Rapid Manufacturing
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Lecture – 19
Polymerization processes (Part 2 of 2)

So, welcome to the next lecture in the course of Rapid Manufacturing which is focused towards rapid prototyping process.

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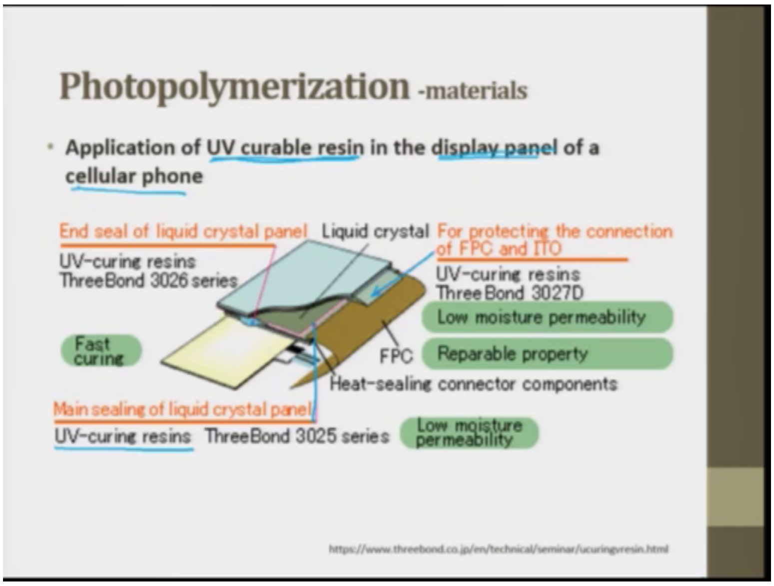

Photopolymerization material here we will see the application of a UV curable resin in the display panel of cell phones. So, in cell phones display panel we use UV curable lasers. So, you can see here these are the cross sectional view of the display panel. So, here you can see end seal of the liquid crystal panel is done here. So, it has a UV curable resin, then you have a liquid crystal here this is liquid crystal, then for protecting the connection of FPC and ITO you have this. So, the UV curable resin is also filled here. So, it has no moisture permeability and repairable properties are here.

Then when you talk about the main sealing this is the main sealing main sealing of liquid crystal panel that is also having a UV curable resin. So, it is very clear from this figure that UV curable resins play a very important role, it is transparent and it also has low moisture permeability.

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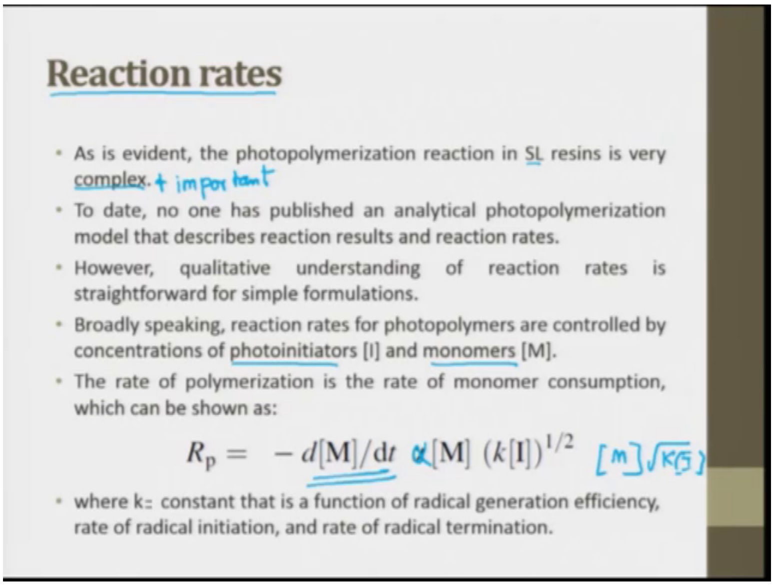

The important property of the entire photo polymerization is the reaction rate because how quickly does the reaction happen such that the liquid is converted into a solid you cannot make it in one shots liquid to solid or liquid viscoelastic nature and then solid. Suppose if this takes a slow duration of time the best part is going to be between spots it is going to jell and form a line very good it. If it is instantaneously curing you might not get the jellation very well and when you talk between layer to layer again there can be a possibility of delamination.

So, in that case reaction rate place a very very important role as it is evident the photopolymerization reaction in stereolithography resin is very complex and important, because if the reaction rate is very slow then the shrinkage might be very high. To date, no one has published an analytical photopolymerization model that describes reaction results and reaction rates. However, qualitative understanding of the reaction rate is straight forward from simple formulations.

Broadly speaking reaction rates for photopolymers are controlled by concentration of photoinitiators and monomers I and M. So, the rate of polymerization is the rate of monomer consumption which can be shown as R p equal to differential of M by t. So, this is the rate which is directly proportion to M, M is the monomer and k I to the power half or this can be written as M root k, I that is the function of radical generation efficiency.

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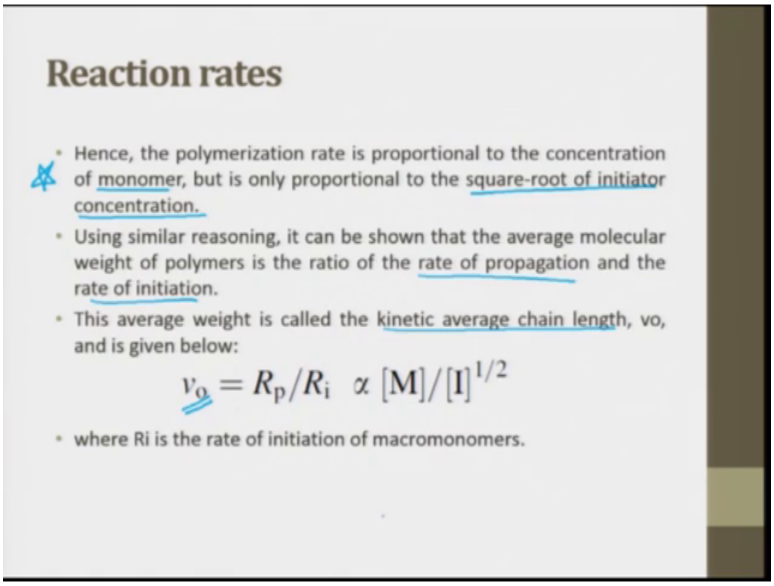

The rate of radical initiation, hence the polymerization rate is proportional to the concentration of monomer, but is only proportion to the square root of the initiator concentration, this is a very very important point. So, what is the effect of the the initiator concentration with respect to monomer.

Using the similar reasoning, it can be shown that the average molecular weight of polymers is the ratio of the rate of propagation and the rate of initiation. Rate of propagation means how quickly the networking is getting formed and the rate of initiation is how quickly it is getting this is forming a network propagation this is how sure your initiating it. So, the average weight which is otherwise called as kinetic average chain length v o can be written in terms of R p by R i ok, R i is the rate of initiation of the macromonomers.

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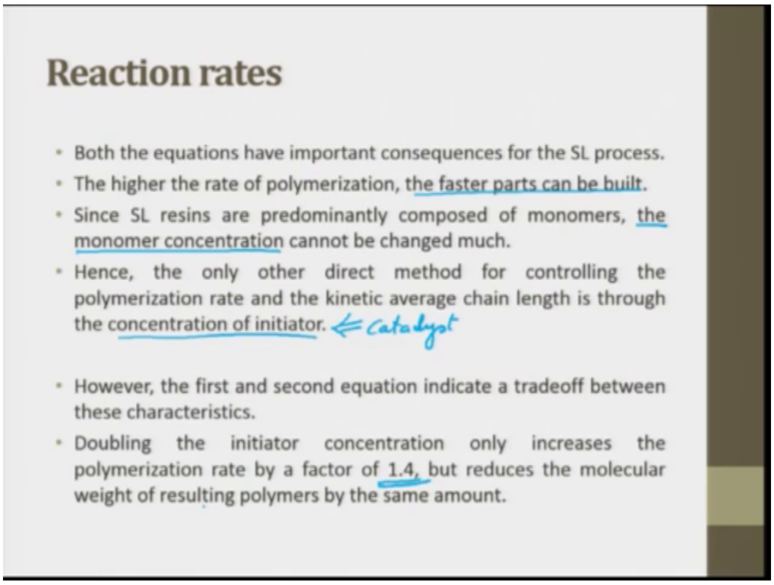

Both the equations has important consequences as well as SL process is concerned. Higher the rate of polymerization faster can be the built time, built time is very important today if you want to have a very high resolution rapid prototyping made it might a small 1 cubic centimetre volume can take almost close to 4 - 5 hours, if you have a very high resolution where the features are very very small you will get this. Since, SL resins are predominantly composed of monomers, the monomer concentration cannot be changed much. So, this is also important thing monomer concentration cannot be changed much.

Hence, the only other direct method of controlling the polymerization reaction and the kinetic average chain length is through concentration of the initiators, they are sometimes very crudely called as catalysts this, this can be changed. However, the first and the second order equation indicate a trade off between these characters. Doubling the initiator concentration only increases the polymerization rate by 1.4 times, but reducing the molecular weight of the resulting polymer by the same amount.

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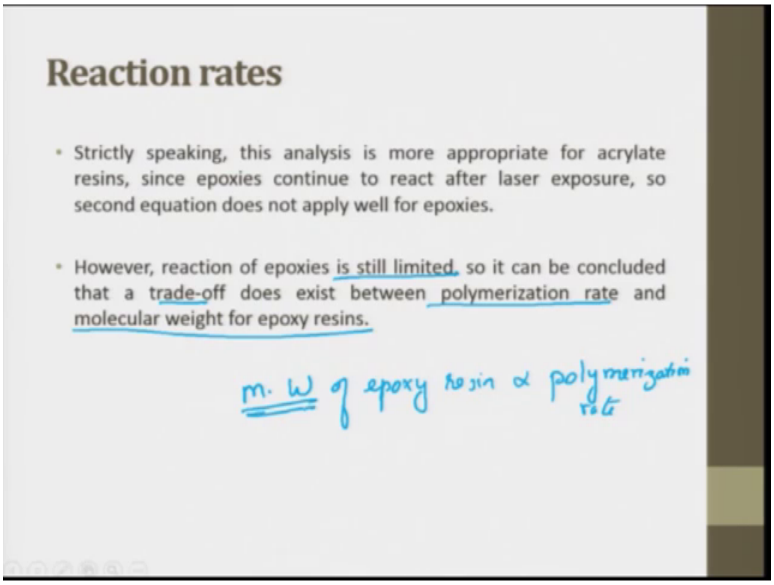

So, strictly speaking, this analysis is more appropriate for acrylate resin since epoxy continuous to react after laser exposure, so second equation does not apply well for epoxies. However, the reaction of the epoxies is still limited, so it can be concluded that a trade - off does exist between polymerization rate and the molecular weight of the epoxy resin. So, molecular weight of epoxy resin is proportional to polymerization rate ok. So, molecular weight you can try to play with the molecular weight and then try to get the polymerization reaction.

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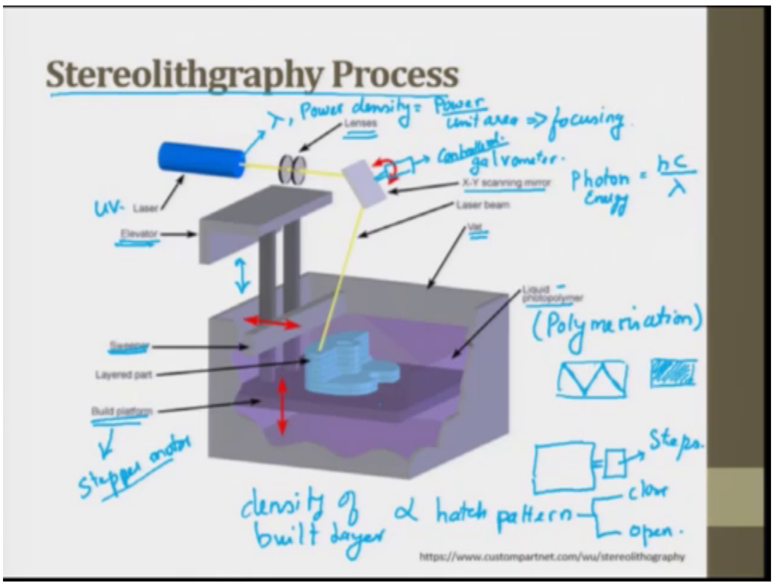

So, now, let us understand more in detail about the process called stereolithography, stereolithography is a process where in which we use a liquid photopolymer where the process of polymerization happens ok. We use a laser which is a UV laser. So, this UV laser, the lambda is very important, the power density is very important, power density is nothing, but power applied per unit area. So, this is nothing, but the focusing and this lambda is the energy photon. So, the laser energy is divided into photon energy, photons are packet of energies is in the light. So, photon energy is equal to h by lambda.

So, now you can see what will be the influence of photon energy, this energy is per photon energy ok, depending upon the wavelength a photon energy can increase or decrease fine so this is very important. So, power density is also important, for power density we play with the lenses. So, it straight passes and here is said as X-Y scanning mirror which is nothing, but a galvometer, you can see here this is attached to your motor this motor is controlled by pulses. So, you can see stepper motor, this motor will be attached to a shaft and this is controlled by steps.

So, this controlled motor can be used to control the rotation of this mirror, this mirror interned reflects on top of the liquid polymer. The liquid polymer is placed inside a vat ok, this vat is placed on top of a table, this is a build platform or a table. So, this table is lowered and highered by a elevator. So, again here you will have a stepper motor attached stepper stepper or servo motor attached. So, this resolution tries to dictate the resolution of the layer.

So, after one layer of exposure the table the built platform sinks down. So, the next layer is of liquid is formed on top, as I said where there is a doctors blade we have a sweeper, the function of the sweeper is to make sure that there is a uniform layer of liquid on top of the built area built platform ok. So, here 2 3 things we have to note, the density of the layer is directly proportion. So, there is something called as density or the built layer; layer is directly proportion to the hatch pattern.

You can establish 2 different types of you can establish close hatch pattern or open hatch pattern. So, basically open hatch pattern gives you only a shape to the layer for example, you can have a layer this is open you can have a layer which is closed a closed layer. So, closed layer will take more time closed layer is heavier closed layer is differ, but if you just wanted to use it as a supporting layer or supporting part then you use this open structure and start building it ok. So, this is about the stereolithography process and here you just by changing the density of the built area you can try to make certain portions weaker. So, this weaker portion can be chiselled off as soon when you start growing it.

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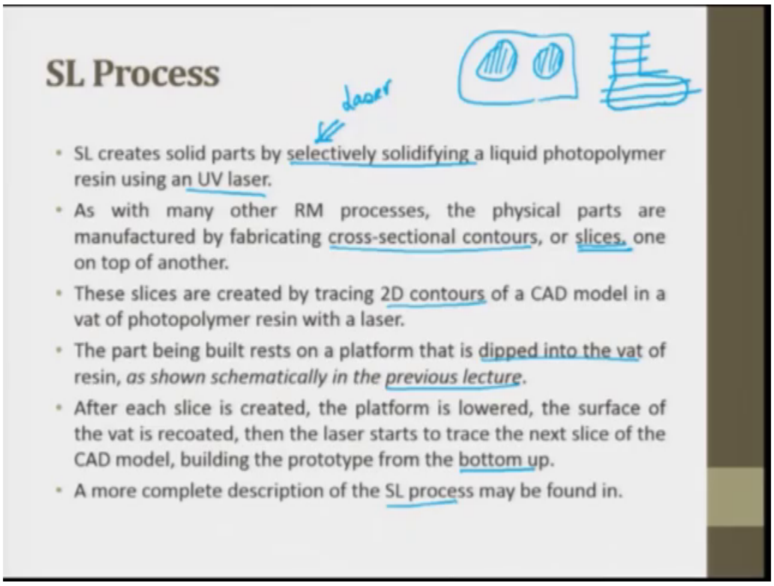

The stereolithography creates a solid part by selectively solidifying the selective word is a very big word and the laser gives you the freedom of doing selective. So, wherever I wanted to cure only those portion will be cured for example, if you have a layer and you have 2 islands ok, only these islands have to be cured it is possible rest all you do not even have to touch possible or 2 islands alone not to be touched rest all layer has to be touched possible so it will cure. So, it is selective solidifying a liquid photopolymer resin using a UV laser that is stereolithography.

As with many other rapid manufacturing processes, the physical path are manufactured by fabricating cross sectional contours or slices one on top of another. For example, I have a shoe so I made this as layer by layer by layer this is what we are saying. So, manufacture fabricating a cross section contour or slice one on top of another. These slices are created by tracing 2 D contour of a CAD model in a vat of photopolymer resin with a laser.

The part being built rests on the platform that is dipped into the vat dipped into the vat of resin, as shown in the schematic diagram in the previous slide. After each slice is created, the platform is lowered, the surface of the vat is recoated then the laser starts to trace the next slice of the CAD model building the prototype from the bottom up. So, you are trying to build the part from bottom to top that is what is called as bottom up approach. A more complete description of SL process may be found in.

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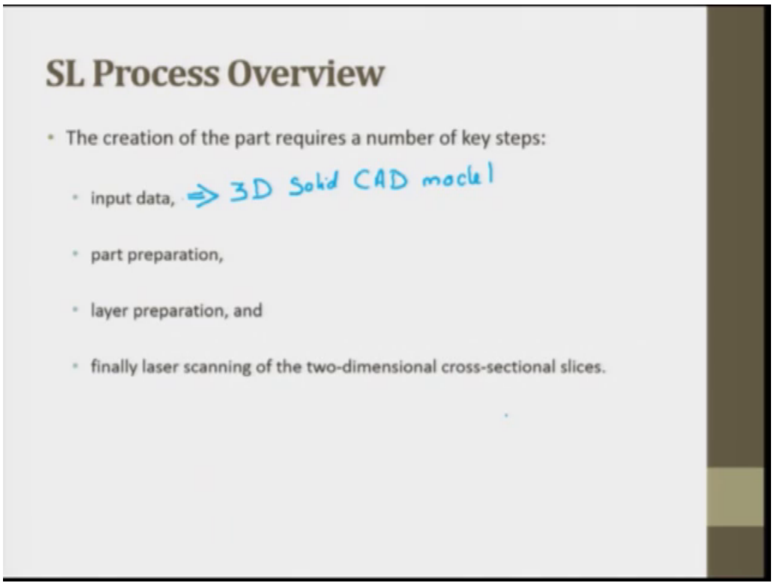

So, the creation of the part requires a number of key steps, one is input data basically the input data comes from 3 D solid CAD model ok, then what we do is we try to make the part preparation, then we try to do the layer preparation and finally, the laser scanning in the 2 dimension cross section in each slices carried out.

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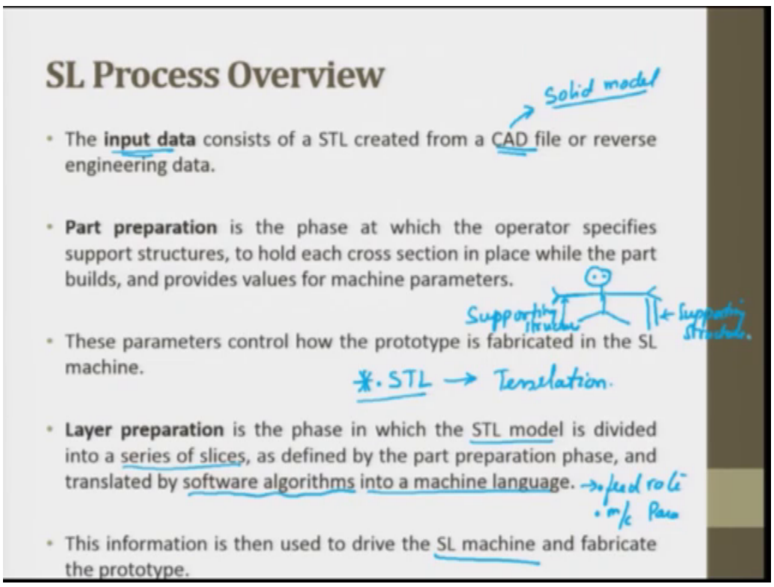

The input data consists of STL created from a CAD file or reverse engineering data input CAD file, this CAD file as I told you has to be a solid model not a surface model predominantly we go for solid model 3 D solid model or reverse engineering data point cloud data or MRI data, CT data, that is what we are saying here.

Part preparation is the phase at which the operator specifies support structures to hold each cross section in place while the part builds and provides values for machining part. For example, let us assume a person who is hanging you are trying to reconstruct him using the SL process. So, you see here there is a overhang of his hand on both sides.

This if you have if you have to cure only in the top layer it is not possible. So, what we do is, we first see how do we support this layer from the bottom to this area and then when it comes to this height or this level you see that the UV laser falls on it and then creates it. These parameters control how the prototype is fabricated in the SL machine.

Layer preparation is the face in which STL model is divided into a series of slices. So, what is this STL model, when you finish the CAD you store the CAD data as star dot STL. So, star dot STL when you store it becomes a STL model. So, STL model is nothing, but you try to convert the solid module into tessellations.

Tessellations are small triangles or measures which we call so, it is convert into that and the STL model is then further divided into a series of slices as defined by part preparation phase part preparation phase and translated by a software algorithm into a machine language. Why are we talking about software algorithm and machine language? Machine here will try to give you the feed rate the other machine parameters, but the software will only slice and give you the data, this information is then used to drive the SL machine and fabricate prototypes.

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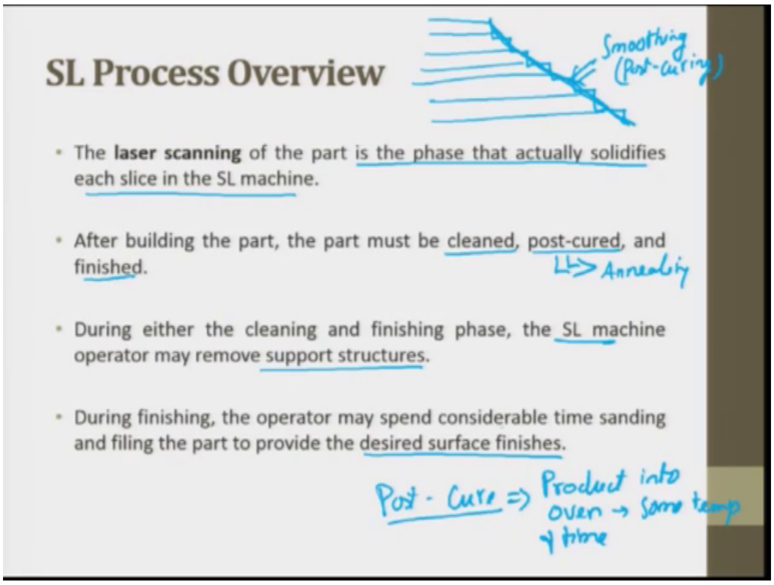

The laser scanning of a part is the phase where the actual solidification happens and the layer is formed, actual solidifies each layer in the SL machine. After building the path the path must be cleaned and post cured and finished. So, what happens is, you will have a staircase effect which is coming up on the because this is layer by layer by layer information so you will have staircase effect coming into action. So, this staircase effect has to be smoothened ok. So, this smoothening operation is called as post curing operation, post curing can be heat treatment can also be smoothening and then getting the finished part.

So, each during either the cleaning or the finishing phase the SL machine operator may remove the supporting structure, what is a supporting structure, if you go back this is called the supporting structure till here it will be on both sides. During finishing, the operator may spend considerable time sanding and filling the path to provide the desired surface finish. So, this is what I said smoothening can happen, by doing this that is basically finishing the surface or if you want you can try to even post cure, post cure is nothing, but we do annealing or maintaining the polymer.

So, here what we do post cure, we put the polymer into a oven, product into oven maybe for some temperature whatever depending upon the polymer and we place it at time. So, we make sure all the networking between the monomers which is in was initiated has to be completed, as such in polymers 100 percent or 99.9 percent curing happens over a period of time.

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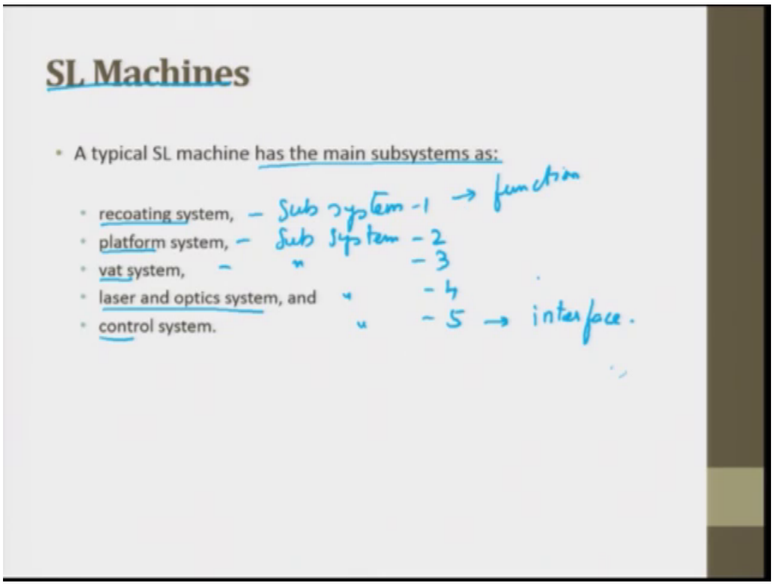

So, the typical SL machines have many subsystems after the processes over you will have subsystems. So, one is recoating system, platform system, vat system, laser and optic system and control system these are the subsystems, when you talk about modular concept this is what we were trying to talk about subsystem 1, subsystem 2, subsystem 3, subsystem 4 and subsystem 5.

So, if you see that in this entire SL machine if the controller is bad so we just replace controller. So, here it also has a proper interface with rest of the machine ok. So, this is what is a product divided into several sub modules each module has a function, which I explained in the previous slides each module has it is own function if one function (Refer Time: 19:19) it does not have any influence on the others. So, you replace this function and then do it and when you do a subsystem again you have several parts in it. So, you remove and strip it off and see which part is defective just replace that, that is how the modular concept works.

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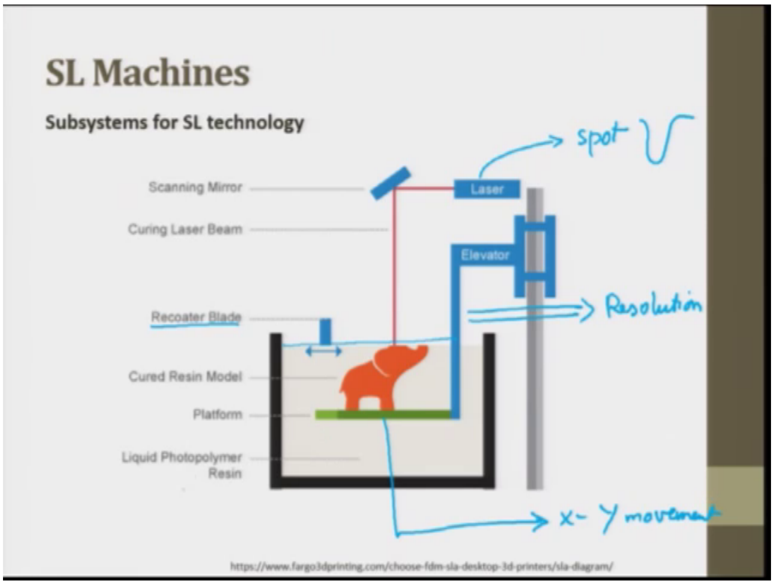

So, this is we saw in detail in the previous system so here we are only seeing the new thing is recoater blade. So, the recoater blade tries to push the liquid on top of this layer when it is getting formed so that you have a uniform thin layer which is getting form. Now which dictates which dictates the layer thickness or how small can the layer thickness be, generally the layer thickness depends on the resolution of the elevator so this resolution dictates the primarily dictates the thickness layer.

The next one is the spot the spot what depth it goes on a Gaussian distribution and the next one is going to be the table X -Y moment. So, all these things dictate the resolution of the object. So, liquid resin that I have explained all these things in detail.

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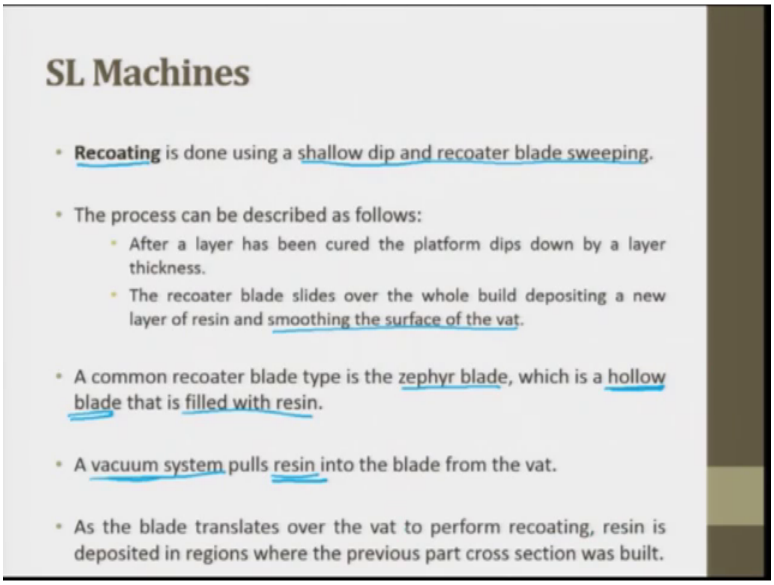

Recoating is done using a shallow dip and a recoater blade sweeps this what I said, the process can be described as follows, after a layer has been cured the platform dips down by a layer thickness. The recoater blade slides over the whole build depositing a new layer of resin and smoothening the surface of the vat.

A common recoater blade type is generally called as zephyr blade, which is a hollow blade that is filled with resin. A vacuum system pulls resin into the blade from the vat ok. So, your hollow system hollow blade, what happens when there is excess it sucks vacuum system pulls the resin into the blade which blade is zephyr blade. As a blade translates over the vat to perform recoating the resin is deposited in the region where the previous part cross section was built.

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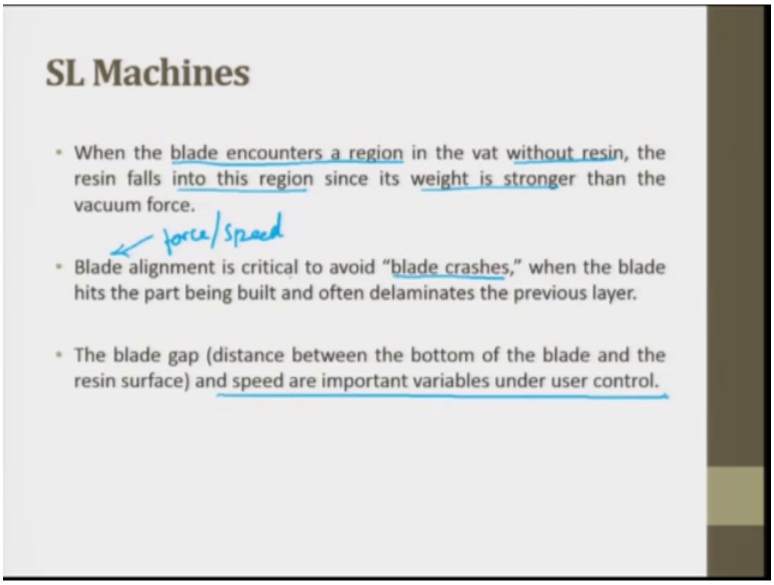

When the blade encounters a region in the vat without resin the resin falls into this region since the weight is stronger than the vacuum force so, you have understood. So, if there is a there is a small vacuum or if there is a small island which is created where there is no resin the blade encounters a region in the vat without resin the resin falls into the region since the weight is stronger than the vacuum force.

The blade alignment is critical to avoid "blade crashes" when the blade hits the path being built and often delaminates the previous layers. So, the when the blade moves it also moves with the certain force, force slash, speed when it is slightly higher when there is an undulation it will try to hit and do. The blade gap the distance between the bottom of the blade and the resin surface and the speed are important variables for the user to control.

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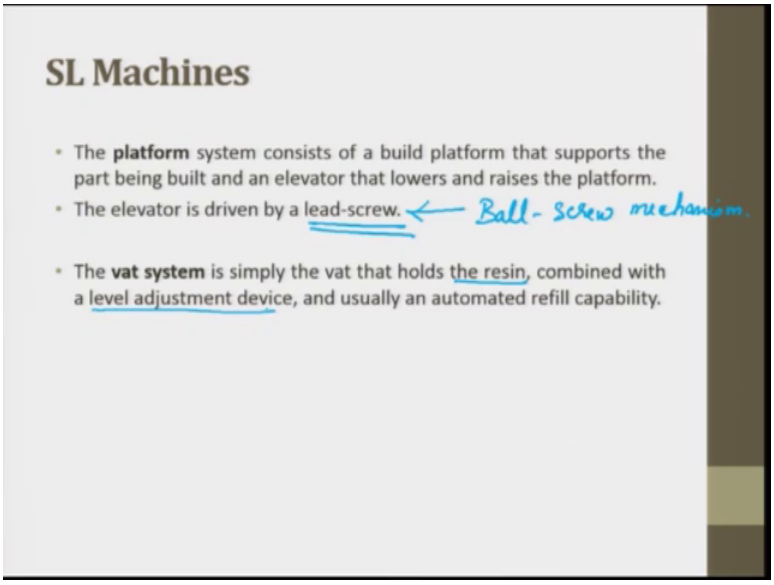

Platform consisting of a build platform that supports the path being built and an elevator that lowers and raises the platform the elevator is driven by a lead screw, lead screw is nothing, but a ball screw mechanism which is there in CNC machine so, you will have to this decide the resolution. A vat system is simply the vat that holds the resin combines with the level adjusting device and usually an automatic refill capability.

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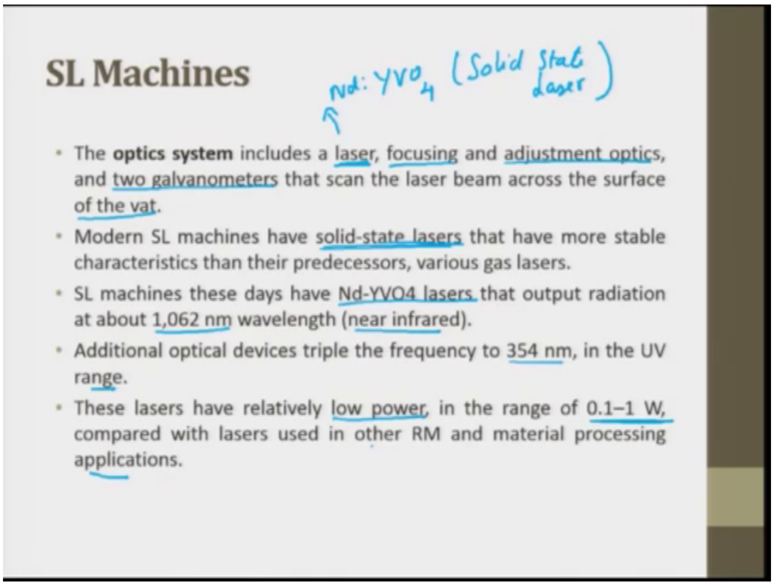

The optic system consists of a laser, focusing and adjusting optics and two galvanometers that scans the laser beam across the surface of the vat. Modern SL machines have solid state laser that have more stable characteristics than their predecessor various gas lasers were there. So, solid state lasers are more efficient. So, today we use Nd-YVO4 laser than that output radiation is 1064 in the near infrared. Additional optic devices triple the frequency of 354 nanometer in the UV range. So, we do the additional tripling doubling is there tripling is there it just divides so you get to this. The laser has a relatively low power in the range of 0.1 to 1 kilowatt as compared with laser used in other RM process and material processing application.

So, the important thing to notice laser this laser is a Nd -YVO4 laser which is nothing, but a solid state laser solid state laser. So, that it has a better life and it can help to give better resolutions.

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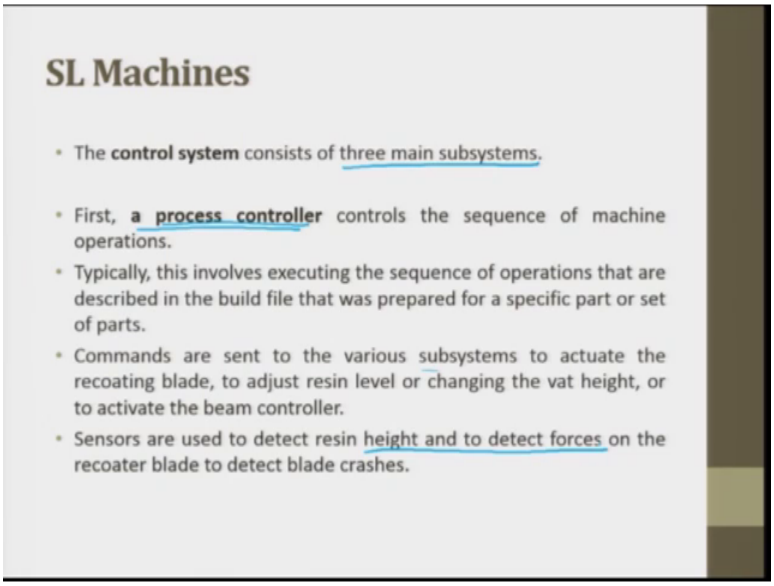

The control system has 3 main subsystems a process controller controls the sequence of machining operation. Typically, this involves executing the sequence of operations that are described in build file that was prepared for a specific part or a set of part process controller. Commands are sent to the various subsystems to actuate the recoating blade, to adjust the resin level or changing the vat height or to activate or to activate the beam controller is done by the process controller. The sensors are used to detect resin height and to detect force on the recoater blade to see whether there is any crash.

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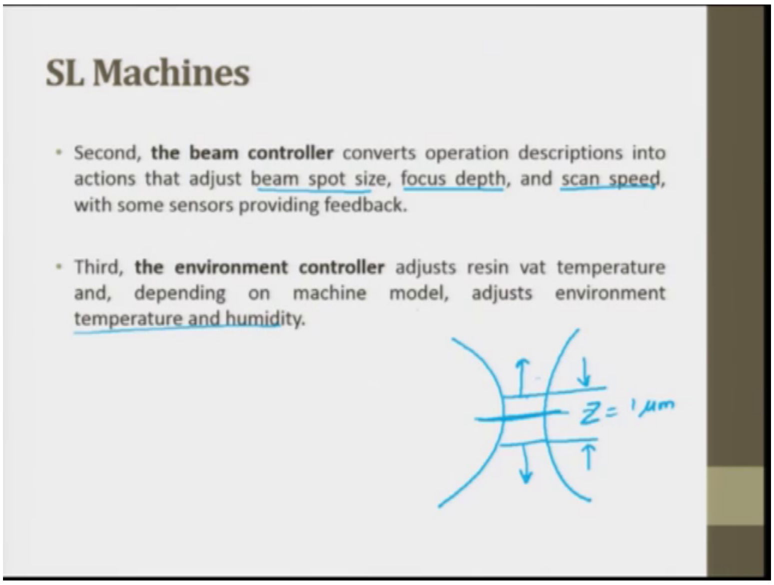

The beam controller converts the operating description into the action that adjust the spot diameter, focus depth, scan speed and other things spot diameter focus depth see when you look of a laser you always have a waist so, from here to here where this z, z will be in 1 micron or something like that. So, here will be your focal plane. So, from here to here wherever you place the focal plane so you can shift the up or down. So, that you get in this distance wherever it is you try to get a same performance and when you push it up you get into defocusing, when you push it down you get into defocusing, what is defocusing.

The beam diameter is expanded, moment beam diameter is expanded the flux reduces, the what is flux, power density flux is heat per joules per millimetre square that reduces. The environmental controller adjusts resin vat temperature and depending upon the machine model, adjusts the environmental temperature and humidity.

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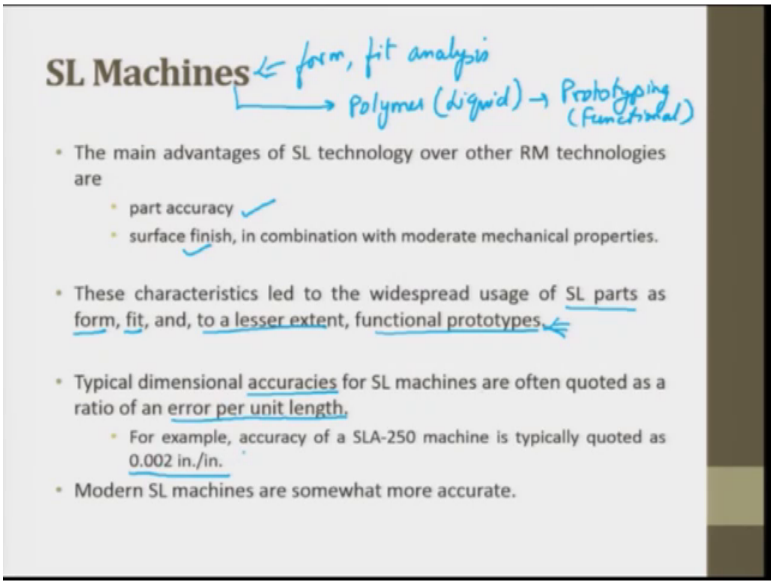

The main advantages of SL technology over the other RM parts is part accuracy and finishing. These characteristics lead to a wide range of usage of SL parts as form fit to a lesser extent functional prototype, it is to a lesser extent functional prototype SL machines are used for form fit analysis ok.

And since it is made out of polymer and that to which is starting from liquid the strengths are weak. So, it will be predominantly used for our prototyping only when we talk about prototyping form fit you can use and sometimes you can use for functional analysis also. The 2 dimensional accuracy for SL machines are often quoted as the ratio of an error per unit length, for example, it is 0.002 inch by inch. So, the error per unit length is told when we talk about the accuracies, accuracies are told in error per unit length modern SL s machines are somewhat better than this.

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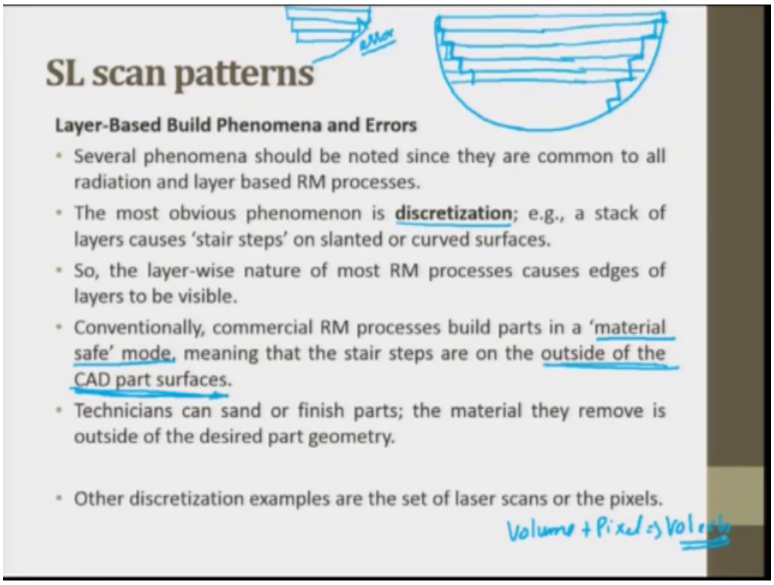

The layer based building phenomena and errors several phenomena should be noted since they are common to all the radiation and layer based RM process. The most obvious phenomena is discretization, example a stack of layers causing staircase effect. Suppose you have an object like this and if I have to divide it into several layers. So, what I get this is effect this effect is called as staircase effect or if I draw it on the other way around if I have a curve like this you can have.

So, you can see here I have exaggerated. So, you will have the effect like this because every layer is like this one layer, stacked on the other layer, stacked on the other layer. So, when you see that this is called as the error, error in the object what you formed and the error in the object what you got. So, all these things are happening because of the phenomenon called discretization. A stack of layer cause a staircase steps on slant or curved region in straight you will not get this effect whenever there is a change in slope you will have this.

So, layer wise nature of most RM process causes edges of layer to be visible, conventionally commercial RM processes build parts in a 'material safe mode' means that the staircase effects are on the outer side of the CAD part surface, please note down this material safe mode outside of a CAD part surface. Technicians can stand can sand or finish part the material they remove is outside the desired part geometry.

So, material safe mode means the staircase step are on the outer side of the CAD. So, when they sand it or finish it is only the outside so they get it. The other discretization examples are the set of laser scans on pixel. So, when we talk on pixel, it is here it is volume pixel so it is walk cells.

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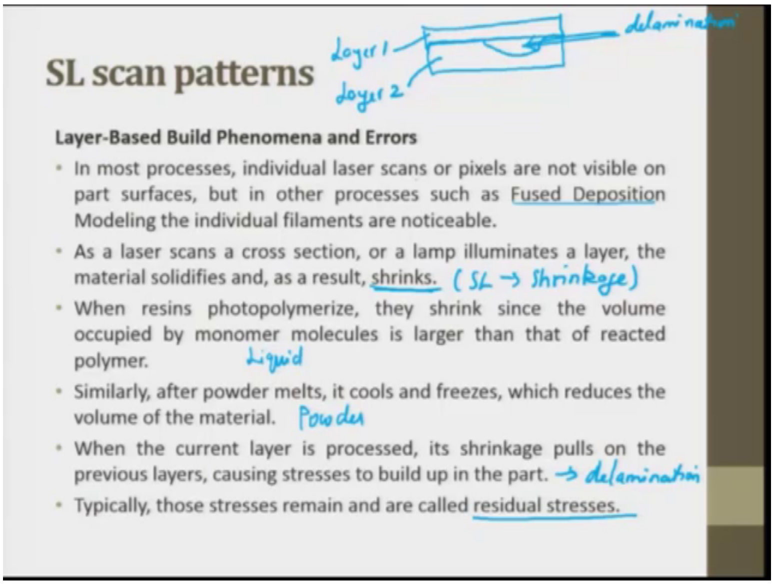

In most processes, individual laser scans or pixel are not visible on part surface, but in other processes such as Fused Deposition Model the individual filaments are noticeable in SL it is not there ok. As the laser scans or a cross section or a lamp illuminates a layer the material solidifies and as a result shrinks.

So, in SL shrinkage is one big shrinkage is one big phenomena which has to be taken care, when resin photopolymerize a polymerizes they shrink since the volume occupied by monomer molecules is larger than the reacted polymer so, there is a shrinkage phenomena happening. Similarly, after powder melts it cools and freezes which reduces the volume of the material. So, it also happens it is not only in liquid this is for a liquid and the next one is for a powder, the powder can be even metal powder, ceramic powder, polymer powder whatever.

When the current layer is processed, it shrinks pulls on the previous layer causing the stresses to be build in the parts. So, this leads to delamination, delamination means it is breaking suppose I have 1 layer, I have another layer something like this. So, this portion is called as delamination breaking this is layer 1, this is layer 2 breaking that is delamination, I have exaggerated just peeling off and this cause the stresses which are remained are called as the residual stresses which has a major influence on the dimensional accuracy of the part.

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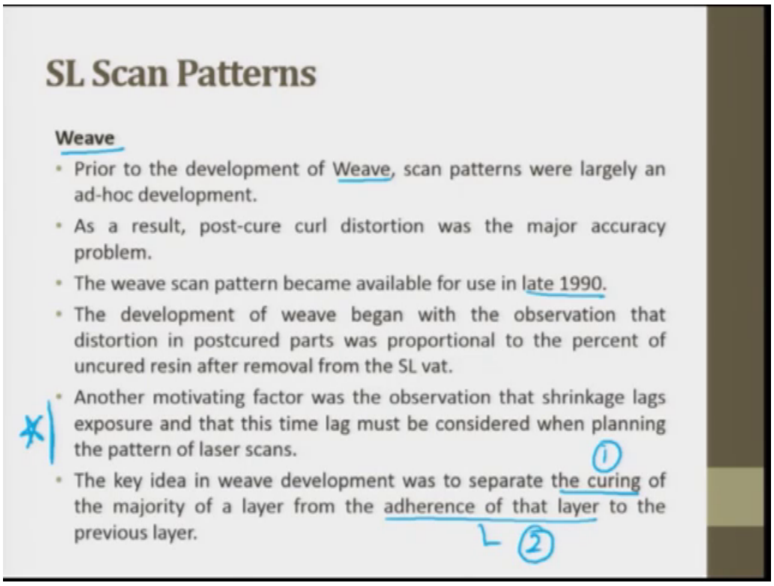

S L scan patterns weaver prior to the development of weave, scan patterns were largely an ad- hoc development weave. As a result post - cure curl distortion was the major accuracy problem. The weave scan pattern became available to use in late 1990s. The development of weave began with the observation that distortion in post curing parts was proportional to the percentage of the uncured resin after removal from the SL vat.

Another motivating factor was the observation that shrinkage lags exposure and that this time lag must be considered when planning a pattern on the scan layer this is very important was the observation that shrinkage lags exposure and that this time lag must be considered when planning the pattern of laser scan. The key idea in weave development was to separate the curing of the majority of the layer from the adherence of that layer to the previous layer. So, curing was to separate curing and adherence.

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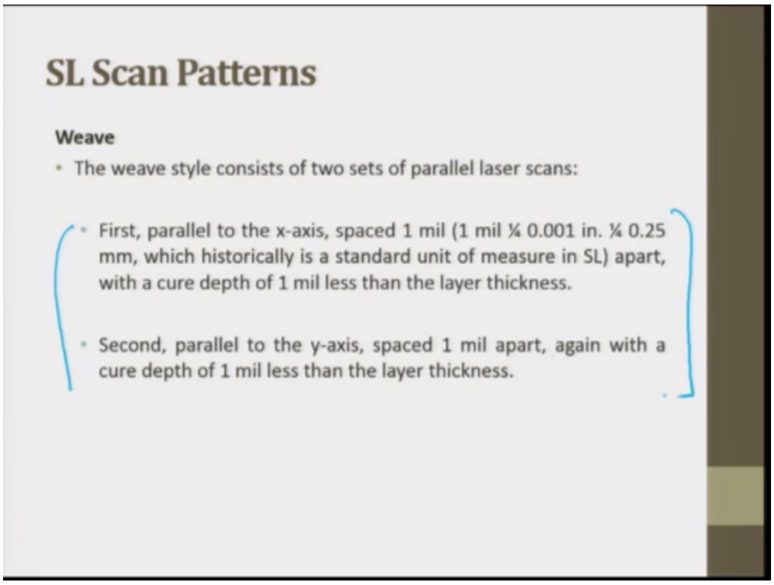

The weave style consists of 2 set of parallel laser scans, first parallel to the x - axis apart with a cured depth of 1 mil less than the layer thickness, second parallel to the y - axis spaced 1 mil apart again with the cure depth of 1 mil less than the layer thickness. So, this is how you form a weave, weave styling.

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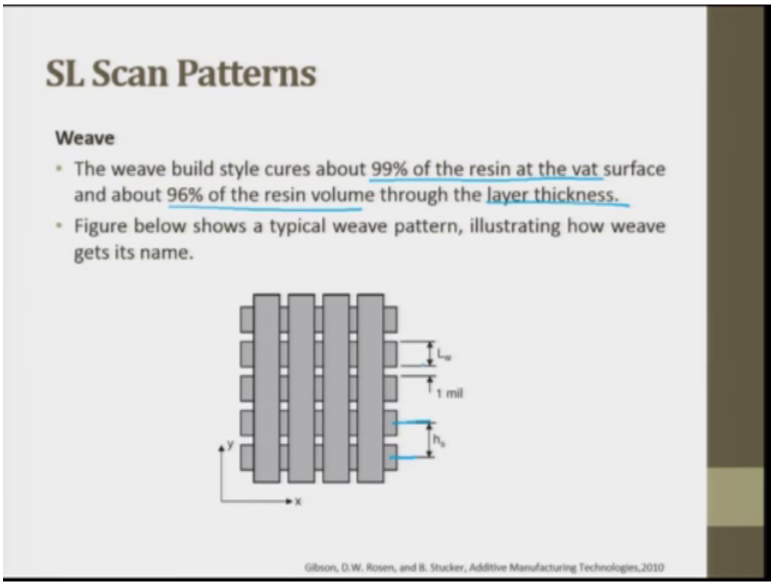

So, this is, what is the weave styling, the weave build style cures about 99 percent of the resin at the vat surface and about 96 percent of the resin volume through the layer thickness.

So, built style cures about 99 percent of the resin at the vat surface, vat surface on the top and about 96 percent of the resin volume through the layer thickness, figure below shows a typical view pattern illustrating how weave gets it is name. So, this is 1 mil in x this is the pitch between the 2 layers and this is the width of 1 1 layer.

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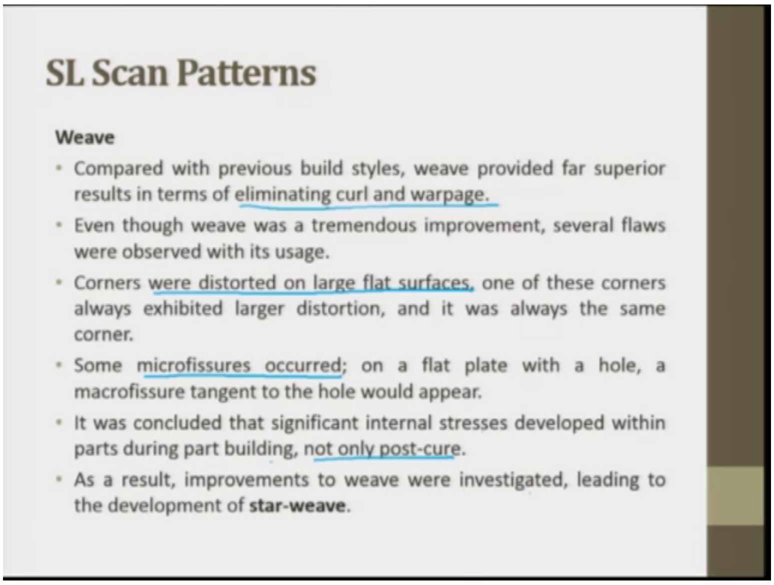

Comparing with previous build styles, weave provides far superior results in terms of eliminating curl and warpage. So, even though weaves was a tremendous improvement several flaws were observed with it is usage. Corners were distorted on large surface, microfissures occurred.

It was concluded that significant internal stress developed within part during the part building not only for curing. As a result, improvements of weave were investigated leading to the development of star - weaves. So, this weave pattern had a problem.

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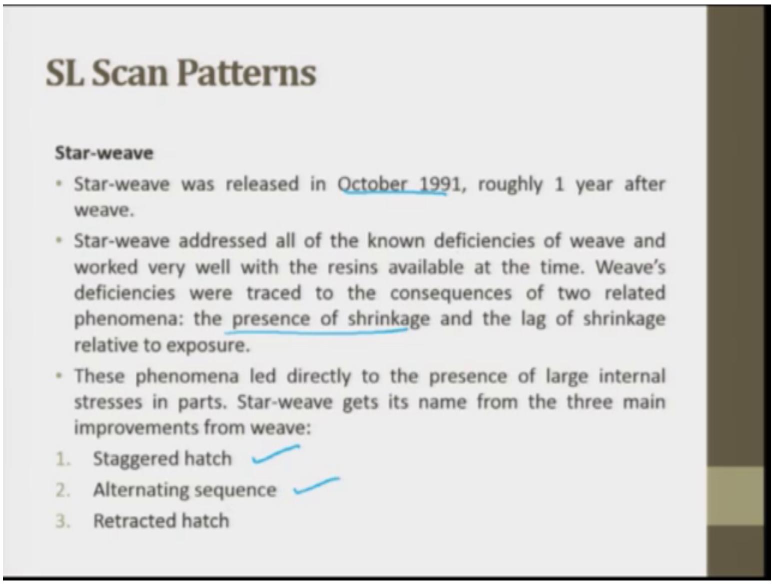

So, then they went for a star view.

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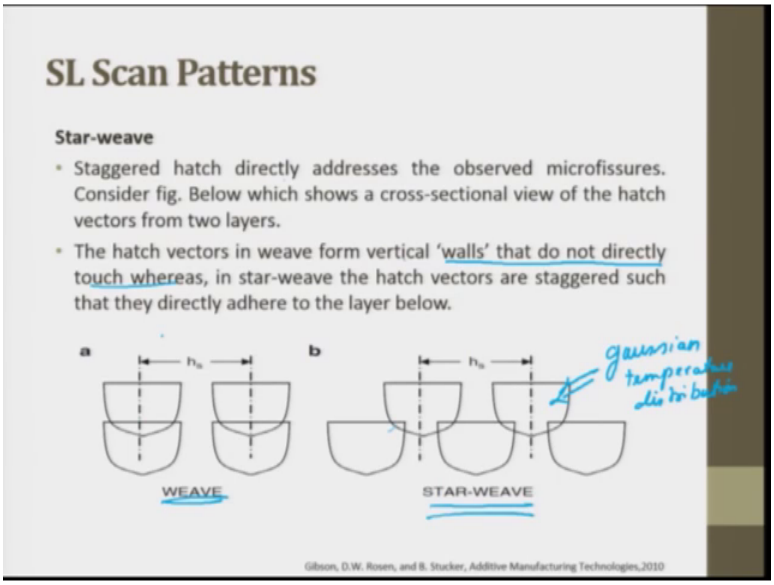

So, this is called the star weave we will see star weave, star weave was released in October 1991 roughly one year after the weave. Star weave addresses all the known deficiency of weave and worked very well with the resin available at times. Weave's deficiencies were traced to the consequences of two related phenomena, the presence of shrinkage and the lag of shrinkage related to the exposure.

These phenomenas led directly to the presence of large internal stresses in the parts, star weave gets it is name from 3 main improvement staggered hatch and then alternating sequence and retracted hatch.

So, this is weave this is star weave, this is weave staggered hatch directly addresses the observed microfissures considering figure below which shows the cross section view of the hatch vector between 2 layers ok. The hatch vector in weaves from vertical walls that do not directly touch whereas, in star weave the hatch vectors are staggered.

So, it is like stitching between 2 Gaussian distribution. So, that that is what it is so here you see it is completely and what is this is nothing, but a Gaussian, Gaussian thermal distribution temperature distribution temperature distribution star weave the hatch vector are staggered you such that they directly adhere to the layer below.

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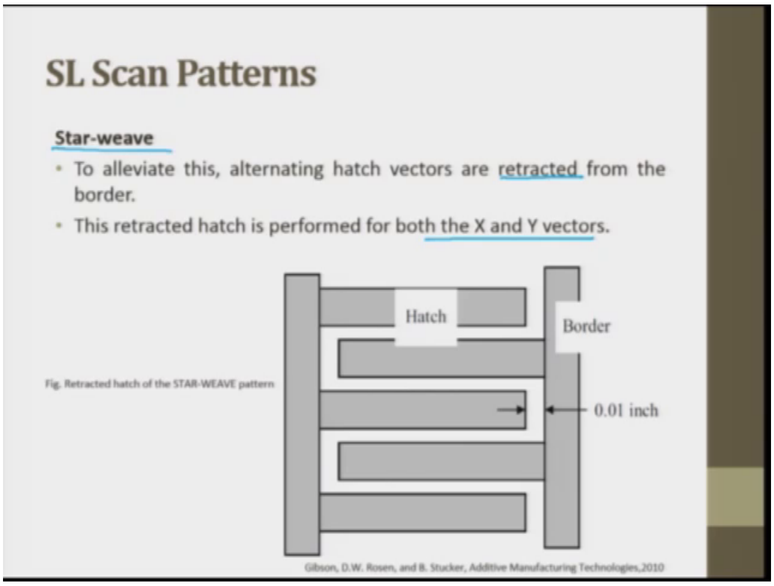

Star weave to alleviate this alternating hatch vectors are retracted from the boundaries. So, from the boundaries alone retracted from the boundaries. So, you can see these are the borders these are the hatches which are done. So, this retracted hatch is performed for both x and y vector. So, that what happens this is like a limiting end, which has on the both sides for doing it?

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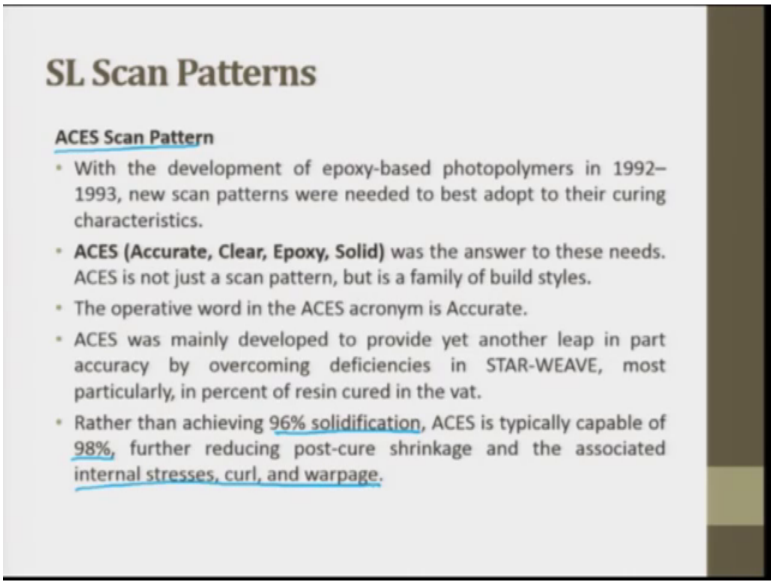

So, ACES scan patterns. So, this is accurate clean epoxy solid was the answer to this needs ACES is not just a scan pattern, but is a family of built style. The operating word of ACES acronym is accurate ok. So, rather than achieving 96 percent typically it talks about 98 percent curing so, it avoids internal stresses cure and warpage.

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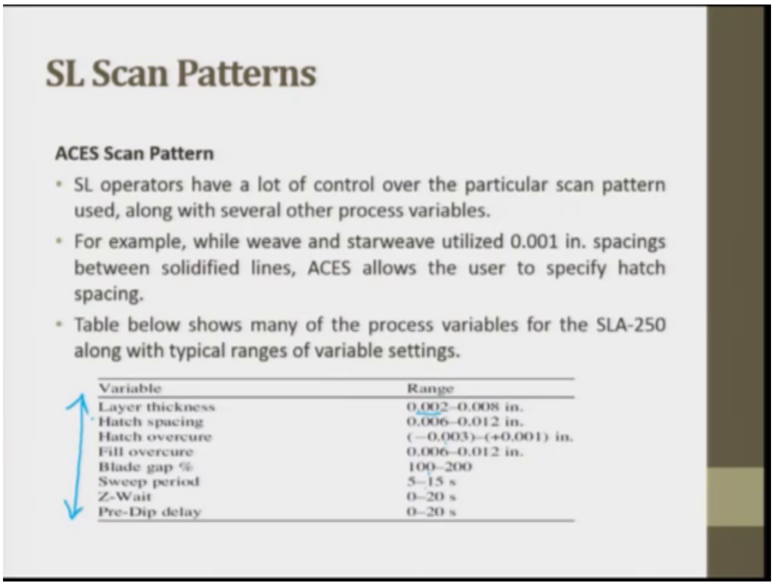

So, this is the scan pattern. So, here are the details varying layer thickness you can see hatch spacing, hatch overcure, fill overcure, blade gap percentage, sweeping time, Z waiting time and pre dip player. So, these are the set of details for various variables which is used in SL where ACES scan patterns are used.

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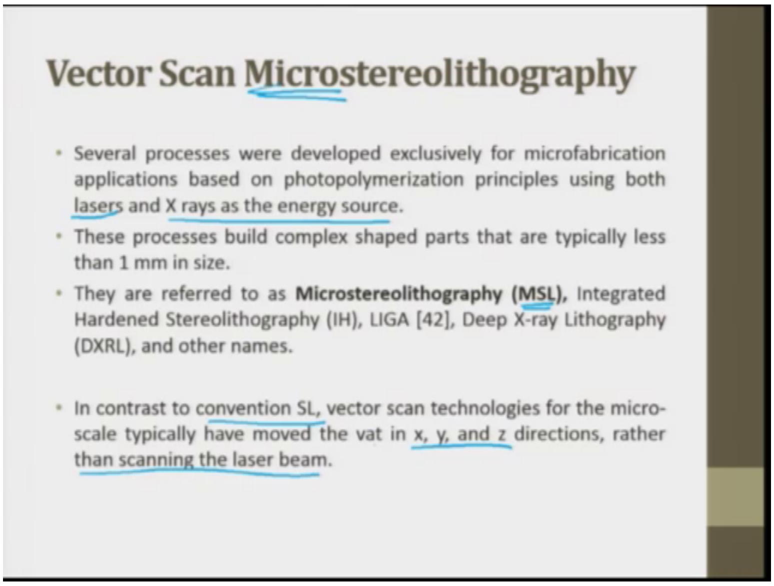

The vector scan microstereolithography is an advancement when the difference between stereolithography and microstereolithography is the word micro where the dimensions of the part whatever is getting developed is very small. Several processes were developed exclusively for micro fabrication application based on photopolymerization principle using the laser and X- ray as the energy source.

These processes build complex shaped parts that are typically less than 1 millimetre in size. They are referred as microstereolithography MSL, integrated hardened stereography, or deep X- ray lithography and other names. In contrast to the conventional SL vector scan technologies for the micro scale typically have moved the vat in x y z direction rather than scanning the laser beam in 2 directions.

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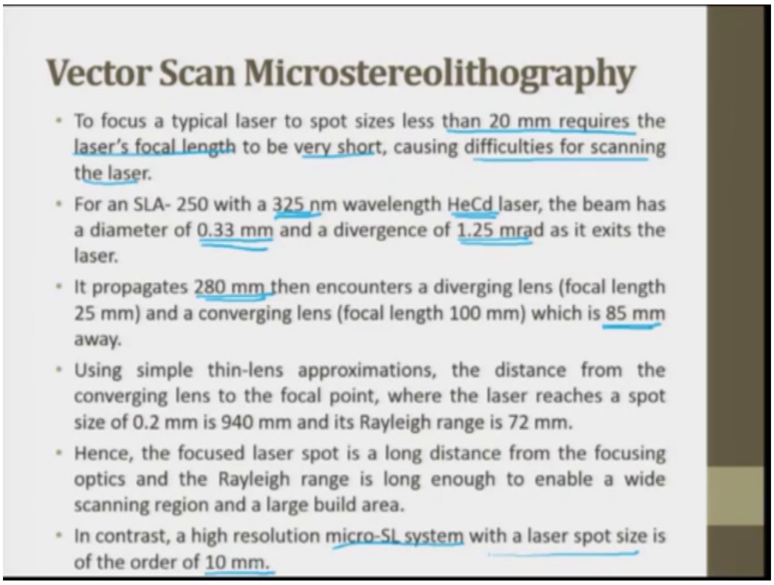

So, to focus a typical laser the spot size less than 20 millimetre requires a laser focal length to be very short, causing difficulty for scanning of the laser. So, laser focal length should be very short so that is what is used in microstereolithography. So, here we use 5 325 nanometre which is helium cadmium laser is used, the beam diameter is around about 0.33 and the divergent the divergence is 1.25 milliradians ok.

It propagates 280 millimetre than encountered a divergence lens and a convergence lens with it is 85 millimetre away. So, with this what we do is we start focusing it to a very stringent spot. So, in contrast the high resolution of microstereolithography system with laser spot size is in the order of 10 millimetre. So, here we talk about the Rayleigh effect, but these things you can read by yourself.

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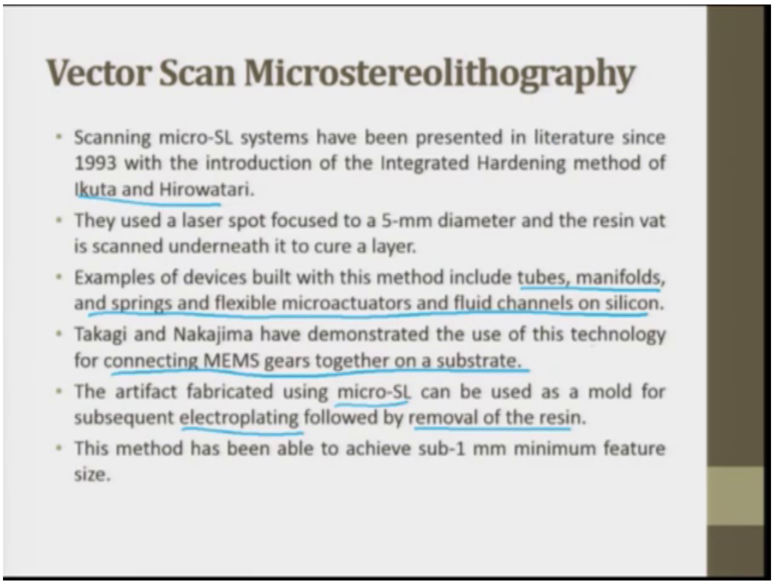

So, the examples of devices built with this method include tubes, manifolds, springs and flexible microactuators and fluid channels on silicon for various MEMS application. Takagi and Nakajima have demonstrated the use of this technology for connecting MEMS gear together on a substrate. The artifact fabricated using micro SL can be used as a mold for subsequent electroplating followed by removing of the resin. So, microstereolithography was used and the literature it was said that Ikuta and Hirowatari were the two who used it exhaustively.

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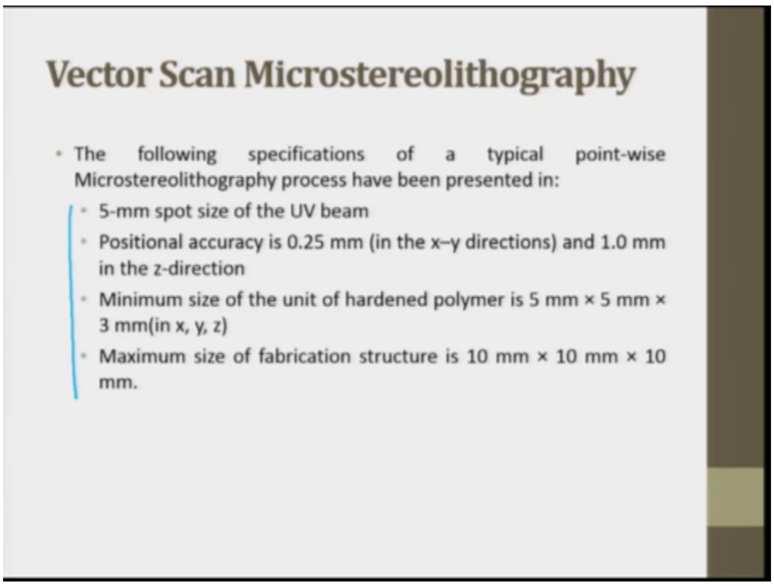

So, here are the resolutions which we talk about these are the capabilities of the machine.

So, 5 millimetre spot size of a UV beam position accuracy is 0.25 and then minimum size of unit of hardness is 5 millimetre cross 5 millimetre, the maximum size of fabrication structure is 10 millimetre cross 10 millimetre.

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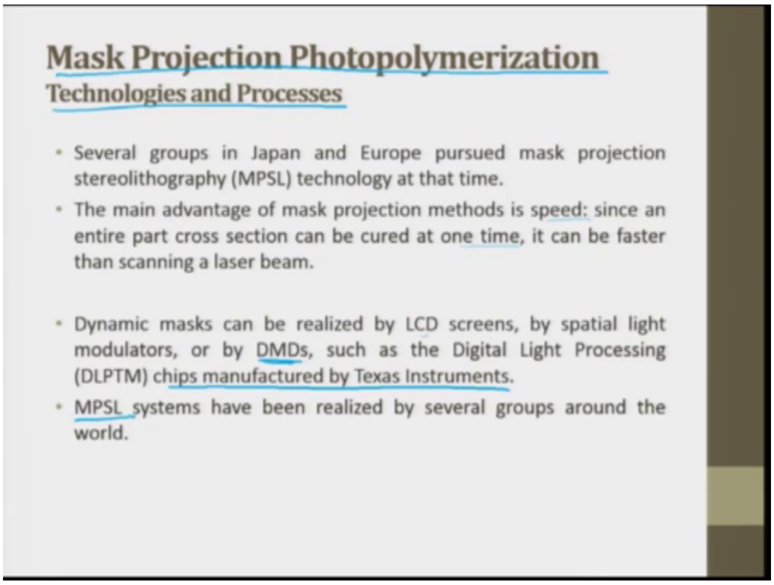

Mask projection photopolymerization technologies and processes, mask projection several groups in Japan and Europe pursued mass projections stereolithography technique. The main advantage of mass projection is the speed since the entire part cross section can be cured at one time it can be faster than the scanning of a laser. The dynamic mass can be realized by LCD screen by spatial lighting modulator or by DMDs such as digital light processing a chip manufactured by Texas can be used for producing this.

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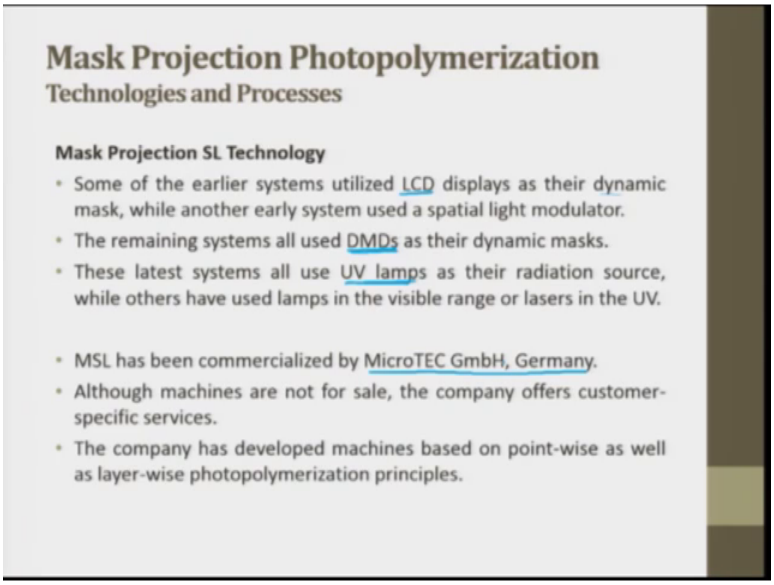

So, the mask projection stereolithography is much faster than the normal one, some of the earlier utilized LCD then it became LED as today led is exhaustively displaced as their dynamic mask while another early system such as spatial light modulator was used. The remaining system uses DMD. So, the latest system uses a UV lamp which is radiated and we get it. So, commercially which was this technique was commercially brought by MicroTEC Germany. So, they were doing this. So, they developed several of these devices for their application.

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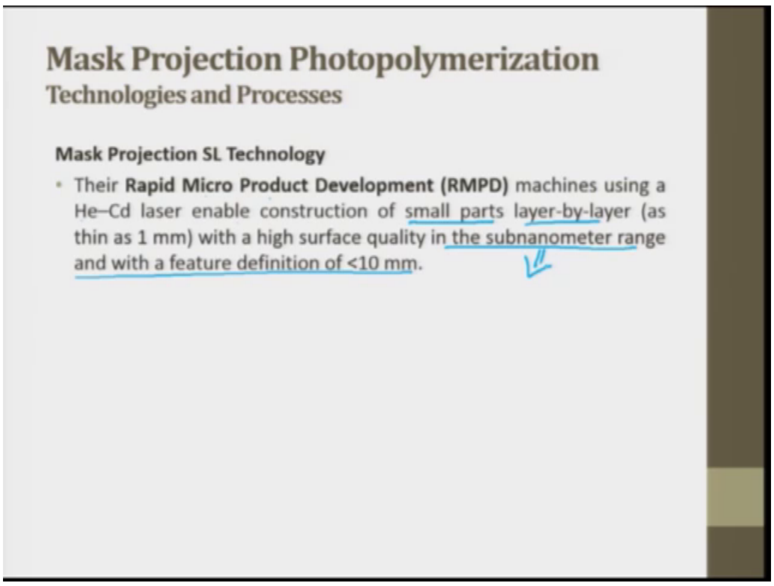

Their rapid micro product development machine using helium cadmium laser enabled construction of small parts layer by layer with a high quality in the subnanometer range and with a feature dimensions less than 10 millimetre. So, look at it feature size is in nanometre range.

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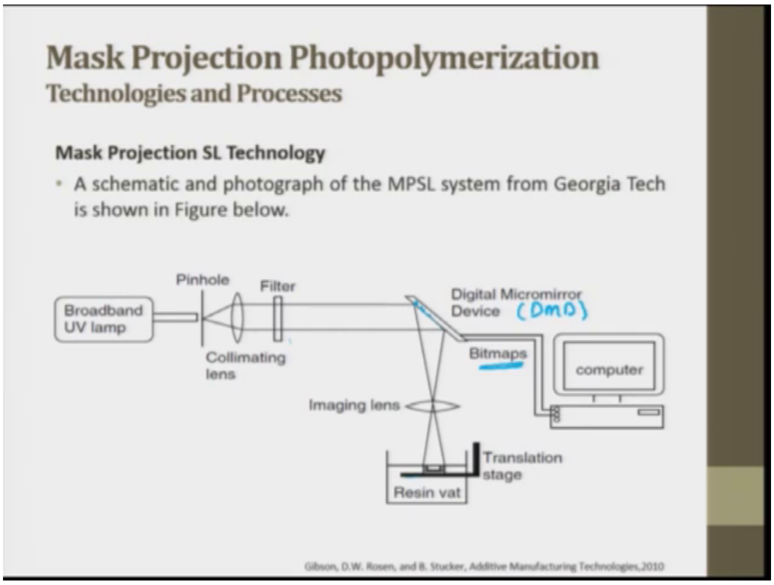

So, this is mask we have seen already we have a broadband UV lamp. So, it is passed through a pinhole, then you have a collimating lens, then you have a filter this filter hits at a DMD digital micromirror device. So, you have lot of small small small lenses. So, these lenses whatever image comes it forms here and it tries to form an imaging lens and this is formed on the surface. So, this is a resin vat translation stage a computer tries to give the information through this. So, here the DMD works on the computer input. So, we do bitmaps, bitmap information is given to the DMD and the mirrors swing switch on switch off and then try to create a mask this mask is projector onto the resin and you try to get it.

So, from Georgia tech shows this figure.

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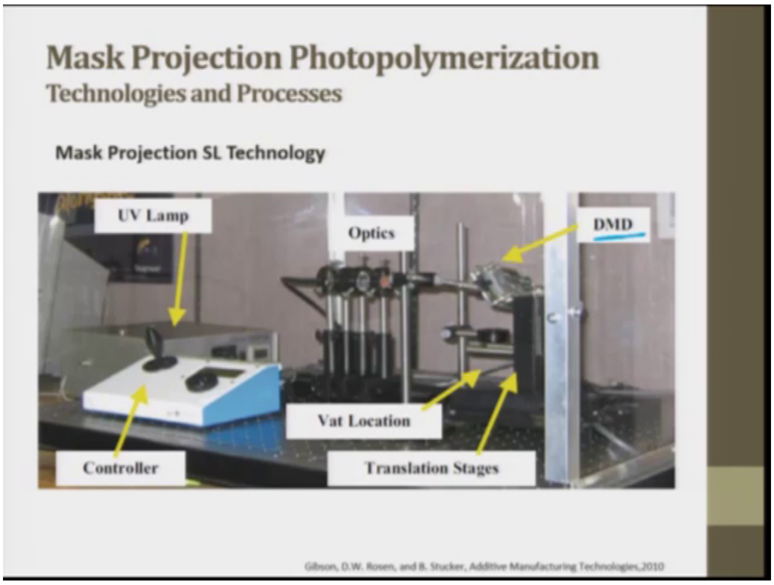

So, this is mask projection stereolithography technique. So, you have a controller, you have a UV lamp, this is a UV lamp, you had optics, you have DMD mirror and then you have a vat location and then you have a stage which moves up and down.

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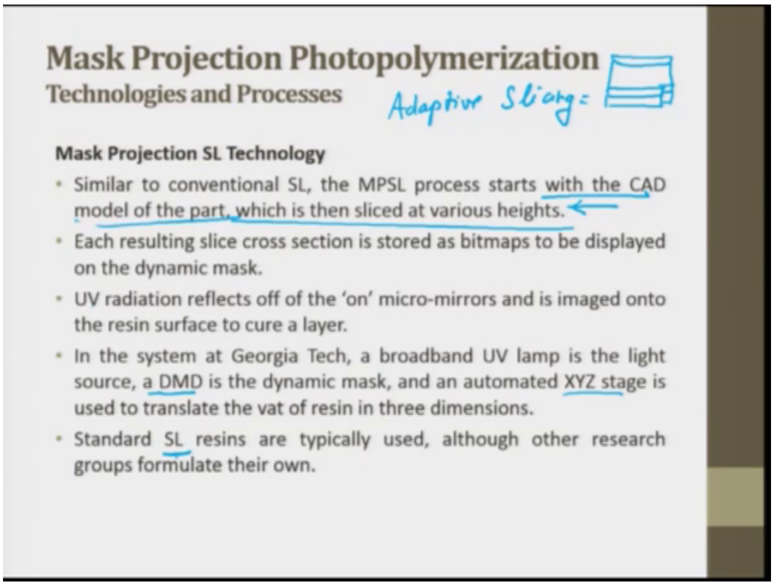

Similar to conventional SL MPSL process starts with the CAD model of a part which is then sliced at various heights. So, CAD model of a part which is then sliced that various heights.

So; that means, to say the layer thickness can be varied today we talk about a technique called as adaptive slicing or in which you can have slice like this slice like this slice like this slice like this. So, this is adaptive slicing layer of varying height. Each resulting slice cross section is stored as bitmaps to be displayed on the dynamic mask. UV radiation reflects off on micro mirror and is imaged onto the resin surface to cure a laser.

In a system at Georgia Tech a broadband UV lamp is the light source a DMD is the dynamic mask automated x y z stage is used to translate the vat of a resin in 3 dimension standard SL resins are typically used in this process.

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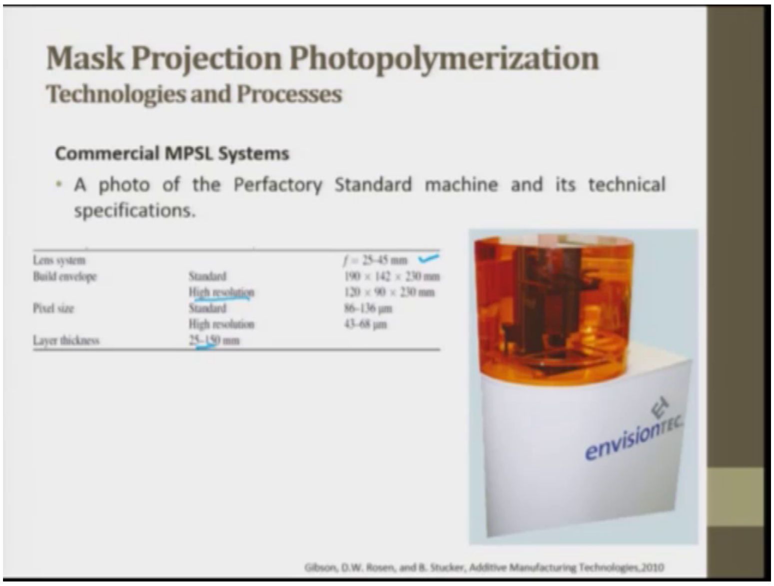

So, this is how the process looks like. So, you can see the lens system we have talked about the built envelope what is a built envelope; that means, to say the area within which the object can be done, look at the resolutions what we talk about and then pixel size, we talk about in microns and high resolution will be this. So, higher the resolution more better will be the clarity of the feature, but the longer will be the time of build you can see the layer thickness can vary from 25 millimeter to 150 millimeter.

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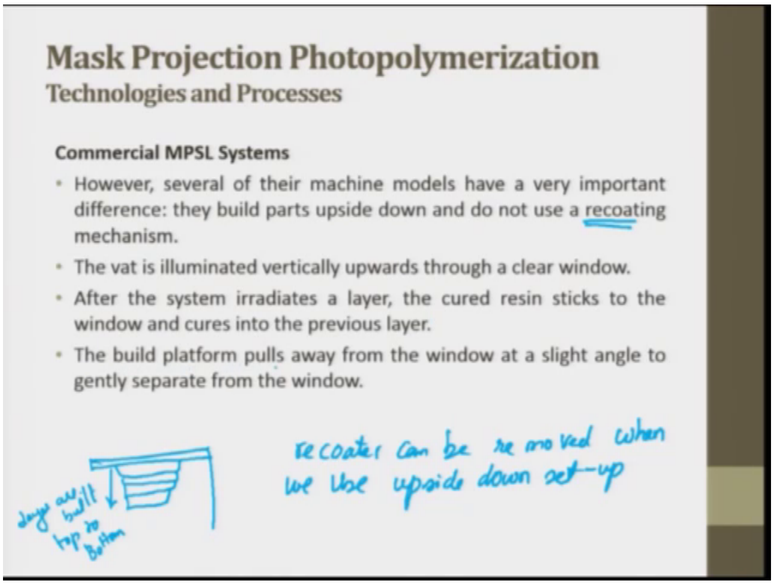

However, several of the machine models have been have a very important difference they build parts upside down and do not use a recoating mechanism. So, recoating can be removed re coater can be removed when we use upside down; that means, to say upside down setup; that means, to say when we go build the object like this. So, it is the layer grow or the layer are built in this layer are built top to bottom.

So, after the vat is illuminated vertically upward through a clear window after the system irradiates a layer the cured resin sticks to the window and cures into the previous layer. The window in platform pulls away from the window at a slight angle to gently separated from the windows.

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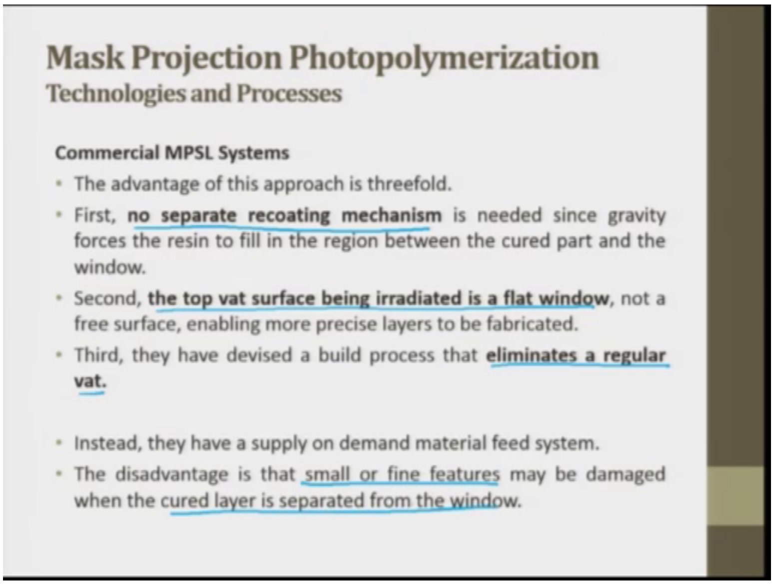

So, the advantage of this approach is in threefold, no separate recoating mechanism see you have also learned as and when you start introducing design for manufacturing we have to reduce as many parts as possible. So, if a coater subsystem itself can be removed the life of the machine is high. So, no separate recoating is there the top vat surface being irradiated in a flat window not a free surface enabling more precise layers to be fabricated.

The third one is going to be eliminating a regular vat. So, the devise process is done. So, instead of having a supply on heavy demand material feed system this can be used, the main disadvantage is small and fine features may be damaged when the cured layer is separated from the window.

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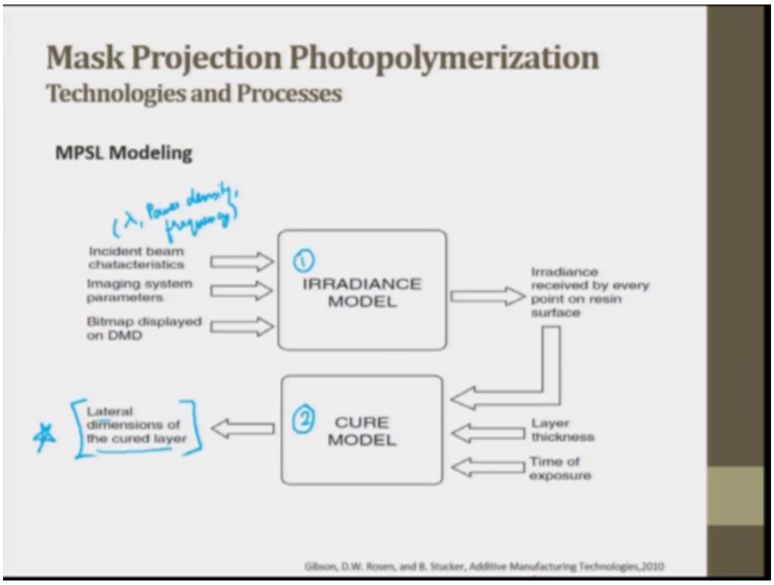

Mask projection photopolymerization so, this can be written as MPSL modeling. So, we have irradiance model and we have curing model. So, for this irradiance model incident beam characteristic is very important. So, here we talk about lambda, we talk about power density, then we talk about frequency ok, then imaging system parameters, then we will have bitmap display of DMDs.

So, all these things are input parameter for irradiance model from the irradiance model the irradiance received by every point on the resin surface is got out and from there it is led to curing. So, you have to do first set of modelling and second set of modelling in order to get the true result of rapid prototyping or to get the true result of the curing cycle.

So, here this comes to curing model so, in curing model we have to give an input of layer, thickness, we also have to give time of exposure, because this time of exposure we saw this is directly proportion to the shrinkage curing and other things. So, this inputs are given and finally, what we get is going to be lateral dimensions of the cured layer. So, this is very important. So, for this we have to do irradiance model and cure model.

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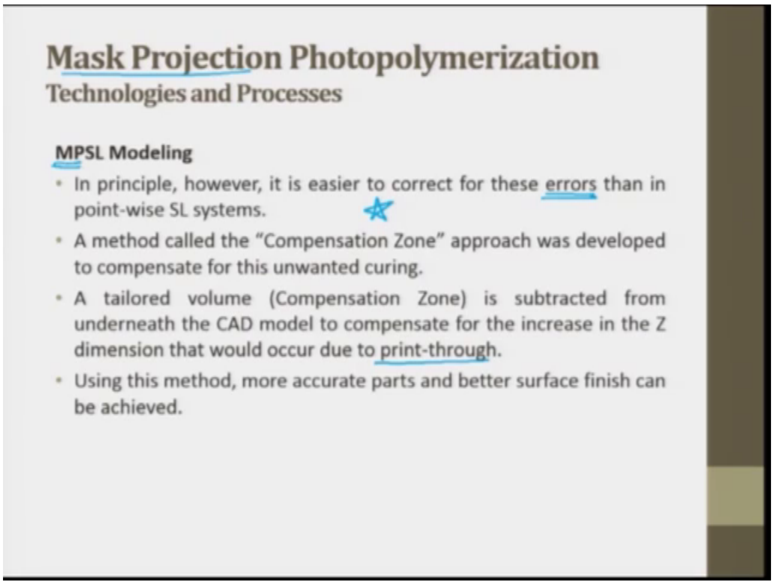

In principle; however, it is easier to correct from these errors than in point wise SL system. So, in this mask projection. So, here error correction is easy important point as compared to that of point right as point wise stereolithography.

The method called as "compensation zone" approach was developed to compensate for this unwanted curing. A tailored volume is subtracted from the underneath the CAD model to compensate for the increase in the Z dimension that could occur due to the print through. So, using this method more accurate parts and better surface finish parts can be achieved. So, this mask projection model is going to give or is giving a better result in terms of part geometry, accuracy and surface finish.

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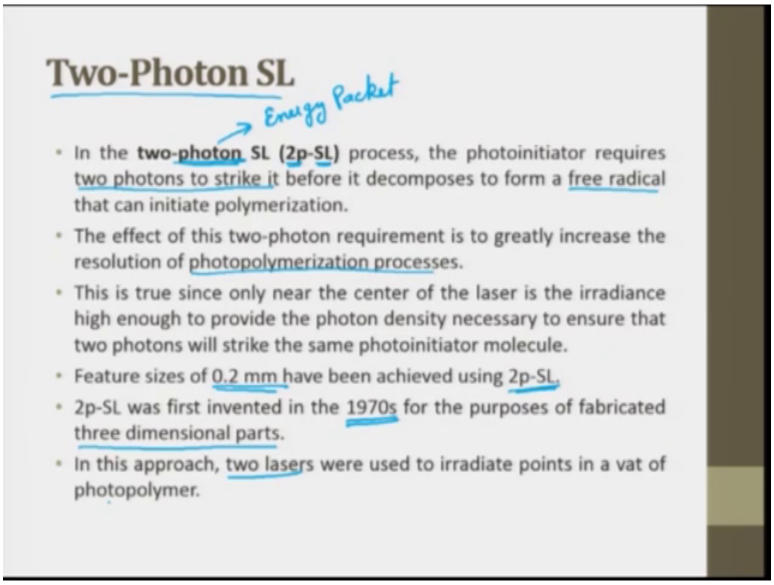

The next technique is two photon stereolithography we saw 3, point wise, then mask projection, then two - photon. In two photon stereolithography 2 p SL 2 p this is two photon, photon is the pulse is the energy packet light energy packet is nothing, but photon processes the photoinitiator requires two photons to strike it before it decomposes to form a free radical that can initiate polymerization.

So, two photons must strike must strike it decomposes to form a free radical that can initiate polymerization. The effect of this two photon requirement is to greatly increase the resolution of the photopolymerization process why because here we do not talk about layer by layer approach ok.

It is true since only near the centre of the laser is the irradiance high enough to provide the photon density necessary to ensure that the two photon will strike the same photoinitiator model. Features size of 0.2 millimeter have been achieved by two photon stereolithography, two photon stereolithography was first invented in 1970 for the purpose of fabrication of 3 dimensional parts. This approach of two lasers were used to irradiate points in a vat of a photopolymer. So, here the concept of layer by layer is not more pushed.

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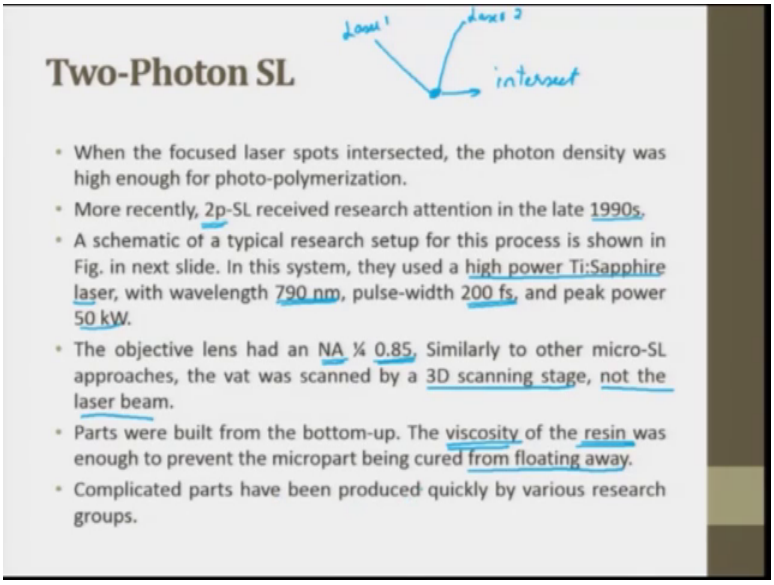

When the focused laser spot intersect laser 1, laser 2, intersect intersect the photon density was high enough to do photopolymerization. Most recently two photon stereolithography receives research attention in the late 1990s we will see the schematic diagram in the next slide.

So, here we use a high power Ti - Sapphire laser of wavelength 790 nanometer pulse width of 200 femtosecond, second, millisecond, microsecond, nanosecond, femtosecond and the peak power of 50 kilowatt.

The objective lens have a have a numerical aperture of 0.85, similar to the other micro stereolithography approach the vat was scanned by a 3 D scanning stage not by laser beam. The parts were built from the bottom up, the viscosity of the resin was enough to prevent the micro parts being cured from floating away, this is also very important. The viscosity of the resin plays a very important role here to do this, then complicated parts have been produced quickly by various research groups using this technique.

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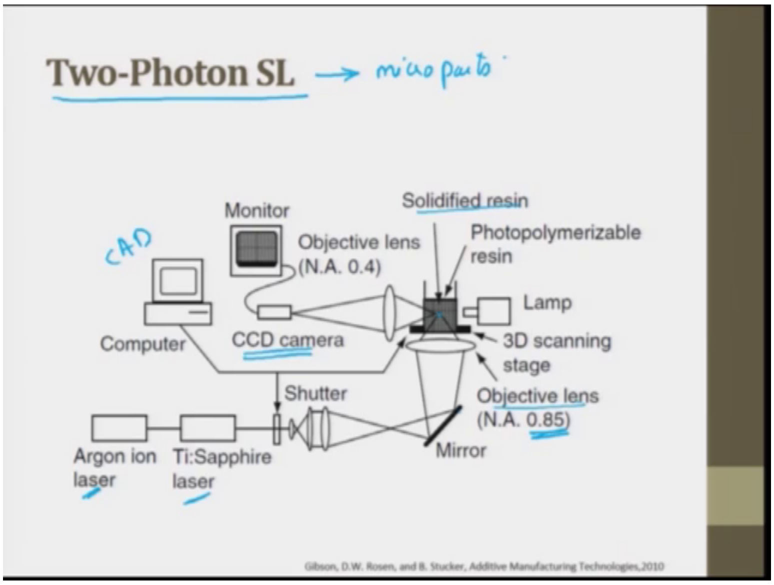

So, this is how a typical setup looks like you have a Argon ion laser, you have a Ti -Sapphire laser. So, this argon ion Ti Sapphire it initiates the photons are emitted then you have shutter it hits a mirror. So, this mirror use the objective lens of zero point objective lens with a numerical aperture of 0.85. So, it tries to strike the objective lens from the objective lens it focuses itself to a or it focuses towards the vat ok.

So, you have you have a lamp from here and then you have a CCD camera to see what is going on in the curing cycle. So, you have a computer from where the CAD data are inputted so it is given to the stage for moment. So, here is what is a photopolymerizable resin is there. So, this is solidified resin is on the top ok. So, this is the, this is on the top and then you get it done ok.

So, these are the 2 lasers which we use Argon ion and Ti Sapphire laser this is used for doing two photon stereolithography, two photon stereolithography for micro parts. So, CCD camera is only for visualizing what is happening. So, we use an objective lens here of 0.4, but the objective lens from the mirror which goes towards the photopolymerizable resin is going to have numerical aperture of 0.85.

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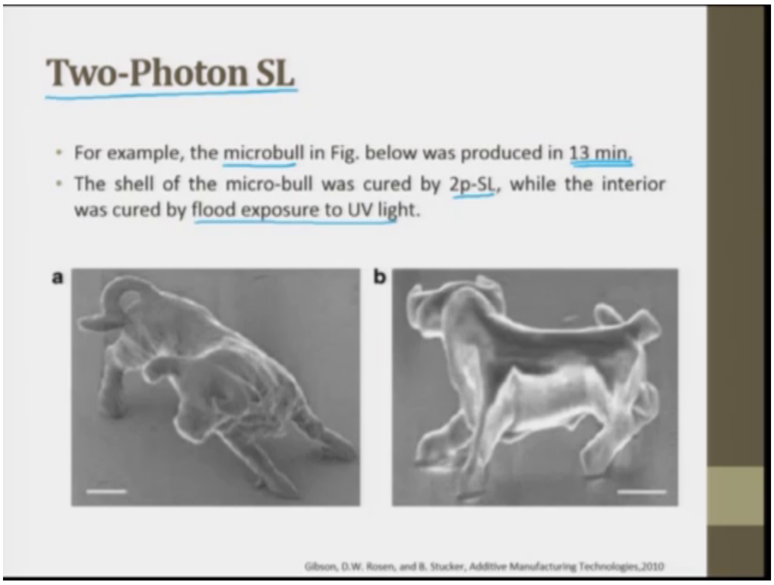

So, these are few examples which are done using two photon stereolithography. So, it is a microbull so, it is produced in 13 minutes in the shell of the micro bull was cured by two photon stereolithography while the interior was cured by flood exposure of UV. So, you see you can use this 2 and you can cure it, from this, what can be inferred, from this we can infer that if you want to make micro parts for prototyping stereolithography can be very very exhaustively used.

And in stereolithography also you can see whether to use a point wise, mask type or two-photon, two - photon is going to give you very high resolution and make very small feature parts. If you want to make large parts then you can always go for mask type and you can also go for point the mask projection stereolithography is going to give you good dimensional accuracy and large parts.

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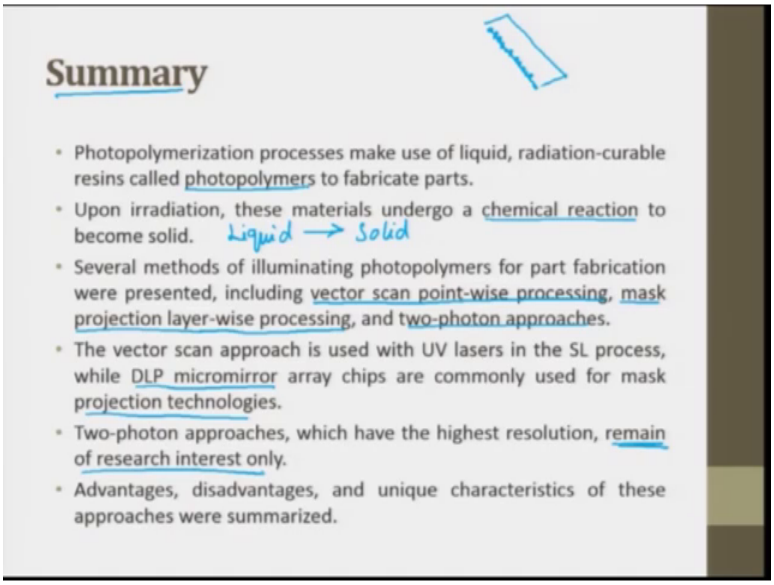

In summary photopolymerization process makes use of liquid, irradiation - curable resin called as photopolymers to fabricate parts. Upon irradiation these material undergo a chemical reaction and become a solid so, liquid becoming a solid converted to a solid by light. Several methods of illuminating photopolymer for part fabrication were presented, including vector scan point wise processing, mask projection laser wise layer wise processing and two photon approach.

The vector scan approach is used with UV laser in the stereolithography process, while DLP mirror DLP mirror array chips are commonly used for mask projection techniques because in vector it will pass through an objective lens. So, here in mask projection you will have a DLP the (Refer Time: 58:04) whatever we were talking about here you will have small mirrors and these mirrors can be swinged to get varying masks made and projected on to the liquid.

The two - photon approach which has the highest resolution remains of research interest only. The advantage, disadvantage and the unique characteristics of all these 3 approaches were summarized.

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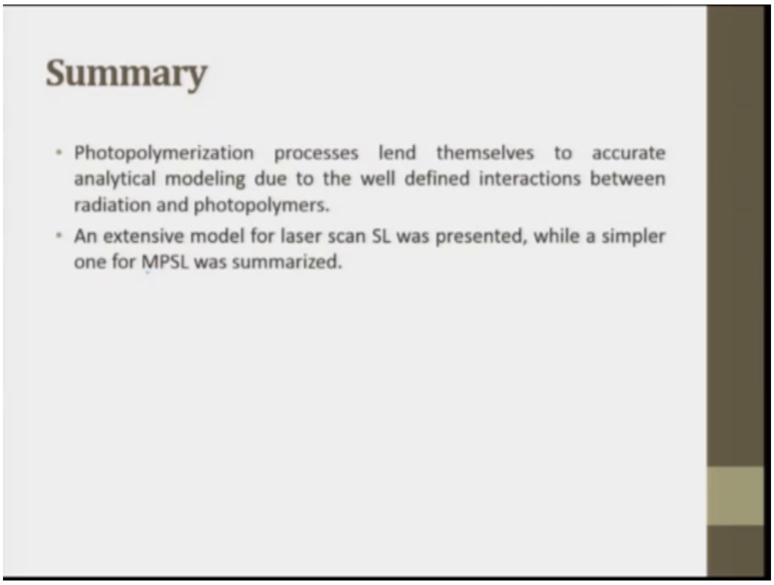

The photopolymerization processes lend themselves to accurate analytical model due to the well defined interaction between the radiation and the photopolymers. An extensive model for laser scan SL was presented while a simpler one for MPSL model was summarized.

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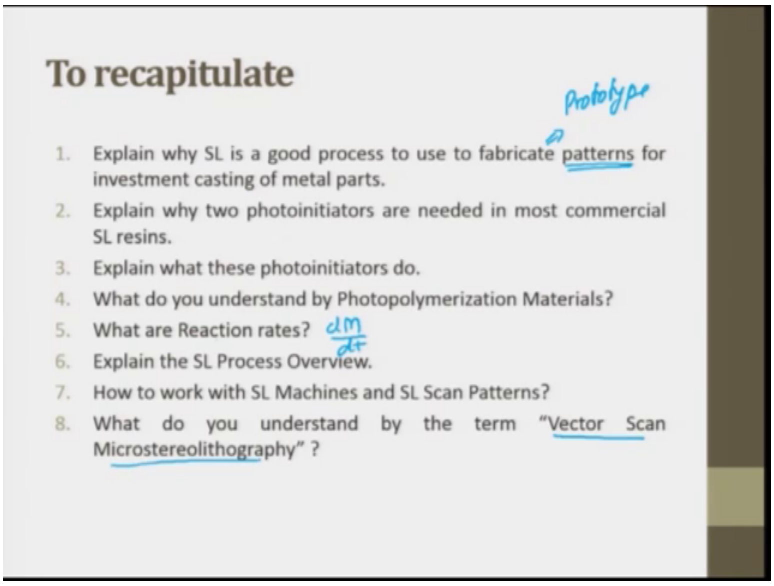

So, to recapitulate whatever we saw in this chapter we explained why SL is a good process to use to fabricate patterns for investment casting and metals. So, whatever comes out of it, whatever you fabricate it is a prototype. So, this prototype can be used for making patterns or the prototypes itself can be used as patterns. So, it is called as direct tooling or we can use this for making a mold so, it is called as indirect tooling.

Explain why 2 photo initiators are needed in most commercial stereolithography resin? Explains what these photoinitiators do, what do we understand by photopolymerization material? What are reaction rates we saw about the dm by dt I explain the SL process overview. How to work with SL machine and SL scanned patterns? What do we understand by the term vector microstereolithography? These are some of the points which we saw in this chapter.

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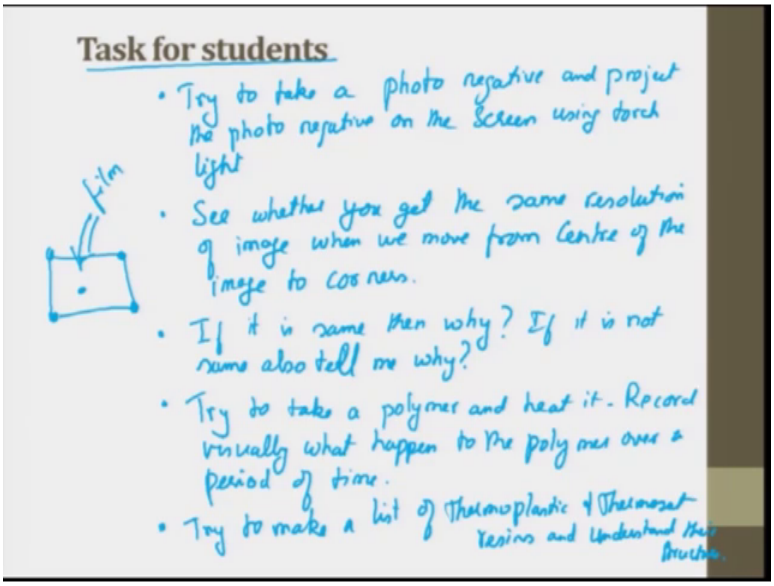

And now the task to students so, the task to students will be try to take a photo negative which in earlier days we use to try in a ordinary analogous camera. So, where and which we put a film roll we get a photo negative try to take a photo negative and project the photo negative on the screen right using torch light or whatever using some light source torch light. See whether you get the same resolution of image of image when we move from centre of the image to corners ok, 3 if it is same then why if it is not same, also tell me why.

Next try to take a try to take a polymer and heat it record visually what happens to the polymer over a period of time and finally, try to make a list of thermoplastic and thermoset resins and understand their structure ok. These are the homework these are small assignments which students you can try and this trying of these tasks will give you more insight about the process.

The question which the third question which I have put you put posted in front of you is a very very challenging question to answer by the way. So, you have to read lot of books and then try to figure out why is it, what I am trying to say is the image quality at this point, this point, this point will not be the same if it is same then why if it is not same why. So, this is the film.

Thank you very much.