VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad

Subject: Digital Fabrication

Department of Mechanical Engineering

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Subject Code	5ME71
Topic	Processes
Sub. Topic	SLA, SLS, FDM

Stereolithography Apparatus (SLA)

PHOTO-FABRICATION

MATERIALS	CURING PROCESS
Acrylate & methacrylate	Free radical polymerization
Epoxides & vinyl ethers	Cationic polymerization
Hybrid (Acrylate + Epoxy)	Radical + Cationic polymerization

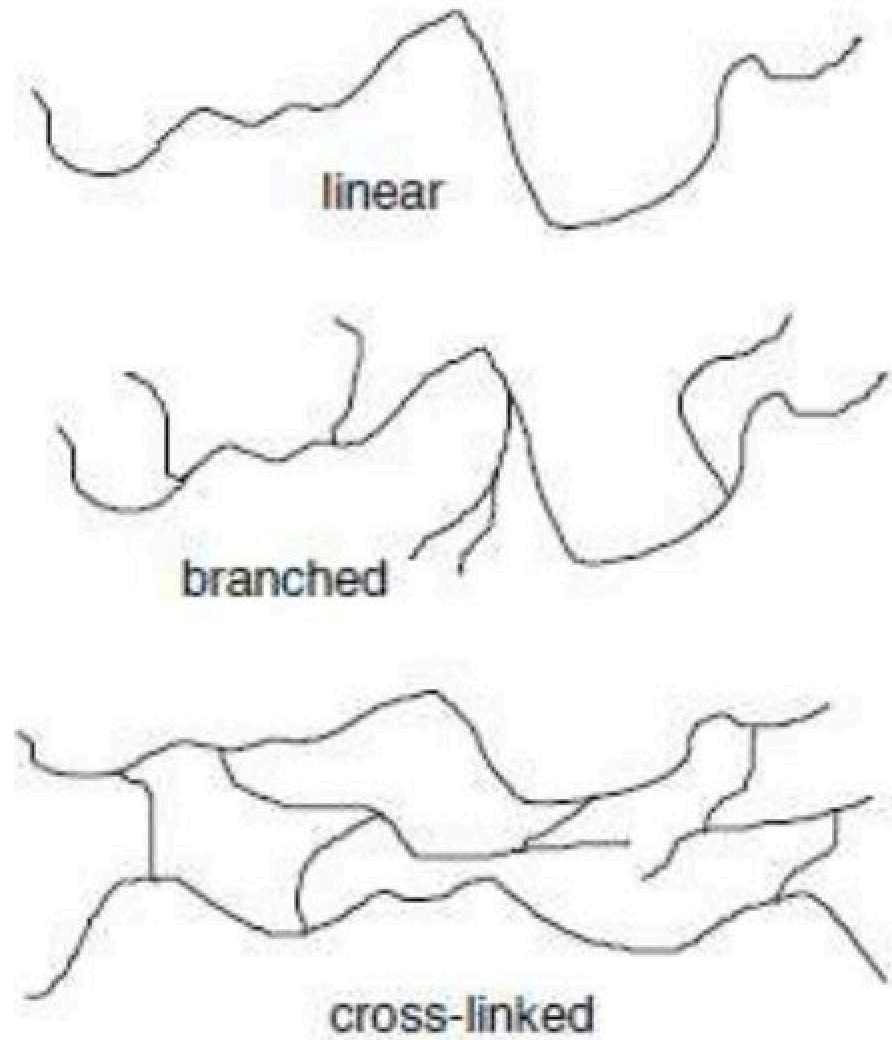
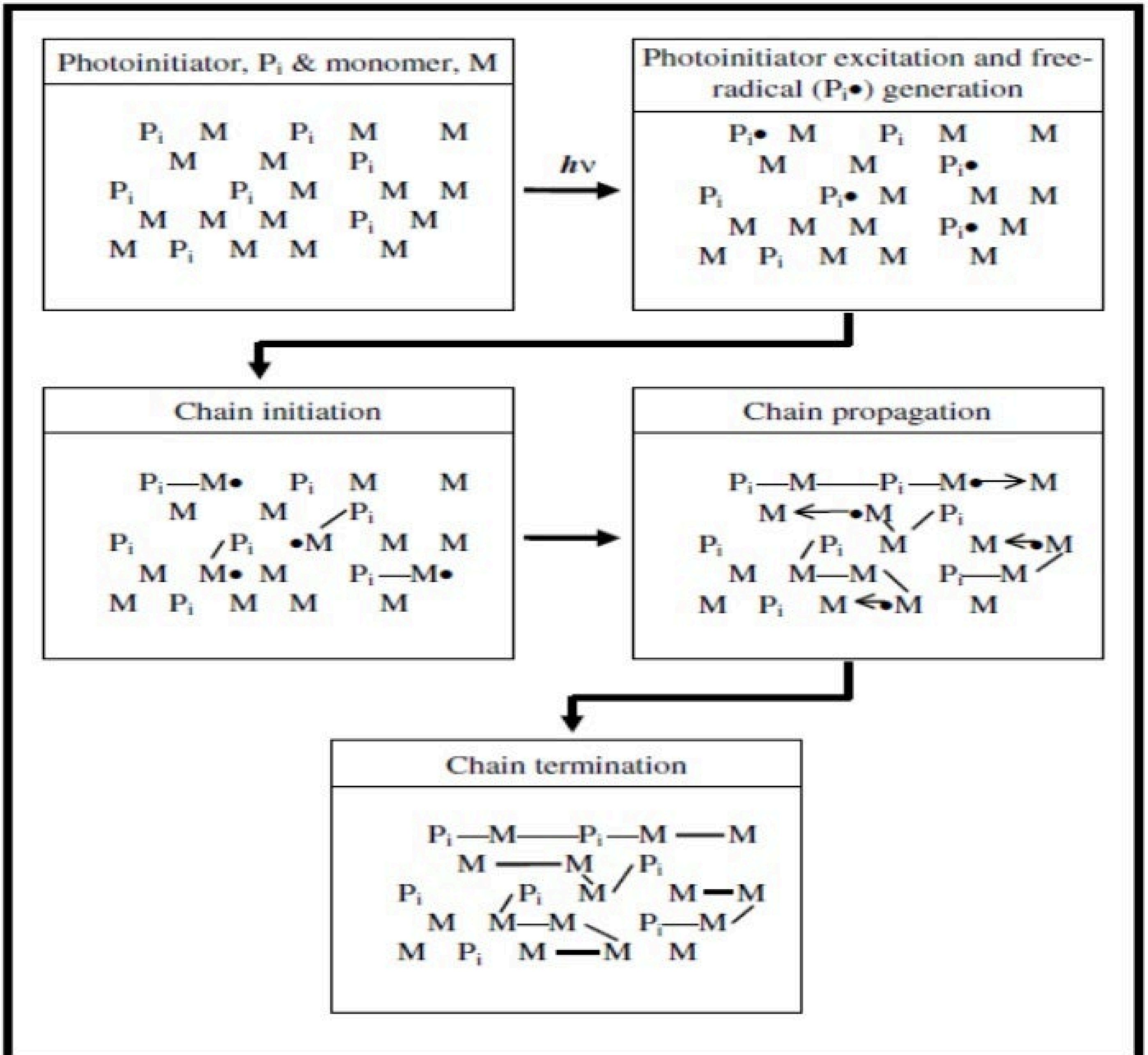


Photo Polymerization Process



DEFINITION OF STEREOLITHOGRAPHY

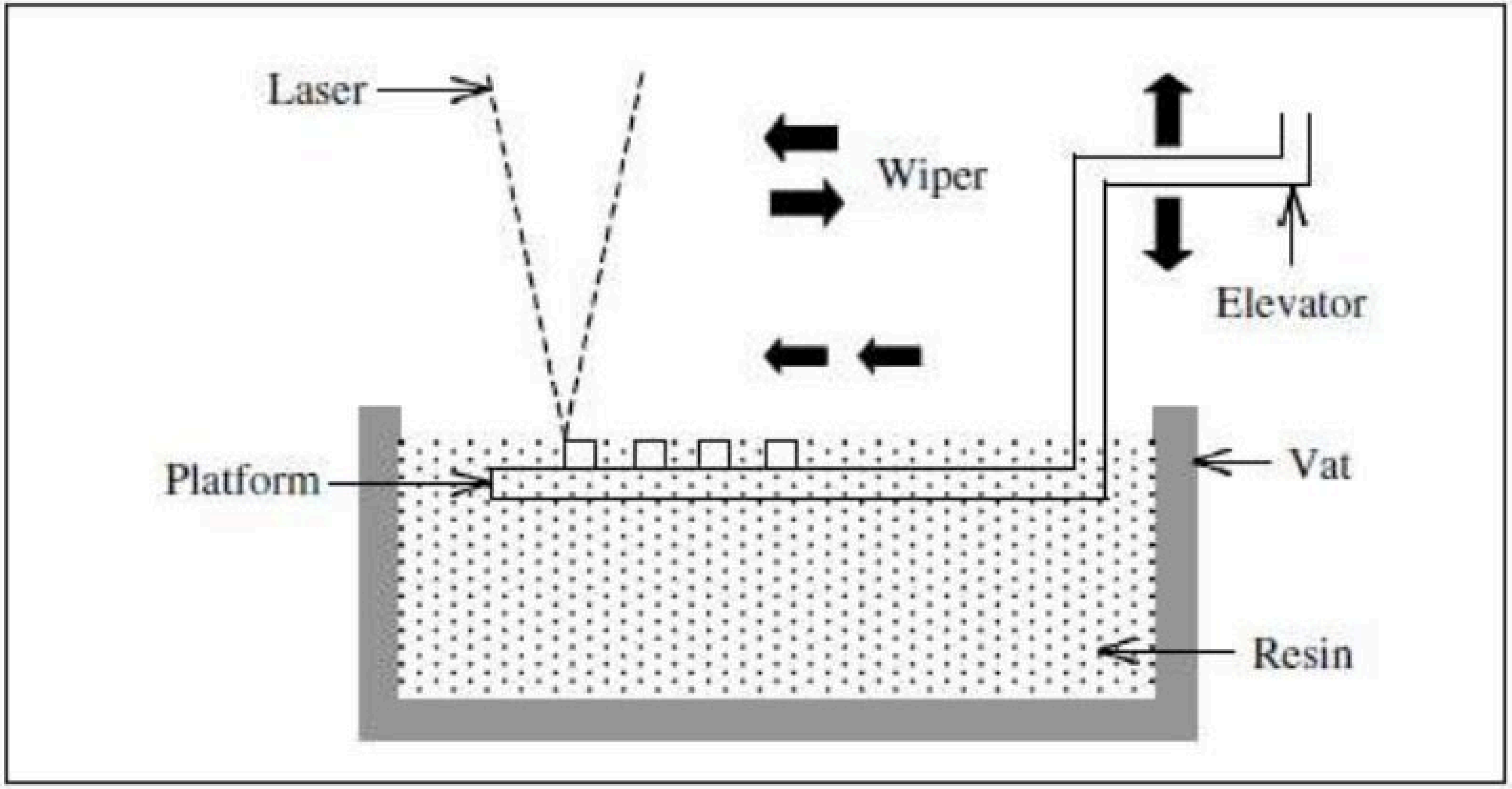
Stereo lithography is an additive manufacturing or 3D printing technology used for producing models prototypes , patterns, and production parts up one layer at a time by curing a photo-reactive resin with a UV laser or another similar power source.

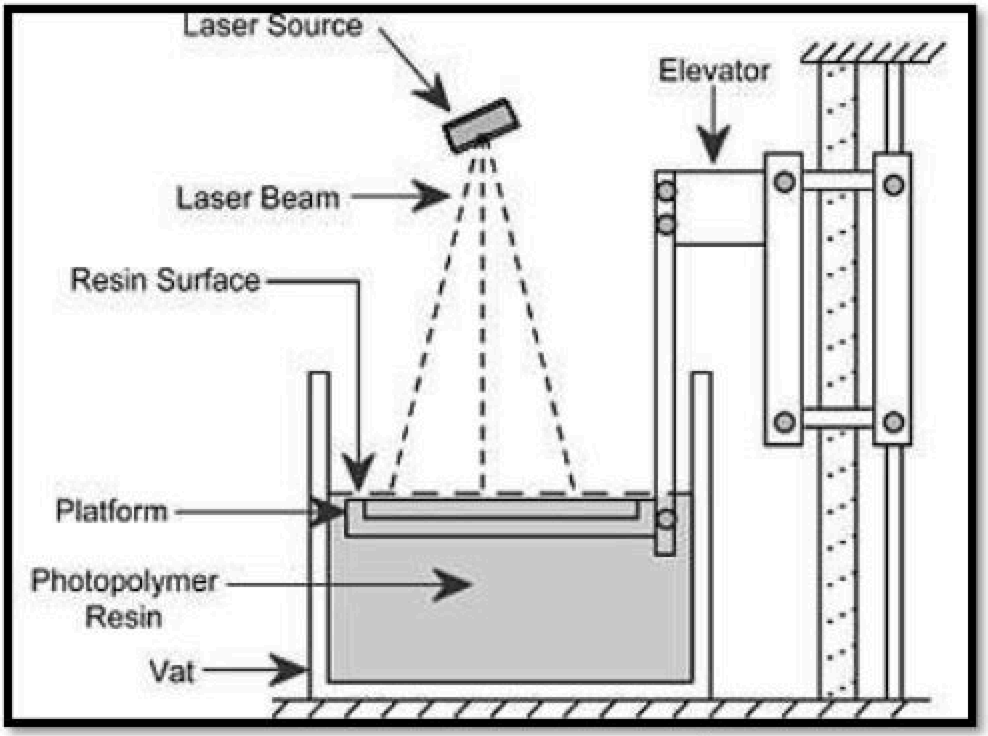
Methods Employed:

- Top-down approach
- Bottom-up approach

POST-PROCESSING:

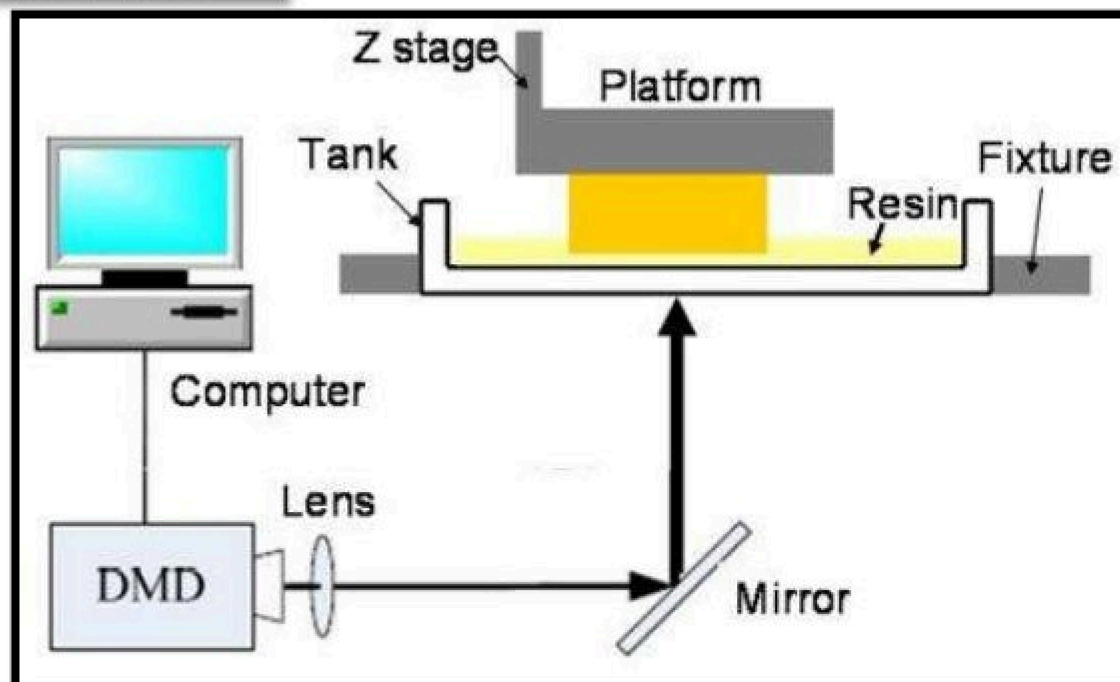
- Post curing/ de-binding/ sintering process for increasing mechanical properties


Laser
Wiper
Elevator
Platform
Vat
Resin



Top- Down Approach

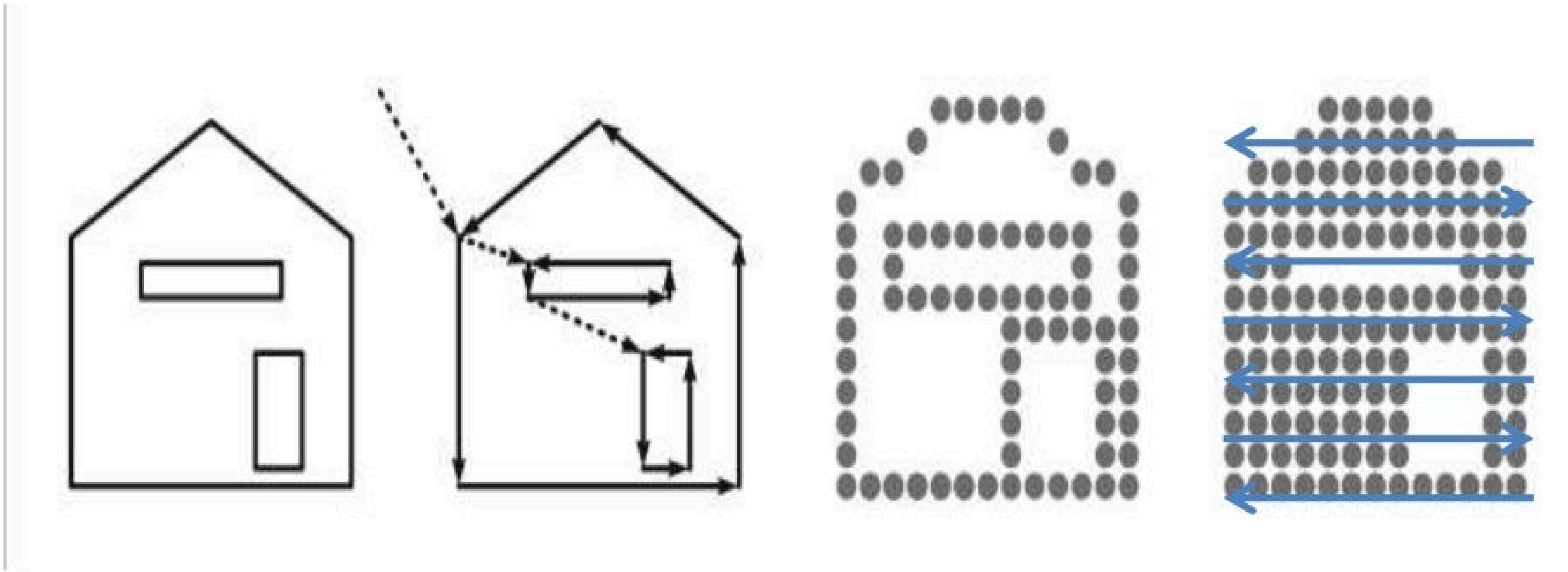
Fig . 1



Bottom- Up Approach

Fig.2

Vector scanning



Principle

- 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. This first principle deals mostly with photo-curable liquid resins, which are essentially photopolymers and the photo polymerization process.

- 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. The second principle deals mainly with CAD data, the laser, and the control of the optical scanning system as well as the elevation mechanism.

Advantages

- Round the clock operation.
- Good user support.
- Build volumes.
- Good accuracy.
- Surface finish.
- Wide range of materials.

Disadvantages

- Requires support structures.
- Requires post-processing.
- Requires post-curing.

APPLICATIONS

- Models for conceptualization, packaging and presentation.
- Prototypes for design, analysis, verification and functional testing.
- Parts for prototype tooling and low volume production tooling.
- Patterns for investment casting, sand casting and molding.
- Tools for fixture and tooling design, and production tooling.

Industrial Applications

- Ford Uses Stereo lithography to Cast Prototype Tooling.
- Black & Decker Saves a Year by Using Stereo lithography to Prototype their Improved Shearer/Shrub Trimmer Power Tool.
- Bose Saves Five Weeks Using Stereo lithography Over Traditional Hard Tooling

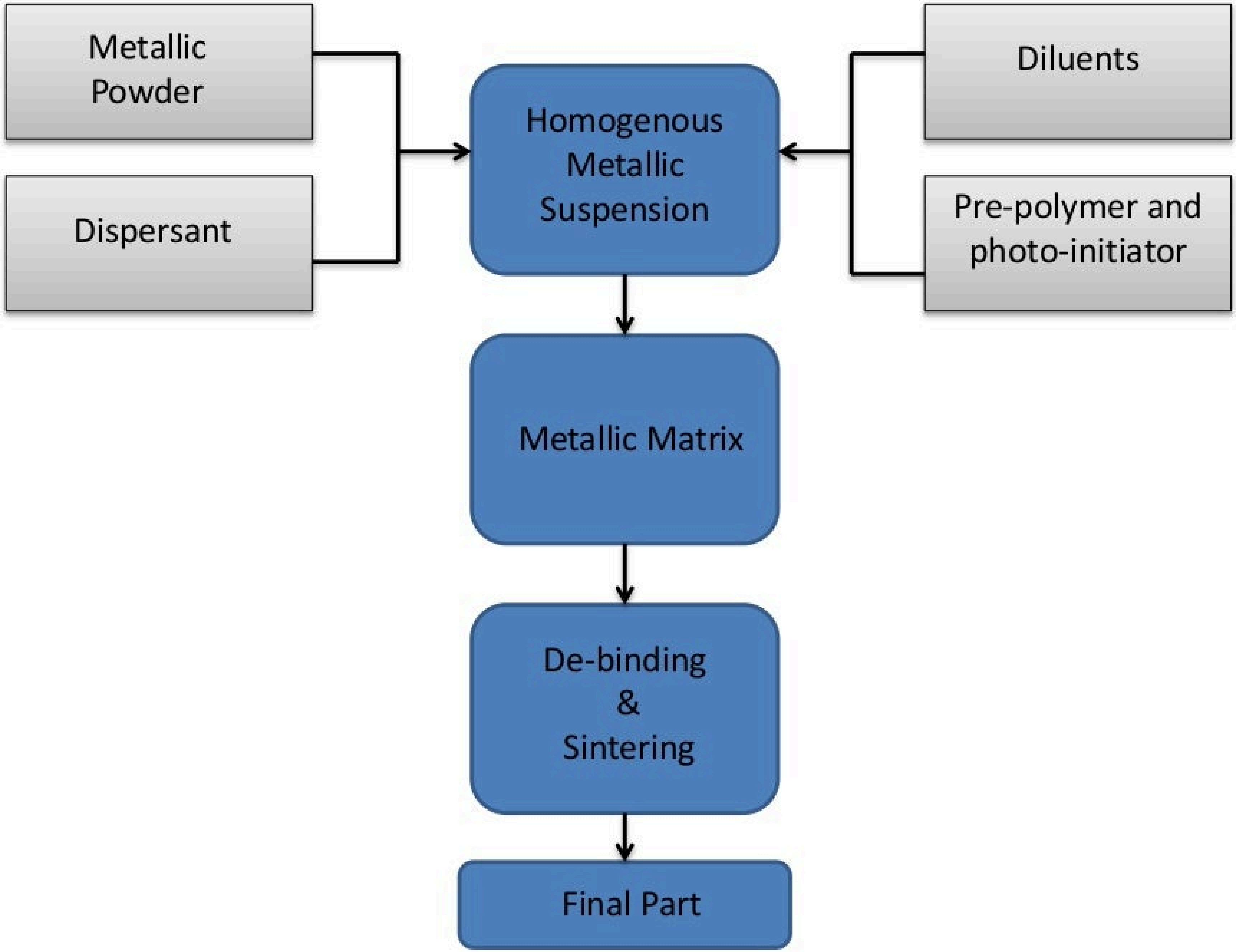
Model	SLA 250/30A	SLA 250/50	SLA 250/50HR
SYSTEM CHARACTERISTICS			
	SmartStart. An economical and versatile SLA starter system.	A supercharged system with higher powered laser, interchangeable vats, and Zephyr recoating system.	A specialty system with small spot laser for high-resolution applications.
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 @ $1/e^2$	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 @ $1/e^2$	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

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 @ $1/e^2$	0.25 +/– 0.025 mm (0.010 +/– 0.001 in)			0.25 +/– 0.025 mm (0.010 +/– 0.001 in)
Beam Diameter; Hatch @ $1/e^2$	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			

Model	SLA 3500	SLA 5000	SLA 7000	Viper si2
FEATURES				
Interchangeable Vat	Yes			
SmartSweep	Yes			No
Auto Resin Refill	Yes			No
SOFTWARE				
3D Lghtyear / Windows NT	Buildstation 5.1			Buildstation 5.2
Buildstation O/S	Windows NT 3.5.1			Windows NT 4.0
RESINS				
General Purpose	SL 5190, SL 5510	SL 5195, SL 5510	SL 7510	SL 5510
Durable	SL 5520		SL 7540	
High Temperature	SL 5530 HT			N/A
WARRANTY				
	1 yr from installation date			

METALLIC STEREOLITHOGRAPHY



HYBRID METALLIC RESIN

Unsaturated Polyester

- High resistance
- Thermal stability
- Hardness
- Flexibility

+

Epoxy

- High elasticity module,
- Excellent thermo and mechanical properties
- Low viscosity
- Low shrinkage

CURING BEHAVIOUR:

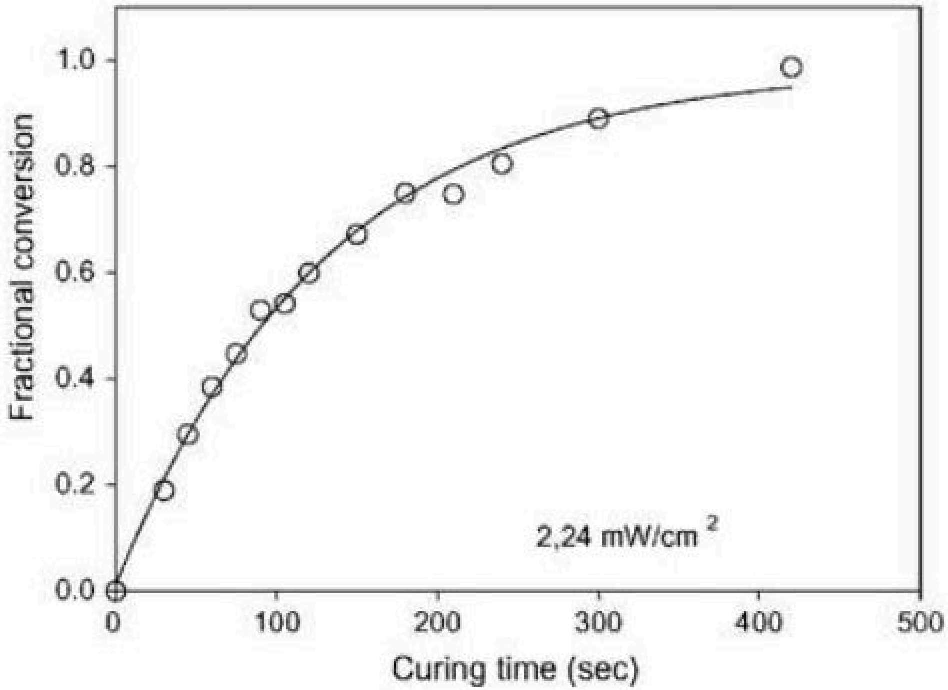
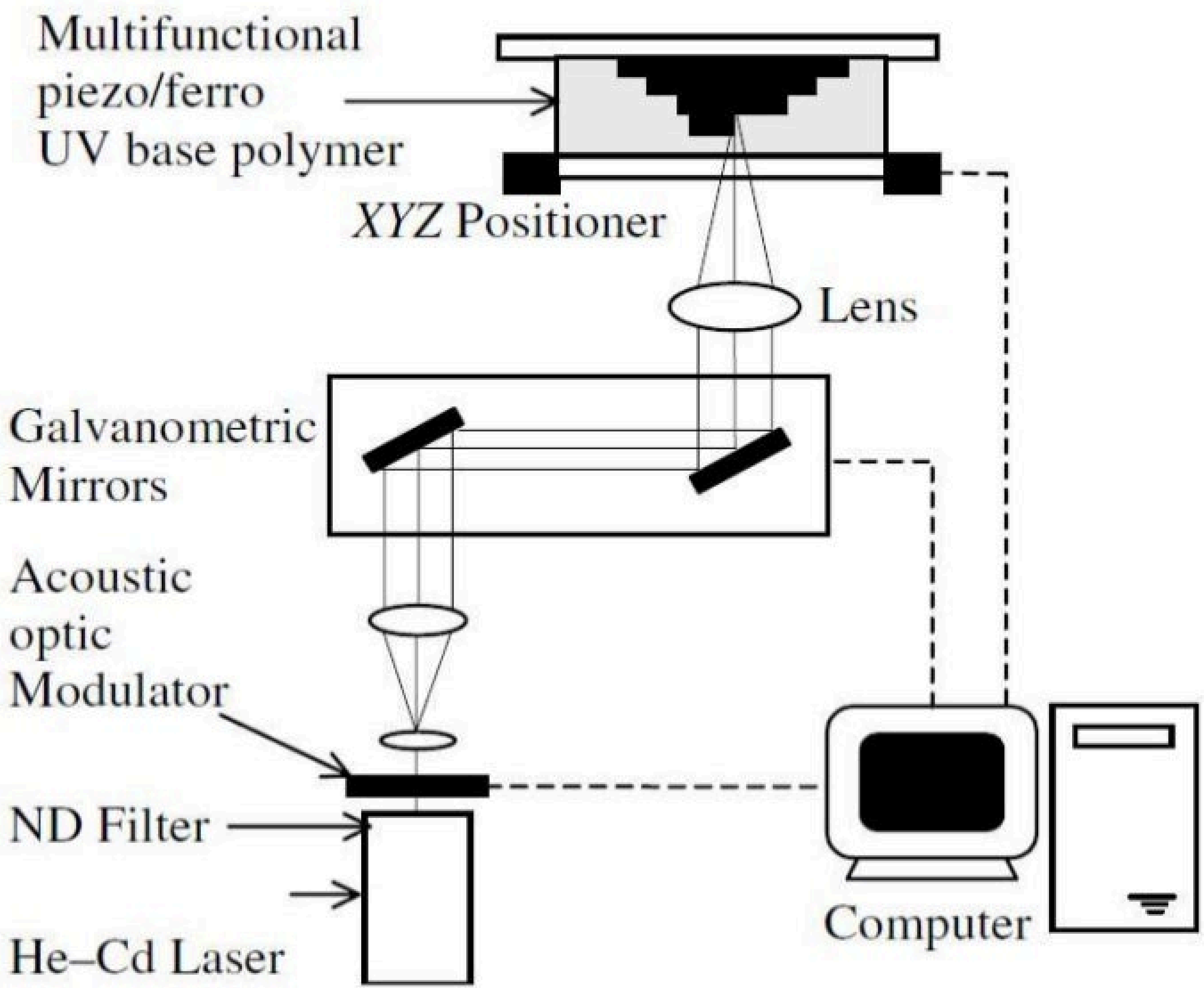


Fig. 3 Variation of fractional conversion Vs. curing time

- The rise in light intensity increases the reaction rate
- The conversion rate increases rapidly followed by a progressive slowing down until the cure profile reaches a plateau.
- This progressive slowing down is due to diffusion limitations because of increase in cross-link density.

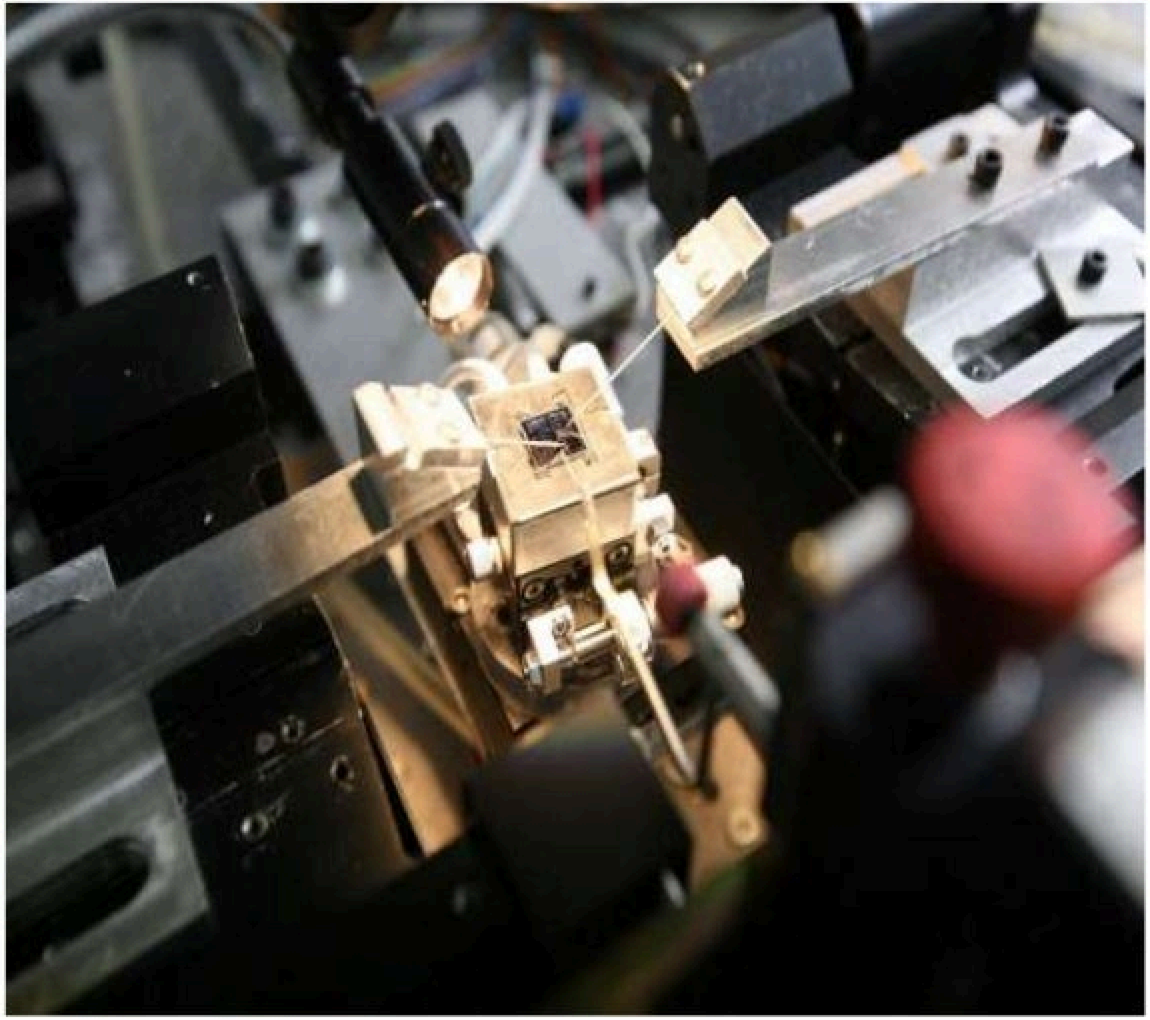
Microstereolithography



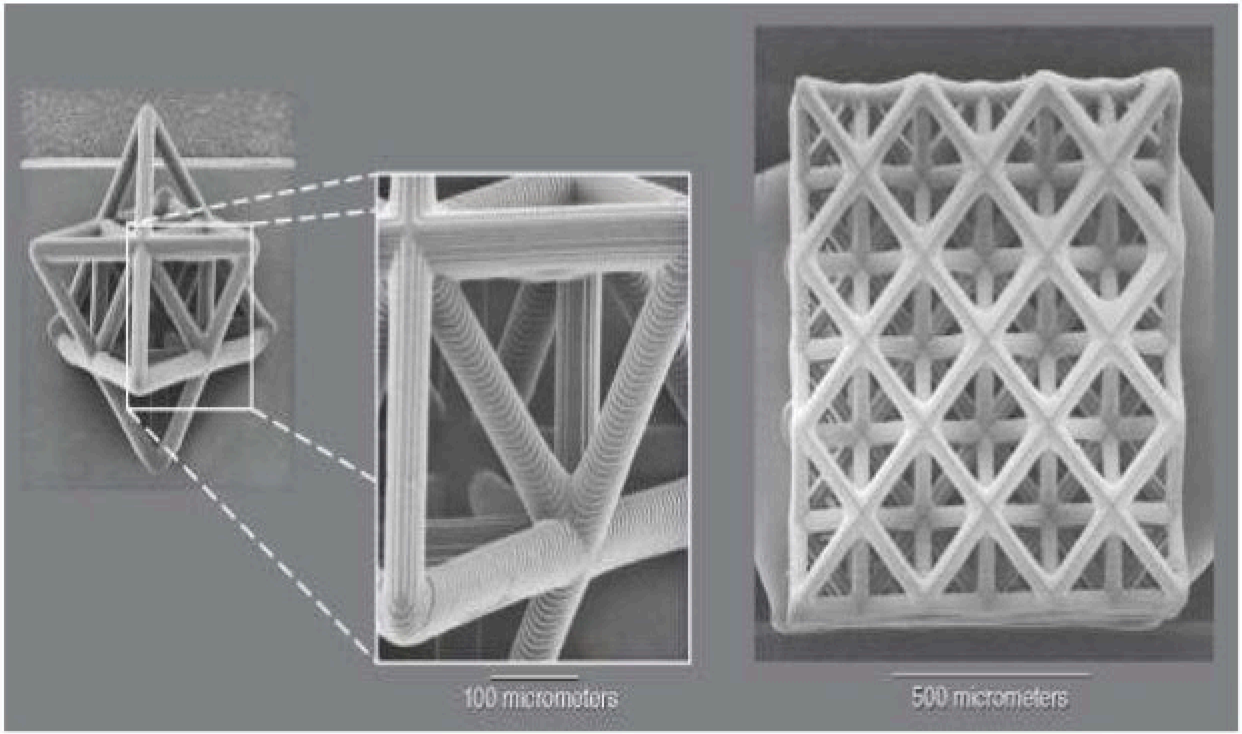
Micro Stereolithography – Specifications and Limitations

- Positioning stage must move slow
- Maximum component resolution is approximately 0.1 mm
- Requires *manipulation* and *micro-assembly* of micro-parts
- 5- μm spot size of the UV beam
- Positional accuracy is 0.25 μm (in the x–y directions) and 1.0 μm in the
- z-direction
- Minimum size of the unit of hardened polymer is 5 μm * 5 μm * 3 μm (in x, y, z)
- Maximum size of fabrication structure is 10 mm *10 mm * 10 mm
- Uses *vector or line scanning*
- Not suitable for *"real" 3D products*

Micro-assembly



Micro Stereolithography Products



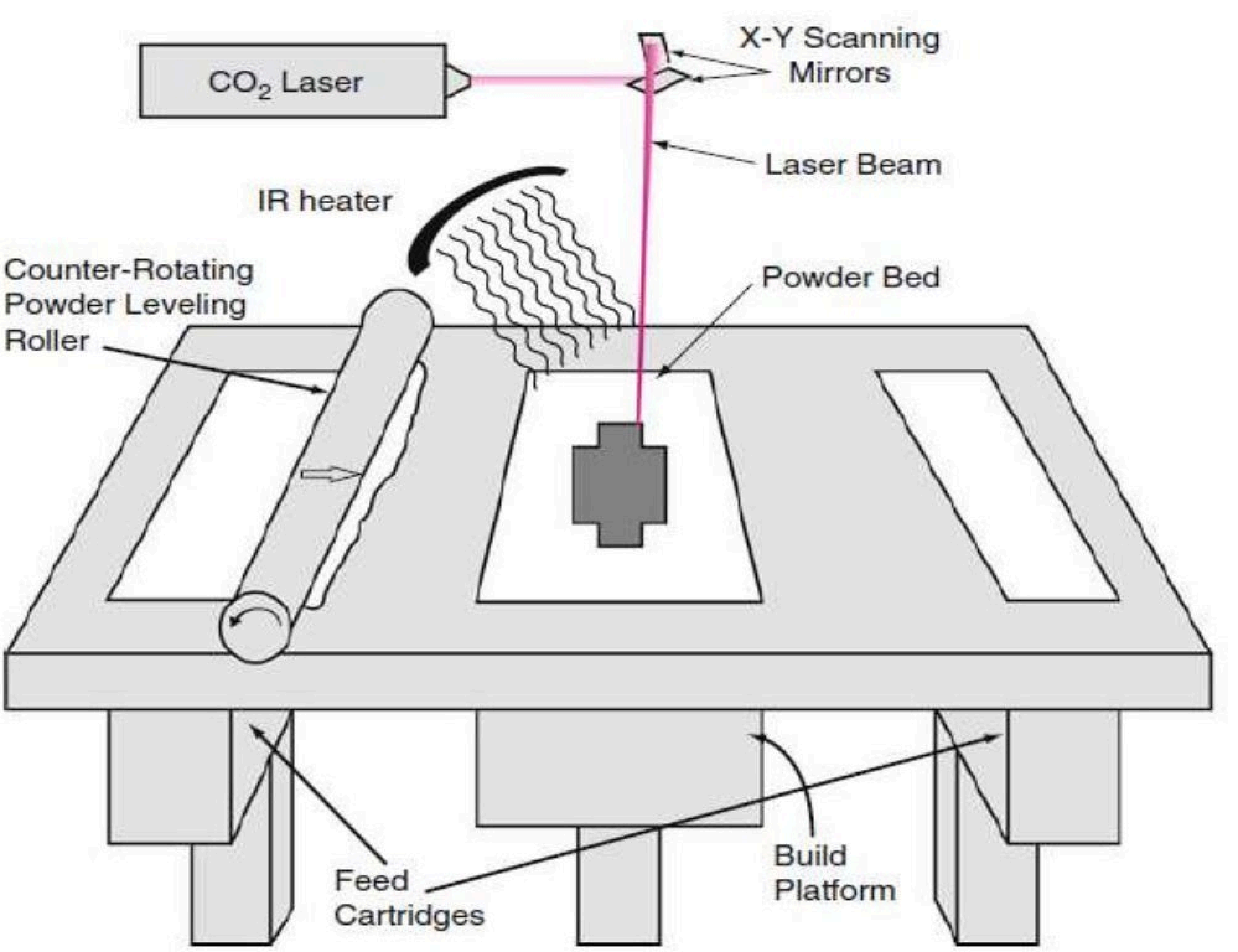
Powder Bed Fusion (PBF) Process

- Developed at University of Texas at Austin, USA by Carl Deckard (master's thesis) in 1989 with the process called selective laser sintering (SLS)

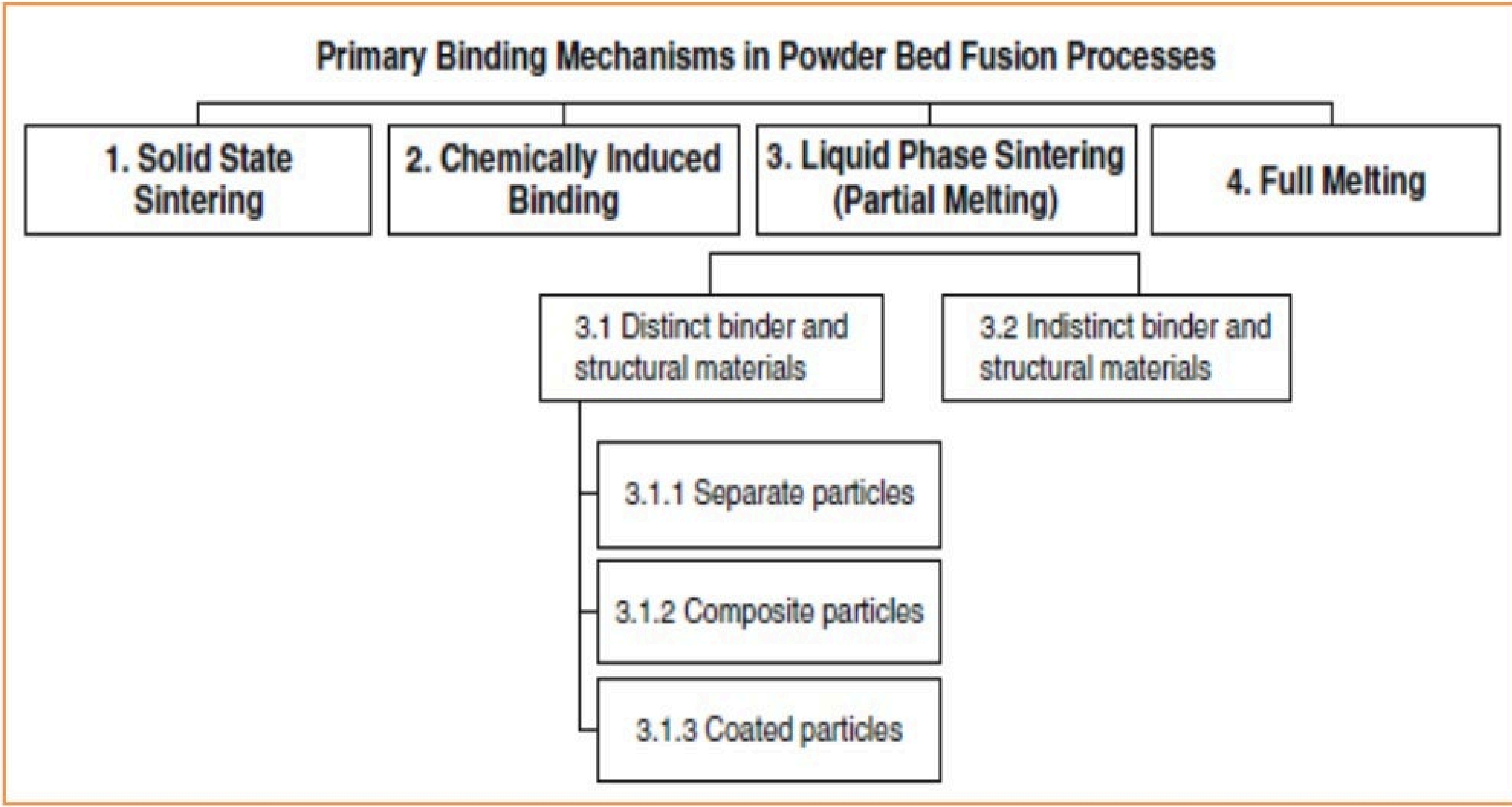
- Characteristics of PBF process
  - Thermal source for inducing fusion between powder particles
  - Controlling powder fusion to a prescribed region of each layer
  - Mechanism for adding and smoothing powder layers

- Materials: polymers, metals, ceramics and composites

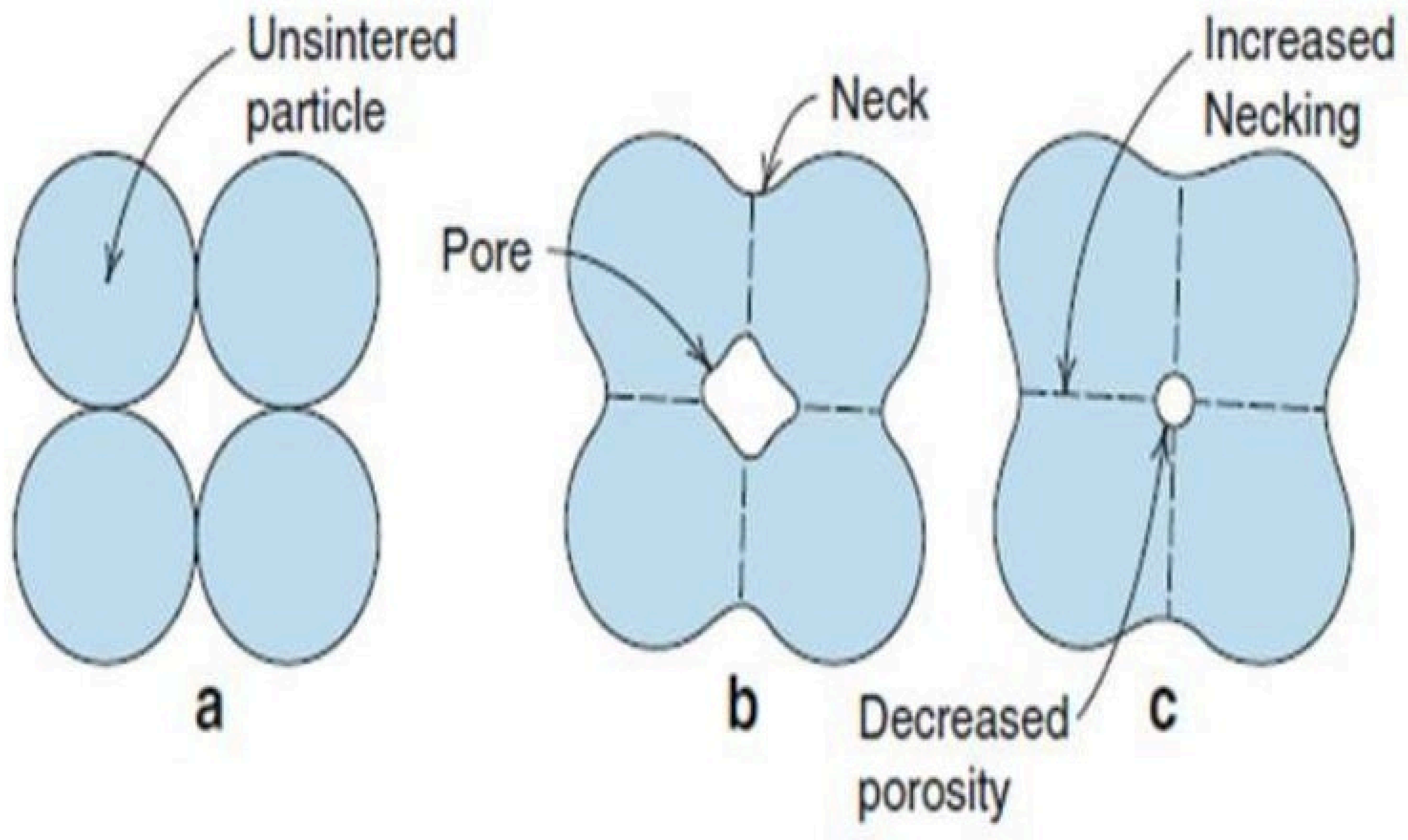
- Direct Digital Manufacturing of end-use products


CO$_2$ Laser
X-Y Scanning Mirrors
Laser Beam
IR heater
Counter-Rotating Powder Leveling Roller
Powder Bed
Feed Cartridges
Build Platform

Binding/Fusion Mechanisms of PBF Processes



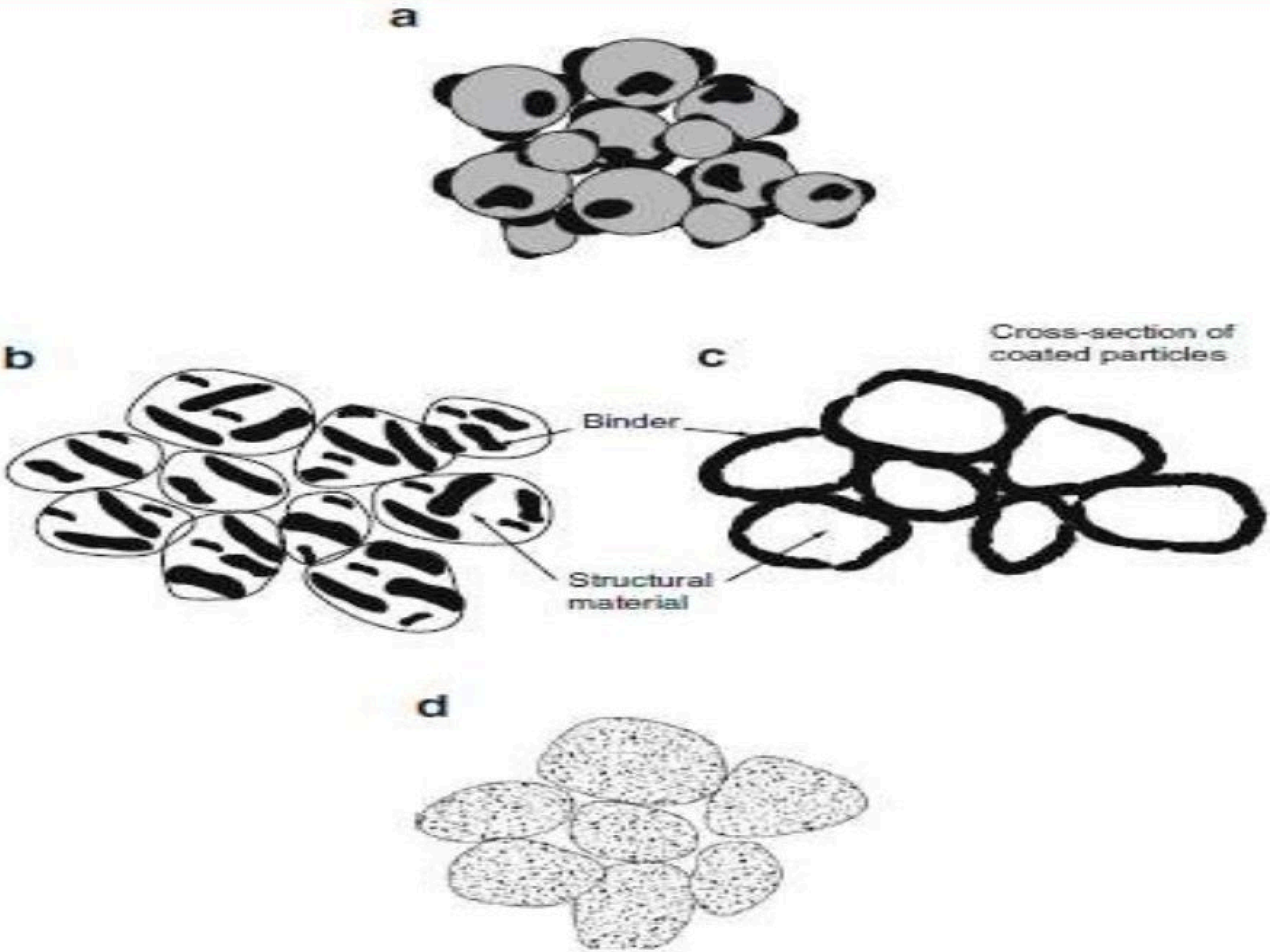
Solid State Sintering



Chemically-induced Sintering

- Thermally-activated chemical reaction between two types of powders/ between powders and atmospheric gases to form by-product which binds the powders together
- Ceramic materials
- Laser processing of SiC in presence of oxygen, SiO_2 forms and binds together a composite SiC & SiO_2
- By adding chemical reaction energy to laser energy, high-melting-temperature structures can be created
- Part porosity/post-process infiltration/high temperature furnace sintering

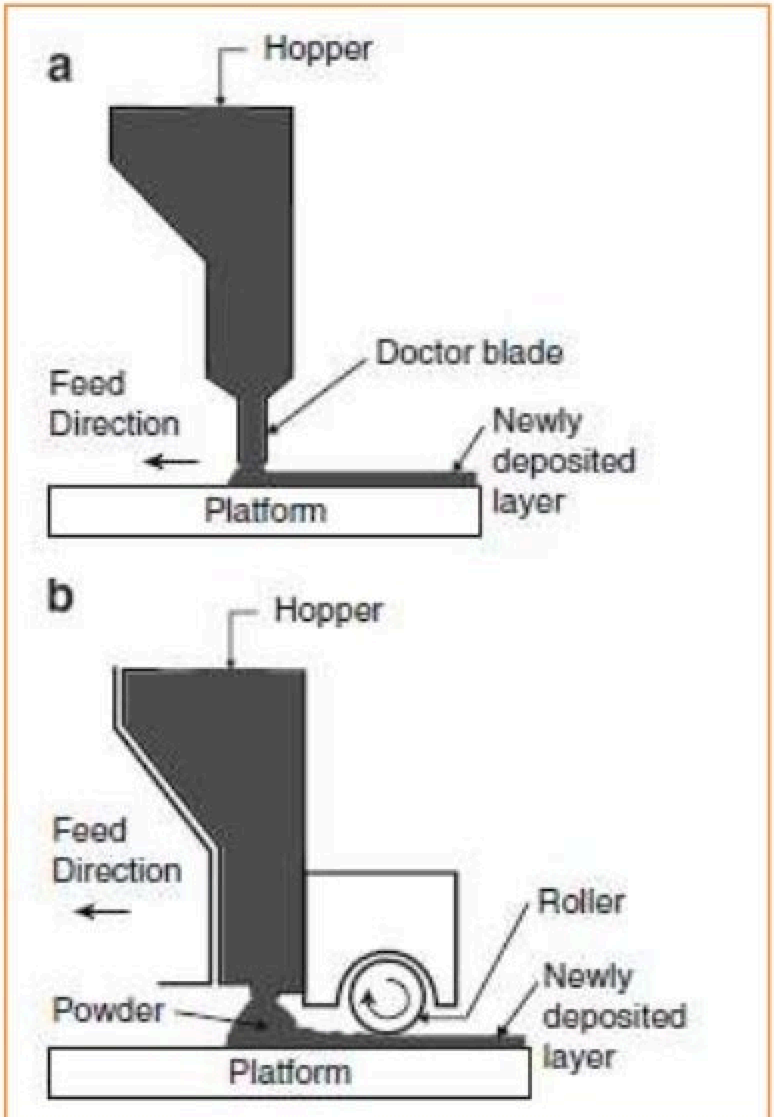
Liquid-phase Sintering(Partial Melting)



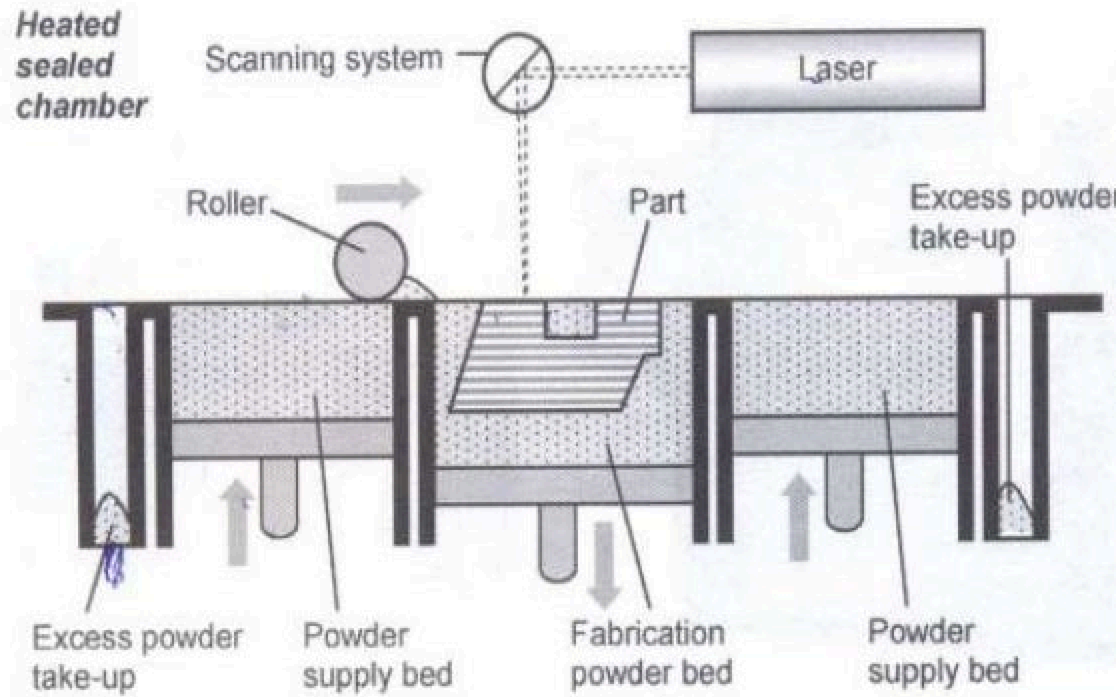
Full Melting

- Most common PBF process of engineering metal alloys & semi-crystalline polymers (nylon-polyamide)
- Entire region of material subjected to heat energy
- Well-bonded/high density structures from metals
- Ti, Stainless Steel, CoCr, etc.
- Rapid melting and solidification: Unique properties
- More desirable than Cast/wrought parts made from identical alloys

Powder Handling Systems



Hooper based powder delivery systems



Counter-rotating roller powder delivery system

Powder Handling Challenges

- Powder reservoir of sufficient volume to build maximum build height without refill
- Correct volume of powder must be transported to the build platform without wasteful excess material
- Powder must be spread to form a smooth, thin, repeatable layer of powder
- Powder spreading must not create excessive shear forces that disturb the previously processed layers
- Particle size decreases: interparticle friction and electrostatic forces increases: lose of flowability
- Surface area to volume ratio of a particle increases: surface energy increases: more reactive: explosive: inert gas
- Small particles: airborne: floats as a cloud of particles: damage the moving parts: better surface finish: higher accuracy: thinner layers

Powder Recycling

- Elevated temperatures: reacting atmospheric gases: Change the chemical nature of the powder particles
- Change of particle size and molecular weight
- 1/3 unused powder
- Particle sorting methods: Vibratory screen-based sifting/ air classifier
- Consistent builds: Powder's melt flow index (MFI)
- MFI for unused & used powders
- Recyclability of a powder and the target MFI/fraction mixing have a significant effect on part properties & cost

Specifications of 3D System Sinterstation HiQ and Pro

	Model			
	Sinterstation® HiQ™ Series SLS®		Sinterstation® Pro SLS®	
	HiQ™ system	HiQ™ + HS system	Pro 140	Pro 230
Laser type	CO_2			
Laser power (W)	30	50	70	
Maximum scan speed (m/s)	5 (Standard Beam Delivery System)	10 (High-Speed Celerity™ BDS)	10	
Build volume, *XYZ*, mm (liters), in.	381 × 330 × 457 (57) [15 × 13 × 18]		550 × 550 × 460 (140) [~22 × 22 × 18]	550 × 550 × 750 (250) [~22 × 22 × 30]
CAD interface	STL			
Power supply	240 VAC, 12.5 kVA, 50/60 Hz, 3-phase or 380 VAC, 12.5 kVA, 50/60 Hz, 3-phase		208 VAC, 638 A, 3-phase	

3D Systems Selective Laser Sintering(SLS): Products

- Sinterstation HiQ Systems
- Sinterstation 2500plus
- Sinterstation Pro

3D Systems Selective Laser Sintering(SLS): Materials

- CastForm: It is similar to standard investment casting wax used by foundries
- DuraForm: It is a polycarbonate, industry standard, engineering thermoplastic. DuraForm PA, DuraForm GF
- Nylon: Durable material
- Somos 201: Rubber/elastomer/flexible
- LaserForm ST-100: 60% Steel + 40% Bronze

3D Systems Selective Laser Sintering (SLS): Strengths

- Good part stability: Functional parts build directly
- Wide range of materials: nylon/polycarbonates/metals/ceramics
- No part supports required
- Little post-processing required: particle blasting/sanding
- No post-curing required
- Advanced software support

3D Systems Selective Laser Sintering (SLS): Weaknesses

- Large physical size of the unit
- High power consumption
- Poor surface finish

Applications of SLS

- Concept Models
- Functional models and working prototypes
- Polycarbonate patterns
- Metal Tools

SLS Applications: Functional Prototypes

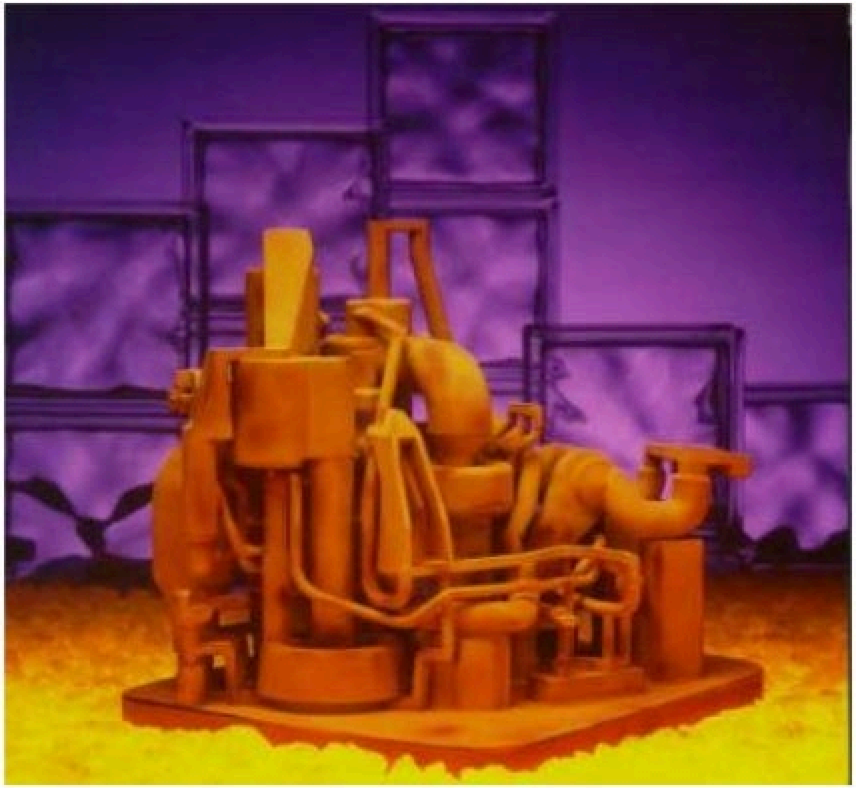
- DuraForm PA, GF, and SOMOS 201 TPE
  - Outstanding durability – mechanical, thermal, chemical
  - Allow aggressive "real-world" testing
  - End-use parts for some low-volume applications

- Future direction = metals

SLS Applications: Investment Casting

- CastForm PS
  - Direct expendable patterns
  - Production-equivalent prototypes and low-volume manufacturing
  - Standard foundry processing
  - Cast all metals, even reactive metals like titanium

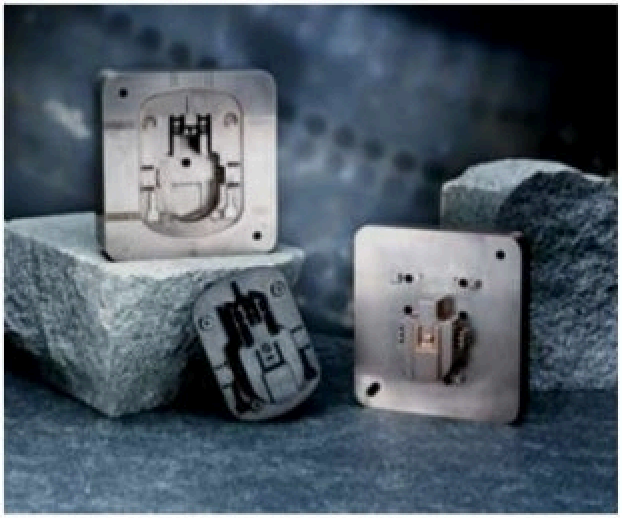
SLS Applications: Sand Casting



- SandForm Si and Zr
  - Direct shell sand cores and molds
  - Production-equivalent prototypes and low-volume manufacturing
  - Unlimited complexity – difficult to manufacture parts

SLS Applications: Metal Tooling

- **RapidSteel 2.0**
  - “Direct from CAD” near-net shape tools in 4-5 days
  - Molded parts in as little as 2 weeks
  - Rapid turnaround prototype injection molded and die cast parts
  - Low volume (< 100,000) production injection molding



Research and Development of SLS

- Developing new and advanced materials
- Improving and refining process
- OptiScan software: Reduced build time by 34%

Solid foil polymerization (SFP)

The part is built up using semi-polymerized foils which are soluble in monomer resin. On exposure to UV light, the foil solidifies and bonds to the previous layer. It also becomes insoluble. Once the cross-sect ion has been illuminated, a new foil can be applied. The unwanted material acts as support and can be removed later.