffusion takes place.

Your objective here would be to increase that contact area.So, that enhanced diffusion can take place if the 2 layer flow side by side; everybody knows there will be diffusion and some amount of mixing will take place.But, that mixing will take place only over that contact area.But, if somehow you can increase the contact area so that is that is the idea here.So, the 2 streams are brought 1 into the other by having a cross having a cross flow.That is the purpose of the groove that it it will bring one stream will be brought into the other stream and they will they will they they will intermingle.

You can have such in fact in in an in a conventional static mixture, you have baffles probably the purpose is very similar.Now of course, 1 one issue there would be if your flow, if you are having a turbulent flow then there would be have there you'll be having all kinds of Eddie's present.You know Eddie's come arising due to turbulence.That is not happening here.These you are very much inside we are having a low Reynolds number and you are very much inside laminar flow.

However you are introducing some amount of chaos in the flow by these by by these methods by these by these by these grooves.So, grooves are encouraging cross flow.So,one grove is encouraging a flow in this direction and other is encouraging flow in this direction right.So,these flow will go and hit the wall and then again it will come back and so there isis aswirl swirling taking place in this direction as well as in this direction.Now, what you will find here is beyond certain distance; this is changed.These thesethese were these were two third say oneone side is longer than the other; you must have noticed one side is longer than the other.

(Refer Slide Time: 30:37)



So if this is two third, then this is 1 third.So what you are doing essentially is if this is the this is theone you have and half of the stream was a and half of it is b and they are fed into the channel then this groove is basically starting oneone groove is starting from here and that is the groove and the other groove is in this direction so you are basically swirling you you have taken 2 third and you are swirling here and 1 third you are taking

and you are swirling here.That is that is what you are trying to accomplish through these grooves.

Beyond certain distance after how many 1 2 3 4 5; beyond 5 grooves you see the pattern changed here it is this part is 1 third and that is 2 third.So, earlier you were swirling with 2 third portion of this.Now, originally your system was, originally the fluid that has entered there that was half and half that was spited half halfhalf to this side and half to that side.However, you started working with 2 third on this and third.So, you picked up a certain portion from this and you are you are putting it into the other stream and then it after the 5 such grooves then you are reversing the flow pattern.

So, by this way you are having cross flow then again moving in other other direction so at the end of it you are accomplishing a through mixing.That is our idea.So, diffusion between two parallel streams in laminar flow enhance the interface between the streams.That is the idea of I say mixing you have enhanced interface between the streams. 2 streams are allowed to intermingle brought close to each other and then then depart from each other due to baffles in the channel.So, 2 streams are allowed to intermingle brought close to each other and then depart from each other due t baffles in the channel or due to this grooves present cross flow between 2 streams is induced by inclined grooves.Now, these this is a typical concentration profile that you see here.This red and blue color these are 2 extremes say concentration in some unit.Blue, extreme blue represents 2.88 into 10 to the power of minus 6 here and 6 0.2 into 10 to minus 3 there.

So these these are the 2 extremes and they are going through the inlet.So, this is the inlet.Half of it occupied by red and half of it occupied by blue and as it flows down you can see that it is getting mixed and it is coming at the end of it is coming almost green which is half way between the 2 concentration.So, that is a typical that is how a passive mixing will work.Now, how to characterize this mixing?How would you know that you should have 1 millimeter length or length of the channel or may be 2 millimeter or 0.5 millimeter?

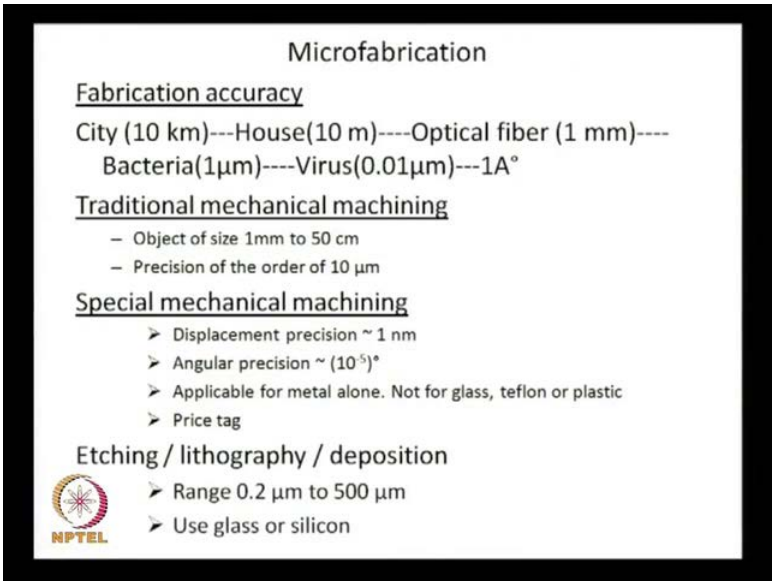
How will you decide? I mean 1 millimeter you accomplish some mixing but, whether it is a complete mixing it will never, you will never have a complete, you will have complete mixing beyond certain distance.Now, you could have stopped here itself.You

could have stopped.youYou could have stopped here itself.Here also you had mixing but, you had some amount of deviation also.Say if we if we put average is 0.5 and extremes as 0 and 1, so here you have a deviation.here you a deviationhere you have deviationHowever, that deviation is between say 0.7 to 0.3 right it is taht5 deviation is not here if you look at this deviation is between 0 and 1.

So this is this is considered completely unmixed.Here there is a deviation I mean half way down the line.If we see there is a deviation.However, that deviation is between this deviation is I mean I am talking this place where the cursor is this deviation is between say 0.7 and 0.3.So, that so there are ways to quantify it.How, what is a mixing?How much mixing have you accomplished?And whether you consider this to be accepted acceptable or not and up to what length you should have?

So how this extent of mixing varies with length?So, all this kind of analysis people have done and we will discuss this down the line.

(Refer Slide Time: 35:01)



This is all what I had as far as this lab on chip is concerned.The next topic that I would like to get into is basically micro fabrication. I will I will spend a few classes on the basics of micro fabrication and then I will go to the essential theories of various operations that we talked about now.For example, electro kinetic pumping and all.So, those we will get into after this discussion on micro fabrication because first you need to understand I mean we have said yes we can do win micro scale, we can do win micro

scale we can do field flow fractionation or we can do electro kinetic pumping ad things like that.

However, first how would you accomplish this practically?How would you make a micro scale device?So, I think it is essential that I spend at least a few classes on this, what are the tools that are available in micro fabrication. When we look at fabrication accuracy when we look at accuracy what we see?These these are some of the scales that we have here a city, the fabrication accuracy is 10 kilometer, house it is 10 meter optical fiber. I mean these are these are the not a fabrication accuracy these are typical length scale that we consider.A house where is the house located and if you say within 10 meters where the house is located you will be just fine.

Whereas where the optical fiber is located if you can say within 1 millimeter I mean it is that way.So, length scale is important were I mean what your objective is the length scale also varies.Similarly, you have the dimension of bacteria virus and all the way going to 1 angstrom, I mean that is the final 1 not the final 1 but, that that is something which we we are aware of.Traditional mechanical machining traditional mechanical machining is the one that we have in the workshops.You youyou must have studied in workshop there is (( )) commonly goes by lathe machine.So this traditional mechanical machining they operate on objects of size 1 millimeter to 50 centimeter 1 millimeter to 50 centimeter.If you go to workshop if you go to a workshop, go to a lathe machine these are these are the typical objects they have I mean if you measured objects that they are working with these are the typical objects and precision of the order of 10 micrometer.It depends what type of machine you have but, if if you go by the route mechanical machining typically that is the most, that is the best precision that you can have.

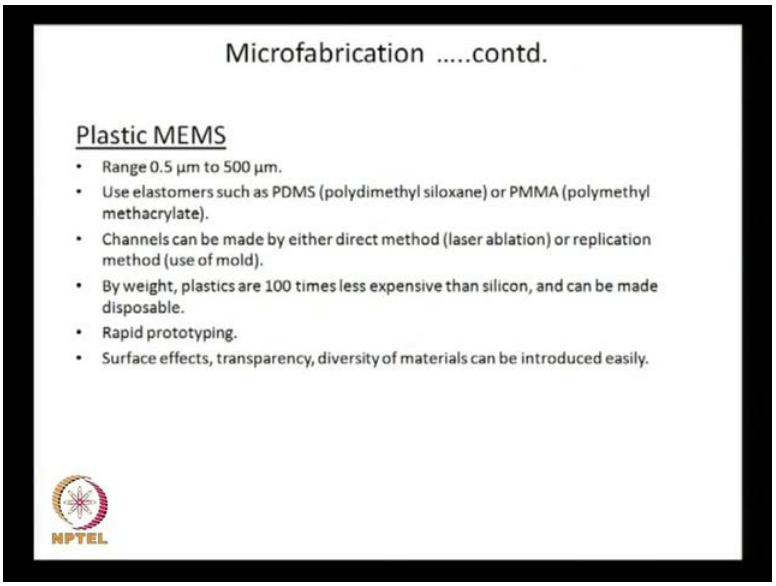
Then you can have what you call a special mechanical machining that is possible.The special mechanical machining is special mechanical machining is this this can have a displacement precision of 1 nanometer, angular precision of 10 to the power minus 5 degree.This is applicable for metal alone not for glass Teflon or plastic and most importantly this special mechanical machining they have a high price tag.

So these these are I mean you can always say traditional mechanical machining that has a limitation in terms of precision.So, when you come, when it comes to doing it in mywhen it comes to making a micro micro scale device traditional mechanical

machining may not work.One can go for special mechanical machining and this displacement precision etc are there.These special mechanical machining can be used.Only thing is it cannot, it is generally not applicable for glass Teflon or plastic.It is mostly applicable to metal and it has a price tag.

So, these are these are some of the disadvantages.However,however when it comes to accuracy this special mechanical machining can can deliver what you want to accomplish in a micro scale device.On the other hand, what people have, what the what is what is done here is the techniques that are used in semiconductor industry.For example, itching lithography deposition these techniques are borrowed to toto develop micro scale devices.II am going to discuss because this itching lithography in deposition.This is something new to you. I will discuss briefly what these techniques are about but, I would like o point out here that here the range is 0.2 micrometer to 500 micrometer and use of glass or silicon is there.You can you can use glass or silicon so, this this itching lithography in deposition, this technique can be used for micro fabrication.These are primarily used in semiconductor industry.

(Refer Slide Time: 40:18)



And are borrowed from there and these work just fine there is another important component of micro fabrication. I mean we said that you can use itching photolithography, these techniques for silicon and glass.Now, silicon and glass these

these are one of the oneof the major the micro micro devices that are made mostly these are made in glass and silicon.

However, a very important class there is plastic mems.The the micro micro scale devices which are made of plastic instead of glass or silicon.primaryThe primary reason is that this plastics can be really cheap and it can be disposable.So, it can be made, used and thrown away.So when it comes to making a sensor which will be used for once; so you put a sample and then you do not want to know what sample has sample has been adsorbed in some place.See you do not want to reuse it.So, you have to throw it off so you want to have something which is which is degradable and which is cheap.

So, these plastic devices, plastic mems they come under that category.Plastic devices these are these are made in a, I mean these these devices cannot be made using photo lithography.However, there are other methods which we will discuss very soon.Now, the range is 0.5 micrometer to 500 micrometer use elastomers such as PDMS or PPMMA.These are the twotwo elastomers which are very common;polydimethylsiloxane and ploymethyl methacrylate. These are two very important plastic materials which are used for micro scale devices when it comes to making it in plastic.

Channels can be made by either direct method which is laser ablation or replication method, use of mold.Use of mold is you you make a negative of it by in silicon or in metal and then you pour the plastic material on to it and or or you you make a stamp out of this, make make a negative stamp from metal or silicon and then heat the plastic material so that it can it becomes soft and the put the stamp and apply some pressure. So what what people do is they melt the PDMA's and pour it on the mold.You you might have already studied molding that you have the negative setting there and on that you pour it, you you melt it and then you pour it.And after it gets cooled down the itit comes out you just spill it off and you get a positive.So that I that is exactly the method that is followed here.

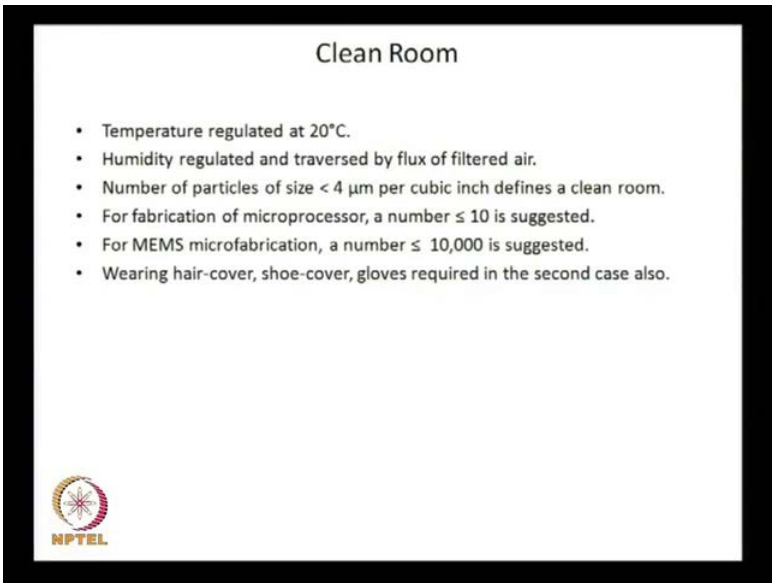
Channels can be made by either direct method that is laser ablation.That means you take the plastic material and then you selectively remove a portion which will form the channel.So, you take a plastic plate the selectively remove theselectively remove a portion using laser ablation that is one but, that is not the direct method is not notnot

followed in general. I mean if you go through, if you read the books you see that these are the replication method is more common were you have the mold, were you have the negative and you either pour the molten polymer or soften the polymer by application of heat and then take the stamp which is the negative and then press it so that you get the channel made by weight plastics are 100 times less expensive than silicon and can be made disposable.That is the advantage that you want to take when it comes to use a plastic.

Other important thing is rapid prototyping. Suppose, you have to make 100 chips within a short time, you want to makeyou want to make large number of such devices because if it is a use and throw away system so it is it has to be made in large numbers.In an industrial scale it is much easier to work with plastics and there are other effects that you can introduce such as surface effects.Plastic can have surface surface effects can be induced to it.For example, it could be hydrophilic, it could be hydrophobic it is hydrophobic but, if you treat treat it with plasma it becomes hydrophilic so things like that. I mean you can have lot of chemical if you oxidize the layer then, you have 1 property then if you do not then you have another property you have those fantastic properties available with the plastic material.

And one very important thing is transparency.Particularly if you are going for an optical detection transparency is very important.You can see what is going on you pass the light through it or you can detect light that is emanating from it.So this is very important and diversity of materials can be introduced easily.So these are some of the plus points of plastic mems.Of course, there are negative points I mean nothing comes free plastic of course,, there is a problem of aging.If you have glass you know glass stand the test of time but, plastic after some time it may age and if if you want to make something which has a high aspect ratio that means very thin channel.But, very deep it could be possible that you press it I mean it is this channel may not maintain its aspect ratio.So there are issues which are which goes on the other side of the balance as well.

(Refer Slide Time: 46:36)



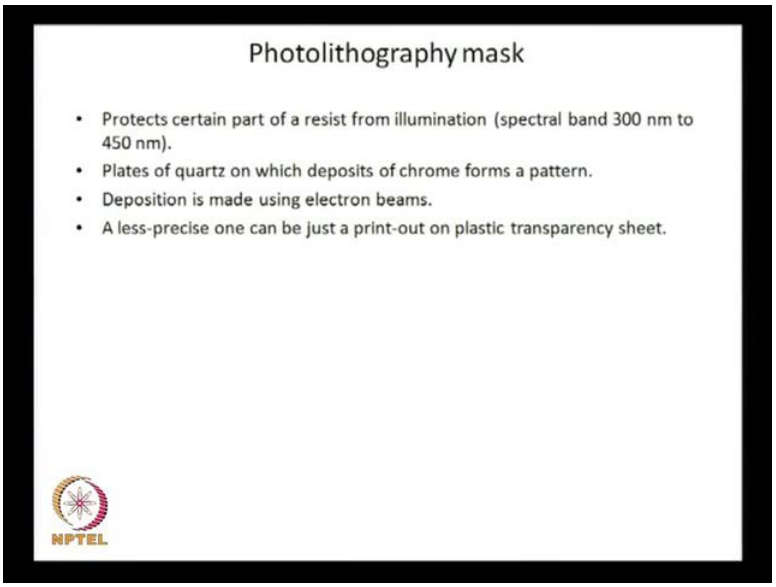
Now, before we get into this micro fabrication process further; I must tell you you already you have heard of clean room.ThisThat you have to have a clean room to do micro fabrication jobs.Now I would like define I mean if you if you go to a definition of a clean room.What we see there is that the temperature has to be regulated at 2 degree centigrade and humidity regulated and traversed by flux of filtered air.Then how do you define a clean room?You have you must have seen, you must have read the clean room of type 1, clean room of type 10 so what is that number?Number of particles of size less than 4 micrometer per cubic inch defines a clean room.number of particles of size less than 4 micrometer per cubic inch defines a clean room

And the number that is given for a clean room if it is less than 10 that is typically suggested for a micro process fabrication of micro processor.Whereas, for mems micro fabrication a number less than 10000 is suggested and is it is less than 10000 typically varying hair cover, shoe cover, gloves etc are required.So, what this means is that the clean room that is required for micro fabrication of mems device that may not have to be same as the clean room that is required for fabrication of micro processor and still thusthe for micro fabrication of mems device you need certain cleanliness and that requirement is here the wearing hair cover, shoe cover, gloves etc these are required and of course, the other other conditions have to be satisfied.

One thing, I would like to point out here is that typically the replication method the for when you make the mold, when you when it comes to making plastic mems device when you make the mold clean room is a must. I mean when you take take because you have to you have to make a silicon master, you have to make a master which either you press it as a stamp or you use at a as a mould on which the liquid molten plastic would be poured now when you make that master it is important that you have the clean room.

But when it comes to the replication method the requirements are no that stringent.That means when you are pouring it or when you are pressing it on the plastic material, the requirements are less stringent.That is what I understand.

(Refer Slide Time: 49:21)



I mean that is what written in references.The other topic I mean as as we go into this itching process, I said we we do not so what what what we are going to do in (( )) this course is I am not going to discuss about the, that special micro machining because traditional micro machining and then more efficient more precise special micro machining, these are already there.I am not going to discuss that.What I will discuss is the itching and the photo lithography and those steps which are as I said are borrowed from the semiconductor industry.Of course, borrowed mean a sense that you make it work for micro scale devices.

So whatever technique I mean you take the essence essence of the technique and then make the appropriate changes so that it suites your requirement.So, that itching in

photolithography, that particular technique I mean if I want to repeat I must say that these these we are not talking about traditional machining or special mechanical machining though these are there.We are focusing on itching lithography and deposition these particular technique and what we will point out here is that this itching lithography and deposition technique will will be used to make micro structure device with glass or silicon and then that device we we can we can make a positive in that device, we can make the negative as well and these device would be used to make a master for plastic memsall right.So we are primarily focusing on this means we are primarily focusing on itching lithography and deposition and then we will we will study how we can pour the plastic material or how we can create that how we can, this this method is known as hot embossing.That means you soften the plastic and create a stamp and put it put some pressure.So how this hot embossing is done that we will discuss down the line but, we are not going to take up this traditional mechanical machining or special mechanical machining.

So, we briefly point out I mean I i do not I I willwillprobably get into this photolithography process at a in the in the next class.What briefly we point out is that there has to be a mask there has to be a mask and there has to be a light source so light would be on the top and then there will be a mask.Mask means a certain portion is black and certain portion is white and below the mask there would be the wafer on which you want to create the channel and you coat that wafer with a photo resist,with with a with aphoto resist which is basically a polymer.

This polymer has some unique property if light is shining on certain portion of the polymer those portions will become soluble in certain solvent.So, these are photosensitive polymer.These are called photo resists so on the wafer you have these coating of photo resist and you have a mask on certain portion it is dark and certain portion it is light certain portion it is dark and certain portion it is white. I mean certain portion is transparent and certain portion is not and on top of that you have the light.So, as the light shines, so light will travel through that transparent portions but, it cannot go through the covered portions, the portions where through which light cannot travel.

So it will go only through the transparent portion and it will heat the photo resist which is the coating basically on the wafer.So it will heat the photo resist.So, it will make those places vulnerable all right wherever light heats.So, those places are vulnerable.So, you

dip it in a solution and those portions will be solubalized.Solubalize means it goes to the solution.So, those portions get exposed.Now, you add a itching chemical, now you add certain chemical which attacks those places, chemical attacks, chemically react with silicon.If it is silicon and that product goes to the solution product does not stick to the surface.

So, if you dip it for say for one minute, you will see some itching taking place only on those exposed portion.The other portions remain as it is because it cannot penetrate the photo resist all right and then when you are done, you remove the photo resist finally, by some method.So, you have those channels engraved on the on the on the wafer.So, this is essentially what is photolithography but, I would this, I said I mean I i did it in a very cursory manner. I would discuss this in detail in the next class how the photolithography takes place.That is all for today.