MEMS & Microsystems
Prof. Santiram Kal
Department of Electronics & Electrical Communication Engineering
Indian Institute of Technology, Kharagpur
Lecture No. # 15
Microstereolithography

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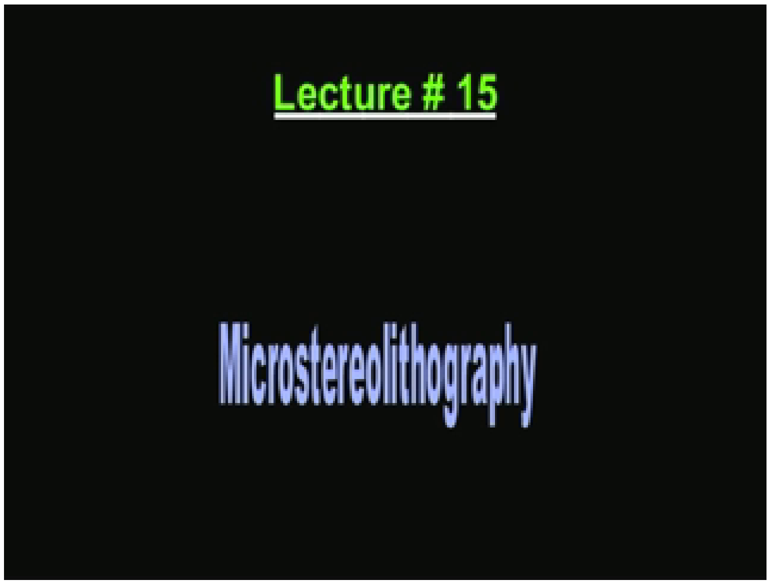

We will discuss today on microstereolithography which is not been covered in either your bulk or surface micromachining class or you have not come across this particular topic in your VLSI technology course. So this is a lithography means basic principle of lithography is there. That means you are getting some structure from mask level on to the wafer level. But here we will not use any mask. This kind of structure fabrication is without using any mask. So that is why it is all together a newandbasically innovative technique of fabrication of various kinds of microstructure which is being used nowadays not only in silicon MEMSbut also in polymer or ceramic or composite material MEMSand in my last lecture on materials for MEMS I told you that MEMS are getting fabricated. Nowadays not only out of silicon but also from other materialslike polymer materials, like ceramic materials, like metals and like composite materials and so on. So if it is different from silicon, so that means that, particular technology may not be compatible with the normal VLSI process.

We can adopt some other technologyand there main emphasize is making of fabrication of microstructure and later on this microstructuremay bepasted or may be transported on to silicon wafer. But the microstructures are fabricated separately using a certain techniqueand that particular technique is known as microstereo lithography. The name stereo is there, as the name stereo you understand that there it will be three dimensional structures. So normally the x, y and z in normal lithography or normal bulk and surface micromachining, there is a limitation on the thickness of the structure. Means along the z directionthethickness of the microstructure or materials, there is a limitation. But here in this particular technique which is known as microstereo lithography, there that limitation is not there. So you can have larger thickness material without any mask, without any micromachining by etching. Either etching or say etching may be liquid or liquid etching or may be plasma etching or dry etching. Those kinds of things we are not using here. So then what is that technique? How do you make the microstructure using this microstereo lithography technique? Thatwe will discussnow.

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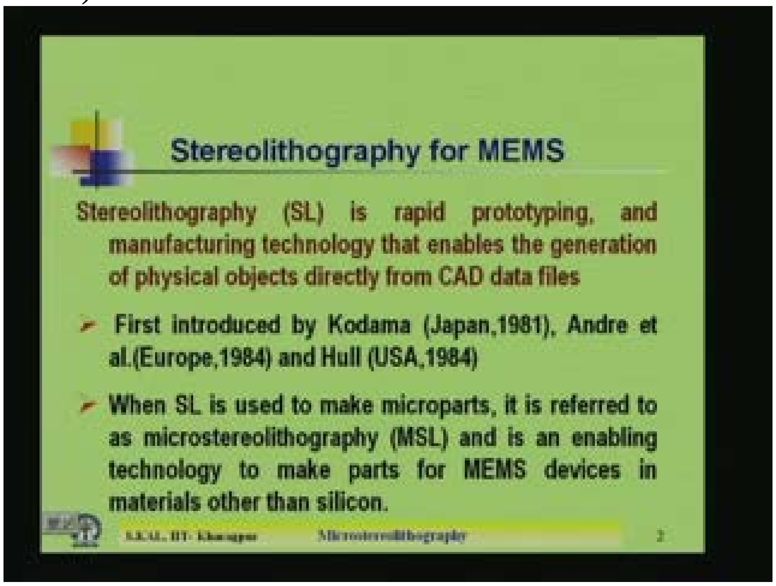

So now this stereo lithography is defined as is a rapid prototyping and manufacturing technology that enables the generation of physical objects directly from CAD data file. So here one important point is a CAD data file and this CAD data file is different from the data file which is being used for making mask in case of the surface bulk micromachining or in case of VLSI process technology. Now here the data files since you are making 3D structure, so data files are some of the data files are making. You are making on two dimensional which is x and y, in this in a planewe can make that x-y plane, some rectangle, some square,various kinds of a structures we can make it. And not only that, here another axis is important which is the z-direction. What we do normally? This any 3D structure is made various kinds of slice horizontally you slice it and after making slice they are almost 2D kind of structure.

So after making the slice, the third direction is a depth direction we make a different file. So the slice structure in 2D is made in a steel formatand now is a special program, these 2D slices are stacked one after another. That is a known as a build file. So it creates another file which is known as a build file and build file will change the manipulator, z manipulator, z axis. So accordingly when the particular build file, where for particular number, you will select that particular file will select a planeand in that plane, then in a steel format. What are the data stored that will beeffective now or the optical source will be scanned on the x-yplane. So when that exposure is over, then it will stop again from the build file, it will take the next build file, means z direction manipulator will move. So it will go to the next layer, so again exposure will be there.

So in this way, that means to complete 3D structure is available is possible to make without any masking and developing and etching or some kind of things. So I will discuss little bit in detail in future slides. Now this microstereolithography technique was not there in before mid of 80s. So after mid 80s and lot of work was there in 90s. To standardize this particular process and this particular technique is mostly useful in non-silicon MEMS. Major application is non-silicon MEMS, that is polymer, ceramic and metal. So there we donot have to bother about the etching solution of the polymer or saythe ceramic materialand those materials etching solution is very difficult to get. So that is why these techniques are widely used in case of non-silicon MEMS mainly in polymer and ceramic MEMS. Now this was first introduced by Japanese group in 1981 by Kodama and in Europe in 1984 by Andre and his group and in USA 1984 by Hull.

So you have seen the three area one group in Japan they have started work in 1981 which is by laid by Kodama. Another is in Europe 1984 and third one in USA 1984. They all together introduced, they started work and later on in 1990s the total technologies perfected. Now the stereo lithography is used to make micro parts. It is referred to microstereo lithography. So basically microstereo lithography is another one step ahead of stereo lithography. Micro word is added with thisstereo lithography, when the feature size is still small and small. What feature size? Resolution in x-y movement the minimum movement of the featureas well as in the z direction the movement if you can makevery small amount, then it is possible tomake very small in a micro levels the parts layer by layer you can build. So that you can have very small sized micro parts or micro structures. That is a micro stereo lithography. So first we will understand, we will discuss on stereo then we will go into microstereo.

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So now this microstereo lithography permits fabrication of true 3D devices on the micron to millimeter scale including curvilinear and re-entrant microstructuresthat are difficult to make using conventional micromachiningcurvilinear. This too important point curvilinear and re-entrant. So curvilinear is possible hereand re-entrant is here, that is also. Re-entrant means, somewhere you want to makesome groovesomewhere. Then again you are coming backyou see in the right hand side. You can see some of the picture. So this is made out of polymer or ceramic material. You see is a motor blades kind of thing here some of the powersome boundsare there like that. So these kind of structures, is can be easily made using this,the best,the stereo lithography which is not possible by conventional microconventional lithographyand sometimes it has got some similarity with some with a technique which already we have discussed. That is the LIGA and sometimes this particular stereo lithography or microstereo lithography is called that Poor man's LIGA process.

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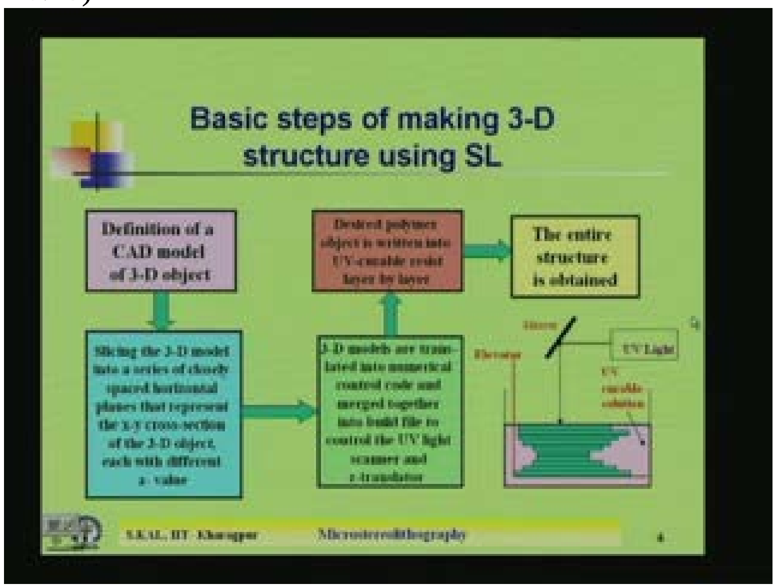

So now what are the basic steps of making 3D structure using stereo lithography? Those are shown in the block schematic diagram. First is the definition of a CAD model of 3D object. So this CAD model is different from conventional. The CAD tools used for the bulk or surface micromachining or mask makingas I mentioned. So one will be the 2Dsurface, x-y surface is a steel format dataand another is thesteel format, the slices are stacked to build the 3D structure. So that definition is very important is special kind of softwares are used to make the data for thisstereo lithography. After that next step is slicing the 3D model into a series of closely spaced horizontal planes that represent the xy cross section of the 3D objecteach with different z values. So x-y cross section of the 3D object, each plane will have different z values. Then 3D models are translated into numerical control codeand merged together into build file to control the UV light scanner and z translator.

That means this data basically the control the data is controlling two things. One is the x-y scan of the optical source; another is the z translator which is changing along z direction. After that the desired polymer object is written into UV curable resist layer by layer. That means it is a direct right kind of thing. So in your VLSI lithography one topic is there, direct write technology. So directly from the mask data it may write on to the wafer without making mask. Direct write technique, so that is used here. So from the mask data directly write on to the polymer photosensitive polymer. So accordingly exposure will be there and polymerization will take place. Now this,the resist which is used here, that is UV curable ultraviolet curable resist. That is layer by layer you can cure it and then the entire structure is obtained after curing. Now what are the things here? In the bottom in this diagram it is little bit elaborated.

You see here the pink color thing is UV curable solution here.Now there is an elevator. What is being done? So first a layer is a layer of thepolymer is spread over a plane. Now this layer, uniform layer is exposed with ultraviolet light. After depending on the data depending on the data then what is happening? This ray will incidenton the data. That means here some shutter will be thereas the normal mask making machine. So there the shutterspeed is also high and the shutter on-off mode can be controlled very fast. So accordingly it will be exposed based on the data. So polymerization will take place that particular each layer one layer is overnext what the elevator elevator will move means elevator will go down then another layer will be deposited there. Automatic micro pumping of the resin layer will be there. So on that layer again the optics beam is incidentthen it is exposed, may be in the bottom you can see exposed from here to hereand in the next layer it is exposed from this point to this point.

Now you can see that, so it is a first layer, it is exposed from this point to this point. Next it is exposed from this point to point. So another third layer when this is over, so the elevator again goes down. So then another layer is spread over the x-y plane. Then it can expose from this point to this point. So in this way each layer the UV light is exposed depending on the data or depending on the requirement of the structure. Soin this way layer by layer when complete thing is made then whole thing is cured. That curing technique is just like the lithography technique.You know it is a prewave,postwave developed, etcetera is there. So that curing technique is done and after curing is over,this isa basically harden and the other portion which is a remaining portion. So that portion is soft softer that if you dissolve. That one in table of a solutionyou will get only the harden portion of structure, 3Dstructure like that.

That is some arbitrary structure the shown which can bemade using this stereo lithography technique. That means the whole thing is a layer by layer. One layer spread all automatic because for that you do not have to take into the different place or different room or different instrument. All are integrated everything, then it is a leveling, is very important. Surface of that layer should be highly plane. So that is very important and thickness of each layer has to be controlled accurately is very important and then you can expose and you can help reaction or photopolymerization processand at the end of each layer exposure. Then you can cure the whole thing and you can get the structure. That is basic principle of the microstereo lithography.

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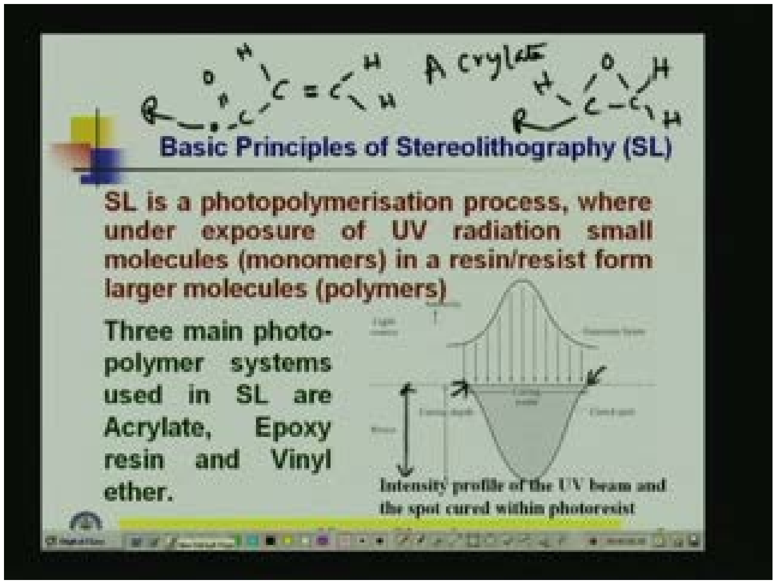

Sothe basic principle is photopolymerizationprocess where under exposure of UV radiation small molecules which is known asmonomers in a resin or resists form. The monomers are there, small molecules are there in the resist or resin. They form larger molecules. Chain reaction will take placeand larger molecules will form after irradiation or ultraviolet or laser. Whatever the exposure source you use, then it will be a long chain formed and that is basically the reaction. That is the photopolymerization. A polymer material when reacts under exposure and the polymer chain is formed or the polymer structure is modified, then this method is known as the photopolymerization. Three main photopolymer systems used in stereo lithography are acrylate, epoxy resin and vinyl ether. So now here one point I would like to stress, these three materials acrylate, epoxy resin and vinyl ether and there if you see the structure of acrylate.

So its structure looks like this. I am just writing here you can see, so there is a double bond. So this double, bond after the polymerization, then this C wills O and from here you are getting one R. So now this is basically the structures of acrylate. Now what happens? So afterthe irradiation of by the UV light or ultraviolet light, this double bond structure breaks. Carbon to carbon double bond structure breaks. Now, when it breaks so it will attract another monomer, another molecule. So then that also one bond breaks and the remaining bond will couple another acralyte monomer. So in that way a chain will be formed. On the other hand there are someresin for example an epoxy resin. There are some photopolymer epoxy resins; there is no double bond carbon. But instead they have some ring structure. So that structure is something like similar kind of structure which is known as a ring structure. That is hydrogen and this is hydrogen and another carbon also wills Hand here will be the R.

So that is the epoxy resin,so here this form is known as a ring. So here is oxygen carbon, carbon the after polymerisation when you expose with UV light then the ring breaks. When the ring breaks,so there are the bonds are available. With those bonds some another monomer of the same resin will join. So in that way either it is a double carbon bond or it is thering structure, that bond or structure breaks and it helps to join other monomer. So that a complete chain will be formed and when the chain is formed, that become harden. That cannot be dissolved in developer solution. That is the basic principle. Now two important points is that the optical source. The important point in the optical source is that intensityof the UV radiation or laser radiation is a Gaussian kind of nature. So if it is a Gaussian kind of nature, so then intensity changes you see as for the depth.

If it is a Gaussian kind of thingand the beam there is width which is known as we called as curing width. From this point to this point is known as the curing widthand curing depth is from this to this is a curing depth. Now the curing depth and curing width these two are important parameter which will decide how precisely, how accuratelyyou can form the micro parts or micro structure. The curing depth we will tell you how much thick size thickness of polymer material it can polymerize. Because beyond that there is no intensity. So this curing depth and curing width in case of stereo lithography system and microstereo lithography system are different. In microstereolithography system obviously the curing width and curing depth will be much smaller in the range of shape few microns. But in case of stereo lithography it ranges from 100 micron to 500 micron or in some case of the more than 500 micron length you can, curing width you can get it. So these are the two parameters which will we will see. Thatis a governing parameter in case of the fabrication of the micro parts.

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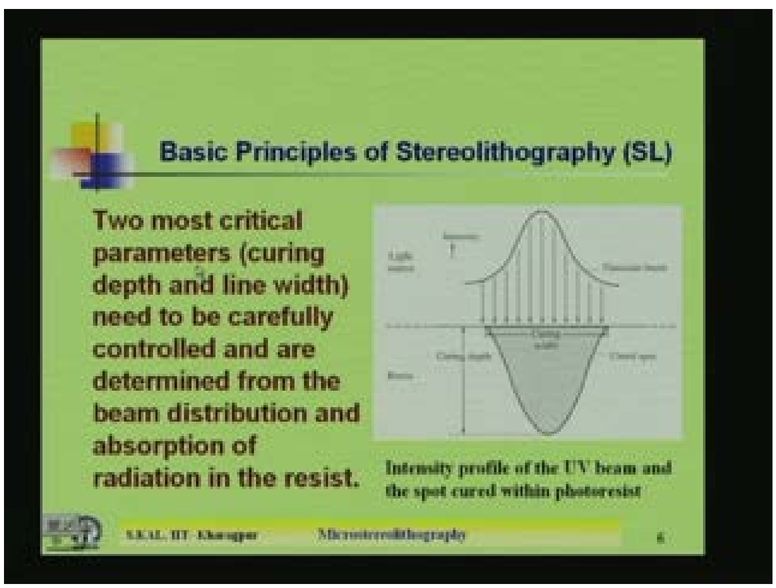

So as I mentioned that two most critical parameters, one is curing depth and line width need to be carefully controlled and are determined from the beam distribution and absorption of radiation in the resist. So this depth will be determined the curing depth will be determined by distribution as well as absorption coefficient of the resist fill. How much it can resist, how much in a radiation it will absorb, depending on that the reaction will take place. Isn’t it? So that two parameterswill be the determining parameter for the structure.

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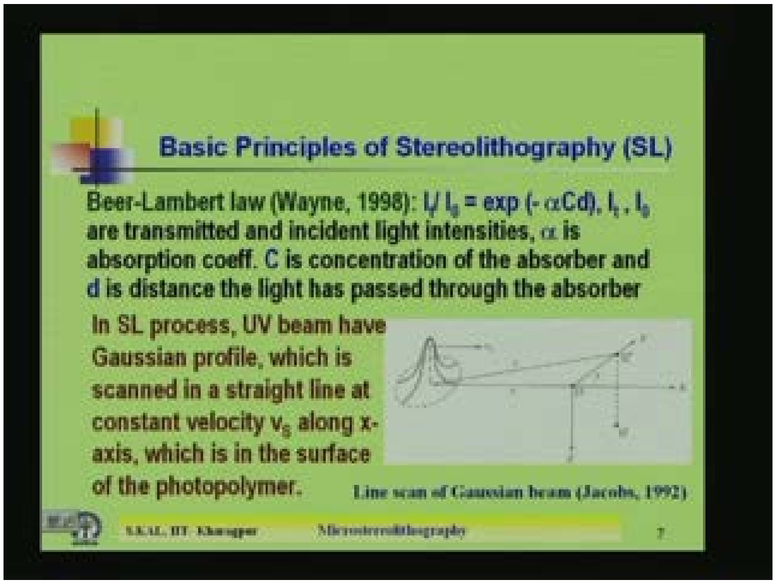

Now these basic principle ofstereo lithography system isgovern by equation which is known as Beer-Lambert law. Beer-Lambert lawin 1998, the law is given by I_t by $I_0$is equal to exponential minus alpha Cd. So where I_t andI_0 are transmitted and incident light intensity. I_t is the transmitted,I_0 is the incident. Intensity of the incident radiationand I_t the how much intensity is transmitted through the layerand alpha is the absorption coefficient. C is concentration of the absorber. Absorber is what, polymer how much concentration of polymer you are using. That is the Cand small d is the distance, the light has passed through the absorber. So that means these three parameters alpha C_d will give you the intensity distribution. There is I_t byI_0. In SL process the ultraviolet beam have Gaussian profile which you have seen in the earlier view graphwhich is scanned in a straight line at constant velocity V_s along x-axis which is in the surface of the photopolymer. The scan method is shown here, the xy surface is here, you can see here xy surface is here and now the scanningis how it scans on the surface is shown here. The scan velocity is V_s the optical spot is scanned on xy plane for a certain value of the z.

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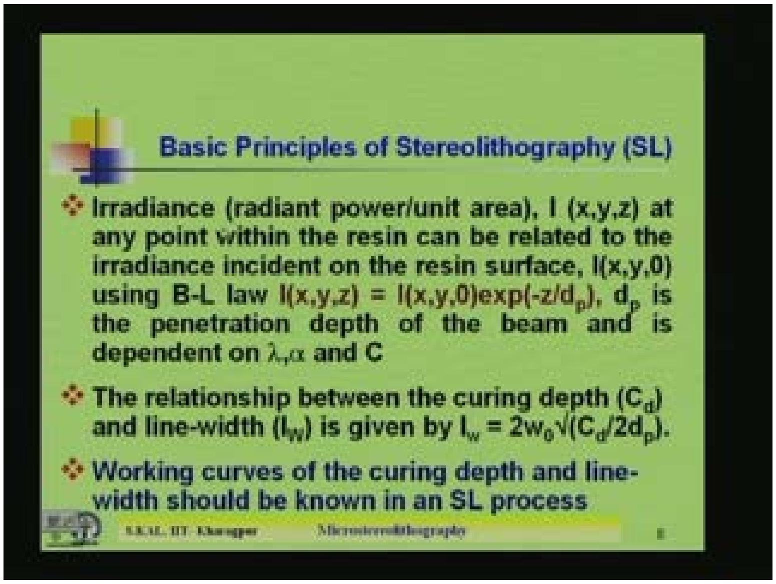

So now, what is the next step? The irradiation which is defined by radiant power per unit area that is irradiation. Ixyz intensity is dependent on xyz three parameters is there xy plane and z is the vertical axis. At any point within the resin can be related to the irradiance incident on the resin surface Ixy0 using the B-L law by this equation, which is Ixyz equal to Ixy0 exponential minus z by dp. Where dp is the penetration depth of the beam and is dependent on lambda alpha and Cwhere dp is the penetration depth. How much the beam will penetrate will depend on the wavelength of the light, absorption coefficient and the value of the Cwhich is the concentration of the absorber. So these three parameters will determinedp or penetration depth. The relationship between the curing depth Cd and a line-width l_w.

That is the curing width and curing depth two things I showed you in the earlier diagram. So that relation is given by l_w is equal to twice $w_0$under root Cd by twice d_p. So those relations are given by the two scientists Beer and Lambert and that is why it is known as B-L law, Beer-Lambert law. So that is l_w is equal to $2w_0$under root Cd by twice d_p. Working curves of the curing depth and line-width should be known in an SL process. So this relation is very much required when you want tostart the process before,know how much curing depth how much line-width. So accordingly the manipulator and timing will be decided. Exposure timing etcetera will be decided.

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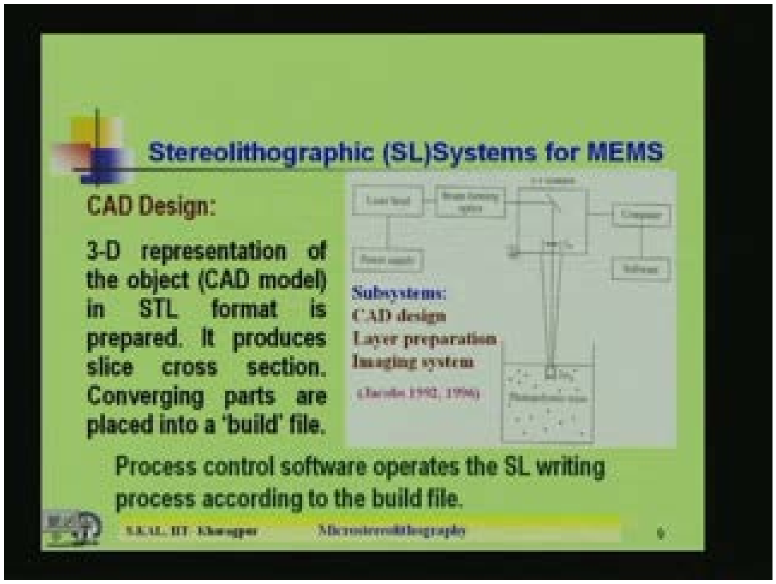

Now this is theschematic view of that totalsystem and here what are the subsystems? There are 3 subsystems in stereo lithography. One is the CAD design, second is a layer preparation, and third is the imaging system. So CAD design means the data you have stored in files in different format so that the scanning will be done based on those data as well as the z axis movement will be there based on that data. That is the CAD design a file you have to create. After that, the layer preparation is another very important and how you are preparing the layer, your intricacy of the device or all the whole method depends on how you are preparing the layer. Which layer? The polymer layer, the photoresist layerand the CAD model in STL format as I mentioned. It produces is a slice cross section converging parts are placed into a build file. That is the first CAD design first as subsystem. Process control software operates the stereo lithography writing process according to the build file. So writing will be done based on the build file which you have created and loaded into a computer.

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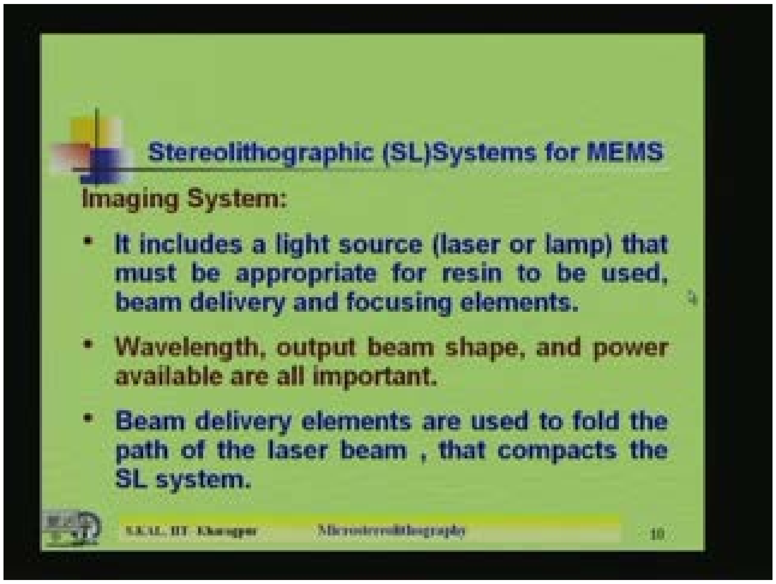

So now the next stepis an imaging system. Optic system basically. It includes a light source that may be laser or ultraviolet source. So you can use a UV lamp also. That must be appropriate for resin to be used. Beam delivery and focusing elements. So that means the light source must be appropriate for beam delivery and focusing element. So focusing element has to be there. So it should not be diverged beam. So either use laser or UV lamp. Sothe optics house comprises of the beam focusing and beam manipulation also. Wavelength output beam shape and power available are all important. Wavelength of the light output beam shape, the beam which is incident on the polymer. That means the diameter of that spotthat is output beam shapeand power available. That means it depends on the intensity. How much intensity is incident on the polymer? So those things are all important when you make the complete system. Beam delivery elements are used to fold the path of the laser beam that compact the SL system.

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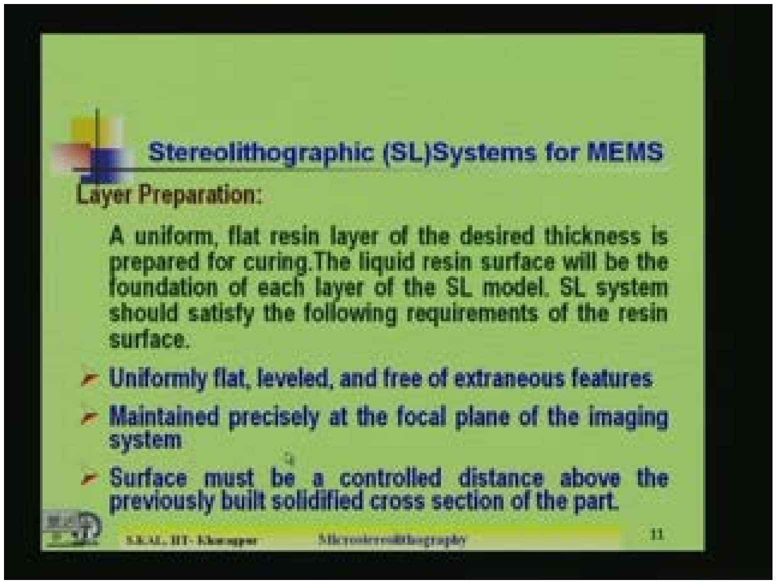

Now the layer preparation. The layer preparation means you have to have a very uniform layer of the resin or photo resist which are being exposed. Flat resin layer of the desired thickness is prepared for curing. The liquid resins surface will be the foundation of each layer of the SL model.SL system should satisfy the following requirements of the resin surface. What are the requirements? First is, it should be uniformly flat, leveled and free from extraneous features. Second is it should maintain precisely at focal plane of the imaging system. The resin layer must be at the focal plane of the imaging system. That means the focus spot where the beam focusbeam is focused at a point the whole layer should be in that particular plane. So that there you will get maximum intensity. Surface must be a controlled distance above the previously build solidified cross section of the part.

That means previously build solidified cross section is a layer preparation. So if a layer is prepared it is exposed and it becomes hard. So on the top of that again you are another layer and then you are exposing that. So that means it the distance. That means you see the focused beam, thefocusing plane remain samelayer is moving along vertical in the direction. Isn't it? So in that way, that has to be accurately controlled so that when these moves it should not depending on the thickness of each layer. The z movement has to be adjusted. So that complete layer will be in the focusing plane and within the region of themaximum intensity width. So now that is penetration drift which I called earlier penetration drift within that.

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Now the recoating and leveling system work together to have a flat layer of liquid resin of proper thickness. Recoating and leveling. Because layer by layer you have to recoat. After just recoating then leveling has to be done. That is done again by sensor electronic sensor. Whether the whole surface is uniformly leveled,the thickness of the layer typically ranges 100 to 500 micrometer. Recoater must be controlled precisely to achieve thinner layers. As 25 micronRecoater error is significant for building layer below 100 microns. That means you see, since a layer by layer you are recoating, so that if there is an error of plus minus 25 micronand each layer thickness is a 100 micron. That error is very high. If you go for 500 micron thickness, each layerthen plus minus 20 or 25 micron will notchange the structure a lot. But if you at thinner layer structure if you make within 100 microns, that 25 microns recoating error is significant. Any shrinkage during curing must be compensated by the excess resin the vat. Because whole system I have shown you in the earlier diagram, you put in resin vat completely. So that during the curing process some layer will shrink and during the shrinking time shrinkage timeso some fresh resin may be supplied from the vat,so that the structure will not be deformed.

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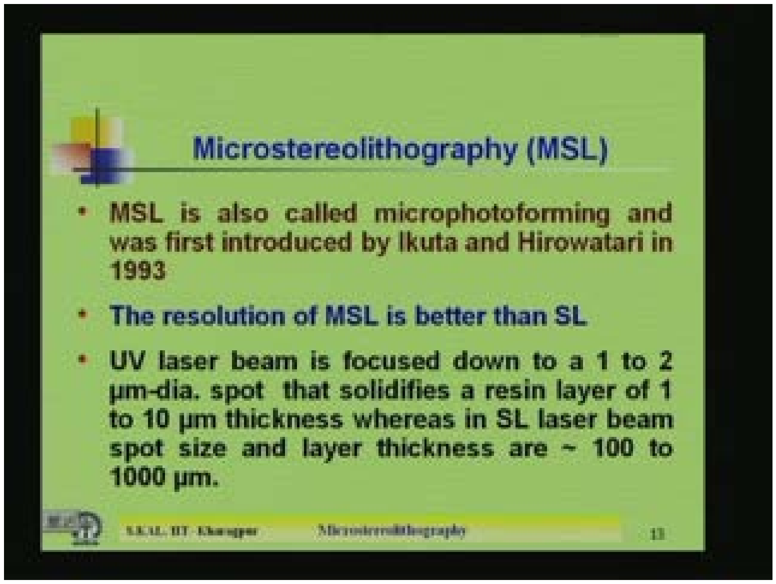

So these are the some points which we have to look. MSL is microstereolithography. Now the microstereolithography is also called a microphotoforming and was first introduced by Ikuta and Hirowatari in 1993. So is a Japanese group, they first introduced the MSL in 1993, the resolution of MSL is better than stereo lithography itself. UV laser beam is focused down to a 1 to 2 micron dia spotthat solidifies a resin layer of 1 to 10 micron thickness. Whereas in SL laser beam spot size and layer thickness are 100 to 1000 micrometer. So where 100 to 500 to 1000 micrometer in stereo lithography, but here the optics is focused to a beam of only 1 to 2 micrometer dia spotwhich can solidify 1 to 10 micrometer thin layer. So that is thedifference between stereo and microstereo lithography.

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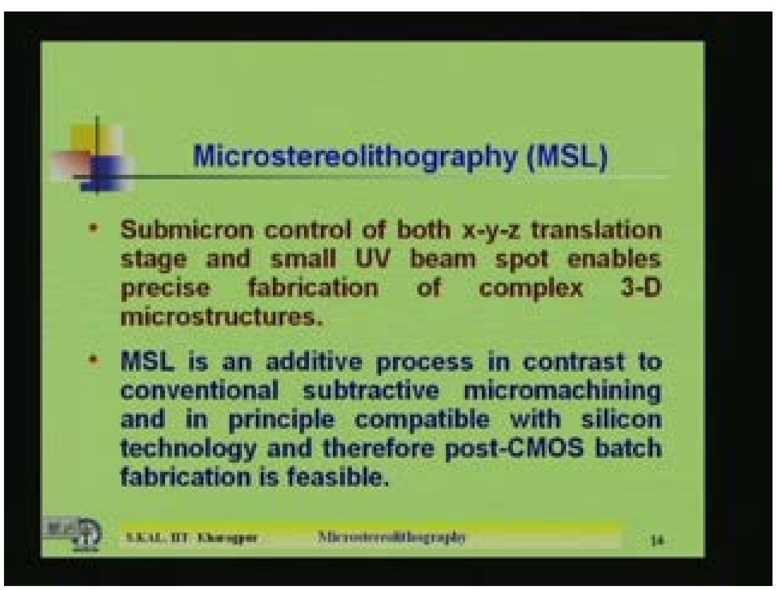

Another point issubmicron control of both x-y-z translation stages. That is that has to be much more accurate control within the submicron rangeand small UV beam spot enables precise fabrication of complex 3D microstructures. Microstereolithography is an additive process. In contrast to conventional subtractive micromachining and in principle compatible with silicon technology and therefore post-CMOS batch fabrication is feasible in some cases. What is mean by that? It is basically subtractive micromachining technique. But normal, the bulk or surface micromachining is not subtractive method that is not additive method; that is subtractive method. Conventional micromachining is subtractive. What is that? Just after lithography you are etching the undesired material? That is subtracting the undesired materialand this is in additive process. MSL is an additive process. I think you can remember an additive process of lithography. That is ripped off technique. That is an example of additive process. You will, in some casesadditive means the total,the final structure you can form by adding certain material. In that sense you can say a LIGA technique you are filling the growth by using the electroplating. That is an additive process. So similarly here the MSL technique, they utilize additive process to make the micro structure.

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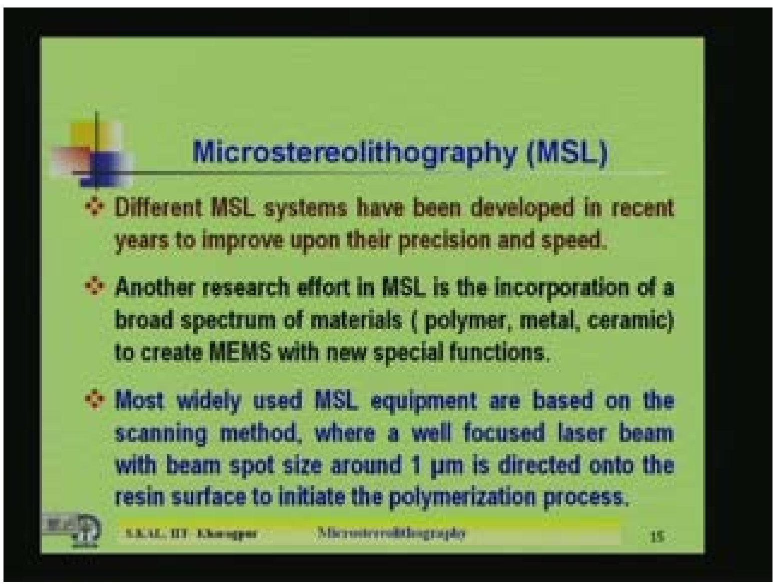

Different MSL systems have been developed in recent year to improve upon their precision and speed. So people arealso concerned about the speed. Because you see, if you make a layer by layer by structure and then expose another layer, then expose, then automatically the throughput of the device will be small. Because layer by layer you are recoating, leveling then exposingthen again recoating, leveling and exposing. Getting the complete thing will be taking a long time. So that is why speed is one important parameterand at the same time you need high precision. So lot of work is going on in recent years towards microstereolithography to increase the speed so that your throughput will be high and you can get high precision structures. Another research effort in MSL is the incorporation of a broad spectrum of materials. That I mentioned earlier also. That is polymer metal ceramic all these materials are being used in MSL technique to get microstructures. Most widely used MSL equipment are based on the scanning methodwhere a well focused laser beam with beam spot size around 1 micron is directed onto the resin surface to initiate the polymerization process. They use recent MSL equipment. They use the laser beam of spot size nearly 1 micron.

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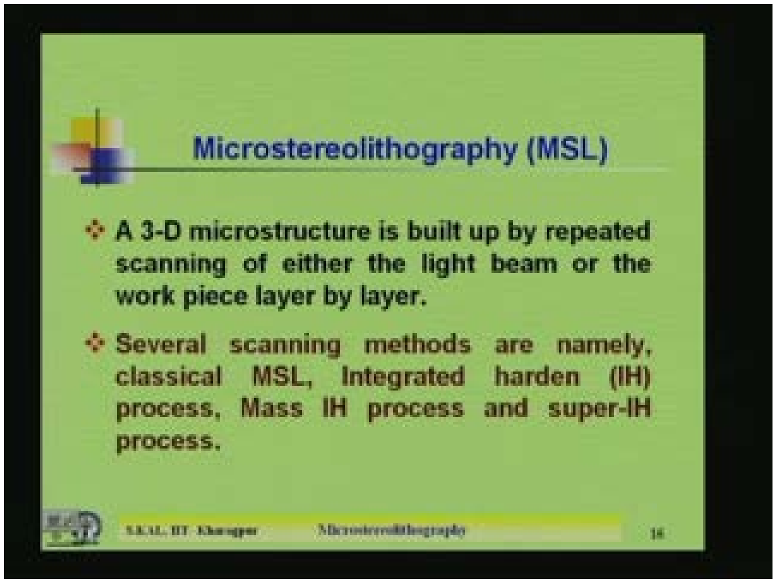

In microstereo lithography a 3D microstructure is built up by repeated scanning of either the light beam or work piece layer by layer. Several scanning methods are used in MSL technique which are classical MSL integrated harden process which is known as IH process, mass IH processandsuper IH process. So the classical ML is similar to the stereo lithography system. Only the spot and microsize,spot size in others are very small. Integrated harden process and there are three kinds of IH process which is known as the integrated harden. One is simple integrated harden. Other is mass IH process and the super IH processand the difference of the super IH process and ordinary IH process, integrated harden process will be discussed in next few slides. So it is known as integrated harden process. That means you are curing the complete thing at the end exposing one by one. That means the each layer you are integrating during the complete curing process. So that is some time is known as integrated harden process. Now a simple IH process is shown in this view graph you can see this picture here.

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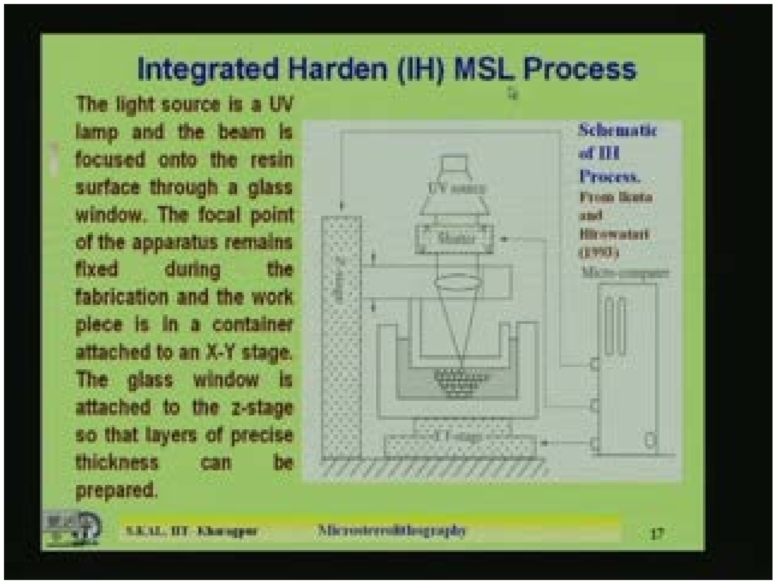

Here is the MSL process which is integrated hardens processand here obviously you can see here, there is a microx-y stage will be thereand this is az stage, z is movement is, this is the liverand in that liver one optic system is lens is fixed up. So that z stage can move based on the microcomputer dataand another is x-y position is there. The x-y movement can be controlled using again the micromicrocomputerso that very precise in a micron level. In some micron level movement of the x-y stage is very expensive. This kind of x-y stage is possiblewith themicro positionaland now this is basically the container where the photo resist or the polymer is kept and nowthis is some leveling arrangements are there and this is the vat where you put the resin and here is the either ultraviolet or laser source which is basically produced here of certain wavelength. And then this is the pollimatedbeams are there and some shutter arrangement will be there.

The shutter is now someacousto electro optic shutters are being used which is much fasterand various kinds of shutters I have tried to improve this speed because shutters are very important. Because when you do not need to expose a certain length or certain area, then you can close the shutter. So that optics is there is no irradiation. So when you need you open the shutter and then you scan. Because this spot size is only 1 micrometer to say a microstereo lithographyit can go down to 1 micron, may be 2, 3 microns there. So we have to scan some scanning arrangement will be there to expose a certain area. Now the whole complete system the shutter is also connected to the microcomputer. So the microcomputer x-y positioner the shutter and the z stage. So this is the IH process, one thing which movement is taking place,xy positioner and z stage and shutterand we will see in super IH process.

The oppositethen I have I will show you in the next one or two slide that there the the xy stage and z stage are fixed. Another layer the optical house the scan which is optical house is moving the focus point is moved inside the the resistthat is the super IH process. Now here in this MSL process the light source we use here UV lampand the beam is focused on to resin surface through a glass window, this is the glass windowhere it shown the glass window. The focal point of the apparatus remains fixed during the fabrication. This is the focal point, it remains fixed so that is not, a focal point is not changed and the work piece,the focal point of the apparatus remains fixed during the fabricationand the work piece is in a container attach to an x-y stage. So this container is attached on x-y stage. The glass window is attached to the zso that layers of precise thickness can be prepared. So that is the complete sets up of micro stereo lithography system using integrated harden method.

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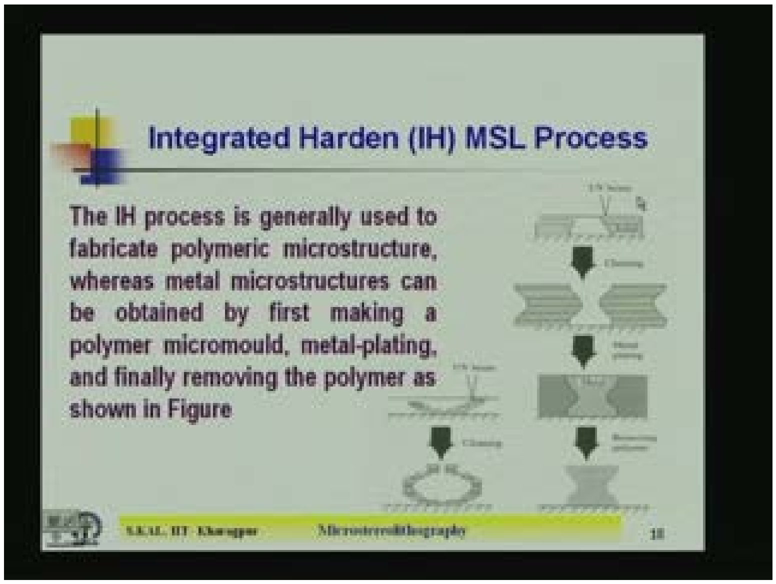

Now here you can see how this structure is being made,that is normally used to fabricate microstructure where metal microstructures can be obtained by first making a polymer micromould then metal plating and finally removing the polymer as shown in the figure. So if you look here it is somewhere similar to your LIGA process. You can see initially in this structure by using the ultraviolet beam it is solidified. So initially whole thing was liquid. So based on the later,so a layer by layer after irradiation the each layer is solidified here and here. Now in this way if you can make the structure like that after cleaning means you developing thingsthat cleaning means this part which is soft remain,this is hardened by irradiationthe remaining portion you remove it by cleaning. So you will get this structure. Then for the next step you make the metal plating. So metal plating if you make so just like of electro plating techniqueyou make the metal place.

So after that you remove this hardened polymer. So then what you will be getting, so after removing the polymer you will get the metal structure like this. So that but first you are making the mould in the polymer by this IH MSL process thenby metal plating you are getting the metal structure. From the very beginning you cannot do with the metal layered. Because there the metal layer cannot after irradiation it not be polymerized the whole structure, basically feature is made the polymerization process. Now similarly here you can see the UV beam you can make the structure like thisand after cleaning the whole thing can be removed from the bottom. So you can have a bowl like this. So as you see here you can get various kinds of structure by using the integrated the harden process.

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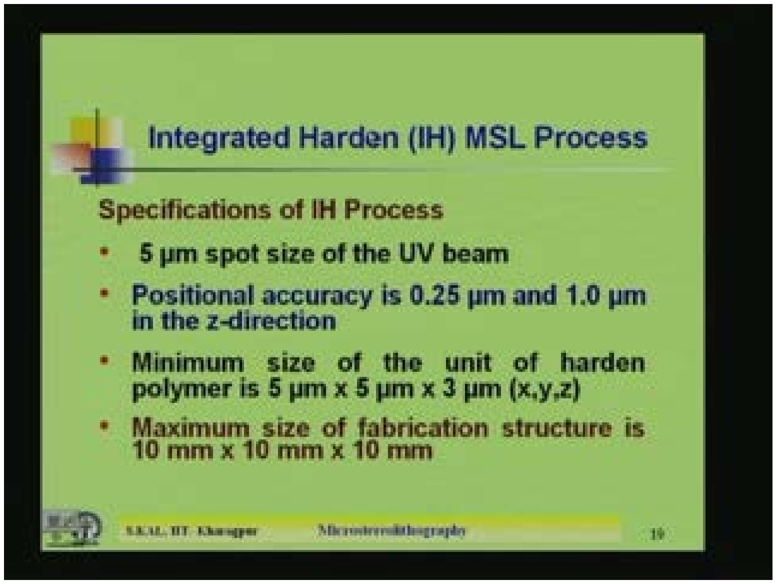

Now here what are the specifications of the IH process? 5 micron spot size of the UV system, positional accuracy is achieved to 0.25 micron and 1 micron in the z direction. Minimum size of the unit of harden polymer is 5 micron by 5 micron by 3 micron in xyz direction is the minimum size is possible. Maximum size of fabrication structure is 10 millimeter by 10 millimeter by 10 millimeter. So that is the maximum size of the complete structure.

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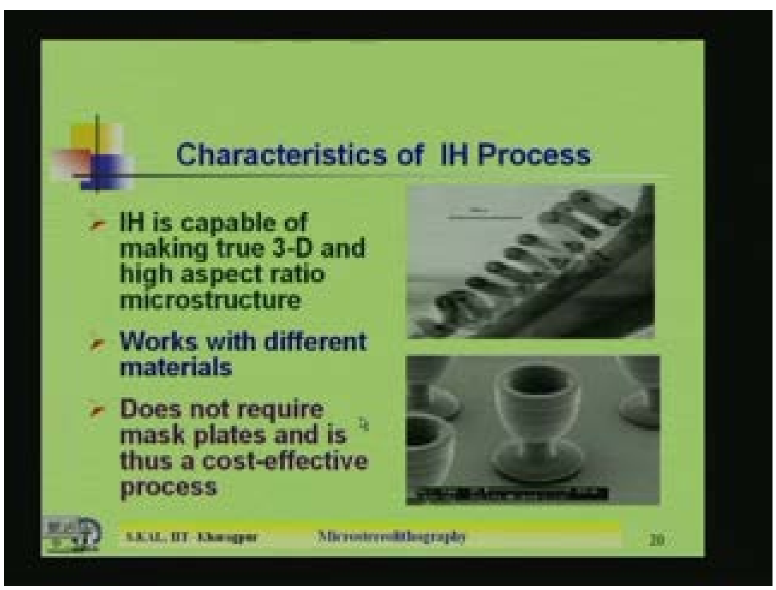

Now here are some of thepictures you can see herewhich may be formed using the IH process. The IH is capable of making two true 3D and high aspect ratio microstructures. Works with different materials is possible. Does not require mask plates is clear, now does not require mask plates and is thus a cost-effective process. Mask making process is highly expensive you know. So if you can avoid that, so it is a cost effective process and this kind of the spinal rings and this kind of things all are possible using the integrated harden process.

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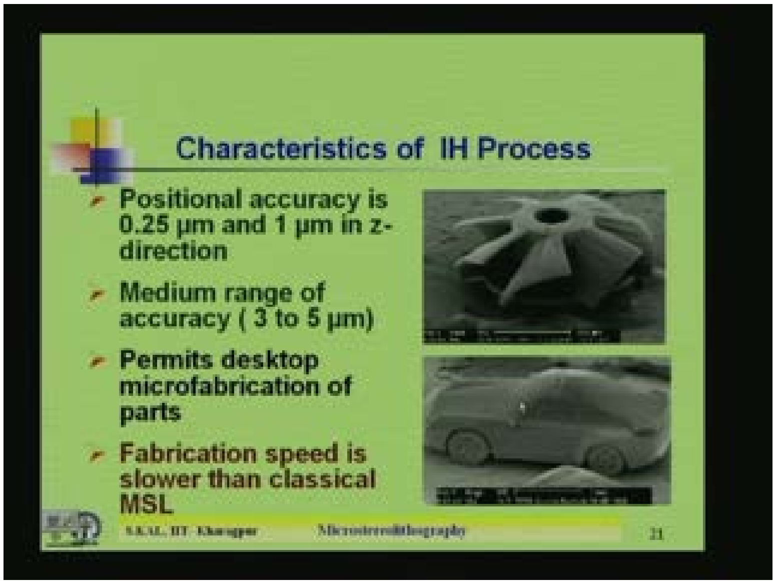

Positional accuracy is 0.25 micron and 1 micron in z direction. Medium range accuracy is 3 to 5 micron of the IH process. It permits desktop micro fabrication of parts. Fabrication speed is slower than classical MSL. So you can see here one picture which is a just complete one automobile,one the polymer car kind of shape, they have fabricated using this IH processand this is one the blade of a motor. So blade or fan somewherelike that you can make using the polymer or ceramic material.

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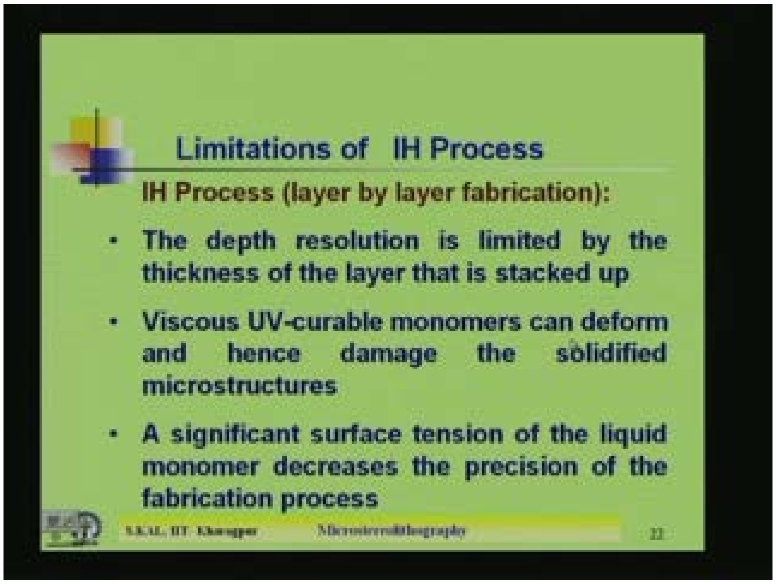

Now there are certain limitations of the IH process. What are those? IH process basically what you are doing layer by layer fabrication. What are the limitations? The depth resolution is limited by the thickness of the layer that is stacked up. Thickness of the layer, how much layer thickness you can make itbe layer by layer you are making. Depending on the layer thickness some limitation is there. Resolution, that means you see in earlier diagramwhere you because layer thickness gives you the resolution when you make the bowl, how it is carbolyticsaydepends on the resolution. How much thinyou can layer you can put on the surface. The second limitation is viscosity of the UV curable monomer.

So polymer monomer will have,that has to be UV curable and this polymer will have certain viscosity and that can deform and hence damage the solidified microstructure. During the whole process, third limitation a significant surface tension of the liquid monomer decreases the precision of the fabrication process. Because layer by layer when you are making, first layer to second layer there is a surface tension. Second to third layer there is a surface tension. That may deform the precision and that may deform the whole structure. So a precision of the microstructures may high precision may not be achieved. So these are the limitation and these limitations can work can beovercome by using super IH process.

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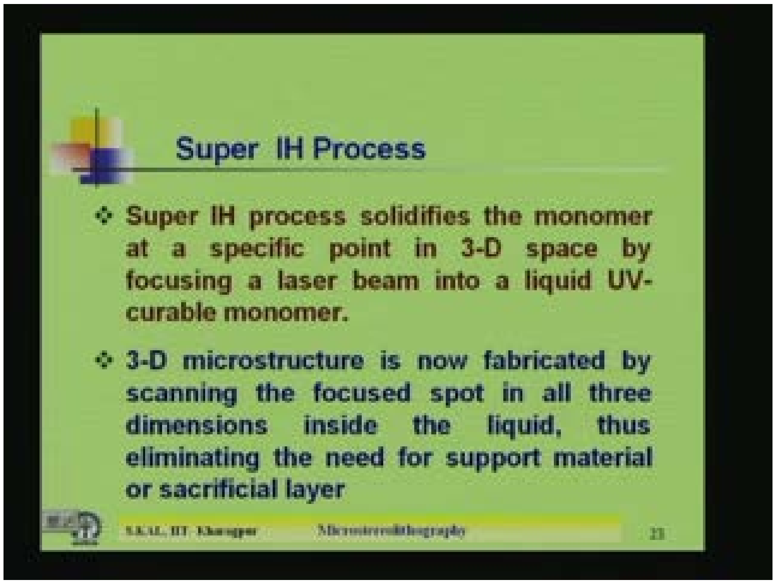

Super IH process solidifies the monomer at a specific point in 3D space by focusing a laser beam into a liquid UV curable monomer. In super IH process is not layer by layer. The complete monomer complete the polymer resists as kept in a container. Then focused beam is scanned and focused beam the whole structure moves vertically also. But it will just reaction will take place at a particular point where the beam is focused inside the liquid. So that means if the focused spot of the optics either laser or UV is moved, is scanned inside the liquid at a different distance at difference depth. So that is the basic difference between IH process and super IH process. Since you are not using layer by layer, there is no question of surface tension, precision hampering, due to the surface tension between layer to layer. So the 3D microstructure can now fabricated by scanning the focused spot.

By scanning the focused spot in all three dimensions focused spot, earlier case is only in twodimensions in a certain plane scanning. But here also all in three dimension you are scanning.Inside the liquid, thus eliminating their need for support material or sacrificial layer. Support material means if you make a layer by layer so you need a support material. On the support material second layer, third third layer is made on the second layer; fourth layer is made on the third layer. So you need a support layer, because you are making a layer. But in the super IH process you do not need the support layer. Because the whole liquid is taken in a container. The beam spot in a 3D movement you are just focusing inside the liquid and now you are hardening the particular spotsand after that you are curing and you are getting the structure. But obviously the complete technology is much more difficult and complicated.

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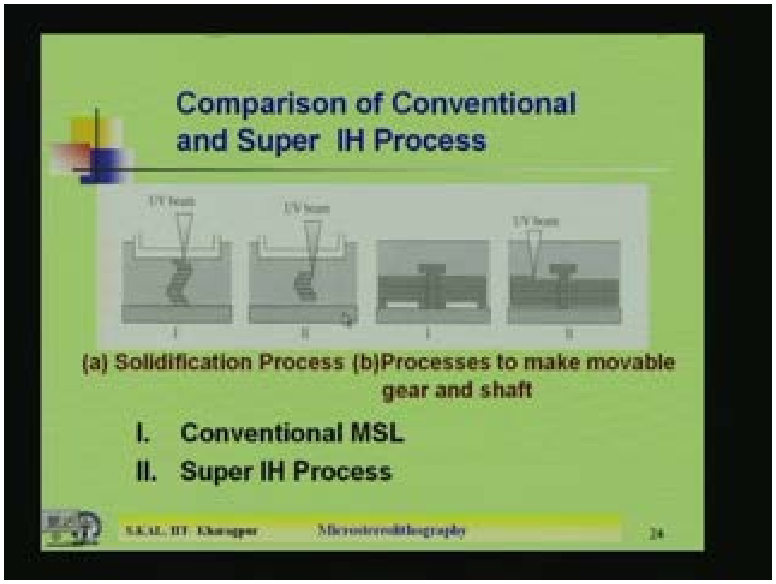

Now these are the some example solidification process you can see here. In this, this is a first one is a conventional IH process and the second one is the super IH process. So in the first conventional process one layer, the second layer, then third layer, then fourth layer. In this waythis beam is fixed here. This is the focal plane of the beam, that is fixed it can scan only xy movement not in z. Z Means this structure container is moving in z direction but in the super IH process there are two.You can see here, that this is the beam goes deeper into {dil} (00:55:28) into the polymer. So the beam moves only not only in the xy plane but it moves on the z plane, also in this plane, also it moves. So that it harden like this. But here layer by layer you make then you can harden it, but super IH is not that. Now here is one example to make movable gear and shaft. So using the first method is a conventional image,so there you see some support layer is there. In the second one is the supervise process the gear and shaft is made without any support layer or sacrificial layer, just this beam spot is scanned vertically and laterallyand you can get this kind of structure. This is the comparison between IH and super IH process.

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Now the ceramic MSL. Ceramic microstereo lithography, these are some ceramic structure you can see at the corner of the figure. So ceramic materials have useful properties such as high temperature or chemical resistance, high hardness, low thermal conductivity,ferroelectricity and piezoelectricity. Because of those properties, ceramic materials are used in some MEMS devices. 3D ceramic microstructures are of special interest in applications such as micro engines and microfluidics. These are the two application areas of ceramic microstructures. Unlike conventional silicon micromachining, MSL can be used to build the complex ceramic 3D microstructures in a rapid free form fashion without the need for high pressures and high temperature. Here you to use the additive process because the ceramic material cannot beexposed and polymer chain reaction will not be there is not polymer. So basically it is little bit different and it needs at the end some curing process. The ceramic powders are mixed with polymeric material and after that you have to have cured and during curing process the polymeric materials will evaporateand the solid ceramic you will get.

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So the resin system for ceramicMSL is composed not only of the monomer and photoinitiators that are used in polymer MSL but also of ceramic powder what I mentioned. Ceramic powders monomers and photoinitiator. The photoinitiators are basically a reactive with the optic systemdispersants and diluents are used to obtain a homogeneous ceramic suspension with a relatively low viscosity. Upon UV polymerisation the ceramic particles are bounded together by the polymer and the ceramic body is formed. This is the complete ceramic MSL process. So with this let me stop here, I discussed the overall the stereo lithography system and micro stereo lithography also and extension of this method in this ceramic MSL process to get ceramic microstructures. Thank you.