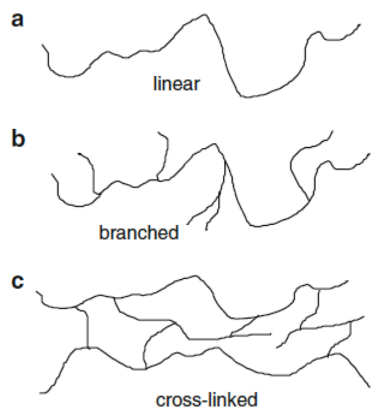
Stereolithography

Vat photopolymerization (VP)

- Also known as Stereolithography (SL) and Stereography.
- Earliest form of AM (80's)
- All AM processes which involve solidification of liquids (raw material) are based on photo-polymerization
- Components are produced by a localized photopolymerization process – (hardening/curing) by UV/visible light of a bath of liquid resins (monomers, photoinitiators)
- Parts are usually cured up to 80%. Post processing for full hardening.
- Photopolymers were invented in 60's. Widely used in coating, printing, dentistry *etc.*
- Various VP technologies exist – arrangement of their components, such as light source, build platform, curing direction, and resin tank.

VP – Photopolymerization

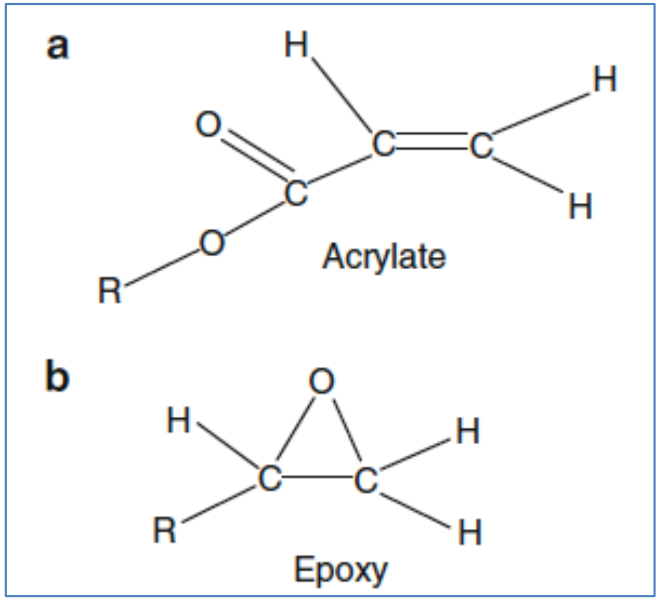
- Thermoplastic polymers (FDM) have a linear or branched molecular structure.
- In contrast, SL photopolymers (thermosetting polymer) are crosslinked, do not melt and exhibit much less creep and stress relaxation.
- SL photopolymers consists of photoinitiators, stabilizers, liquid monomers *etc.*
- Once the SL resin is irradiated with UV light, photoinitiators become reactive and react with the liquid monomer to form a polymer chain.
- Subsequent reactions occur to build polymer chain and cross linking occurs → strong covalent bond formation b/w polymer chains



Photopolymerization *contd…*

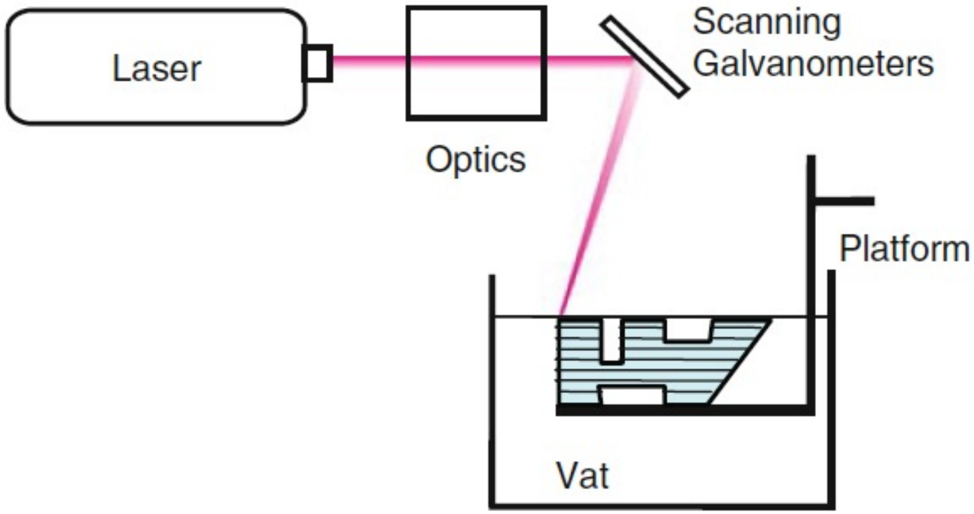
- Polymerization is the term used to describe the process of linking small molecules (monomers) into larger molecules (polymers) composed of many monomer units.
- The first SL resins were acrylates based.
  - Weak parts were produced due to shrinkage (5 – 20 %) and curling issues.
  - Curing of 46% only.
  - Partially cured layer undergoes additional crosslinking under laser irradiation, which leads to additional shrinkage and stresses.
  - Partially cured layer is not inhibited to atmospheric oxygen, *i.e,* extensive crosslinking.
- Later, epoxide based SL resins were invented.
  - More accurate, stronger and harder.
  - Lesser shrinkage (1–2 %).
  - Slow photospeed and brittleness of the cured parts.
  - Sensitive to humidity, which can inhibit polymerization.
- ***Most commercial SL resins are epoxides with some acrylate content.***

Photopolymerization *contd…*



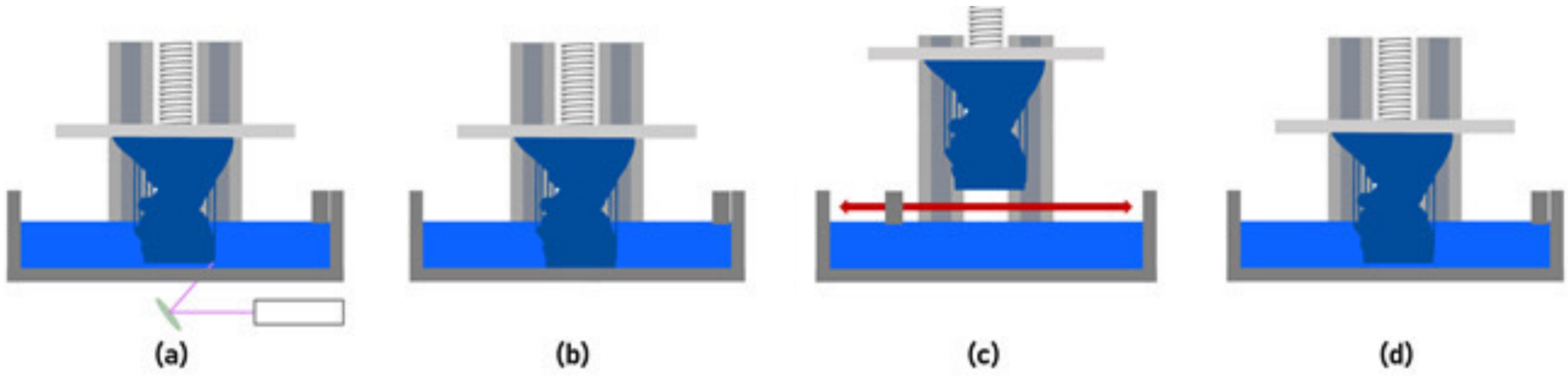
Molecular structure of SL monomers

- Point-by-point approach
  - A fine laser beam forms the contour of the respective cross section on the surface of a resin bath and generates locally the critical energy density that is required for the polymerization and thus the desired solidification.



Point-by-point scanning

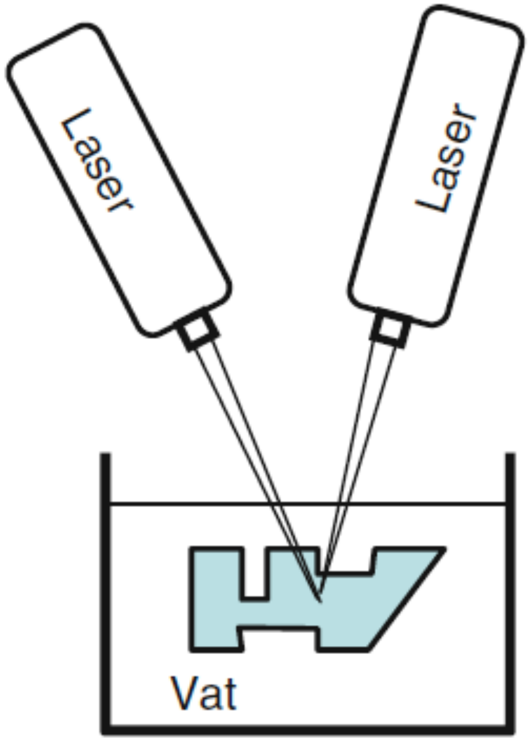
VP



SLA printer prints a layer between the build platform and the vat (a & b), raises the platform and resets the liquid using the sweeper (c), and then lowers the part back down to print another layer (d)

VP

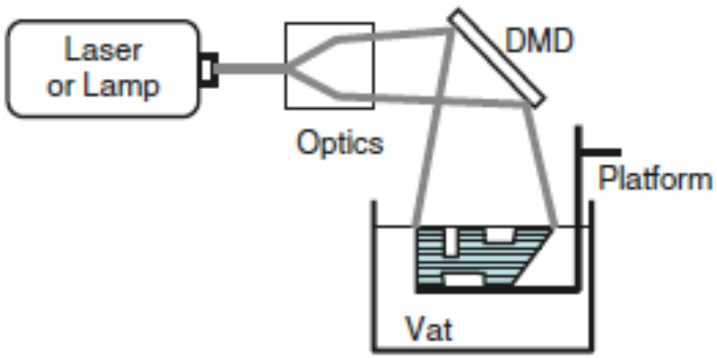
- Point-by-point approach
  - In the two photon approach, photopolymerization occurs at the intersection of two scanning laser beams. Femtosecond laser pulses with a very small spot size are used.
  - A very high resolution is possible (sub 100 nm!)



Two-photon approach

VP

- Mask projection
  - Or layer wise approaches, irradiate entire layers at one time
  - DMD (digital micromirror device), an array of several millions of mirrors can be controlled independently to produce mask patterns
  - Sub micrometer resolution is possible. Very fast.

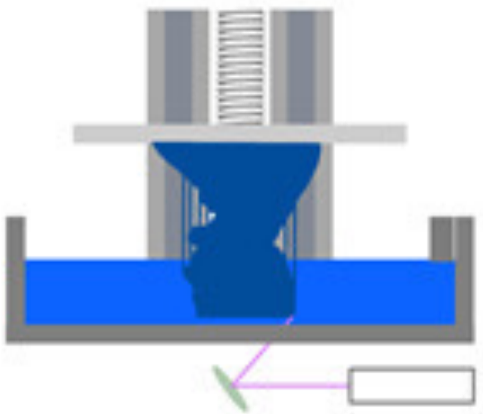


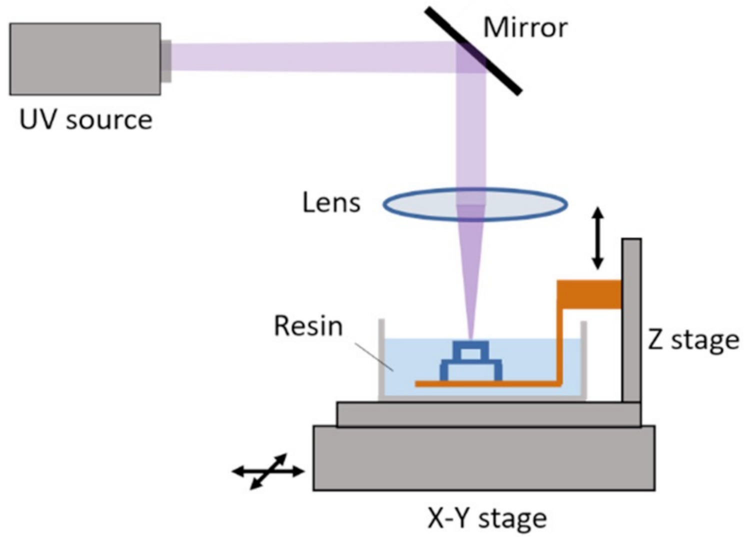
Schematic of mask projection approach to SL.

Digital Light Processing (DLP)

VP

1. Expose resin to UV light.
2. The cured part mechanically moved either to separate from the surface of resin vat (for bottom-up systems) or to lower into the resin (for top-down systems) for resin renewal.
3. Re-positioning.





Not a continuous process!

Printing speed is restricted to a few millimetres per hour

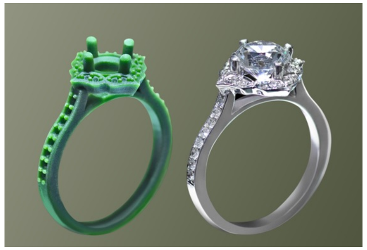
VP – CLIP

- CLIP (continuous liquid interface production)
  - Patented by Carbon.
  - Oxygen permeable window creates a thin oxygenated resin layer, where polymerization does not occur. **Incredible!**

Digital Light Synthesis (DLS)

Vat Photopolymerization (VP)

- High Resolution
- Surface finish
- Clear parts possible
- UV degradation (limits life)
- Limited performance (brittle)



Images – 3D printing handbook, desktop metal

Vat Photopolymerization (VP)

Manufacturers

SLA
- 3D systems
- FormLabs

DLP
- Envision Tec (now Desktop Metal)

DLS
- Carbon

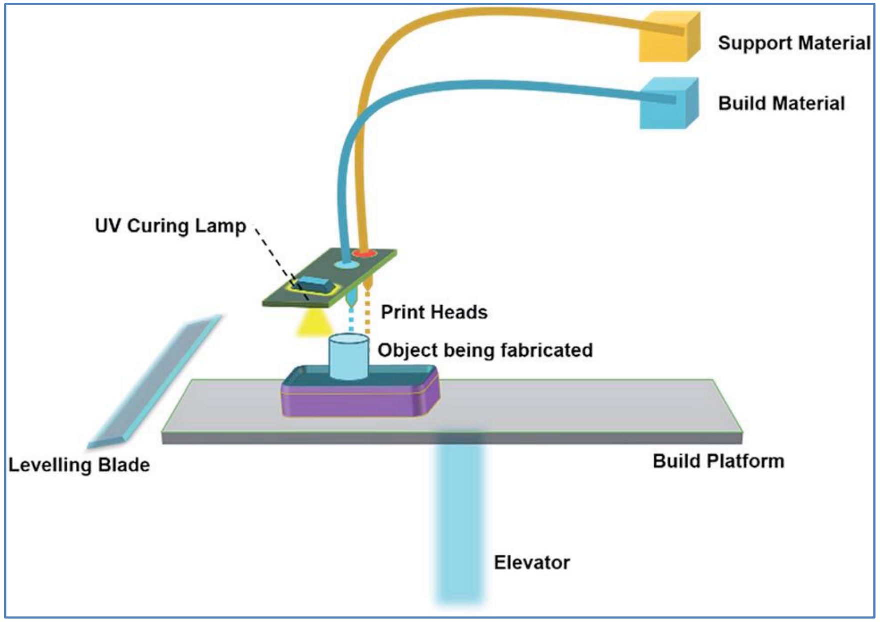
Materials

Class	Key characteristics
Standard	• Smooth surface finish • Brittle
Translucent	• Clear
Tough/Durable	• ABS-like or PP-like
High Temperature	• Useful for injection molding & thermoforming tooling
Dental	• Biocompatible • Abrasion resistant • High cost
Flexible	• Rubber-like
Ceramic precursors	• Print is followed by pyrolysis

Material Jetting

Material Jetting

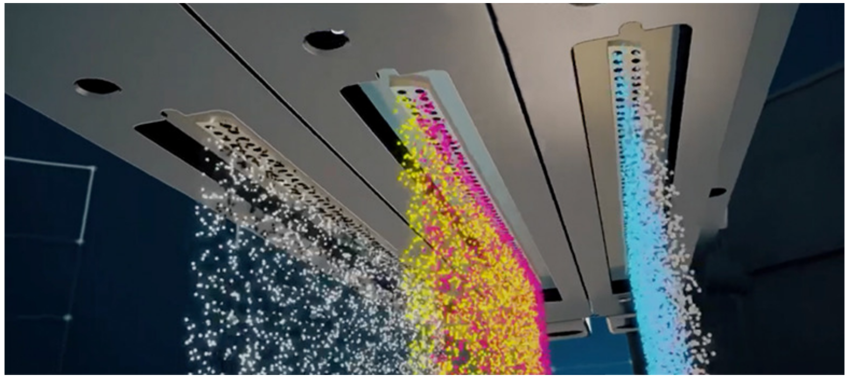
- Droplets of feedstock material are selectively deposited.
- A print head, similar to that of an inkjet printer is used.
- Liquid photopolymer materials are deposited drop by drop (spray) for each slice of the model.
- A UV light source, attached on the print head, cures the deposited droplets as it passes over them.
- Print head deposits both the part and the support material.

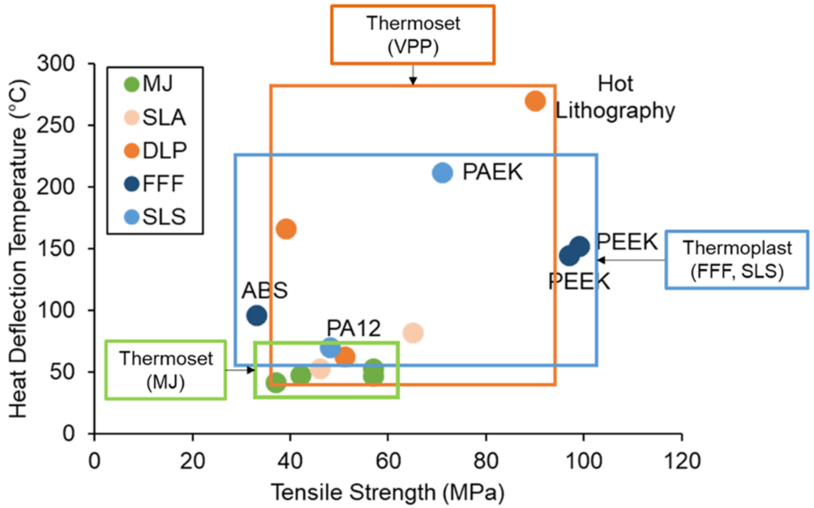


A schematic representation of material jetting printer

Material Jetting

- High resolution parts are possible. Layer thickness ~ 16 µm. Most accurate.
- 100's of nozzles. Nozzle diameter ~ 70 µm (or less!)
- Multi-material printing is possible.
- Plastic-like, elastomeric materials. Wax for investment casting.
- No UV post-processing.
- Applications restricted to color models and ones that are not subject to heavy loads such as molds.
  - Low mechanical and thermal performance of the photopolymer inks.





Material Jetting – Applications

- **For prototyping**

– Most applications, and one of the favourite technologies for cosmetic prototypes (together with vat photopolymerization) because of the high level of detail and surface quality.

- **For production**

– Applications where the product will not be exposed to ambient UV for extended periods (Hearing aids, for example).

– Investment casting patterns.

– For short-run injection molding tools.

Left – part with support. Right – wax ring

Metal part created by material jetting