Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology- Part- 2

Module – 06
Soft Lithography

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So welcome to this manufacturing process technology part 2 module 6.

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We were talking about the various soft lithography approaches, soft lithography processes and in context of that we had already looked into one of the processes which is replication and molding the other process which is of substantial importance and particularly when it comes to developing of platforms.

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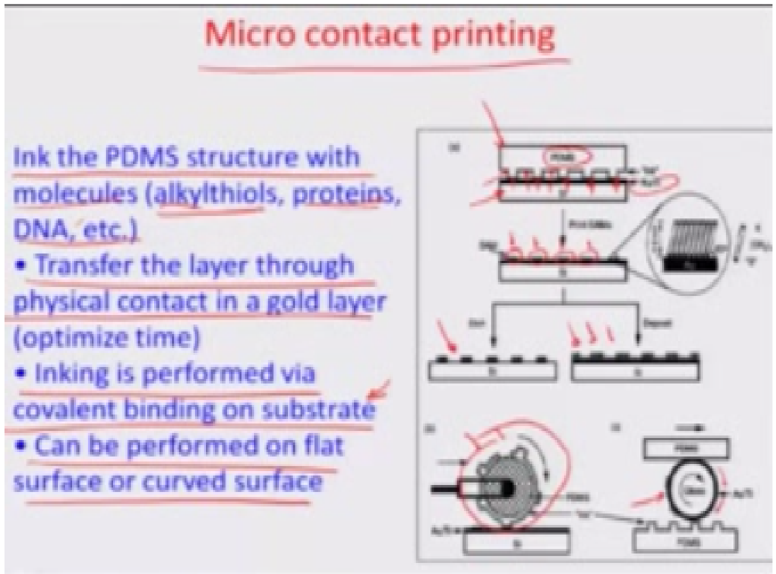

Related to biological detection is micro contact printing this is based on you know a method again which is like stamping at a very small scale. So in a in a stamping exercise what we normally do is that there is a stamp and there is ink and we are actually adhering the ink from a pad on to the stamp surface and then when the stamp comes and sits from the paper the portions which are projected on the surface of the stamp with the ink imprinted is transferring the ink again by virtue of the capillary action you know which is done by the pores of the paper and the ink goes into the paper in those regions which are elevated and you can see you know the print of what elevations are there on the surface of a stamp.

So in a similar manner we do this micro contact printing, so in this particular case for example you see there is a PDMS structure which has been created by earlier step of replication and molding at a very fine structure level and we inked the PDMS structure with molecules and molecules could be alkylthiois, it could be proteins DNA so on so forth and then you basically lay out the PDMS structure on the top of a thin film of gold with titanium which is sitting on a silicon wafer.

And if with lithography we could change the dimensions of this AU TI layer they could be very small structures or small posts of gold over which the PDMS structure would be incorporated okay. So these kind of you know the purpose here is to transfer the layer through physical contact so whatever was on the PDMS surface in terms of these adsorb molecules now is going to get transferred on the contact regions these are the contact regions okay, so they are going to get transferred on the contact regions and the molecules are transferred by a physisorption process over this gold surface.

So supposing we had a thiyolated molecule like I was already talking about alkythiois or I was talking about let us say proteins which are thiyolated or DNA which is thiyolated there is a tendency of the thiyolated group two phases or bond the top of these gold layers, okay. So in the portions where contact is being established between the PDMS stamp and the gold layer there is a transfer of these molecules by virtual physisorption it is replicating the capillary action process of the paper in the case of real stamp.

And you know you have to give it sufficient time of contact so that there action chemistry between the gold and the let us say the absorption chemistry between the gold and the molecules are executed successfully, so inking is performed via covalent binding on to the substrate and it can be performed on a flat surface or a curved surface you can see these are deposits done on a flat surface they are multi layer deposits or single layer deposits or they are even done on curved surfaces for high-throughput processes.

For example, this is again a stamp which is done on a circular PDMS membrane and it is rotated and then you know obviously either the stamp can be rotated or the substrate can be rotated in this case for example the glass is being patterned in it is circular curvature with these molecules by just rotating simply the glass over the PDMS film and the glass is used for transferring the PDMS the ink molecules from the PDMS film in the spacing done by the PDR in the spacing designed in the PDMS to the another PDMS membrane okay. So you can do multiple transfer processes on curved surfaces or flat surfaces using this micro contact printing methods.

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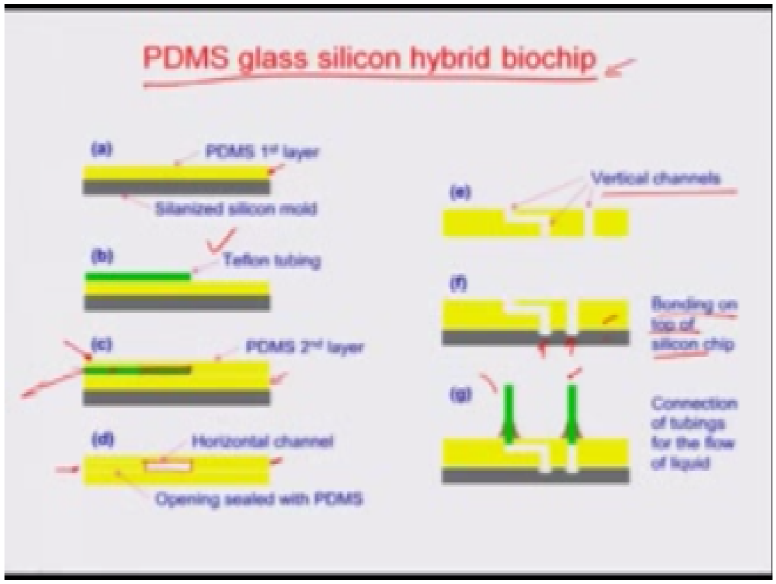

So the other process of you knows soft lithography which is of importance is you know how to use different other structures for doing replication. For example in this case as you can see again through the replication process but using just a Teflon tubing, as you can see right here you can actually develop a small chamber you know so the Teflon tubing is placed on the top of a pre cured PDMS first layer and then there is another layer of PDMS deposited on the top of it, and then the idea is that. Once this has been done the Teflon tube is removed Teflon is highly hydrophobic so there is no problem in removing of this Teflon tubing with the PDMS keeping intact.

And from the other side you are injecting PDMS, so that there is a small chamber which is created here in corresponding to the cavity in this region of the Teflon tube. The different tube the other portion is now completely injected with PDMS. So that is how you create a channel and you know you can also create in a similar manner vertical channels like, you are seeing here and the vertical channels can actually be placed on the top of a silicon chip which is already sort of you know pre etched and then you can have again the connecting tubing on both sides which can supply fluid at these particular places.

So these are many ways of doing an application by using different strategies together where you can either make a hybrid device including two or more different materials and a single you know device which is there on let us say complete PDMS and so on so forth using just the replication and without the use of any particular printed mold or patterned mold okay.

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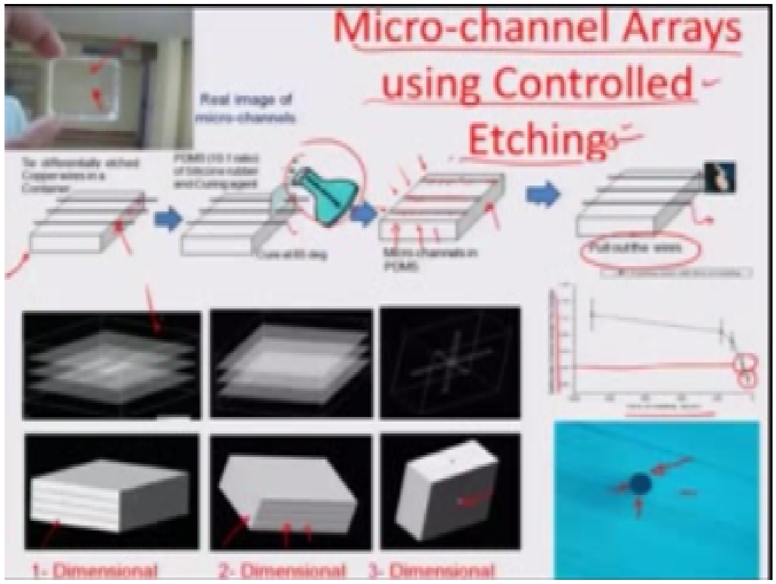

This is another way that you know you can control the with the application you can develop micro channel rays using sort of a you can say you know high aspect ratio why are like structural wire, so in this case what we essentially do is take a copper wire and this copper wire is subjected to controlled etching, so that there is a uniform dimension of this copper wire which comes out, in terms of some let us say 80 microns or so. And there is a box which again is laser micro machine with different holes where these wires are put from end to end.

So there is actually holes done on both walls of the box where the wires are inserted and the wires are stretched at a certain tension and then PDMS poured and 10:01 and later on the PDMS actually goes around the wires you know, so there is the wires are in these particular regions and the PDMS has already gone around the wire and it gets solid if I okay. So once this is solidified what we essentially do is to dip this PDMS in a solvent which can you know solvent like toluene for example which kind of goes into the void of the bonded structure or the cross bonded structure of PDMS and it expands the structure, so that it releases its grip on the wires and then the wires are slowly pulled out one by one.

To result in micro channels a very fine you know nature of circular cross section, as well as you can see the cross section for example this is a circular completely circular cross section of the channel which has been formulated okay and there is an optimization in this particular work which has been done by you know studying off it is a time of swelling as opposed to the swelling index okay. Which is actually the channel diameter to the wire diameter ratio and it has been found out that you know there is an optimum time of swelling based on which you could have almost you know close to unity value, of the channel diameter 2d to the wire diameter.

And in some cases even it goes beyond that that means if the channel was let us say 80microns you could obtain even lower sizes because you know now the swelling and the shrinkage which is done on the material would allow it to actually go to a lower dimension because there is avoid collapse happening within the PDMS by means of evaporation of the solvent. So this way is fantastic way of developing micro channel arrays within blocks of PDMS and it is important because you know there are there are embedded fluidic applications where it is important to study the fluid flow within the bulk volume of this polymer and there you can easily apply such a replication technology to lay out an array of or a group of channels or you know even features etc.

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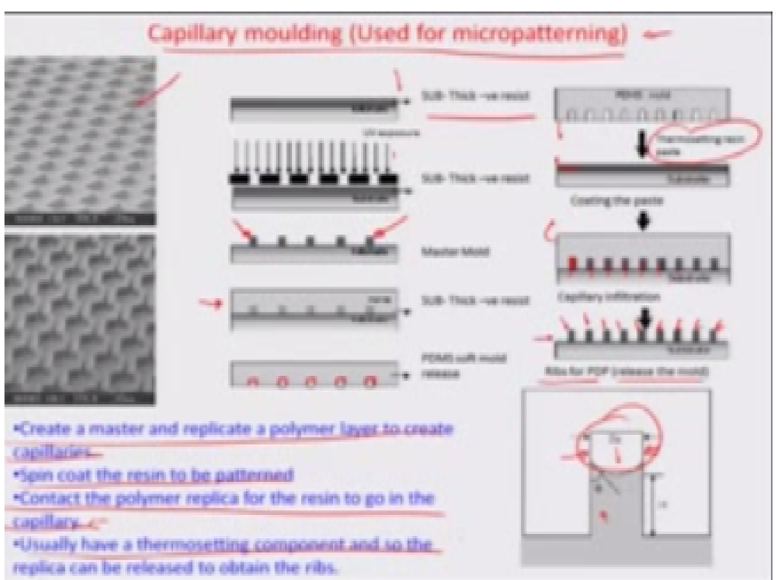

So the other process which is of use and which involves soft lithography again is called capillary molding, using micro patterning so you can see the steps for example you have a SUA thick negative photo resist you have exposed and created a feature the surface which is micro structured through master mold and then you basically pour the PDMS and try to create negative impression of the mold in terms of these small cavities and you know this cavity can again be placed. With respect to again a thermo setting resin paste and the resin actually flows into such cavities okay because of the pressure.

So there is always a inflow of these resin because of the pressure between this surface and this surface into these small cavities and then the idea is you thermally set this resin by thermal cycle by applying a thermal cycle and then remove the PDMS, so if you remove the PDMS the structures that were initially imprinted onto the PDMS are now completely realized using this thermo setting resin okay over the substrate, but there are various complex complexities here imposed by the different surface energies. For example if this PDMS and the thermosetting resin that we are using has certain difference in the surface energy.

There is going to be a meniscus formulation as seen here and there is also going to be a contact angle of the way that you know the capillary really would proceed into the into the cavity okay. Capillary formulated by the thermo setting resin would proceed into the PDMS cavity, so you can develop these small rip like structures using this capillary micro molding process and it is a very useful technique to develop again micro patterned surfaces. So essentially you are creating a master replicating a polymer layer to create capillaries spin coating the result to be patterned and contact the polymer replica for there in to go into the capillaries.

And usually the resin has a thermo setting component, so replica can be released to obtain the ribs placed on the top of the substrate okay. So that's how micro molding capillary assisted micro molding is done.

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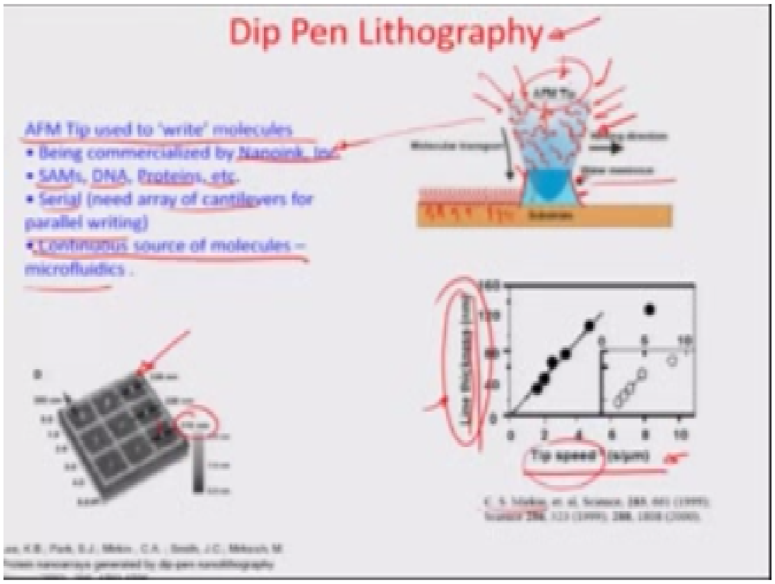

This is again a very important process from the viewpoint of placing molecules also in the in the sort of the nanotechnology domain and in fact this process was developed by shadmerk in you know up at Northwestern and he for the first time observed that you know you this kind of reputation of the fountain pen principle on a very small scale, in a fountain pen for example there is a liquid ink which is stored inside the in the in the tube attached to the name of the pen or the dispenser of the pen and there is a slow release of the zinc from the tip of the de pen and this release through gravity action is again capillary.

You know by capillary forces is sucked into the paper and wherever there is a raftering of the pen on the paper there is a mark of the ink made by virtue of all these different processes together now this particular process, uses a similar kind of a technique although the scale is much more smaller it is done using an AFM tip it is a STM probe which is actually transferring these molecules and the way that the molecules are sort of dispensed onto the substrate is by virtue of releasing the molecule on to the tip of an AFM atomic force micro scope, which is again atomically very sharp and by control of the temperature and the humidity condition in a way.

So there is a water meniscus which develops you know along this particular tip so the water meniscus helps in transporting of this molecule and the idea is that the there should be some kind of an adsorption mechanism on the substrate which is concerned, so whenever the molecule is dispensed on the substrate it kind of attaches to the substrate and the dispensing is normally done through this meniscus and so as the AFM tip moves on the surface the meniscus kind of follows the tip and is able to dispense the molecules in the way that it is moved over the substrate. So in fact very good features of proteins, for example a protein nano array here this is an AFM scan of a protein narrow array has been formulated by this technique.

Where you can see that the minimum size the feature size which is resolvable here is about 100 and 10 nanometers, so this is how small feature of protein can be assembled onto a substrate surface okay, so typically this is a when it was formulated for the first time it was a serial process but later on there were many other versions which were developed of this depended on goofy process where it made into a parallel process with many tips being fed with these molecules and you know a rapid array of such tips marking or structuring different molecules on a surface. So if we look at some of the characteristic parameters for this process there is a plot between the line thicknesses that is obtained of these molecules versus the inverse of the tip speed.

So intuitively also as one would realize that if the tip speed is higher the inverse of tip speed is going to be lower, and there the line thickness would appreciate or sort of decrease okay. So if there is more dwell time on the other hand or the tip speed is high let us say on the lower side or the inverse of stiff speed on the higher side the line thickness would increase. So with the inverse of tip speed there is an inverse relationship of the line thicknesses can be noted here with the inverse of tip speed there is a direct relationship of the line thickness and sorry as can be noted here in this module.

So that is how Dip pen Lithography process is carried out, so if tip being used to write the molecules and by the by this depended was commercialized by a company called nano Inc and it can be used for printing self-assembled mono layers DNA proteins etc. On different surfaces and you know typically when the process targeted force real but now there is an array of cantilevers which can do parallel writing for, you know for this particular process and there has to be of course a continuous source of molecules at the tip which is actually done by using micro fluidic delivery of small solution volumes across these tips. So that is how dependent lithography is carried out.

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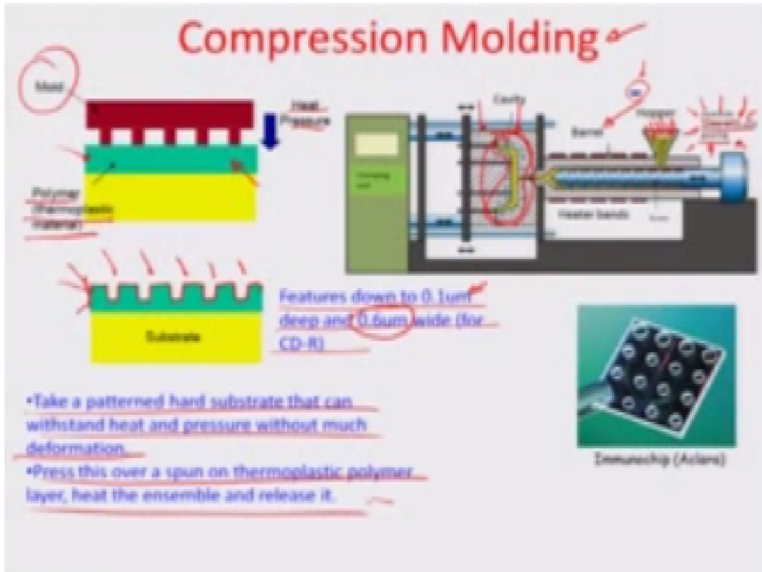

So there is another very important process related to the polymers which is known as compression molding and in this particular process it is really same as any other compression molding process which would exist that there is a mold which is able to withstand high temperatures and pressure conditions there is a polymer you know which is like a thermoplastic material and again you know there is a application of heat and pressure to the substrate and it kind of dicks and buries it to the green layer here on the thermoplastic layer.

And the thermoplastic layer actually formulates a negative of the patterned surface which is you know plunged in to this polymer surface and later on because of the thermal cycling this heat cures when you can remove the substrate and a negative pattern is kind of imprinted on to the top of this green foam you know which is like a polymer. So the process includes take a patterned hard substrate able to withstand high in temperature and pressure without much deformation press this over a span on thermoplastic polymer heat the insane bill and release it and you are able to get feature in the structure a structure or features on the surface of this green layer.

The other very interesting process which is actually very often used for even printing compact discs is these injection molding processes, so you have a die cavity. so that die split up into two halves there is a cavity in between and then there is a hopper arrangement which throws in the basic raw material which is the polymer granules. So in this particular case the polymer now is heated and the polymer the melt is actually injected into this cavity the die cavity and features down to the level of about point 1 microns and deep and about point 6 microns wide can be easily made using this technique.

Typically for a compact disc this is a very widely applicable process which is also borrowed from the conventional injection molding of polymers.

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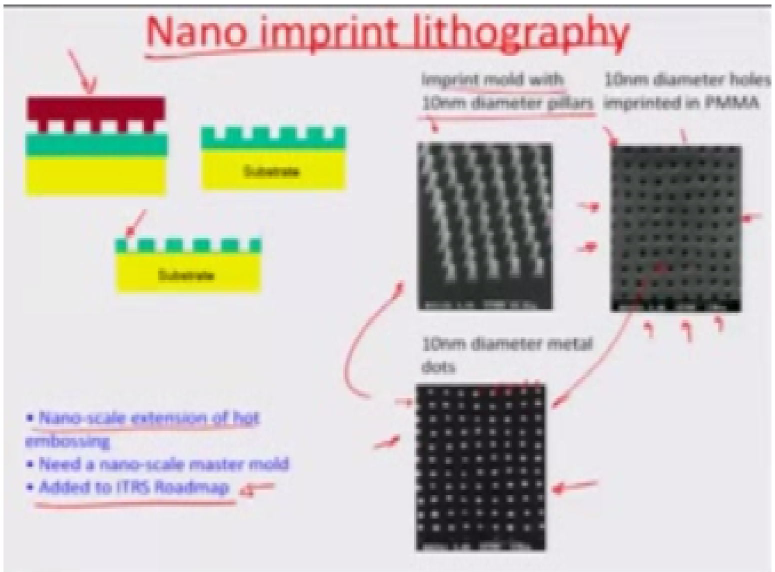

The other important process related to polymer micro structuring or nano structuring is this very interesting process of nano imprint lithography, so this is based again on compression molding processes and in fact let me just add to all this information that there is a process which is so important that it has been included as an end of the road.

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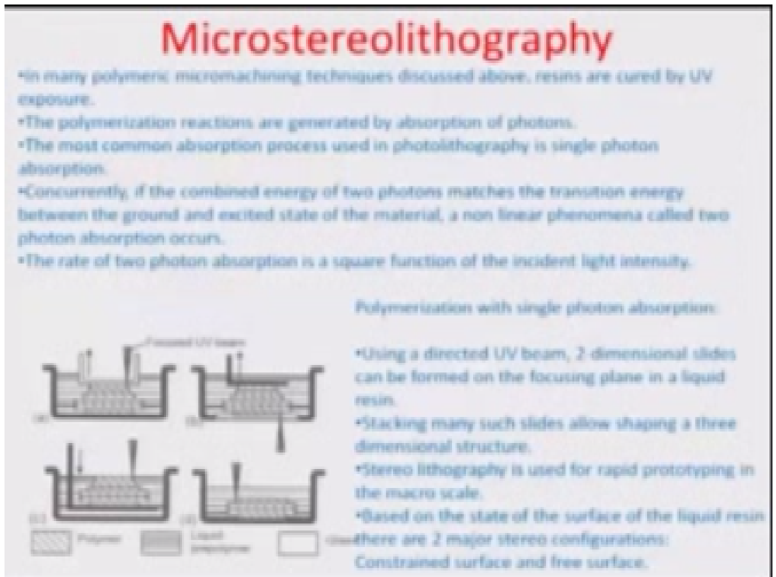

Process for the international semiconductor technology roadmap which has been created as probably you know a process for the end of the road devices you know and that is utility or that is the basic sense of this particular process. So what happens here is that again in the same manner as we had done a compression molding we are creating let us say pillars okay, and the pillars are created in PA by using a shadow mask.

So there is a shadow mask made in pm ma which is again fabricated through e-beam lithography and you can see the whole size that has been obtained here is roughly about close to about 20 nanometers and the difference between two holes of the resolution at which these holes have been printed are close to almost about 40nanometers.

And now this is used as a shadow mask so it means that whenever you are depositing metal electrodes metal dots these dots are made by having the mask which is having hollow cavity is all round and so there is a sputtering of the metal which goes over this particular you know perforated structure and this metal gets deposited on to the top of a silicon wafer.

You can see here for example the metal dots are deposited because of the shadow mask you know so the metal has been overlaid with the shadow mask and the sputtering experiment has been done on the top of this so the metal vapors have been captured on the top of the shadow mask. So you have these small dots okay and then once these small dots are made you can use them as again a mold for which can be able to withstand high pressure high temperature.

And could be able to structure a polymer layer a thermosetting polymers layer, so you have exactly the negative imprint of the you know of this particular metal dots to create this 10 nanometer diameter pillars okay. So you are having again a very good resolution as defined by the e-beam lithography system and you can really have diameters a very small diameters 10 nanometers or 20 nano meter diameter pillars separated by a distance above out close to 40 nanometers.

So this is the kind of resolution at which you are working in nano imprint lithography. So it is essentially a nano scale extension of the hot embossing or the compression molding process that we had shown before. So these are sort of you know range of processes which are applied to handle polymers or make polymeric micro or nano structures so I would like to now sort of go into another aspect about polymer fabrication which is you know about development of three-dimensional structures of in a planned manner and that to very complex structures. So there is a process called micro stereo lithography.

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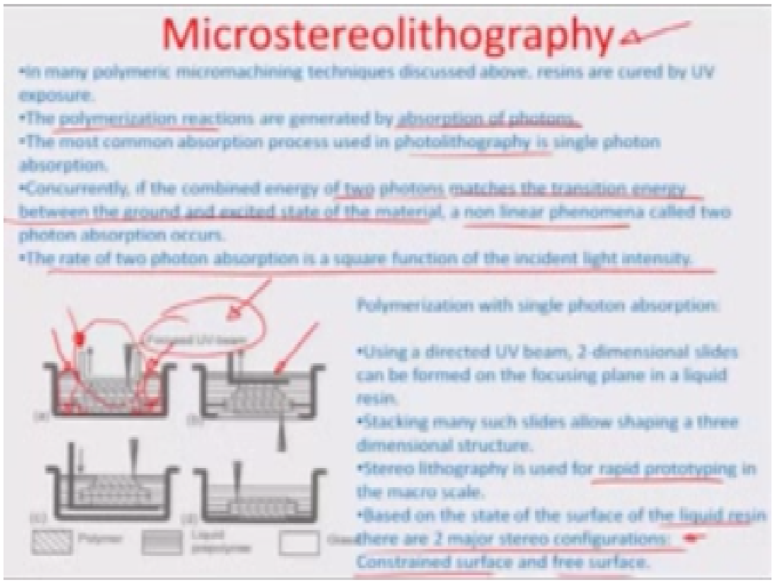

Which is being done in order to address this issue of memes being or photolithography being limited to only two and a half dimensions, so there is a layer by layer lithography which which exists based on changed focus of the of the incident beam you know in this particular case for example there is there is a polymer which is actually resist and whenever it gets imprinted with light it does so to change the property and gets cross bonded on exposure to a certain wavelength of light.

So we have a focused UV okay, so there is maybe a lacing source from which the civilizing is being done on a focused manner and the focus the depth of focus is continuously being changed so what we typically do is that you know we try to write the resist layer by layer through a process where there is a there is some kind of a glass slide and the slide is moved with extreme precision with maybe about 100 microns length of Travers.

So when the slide is at the bottom there is no resist typically which is shown here by this hash to region, so there is no liquid resist and the slide moves slightly by a few micros few hundreds of microns and allows the resist to flow in okay. So as the resist flows in the laser beam which is supposed to raster at a predefined path is able to write on this particular resist to make it harder as in as a next step the slide moves again by another small distance from the existing position.

So that some more resist can come in so each layer in this way is made by moving the slide up by some hundred microns and let the photo resist flow end where you can actually sort of right on the photo resist with the laser beam and the idea is that any object that you want to pattern now using the power of CAD can be just as we do in rapid prototyping or just as we do in 3d printing your sectioning an object into small, small sort of hundred microns or you know even hundred fifty microns slices.

And the slices are being patterned selectively by means of a glass slide going up every time by about 100 microns or so and taking care of fresh resist which flows back and that is again used to pattern so this way you can create complex features and structures. So you know the polymerization reactions which happen are typically related to the absorption of photons by the polymer material and for example in the photo lithography process it is only a single photon which is absorbed but concurrently you if you can do that with two photons.

So that it matches the transition energy between the ground and excited state of the material and you know you can actually use a two-photon absorption phenomena which is actually a nonlinear phenomena to do this kind of lithography. So obviously the rate of two-photon absorption is a square function of the incident light intensity and you can have this stereo lithography as a scaled-down version of the normal rapid prototyping or 3d printing process that exists in the macro scale okay.

And based on the state of the surface of the liquid resin there are two different configurations of stereo lithography one is the constraint surface another is a free surface configuration of the stereo lithography system. So the basic steps here are the polymer layer okay and the liquid pre polymer and the first hearing of the polymer and also a translation of a sort of slide which would give you a layer by layer orientation of the whole geometry in question.

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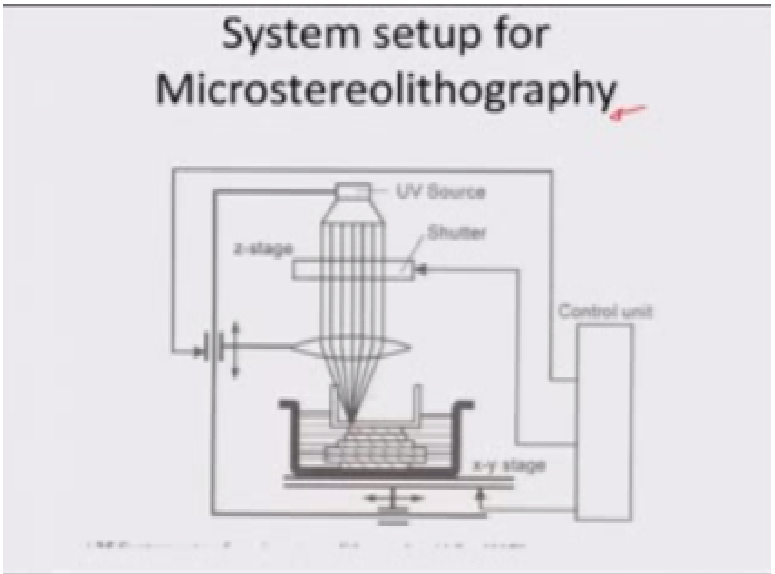

So typically when the system was initially formulated the micro stereo lithography again was a serial process where there would be a single beam of laser which would raster and do these slices but now there are many other you know ways of doing it for example you can have a parallel set of optical fibers.

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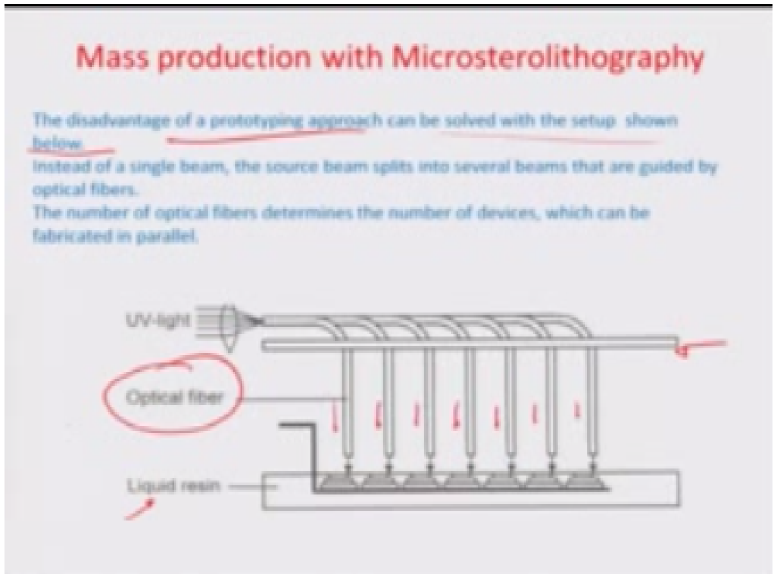

Which can do a very high through put stereo lithography you can see here that with this optical fiber bundle you have each fiber doing one step of lithography and then the question is how to sort of manipulate this platform here micro manipulate this platform here. So that it corresponds to at least identical features many at a time replicated on a certain surface by using the liquid resin and the Selective stereo lithography option.

So the disadvantage of a prototyping approach of rapid you know of less true put can really be a coupled with this optical fiber technology and this can make parallel devices of identical types fabricated within the within the plates, so that is how you can think of micro stereo lithography and three dimensional feature. So you have seen two and a half D features using for the basic photo lithography you have seen three dimensional features using micro stereo lithography.

The next in line would be a little more on the subtractive etching technique which is actually a directional subtractive etching technique we also know this as anisotropic etching but I will talk that in the next module in the interest of time, so I will close this module as of now thank you so much.

<u>Acknowledgement</u>

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