Rapid Prototyping Processes: Chapter 5

Rapid Prototyping (RP)

A family of fabrication processes developed to make engineering prototypes in minimum lead time based on a CAD model of the item.

- Traditional method is machining
  - Can require significant lead-times – several weeks, depending on part complexity and difficulty in ordering materials.
- RP allows a part to be made in hours, given that a computer model of the part has been generated on a CAD system.

History of RP

The first type of RP system was Stereo-lithography introduced 1986 by 3D Systems based on the work of **Charles Hull**.

This RP process for fabricating a solid plastic part out of a photosensitive liquid polymer using a directed UV/laser beam to solidify the polymer.

- Part fabrication is accomplished as a series of layers - each layer is added onto the previous layer to gradually build the 3-D geometry.

RP – Two Basic Categories

1. Material removal prototyping - machining, using a dedicated CNC machine that is available to the design department on short notice
   - Starting material is often metals/alloy
     - Easy to machine Hi-Fi prototypes
   - The CNC machines are often small - called desktop machining
2. Material addition prototyping- adds layers of material one at a time to build the solid part from bottom to top

Starting Materials in Material Addition RP

There are various ways to classify the RP techniques that have currently been developed

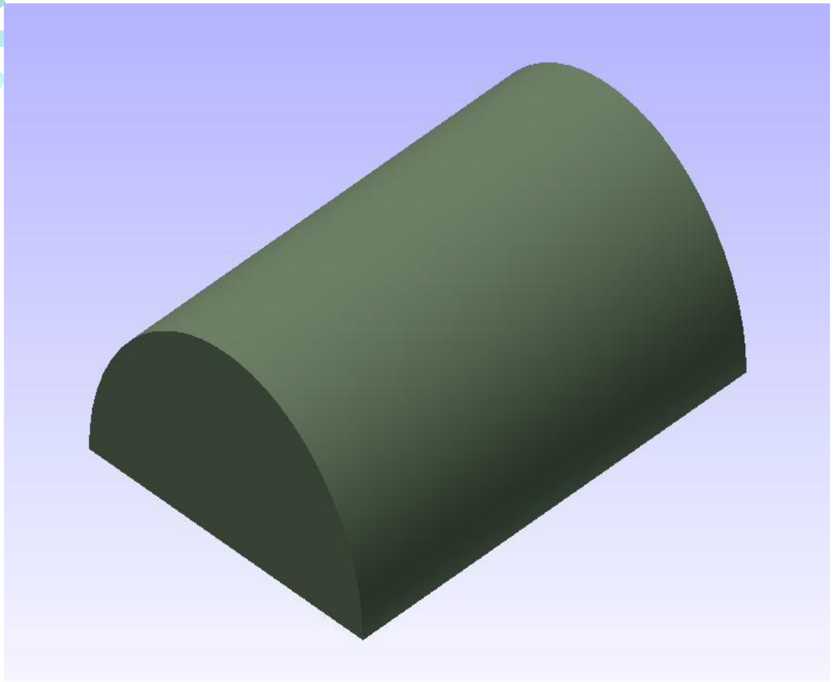
1. Liquid monomers that are cured layer by layer into solid polymers
2. Powders that are aggregated and bonded layer by layer
3. Solid sheets that are laminated to create the solid part

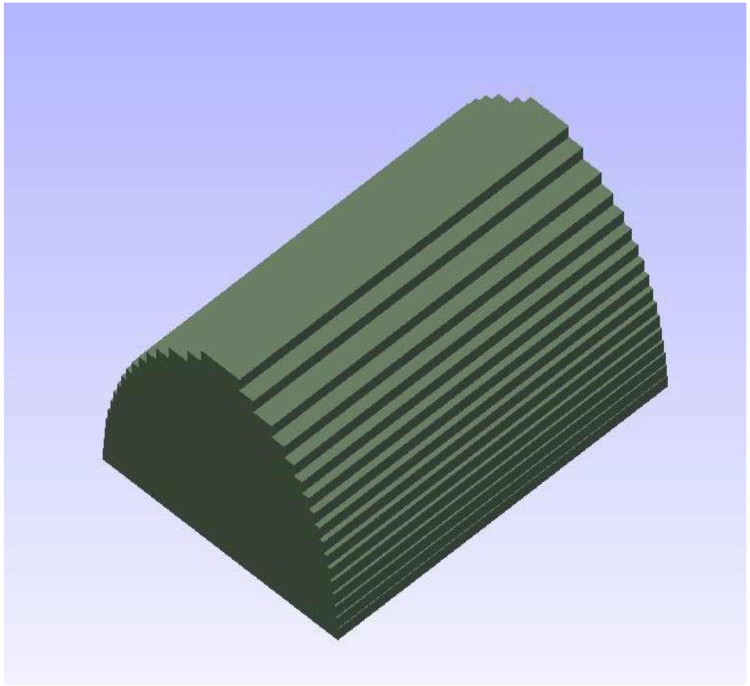
Additional Methods

- In addition to starting material, the various material addition RP technologies use different methods of building and adding layers to create the solid part
    - There is a correlation between starting material and part building techniques

Steps to Prepare Control Instructions

1. Geometric modeling - model the component on a CAD system to define its enclosed volume
2. Tessellation of the geometric model - the CAD model is converted into a computerized format that approximates its surfaces by facets (triangles or polygons)
3. Slicing of the model into layers - computerized model is sliced into closely-spaced parallel horizontal layers
4. Cleaning

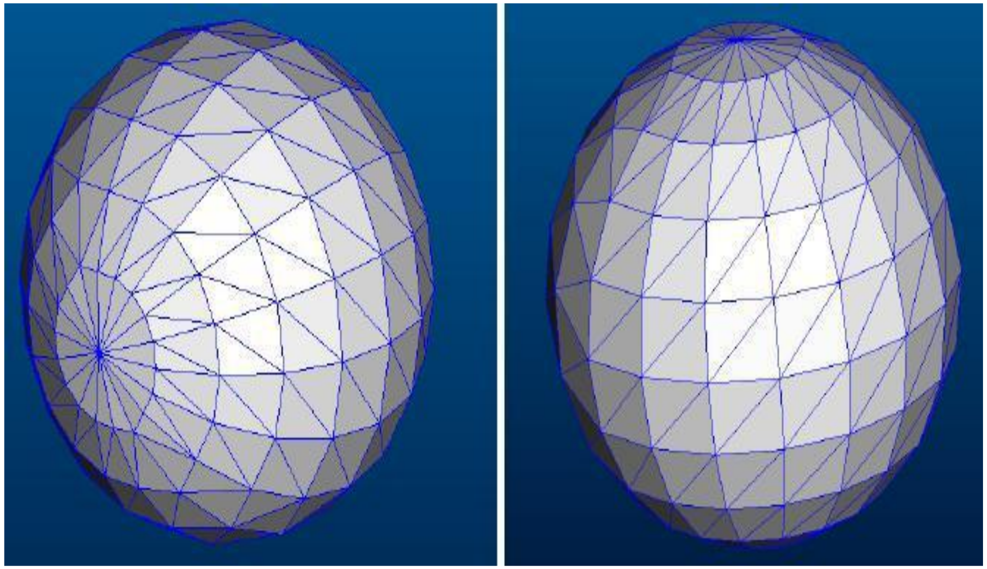




Typical layer thickness could be ≈ 0.05 –0.15 mm

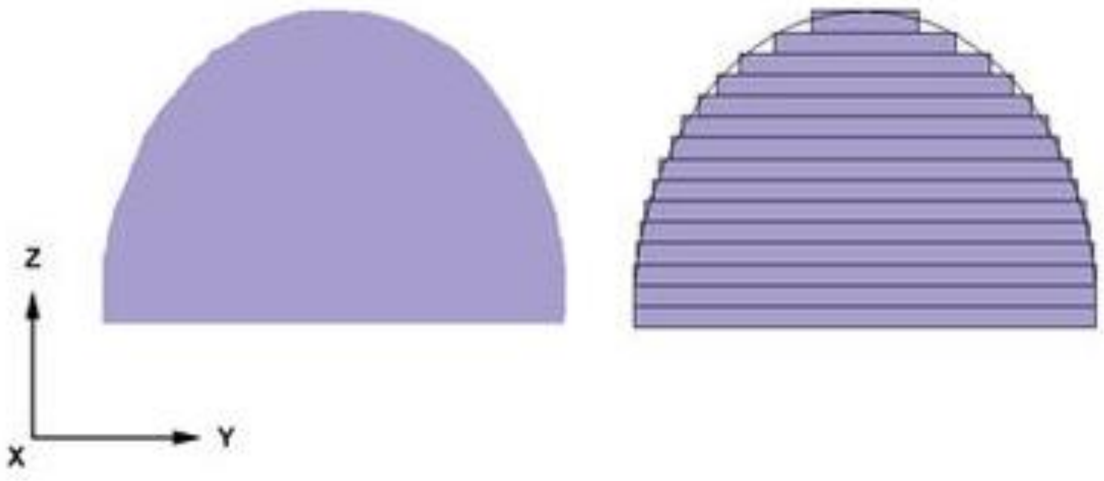
Convert in STL format

- The standard data interface between CAD software and the machine is the STL-format (**Stereolithography**).
- An STL-file approximates the **shape of a part using triangular facets**. **Small facets** produce **a high quality surface**



Since the .stl format is universal, this process is identical for all of the RP build techniques.

Solid Model to Layers



RP Applications

- Applications of rapid prototyping can be classified into three categories:
  1. Design
  2. Engineering analysis and planning
  3. Tooling and manufacturing

Problems with Rapid Prototyping

- Part accuracy
  - Staircase appearance for a sloping part surface due to layering
  - Shrinkage and distortion of RP parts
- Limited variety of materials in RP
  - Mechanical performance of the fabricated parts is limited by the materials that must be used in the RP process
- The price of machinery and materials.
- The strength of RP-parts are weaker

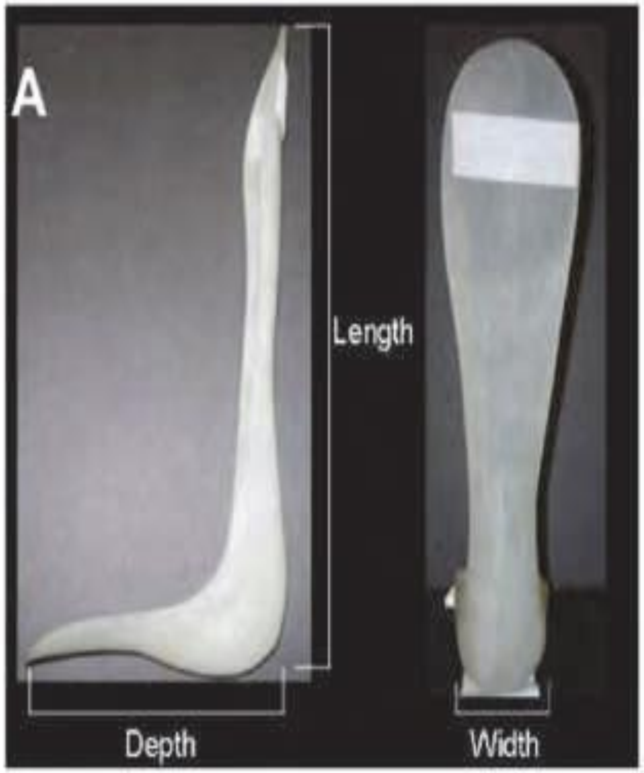
Advantages of Rapid Prototyping

1. Almost any shape or geometric feature can be produced.
2. Reduction in time and cost (could range 50 –90%, Wohler's Report)
3. Errors and flaws can be detected at an early stage.
4. RP/RM can be used in different industries and fields of life (medicine, art and architecture, and marketing)
5. Assemblies can be made directly in one go.
6. Material waste is reduced.
7. No tooling is necessary.

DIFFERENCE BETWEEN RAPID PROTOTYPING AND TRADITIONAL FABRICATION

RP	Traditional
1. RP processes are "additive". Parts are built up by adding, depositing, or solidifying in a horizontal layer-wise process.	1. Subtractive processes, as the name implies, create objects by removing unwanted material from a large block or sheet in the form of chips.
2. RP technologies are able to create one-piece part geometries.	2. Part is made in assemblies.
3. Undercuts, overhangs, difficult shapes can me made.	3. Useful for making simple shapes only.
4. No tooling required.	4. Tooling is always required (jigs and fixtures).
5. Part can be fabricated in hours.	5. Take more time.
6. Rough surface finish.	6. Good surface finish.
7. Less human interaction.	7. More human interaction.
8. Non dangerous in nature (dust free, noise free).	8. Dangerous in nature.

Applications of Rapid Prototyping



Liquid Based Rapid Prototyping Processes

1. The objective of this section is to help understand the concept of liquid-based rapid prototyping processes, such as Stereolithography Apparatus (SLA), solid ground curing (SGC), inkjet printing, rapid freeze processes.
2. Liquid-based rapid prototyping has its initial materials in liquid state.
3. In general, liquid-based processes have the advantage of smoothness of liquid surface in steady state, and result in parts with a quality surface finish.
4. However, its limitation is on the type of materials that can be solidified.
5. Most of the liquid-based processes use a heat source to scan a 2D profile within a container of heat sensitive epoxy resin.
6. Through a process commonly known as curing, the liquid is converted into a solid state. The heat source, such as a UV laser, is chosen to control the curing in a tiny spot to gain good part accuracy.

Rapid Prototyping Techniques

- Stereolithography

- **Patented in 1986**, stereolithography started the rapid prototyping revolution. **The technique builds three-dimensional models from liquid photosensitive polymers that solidify when exposed to ultraviolet light**.

Stereolithography

1. The Stereolithography Apparatus (SLA) process is the first commercialized RP process, and is the representation of the stereolithography process.
2. Patented in 1986, stereolithography started the rapid prototyping revolution.
3. It works on the principle of solidifying a photosensitive resin using UV laser light layer-by-layer to develop a 3D object.
4. The UV laser is controlled by a scanner to generate X–Y motion, and thus the table does not need to move in the x and y directions.
5. Stereolithography uses a photo curable resin that can be classified as an **epoxy, vinyl ether, or acrylate.**
6. Acrylics only cure about 75% or 80% since curing stops as soon as the UV light is removed.
7. Epoxies continue to cure, automatically, even after the laser is not in contact.

Stereolithography (SL or SLA)

- Builds 3D model from liquid photo sensitive polymers when exposed to UV rays.
- Model is built upon a platform situated just below the surface of liquid epoxy or acrylate resin.
- A low power highly focused UV laser traces out the first layer, solidifying model cross section.
- An elevator incrementally lowers the platform into the liquid polymer.
- Process is repeated until prototype is complete.
- Model is the placed in an UV oven for complete curing.

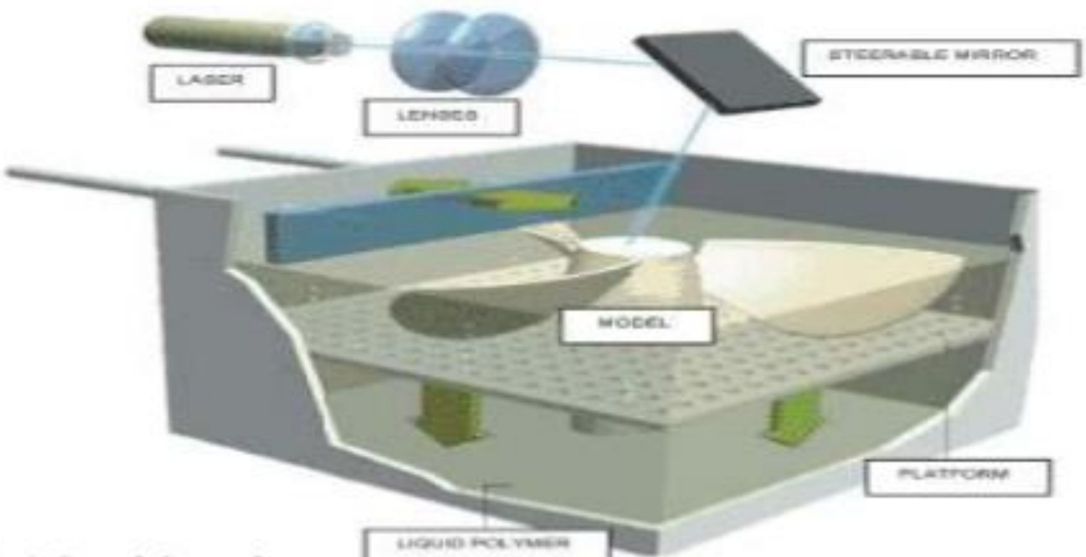
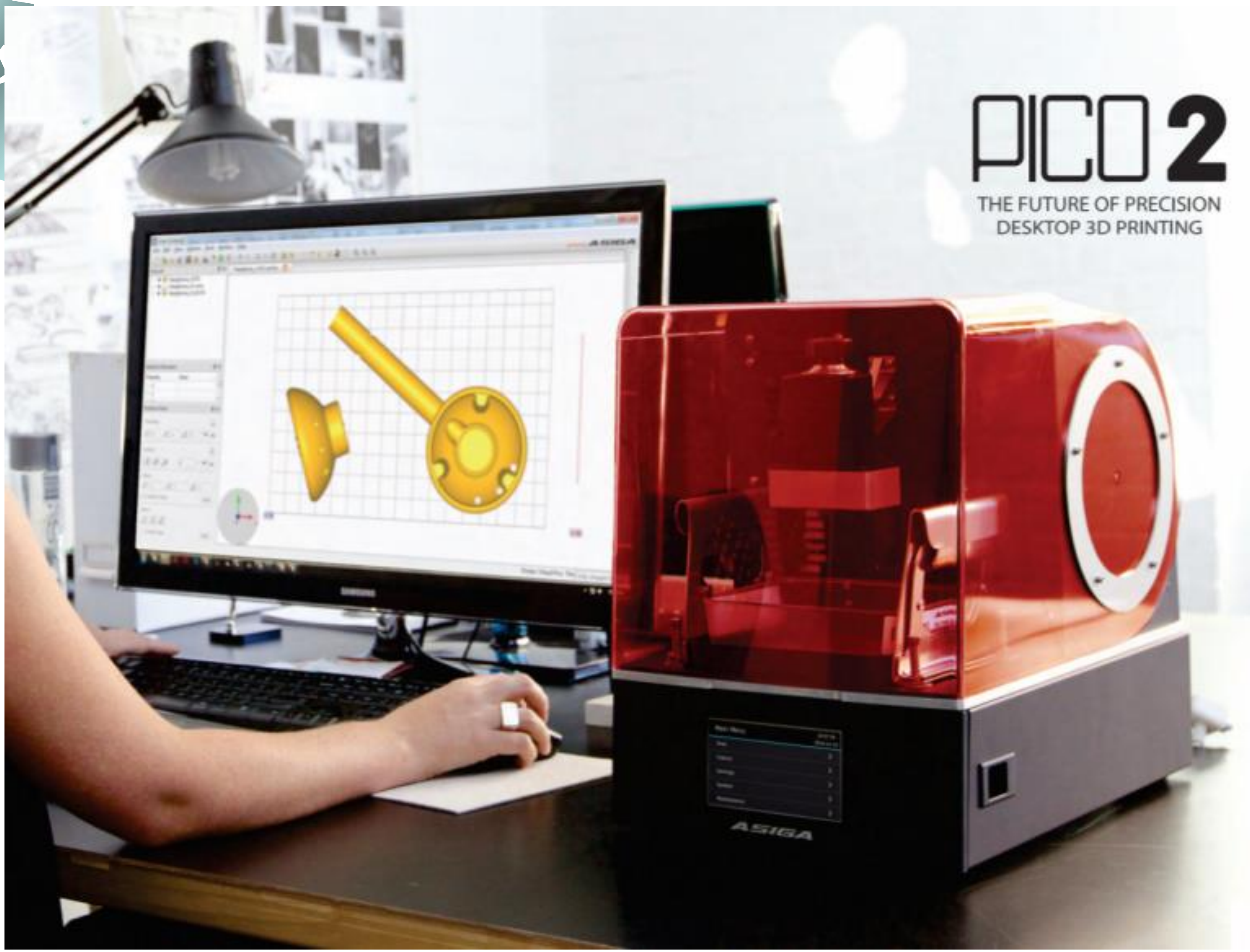
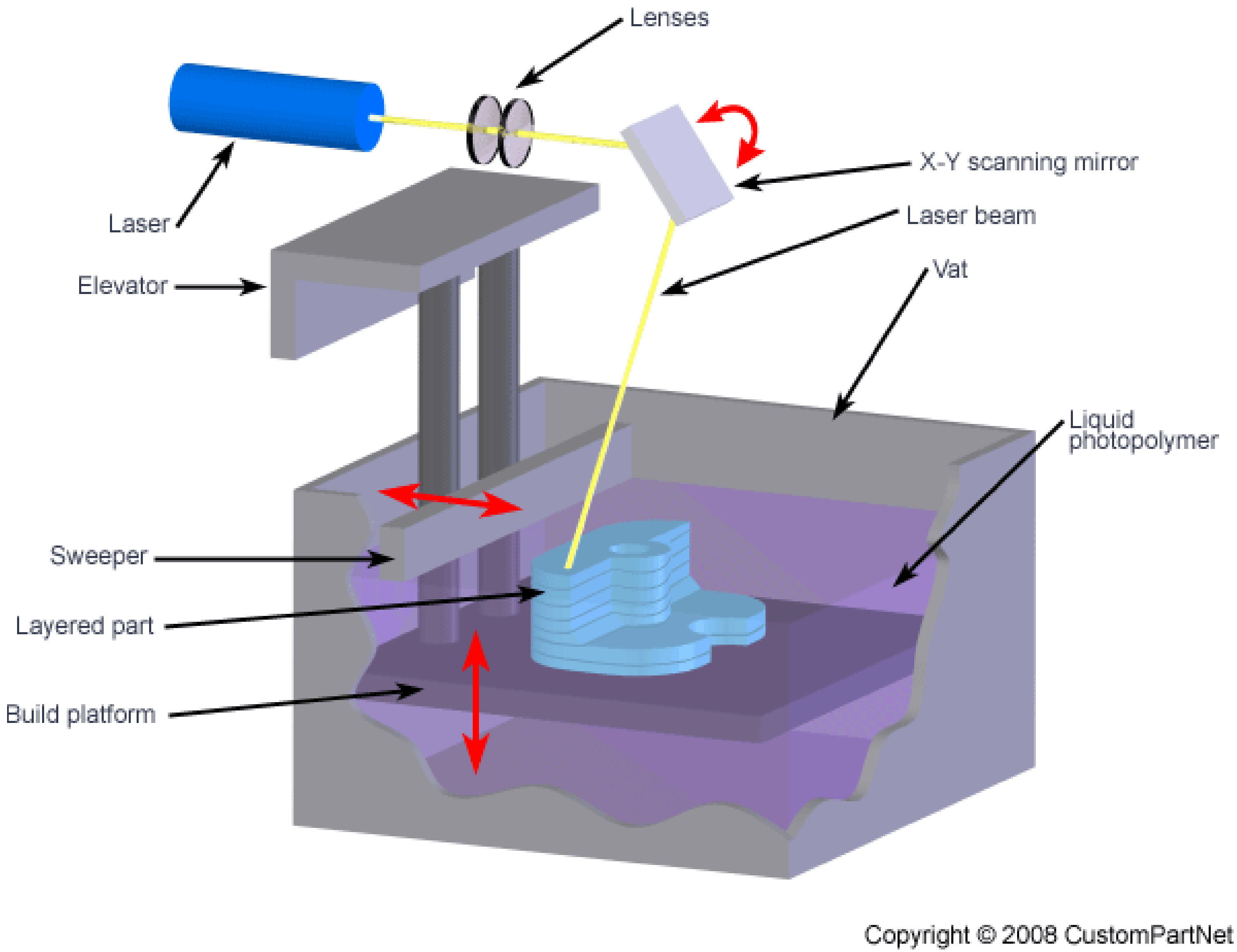


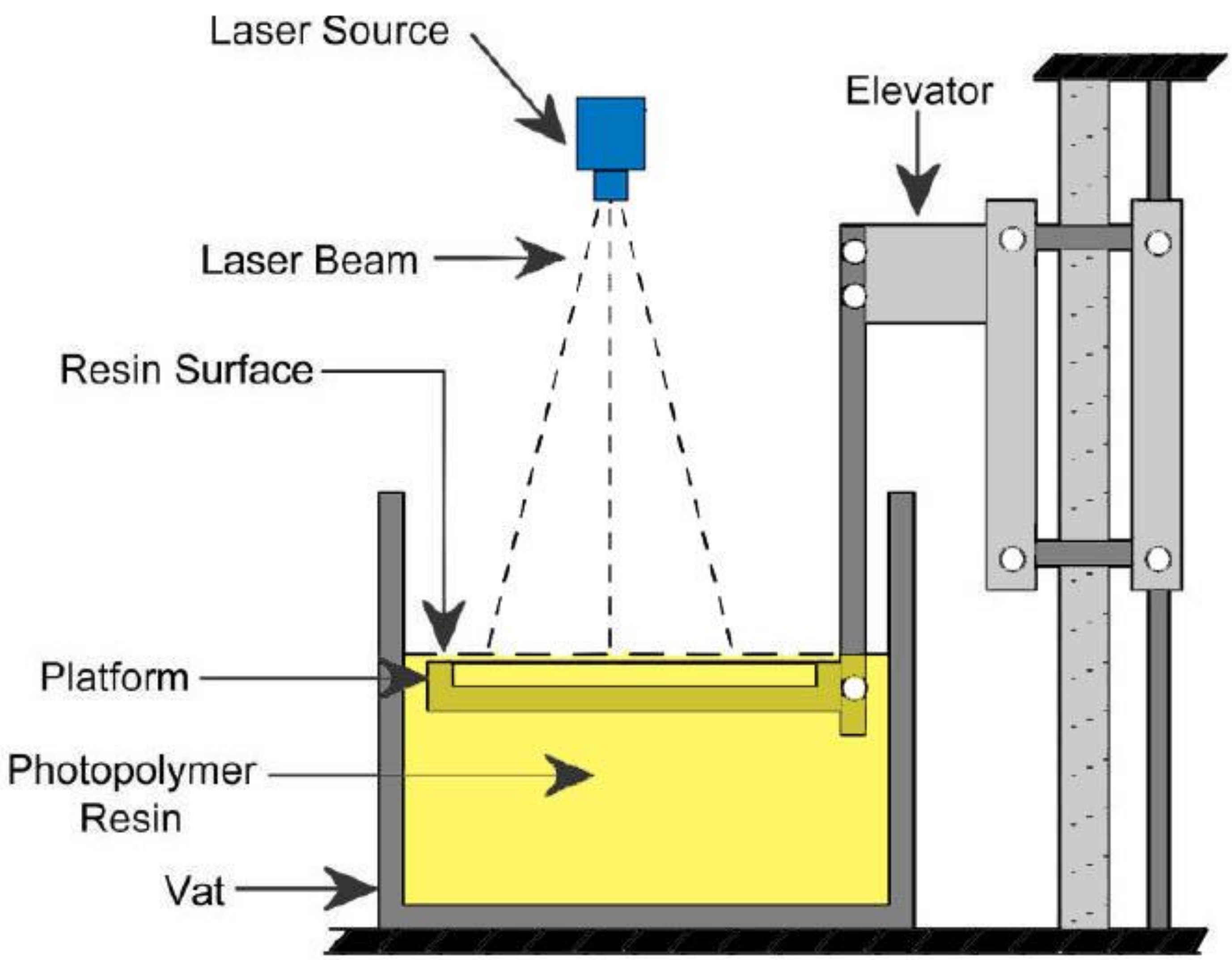
Fig 4: Stereolithography

The Stereolithography Machine

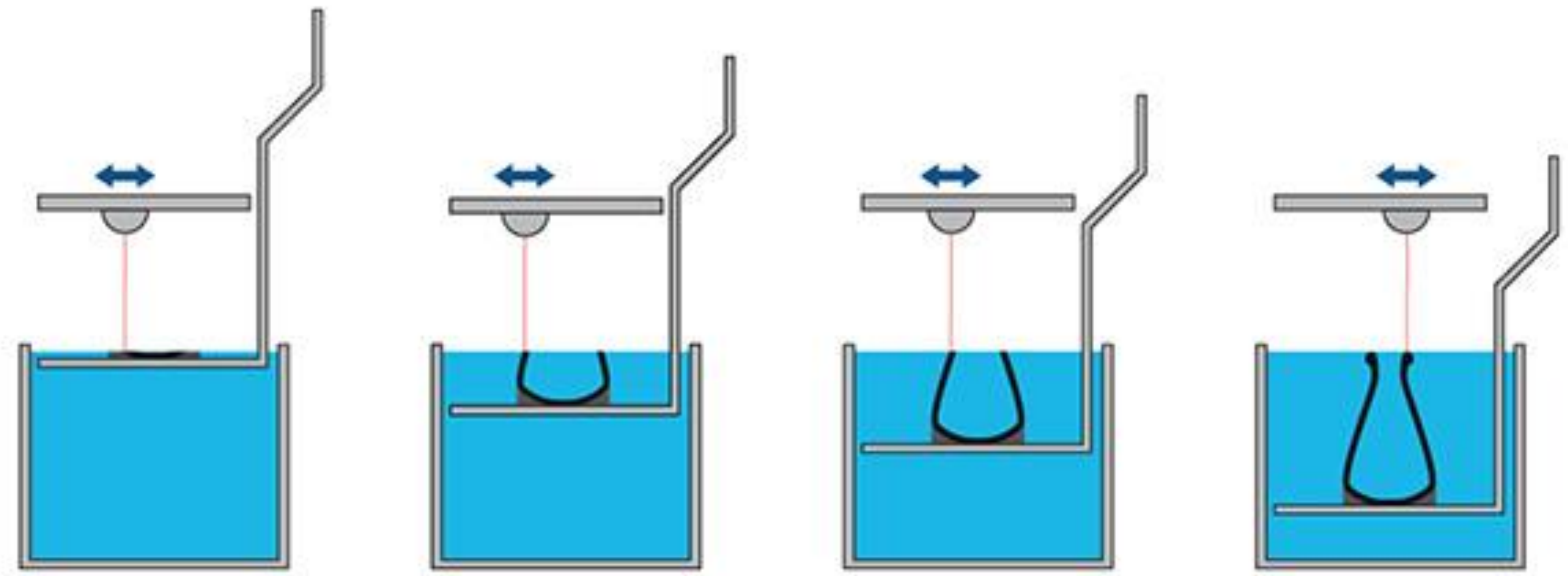
PT CAM uses a stereolithography machine produced by 3-D Systems and shown here:

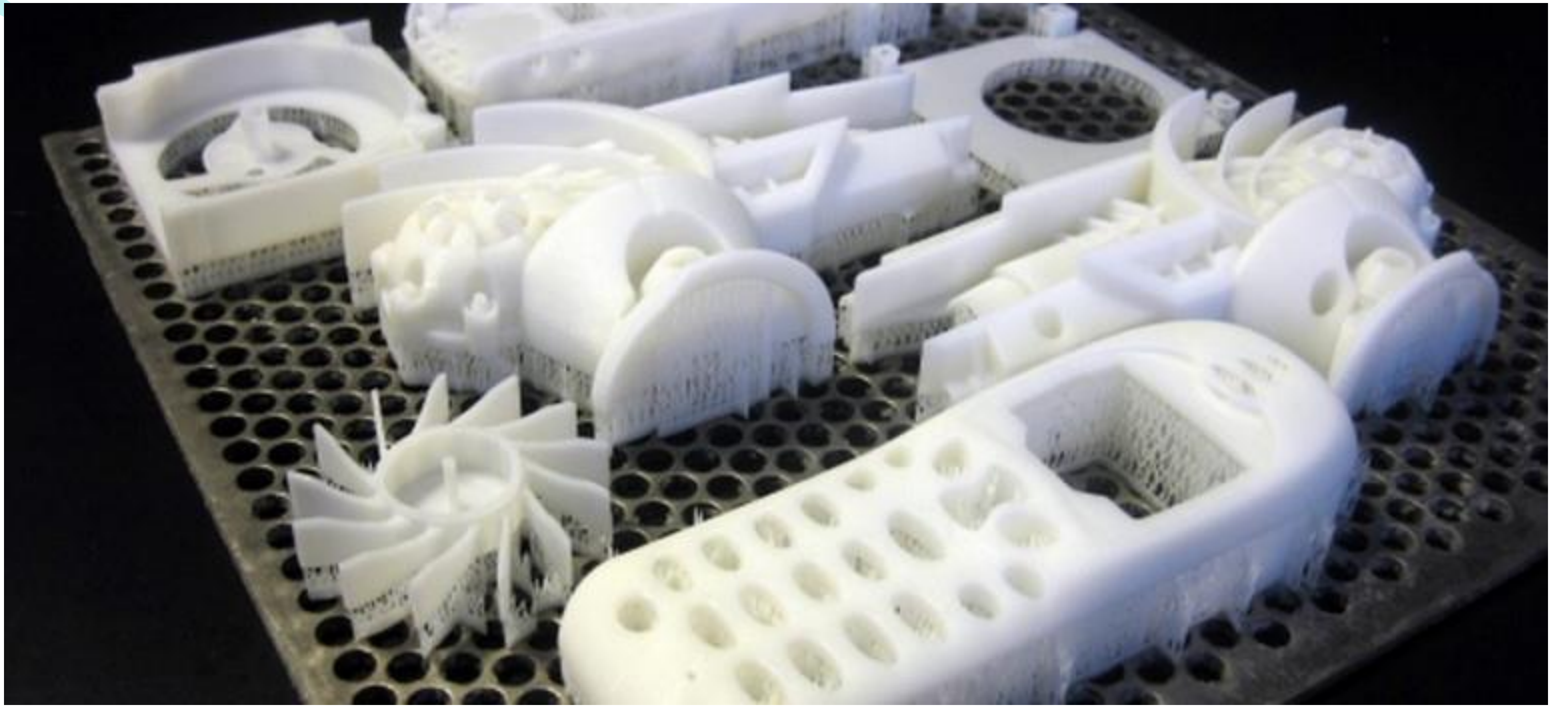

PICO 2
THE FUTURE OF PRECISION
DESKTOP 3D PRINTING
ASIGA

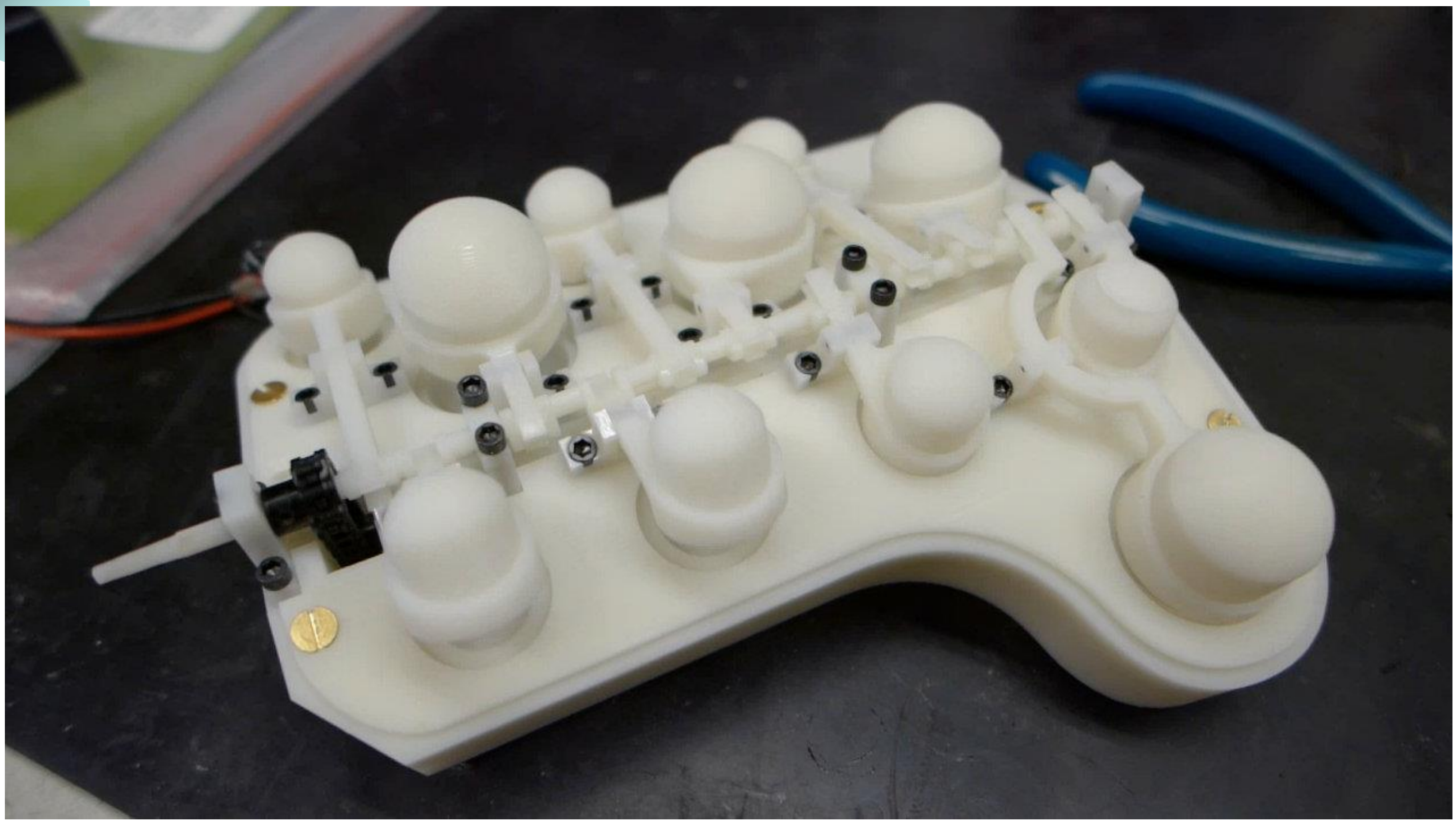

Lenses
X-Y scanning mirror
Laser beam
Vat
Laser
Elevator
Liquid photopolymer
Sweeper
Layered part
Build platform
Copyright © 2008 CustomPartNet

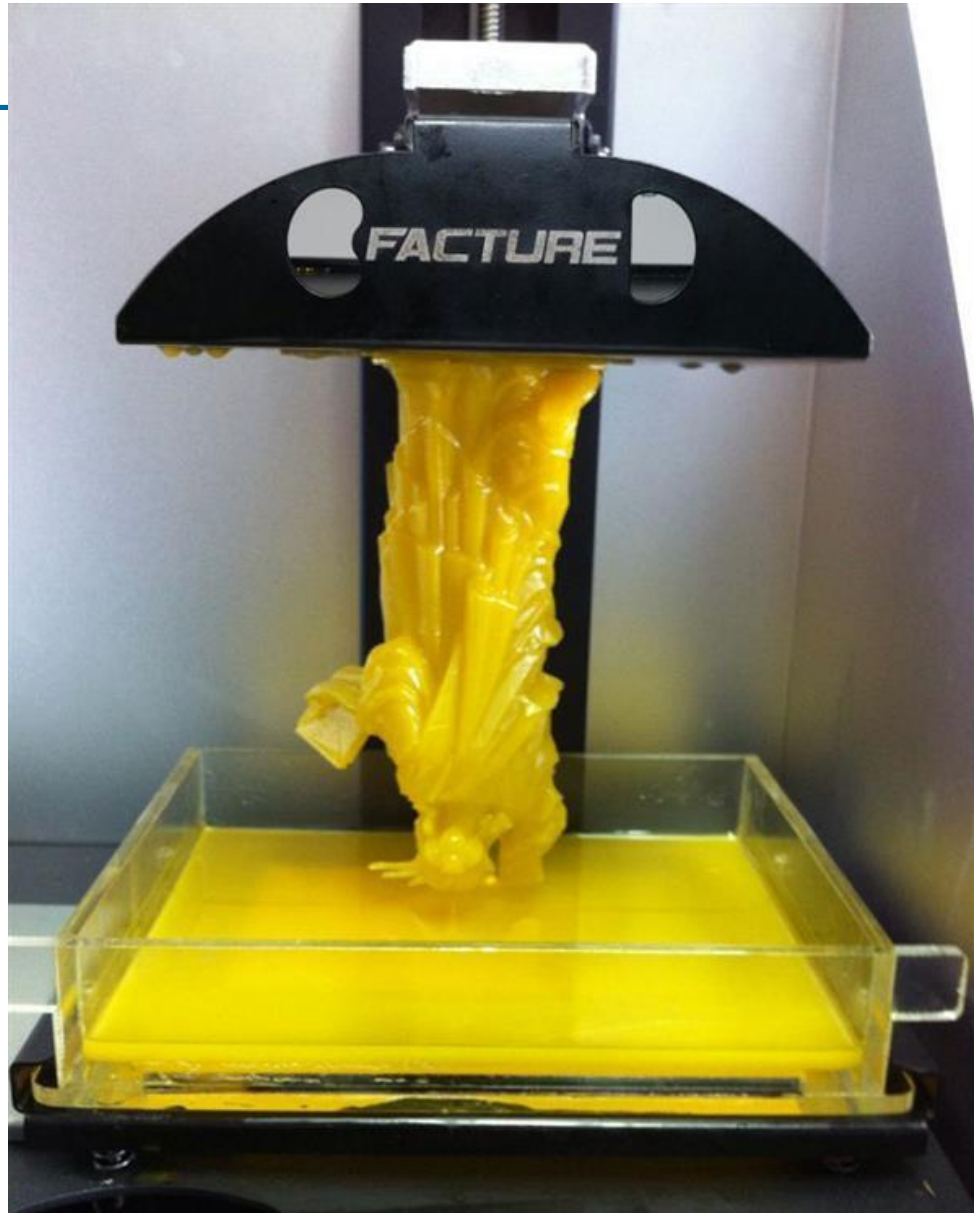


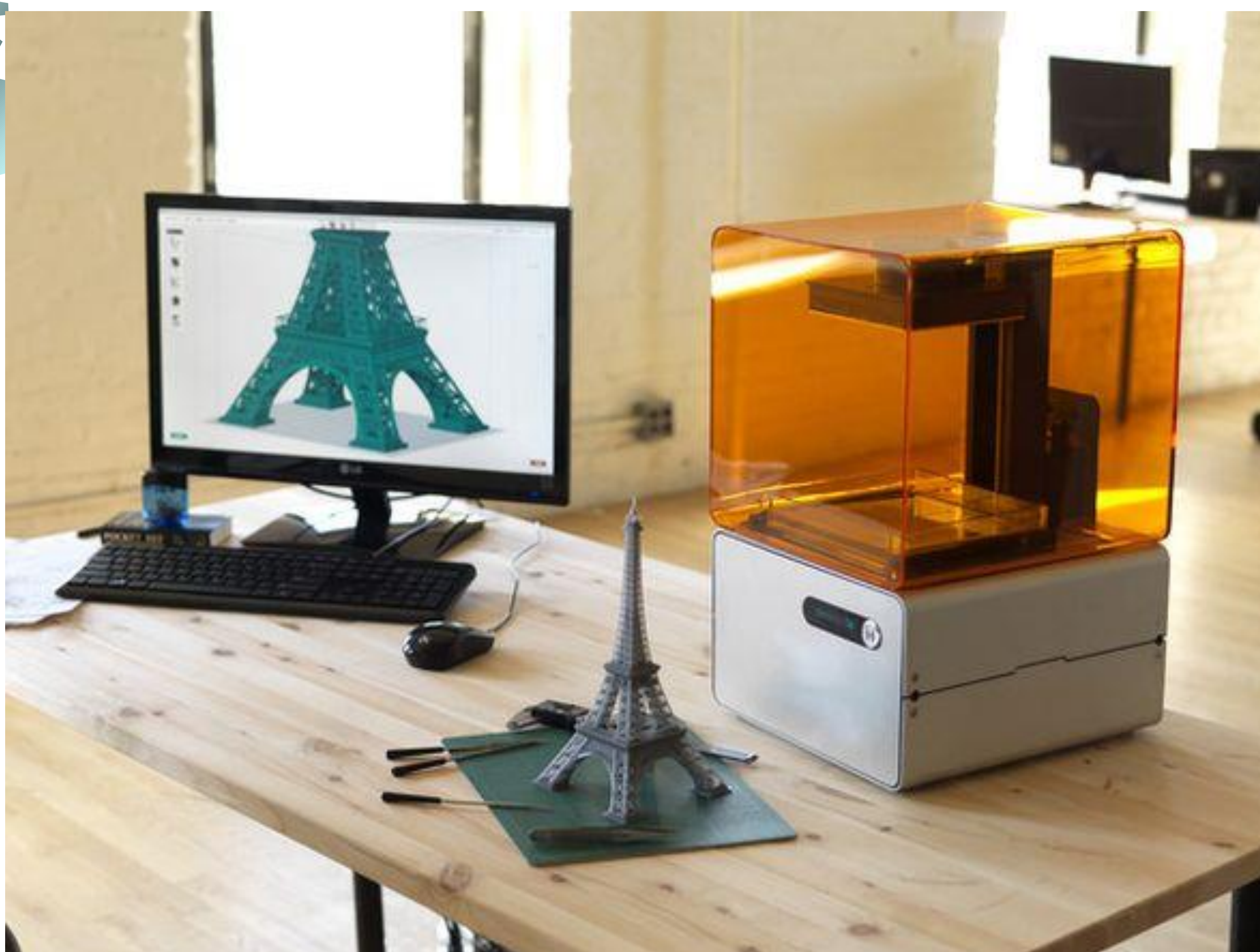
SLA printing process

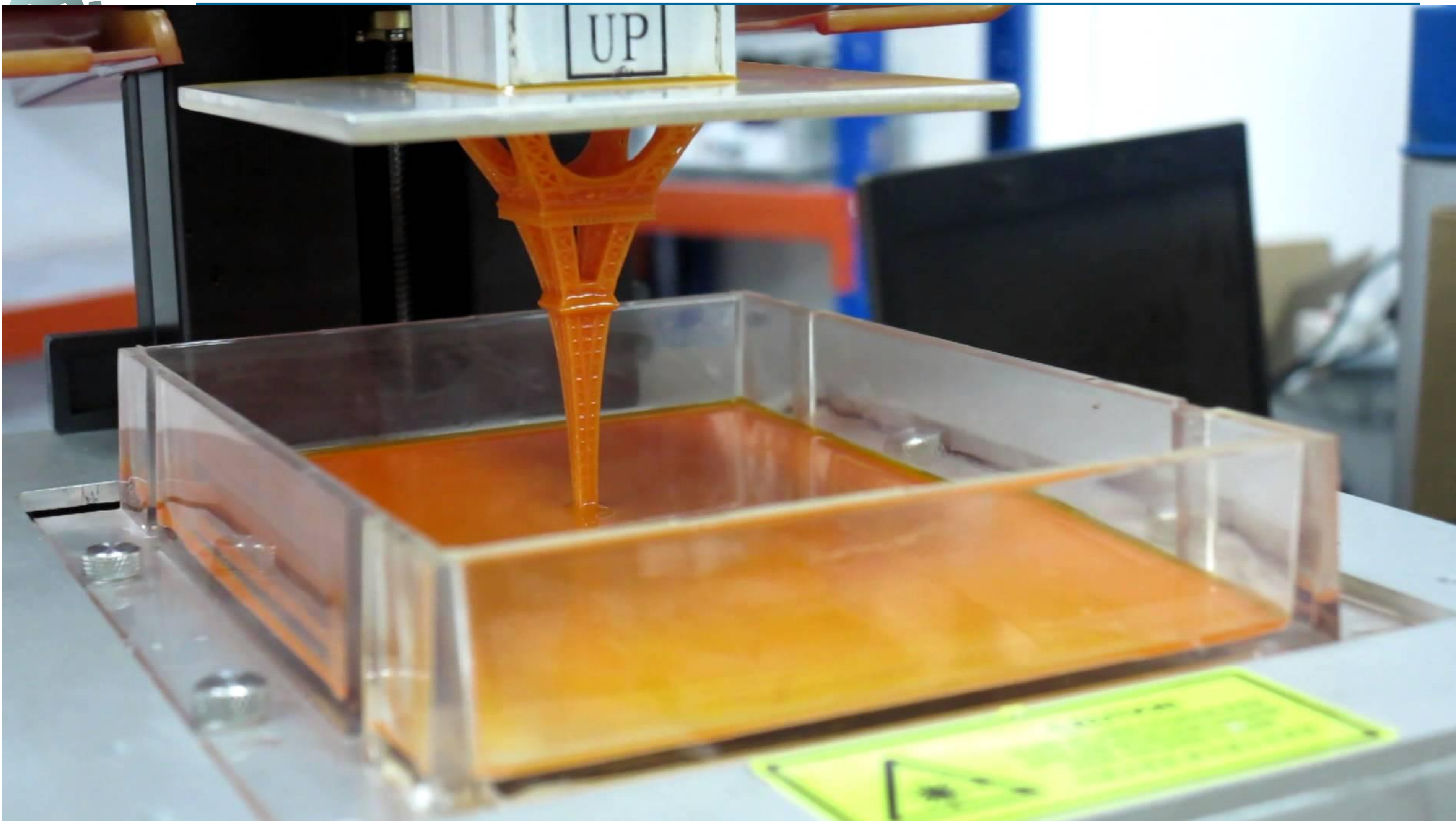







FACTURE

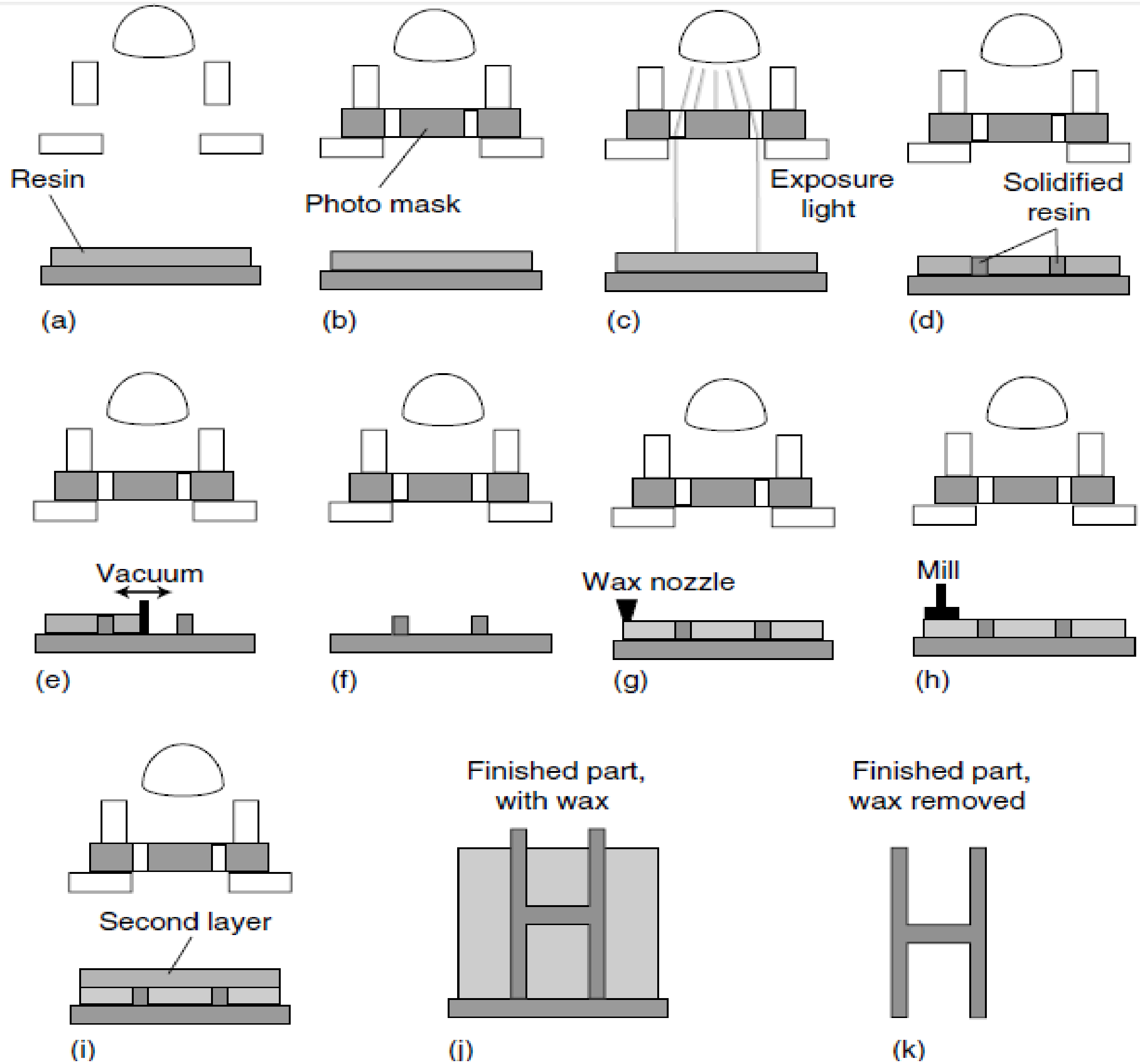



UP

Solid Ground Curing (SGC)

1. Solid ground curing utilizes the general process of hardening of photopolymers by a complete lighting and hardening of the entire surface, using specially prepared masks.
2. In SGC process, each layer of the prototype is cured by exposing to an ultra violet (UV) lamp instead of by laser scanning.
3. So that, every portion in a layer are simultaneously cured and do not require any post-curing processes.

Solid Ground Curing (SGC)

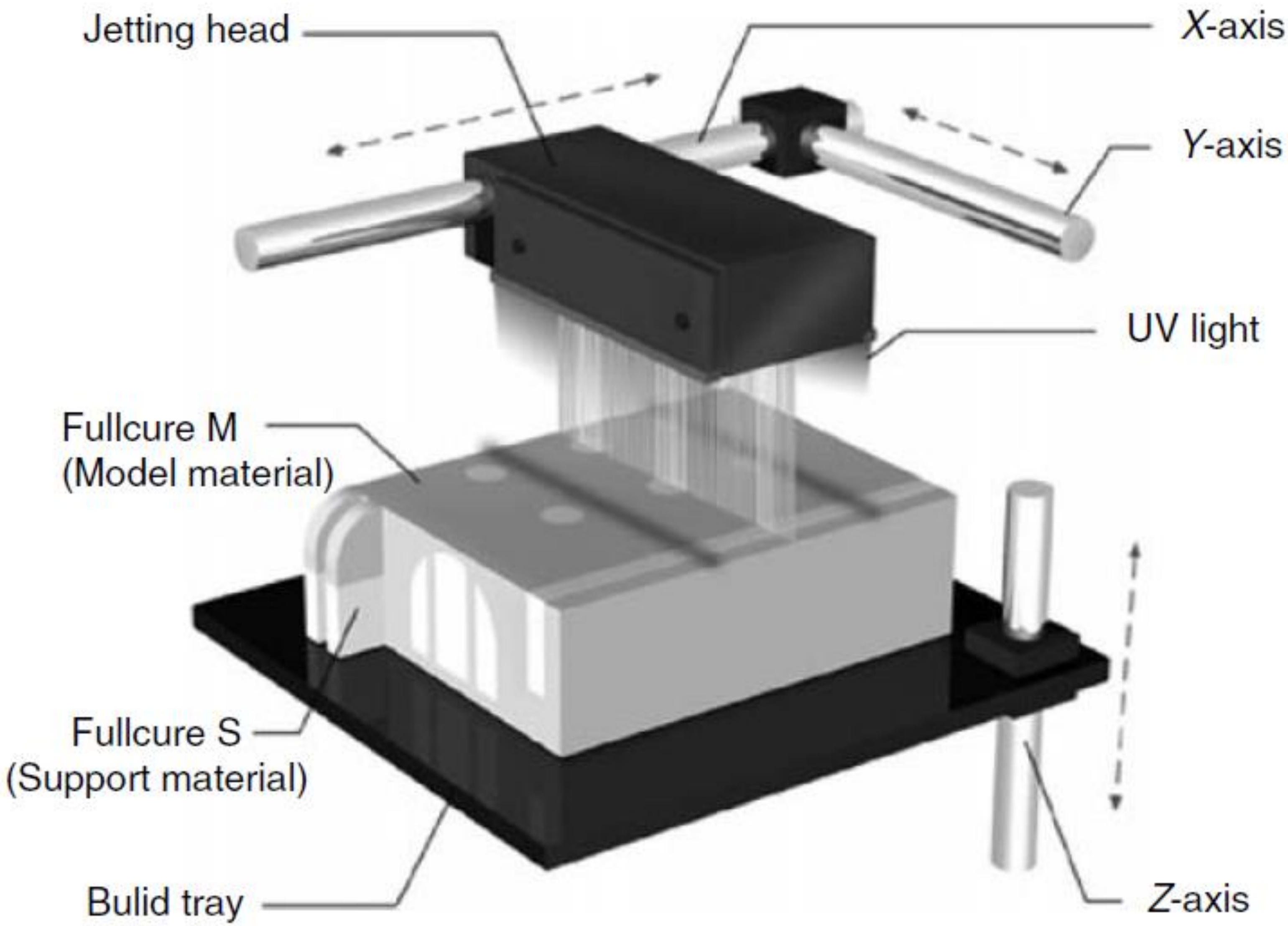


Inkjet Printer

1. One representative inkjet-based liquid process is PolyJet, a hybrid of material jetting and stereo-lithography.
2. As engineers are very familiar with the desktop printing process, the process by *Objet Geometries* uses printing technology to deposit supports and build material combined with UV curable materials.
3. It is capable of producing results similar to those from stereo-lithography processes.
4. In this process, the jetting head slides back and forth along the X and Y-axis, depositing a single super thin layer of photopolymer onto the build tray.
5. Immediately after building each layer, UV bulbs alongside the jetting bridge emit UV light, immediately curing and hardening each layer.
6. This step eliminates the need for additional post modeling curing, as required by other technologies.

Inkjet Printer

7. The internal jetting tray moves down with extreme precision and the jet head begins building the next layer.
8. This process is repeated until the model is complete.
9. *This results in an even and smooth surface.*
10. Two different materials are used for building; one is used for the actual model, while another gel like photopolymer material is used for support.
11. Separation of support and model materials is carried out with a high-pressure water jet, or by hand.
12. This process allows finishing of most parts within a reasonable amount of time.

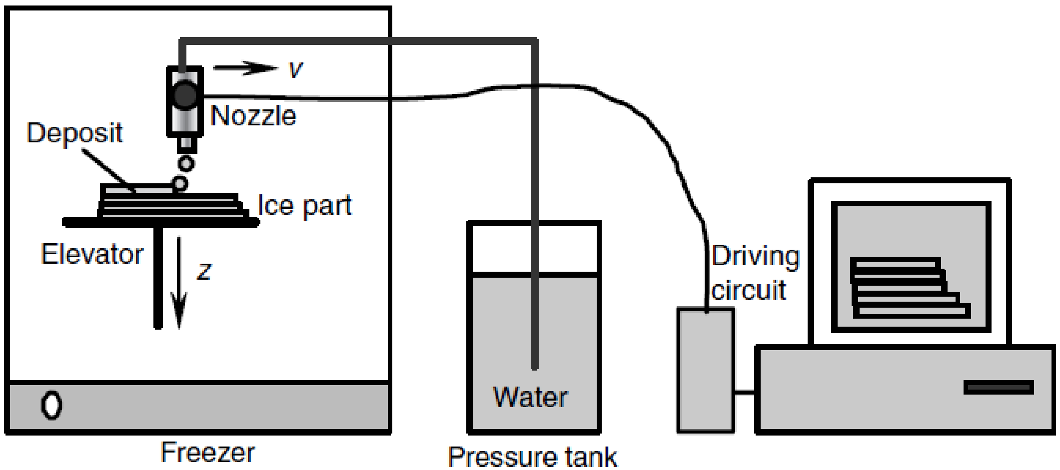

Jetting head
X-axis
Y-axis
UV light
Fullcure M
(Model material)
Fullcure S
(Support material)
Bulid tray
Z-axis

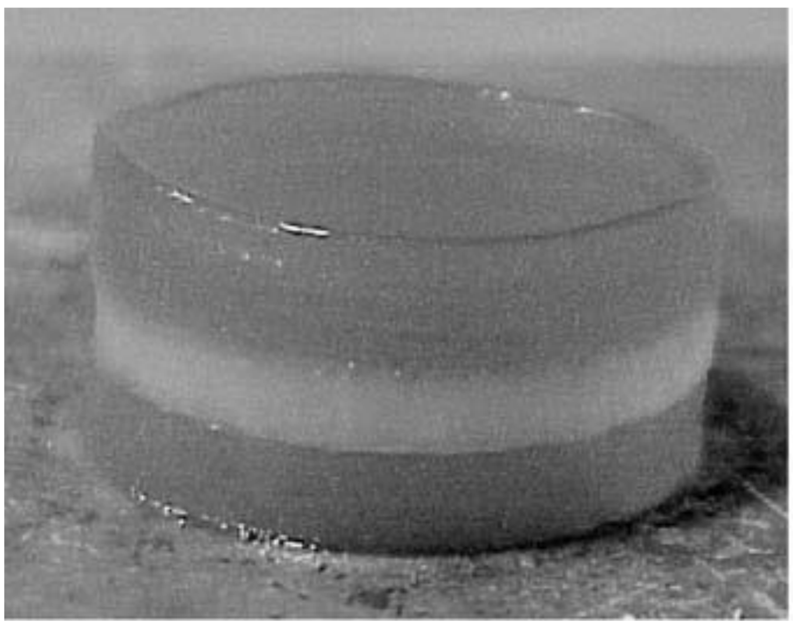
Rapid Freeze Prototyping

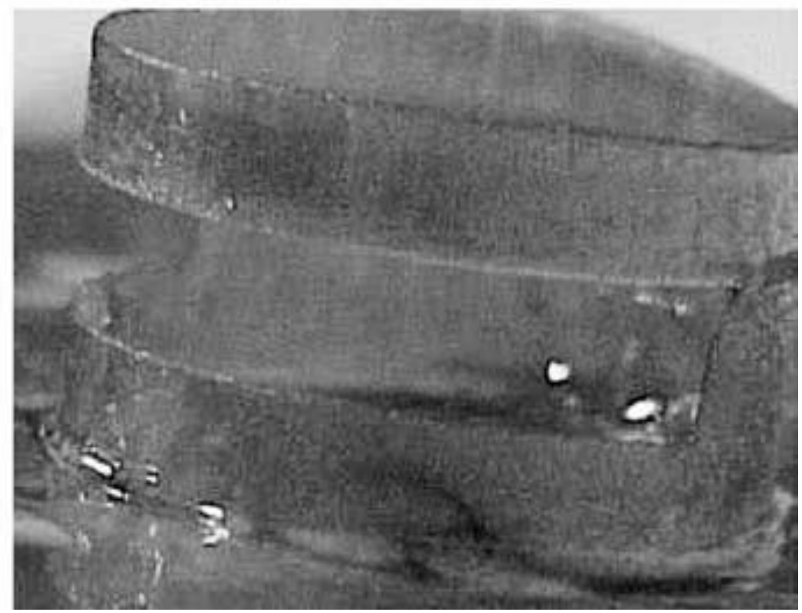
1. Another interesting liquid-based process is called rapid freeze prototyping (RFP), in which a cold source is used to freeze the liquid point by point and thus transfer liquid into a solid part.
2. This process builds a 3D ice part from a CAD model by depositing and rapidly freezing water in a layer-by-layer manner.
3. This is a low-cost and environmentally gentle process as it uses water and inexpensive equipment to build the part.
4. Water is ejected drop-by-drop from the nozzle of a deposition head and deposited onto a substrate or the previously solidified ice-surface in a drop-on-demand mode.
5. The build environment is kept at a temperature below the freezing point of water.
6. As a result, the deposited water freezes rapidly and binds firmly onto the previous layer through hydrogen bonding.

Rapid Freeze Prototyping

7. After a single layer is deposited, the nozzle is elevated by one layer thickness, waiting for a predetermined period of time for complete solidification of the deposited water, and then deposits water droplets again to build the next layer.
8. To build 3D ice parts that require the use of support structures during the part building process, the eutectic sugar solution ($C_6H_{12}O_6$ – H_2O).
9. Among potentially promising applications of the RFP process is the use of the generated ice-patterns in investment casting to make metal parts of the same shape for purposes of manufacture prototyping and small-quantity production by aiding investment casting.
10. A main advantage of investment casting with ice patterns is that the process does not cause shell cracking because the ice shrinks when it melts.


v
Nozzle
Deposit
Ice part
Elevator
z
Driving
circuit
Water
Freezer
Pressure tank





Solid based Rapid Prototyping Processes

1. Solid-based RP processes are meant to encompass all forms of materials in solid state.
2. The solid form can include the shape in the form of a wire, a roll, laminates, and pellets.
3. The presentations of extrusion-based, contour-cutting, and Ultrasonic Consolidation (UC) processes are introduced in the following sections.

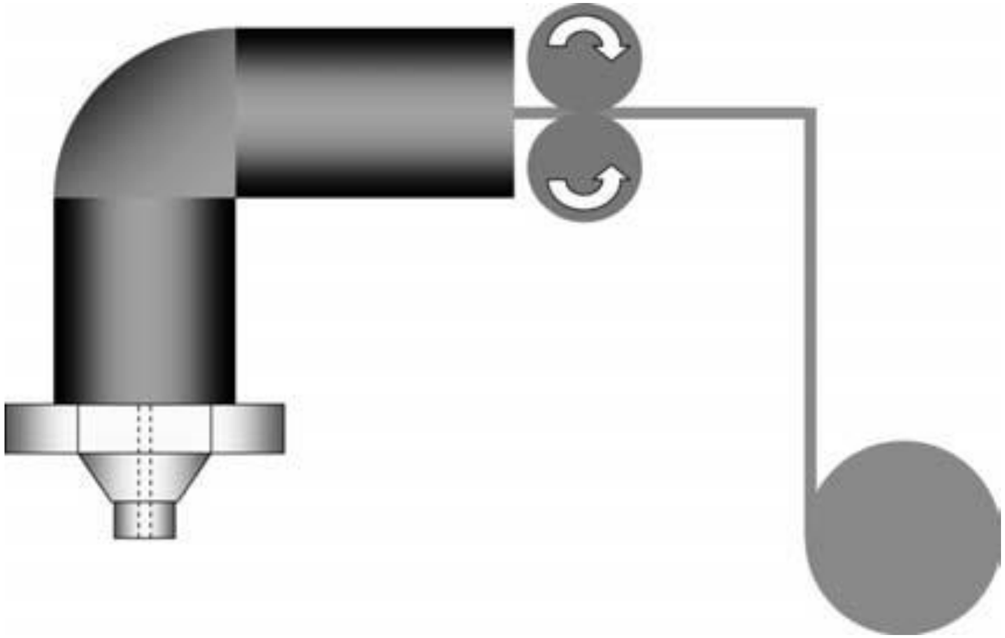
Extrusion Based Process

1. Unlike a liquid-based process, which changes material from liquid into solid state, an extrusion-based process feeds material in solid wire form and then melts it into a shape and forms a solid.
2. The FDM process was originally developed by Advanced Ceramics Research in Tucson, Arizona, but the process has been significantly advanced by Stratasys, Inc. Minnesota.
3. FDM is a non laser filament extrusion process that utilizes engineering **thermoplastics**, which are heated from filament form and extruded in very fine layers to build each model from the bottom up.
4. The models can be made from **acrylonitrile butadiene styrene** (ABS), polycarbonate, **poly phenyl sulfone**, and various versions of these materials.
5. Furthermore, the models are tough enough to perform functional tests.

Extrusion Based Process

The key steps are:

1. *Starting with the filament being fed into the drive wheels*
2. *The drive wheels force the filament into the **liquefier***
3. *The **heater block melts the filament***
4. *The solid filament is used as a **linear piston***
5. *The melted filament is forced out through the tip*



Extrusion Based Process

6. The platform is maintained at a lower temperature to ensure the deposited thermoplastic hardens quickly in 0.1s.
7. After the platform lowers, the extrusion head deposits a second layer upon the first. The material then cools and solidifies in place.
8. The speed of the drive wheels can determine the width of the extrusion path that is controlled using the software.

Fused Deposition Modeling

FDM 2000 Specifications

- Build Volume: 10" x 10" x 10"
- Materials:ABS, Casting Wax
- Build Step Size: 0.005" to 0.030"

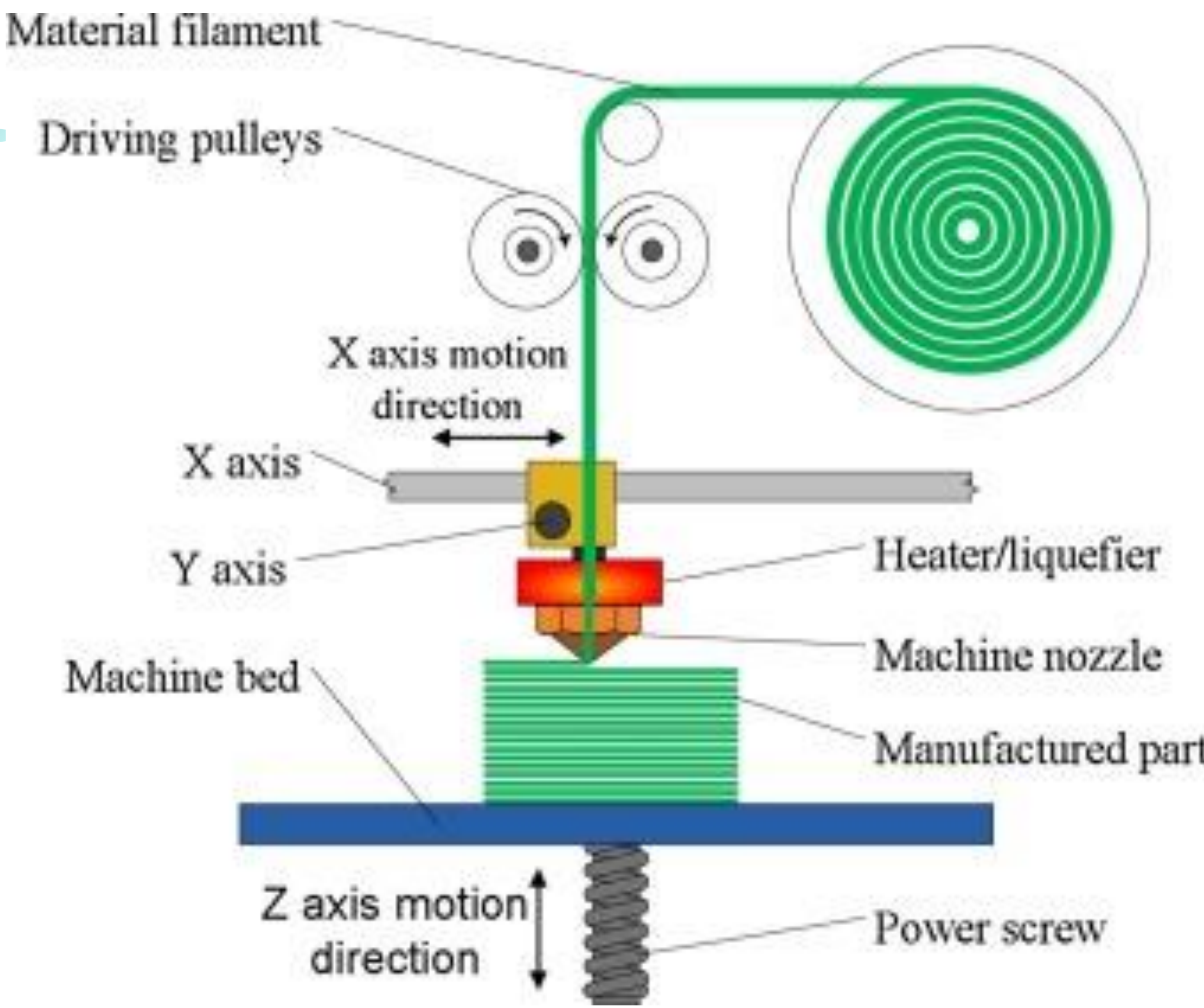
Prodigy Specifications

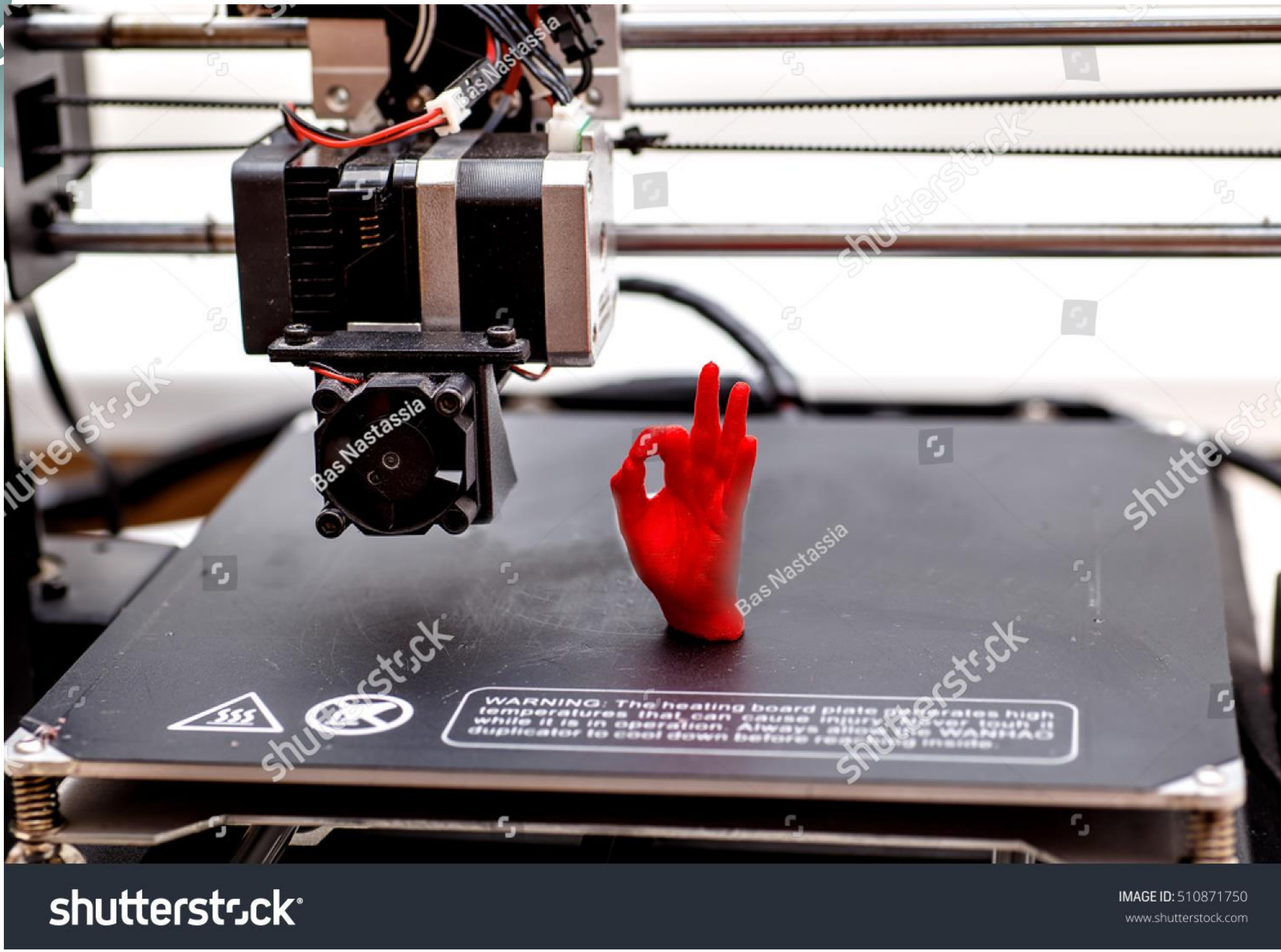
Build Volume: 8" x 8" x 10"

Materials: ABS, Casting Wax

Build Step Size: 0.007", 0.010", 0.013"

Up to 4x faster than the FDM 2000


Material filament
Driving pulleys
X axis motion direction
X axis
Y axis
Heater/liquefier
Machine nozzle
Machine bed
Manufactured part
Z axis motion direction
Power screw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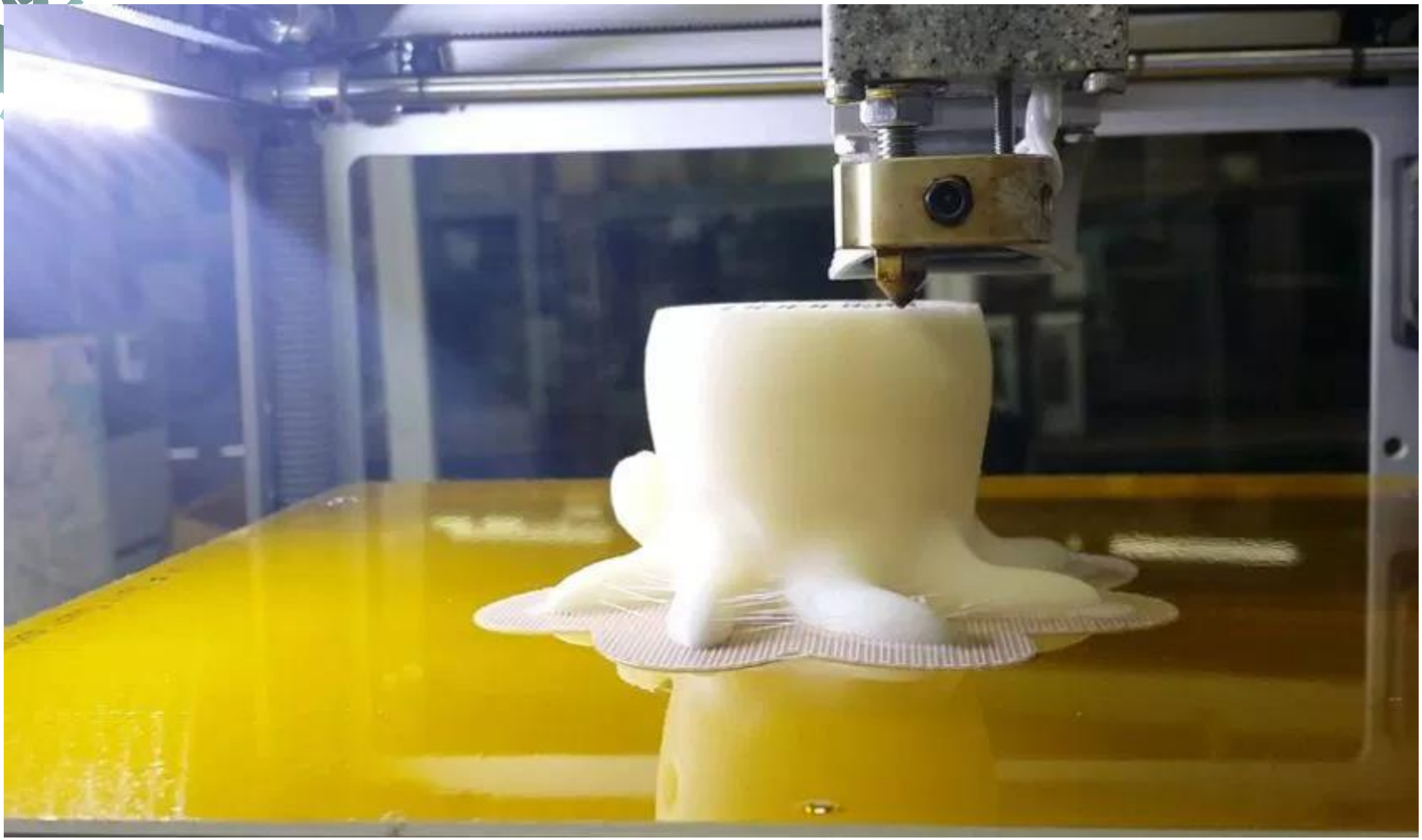


Examples of Fused Deposition Modeling

Advantages of FDM Process

- High strength
- Cost-effective
- Waterproof
- ABS material
- Multiple material colors

Some FDM printers — like 3D System's Cube, MakerBot's Replicator and Stratasys' Mojo — are designed for use by inventors, do-it-yourselfers and small business owners. They're small, efficient and user-friendly.

But having one of these 3D printers in your home doesn't come cheap.
The Cube is among the most affordable desktop FDM printers on the market at $1,299.
MakerBot's machines are even more expensive, ranging in price from $2,549 to $3,299. And Stratasys' Mojo costs just under $10,000.

3D Systems Corporation offers the Cube home 3D printer.

Credit: 3D Systems Corporation / cubify.com

Contour Cutting Process

1. A contour-cutting process utilizes the layered manufacturing technique for rapid prototyping.
2. However, it differs from other RP systems in that, rather than building up a part by adding materials to a stack through a forming process, layers of sheet materials such as paper, plastics, or composites are attached to a stack, and a laser cuts away the unused portions.
3. A representative contour-cutting process is Laminated Object Manufacturing (LOM) developed by Helisys Inc. in 1985.
4. The process begins with a **computer slicing a 3D solid model of the part into 2D cross-sections.** Input data is in the STL file format.
5. The thickness of the computer-generated cross-section corresponds to the thickness of the sheet material.
6. The sheets can be **0.02–0.13mm thick and a winding and an unwinding roll provide a ribbon of the material.** The paper is unwound from a feed roll onto the stack and bonded to the previous layer using a heated roller.

Contour Cutting Process

7. The roller melts a plastic coating on the bottom side of the paper to create the bond between layers.
8. The profiles are traced by an optics system that is mounted to an X–Y stage.
9. The process generates considerable smoke. Either a chimney or a charcoal filtration system is required and the build chamber must be sealed.
10. After the cutting of the geometric features of a layer is completed, the excess paper is cut away, with CO_2 laser to separate the layer from the web.
11. The extra paper of the web is wound on a take-up roll.

Laminated Object Manufacture

- As the name implies the process laminates thin sheets of film (paper or plastic)

- **The laser has only to cut/scan** the periphery of each layer

Laminated Object Manufacture

- The process:
  - The build material (**paper with a thermo-setting resin glue on its under side**) is stretched from a supply roller across an anvil or platform to a take- up roller on the other side.
  - A **heated roller passes over the paper bonding it to the platform or previous layer**.
  - A **laser, focused to penetrate through one thickness of paper cuts the profile of that layer.** The excess paper around and inside the model is etched into small squares to facilitate its removal.

Laminated Object Manufacture

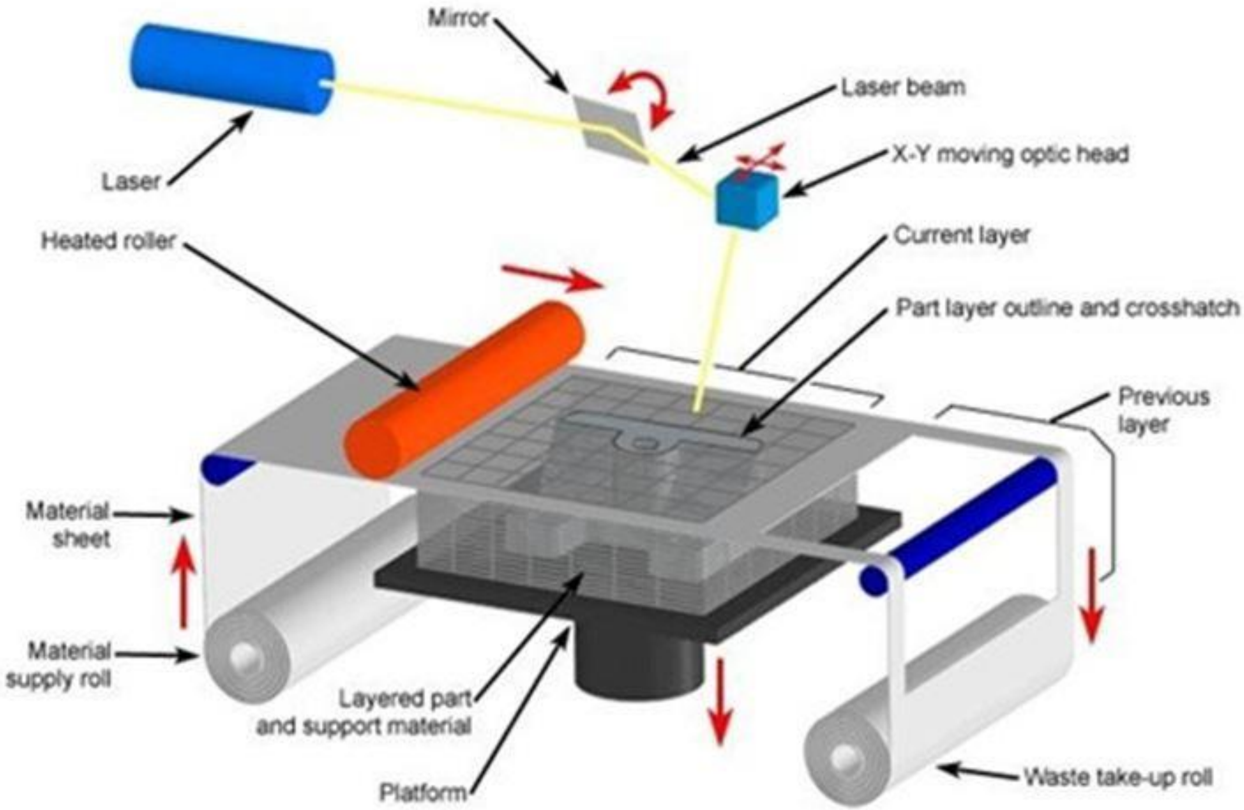
- The process continued:
  - The **process of gluing and cutting continuous layer by layer until the model is complete**.
  - To reduce the build time, double or even triple layers are cut at one time which increases the size of the steps on curved surfaces and the post processing necessary to smooth those surfaces.

Laminated Object Manufacture

- Applications of LOM objects:
  - **LOM objects are durable, multilayered structures which can be machined, sanded, polished, coated and painted**.
  - Used as precise patterns for secondary tooling processes such as **rubber moulding, sand casting and direct investment** casting.
  - Used for limited testing.
  - Used as visual models.

Laminated Object Manufacturing (LOM)

- **Paper material is the base material** used in this technology
- In this method, layers of **adhesive-coated** plastic, paper or metal laminates **are fused together** and **cut into shape** with the aid of a **knife or a laser cutter**



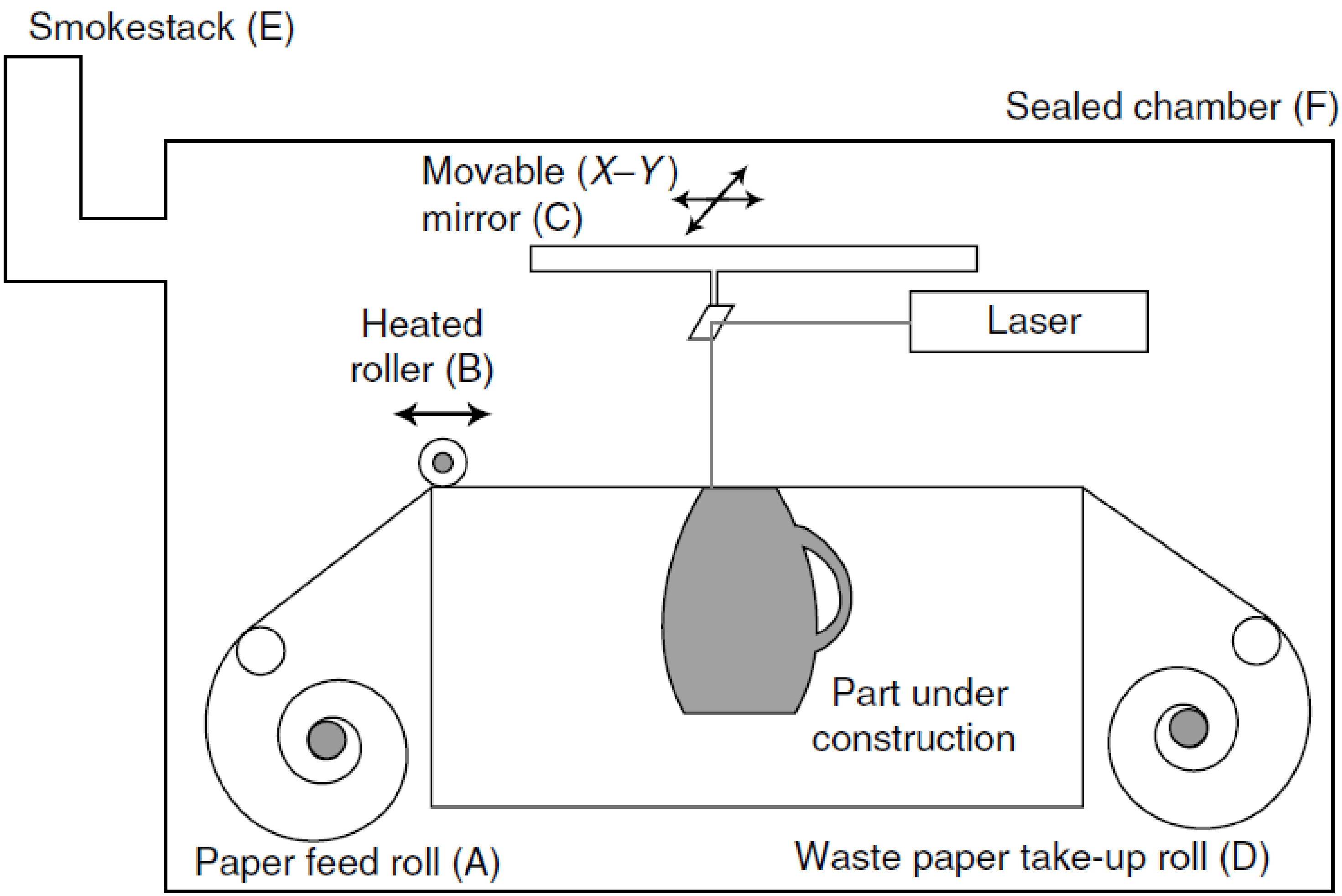
Examples of Laminated Object Manufacture

Wind Turbine

- In this case the LOM process was initially used to check the CAD geometry: subsequently the model was used as a sand casting pattern. The picture opposite shows 5 identical blades assembled around an SLA hub.

Examples of Laminated Object Manufacture

- A LOM model was built for a customer who required a prototype to test the fit and operation of internal components in an electrical housing.



Smokestack (E)
Sealed chamber (F)
Movable (X–Y)
mirror (C)
Laser
Heated
roller (B)
Part under
construction
Paper feed roll (A)
Waste paper take-up roll (D)

Ultrasonic Consolidation

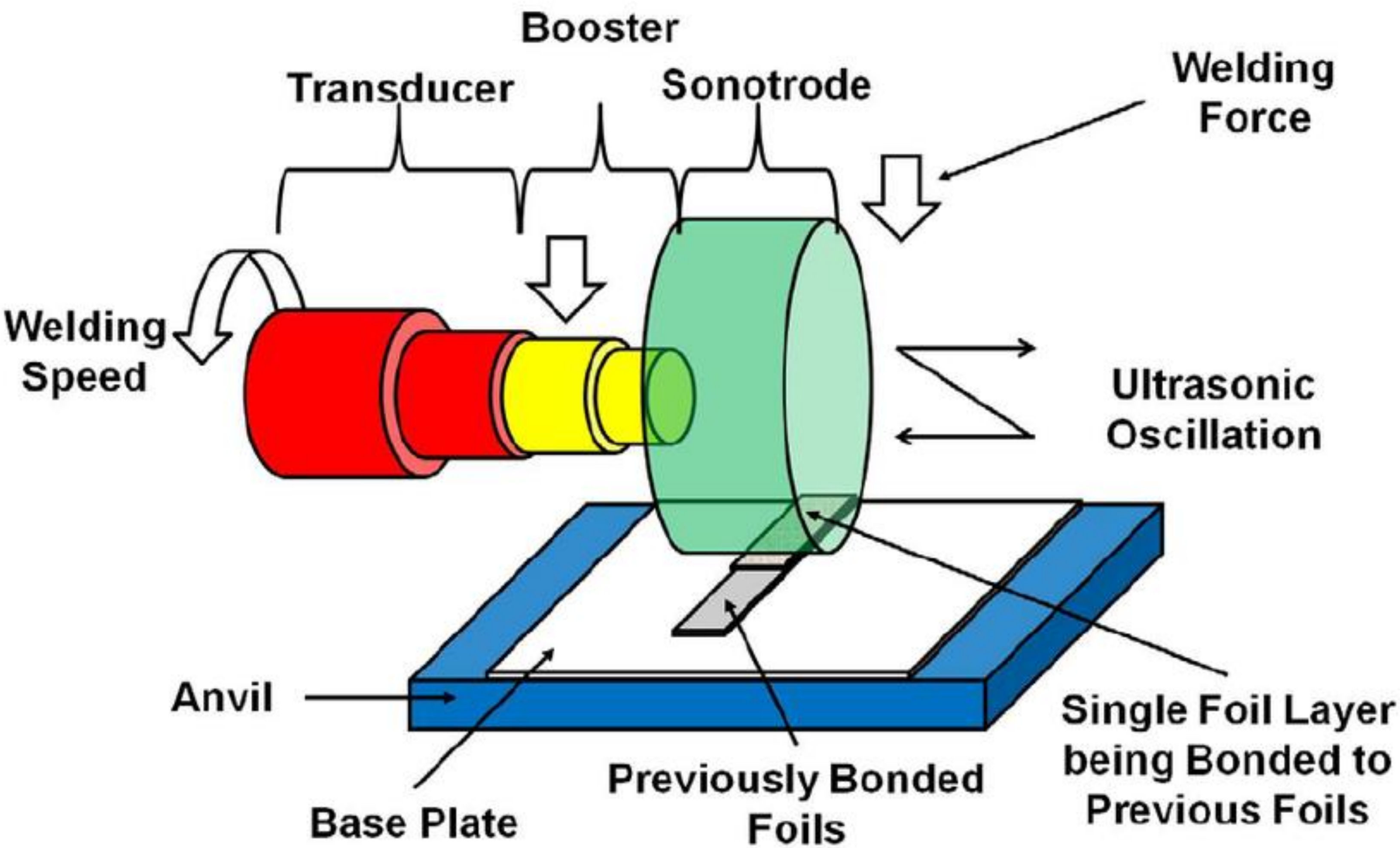
1. The Ultrasonic Consolidation (UC) process is a solid-state manufacturing method invented and patented by Solidica Inc. for rapid prototyping.
2. At the heart of the UC process is an ultrasonic metal welding system (UMW) that creates true metallic bonds between thin layers of metal.
3. The UC process can be used to build solid metal objects with complex internal geometries that would otherwise be impossible by conventional manufacturing methods.
4. Solidica integrates this technology with a CNC platform, thereby bringing about the Formation machine tool system.
5. The UC process approach, with its unique ability to grow parts in a "cold" solid-state fashion, holds great promise.
6. Solid-state fabrication—There is no liquid to metal transition in the UC process, thus dimensional accuracy easily meets engineering requirements that are far out of reach.

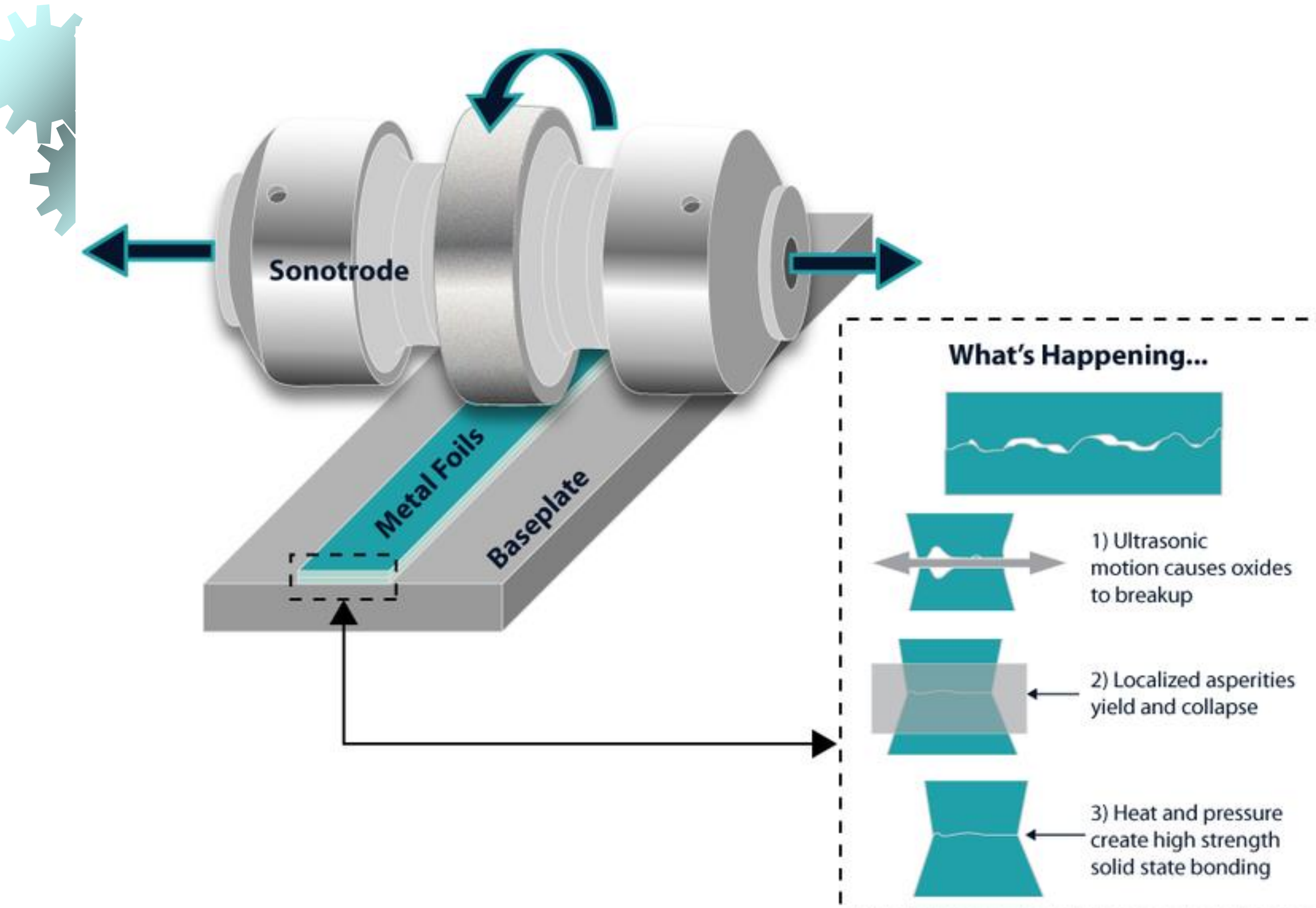
Ultrasonic Consolidation

Ultrasonic Additive Manufacturing (UAM)

7. Integrated three-axis milling center—UC is a hybrid additive metal process in that the deposition stages are periodically followed by precise material removal stages using conventional CNC technology.
8. Ultrasonic bond quality—The UC process utilizes ultrasonic joining of thin foil layers for a solid-state process. The resultant inter-laminar bond quality is that of a metallurgical bond and is characterized by fine grain structures unlike the coarse re-cast layers common within other processes.
9. Multi-material laminates—UC enables bonding and joining of dissimilar materials, such as metal–metals, Al–Ti, Cu–Al etc.

Solidica's Formation 2030 combines an ultrasonic material deposition technology with machining capability, providing both additive and subtractive manufacturing in a single machine.


Booster
Transducer
Sonotrode
Welding
Force
Welding
Speed
Ultrasonic
Oscillation
Anvil
Single Foil Layer
being Bonded to
Previous Foils
Previously Bonded
Foils
Base Plate


Sonotrode
Metal Foils
Baseplate
What's Happening...
1) Ultrasonic motion causes oxides to breakup
2) Localized asperities yield and collapse
3) Heat and pressure create high strength solid state bonding

A **sonotrode** is a tool that creates ultrasonic vibrations and applies this vibrational energy to a gas, liquid, solid or tissue.

A sonotrode usually consists of a stack of piezoelectric transducers attached to a tapering metal rod

An alternating current oscillating at ultrasonic frequency is applied by a separate power supply unit to the piezoelectric transducers.

The current causes them to expand and contract.

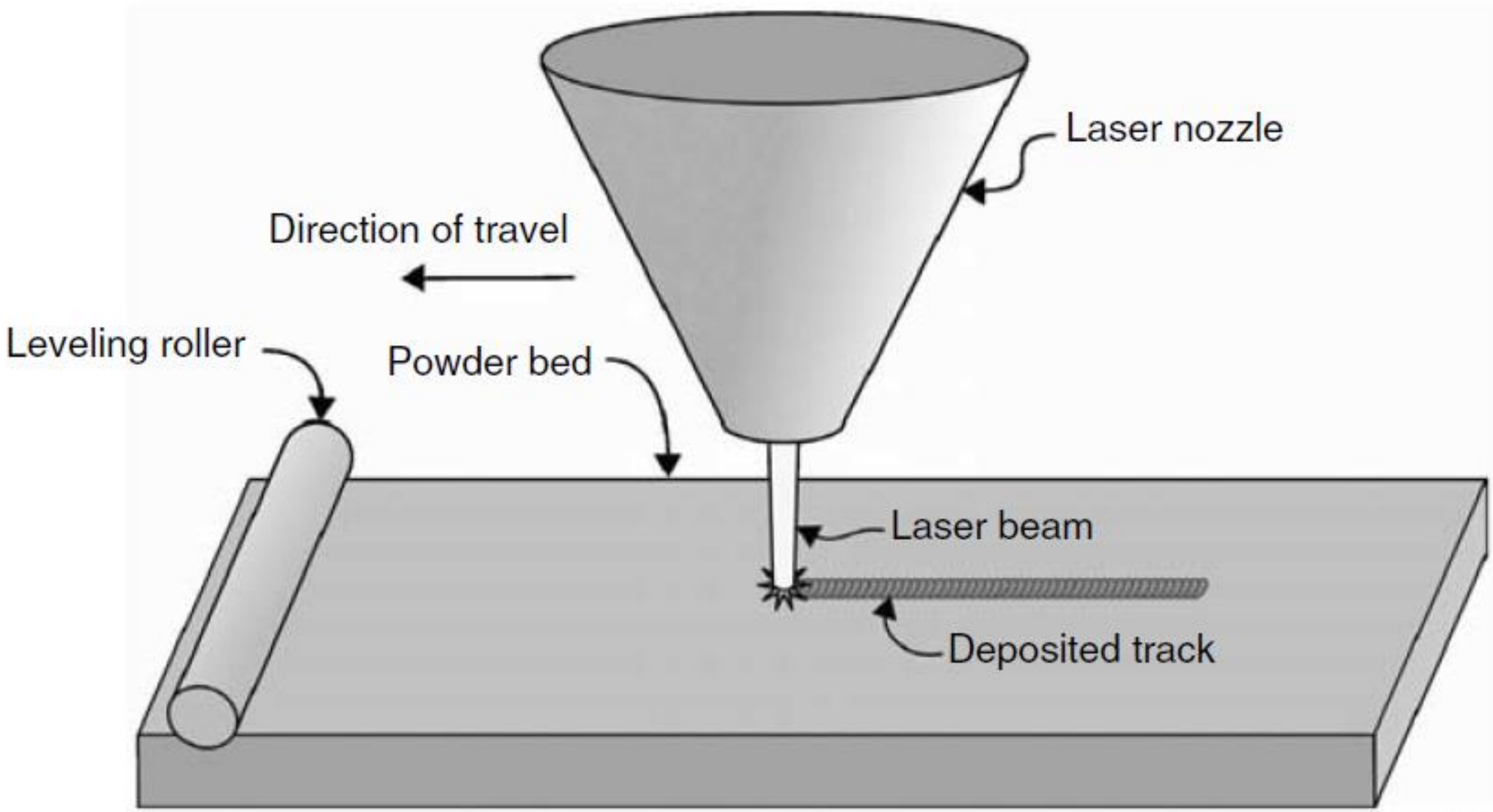
The standard frequencies used with ultrasonic sonotrodes range from 20 kHz to 70 kHz. The amplitude of the vibration is small, about 13 to 130 micrometres.

Powder based Rapid Prototyping Processes

1. Powder-based RP processes are meant to encompass all forms of materials in powder form.
2. The powder form can include the metallic, alloy, plastic and ceramic powder as feedstock material.

Laser Sintering Processes

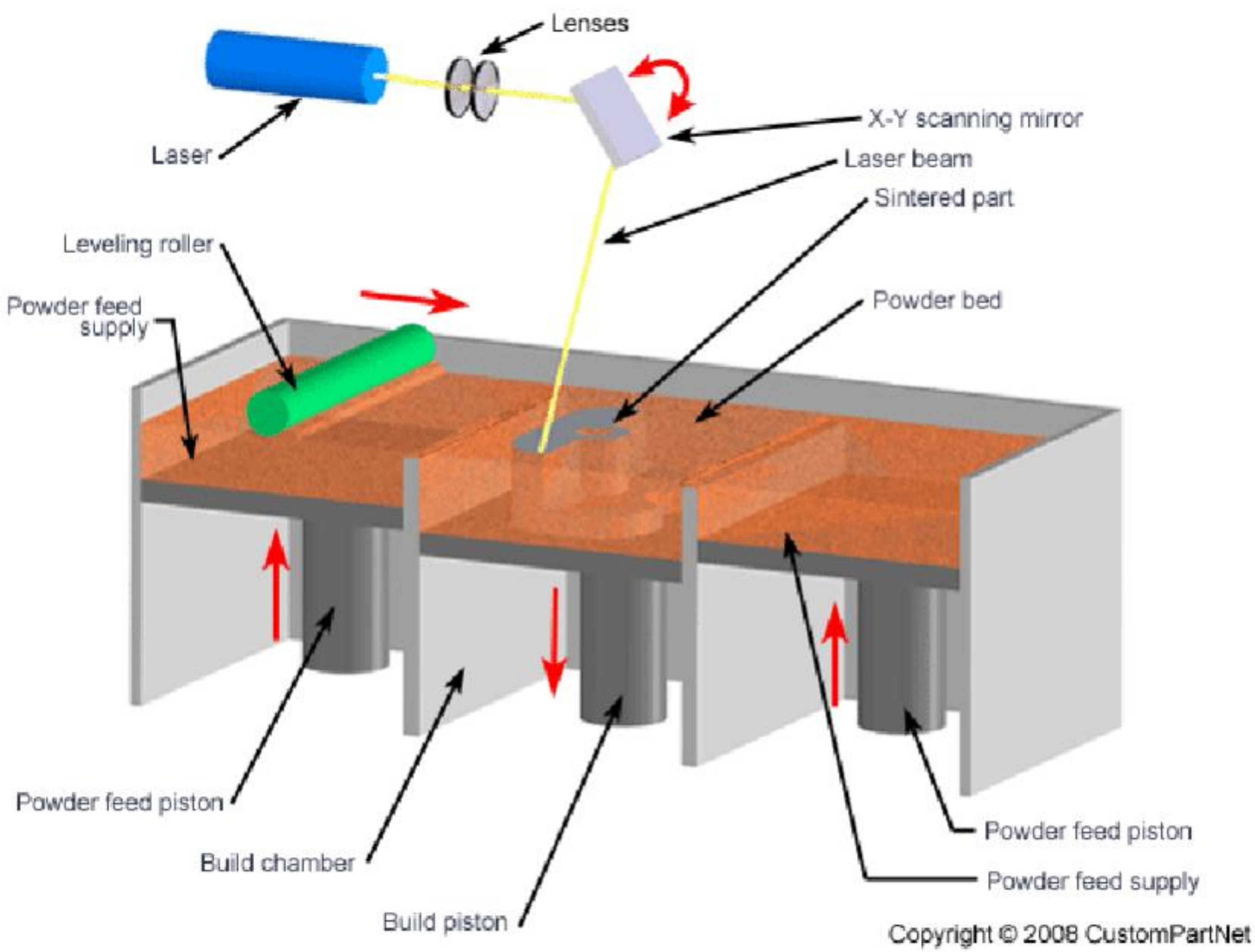
1. The earliest powder-based laser sintering process is SLS patented in 1989, using a laser to bond or sinter powdered material into the solid part.
2. This process is similar to the stereo-lithography process, but the photosensitive resin is replaced with a powdered thermoplastic or high-temperature material with a thermoplastic binder.
3. The laser sintering process is a thermal process that uses a laser to sinter (fuse) layers of powdered thermoplastic materials together to form solid 3D objects.
4. The powder needs fine grains and thermoplastic properties so that it becomes viscous, flows, and then solidifies quickly.
5. A variety of materials are possible and these materials can approximate the properties of thermoplastics such as polycarbonate, nylon, or glass-filled nylon.

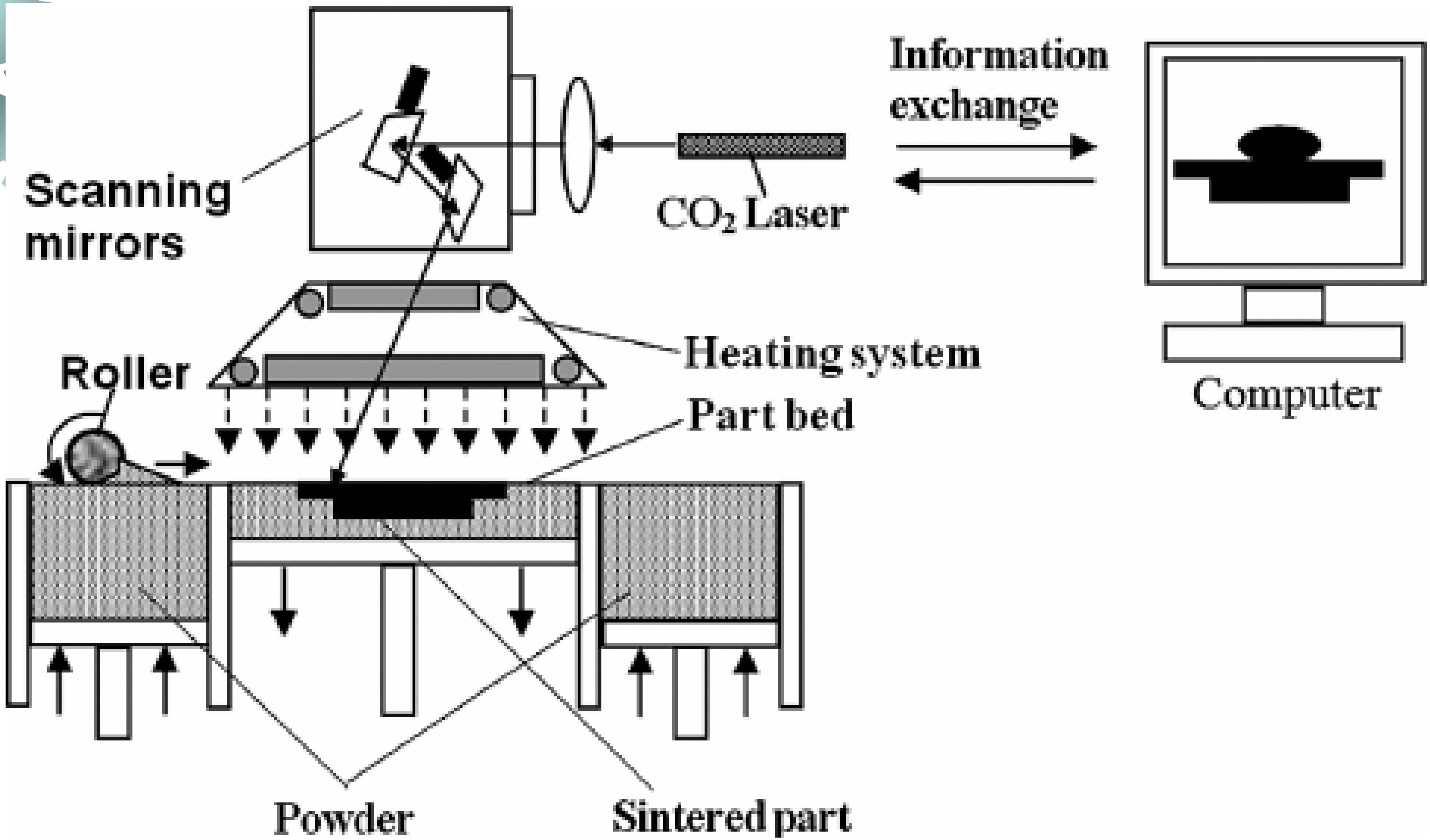

Laser nozzle
Direction of travel
Leveling roller
Powder bed
Laser beam
Deposited track

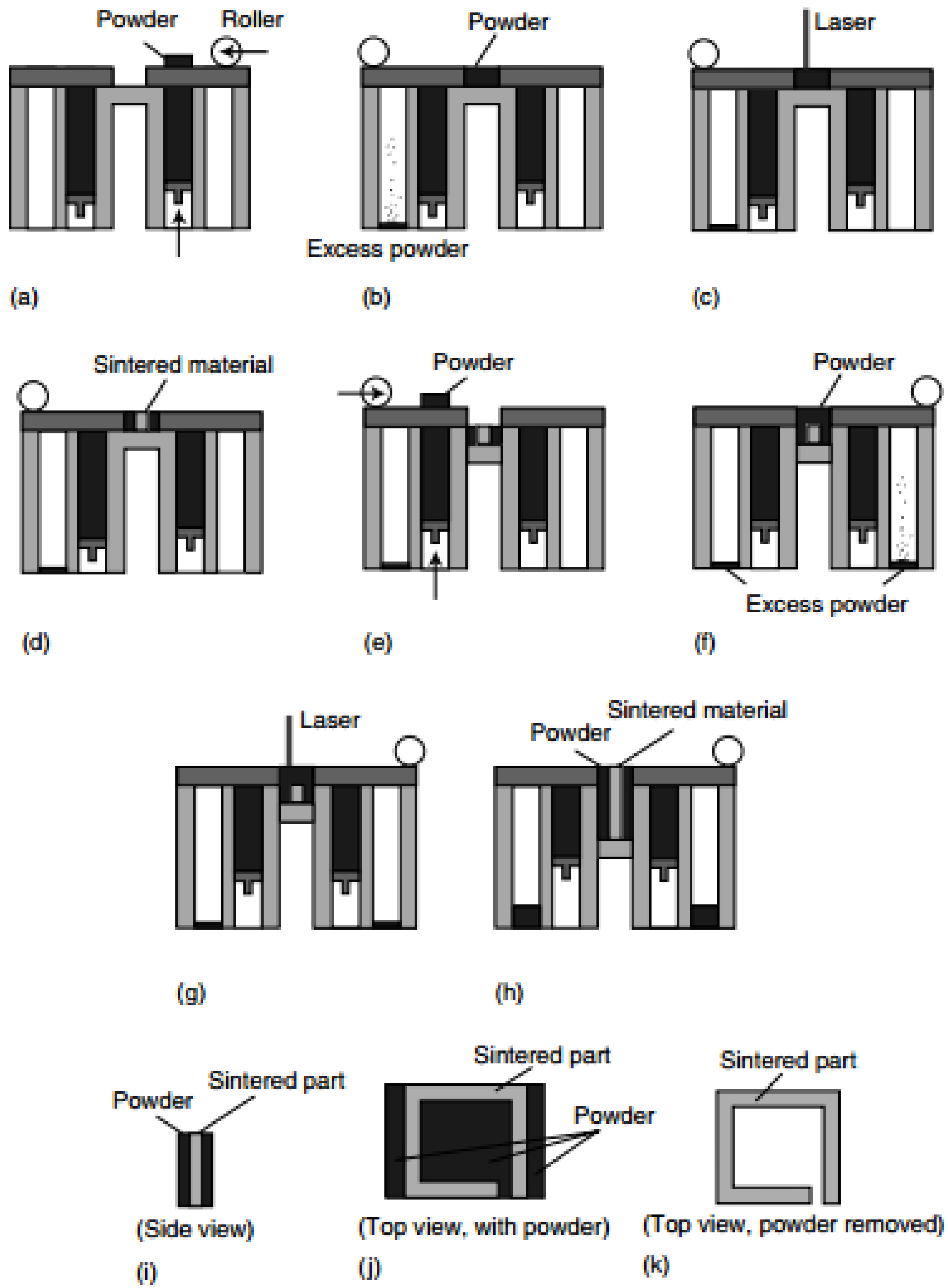
Selective Laser Sintering Process

1. The laser sintering process basically consists of two powder beds and a laser. One of the powder beds hold the feed powder and the other bed holds the part.
2. The part bed is in the middle of the beds with the laser acting directly perpendicular to this bed.
3. A roller is used to push the layers of powder over the part bed and all three beds have their own heater source.
4. In this case, however, a laser beam is traced over the surface of a tightly compacted powder made of thermoplastic material (A).
5. The powder is spread by a roller (B) over the surface of a build cylinder (C). A piston (D) moves down one object layer thickness to accommodate the layer of powder.
6. The powder supply system (E) is similar in function to the build cylinder. In the laser sintering process, heat from the laser melts (CO_2) the powder where it strikes under guidance of the scanner system (F).

Selective Laser Sintering Process




Scanning mirrors
CO2 Laser
Information exchange
Computer
Heating system
Roller
Part bed
Powder
Sintered part



Powder
Roller
(a)
Powder
Excess powder
(b)
Laser
(c)
Sintered material
(d)
Powder
(e)
Powder
Excess powder
(f)
Laser
(g)
Sintered material
Powder
(h)
Powder
Sintered part
(Side view)
(i)
Sintered part
Powder
(Top view, with powder)
(j)
Sintered part
(Top view, powder removed)
(k)

MATERIAL THAT CAN BE USED:

- Plastic powders
- Metal powders (direct metal laser sintering),
- Ceramic powders
- Glass powders

PROCESS PARAMETERS

1. Part bed temperature
2. Layer thickness
3. Laser power The longer the laser dwells in a particular location, the deeper the fusion depth and the larger the melt pool diameter. Typical layer thicknesses range from 0.1 to 0.15 mm
4. Laser scan speed
5. Energy density
6. Powder shape

Selective Laser Melting Process

1. In metal parts, the selective laser melting (SLM) is very similar to SLS in terms of equipment but uses a much higher energy density (ND-YAG) to melt the powders.
2. Therefore, the fabricated parts exhibit a density very close to the theoretical one.
3. The process works with a variety of materials such as zinc, bronze, stainless steel, tool steel, etc.
4. However, for some metals, such as Ti-6Al-4V and Ni-based super alloys, it may be difficult to produce sound microstructure, and thus research is still under investigation.

Advantages

A distinct advantage of the SLS process is that because it is fully self-supporting, it allows for parts to be built within other parts in a process called nesting – with highly complex geometry that simply could not be constructed any other way.

Parts possess high strength and stiffness

Good chemical resistance

Various finishing possibilities

Bio compatible according to EN ISO 10993-1 and USP/level VI/121 °C

Complex parts with interior components, channels, can be built without trapping the material inside and altering the surface from support removal.

Fastest additive manufacturing process for printing functional, durable, prototypes or end user parts.

Vast variety of materials and characteristics of Strength, durability, and functionality, SLS offers Nylon based materials as a solution depending on the application.

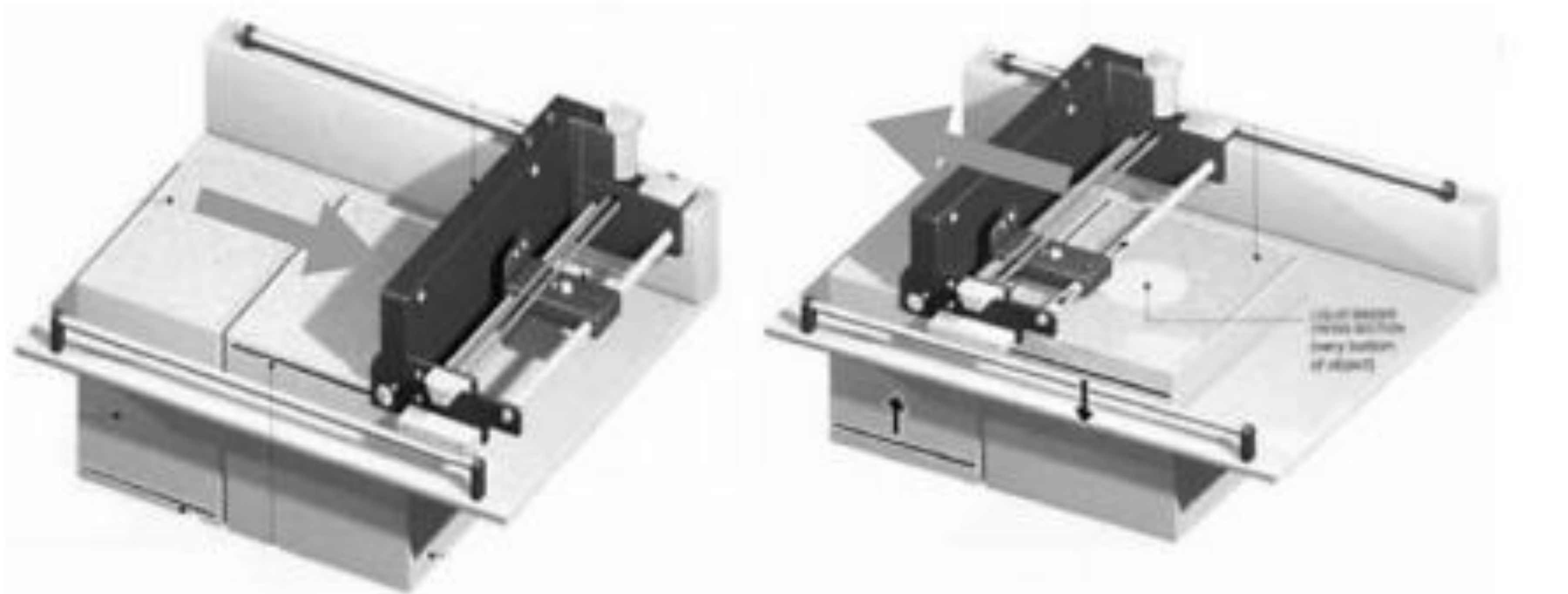
Due to the excellent mechanical properties the material is often used to substitute typical injection molding plastics.

Disadvantages

SLS printed parts have a porous surface. This can be sealed by applying a coating such as cyanoacrylate.

3D Inject Printing Process

1. One representative of the inject printing process is Three-Dimensional Printing technology (3DP), originally developed at Massachusetts Institute of Technology (MIT) in 1993.
2. This technology is very similar to laser sintering technology, but instead of using a laser, it uses the printing technology to bind powder together and thus can operate at very high speeds and low costs.
3. The inject printing process uses standard inkjet printing technology to create parts layer by- layer by depositing a liquid binder onto thin layers of powder.
4. A roller mechanism spreads powder fed from the feed piston onto the build platform; intentionally spreading approximately 30% of extra powder per layer to ensure a full layer of densely packed powder on the build platform.
5. Once the layer of powder is spread, the inkjet print heads print the cross-sectional area for the first, or bottom slice of the part onto the smooth layer of powder, binding the powder together.



(a) (b)

FIGURE 6.87 (a) Spread a layer of powder and (b) print binder on the cross-section. (Courtesy of Z Corp.)

FIGURE 6.88 These examples of models if in colors can provide meaningful and creative applications for color 3D printing including product labeling, topographical analysis, and production planning. (Courtesy of Z Corp.)

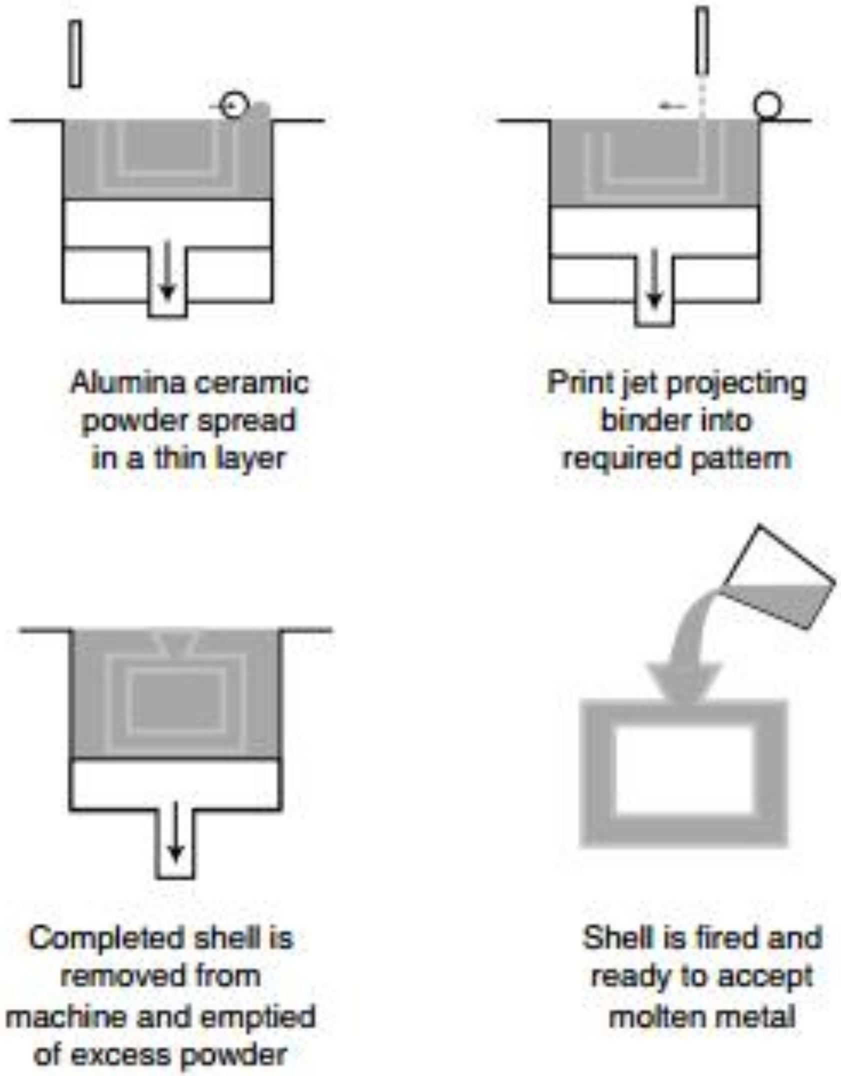


FIGURE 6.89 Direct shell production casting.

Direct Laser Deposition

1. A direct laser deposition (DLD) or direct metal deposition (DMD) process is a laser-assisted (YAG) direct metal manufacturing process that uses computer controlled lasers that, in hours, weld air blown streams of metallic powders into custom parts and manufacturing molds.
2. A representative process is called the Laser Engineered Net Shaping (LENS) process.
3. An additional benefit is its unique ability to add material to existing components for service and repair applications.
4. Powder-metal particles are delivered in a gas stream into the focus of a laser to form a molten pool of metal.
5. The laser beam is moved back and forth across the part and creates a molten pool of metal where a precise stream of metal powder is injected into the pool to increase its size.

Direct Laser Deposition

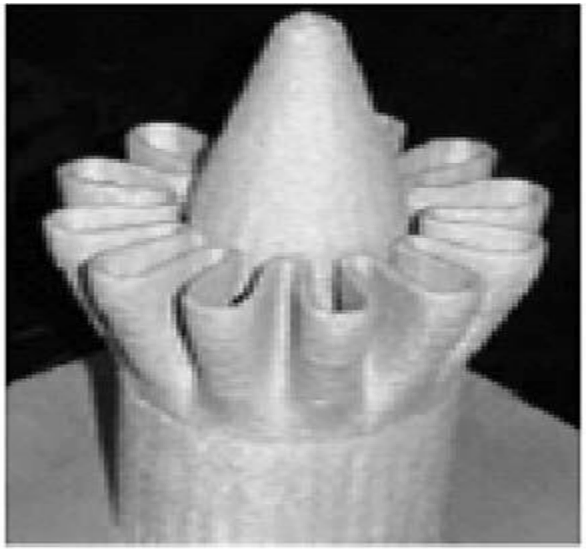
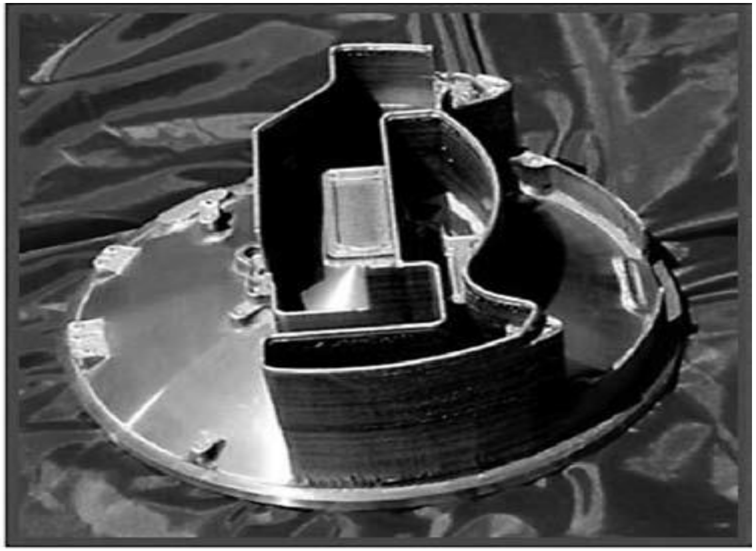
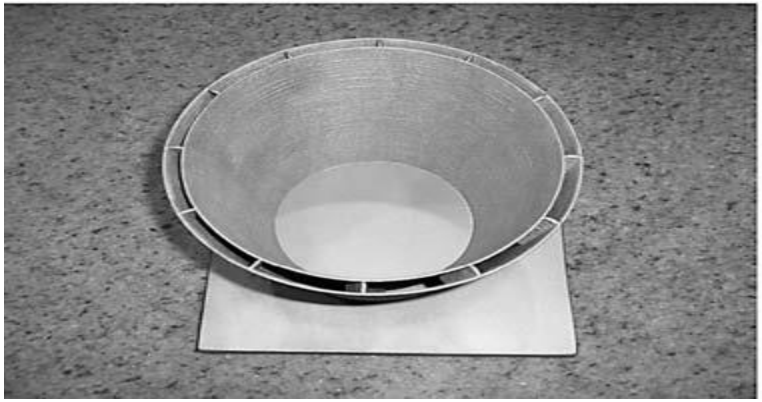
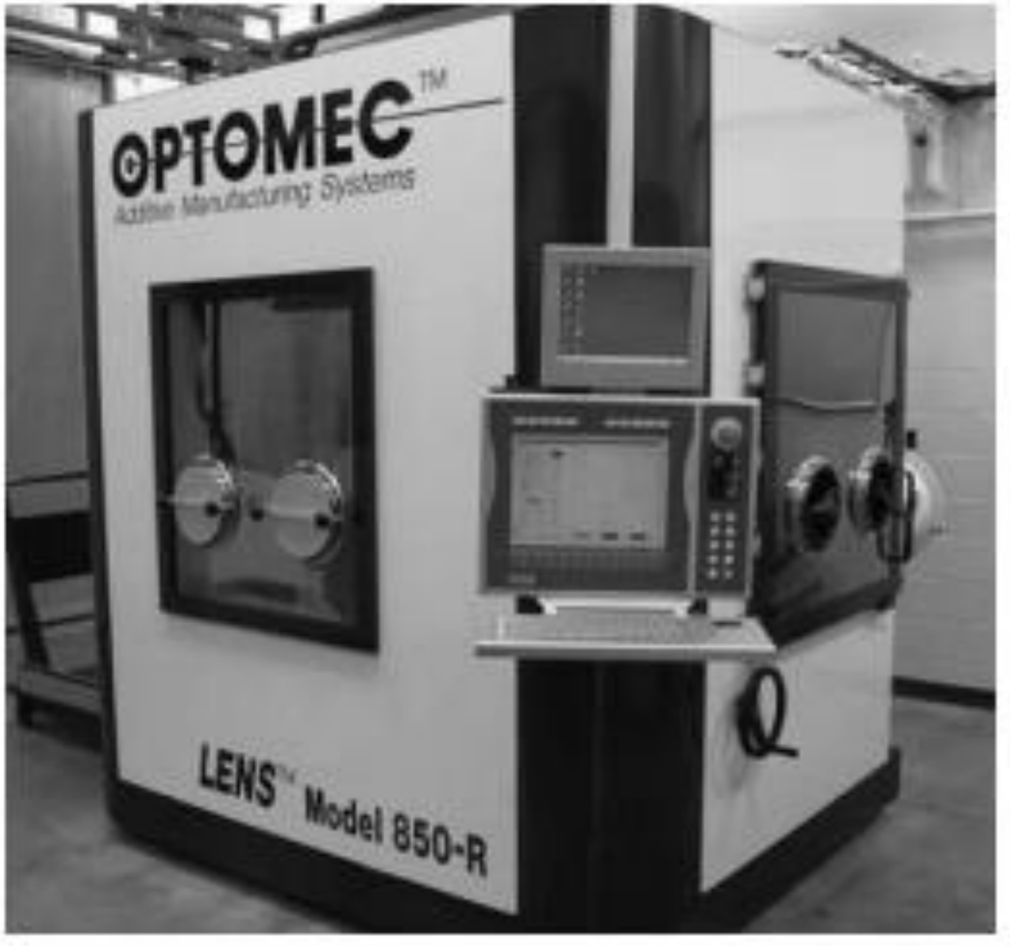




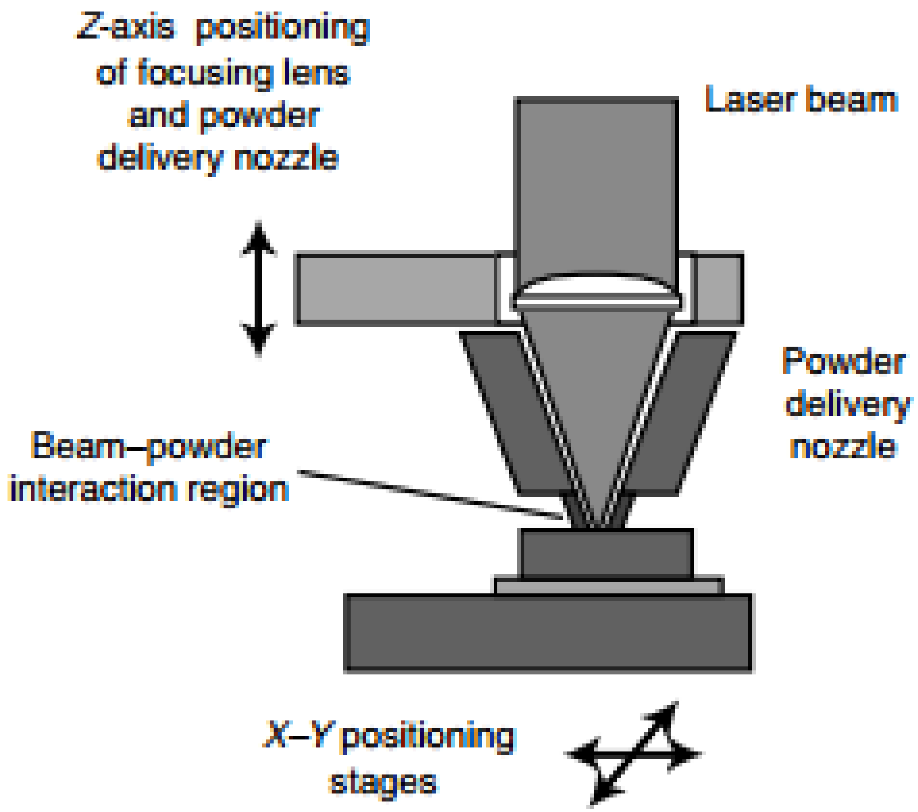

FIGURE 6.90 LENS 750 machine. (Courtesy of Optomec.)



LENS 850-R Machine. (Courtesy of Optomec.)

Direct Laser Deposition

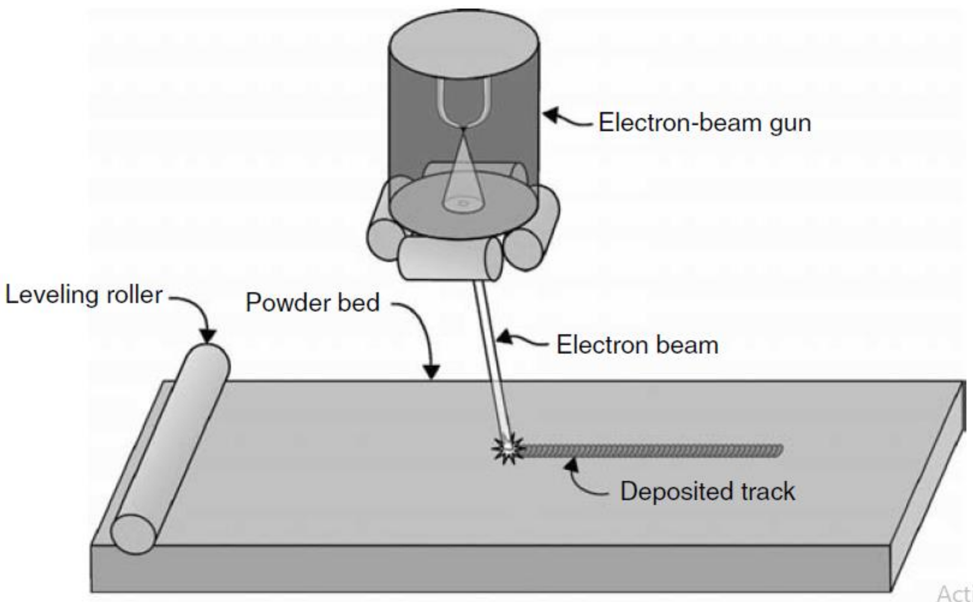
1. The strength of DLD lies in the process' ability to fabricate fully dense metal parts with good metallurgical properties at reasonable speeds.
2. DLD can even be used to add features to cast or forged parts.
3. The DLD process can be used for prototype or production tooling in a variety of industrial applications.
4. Using DLD, it is possible to modify or add material to existing aluminum, steel, or other metallic parts, or make a fully functional prototype directly from the CAD design.
5. In die repair and refurbishment, downtime costs can mount quickly when a mold or die cracks or becomes worn.
6. The other capability that opens up a whole new world to the imagination is the possibility of changing from one type of material to another within a part.



The schematics of the DLD process.

Electron Beam Melting

1. The electron beam melting (EBM) process was originally developed at Chalmers University in Sweden in the 1990s. It is a powder-based method having a lot in common with SLS.
2. This method projects electrons at half the speed of light onto the powder surface, and the kinetic energy of the electrons induces melting.



Electron Beam Melting

1. The electron beam is energy efficient than laser for conductive materials. A layer of metal powder is distributed over a platform in a vacuum chamber.
2. To reduce the concentration of residual stresses that cause distortion in a fabricated part, an electron-beam gun preheats the powder layer. After the preheating is finished, the layer is selectively melted by increasing the beam power or decreasing the speed.
3. In the melting process, electrons are emitted from a filament that is heated to over 2500C.
4. The electrons are accelerated through the anode to half the speed of light as shown in Figure. A magnetic lens brings the beam into focus, and another magnetic field controls the deflection of the beam.

Future Based RP technologies

1. Inexpensive
2. More varieties of materials
3. More accurate
4. Much larger/smaller parts
5. Rapid manufacturing
6. Repair and reuse
7. Functionally graded materials