Microfluidics
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Lecture – 26
Microfabrication Techniques (Continued...)

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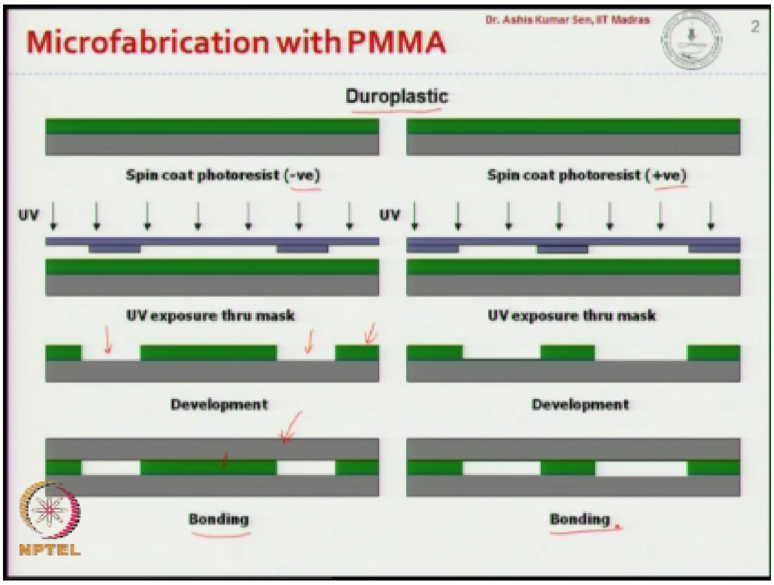

Okay, so let us continue our discussion on polymer based fabrication. Here, we talk about micro fabrication of micro channels with PMMA substrate; PMMA stands for poly methyl methacrylate, so it is a duroplastic as we have discussed earlier and so we start with spin coating photoresist on polymer PMMA wafer and so depending on the photoresist, whether it is positive or negative we end up with different structures.

So, here for example, we spin coat a negative photoresist through a mask okay and so in case of negative photoresist all the exposed areas become hardened and they become resistant to developer solution and the unexposed areas become dissolved in the developer solution, so we get a open channel configuration on PMMA substrate. Now, to seal the channel, we can use another PMMA substrate and take it through the bonding process.

So, that SU 8 on top of the PMMA; the top side of SU 8 is cross linked with the PMMA layer, so we achieve a bonding and similarly if the photoresist is negative, we go through the similar process but in case of positive photoresist as we have learnt earlier, the exposed areas get dissolved in the developer solution and we can do the bonding to get the channel structure.

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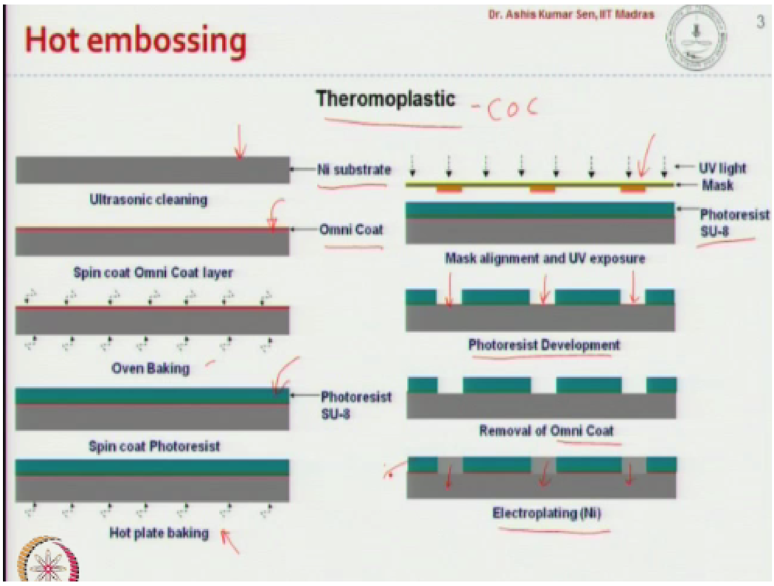

Now, we talk about the hot embossing process that we use for thermoplastics like cyclic olefin copolymer COC, so in this case we will talk about one example, where will be preparing a master, so for the hot embossing process, which is normally done once with say a cyclic olefin co polymer substrate, we will require a master okay which would have the configuration of the channel structure that we want to fabricate.

And this master in this example that we consider is fabricated from nickel and then we would be fabricating a COC based microfluidic device okay. So, we start with a nickel substrate, so this nickel substrate has to be ultra-cleaned, so it is cleaned in sonication; using sonication and it has to be ground so that the top surface is optically flat. Now, we want to take this substrate through the photolithography process.

But SU 8 will not stick to nickel okay, so we use an Omni coat layer as a adhesion layer for the photoresist to stick to the nickel substrate. So, after we put Omni coat layer, we do a baking stiff in oven and then we spin coat for photoresist SU8 on top of the Omni coat layer. Then after pre baking, we do exposure through a mask depending on the channel structure and then we do the development of the photoresist.

After the photoresist is removed on the etched; on the etched you know; developed areas of the photoresist we remove the Omni coat layer okay. So, in these areas Omni coat is still present, so at those regions, the Omni coat is removed and then we take the wafer through the electroplating process okay. So, in electroplating nickel is deposited onto the exposed nickel surface and then we strip off the photoresist okay and the Omni coat.

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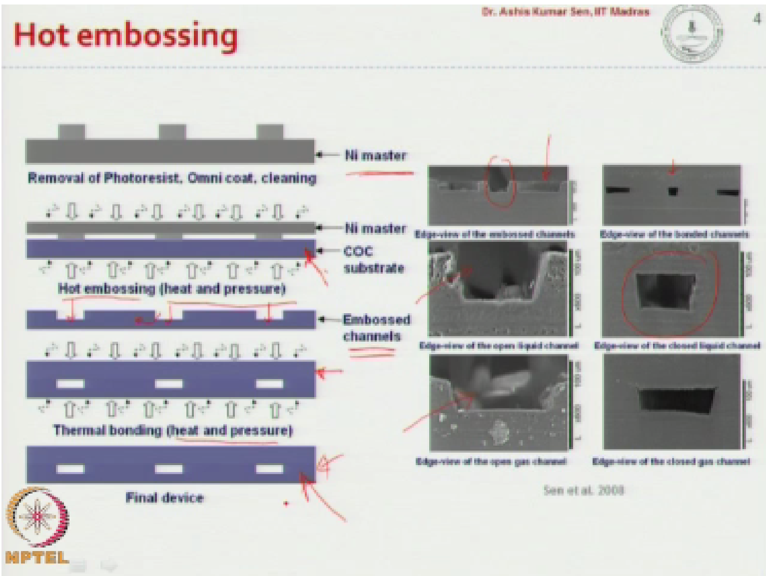

So, after we do electroplating and we strip off you know, the photoresist and Omni coat, we get this nickel master. So, this nickel master can be used repeatedly to fabricate the COC based microcredit devices. The way it is done is we take a COC substrate okay, so COC substrates are commercially available and in some cases, there are some COC grains also available from companies like G and R.

So, you can buy grains and do a heat and pressure based molding to create COC based substrate and these substrates can be used to do hot embossing to create channel structures okay. So, as you can see here, so this is the COC substrate we take the nickel master with the pattern metal layer facing down onto the COC substrate and the hot embossing process basically involves application of heat.

So, this is done typically in a hot place, where the top and bottom surfaces of the hot place will be heated to the desired temperature normally above the glass transition temperature okay, the glass transition temperature of COC and then pressure is applied from top and bottom surfaces okay. So, in presence of heat and pressure, the patterned areas of nickel on the nickel master penetrate into the COC substrate.

And so we have these penetrated regions where the; you know the channel structures are formed, so this is because of the plastic flow of material; COC material from these pattern nickel areas into the bulk of the substrate, okay. So, create channel embossed channel structures, so these are open channel structures, so we have to bond another planar COC substrate, so that is also done on a hot press in presence of heat and pressure.

So, we create a final device, so this shows an example of you know; how to create COC based microfluidic device, so these are some open channel structures, so that you know 2two bigger channels around one central smaller channels that is shown. So, these are open channels, some zoomed images of open channels and here you see the closed channels okay after this COC is; a planar COC is bonded on top of the open channel.

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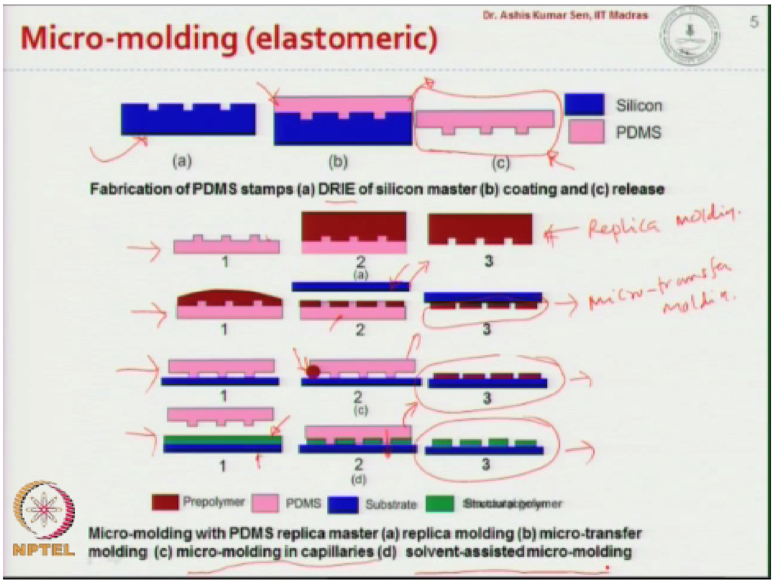

So, here we talk about micro molding using elastomeric substrate, so you know if you look at here, we take a silicon substrate that is; so this is basically silicon master which has a channel pattern, which can be fabricated using dry reactive ion etching okay, which gives straight channels and in the second step, we put a layer of PDMS on the tops which can be done using spin coating.

And then after curing of PDMS, we fill this layer off, so we get a structure; PDMS structure which can be used as a master as well. So, in this particular case we will be talking about how to use this silicon master to create different polymer structures, so this master is used in the first case here, I will be talking about replica molding where you know a pre polymer is poured onto this PDMS master and it is cured and peeled out.

So, we get a channel structure on this pre polymer okay, this is called replica molding okay, this is called replica molding . In the second process, we pour a layer of pre polymer on the surface of the PDMS and then we bring in another substrate okay on in touch with this poured pre polymer and then if we do a UV best curing okay because this PDMS is already cured.

And depending on the characteristics of the surface, the pre polymer can transfer; gets transfer onto this substrate. So, here after curing if you peel this substrate off, pre polymer gets spattered onto the surface of the substrate and this is known as micro transfer molding okay, this is known as micro transfer molding and in this technique, we are putting the PDMS master in touch with a substrate.

And then we allow this pre polymer to creep into the voids formed between the PDMS and the substrate using capillary action. So, once they, it gets you know; filled out, we do curing and then when we remove this PDMS substrate, we get a pattern on the substrate and this is known as micro molding in capillaries okay, so this is known as micro molding in capillaries. In the fourth process here, we have a structural polymer.

So, this is a structural polymer, which is put on a substrate and we bring in this pattern, sorry; the master; the PDMS master in touch with the structural polymer and before we bring the master in contact with the structural polymer, we expose the structural polymer to some kind of solvent okay and that solvent allows this structural polymer to flow easily, when this master is forced against the structural polymer.

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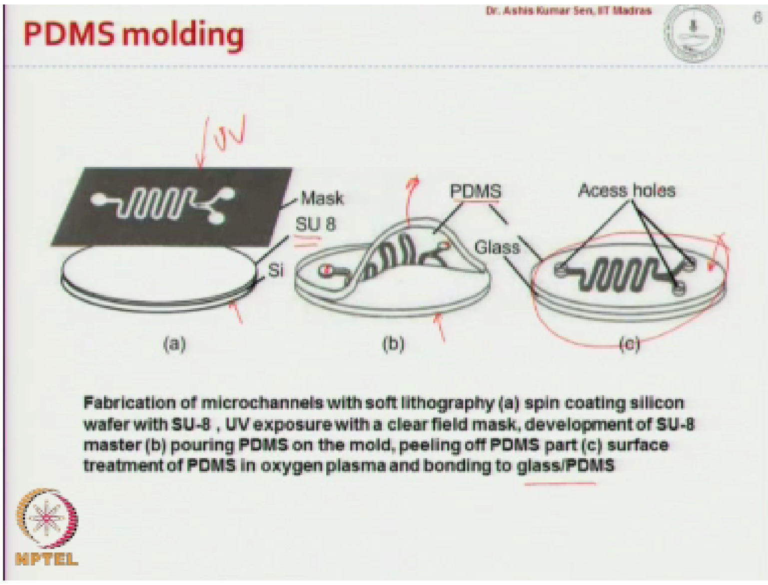

And when this master is taken out, we create a structure, a pattern on the surface of the substrate and this is known as solvent assisted micro molding okay. Here, we look at a typical PDMS molding based microfluidic device fabrication; it is starts with photolithography process, where you know SU 8 is patterned on top of the silicon wafer, so this is the Su 8; so this is the Su 8 that you see here which is pattern on the silicon substrate.

And through a mask, so UV exposure through a mask and once we have a pattern on the silicon wafer, we pour PDMS onto the mold and after putting PDMS and curing in an oven, we remove this PDMS layer, we separate it from the master and then we drill access holes, so let us say, this is the fluidic channel and this is the inlet and this is the outlet. In this case, there are 2 outlets, so we create you know; fluidic holes by punching.

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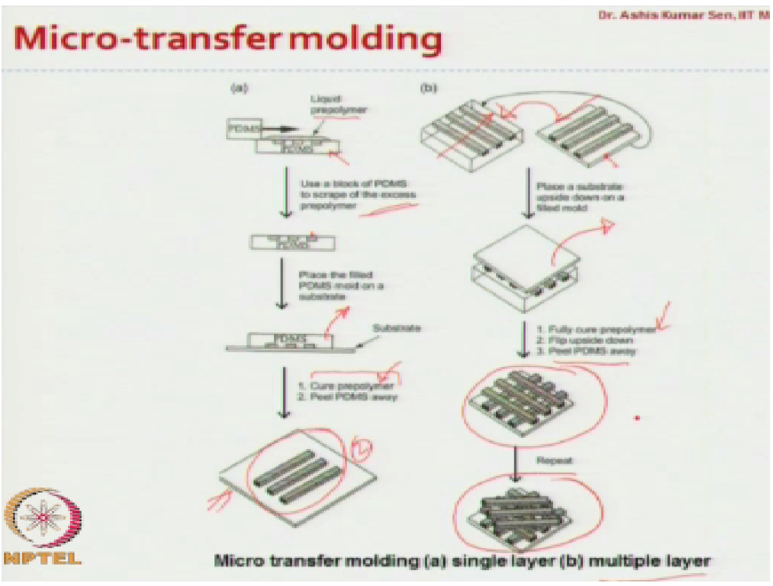

And then we can bond this PDMS open channel against a glass or a PDMS layer okay; a planar glass or PDMS layer, so we can create a microfluidic device with fluidic access holes okay. So, here we talk about a technique called micro transfer molding and so in this case, you know here we have a PDMS layer with grooves okay, so this act as a master, so PDMS act as a master that has grooves on it.

And we are trying to pattern some pre polymer on the surface, so we pour some; you know liquid pre polymer on the surface and then use another PDMS to scrap this additional pre polymer that are present after filling these grooves in the PDMS. So, use a block of PDMS to scrap of the excess pre polymer, so then we would have this PDMS with the grooves filled with 3 polymers okay.

And now, we place the PDMS mold on a substrate upside down okay in contact with a substrate, now if you cured the pre polymer and then we fill out this PDMS, we get a pattern of pre polymer on the substrate. So, this is a single layer you know micro transfer molding, we can do 2 of these single layers and we can use one on top of another as for example, this pattern is placed on this pattern in the transfer direction, okay.

So, this length is aligned in the transverse direction this way as you can see here and then, so these are not fully cured okay, so these are not fully cured, so here the curing is half done okay. So, now if you have 2 of these, (()) (15:05) your single layers, we put it in contact with each other and now we fully cure the pre polymer and then peel the PDMS layer away. Let us say this top PDMS layer; the thinner PDMS substrate here is spilled off.

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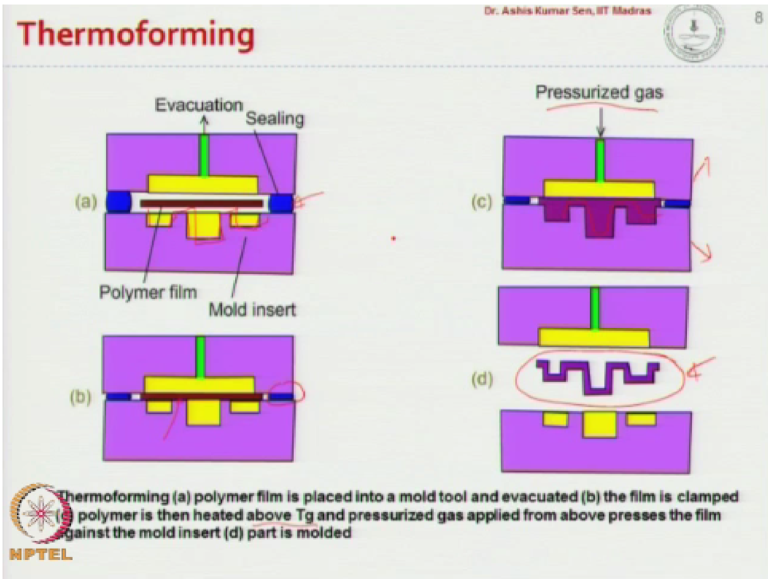

Then, we would have a multi-layer patterning on the surface and we can do it multiple time to create as many multiple layers that are possible, so that is known as micro transfer molding. Here, we talk about a process called thermo forming okay. In thermo forming; so this is the situation we have, here the polymer film is located inside the mold cavity, so this is the mold cavity.

So, the structure of the pre polymer film we want to form it to, it would have the negative you know fabricated in the form of this mold cavity okay. So, initially you would place the polymer film inside and the 2 blocks will be spaced using a ceiling while we were evacuating the pressure inside the chamber is reduced and as the next step the; you know the film is a clamped by you know applying by removing this pressure and applying pressure.

So, that the ceiling is maintained at the same time, this is the film is clamped around the periphery and then here we would have heating arrangement, so that we increase the film temperature above the glass transition temperature of the film and then we supply a pressurized gas on to the mold and the pressurized gas basically deforms this polymer film to hold to the profile of the mold cavity okay.

And then, when we separate these 2 blocks away, we take out the polymer film which is having the structure same as the structure of the mold cavity that we had initially used, okay and this is known as thermoforming okay. So, it is using heat to increase the temperature of the polymer film above the glass transition temperature and it also uses pressure okay, so that is the reason it is known as thermo forming.

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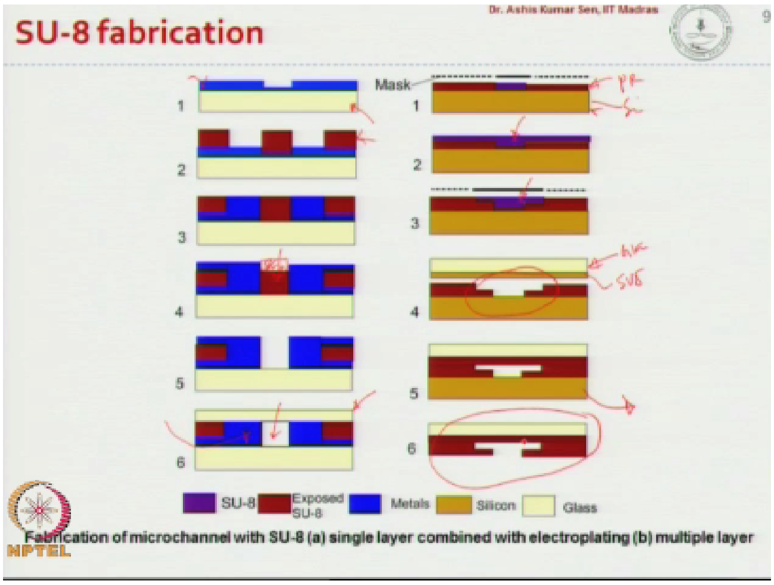

Fabrication of microchannel with SU-8 (a) single layer combined with electroplating (b) multiple layer

Here, we are using Su 8 photoresist as a structural layer, you know here we see the fabrication process, you know we have the glass substrate in this case, which is coated with some kind of metal okay and so this is the metal layer okay. So, you put photoresist here and then we metalize this further to fill out this cavity with metal and then we again metallized and pattern okay.

So, you know remove metal from these areas by selective etching and then in the fifth step, we remove the photoresist from this area okay, so you have the glass exposed here, so this is the open channel and then we can bond another planar glass layer with this to have the sealed microfluidic device. So, here in this case we would have the fluidics present here but at the same time we would have the metal layer adjacent to the fleet, you apply; supply electrical energy or thermal energy to interface with the fluidics.

And here is an example of multi-layer, how you can use multiple layers of you know; channel structure using Su 8. So, this is you know; the substrate and we put a layer of Su 8 here okay, so this is basically silicon and we put a layer of photoresist on top and after patterning of the photoresist, you know put a; so this is the photoresist which is not fully you know, cured. Then after curing, we put another layer of Su 8, okay.

This is the Su 8, which is not cured fully, this is just spun coated, then we expose EV through this mask and up to that, you know this is developed, so we take out that area of Su 8 from the structure, so you have a structure something like this okay. So, this is a 2-layer channel structure that is fabricated on top, we create a, you know; another, this is the glass layer with a layer of Su 8 and we borne them in contact with each other.

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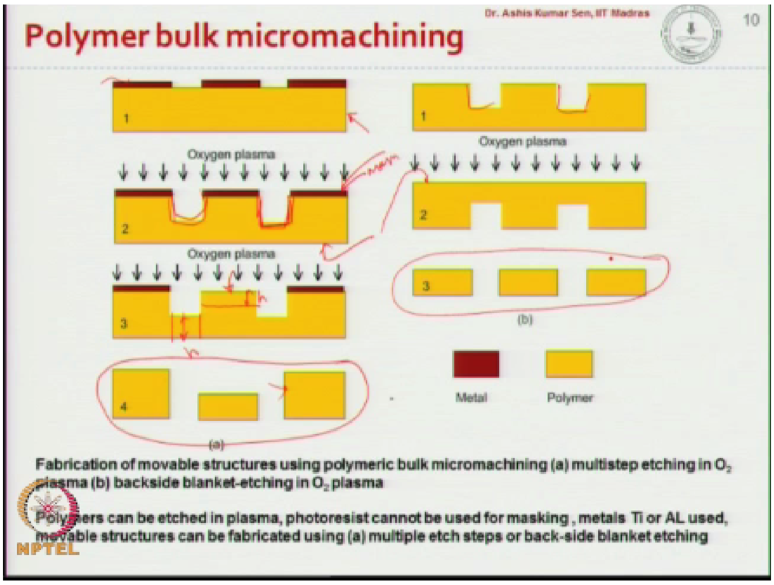

And then we remove this silicon layer away, so we have a double layer channel structure in this way, okay. So, here we want to create you know, movable structure using polymer bulk micromachining, so here we have the polymer substrate and which is coated with a layer of metal on top and then we go for oxygen plasma. The oxygen plasma basically removes this you know, the polymer where the metal act as a mask okay.

And then, you know once the etching is; the oxygen plasma etching is done, then we etch out selectively this metal layer okay. This metal layer is removed first and then we do further oxygen plasma etching okay. So, if you do further external plasma etching, then this thickness goes off completely okay and so if this is etch; equal thickness here also gets consumed.

So, we create a structure like this, which is a hanging structure okay, so there is a gap between the substrate and the surface of this structure. So, this structure is a movable structure okay. Similarly, we can do; you know multi step etching for example, here we have etching, this is a; you know channel structure and switch has been done using oxygen plasma, so here we do not have the metal layer okay.

So, we do; we use this metal layer to etch these channels and then we completely remove the metal layer. After removing the metal layer, we do etching from the backside okay so this backside, we start to etch okay. So, if you do that we get a free hanging structure something like this. So, what it tells is that the polymer can be; structures can be machined using oxygen plasma etching to create free hanging structures okay.

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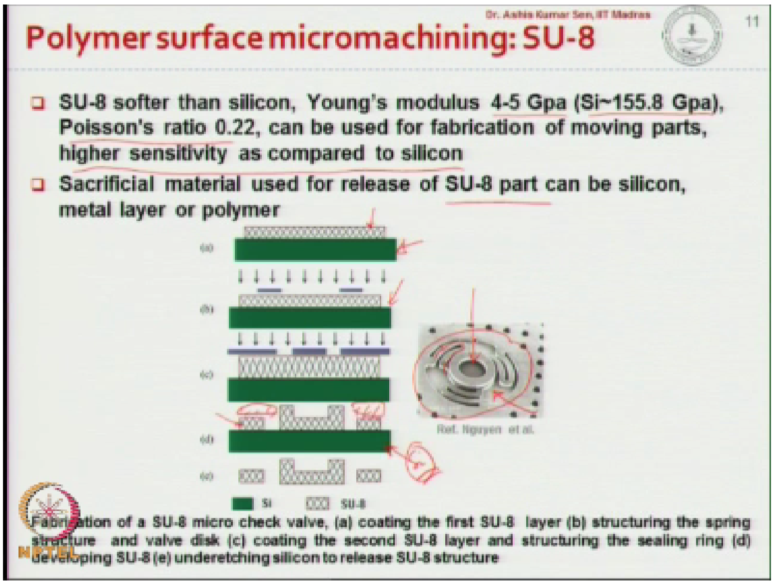

So, this is polymer surface micromachining using Su 8 and as you know Su 8 is softer than silicon and its young modulus; Young's modulus is about 4 to 5 Giga Pascal, whereas silicon has Young's modulus about 155.8 Giga Pascal okay, so it is about 30 to 40 times smaller, it has 30 to 40 times smaller young modulus as compared to silicon. The Poisson's ratio of Su 8 is about 0.22, so for that reason this can be used for fabrication of moving parts, okay.

Because since, the Young's modulus is less, I could have higher sensitivity in some applications as compared to silicon. So, here we would be using sacrificial material to release the Su 8 part and we would be using silicon as the sacrificial layer okay, so this is a process to create this spring like structure, so this is an example of a spring like structure made of Su 8, okay. So, this is the procedure that is used.

So, we start with a silicon wafer with a layer of Su 8 on top, then we do exposure; UV exposure through a mask and after UV exposure, we do development, so we get a Su 8 pattern on the surface okay and then we do selective etching and removal of Su 8 in these 2 areas here okay. So, after we remove Su 8, we get a free then, we what we do is; you know this silicon here is used as the sacrificial layer.

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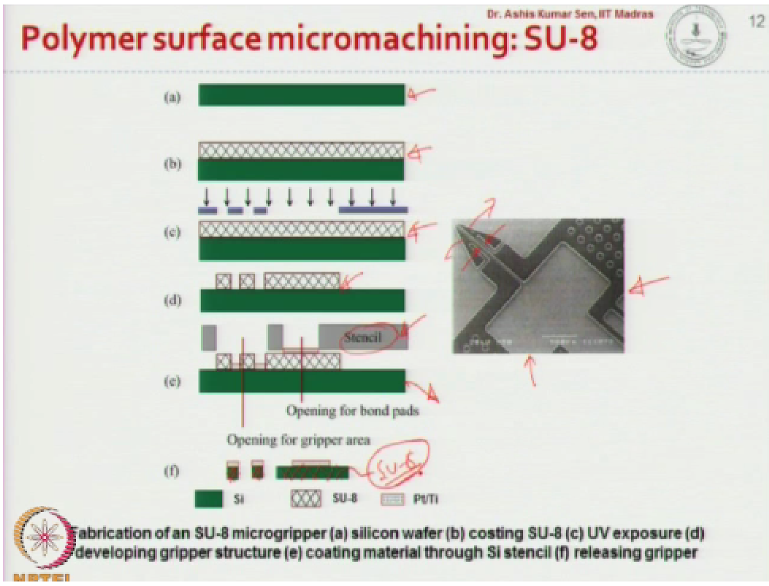

So, where H silicon in an H; suitable etchant, we do not attack Su 8 but it removes the silicon sacrificial layer. So, when we do that, so this structure is made of Su 8, whereas underneath these areas, which where silicon was present has been removed, so this structure act as a spring okay. Here, you know polymer surface micromachining has been used for fabricating a micro gripper okay.

Micro grippers are used for cell manipulation okay, so for example, you can have electrodes pattern on the surface of the Su 8 and by applying you know, using Joule heating by applying voltage in the positive cycle, when you are applying the thermal energy because of the Joule heating, the prongs of the gripper can expand and then it can hold a cell and then when you take off the electrical supply, it will compress.

So, then it can grip the cell, it can take it to the location to where you can again apply an electrical pulse, so the prongs will be opening up and then you can release the cells. So, micro grippers are used for cell manipulation okay, so here you will be looking at a procedure to fabricate micro grippers using SU 8 as the structural layer. So, as you can see, this is an image of the micro gripper typically you would have; you know metal patterns on the prong itself.

And when electrical supply is there, these prongs will open up and it can hold; you know biological objects for manipulation. So, it starts with you know; silicon substrate, then coating photoresist, exposing for development, so you would have a pattern photoresist layer here. Now, we want to you know; metalize the surface of Su 8 okay, so here we have a stencil meaning a mask through which this metallization is going to take place.

So, we can have a stencil in physical contact with the pattern Su 8 substrate and we can put this mask in physical contact and put it in a thermal evaporation, for example you can put in a sputtering system, where the top surface will be metallized; the exposed surfaces will be metallized and you know, this stencil will be used as a mask. So, all the exposed areas are going to be metallized okay.

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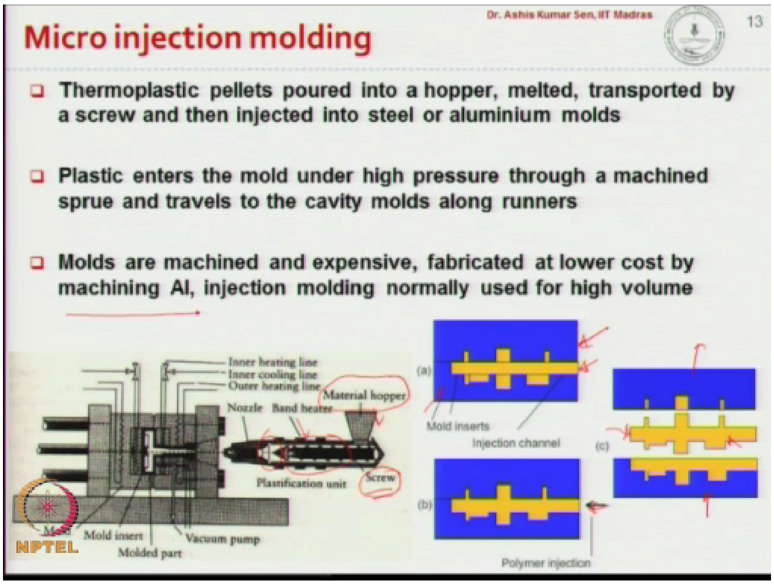

So, you know; after you know; metallization we remove the silicon substrate, so we have this is actually Su 8 okay, so this is actually the Su 8, so it have the metal layer on the surface of the Su 8 okay, which is what is shown here okay. So, this is actually SU8 not silicon okay, so okay; so this is Su 8 on which we are patterning the metal layer. The next procedure is micro injection molding.

So, in a typical micro injection molding system, we have this setup, we would have a mold insert which would have the inside configuration similar to the profile of the part that we want to fabricate using injection molding. Now, in a typical system the; you know; the thermo plastic pellets like COC pellets will be introduced into a hopper and then, so these pellets will come here of where would be a heater okay.

So, in presence of heat, we would you know; on the screw to; you know bring this thermo plastic pellets into molten states, so here we will have molten thermoplastic. For example, molten COC, which will be applied into this mold cavity by applying the screw and so here for example, we have the mold inserts, so these 2 blocks form this mold and the polymer injection comes in from the top so it fills the cavity.

And after we separate these 2 blocks, we will have the molded component coming here okay. So, typically one important component of injection molding is the fabrication of the mold itself, which is challenging and many times depending on the; you know structure that you are going to fabricate; we want to fabricate the mold using different metals okay. One of the cost effective approach; if you can fabricate a mold, using by machining aluminum okay.

And the micro injection molding setup is very expensive because the fabrication of the mold can be very intricate, it has to match on the surface of the surface profile of the structure that we are going to fabricate and for that reason, the initial investment on fabricating the mold for injection molding is expensive, so that is the reason this is not typically used for prototyping but it is used for high volume manufacture, okay.

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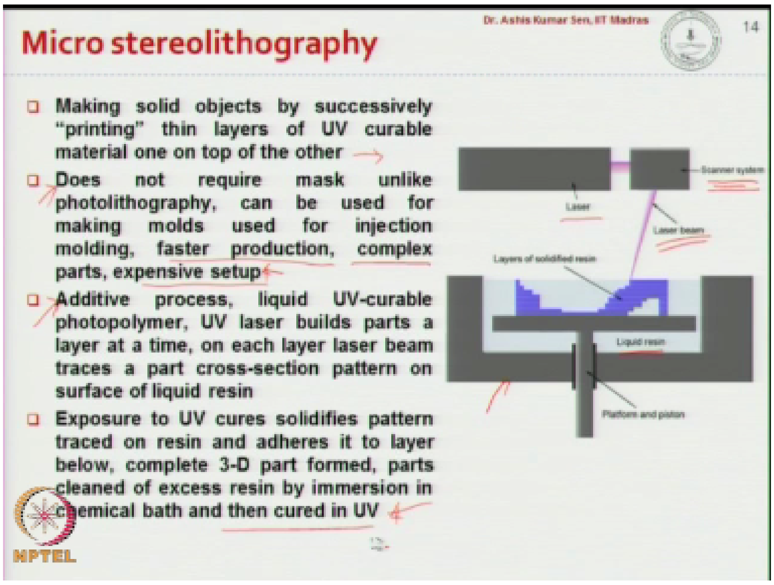

So, move on to next fabrication technique, which is micro stereolithography and in micro stereolithography, we make solid objects by successive printing thin layers of UV curable material on top of the other. So, this is what you have seen here; you see here, we have the liquid resin present inside this chamber and we have the laser; giving a laser beam and this laser beam is scanned onto this liquid resin layer by layer okay.

And depending so; if you have a 3 dimensional structure, it is going to scan layer by layer starting from the bottom layer okay, so depending on the 3D profile, it is going to scan the very bottom layer, so as it is scanning on the surface of the; in a liquid resin it is going to cure okay, so that becomes solidified and at each step, the laser is going to move up okay starting from the bottom layer to the top.

So, you know this system is intricate because one of the important components of the system is going to the scanner system, which is going to read the 3D profile, the CAD of the 3D profile and accordingly, selectively in a scan layer by layer switch on and off, you know depending on the profile in the third dimension okay. So, one good thing about the stereo lithography is that it does not require a mask unlike photolithography.

And can be used to make molds to; that can be used for injection molding. In this case, the production rate is fast you know, complex 3 dimensional parts which cannot be manufactured other ways can be manufactured using micro stereolithography however, the setup is very expensive okay, it requires laser, it requires the scanner, you know scanner system which makes the system quite expensive.

So, this is an example of additive process meaning; we are not subtracting material from the bulk of the material but we are adding energy to cure the material selectively okay, so this is an additive process. So, UV curable photopolymer is cured by using the UV laser okay and so the exposure to UV would solidify the pattern and so as and when it is doing in multiple layer, the next you know; the immediate layer is going to be bonded to the previous layer, okay.

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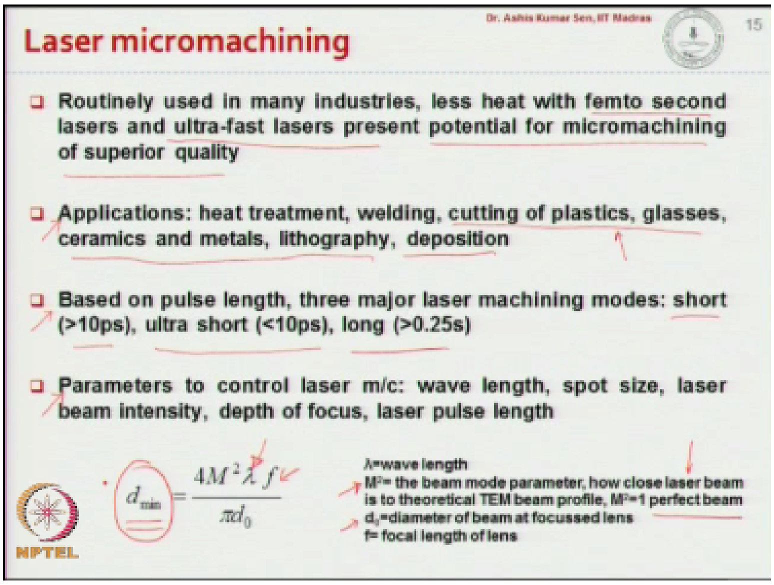

So, that is how the 3D part is going to be formed, so after the laser curing the parts are going to be cleaned by emerging in a chemical bath and then cured using UV, okay. So, that is when we get our structure. Next, we move on to laser micromachining; laser micromachining are routinely used in many industries and so you know, but one of the major limitations of lasers is that it produces heat.

But nowadays, we have you know; femto second lasers or ultra-fast lasers, which you know reduces the difficulty associated with the heat and for which they create potential for micromachining of superior quality okay, so these are some of the applications of laser micromachining, it can be used for heat treatment, welding cutting of plastics and glasses which is relevant for microfluidic applications, machining ceramics, metals.

And they can be used for lithography, laser based lithography and for deposition as well. So, based on the pulse length, the laser can be categorized in through 3 different categories; 1 is the short pulse laser, which has you know; timescale, you know > 10 pico second. Then, there are ultra-short, which has timescale < 10 pico second and long pulse laser, which has time > 0.25 second.

The different parameters that are used to control the laser machining, so D is the minimum feature size that can be machined using laser, which is dependent on different parameters; one is the wavelength of the laser that we want to use for the machining and the second parameter is M square okay. M square is the beam mode parameter, which defines how close the laser beam is to the theoretical transmission electron microscope beam profile.

So, what it tells is; as you heat the laser on to the surface, how the beam is going to diverse from a uniform cylindrical shape. If it is perfectly cylindrical, which is the case, in case of you know; transmission electron microscopy, then the M square is going to be 1, okay. So, if M square is 1, then it is a perfect beam okay and d0 is the diameter of the beam at the focused lens and f is the focal lens.

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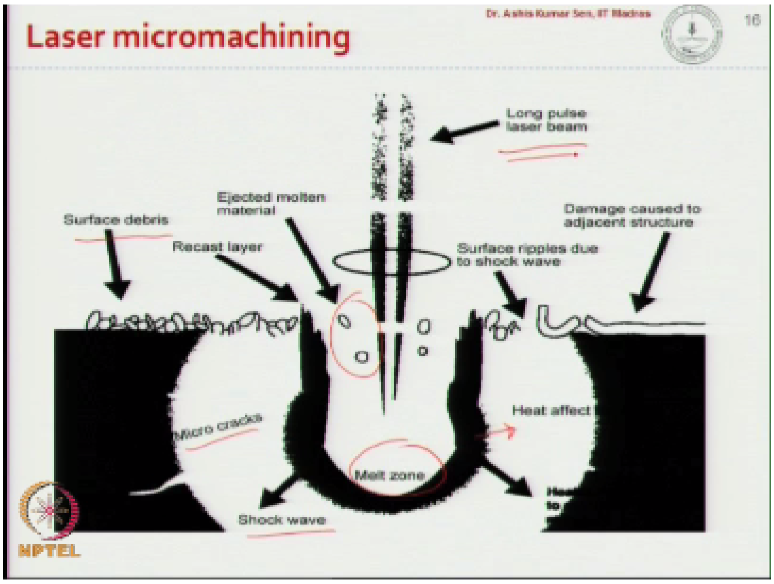

So, that is how, we can find for a given set of parameters, what is the minimum size of the feature that can be fabricated using lasers. So, here we see a typical you know; micro scan of a laser micromachining structure using long pulse lasers. So, long pulse laser as I was telling, it is not favourable but because it creates fex in the structures. So, when you have this long pulse laser comes in, it creates a melt zone.

So, when this long pulse laser comes in, it creates a melt zone and around the melt zone, you would have a heat affected zone and since this laser is; you know very long, it creates shock waves into the structure, it creates micro cracks and because of the long pulse, there are molten metals that are rejected in the form of particles, we would get; you know which form surface debris on the surfaces.

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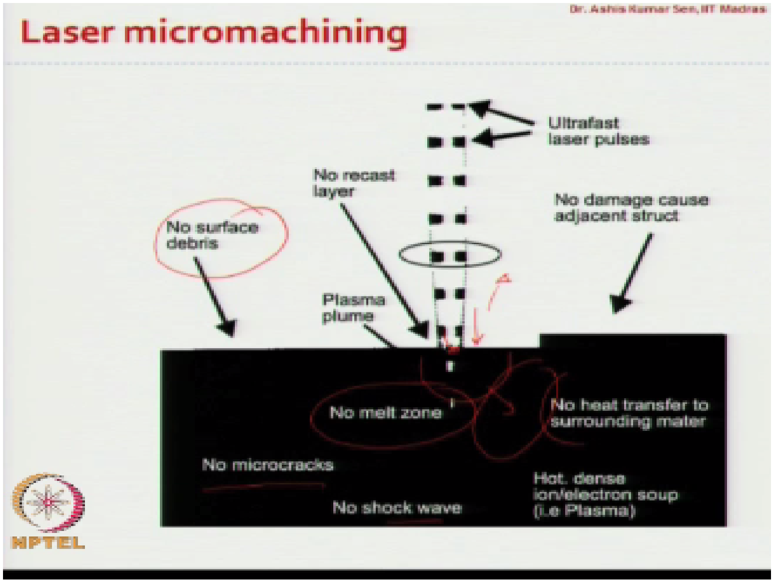

So, there are you know; various unwanted undesirable effects that come in, when the long pulse laser is used, so definitely long post laser are not suitable for fabricating micro channel structures. On the other hand, if we go for the ultra-fast laser pulses; in case of ultra-fast lasers, we do not have a specific melt zone here, so because the laser is very fast as soon as it falls, the metal in very locally gets evaporated and removed okay.

So, there is no specific melt zone that we see in case of the long pulse laser, where the laser is very slow, the time period is more. So, here in this case, the time period is very less you say, altar the first laser that we are talking about. So, there are no problems associated with micro cracks, no shockwaves and there is no heat transfer to the surrounding matter, before the heat gets transferred and it creates a heat affected zone, this area is cooled.

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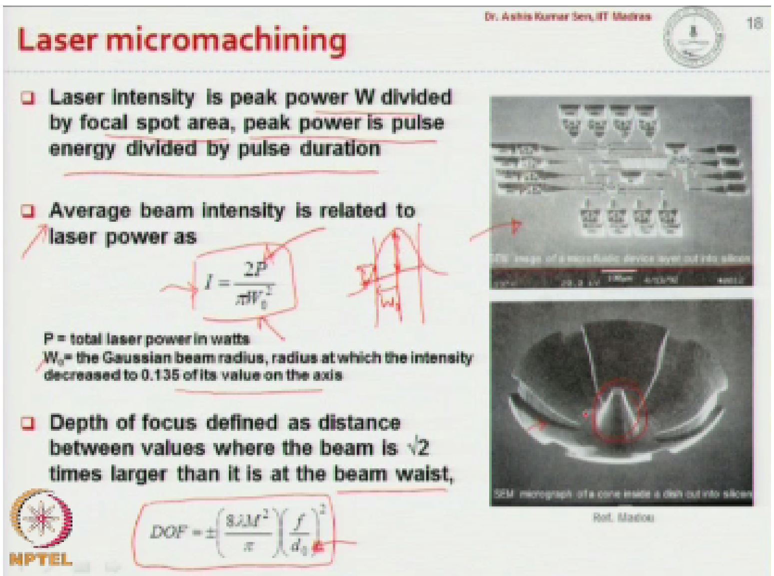

Because the pulse is very fast, so there are no surface debris as well because the metal get evaporated locally and it gets removed to ambient okay. So, ultra fast lasers can be used to fabricate micro channel structures. Now, in case of laser micromachining, there are different parameters that are involved, the laser intensity is defined as the peak power W divided by the focal spot area, okay.

So, if you have; you know power W coming on this certain area; spot area we can define what is the laser intensity and this peak power is the pulse energy divided by the pulse duration, okay. So, average beam intensity is related to laser power using this equation, so I is the average beam intensity and P is the laser power and W0 is the Gaussian beam radius okay. So, when you talk about a laser beam, typically it will have; the intensity will vary in a Gaussian manner.

So, the Gaussian W0 stands for the Gaussian beam radius is the radius at which intensity decreased to 0.135 of its value on the axis. So, here; so this radius is, so W0 is the radius at which this value here would be this value is 0.13 pi times the value at the centre okay, so that is W0. The depth of focus is defined as the distance between values, where the beam is square root of 2 times larger than it is at the beam waist okay.

So, that is known as the depth of focus, which is given by this expression okay; lambda is the wavelength, F is the focal length, d is the diameter of the beam that we have already defined here and M square is the; if the beam is perfect, then M square becomes 1, okay. So, on the right, we see some structures; examples of some structures, so here this one is an SEM image of a microfluidic device layer cut into silicon, okay.

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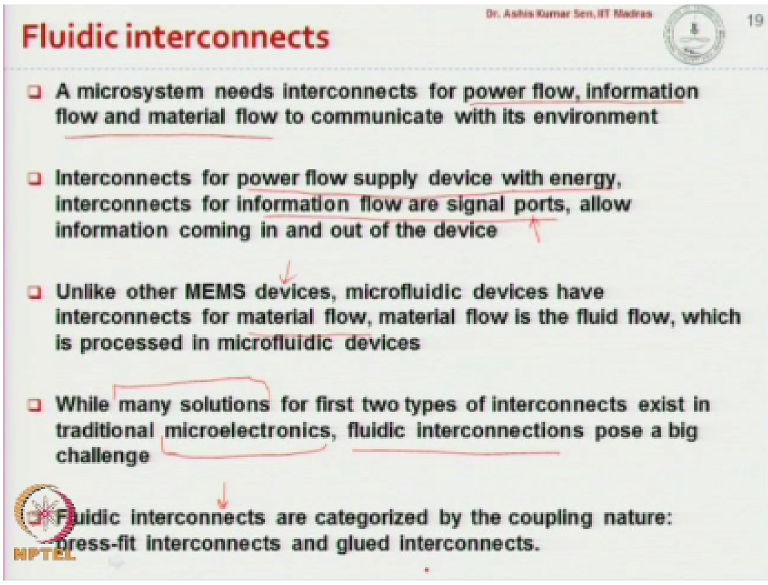

So, this has been fabricated using laser micromachining and on the bottom, you see a SEM micrograph of a cone, okay. This is the cone that has been cut inside a, this; this is like a disc shape and there is a cone which has been cut using laser micromachining. Now, let us talk about fluidic interconnection. So, we have learnt you know different techniques that can be used to fabricate microfluidic devices.

Once we fabricate the microfluidic devices, we need to have a mechanism to connect external capillary; external fluidics with the microfluidic devices okay. Now, you know a typical micro system needs to be connected for the power flow for information flow as well as the material flow. So, there are 3 types of communication that happens between the external world and a typical micro system.

Now, the interconnect for a power flow you know; supply the device with energy so, the external energy can be supplied to the device using power flow and information flow can be supplied using signal ports and so those; but unlike MEMS devices, the microfluidic devices have interconnection for material flow, where we are going to put fluidics from the external world into the micro fluidics.

That does not mean that; in some cases, where we have an electrode structure, you know coupled with microfluidic devices in that case also, we need interconnection for energy flow where we apply external energy to the microfluidic device okay. So, in some cases you would also have control capability for example, you know we are controlling a valve in that case, we would also need a mechanism to interface control capability with the microfluidic device.

But in a generic sense, we would deal with the material; you know communication with microfluidic devices. So, you know we would have many different solutions for; you know interconnecting power flow and information flow into devices, so that is; that can be borrowed from microelectronics, which mainly deals with the first 2 types of interconnection. However, the fluid interconnection is a big challenge in micro fluidics okay.

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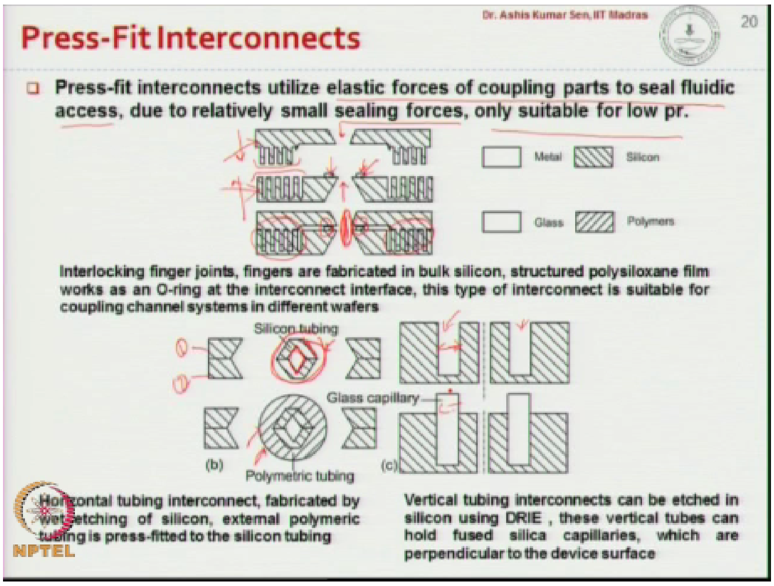

Now, depending on the interconnections the fluidic interconnections are categorized as press fit interconnection and glued interconnection. So, here will be looking at these 2 types of interconnection mechanisms. Now, first let us look at press fit interconnection, so the press fit interconnection basically utilizes elastic forces of coupling parts to seal fluidic access, okay and since it is based on elastic force, the sealing force is quite low.

And for which it could be only applied for low pressure okay, so as you can see here, we have you know; 2 features, which have interlocking finger joints, so these are interlocking fingers joints, as you see here and basically we have an infinite, you know fluidics supply here and fluid reservoir there and we want to establish fluidic connection between these parts okay.

So, we; you know have these interlocking finger joints and then we can have a PDMS film here that will work as a whirring okay. Now, when these 2 components are pressed against each other, then there is an interlocking effect that takes place okay based on press fitting and because of the press fit, there is going to be ceiling here okay, around the perimeter of this PDMS ring, where the fluidic ceiling will be achieved, okay.

So, that is how we achieved a fluidic connection between the 2 parts and fluidic ceiling okay. So, but this sort of press fit interconnection can only withstand low pressures okay, because it is purely based on elastic force. Now, here is another example, where you know you have; let us say a silicon channel and we could fabricate the edge of a silicon device as a silicon tube, so that we can do for example, we can have you know; you can use anisotropic etching on 2 such substrates to create; you know rectangular sorry; the trapezoidal grooves okay.

As you can see here on both the wafers, we can create trapezoidal grooves and when we bond these 2 wafers together, then we would get; so let us say we have this V groove here and this V group here and the second wafer when you bond them together we would create a tubing structure okay and then for fluidic connection, a polymeric tubing can be fitted on to this silicon tubing using press fit.

So, the internal diameter of this polymer tube has to be little bit less than the external diameter of this silicon tubing, so elastically the external polymeric tubing can expand a little bit and then do a press fit on the silicon tubing. Here, you can see; we have vertical tubing interconnects, so these 2 interconnects can be fabricated using dry reactive ion etching for example, and these capillaries can be pressed fitted into the holes here, okay.

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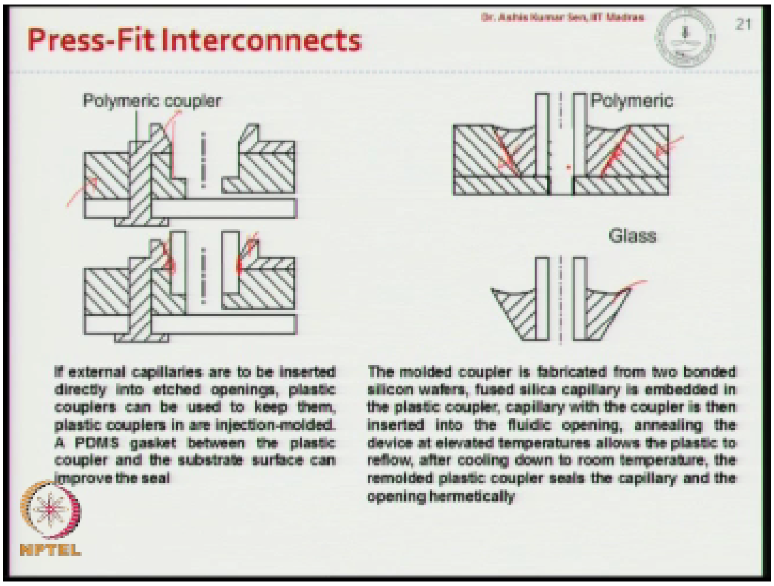

And typically, the diameter of these holes little bit smaller than the outer diameter of the capillary, so they can be pushed and fitted onto the hole. Here, we use you know; polymeric coupler for example, this is a polymeric coupler which is attached to the silicon substrate, so this is silicon and this is a polymeric coupler and so the capillary can be put it in this way. So, that this polymeric coupler acts as (()) (50:34) gripping.

This tubing in a better way, so that the fluidic sealing is established around the perimeter okay. Now, in this case we have this capillary with a molded coupler; this is a molded coupler and let us say this molded coupler is put inside this; you know silicon substrate and then if you do an annealing, this molded polymeric coupler will flow and gets bonded to the silicon substrate okay.

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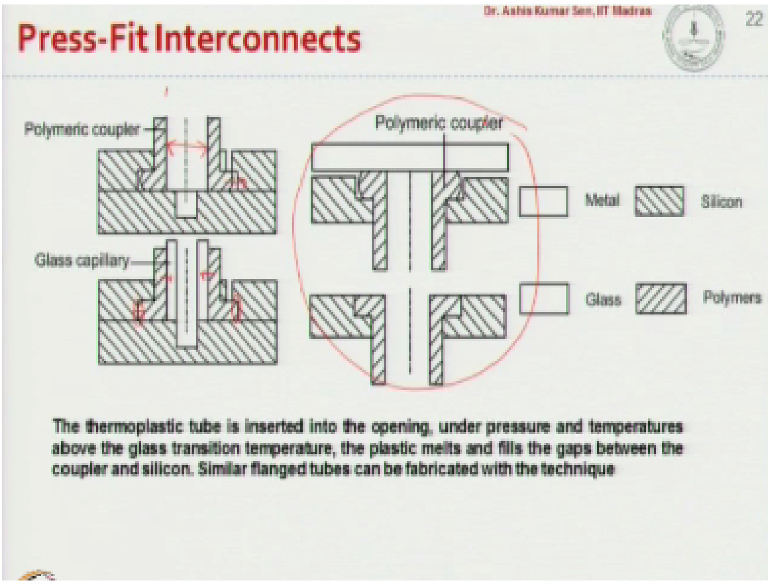

So, it will expand and get a very good grip around these areas, so we can achieve fluidic sale. So, here it again uses a press fit configuration using polymeric coupler and so you know here, we use a polymeric coupler and if you use pressure, so if you use pressure the polymeric coupler will expand and fill this gap here okay. So, this gap is completely filled here and now we choose a capillary whose outer diameter is more than the inner diameter of the polymeric coupler.

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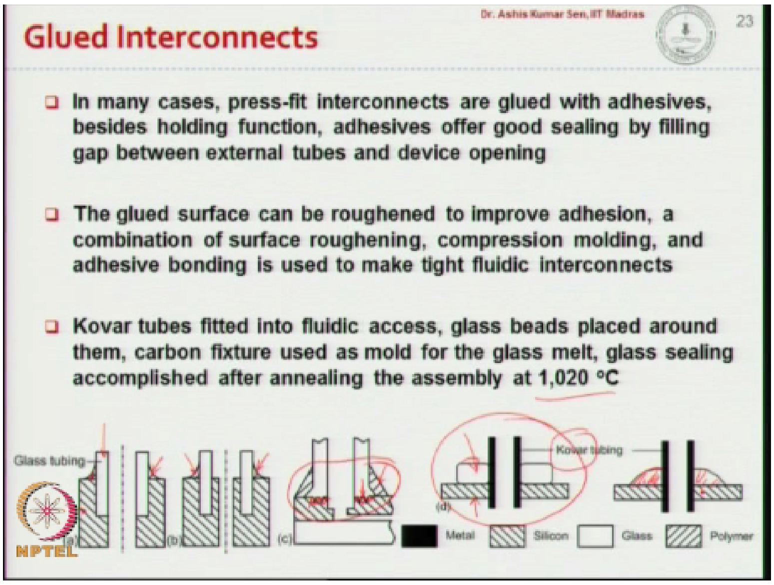

So and; because the polymeric coupler is you know, soft it can expand deform easily, we can get a better grip and fluidic sealing around the interface, so that is the reason we use polymeric coupler. So, this is so; you know this is a close of view of what happens typically in a polymeric coupler or sealing. Now, in some cases, you know the press fit interconnections or glued using adhesives.

So, you know the adhesives would offer better sealing as compared to just you know press fit interconnection and so here, as you can see, we have; this is the silicon substrate and we put the glass tubing around the glass tubing, we put some adhesive okay. This is where we put adhesive and this adhesive can be cured, so that it they form a very good fluidic seal around the perimeter of the glass and silicon interface.

So, in some cases the; you know the silicon in these areas where it meets the glass tube are roughened and roughening of the surface enhances the bonding of the glue with the silicon and glass surface, so it gives enhanced sealing capability. Here is an example, where a covert tube, this is a metal tube, which is put into the silicon substrate for fluidic interconnection and around it, we have this you know glass beads.

Now, we heat this you know; interconnection mechanism inside a woven to about to 1020 degree centigrade, 1000 degree centigrade. If you do that, this glass will melt and it will form a permanent sealing around the covert silicon interface okay. So, there are different mechanisms available, you can use simple glue to connect the tube to micro fluidic devices, you can roughen the surface of silicon to enhance; you know better sealing.

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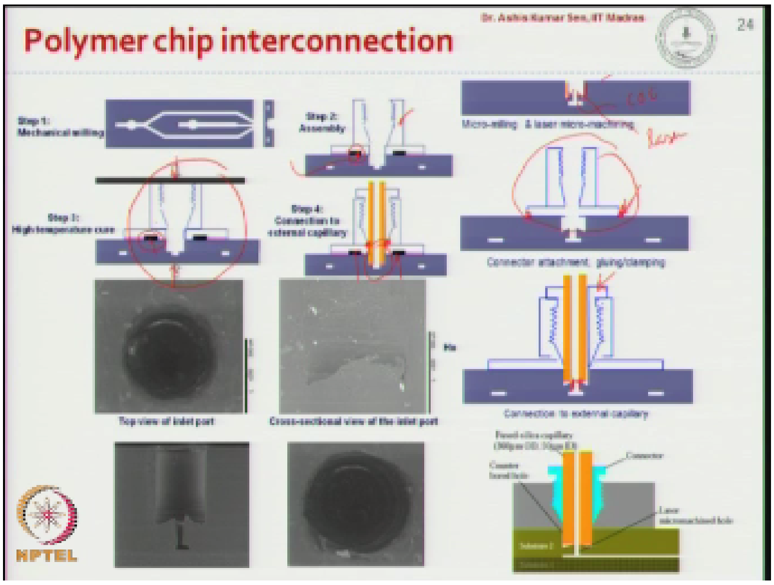

You can use things like glass beads and cure it at elevated temperature to create permanent and strong joints, so different options are available. So, here we talk about an interconnection system, so typically in; let us say in thermoplastic like COC microfluidic devices for fluidic interconnection, we normally go for nano port base interconnection, so in nano port based interconnection, we have this mechanism where we you know have a glue, which is solid.

And that is put around the hole, where we want to put the interconnection and after you put this glue, which is in solid form in a membrane form, we put in the connector and press it against the chip. Then, in presence of heat; in presence of pressure, you put this assembly inside a oven and do a curing okay, so during the curing process, the glue will melt and form a very good bonding between the connector and the thermoplastic surface like COC surface okay.

And then we can put in the capillary and we can tighten the capillary, so there is 1 fluidic sealing that is happening around here and when we tighten this capillary, we get another fluidic sealing around here. So, this fluidic connection is completely sealed. Now, here we discuss another mechanism, where let us say this is a COC wafer and this is the microfluidic channel inside, now we do an interconnection mechanism, which is you know have 2 parts.

One is this part is done by micro milling, so it is basically a hole and then, so this hole has a rustic conical bottom, this as the inverse taper at the bottom, which can be fabricated using special milling tool and then the connection between the mill tool and the channel can be done using laser micromachining. So, this vertical small portion can be done using laser.

Now, if you have an assembly like this, now we just manufacture a; you know connector which does not have to be commercially but because you do not need this glue here and this can be commercially built and we can glue it all around this interface that will be adequate you know, then when you put this; this is for structural holding not for sealing. Now, when we put in this capillary and we tighten this knot.

What happens is the bottom surface of the capillary get pressed against the inner bore of the inner hole okay, so the capillary gets pressed around here and because of which the fluidic sealing is achieved around here, okay. So, there is no requirement for adhesive sealing around here. So, the fluidic sealing is achieved around here using this new mechanism, okay. So, you know we talked about different mechanisms that can be used to establish a fluidic interconnection between external capillaries and microfluidic devices, so with that let us stop here.