M.Tech
Digital Manufacturing

BITS Pilani
Pilani Campus

Jayakrishnan J
Guest Faculty

innovate achieve lead

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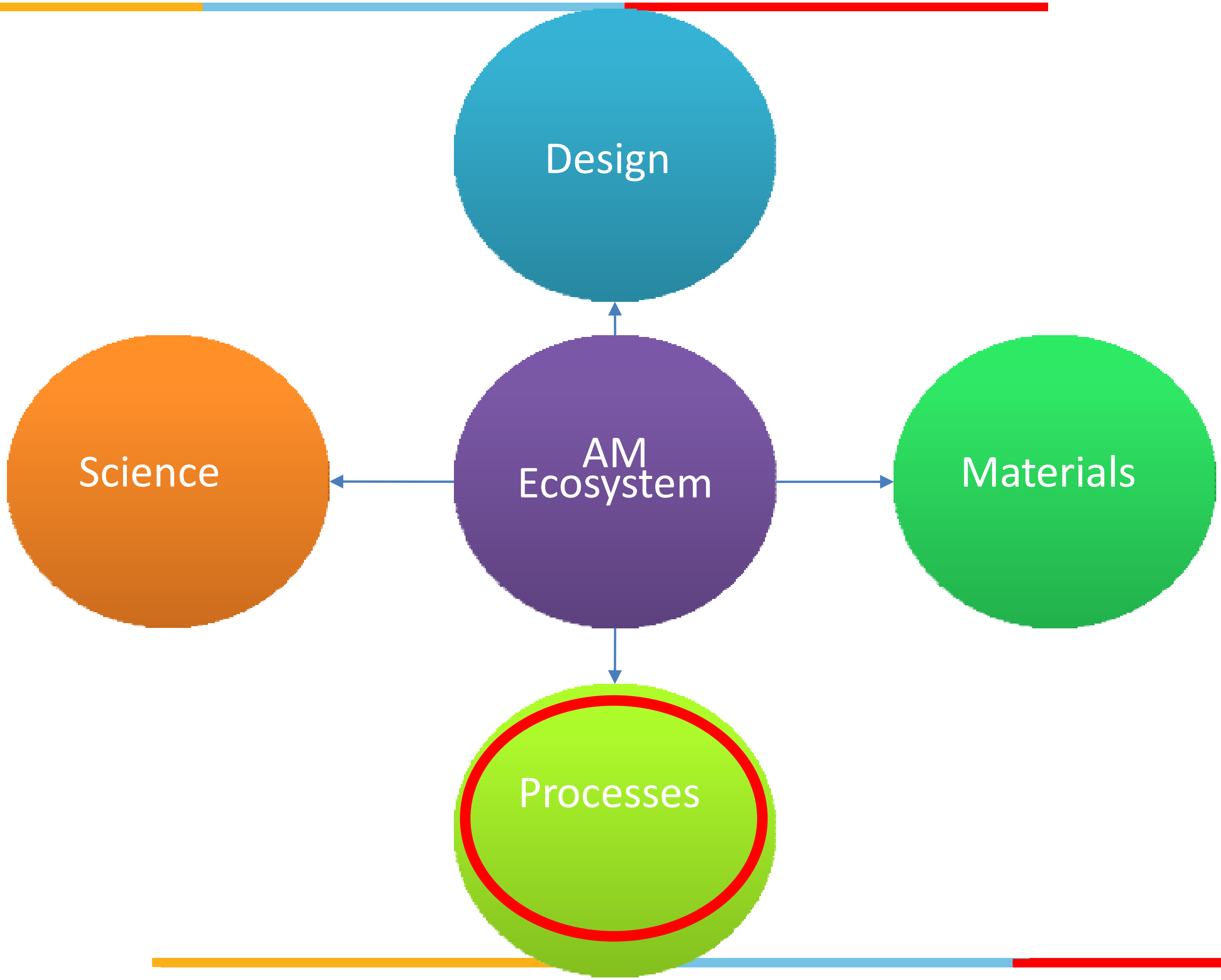
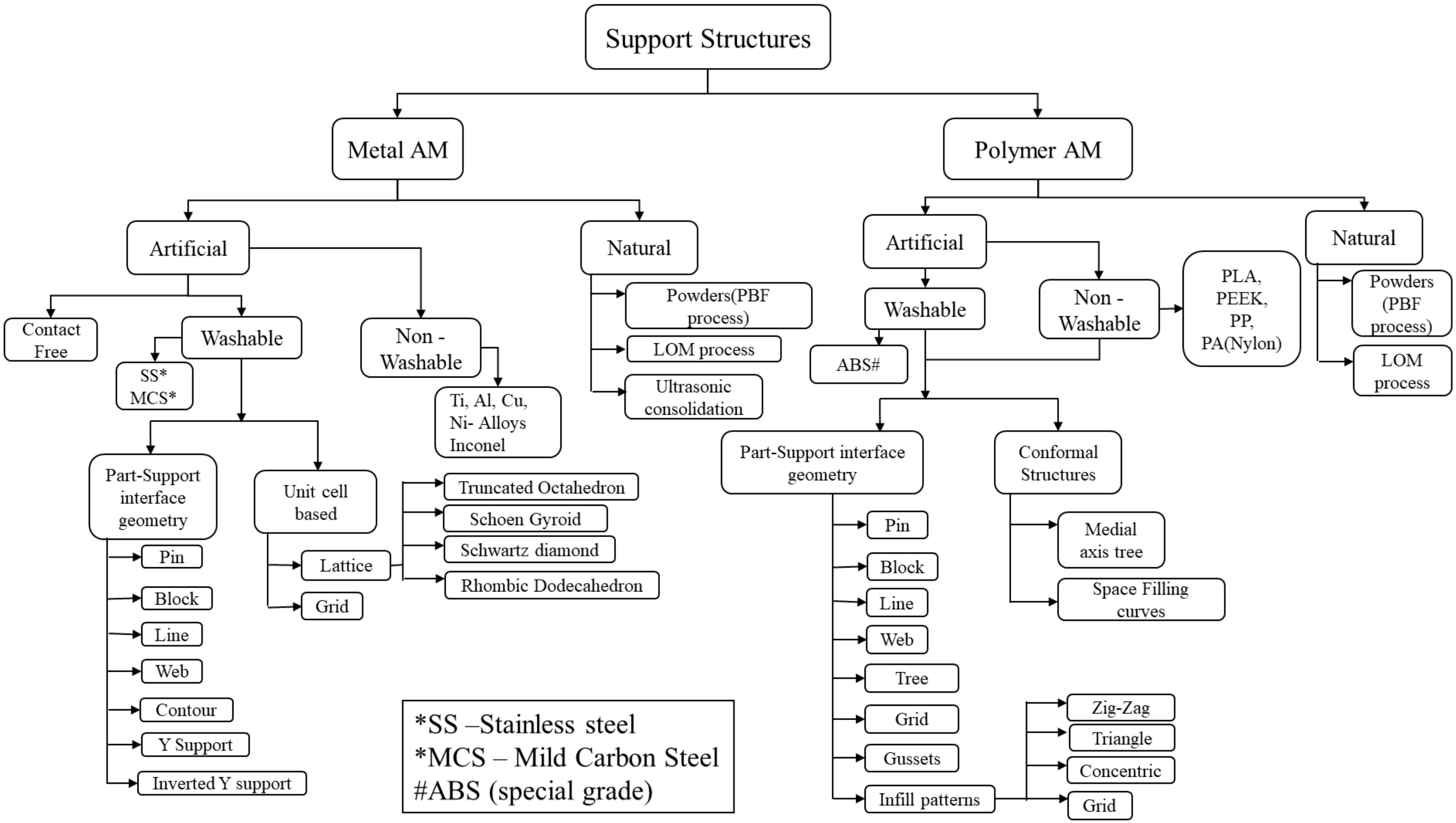
DMZG521- Design for Additive Manufacturing
Session 2 & Lecture 3-4

Additive Manufacturing Ecosystem



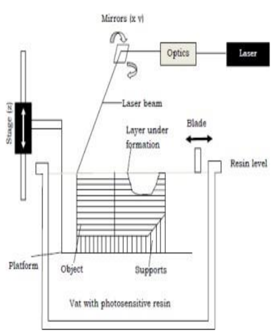
Support Structures in AM

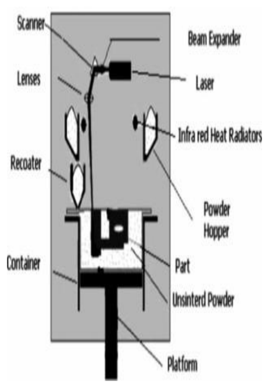


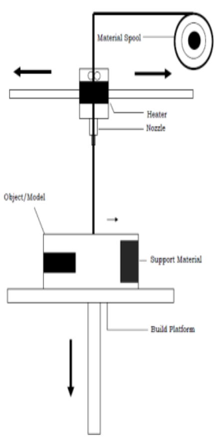
ASTM Classification

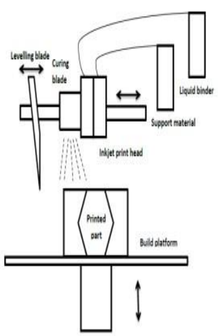
Additive Manufacturing

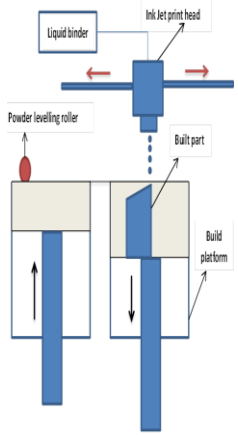
- Vat Polymerization
- Powder Bed Fusion
- Material Extrusion
- Material Jetting
- Binder Jetting
- Sheet Lamination
- Directed Energy Deposition

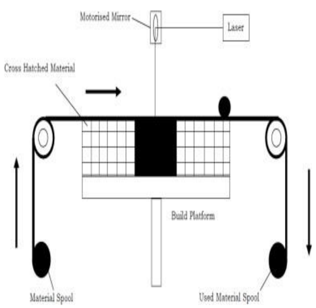


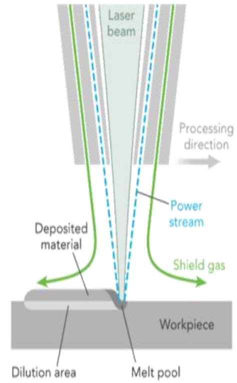




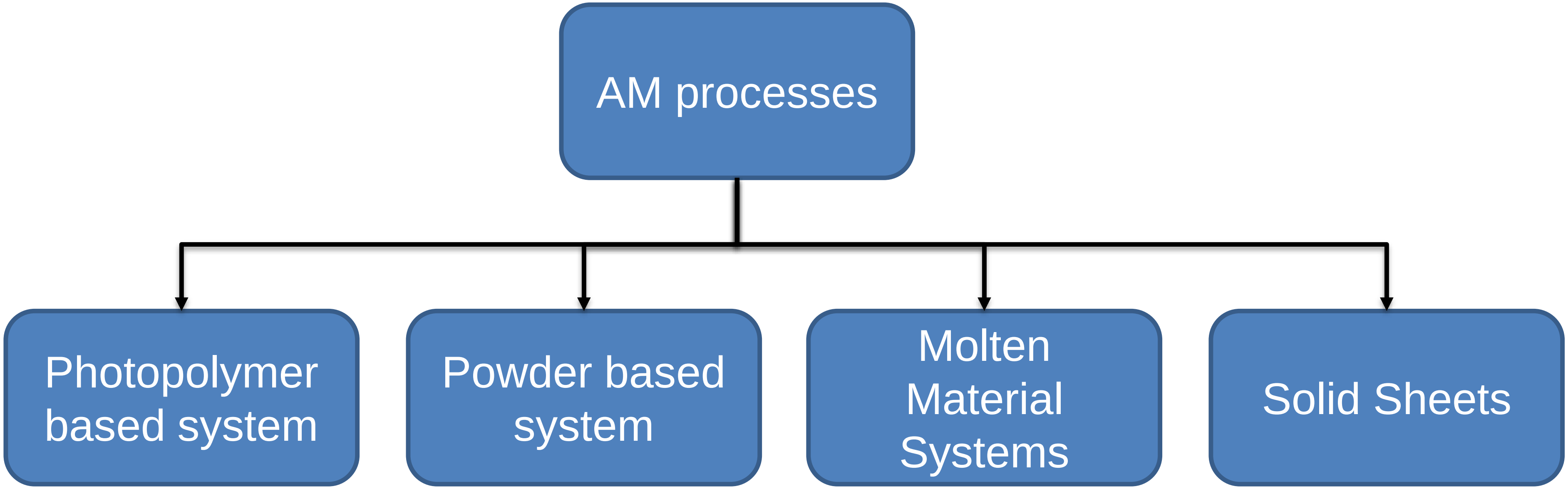








General classification of AM processes



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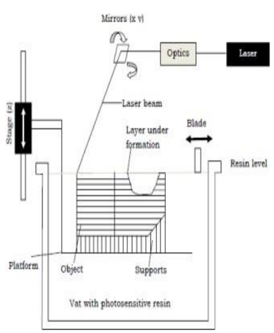
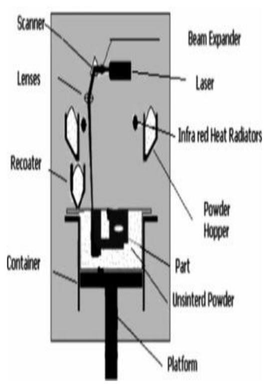
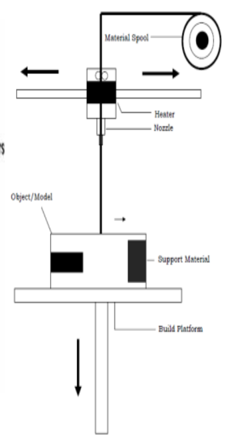
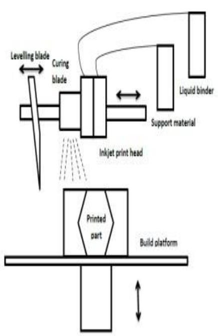
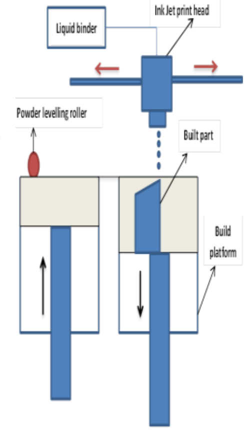
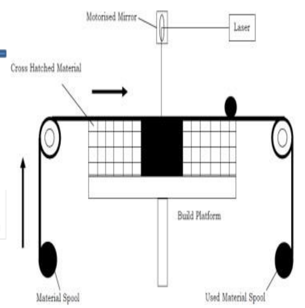


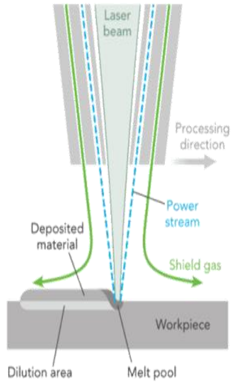






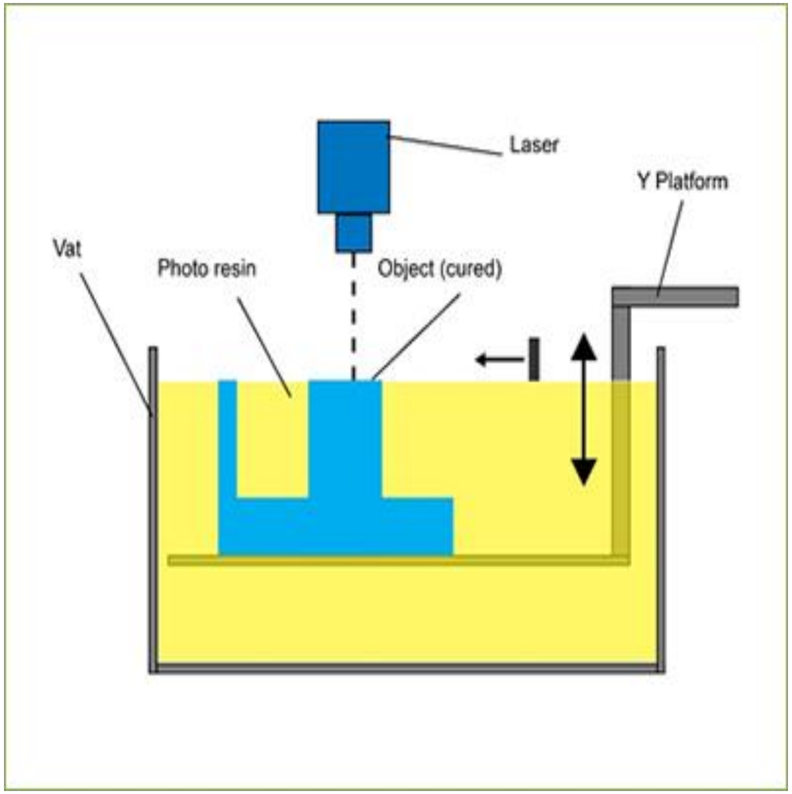






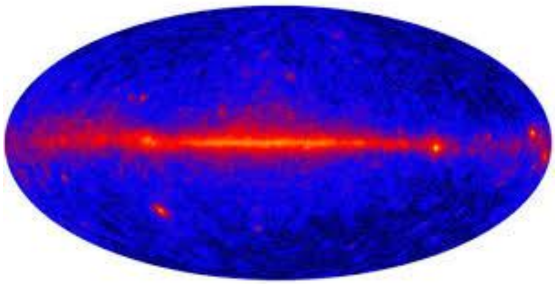
Vat photopolymerization process

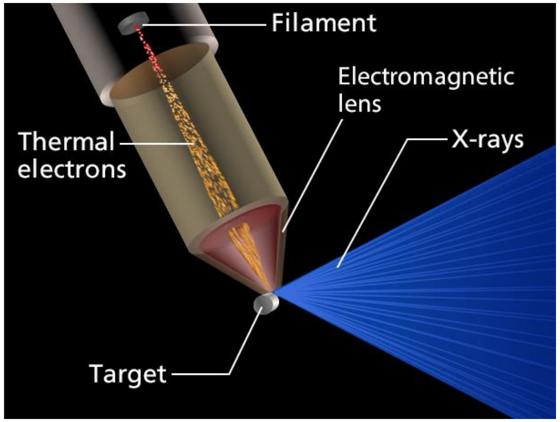
- Makes use of liquid polymers which are cured by laser radiation or UV light
- Chemical reaction from monomers to cross linked or linear chain polymerization
- Used in various industries since 1960
- Generally in coating, dentistry and printing industry

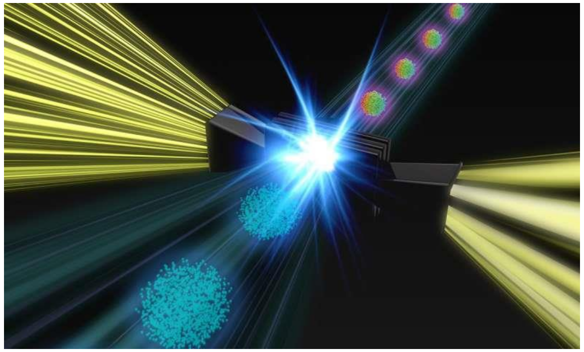


Types of Energy Sources

- Gamma Rays
- X-Rays
- Electron beam
- UV
- Visible light

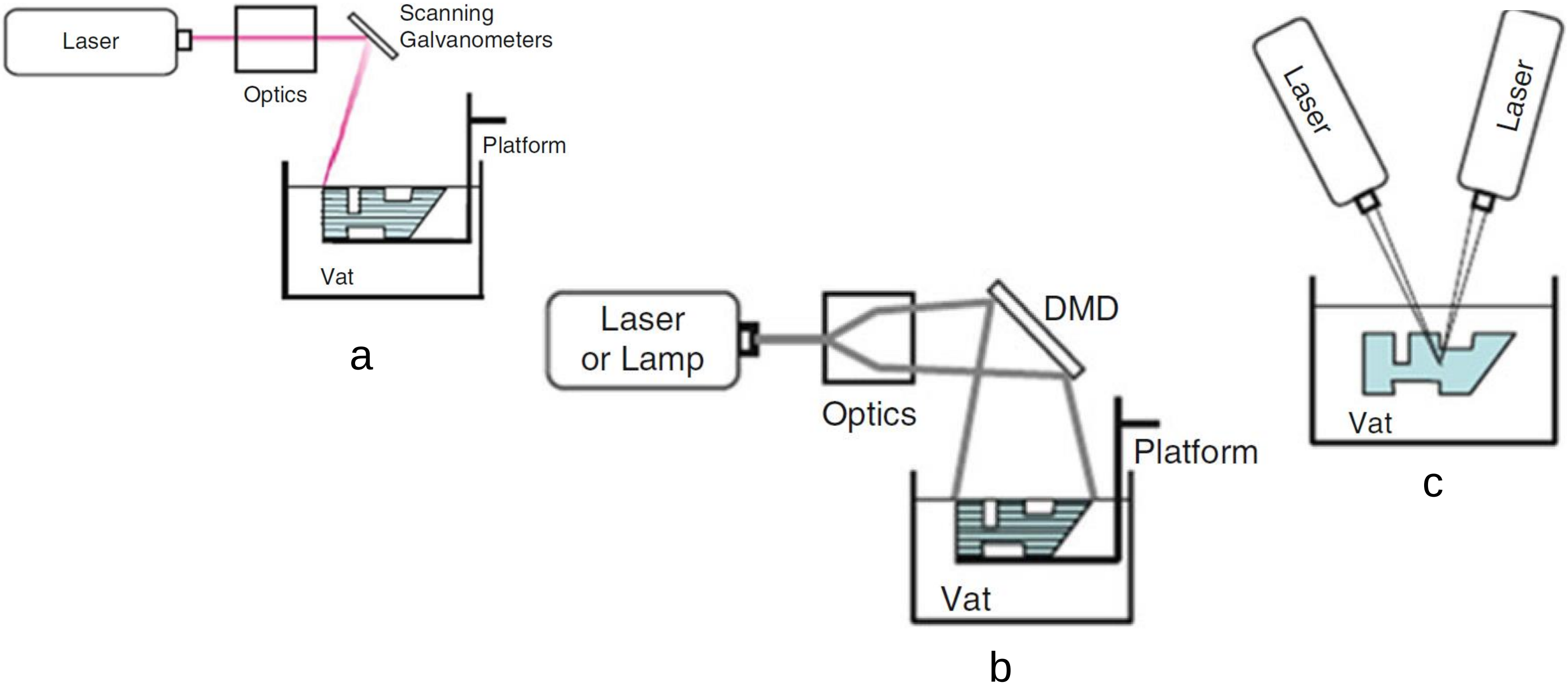




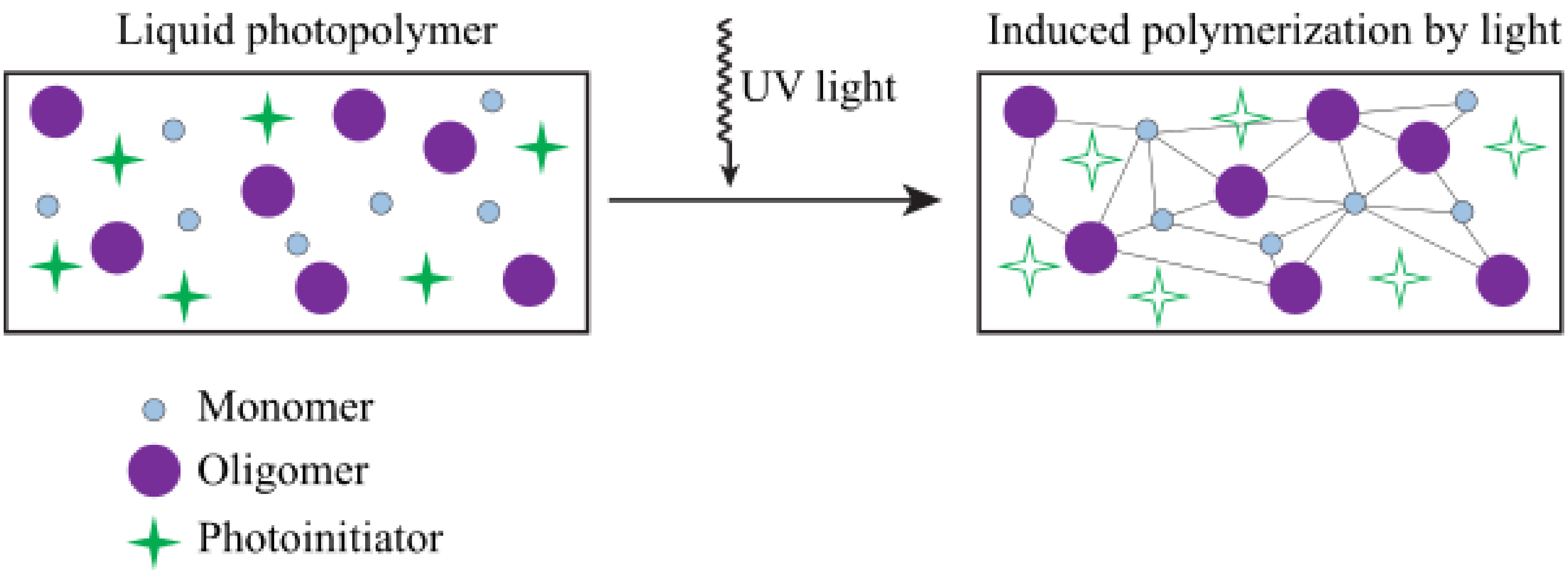


Processing Steps

a) Vector Scan(point-wise)
b) Mask Projection (layer wise)
c) Two-photon approach (high resolution point to point)

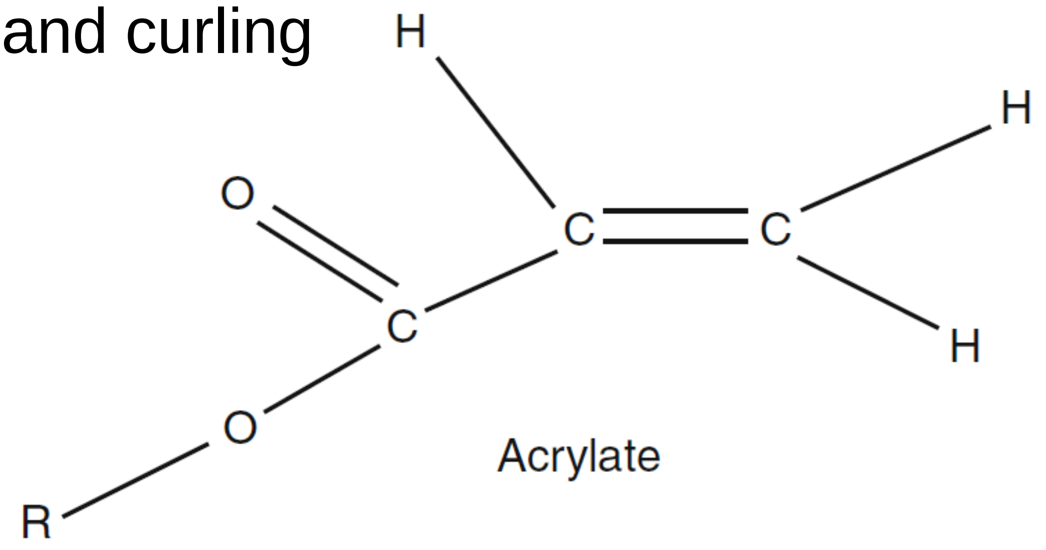


Photopolymerization



Materials used

- Acrylates
  - High Reactivity
  - Weak parts
  - Partial curing up to 46%
  - Prone to shrinkage and curling

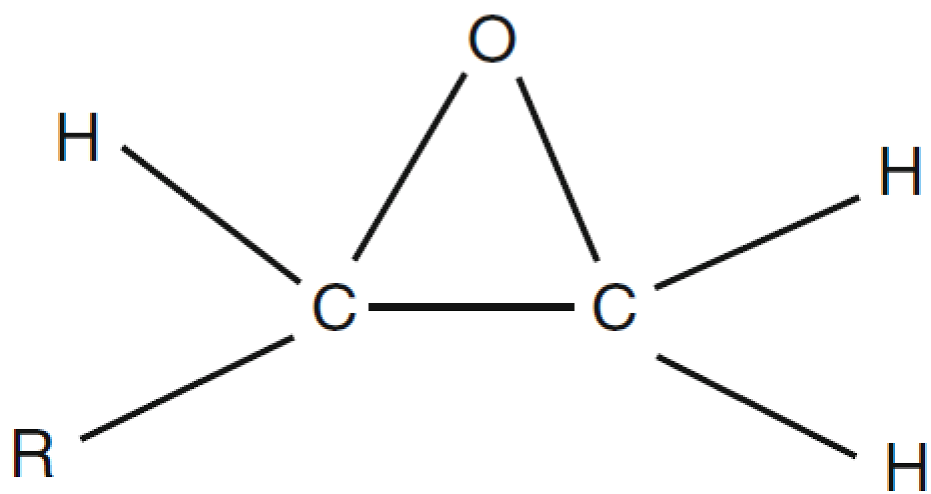


Acrylate

Materials

Epoxy based

- Slow photo speed
- Brittleness after curing
- Sensitive to humidity



Epoxy

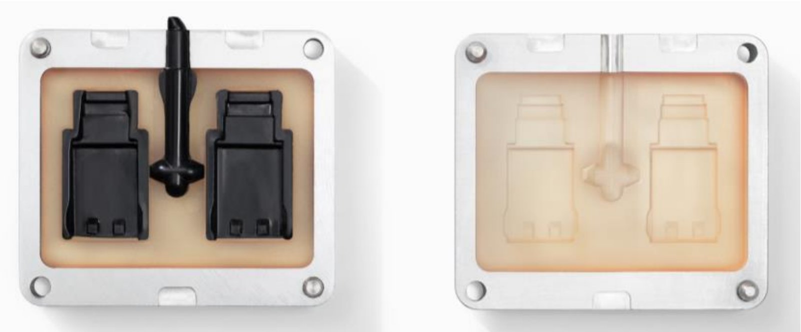
Materials

Acrylate +epoxides Resins

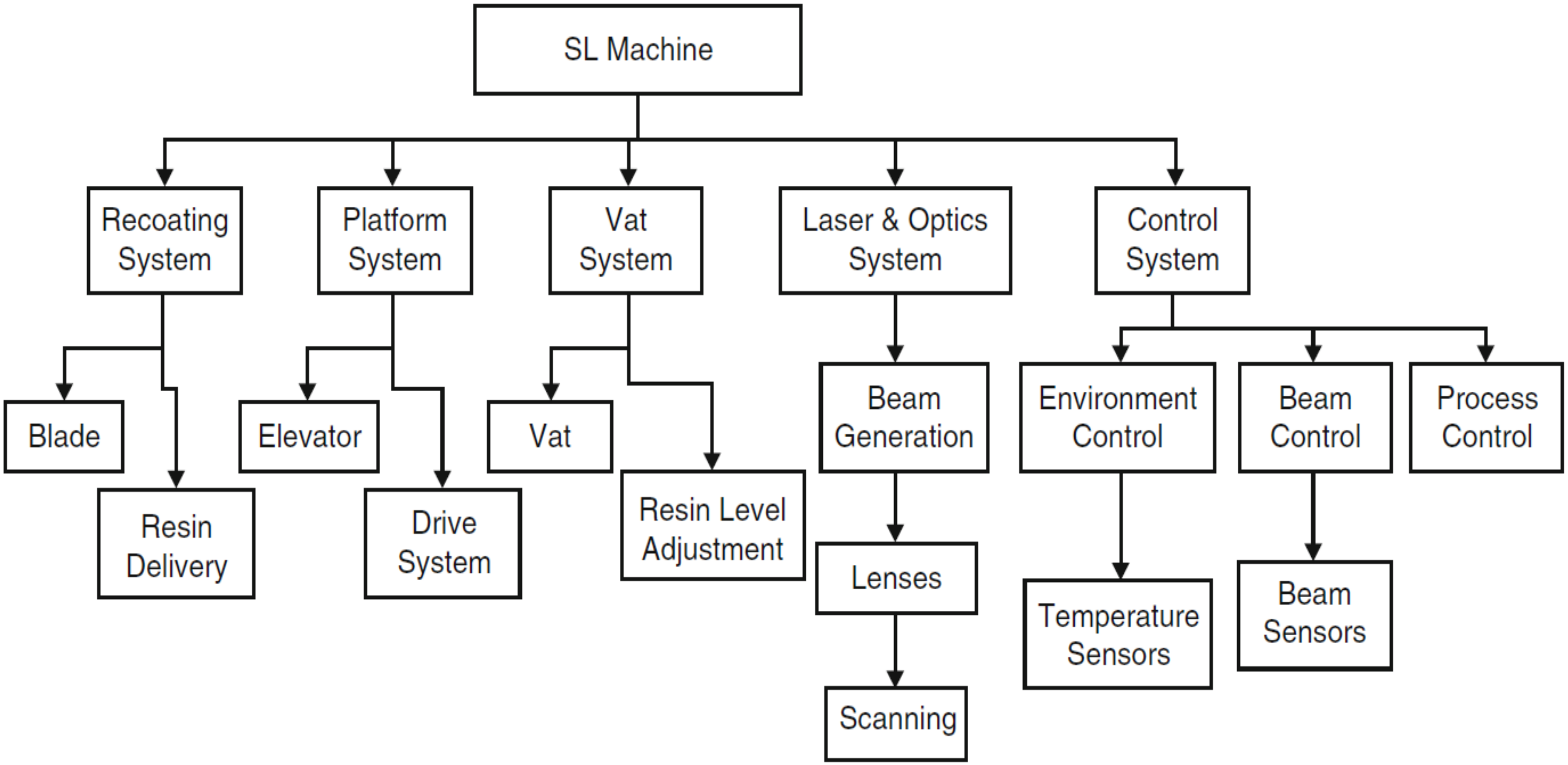
- Combination of both these resins overcome the weaknesses displayed by the polymers
- Increased hardness
- Less susceptible to atmospheric oxygen and humidity
- Improved accuracy and part build
- Enhanced build quality and part conformance

Common SLA Materials

- Standard and clear resins
- Engineering SLA resins
  - Tough resin(ABS-Like)
  - Durable resin(PP-Like)
  - Heat resistant resin
  - Flexible resin
  - Ceramic filled resin(Rigid)



Subsystems for SL technology



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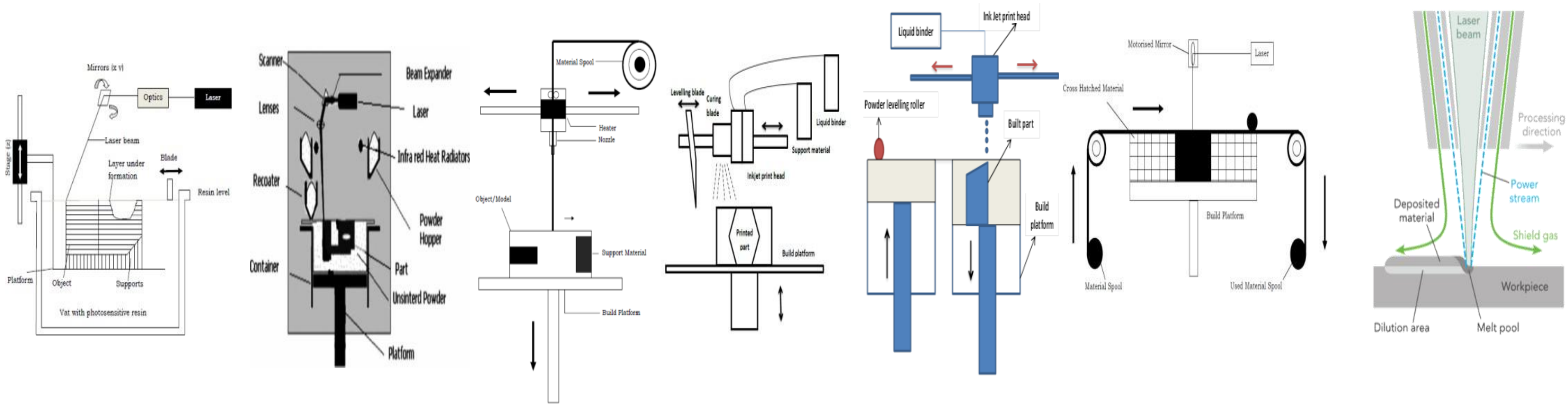
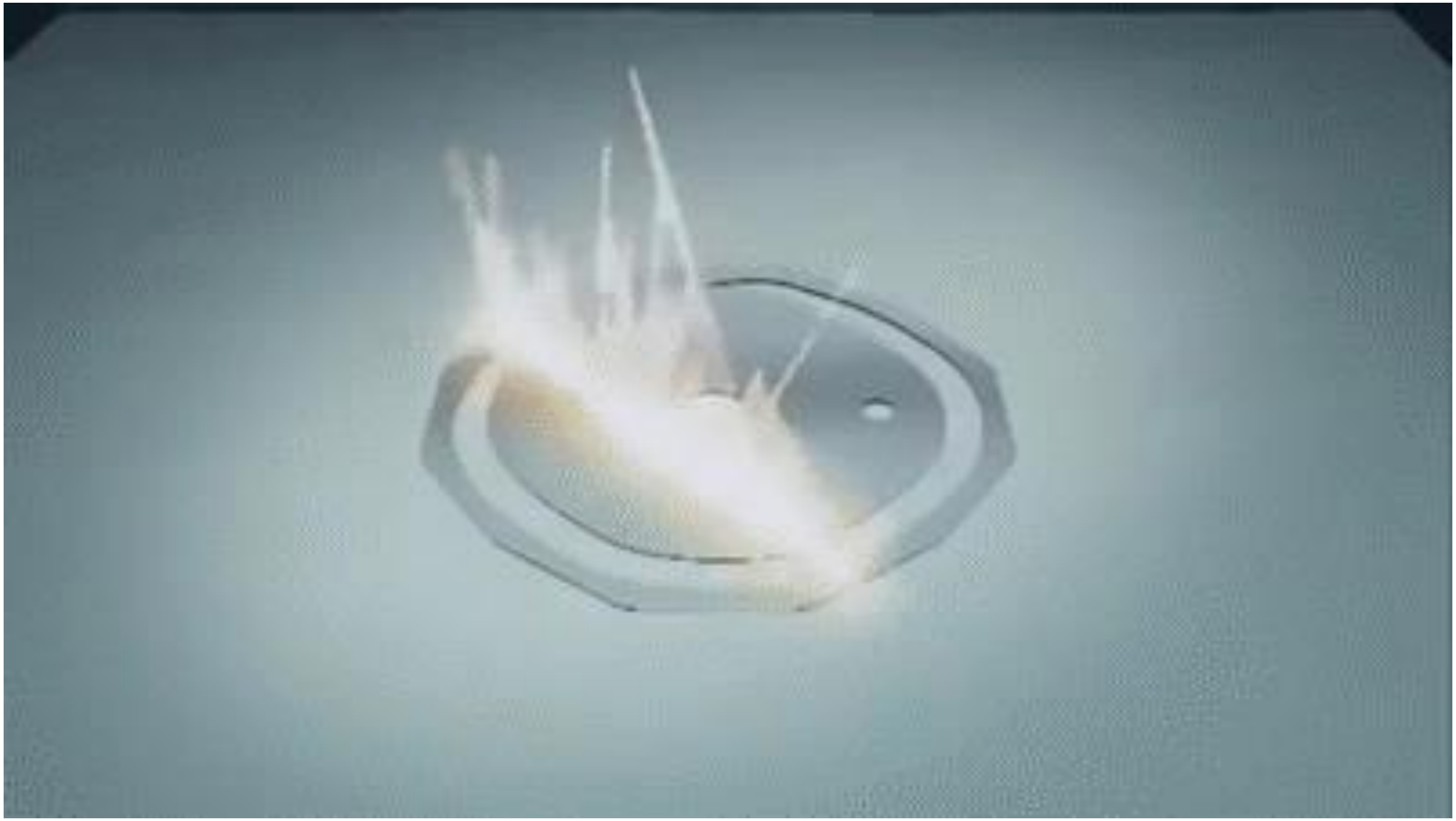
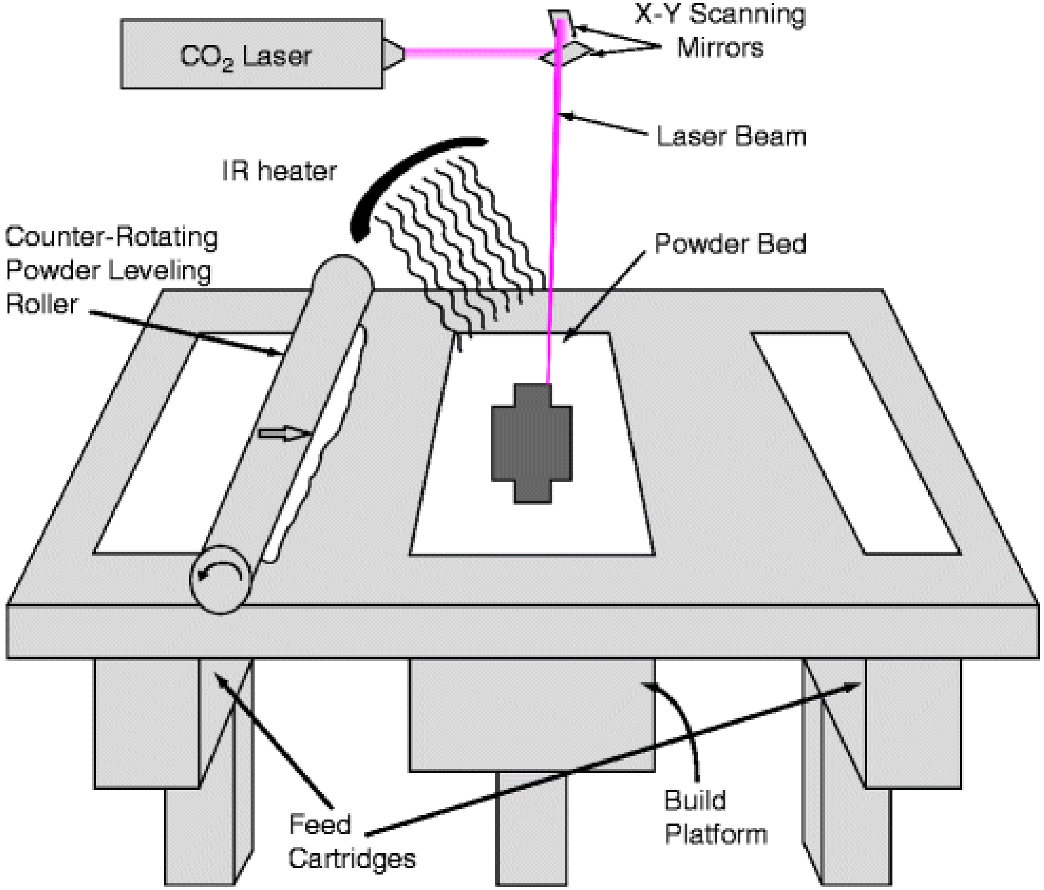


Powder Bed Fusion

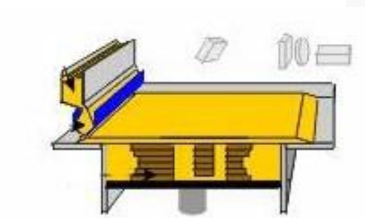


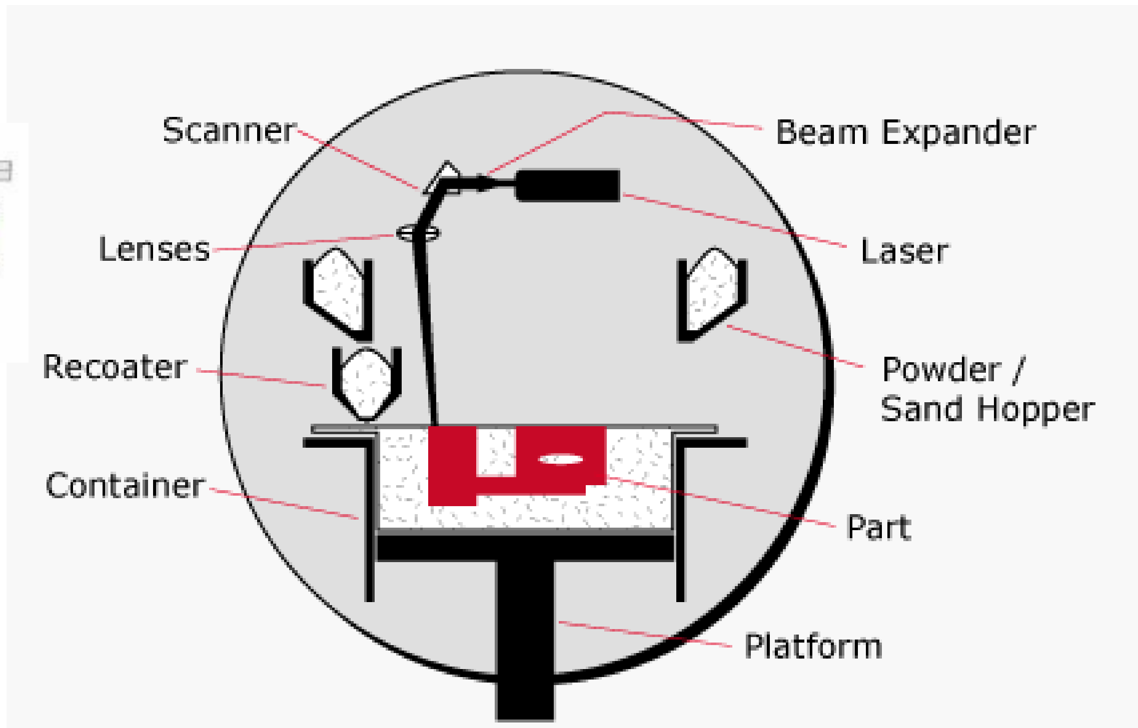
PBF Schematic



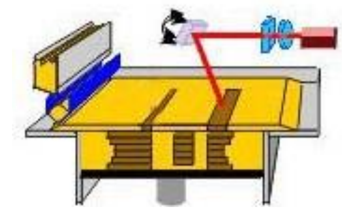
Schematic and operation of SLS machine

Powder spreading by recoater

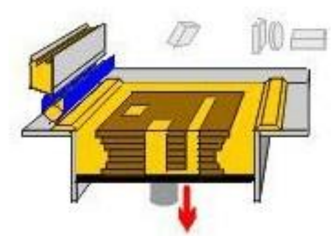




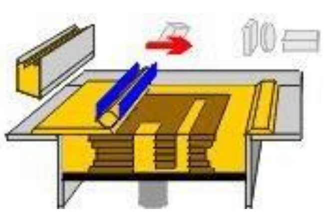
Powder bed exposed to laser beam



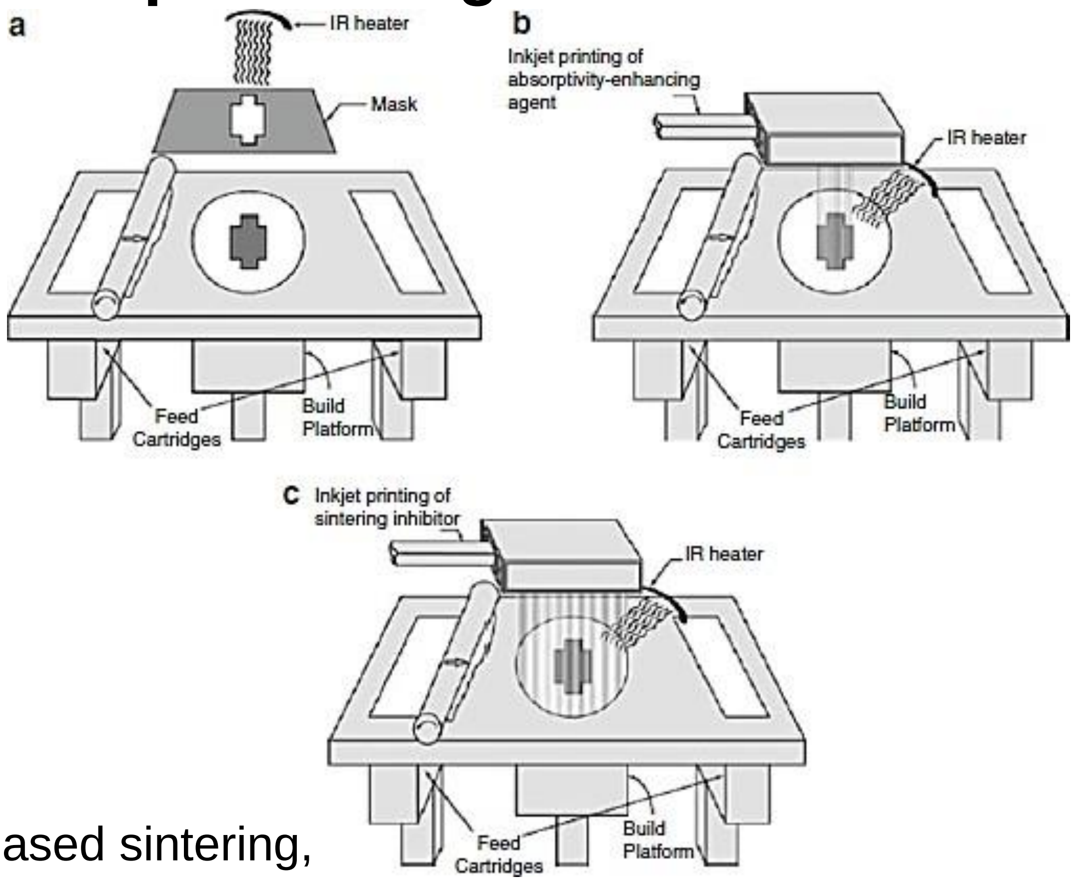
Platform moves downward



Recoating for next layer



Three different approaches to line and layer- wise powder bed fusion processing



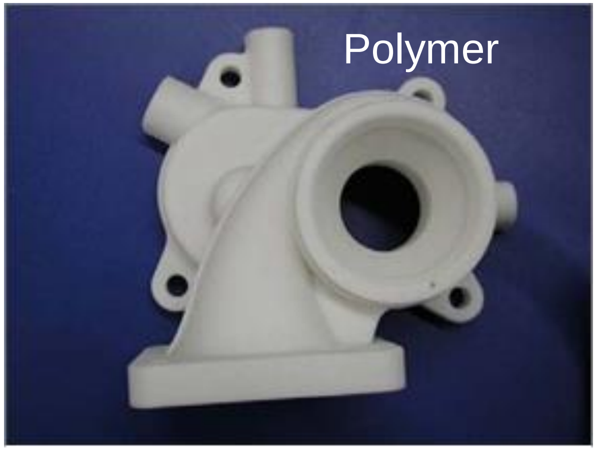
(a) mask-based sintering,

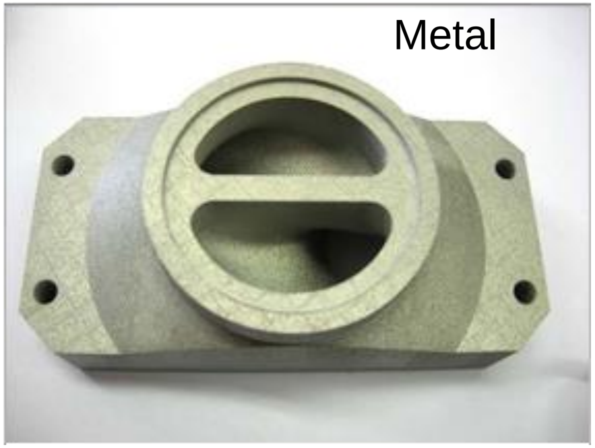
(b) printing of an absorptivity-enhancing agent in the part region,

(c) printing of a sintering inhibitor outside the part region

PBF

- Plastics
  - Selective Lase Sintering (SLS)
  - Multi Jet Fusion (MJF)
- Metals
  - Direct Metal Laser Sintering (DMLS)
  - Selective Laser Melting (SLM)
  - Electron Beam Melting (EBM)



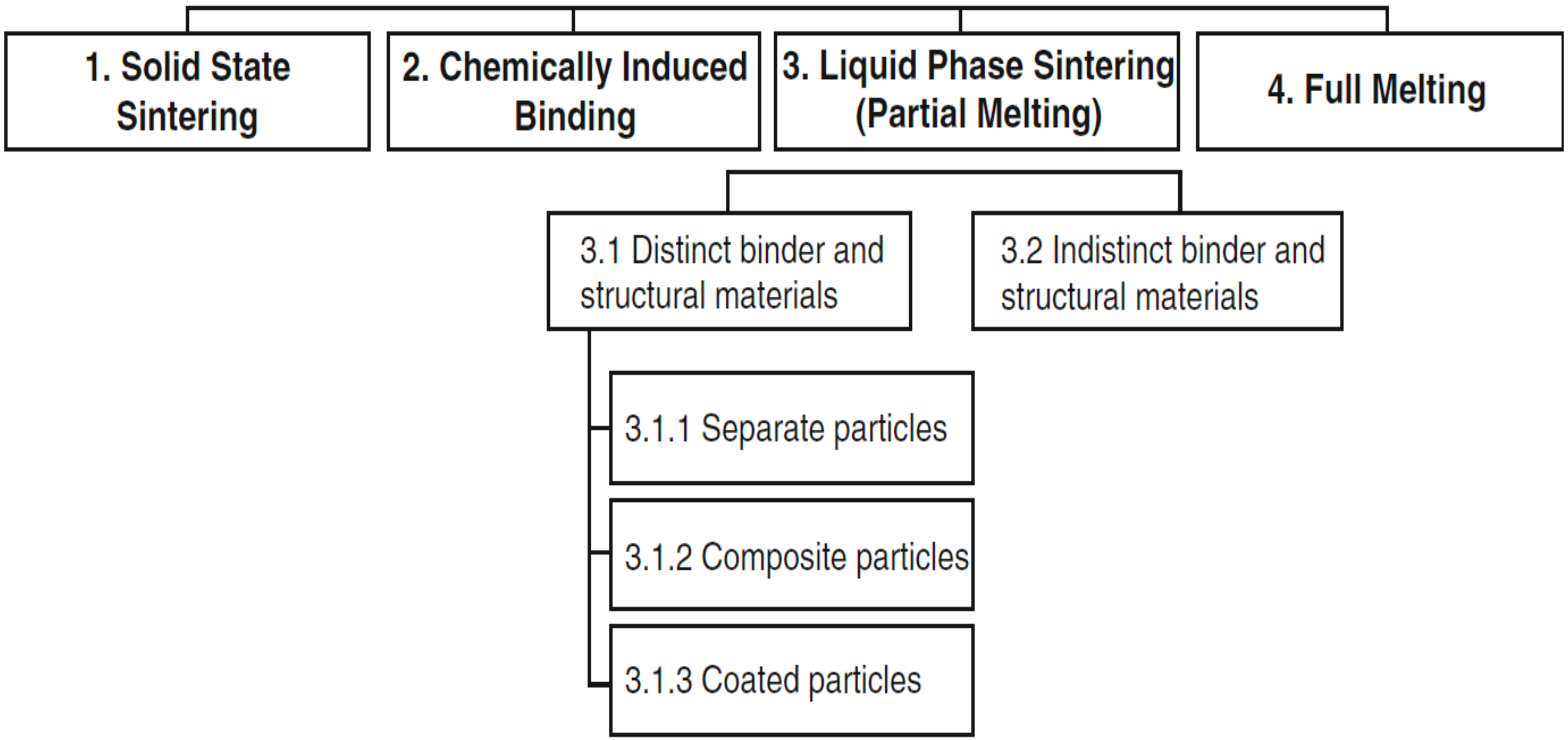


PBF Example Materials

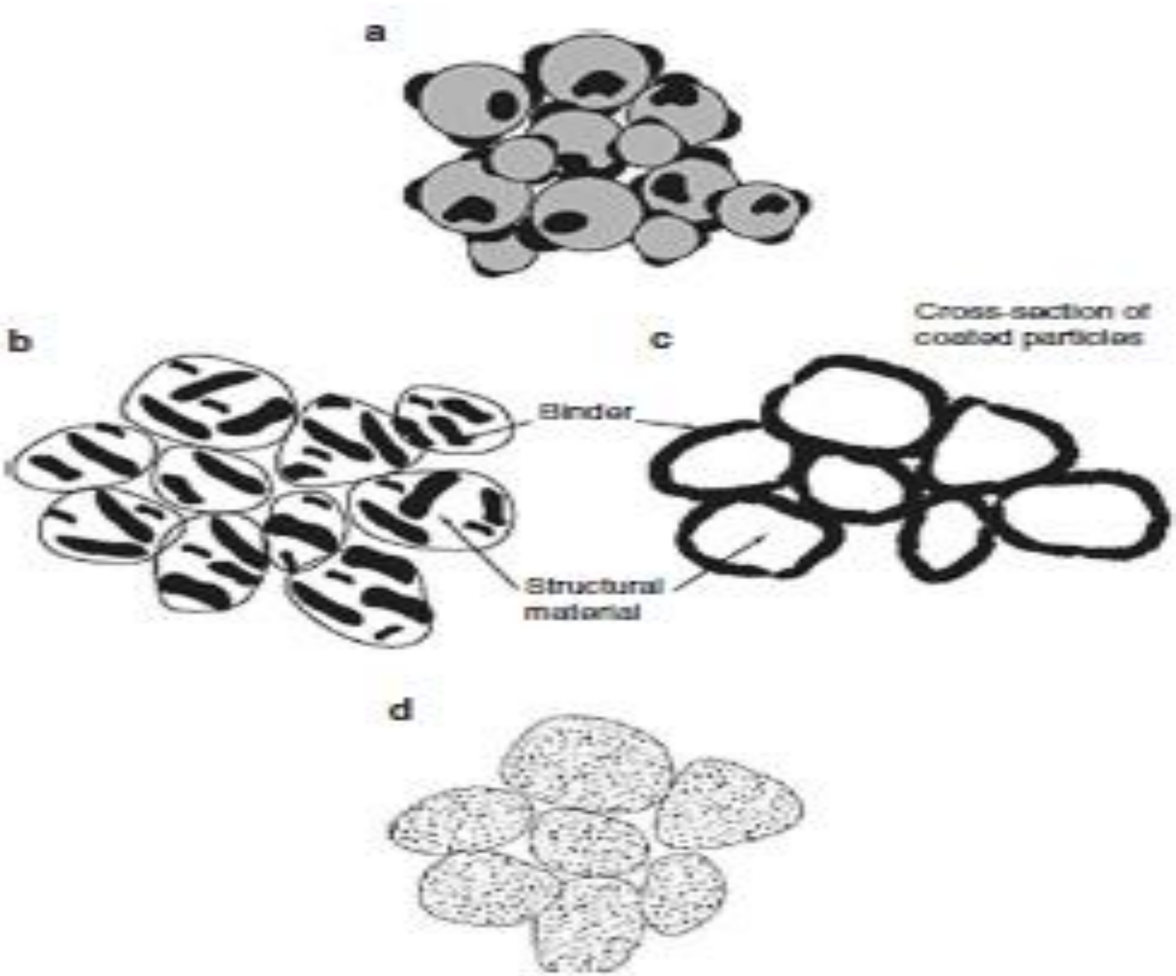
- Plastics
  - Nylon 11
  - Nylon 12
  - Al-filled Nylon
  - Fire Retardant Nylon-12
  - Glass Filled Nylon
- Metals
  - Al alloys
  - Co-Cr
  - Nickel alloy (Inconel 625, Inconel 718)
  - Stainless steel (316,316L, 15-5,17-4)
  - Maraging steel (MS1)
  - Hastalloy X
  - Ti and Ti- Alloy
  - Tool Steel

Binding Mechanism

Primary Binding Mechanisms in Powder Bed Fusion Processes

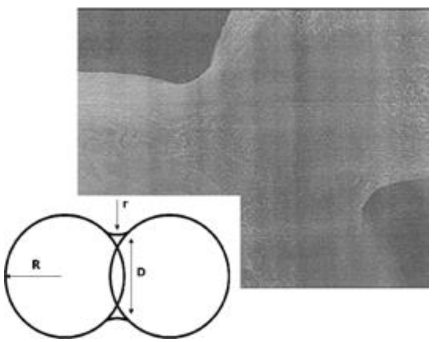


LPS or Partial Melting Particles

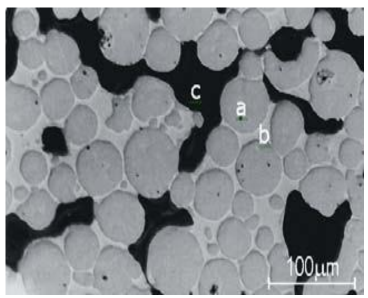


Binding Mechanism

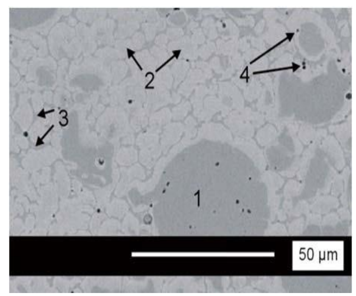
Solid State Sintering



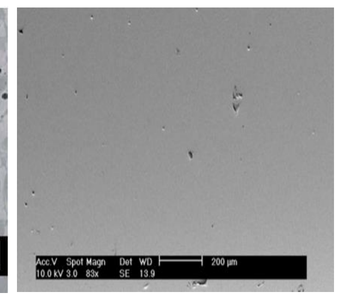
Liquid Phase Sintering



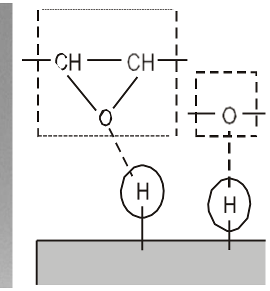
Partial Melting



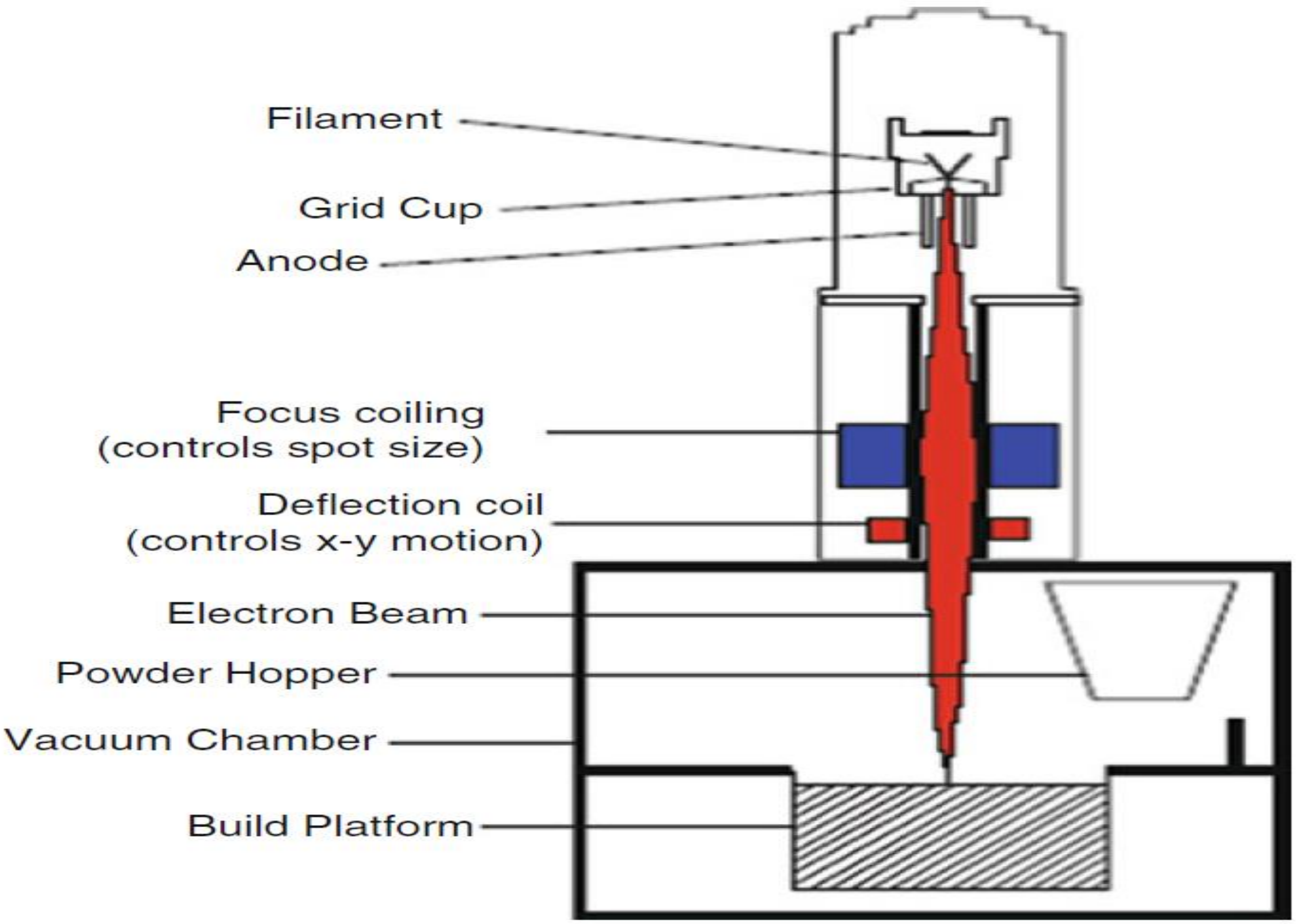
Full Melting



Chemical binding



EBM Schematic



Two different Thermal sources

Characteristics	Electron Beam Melting	Laser Melting
Thermal Source	Electron Beam	Lase
Atmosphere	Vacuum	Inert Gas
Scanning	Deflection coils	Galvano scanners
Energy absorption	Conductivity-limited	Absorptivity-limited
Powder preheating	Electron beam	IR or resistive heaters
Scan speeds	Very fast, Magnetically driven	Limited by galvano scanners
Energy Cost	Moderate	High
Surface Finish	Moderate to poor	Excellent to moderate
Feature Resolution	Moderate	Excellent
Materials	Metals(Conductors)	Polymers, Metals and Ceramics
Powder Size	Medium	Fine

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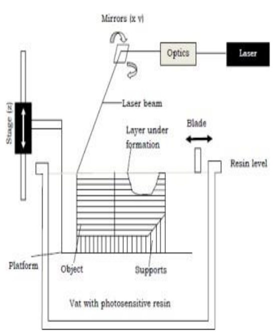
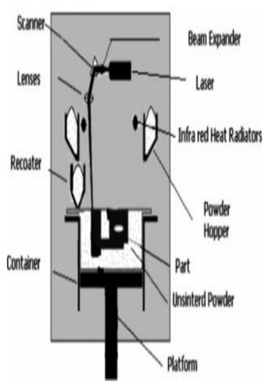
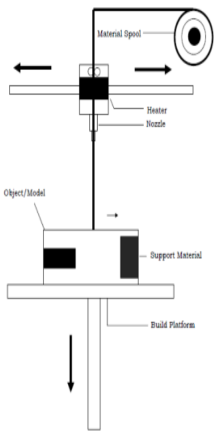
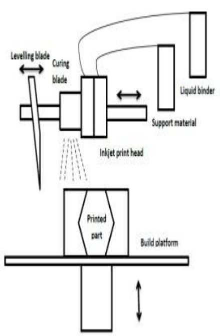
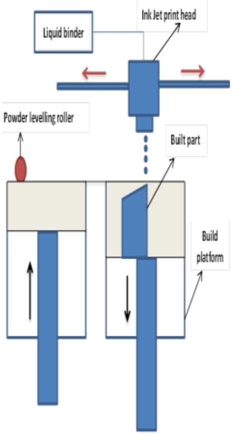
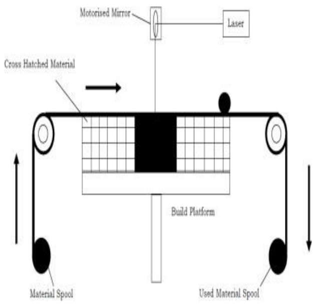


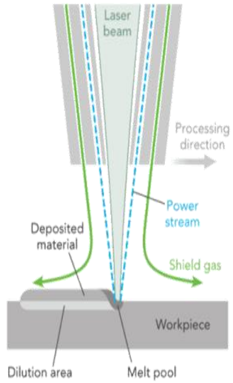




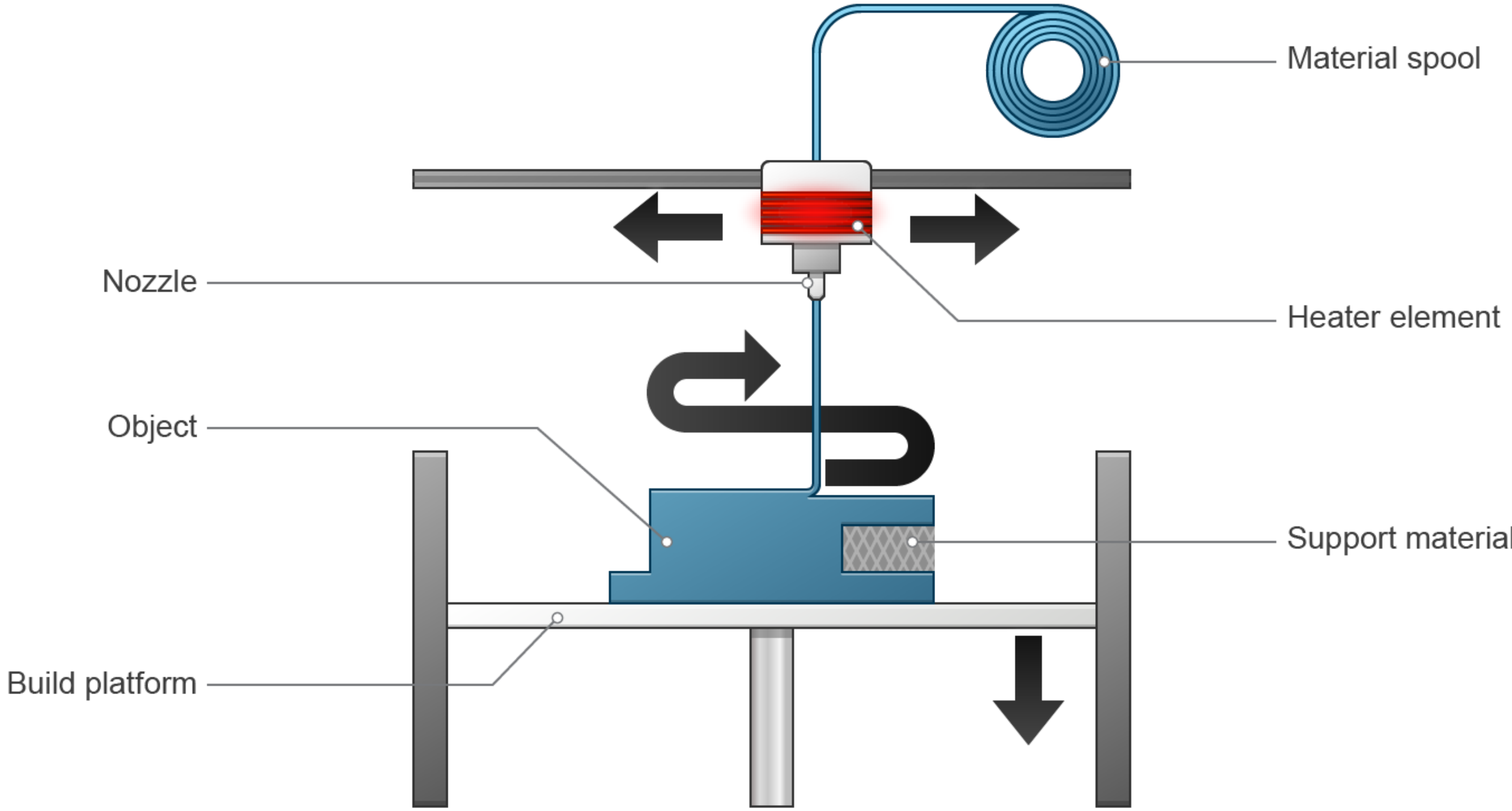






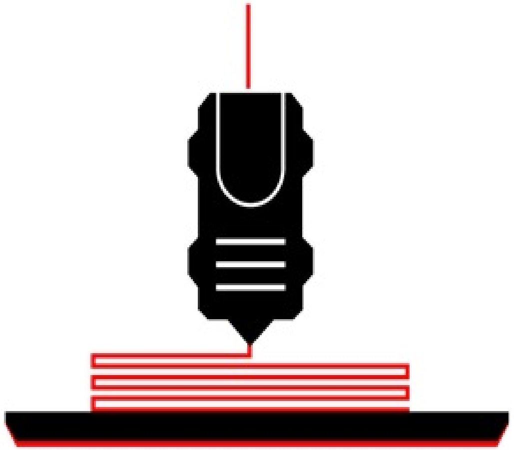


Material Extrusion

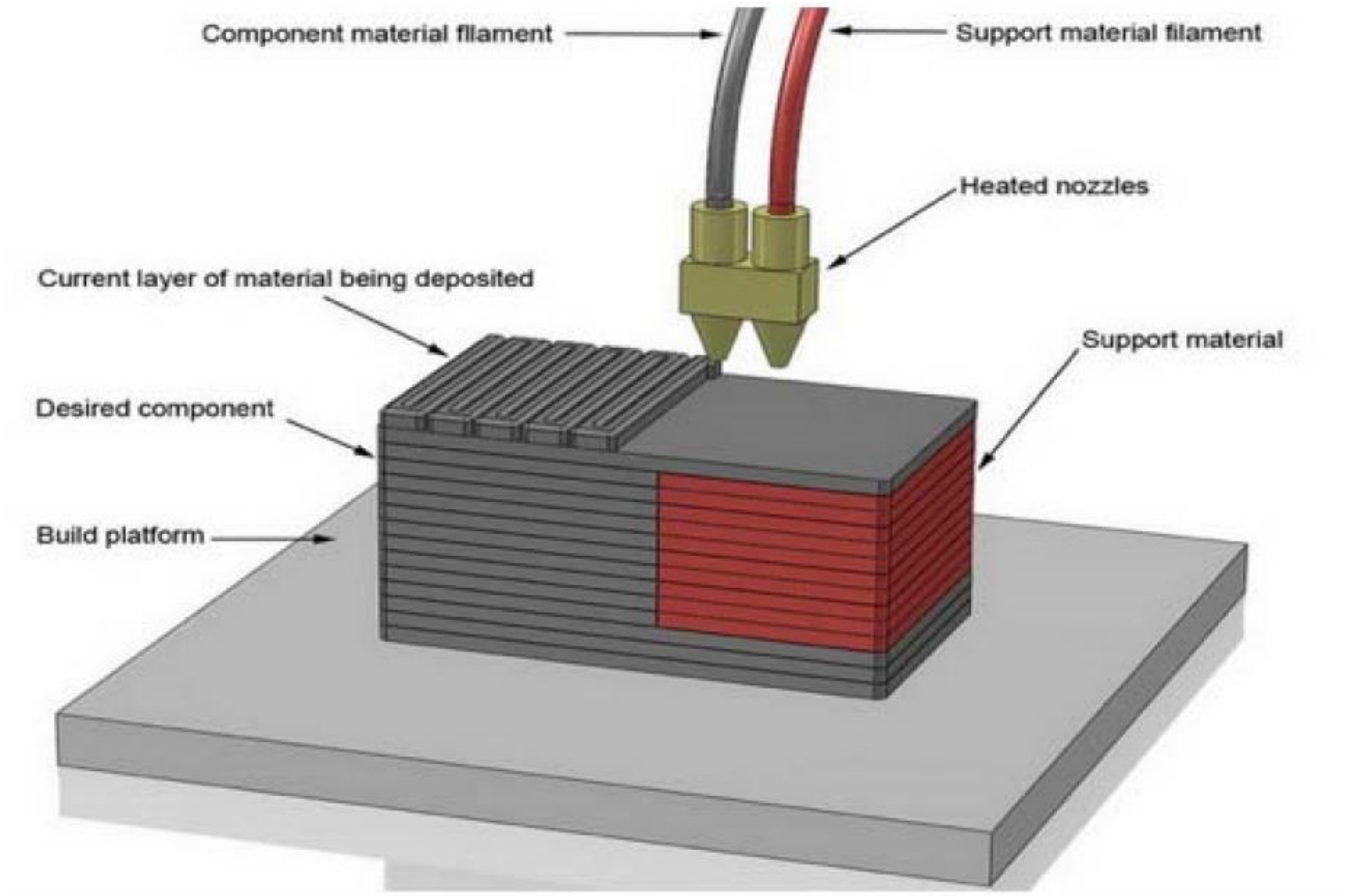


Fused Deposition Modelling

- Name given by Scott Crump
- First commercialized by Stratasys
- Most popular processes for hobbyist grade 3D printing



Dual Extruders



Materials

- Thermoplastics
  - ABS
  - PLA
  - TPU
  - PETG
  - PEEK
- Solvable supports
  - PVA(In water)
  - HIPS(In Limonene)

Source:https://www.allthat3d.com/3d-printer-filament/

Advantages

- Low initial and running costs
- Comparable faster print time for small and thin parts
- Printing tolerance of +/- 0.1 (+/- 0.005″)
- No supervision required
- Small equipment size compared to other AM
- Comparably low-temperature process

Disadvantages

- Visible layer lines
- The extrusion head must continue moving, or else material bumps up
- Supports are required
- Susceptible to warping

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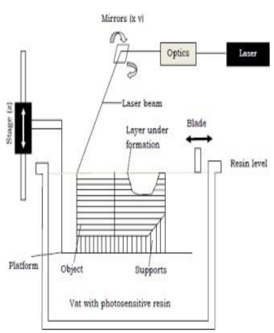
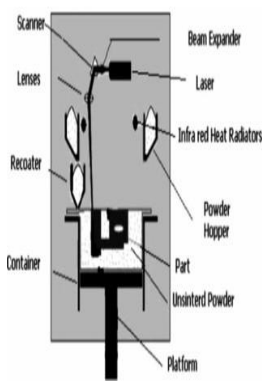
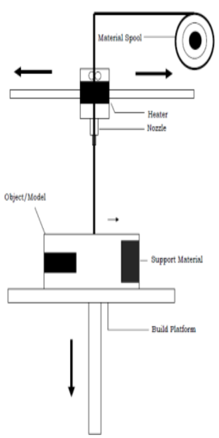
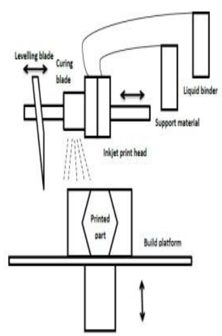
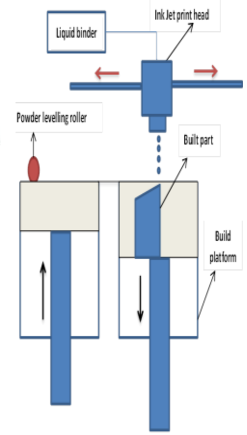
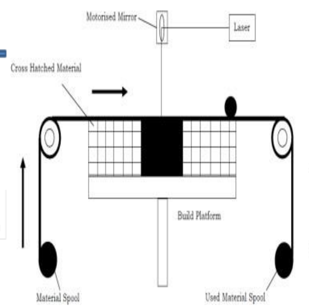


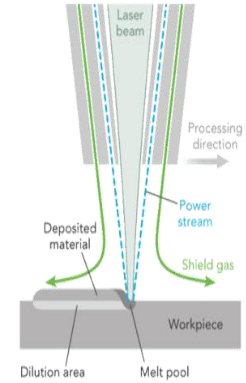




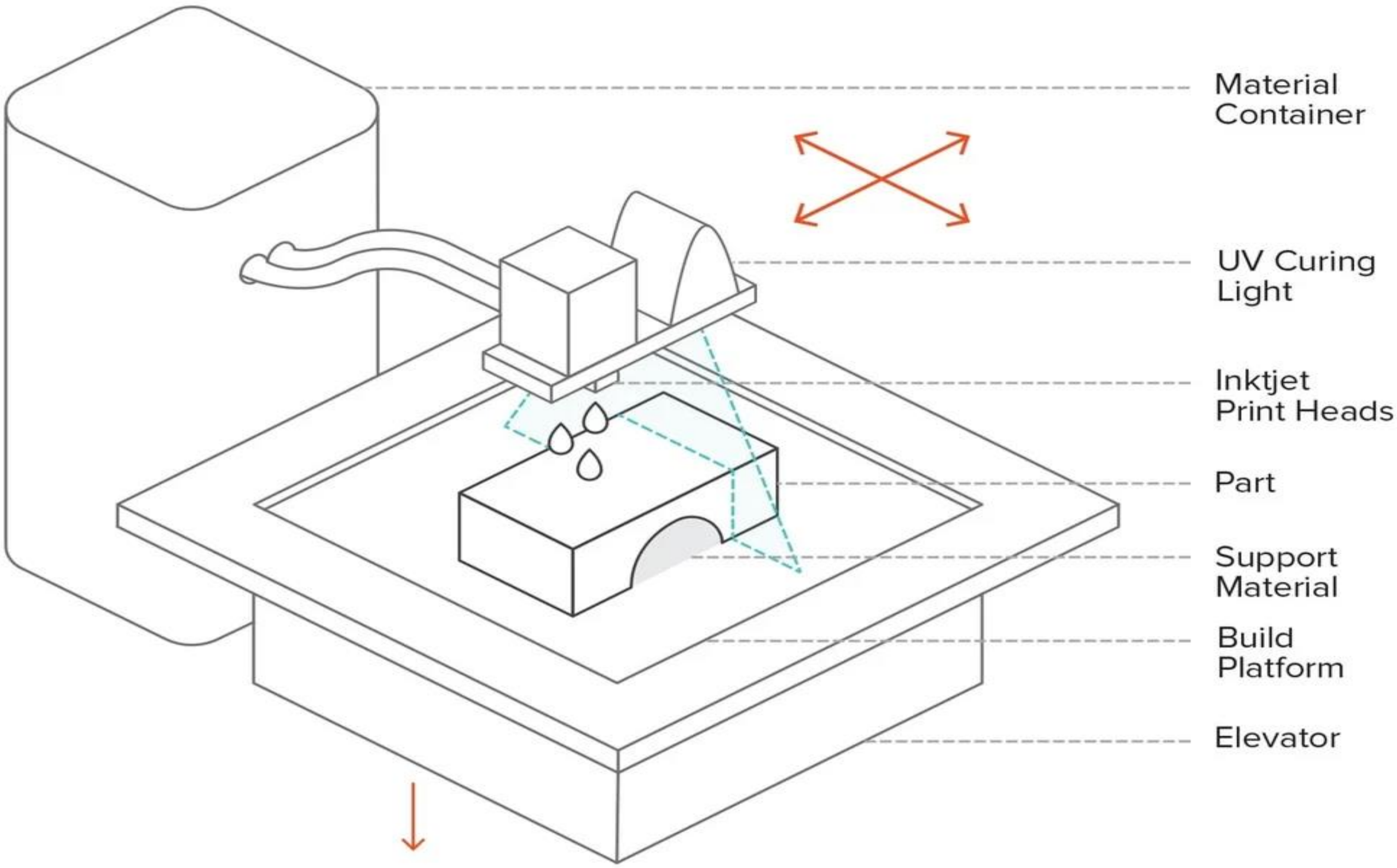






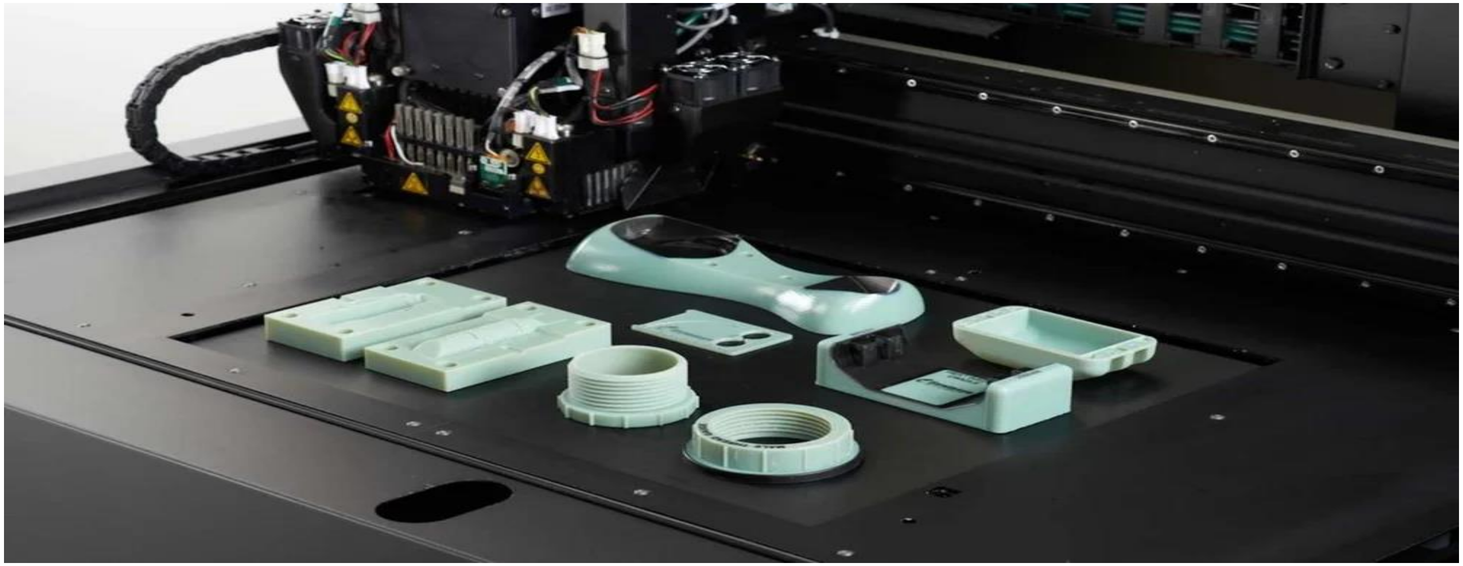


Material Jetting

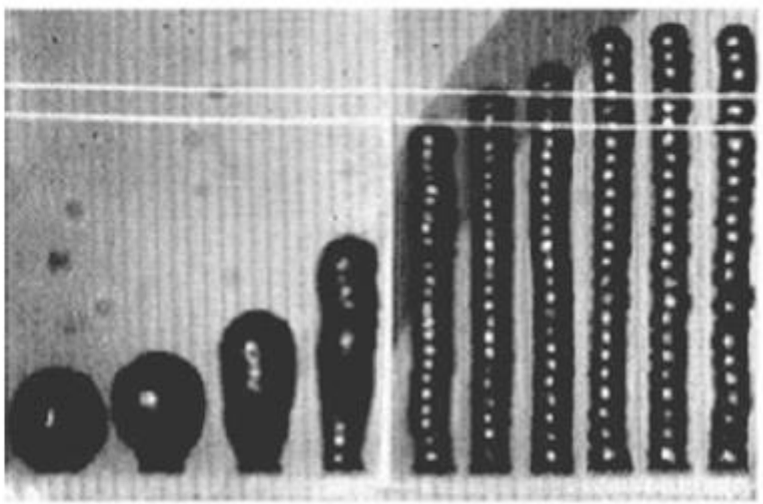


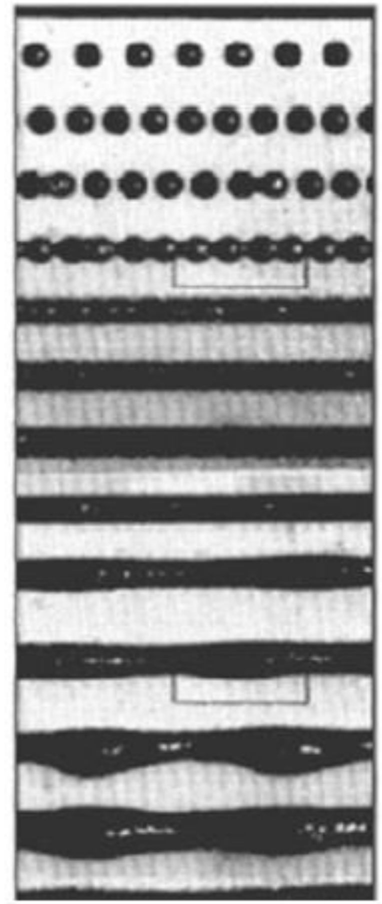
Material Jetting

- Fastest and most accurate 3D printing process
- Build parts using photopolymers and cured using UV lights
- Difference from SLA 3D printer, Jet droplets of photopolymers and cure it using UV light

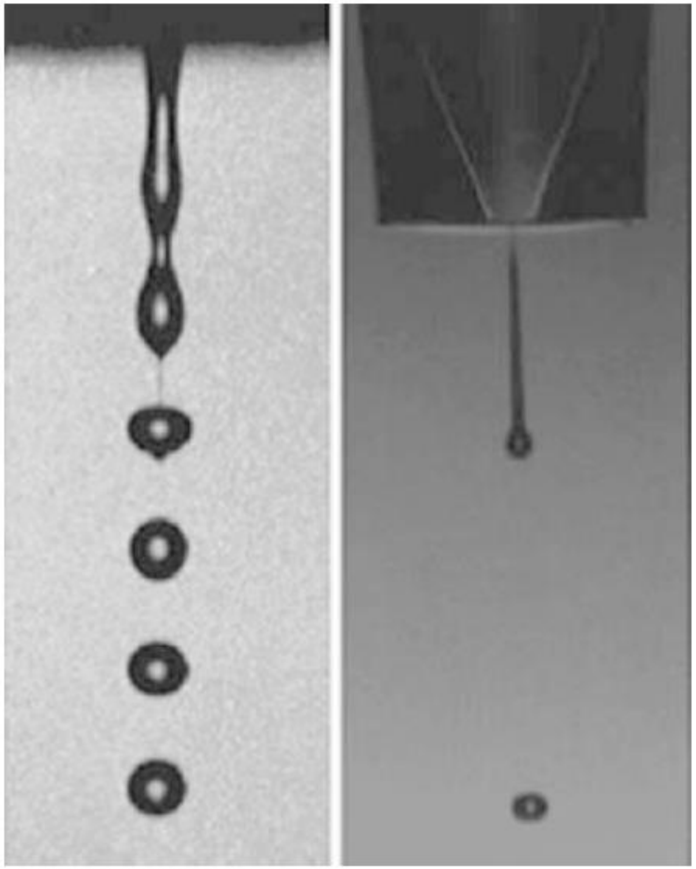


Material Jetting



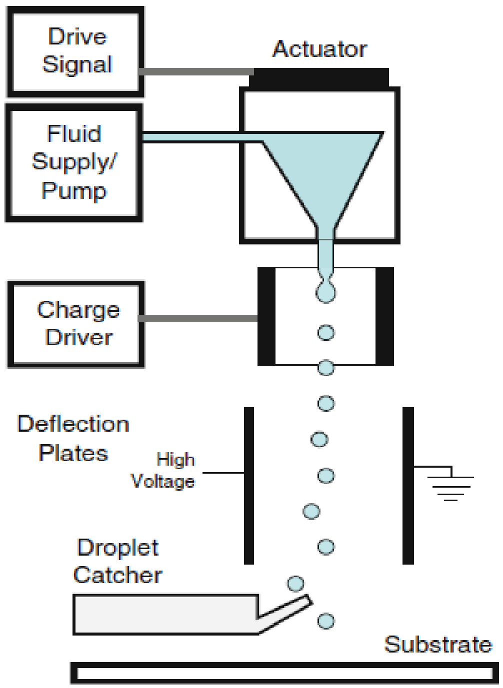


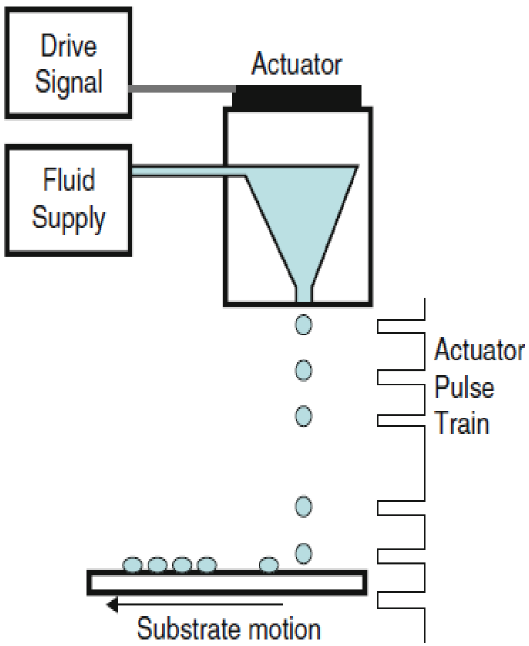
Droplet formation technologies



Continuous Drop-On-Demand

Mechanism of Droplet formation

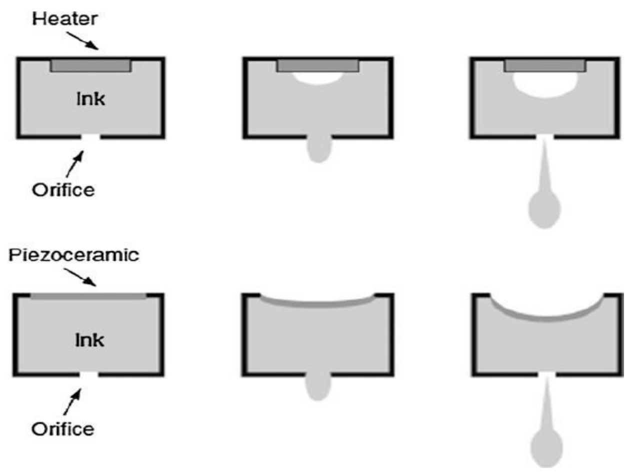


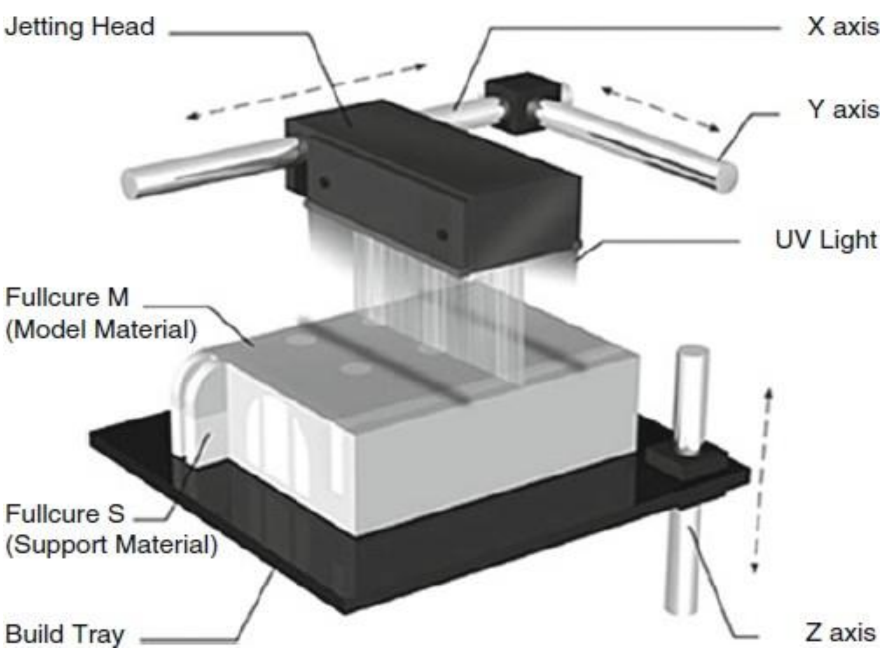


Binary deflection continuous printing

Schematic of
drop-on-demand printing system

Thermal (top) and piezoelectric (bottom) DOD ejection

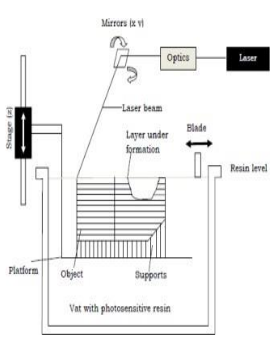


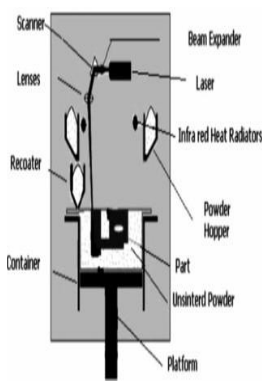


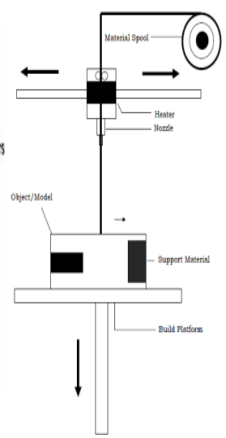
Polyjet build process

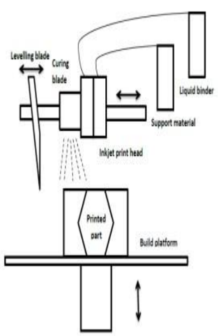
ASTM Classification

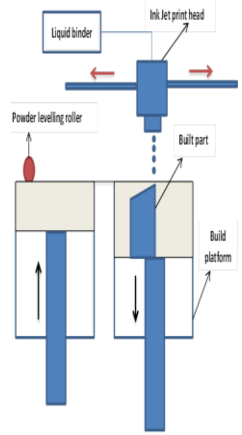
- Additive Manufacturing
  - Vat Polymerization
  - Powder Bed Fusion
  - Material Extrusion
  - Material Jetting
  - Binder Jetting
  - Sheet Lamination
  - Directed Energy Deposition

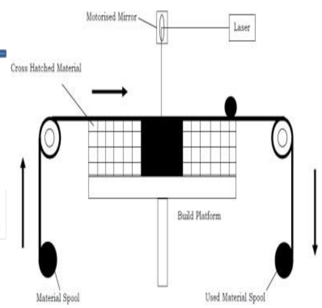


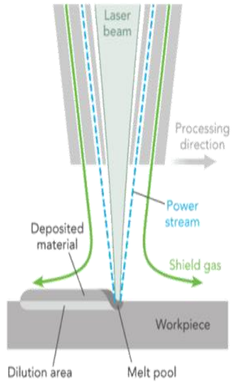




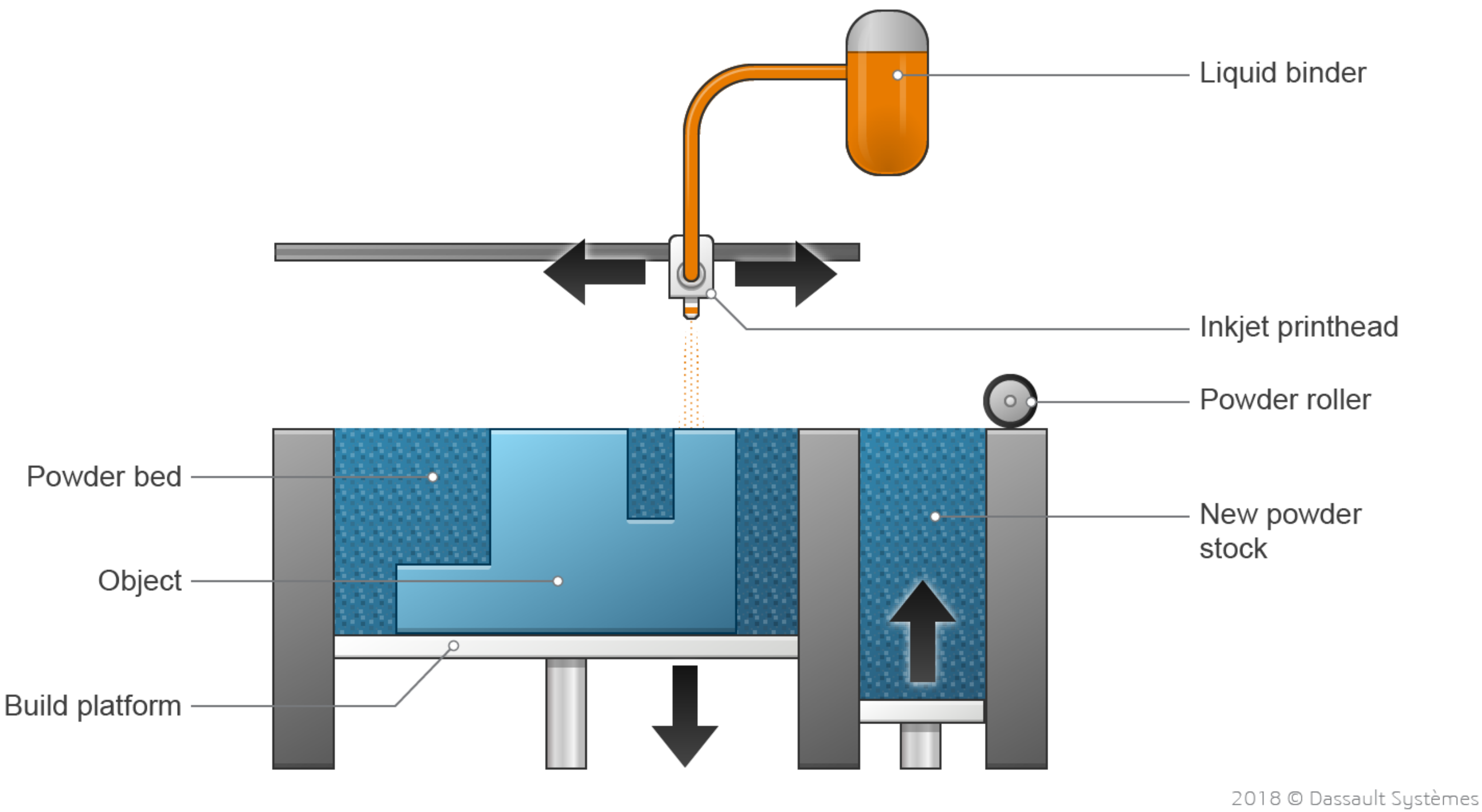






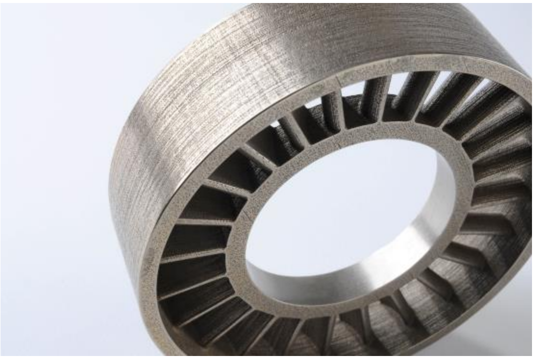


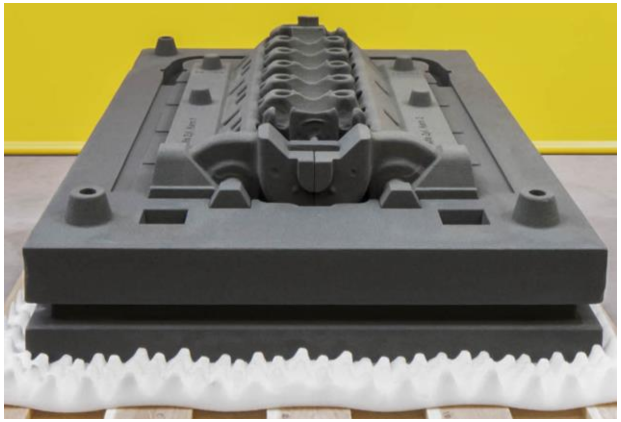
Binder Jetting



Binder Jetting

- The binder jetting 3D printing process can work with a variety of materials including metals, sands, and ceramics
- Binder Jetting is unique in that it does not employ heat during the build process.
- For metals an infiltration process is required for improving the mechanical properties of the parts
- Colored parts can be printed





Additional info:https://www.youtube.com/watch?time_continue=253&v=0Q0iHS-9Ti0&feature=emb_logo

Materials

Material	Characteristics
Full Colour Sandstone	Full colour non functional parts Very brittle
Silica Sand	Very High Thermal resistance Excellent for sand casting application
Stainless steel(bronze infiltered)	Good Mechanical Properties Can be machined ~10% internal porosity
Stainless steel(sintered)	Very good mechanical properties High corrosion resistance ~3% internal porosity
Inconel alloy (sintered)	Excellent mechanical properties Good temperature resistance High chemical resistance
Tungsten carbide (sintered)	Very high hardness Used for the production of cutting tools

ASTM Classification

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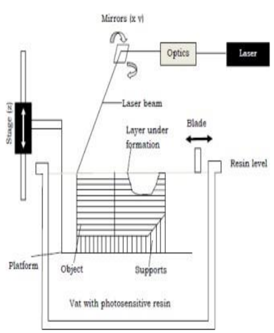
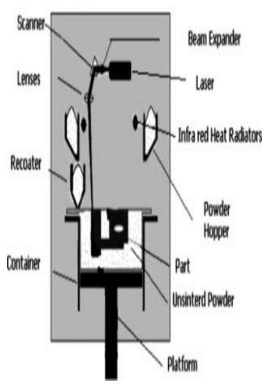
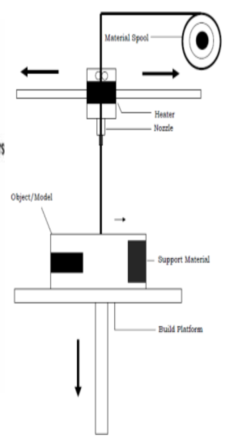
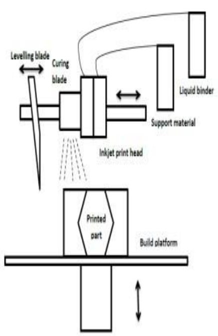
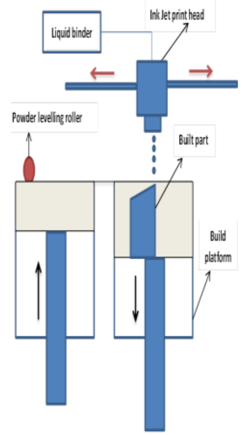
  - Binder Jetting
  - Sheet Lamination
  - Directed Energy Deposition

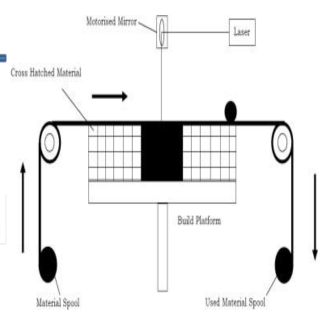


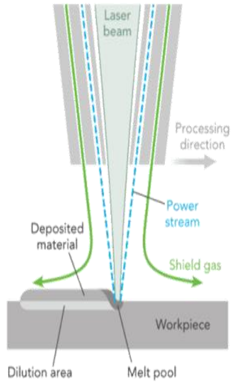




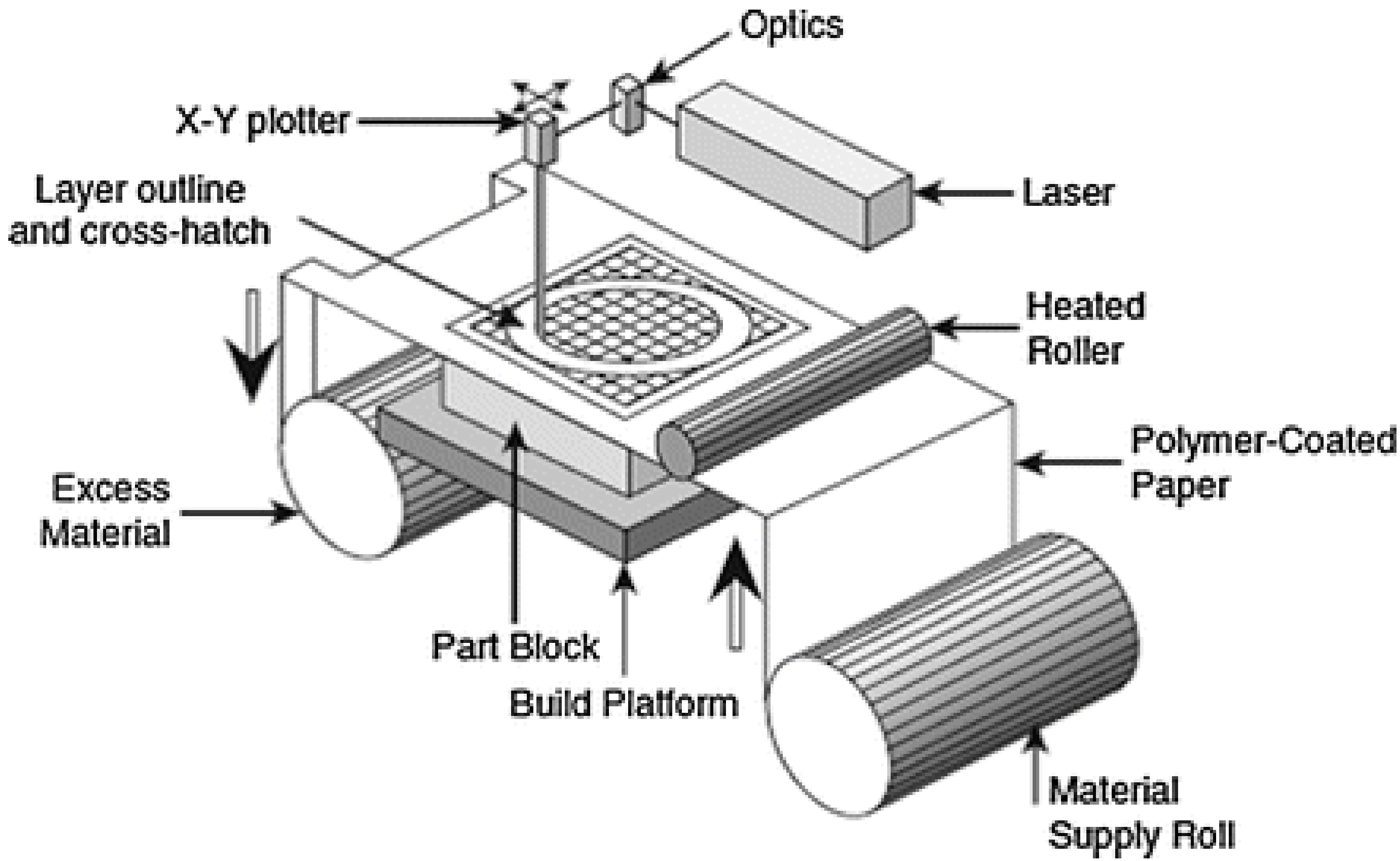








Sheet Lamination

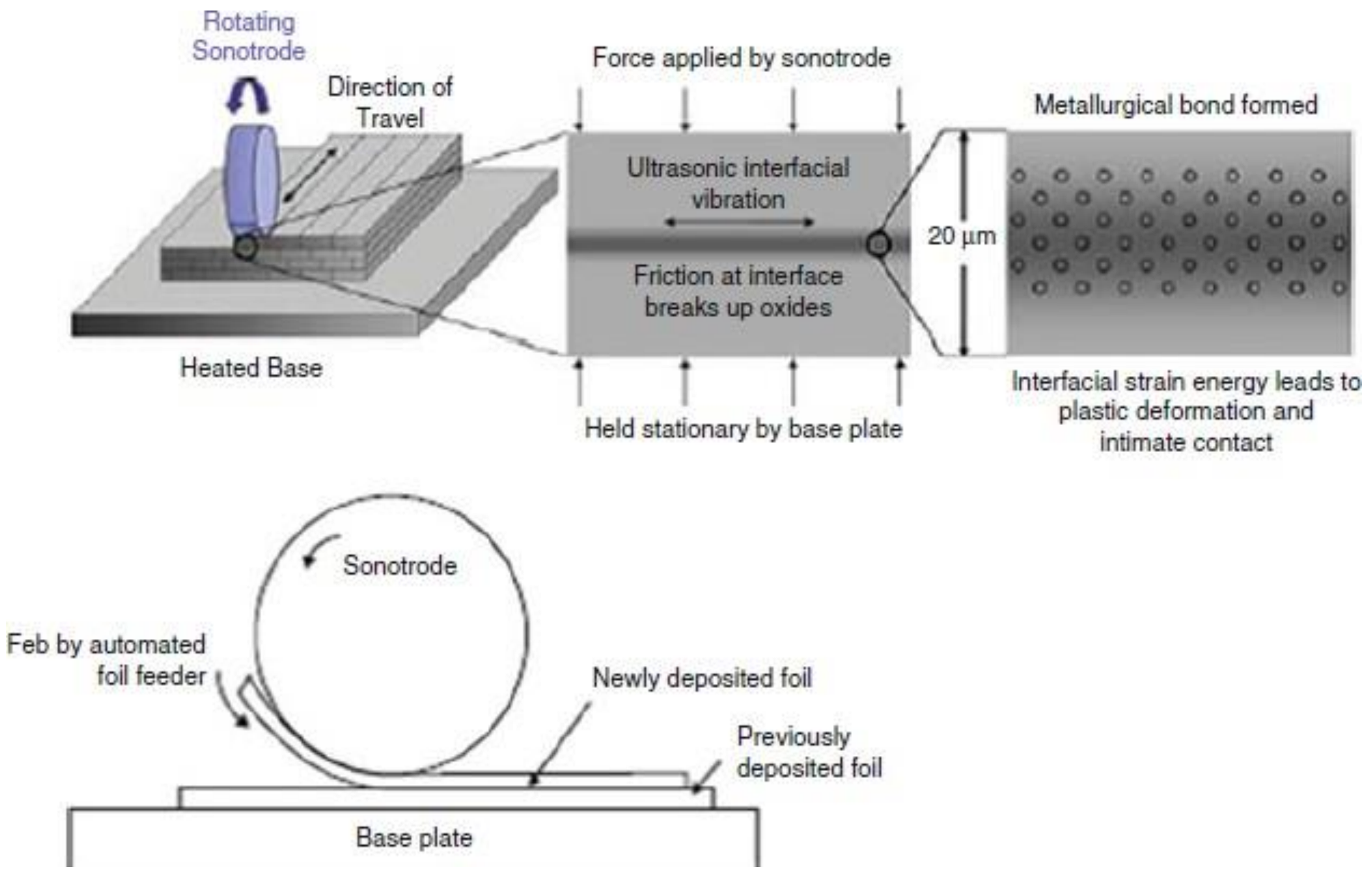


Courtesy: IanGibson

Sheet Lamination Process

- **Composite Based Additive Manufacturing (CBAM) by Impossible Objects** Fiber-reinforced composites are fused with a thermoplastic to create very strong parts.
- **Selective Lamination Composite Object Manufacturing (SLCOM) by EnvisionTEC.** SLCOM uses thermoplastics as a base material and woven fiber composites
- **Laminated Object Manufacturing (LOM)**
- **Selective Deposition Lamination (SDL)**
- **Ultrasonic Additive Manufacturing (UAM)**

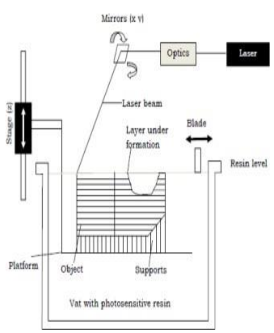
Schematic of ultrasonic consolidation

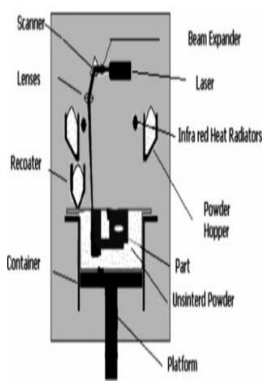


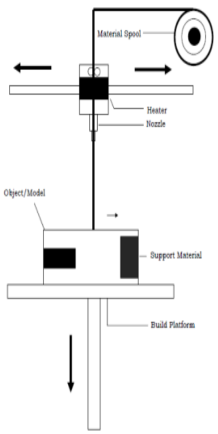
ASTM Classification

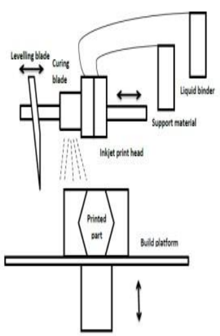
Additive Manufacturing

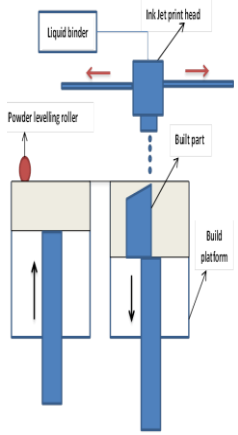
- Vat Polymerization
- Powder Bed Fusion
- Material Extrusion
- Material Jetting
- Binder Jetting
- Sheet Lamination
- Directed Energy Deposition

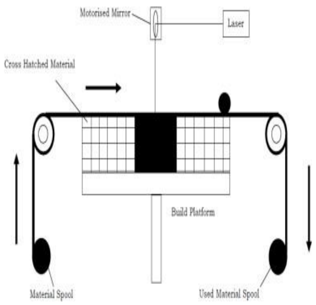


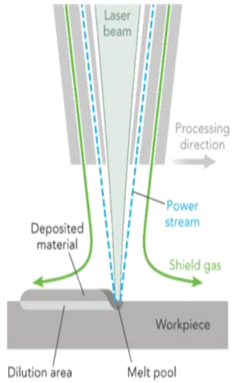




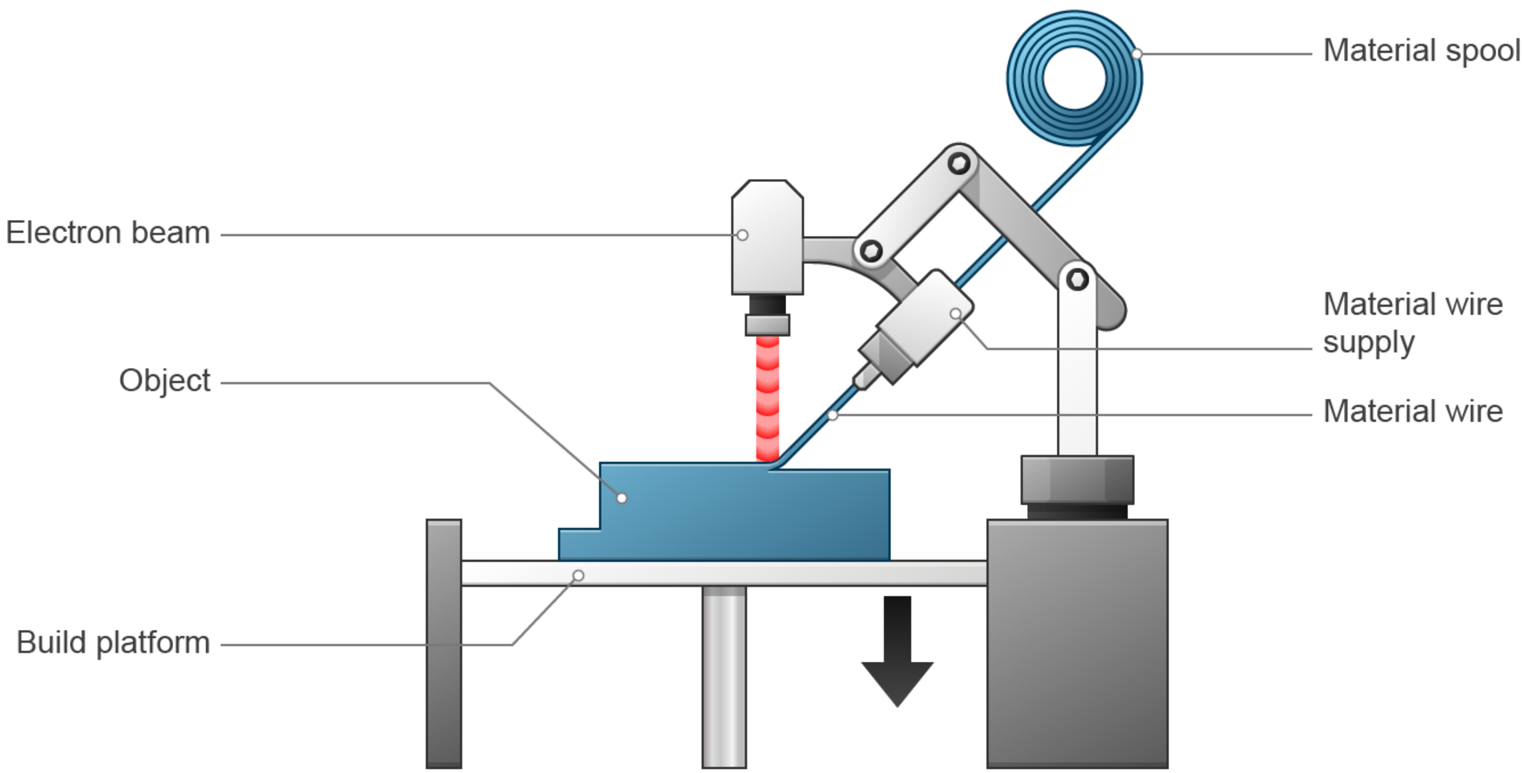




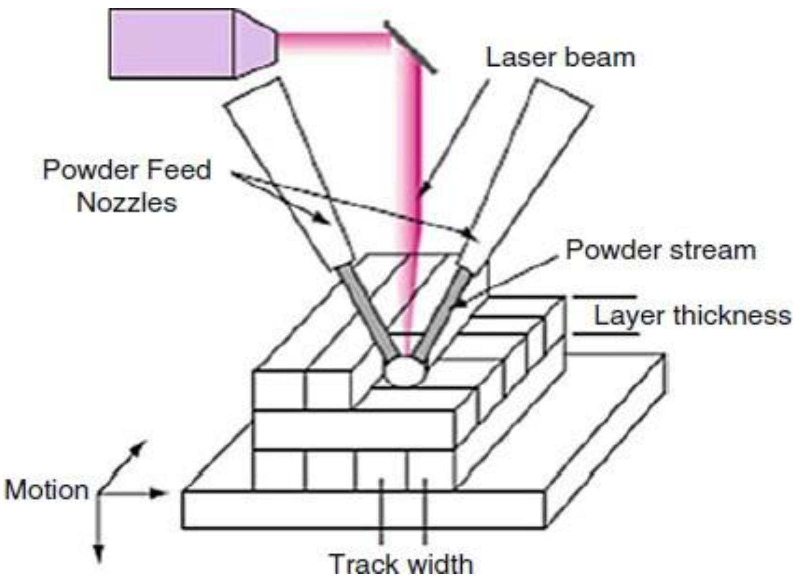


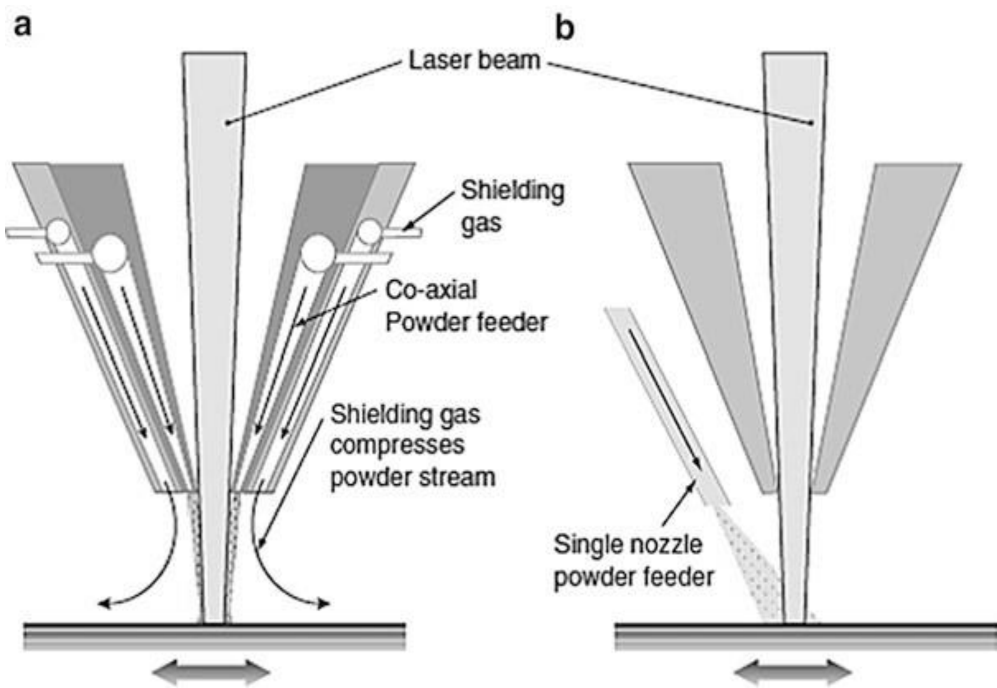


Directed Energy Deposition



Schematic of a typical laser powder DED process

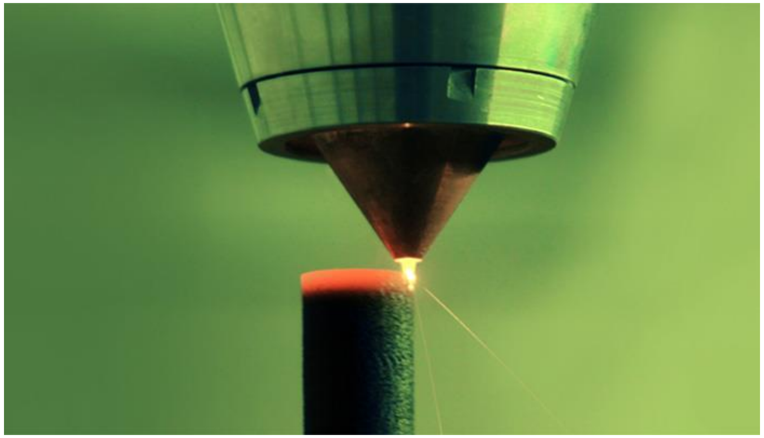




(a) coaxial nozzle feeding and
(b) Single nozzle feeding

DED

- DED has the ability to produce relatively large parts (build volume > 1000 mm^3)
- DED processes can be used to produce components with composition gradients, or hybrid structures consisting of multiple materials having different compositions and structures.



DED

- LENS
- Electron Beam Additive Manufacturing
- Laser deposition Welding and Hybrid manufacturing by DMG Mori

Materials

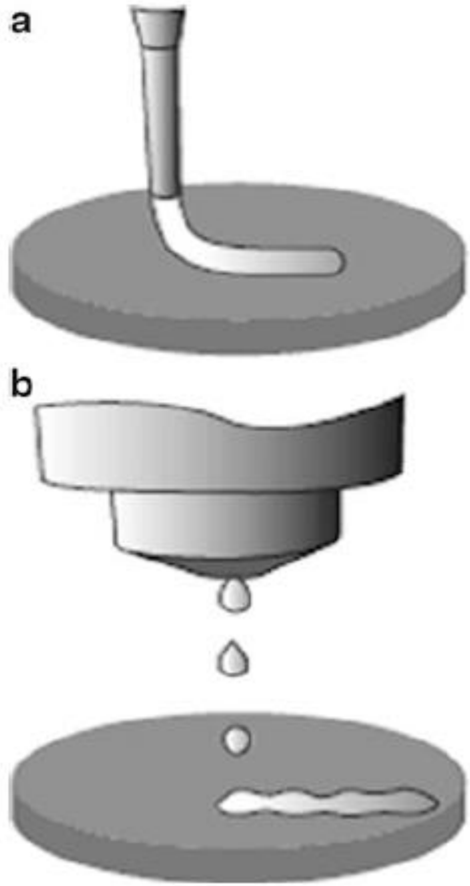
- For metals, almost any metal that is weldable can be 3D printed with DED.
- Titanium and titanium alloys, Inconel, tantalum, tungsten, niobium, stainless steel, aluminium, etc.

Direct Writing

- Ink based Writing
- Laser Transfer DW
- Thermal Spray DW
- Beam deposition DW
- Liquid Phase direct Deposition

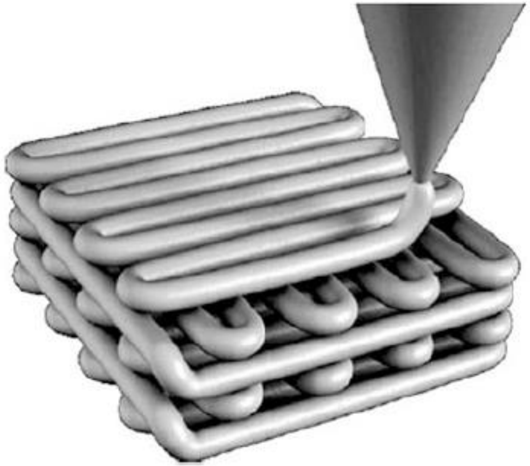
Ink Based Direct Writing

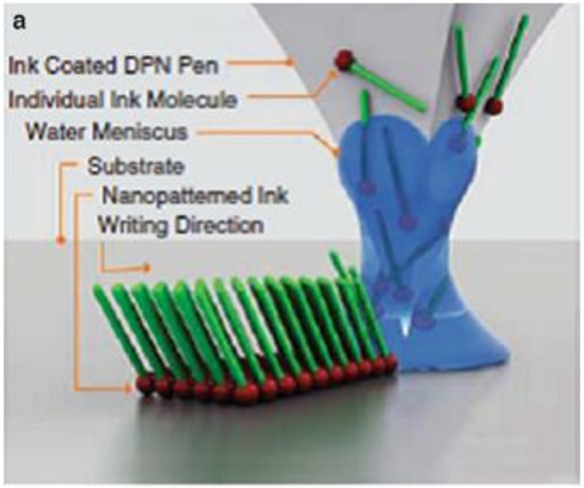
a) Continuous Filament Writing
b) Droplet Jetting (courtesy: nScrypt)



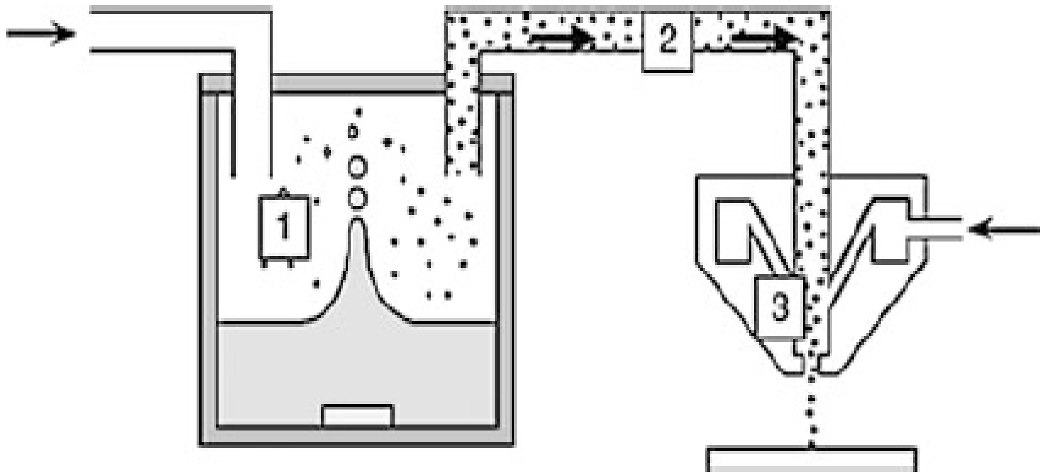
Ink Based DW

- Nozzle Dispensing
- Quill type process
- Ink Jet printing
- Aerosol DW





Aerosol Jetting



Aerosol Jet System. (1) Liquid material is placed into an atomizer, creating a dense aerosol of tiny droplets 1–5 μm in size. (2) The aerosol is carried by a gas flow to the deposition head (with optional in-flight laser processing). (3) Within the deposition head, the aerosol is focused by a second gas flow and the resulting high-velocity stream is jetted onto the substrate creating features as small as 10 μm in size (Courtesy of Optomec)

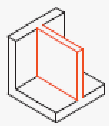
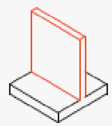
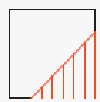
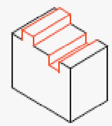
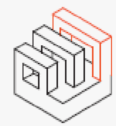
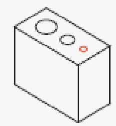
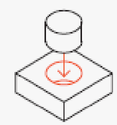
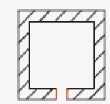
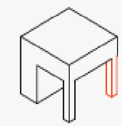
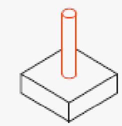
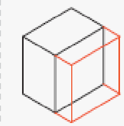
Next Session

- Design capabilities of each AM processes
- Opportunistic and Restrictive DfAM

innovate achieve lead

Design rules for 3D Printing

Courtesy:3DHubs

	Supported Walls	Unsupported Walls	Support & Overhangs	Embossed & Engraved Details	Horizontal Bridges	Holes	Connecting /Moving Parts	Escape Holes	Minimum Features	Pin Diameter	Tolerance
	Walls that are connected to the rest of the print on at least two sides.	Unsupported walls are connected to the rest of the print on less than two sides.	The maximum angle a wall can be printed at without requiring support.	Features on the model that are raised or recessed below the model surface.	The span a technology can print without the need for support.	The minimum diameter a technology can successfully print a hole.	The recommended clearance between two moving or connecting parts.	The minimum diameter of escape holes to allow for the removal of build material.	The recommended minimum size of a feature to ensure it will not fail to print.	The minimum diameter a pin can be printed at.	The expected tolerance (dimensional accuracy) of a specific technology.
											
Fused Deposition Modeling	0.8 mm	0.8 mm	45°	0.6 mm wide & 2 mm high	10 mm	Ø2 mm	0.5 mm		2 mm	3 mm	±0.5% (lower limit ±0.5 mm)
Stereo-lithography	0.5 mm	1 mm	support always required	0.4 mm wide & high		Ø0.5 mm	0.5 mm	4 mm	0.2 mm	0.5 mm	±0.5% (lower limit ±0.15 mm)
Selective Laser Sintering	0.7 mm			1 mm wide & high		Ø1.5 mm	0.3 mm for moving parts & 0.1 mm for connections	5 mm	0.8 mm	0.8 mm	±0.3% (lower limit ±0.3 mm)
Material Jetting	1 mm	1 mm	support always required	0.5 mm wide & high		Ø0.5 mm	0.2 mm		0.5 mm	0.5 mm	±0.1 mm
Binder Jetting	2 mm	3 mm		0.5 mm wide & high		Ø1.5 mm		5 mm	2 mm	2 mm	±0.2 mm for metal & ±0.3 mm for sand
Direct Metal Laser Sintering	0.4 mm	0.5 mm	support always required	0.1 mm wide & high	2 mm	Ø1.5 mm		5 mm	0.6 mm	1 mm	±0.1 mm

End of Lecture 3-4