philosophy. What is commitment? Relating it to the proverbial American breakfast of bacon and eggs, the chicken is involved, but the pig is totally committed. Top management provides a vision of the future and a time-to-market goal that product developers continually strive to meet and exceed. Inter-departmental processes must be put in place to fit the new concurrent engineering direction. Top management also provides the tools, in this case the computer systems and other high technology capabilities necessary for rapid communication Lastly, top management never accepts the status quo. Change, innovation, and improvement are continual. The "accelerators" of tomorrow will, by definition, emerge from nowhere. The competitors and the market will be taken by surprise; market shares and profitability will be affected. Time-to-market is tomorrow's competitive issue.

STEREOLITHOGRAPHY APPARATUS (SLA)

It is the first RP system developed by 3D systems of varencia in California, USA in 1996. First Model developed ewas 250/50 followed by 250/30,3500,5000 and 7000.

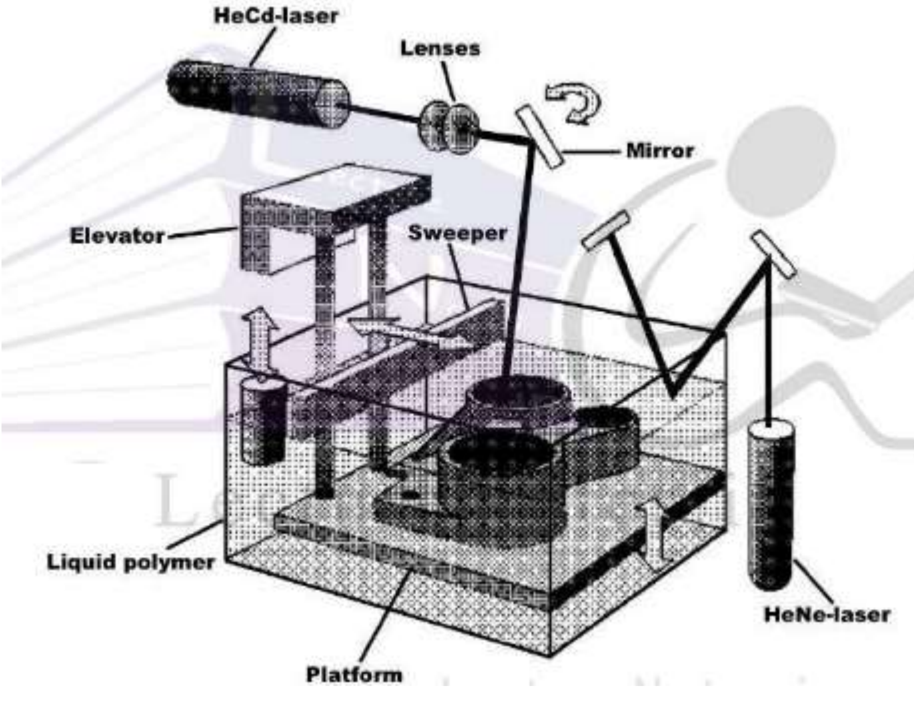

Fig: 1.8: Stereolithography Apparatus

Company

3D Systems was founded in 1986 by inventor Charles W. Hull and entrepreneur Raymond S. Freed. Amongst all the commercial RP systems, the Stereolithography Apparatus, or SLA® as it is commonly called, is the pioneer with its first commercial system marketed in 1988. It has been awarded more than 40 United States patents and 20 international patents, with additional patents filed or pending inter-nationally. 3D Systems Inc. is currently headquartered in 26801 Avenue Hall, Valencia, CA 91355, USA.

Products

Models and Specifications

3D Systems produces a wide range of machines to cater to various part sizes and throughput. There are several models available, including those in the series of SLA 250/30A, SLA 250/50, SLA-250/50HR, SLA 3500, SLA 5000, SLA 7000 and Viper si2. The SLA 250/30A is an economical and versatile SLA starter system that uses a Helium Cadmium (He–Cd) laser. The SLA 250/50 is a supercharged system with a higher-powered laser, interchangeable vats and Zephyr recoater system, whereas the SLA 250/50HR adds a special feature of a small spot laser for high-resolution application. All SLA 250 type systems have a maximum build envelope of 250* 250 *250 mm and use a He–Cd laser. For bigger build envelopes, the SLA 3500, SLA 5000 and SLA 7000 are available. These three machines use a different laser from the SLA 250 (solid-state $Nd:YVO_4$). The SLA 7000 (see Figure 1.8: below) is the top of the series. It can build parts up to four times faster than the SLA 5000 with the capacity of building thinner layers (minimum layer thickness 0.025 mm) for finer surface finish. Its faster speed is largely due to its dual spot laser's ability.

Figure 1.9: 3D Systems' SLA 7000 (Courtesy 3D Systems)

This means that a smaller beam spot is used for the border for accuracy, whereas the bigger beam spot is used for internal cross-hatching for speed. 3D Systems' new Viper si2 SLA system is their first solid imaging system to combine standard and high-resolution part building in the same system. The Viper si2 system lets you choose between standard resolution, for the best balance of build speed and part resolution, and high resolution (HR mode) for ultra-detailed small parts and features. All these are made possible by a carefully integrated digital signal processor (DSP) controlled high speed scanning system with a single, solid-state laser that delivers a constant 100 mW of available power throughout its 7500-hour warranty life. The Viper si2 system builds parts with a smooth surface finish, excellent optical clarity, high accuracy, and thin, straight vertical walls. It is ideal for a myriad of solid imaging applications, from rapid modelling and prototyping to injection moulding and investment casting.

Principle

SLA is a laser based Rapid Prototyping process which builds parts directly from CAD by curing or hardening a photosensitive resin with a relatively low power laser.

Stereolithography (SL) is the best known rapid prototyping system. The technique builds three-dimensional models from liquid photosensitive polymers that solidify when exposed to laser beam. The model is built upon a platform in a vat of photo sensitive liquid. A focussed UV laser traces out the first layer, solidifying the model cross section while leaving excess areas liquid. In the next step, an elevator lowers the platform into the liquid polymer by an amount equal to layer thickness. A sweeper recoats the solidified layer with liquid, and the laser traces the second layer on the first. This process is repeated until the prototype is complete. Afterwards, the solid part is removed from the vat and rinsed clean of excess liquids. Supports are broken off and the model is then placed in an ultraviolet oven for complete curing.

The SLA process is based fundamentally on the following principles:

(1) Parts are built from a photo-curable liquid resin that cures when exposed to a laser beam (basically, undergoing the photo polymerization process) which scans across the surface of the resin.
(2) The building is done layer by layer, each layer being scanned by the optical scanning system and controlled by an elevation mechanism which lowers at the completion of each layer.

These two principles will be briefly discussed in this section to lay the foundation to the understanding of RP processes. They are mostly applicable to the liquid-based RP systems described in this chapter. This first principle deals mostly with photo-curable liquid resins, which are essentially photopolymers and the photo polymerization process. The second principle deals mainly with CAD data, the laser, and the control of the optical scanning system as well as the elevation mechanism.

In this process photosensitive liquid resin which forms a solid polymer when exposed to ultraviolet light is used as a fundamental concept. Due to the absorption and scattering of beam, the reaction only takes place near the surface and voxels of solid polymeric resin are formed. A SL machine consists of a build platform (substrate), which is mounted in a vat of resin and a UV Helium-Cadmium or Argon ion laser. The laser scans the first layer and platform is then lowered equal to one slice thickness and left for short time (dip-delay) so that liquid polymer settles to a flat and even surface and inhibit bubble formation. The new slice is then scanned. Schematic diagram of a typical Stereolithography apparatus is shown in figure 1.9.

Process

3D Systems' stereolithography process creates three-dimensional plastic objects directly from CAD data.

The process begins with the vat filled with the photo-curable liquid resin and the elevator table set just below the surface of the liquid resin (see Figure 1.9: below).

The operator loads a three-dimensional CAD solid model file into the system. Supports are designed to stabilize the part during building.

The translator converts the CAD data into a STL file. The control unit slices the model and support into a series of cross sections from 0.025 to 0.5 mm (0.001 to 0.020 in) thick.

The computer-controlled optical scanning system then directs and focuses the laser beam so that it solidifies a two-dimensional cross-section corresponding to the slice

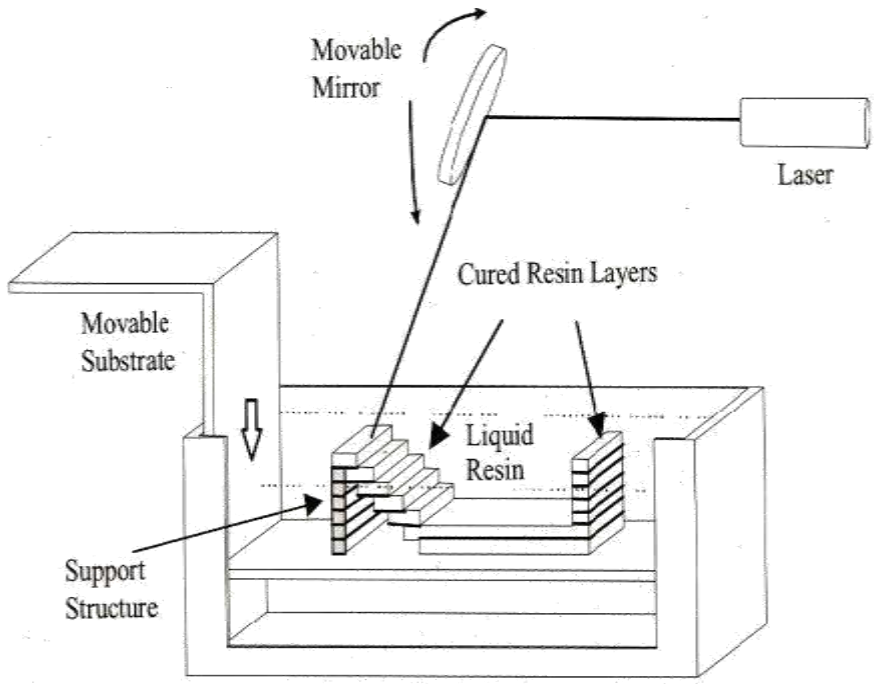

Fig. 1.10: Stereolithography Apparatus (SLA)

The computer-controlled optical scanning system then directs and focuses the laser beam so that it solidifies a two-dimensional cross-section corresponding to the slice on the surface of the photo-curable liquid resin to a depth greater than one-layer thickness. The elevator table then drops enough to cover the solid polymer with another layer of the liquid resin. A levelling wiper or vacuum blade (for Zephyr™ recoating system) moves across the surfaces to recoat the next layer of resin on the surface. The laser then draws the next layer. This process continues building the part from bottom up, until the system completes the part. The part is then raised out of the vat and cleaned of excess polymer.

The main components of the SLA system are a control computer, a control panel, a laser, an optical system and a process chamber. The workstation software used by the SLA system, known as 3D Light year exploits the full power of the Windows NT operating system, and delivers far richer functionality than the UNIX-based Maestro software. Maestro includes the following software modules:

(1) dverify™ Module. This module can be accessed to confirm the integrity and/or provide limited repair to stereolithography (STL)

files before part building without having to return to the original CAD software. Gaps between triangles, overlapping or redundant triangles and incorrect normal directions are some examples of the flaws that can be identified and corrected.

(2) *View™ Module*. This module can display the STL files and slice file (SLI) in graphical form. The viewing function is used for visual inspection and for the orientation of these files so as to achieve optimal building.

(3) *MERGE Module.* By using MERGE, several SLI files can be merged into a group which can be used together in future process.

(4) *Vista™ Module.* This module is a powerful software tool that automatically generates support structures for the part files. Support structures are an integral part to successful part building, as they help to anchor parts to the platform when the part is free floating or there is an overhang.

(5) *Part Manager™ Module*. This software module is the first stage of preparing a part for building. It utilizes a spreadsheet format into which the STL file is loaded and set-up with the appropriate build and recoat style parameters.

(6) *Slice™ Module.* This is the second stage of preparing a part for building. It converts the spreadsheet information from the *Part*

(7) *Manager™* module to a model of three-dimensional cross sections or layers.

(8) *Converge™ Module.* This is the third and last stage of preparing a part for building. This is the module which creates the final build files used by the SLA.

Table: 1.2: Summary specifications of SLA-250 machines (Source from 3D Systems)

Model	SLA 250/30A	SLA 250/50	SLA 250/50HR
SYSTEM CHARACTERISTICS			
	SmartStart. An economical and versatile SLA starter system.	A supercharged system with higher powered laser, interchangeable vats, and Zephyr recoating system.	A specialty system with small spot laser for high-resolution applications.
VAT CAPACITY			
Maximum Build Envelope	$250 \times 250 \times 250$ mm^3 $10 \times 10 \times 10$ in^3	$250 \times 250 \times 250$ mm^3 $10 \times 10 \times 10$ in^3	$250 \times 250 \times 250$ mm^3 $10 \times 10 \times 10$ in^3
VOLUME			
L (U.S. gal)	29.4 (7.8)	32.2 (8.5)	32.2 (8.5)
LASER			
Type	Helium Cadmium (He–Cd)	Helium Cadmium (He–Cd)	Helium Cadmium (He–Cd)
Wavelength	325 nm	325 nm	325 nm
Power at Vat @ hrs	@ 2000/hrs 12 mW	@ 2000/hrs 25 mW	@ 2000/hrs 6 mW
Warranty	2000 hrs	2000 hrs	2000 hrs
OPTICAL & SCANNING			
Dual Spot	No	No	No
Beam Diameter; Border @ l/e^2	0.24 +/– 0.04 mm (0.0095 +/– 0.0015 in)	0.24 +/– 0.04 mm (0.0095 +/– 0.0015 in)	0.07 +/– 0.01 mm (0.003 +/– 0.0005 in)
Beam Diameter; Hatch @ l/e^2	0.24 +/– 0.04 mm (0.0095 +/– 0.0015 in)	0.24 +/– 0.04 mm (0.0095 +/– 0.0015 in)	0.07 +/– 0.01 mm (0.003 +/– 0.0005 in)
RECOATING SYSTEM			
	Doctor	Zephyr	Zephyr

Model	SLA 250/30A	SLA 250/50	SLA 250/50HR
FEATURES			
Interchangeable Vat	Available Option	Yes	Yes
SmartSweep	No	No	No
Auto Resin Refill	No	No	No
SOFTWARE			
3D Lghtyear / Windows NT	With Build-station 3.8.4	With Build-station 3.8.4	With Build-station 3.8.4
Buildstation O/S	MS DOS	MS DOS	MS DOS
RESINS			
General Purpose	SL 5149, SL 5170, SL 5220	SL 5149, SL 5170, SL 5220	SL 5149, SL 5170, SL 5220
Durable	N/A	N/A	N/A
High Temperature	SL 5210	SL 5210	SL 5210
WARRANTY			
	1 yr from installation date	1 yr from installation date	1 yr from installation date

Table 1.3: Summary specifications of the rest of the SLA machines (Source from 3D Systems

Model	SLA 3500	SLA 5000	SLA 7000	Viper si2
SYSTEM CHARACTERISTICS				
	A mid-sized system up to 2.5 times faster than SLA 250 with productivity enhancements like auto resin refill and SmartSweep.	A large-frame system with three times the build volume of SLA 3500.	A supercharged large-frame system two times faster than SLA 5000 with the capability of building thinner layers for finer surface finish.	A dual-resolution, constant power, longer-life laser.
VAT CAPACITY				
Maximum Build Envelope	$350 \times 350 \times 400$ mm^3 $13.8 \times 13.8 \times 15.7$ in^3	$508 \times 508 \times 584$ mm^3 $20 \times 20 \times 23$ in^3	$508 \times 508 \times 600$ mm^3 $20 \times 20 \times 23.6$ in^3	$250 \times 250 \times 250$ mm^3 $10 \times 10 \times 10$ in^3
VOLUME				
L (U.S. gal)	99.3 (25.6)	253.6 (67)		32.2 (8.51)
LASER				
Type	Solid-State (Nd:YVO_4)			
Wavelength	354.7 nm			
Power at Vat @ hrs	@ 5000/hrs 160 mW	@ 5000/hrs 216 mW	@ 5000/hrs 800 mW	@ 7500/hrs 100 mW
Warranty	5000 hrs			7500 hrs
OPTICAL & SCANNING				
Dual Spot	No		Yes	
Beam Diameter; Border @ l/e^2	0.25 +/- 0.025 mm (0.010 +/- 0.001 in)			0.25 +/- 0.025 mm (0.010 +/- 0.001 in)
Beam Diameter; Hatch @ l/e^2	0.25 +/- 0.025 mm (0.010 +/- 0.001 in)		0.7615 +/- 0.0765 mm (0.03 +/- 0.003 in)	0.075 +/- 0.015 mm (0.0030 +/- 0.0006 in)
RECOATING SYSTEM				
	Zephyr			

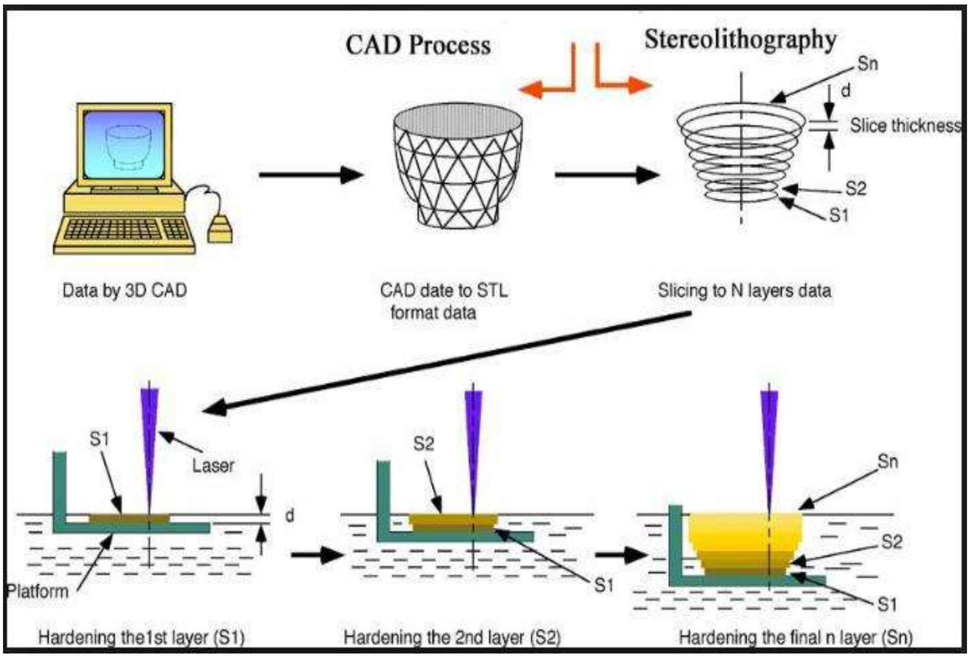

Fig.1.11: Stage wise SLA Process

In new SL systems, a blade spreads resin on the part as the blade traverses the vat. This ensures smoother surface and reduced recoating time. It also reduces trapped volumes which are sometimes formed due to excessive polymerization at the ends of the slices and an island of liquid resin having thickness more than slice thickness is formed. Once the complete part is deposited, it is removed from the vat and then excess resin is drained. It may take long time due to high viscosity of liquid resin. The green part is then post-cured in an UV oven after removing support structures. Overhangs or cantilever walls need support structures as a green layer has relatively low stability and strength. These overhangs etc. are supported if they exceed a certain size or angle, i.e., build orientation. The main functions of these structures are to support projecting parts and also to pull other parts down which due to shrinkage tends to curl up. These support structures are generated during data processing and due to these data grows heavily specially with STL files, as cuboid shaped support element need information about at least twelve triangles. A solid support is very difficult to remove later and may damage the model. Therefore a new support structure called fine point was developed by 3D Systems (figure 1.10) and is company s trademark. Build strategies have been developed to increase build speed and to decrease amount of resin by depositing the parts with a higher proportion of hollow volume. These strategies are devised as these models are used for making cavities for precision castings. Here walls are designed hollow connected by rod-type bridging elements and skin is introduced that close the model at the top and the bottom. These models require openings to drain out uncured resin.

OPERATIONS

i) The process begins with the solid model in various CAD formats.

ii) The solid model must consist of enclosed volumes before it is translated form CAD formats into .STL FILE

iii) The solid model is oriented into the positive octant of Cartesian coordinate system and then translate out Z axis by at least inches to allow for building of supports.

iv) The solid model is also oriented for optimum build which involves placing complex curvature in XY plane where possible and rotating for least Z heights as well as to where least amount of supports are required.

v) The .STL FILE is verified.

vi) The final .STL FILE one which supports in addition to original file are then sliced into horizontal cross section and saved as slice file.

vii) The slice file are then mashed to create four separates files that control SLA machine ending with extension L,R,V and PRM.

viii) Improvement one is V file.Le. Vector file. The V file contains actual line data that the laser will follow to cure the shape of the part.

ix) R file is the range file which contains data for solid or open fields as well as re-coater blade parameters.

The four build files are downloaded to SLA which begins building supports with platen adjust above the surface level. The first few support layers are actually cured into perforations into platen, thus providing a solid anchor for the rest of the part.

By building SLA uses laser to scan the cross section and fill across the surface of resin which is cured or hardened into the cross-sectional shape. The platen is lowered as the slices are completed so that more resin is available in the upper surface of the part to be cured. Final step is post processing.

POST PROCESSING

i) Ultraviolet Oven (Post Curing Apparatus)

ii) An Alcohol Bath

Clean the part in the alcohol bath and then go for final curing.

SLA Software

i) SLA CONTROL AND SET UP SOFTWARE: It operates on SLA and SLA machines. It has got three packages.

a) SLA VIEW: UNIX based system for viewing and positioning.

b) BRIDGE WORKS: UNIX based software for generating support structures.

c) SLA SLICE: slicing and system operation software.

ii) MAESTRO: UNIX based software.

iii) MS WINDOWS NT SOFTWARE (SD LIGHT YEAR): It is used for viewing, positioning, support generation and slicing, build station for operating SLA machine.

The SLA control and setup software has gone through various changes since the inception of the original MS-DOS version, which still operates on many SLA250 and SLA500 machines today. For a while, there were three packages required: a UNIX-based system **T\/f** for viewing and positioning (SLA View). another UNIX-based third-party software for generating support structures (Bridge-Works); and finally, the slicing and system operation software

(SLA Slice) located on the PC attached to the SLA machine. The next generation of software combined the view/positioning and the support generation into a more powerful UNIX-based software deemed Maestro™, but still maintained the same DOS software for operation of the system. The latest systems have Microsoft.

Windows NT® software for all operations: 3D Light year for viewing and positioning, support generation, and slicing; and Build station for operating the SLA machine. Fortunately, the newer software can still write code for the old DOS-operated machines as well.

Build Materials

Epoxy resin, Acrylate Resin

Epoxy resin has better material properties and less hazardous but require large exposure time for curing.

The SLA is a liquid-based RP process, which builds parts directly from CAD by selectively curing, or hardening, a photosensitive resin with a relatively low-powered laser. Polymerization is the process of curing a plastic or polymer by introducing a catalyst. In other words, polymerization links small molecules (monomers) to create larger chain molecules (polymers), this finally develops into a fully cross-linked solid polymer. Photo polymerization is essentially the same effect, only that the catalyst introduced is light energy.

The light energy kicks off a free-radical polymerization, where the liquid photopolymer is phased from liquid to gel to solid. The solid obtained is, however a thermo-set, so it can only be used one time after it has been cured (non-recyclable). In the SLA process, the light energy is introduced by a focused laser, which selectively cures the resin in a desired shape following a CAD file. The original SLA build materials were acrylate based. They were improved upon by epoxy-based materials, also known as the ACES (Acrylic Clear Epoxy System) build style. The epoxy materials provide advantages over the acrylate resins in that they have better materials properties and are less hazardous. The integration of the epoxies did require, though, longer exposure time for cure as well as higher-powered lasers. There are now a wide variety of resins available not only from the vendor but also from third-party vendors as well. The competitive market continues to open up with higher-performance build materials at slightly lower costs. Resins can be purchased to improve resolution, temperature capacity, or even speed of the build.

The SLA Hardware

The build chamber of SLA contains

a) A removable VAT that holds the buld resins.
b) A detachable perforated build platen on a Z axis elevator frame
c) An automated resin level checking apparatus
d) VAT has a small amount of Z movement capability which allows computer to maintain a exact height per layer.
e) A recoated blade rides along the track at the top of the rack and serves to smooth the liquid across the part surfaces to prevent any rounding off edges due to cohesion effects.
f) Some systems have Zaphyrrecoater blade which actually softens up resin and delivers it evenly across the past surface.
g) Behind the build chamber resides the laser and optics required to cure resin.
h) Laser unit is long rectangular about feet long and remains stationary.

The build chamber of the SLA contains a removable vat that holds the build resin, a detachable, perforated build platen on a –z axis elevator frame, and an automated resin-level checking apparatus. The vat has a small amount of -z movement capability, which allows the computer to maintain the exact height per layer. A recoated blade rides along a track at the top of the vat, and serves to "smooth" the liquid across the part surface to prevent a rounding of edges due to cohesion effects. Some systems now have a Zephyr recoated blade, which actually siphons up resin and delivers it evenly across the part surface. In an enclosed area above and behind the build chamber, resides the laser and optics required to cure the resin. The laser unit is long and rectangular, about 4 feet long, and remains stationary. The laser beam is transferred to the part surface below by a series of optics, the final of which moves to scan the cross section of the part being built. Also required, however, are the post processing units; an ultraviolet oven call the Post Curing Apparatus (PCA); and an alcohol bath large enough to hold entire build platens with parts attached. Parts are washed in the alcohol or a similar solvent immediately after being removed from the machine (while still attached to the build platen). This step removes any extra resin that clings to the surfaces of the part. After the final supports are removed, with some build styles the parts are required to be placed in the PCA to finish fully curing.

- **The main advantages of using SLA are:**
- Parts have best surface quality
- High accuracy
- High speed
- Finely detailed features like thin vertical walls, sharp corners & fall columns can be fabricated with ease.

(1) *Round the clock operation.* The SLA can be used continuously and unattended round the clock.

(2) *Good user support.* The computerized process serves as a good user support.

(3) *Build volumes.* The different SLA machines have built volumes ranging from small to large to suit the needs of different users.

(4) *Good accuracy.* The SLA has good accuracy and can thus be used for many application areas.

(5) *Surface finish.* The SLA can obtain one of the best surface finishes amongst RP technologies.

(6) *Wide range of materials.* There is a wide range of materials, from general-purpose materials to specialty materials for specific applications.

The main disadvantages of using SLA are:

- It requires post processing i.e.post curing
- Careful handling of raw materials required
- High cost of Photo Curable Resin

(1) *Requires support structures*. Structures that have overhangs and undercuts must have supports that are designed and fabricated together with the main structure.

(2) *Requires post-processing.* Post-processing includes removal of supports and other unwanted materials, which is tedious, time consuming and can damage the model.

(3) *Requires post-curing.* Post-curing may be needed to cure the object completely and ensure the integrity of the structure.