Additive Manufacturing Technology and Trends

MCA Session Topic: Generalizing Fundamental AM Principles

4/10/24

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Machine Movement Overview

- Machine component movements and material bonding methods must work together
- A machine with specific movements can use different materials
- Material properties are part of designing an AM machine
  - This makes AM fundamentally different than any other manufacturing technology
  - The machine component movement capabilities are always better than the tolerances of the produced part
  - Analogous to designing a Quality Assurance device
- Non-linear relationship between machine movement accuracy and final part accuracy

Simple Definitions for “Complex” AM Systems

Machine Movements	Materials & Bonding Methods
Active vs. Passive	Plastic Filament, Heat & Pressure
Motors & Gears	Glue & powder
Motors & Jets	Resin & UV
Mirrors & Motors & Masks	Resin & Lasers
Mirrors & Lasers & Lenses	Special Powders & Lasers

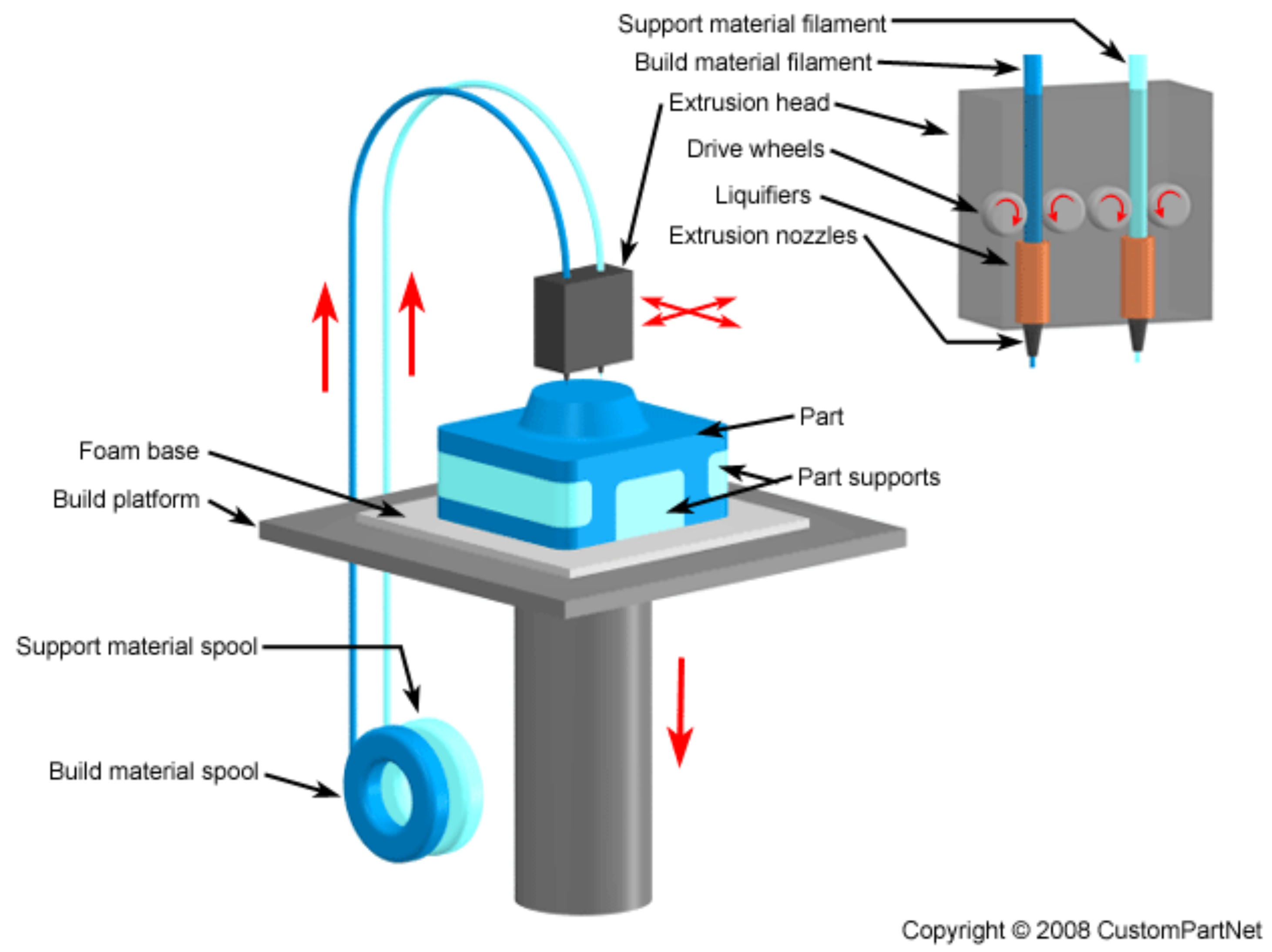
Platform Movements

- Passive systems:
- Support Material moves with part
  - StereoLithography
  - 3D printed (glued powder, Zcorp)
  - Thermo and Multi-Jet Printing
  - Sintering
- Purpose/Use-case priority
  - Aesthetics / Display
  - Feel
  - Function

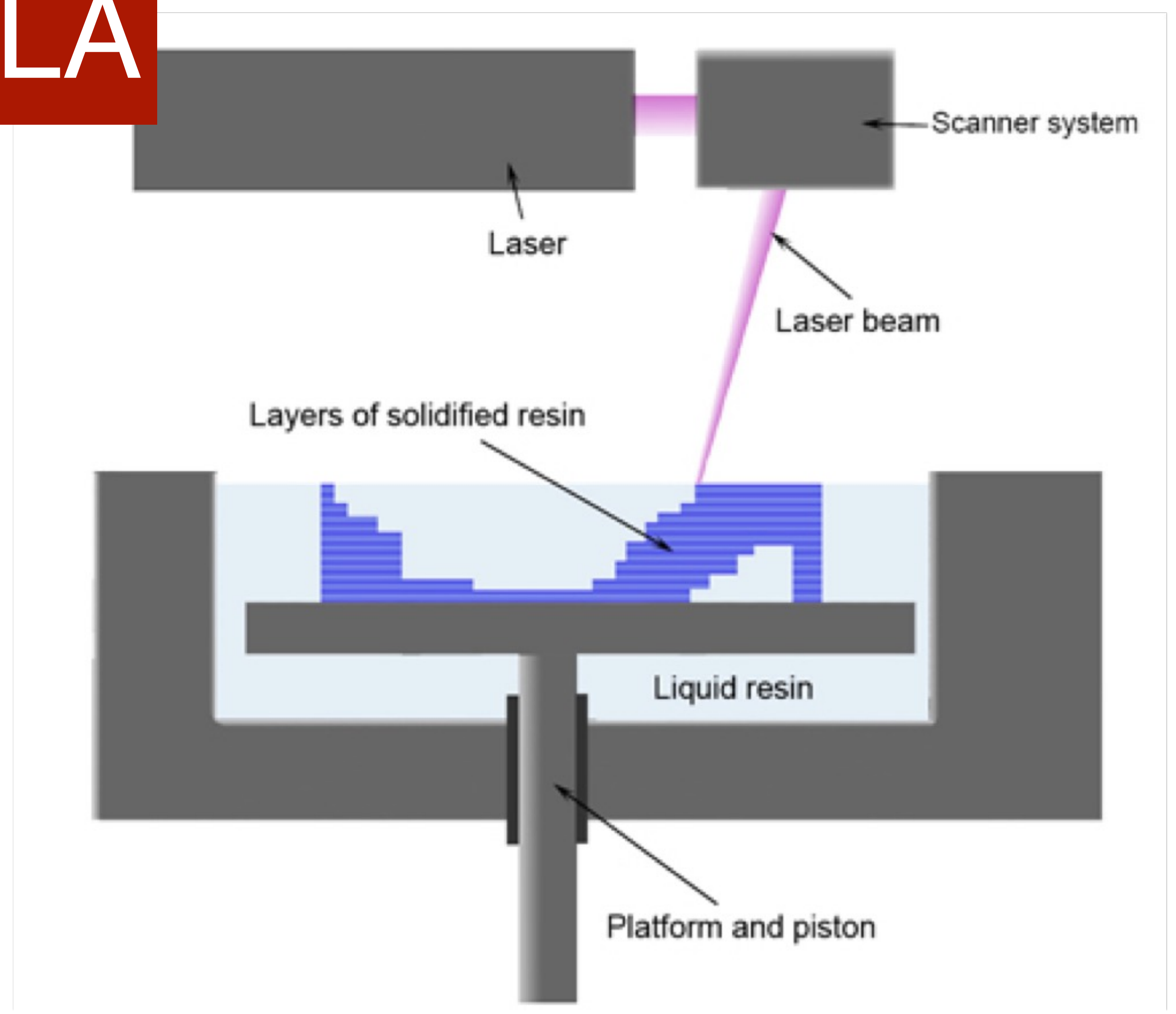
- Active systems:
- Support (if needed) created simultaneously with part
  - Deposition:
    - FFF, FDM, MEMS
    - 3D printed (glued powder, Zcorp)
    - Thermo and Multi-Jet Printing
  - Melting
    - SLM, LENS, EBM
- Purpose/Use-case priority
  - Function
  - Feel
  - Aesthetics / Display

AM Processes

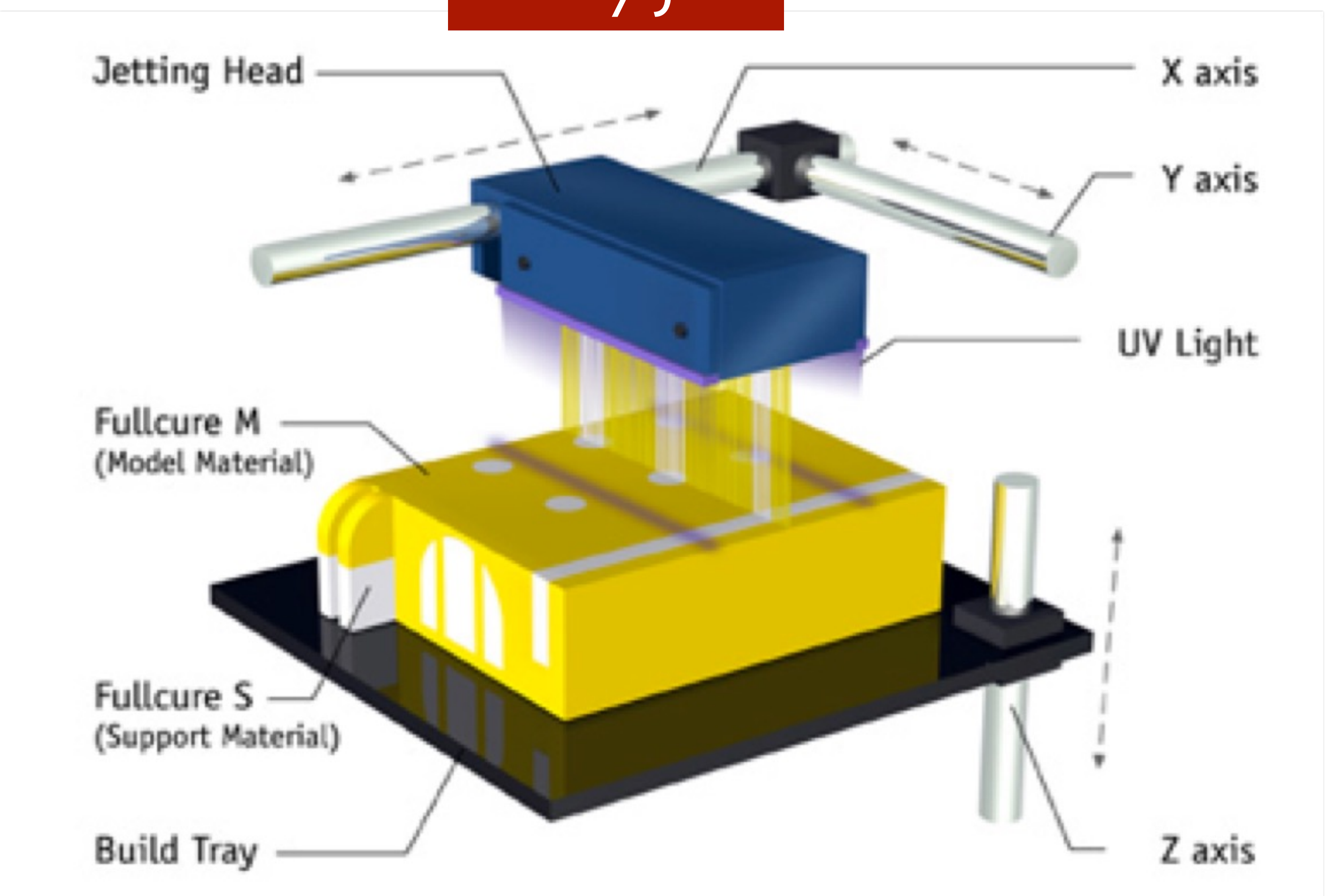
FDM



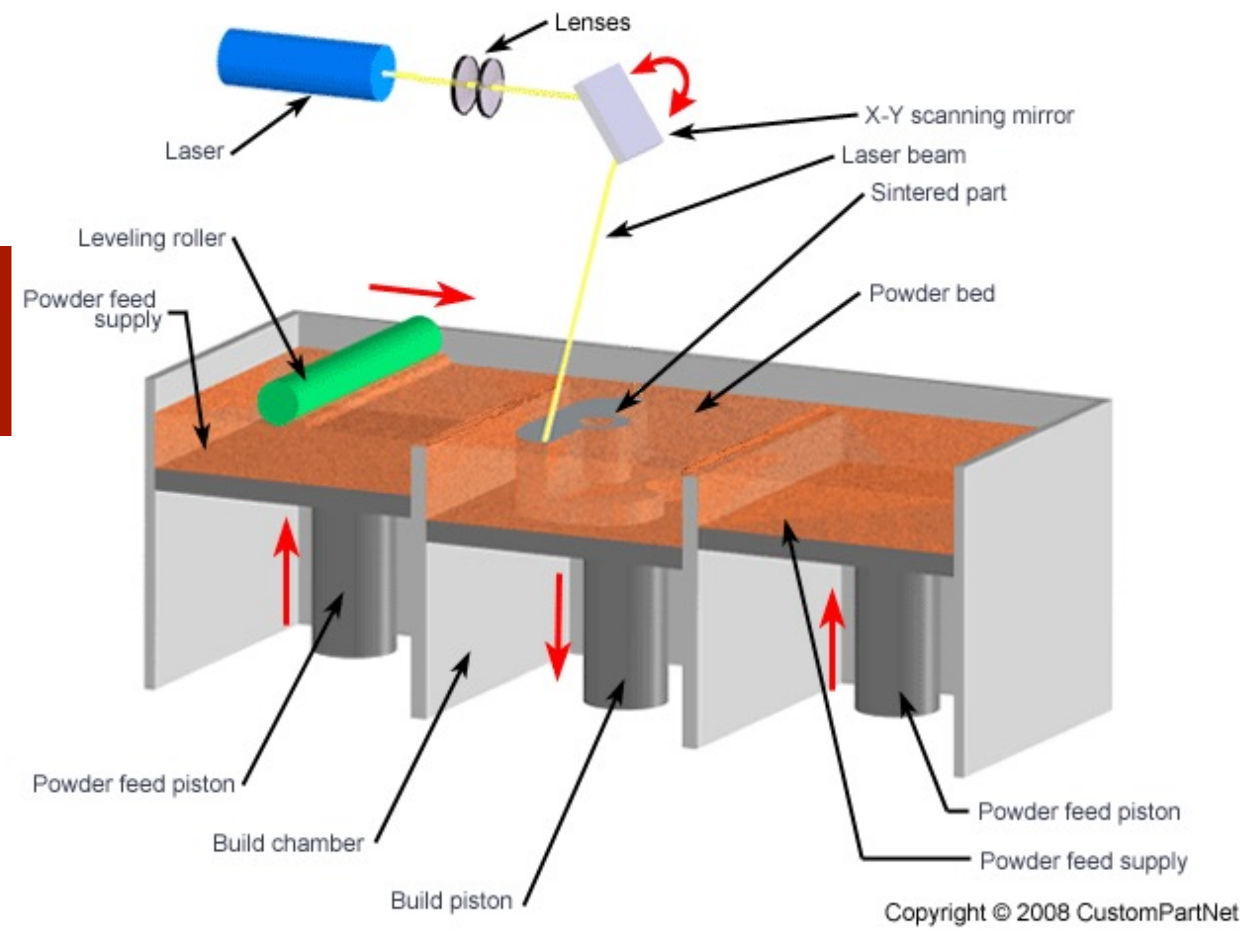
SLA



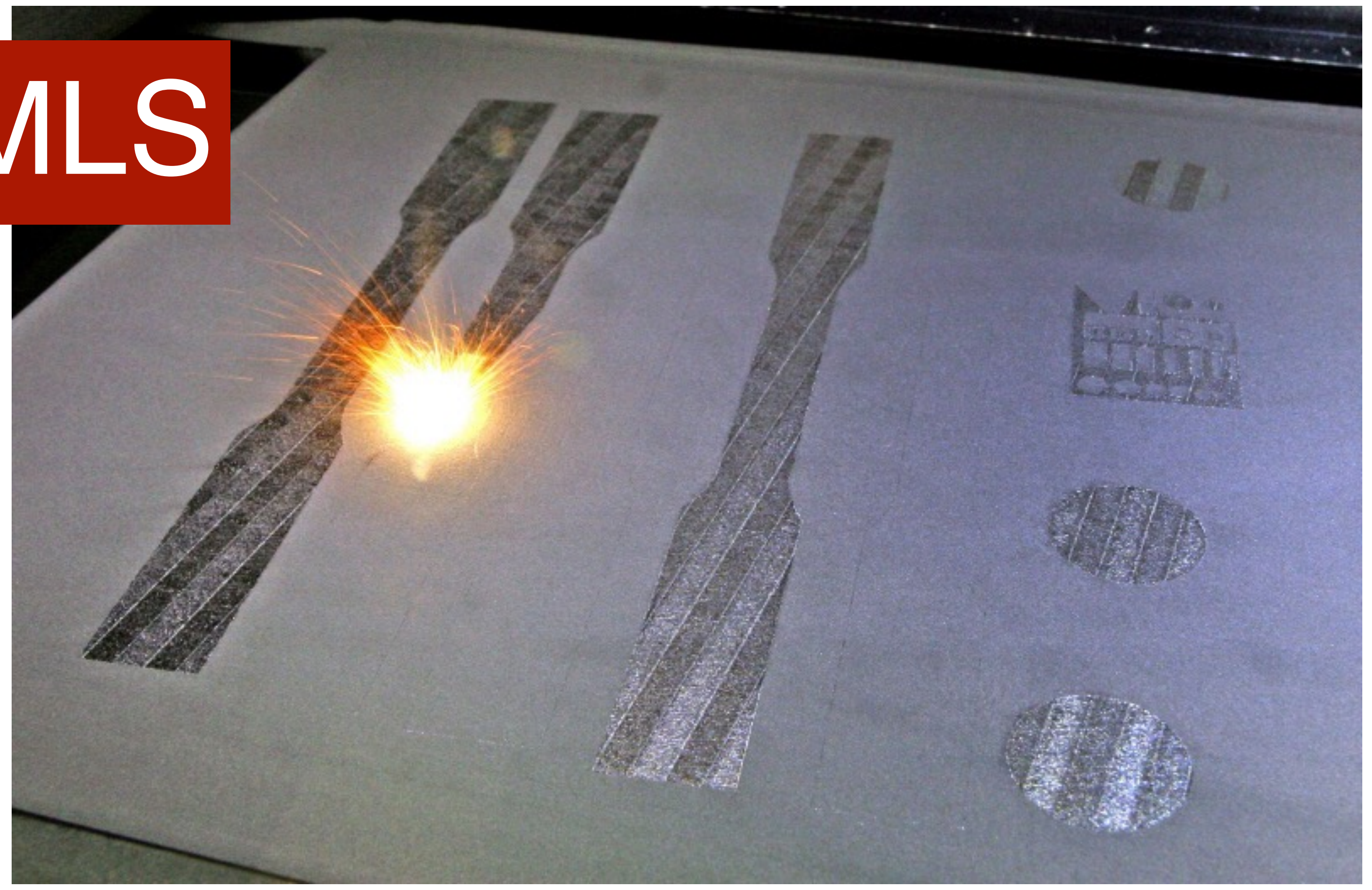
Polyjet



SLS



DMLS



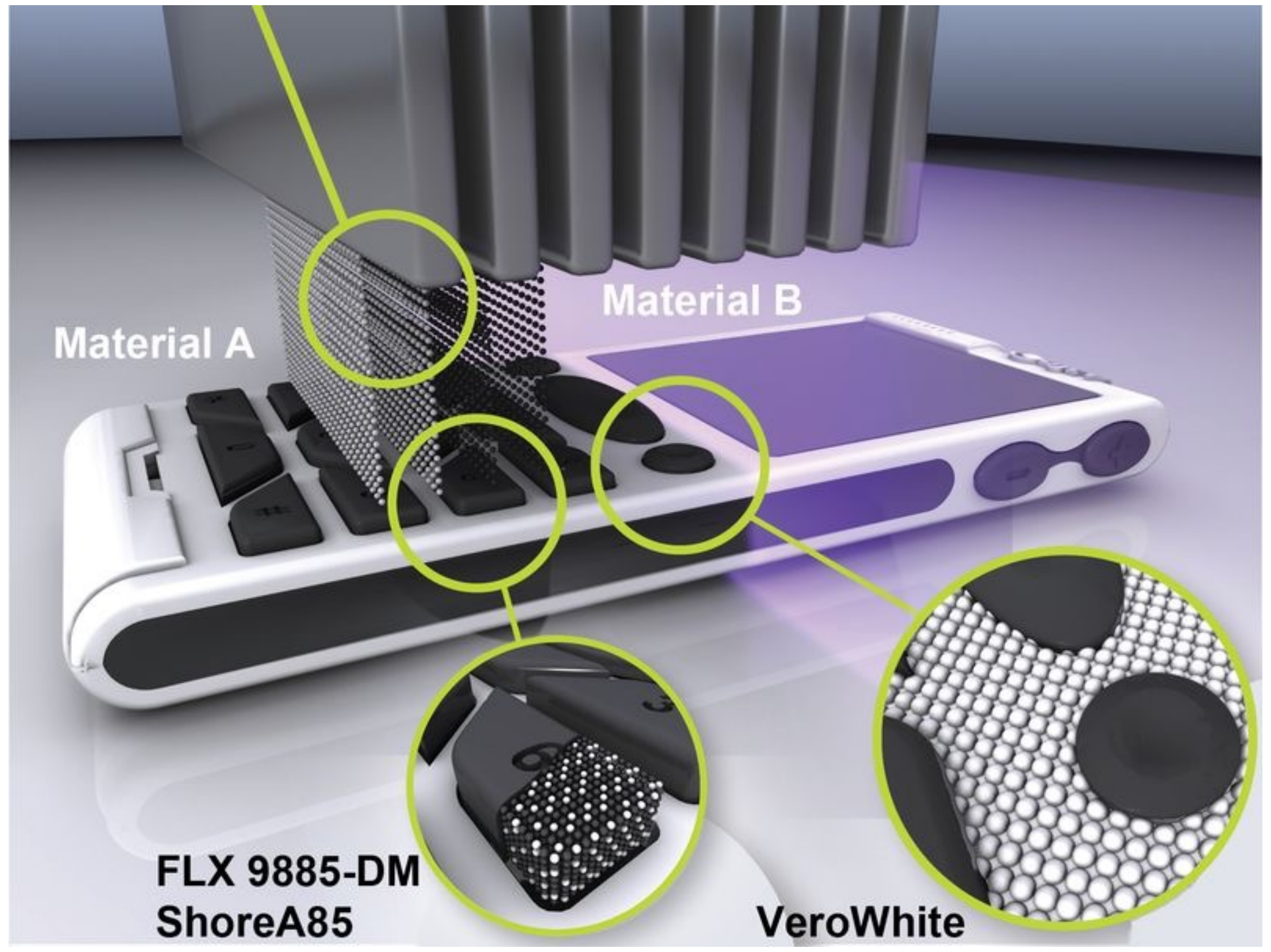
Passive Supports Post-Processing

AM Machine Specifications

Machine Type	Tolerance Range (in.)	Materials	Material & Part Properties	Typical Applications
FFF	0.0000X -> 0.0X	Thermoplastic filament	Varies based on user	Function of Cost
FDM	0.001 -> 0.010	ABS filament	> 60% of other mfg. processes	Fit, and some function
Fused Powder	0.0001 -> 0.005	Thermoplastic & thermoset powders	Poor, requires post-processing	Fit, Form, Function, Communication
SLA	0.0001 -> 0.003	UV cured polymers	Fair	3D shape and
Polyjet	0.00005 -> 0.0005	UV cured polymers, plastics, rubber	Good	Small features, multi-material prototypes
SLS	0.0001-> 0.001	Ceramics, Thermoplastics	Good	Wide variety, based on material
DMLS	0.0001 -> 0.001	Ceramics, Metals	Very Good, semi-porous	Industrial use, complex internal geometric features
SLM, LENS, EBM	> 0.0001	Metals	Fully Dense	When it can't be made or repaired in any other way

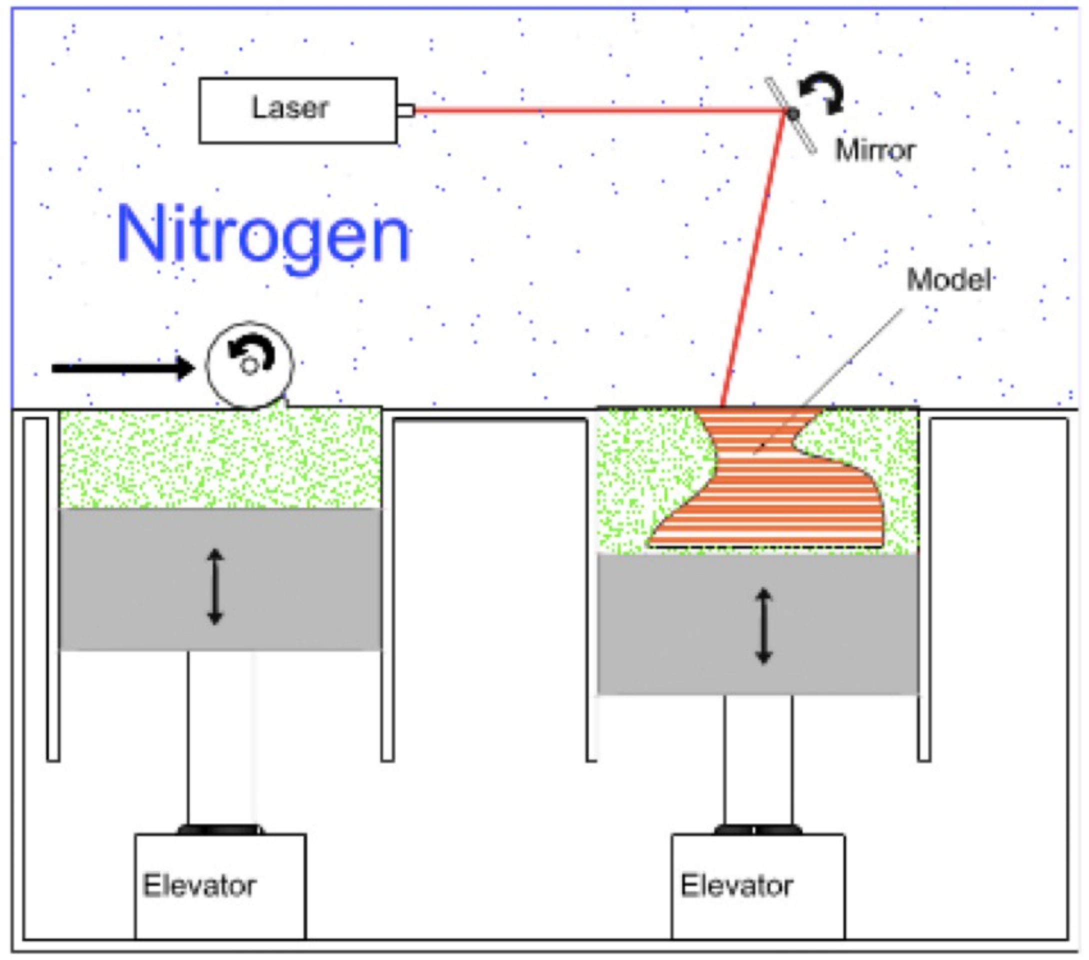
PolyJet

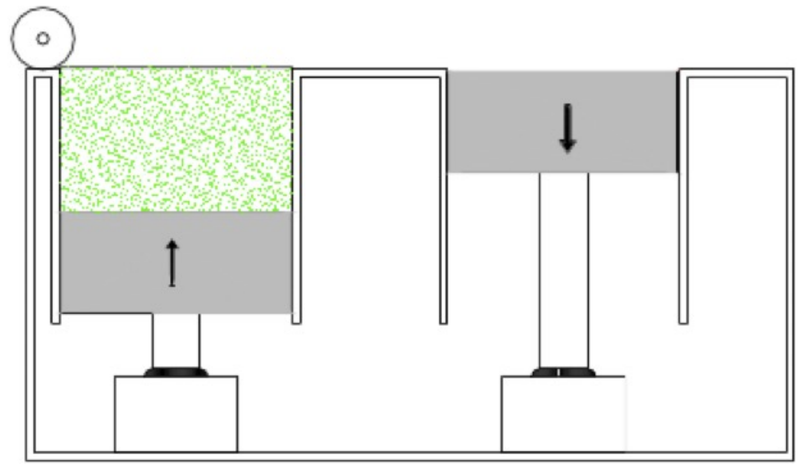
- Stratasys trade name for multi-jet technology for UV cured photopolymers
- Cannot be used with Thermoplastics which require FDM/FFF processes

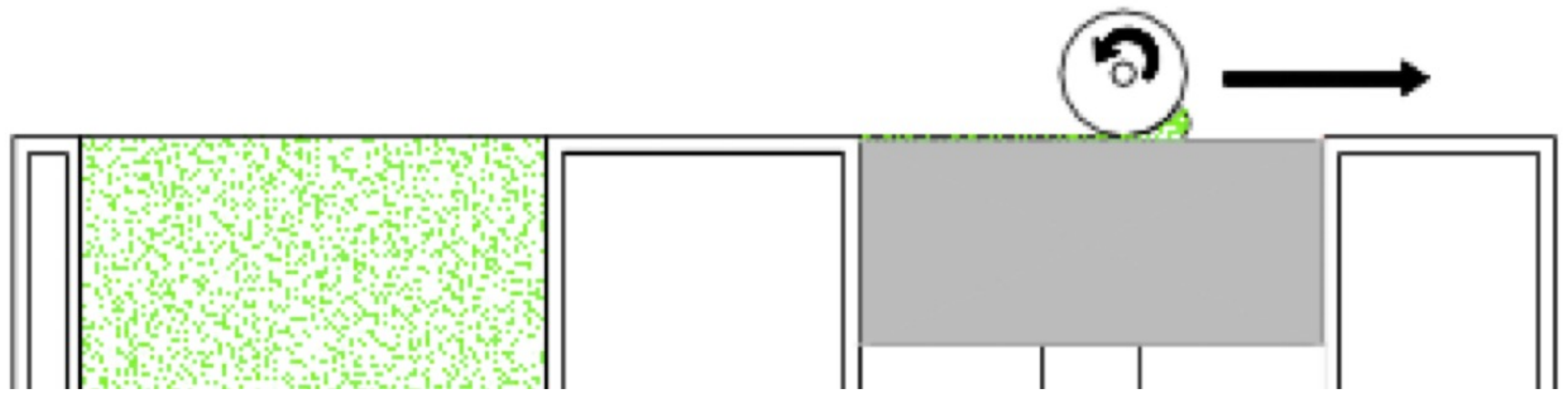


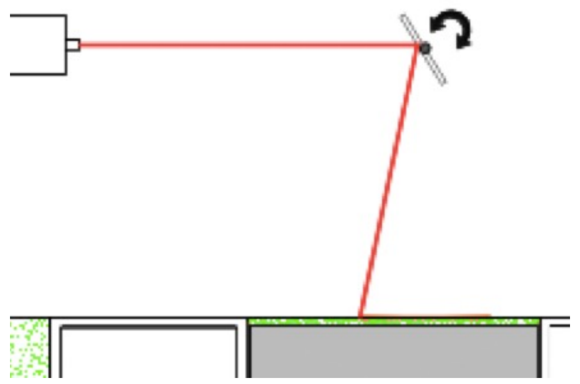
Selective Laser Sintering

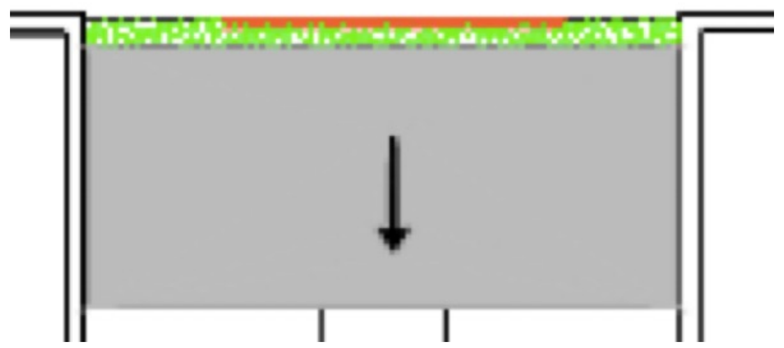
- Sintering is not melting
  - Laser power dependent on material, 25-100W laser is typical
  - Chamber is heated to below melt temperature of material
  - Nitrogen used to avoid oxidation and/or explosion
- Process Steps:
  - Laser beam directed through use of galvanometric mirrors
  - Un-fused powder serves as passive support structure
  - Supply platform raises and build platform lowers
  - Counter-rotating roller sweeps powder layer from supply
  - One layer thickness of powder ready for sintering
  - Laser sinters a layer
  - Platform moves down after sintering
  - Fresh new powder layer (slow step, compared to laser sintering step)
  - Build Platform raises out of the build chamber

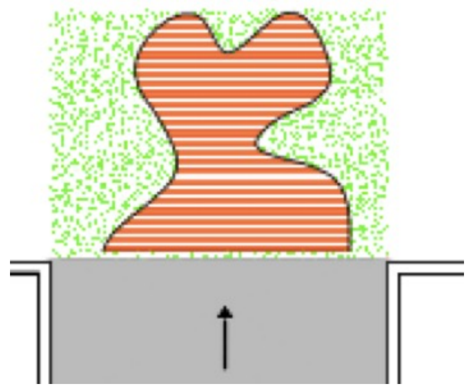












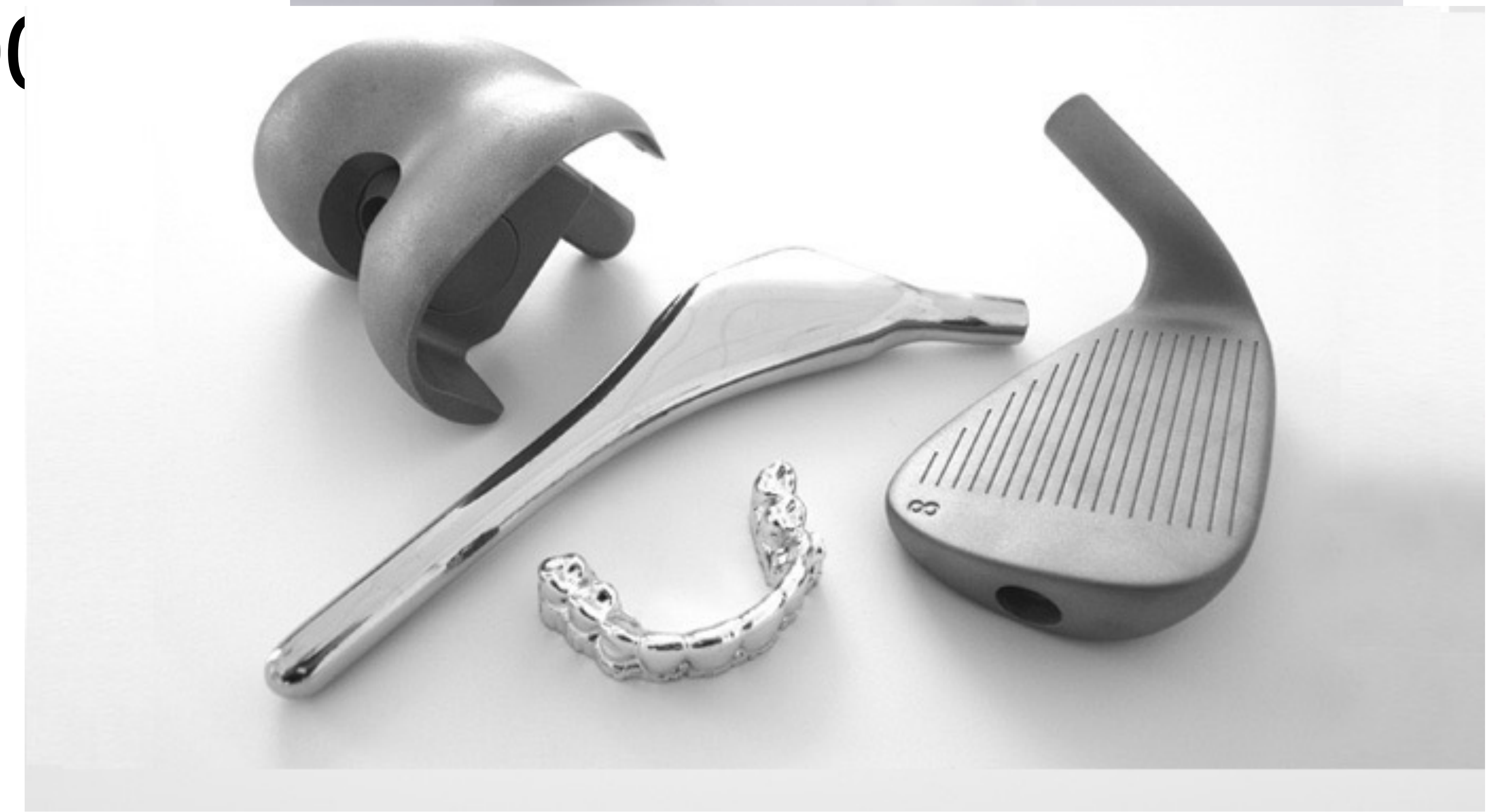
Direct Metal Laser Sintering (DMLS)

- Higher power lasers and chamber temperatures allow direct sintering of metal powders or selective melting

- Lasers 200W +

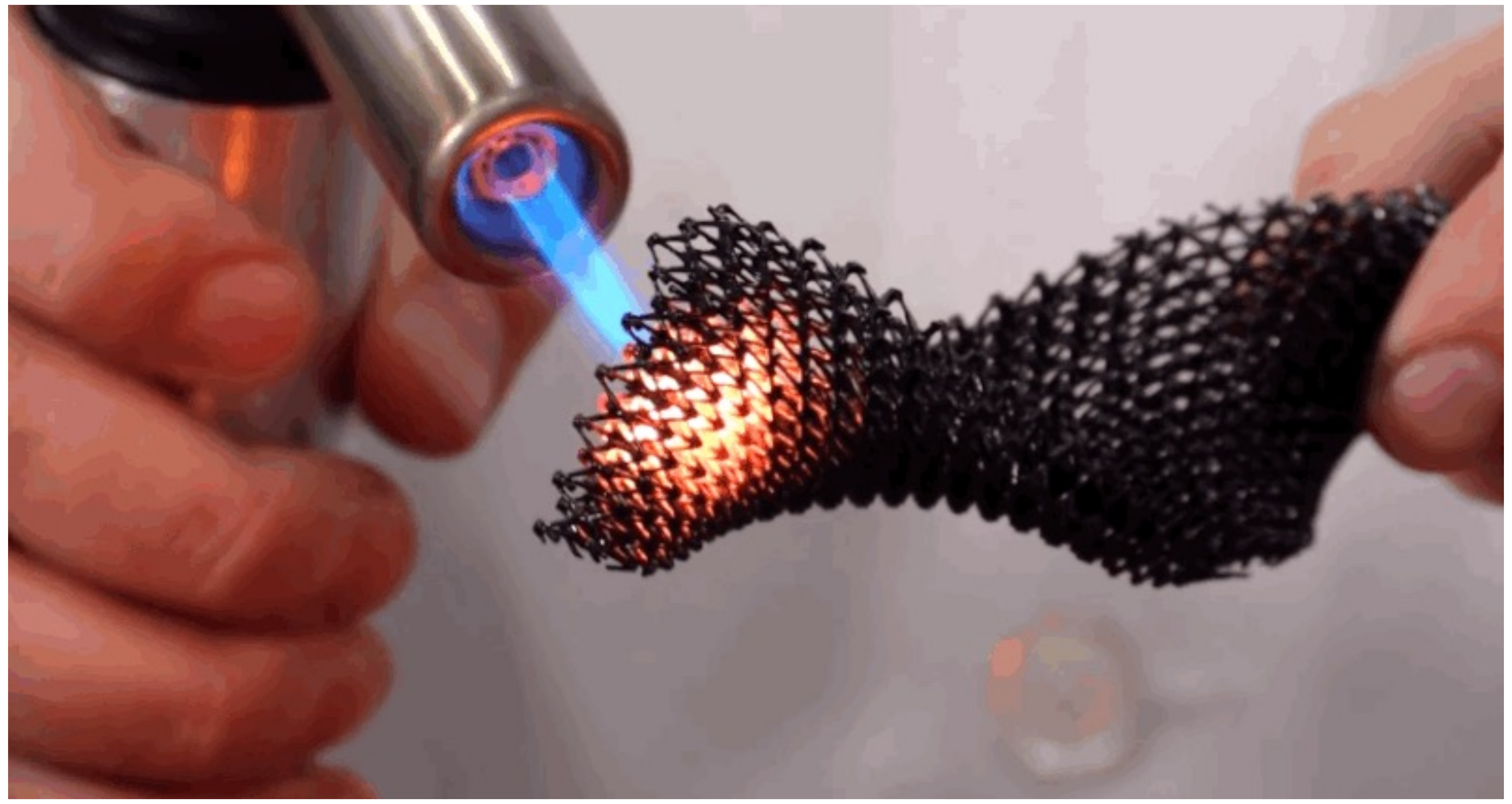
- Slower scan speed (~ 118 ips) versus 300-40
ips for SLS

- Layer thickness (~0.001”-0.004”)



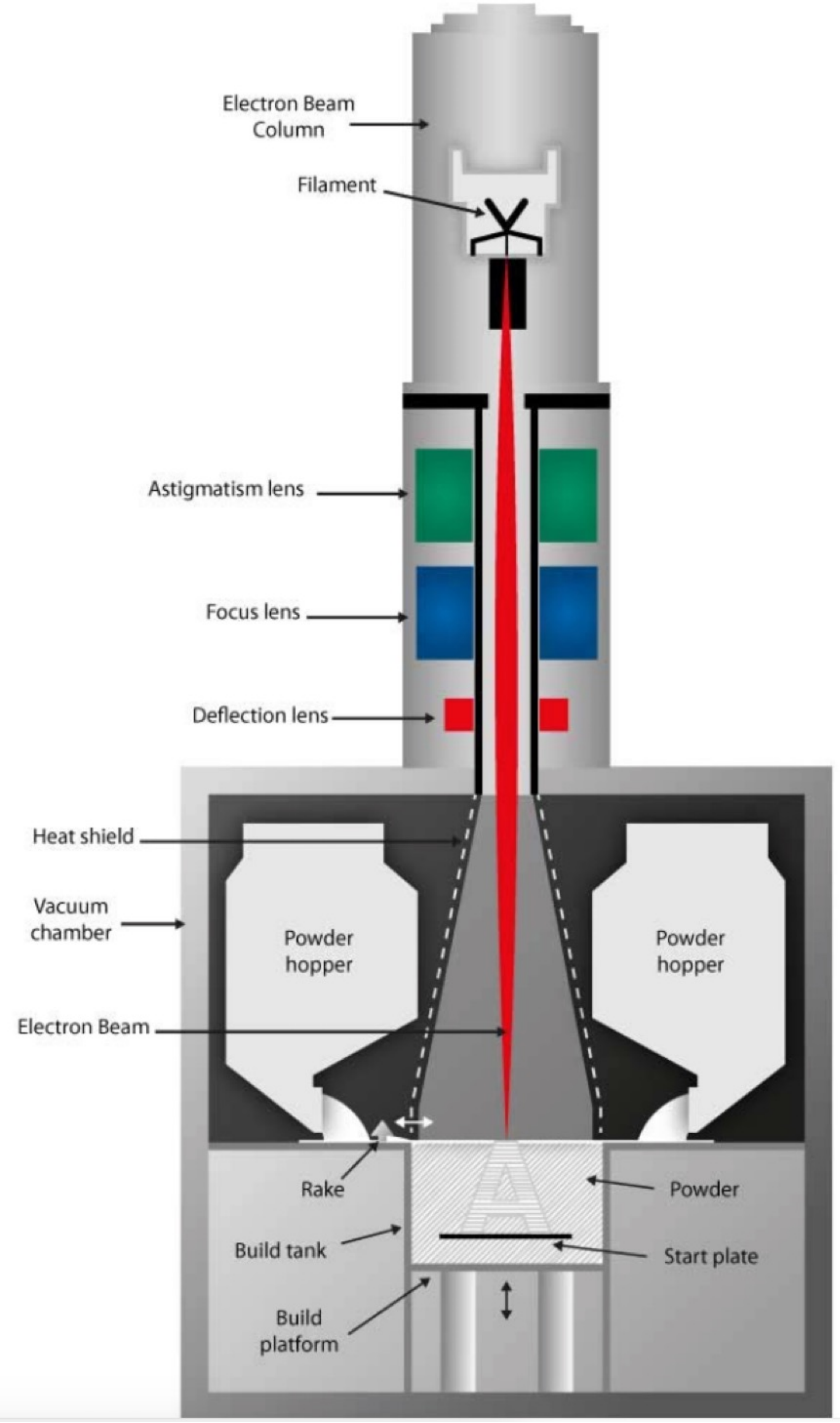
DMLS: Materials and Processing

- Polyamide (Nylon)
- Glass filled Polyamide
- Polycarbonate
- Elastomeric materials (rubber like)
- Zircon ($ZrSiO_4$) and Silica (SiO_2) sand (coated)
- Metal powders (coated)



Melting: Selective Laser (SLM), Electron Beam (EBM)

- EBM uses electron beam for power and must have conductive materials (lasers can heat others)
- Surface finish in all processes can be a challenge
- Shrinkage and distortion of parts can be a problem
- SLM and EBM can make fully dense parts in metal
- All machines are relatively expensive, EBM and SLM being the most
- Relatively small build envelopes for metal parts

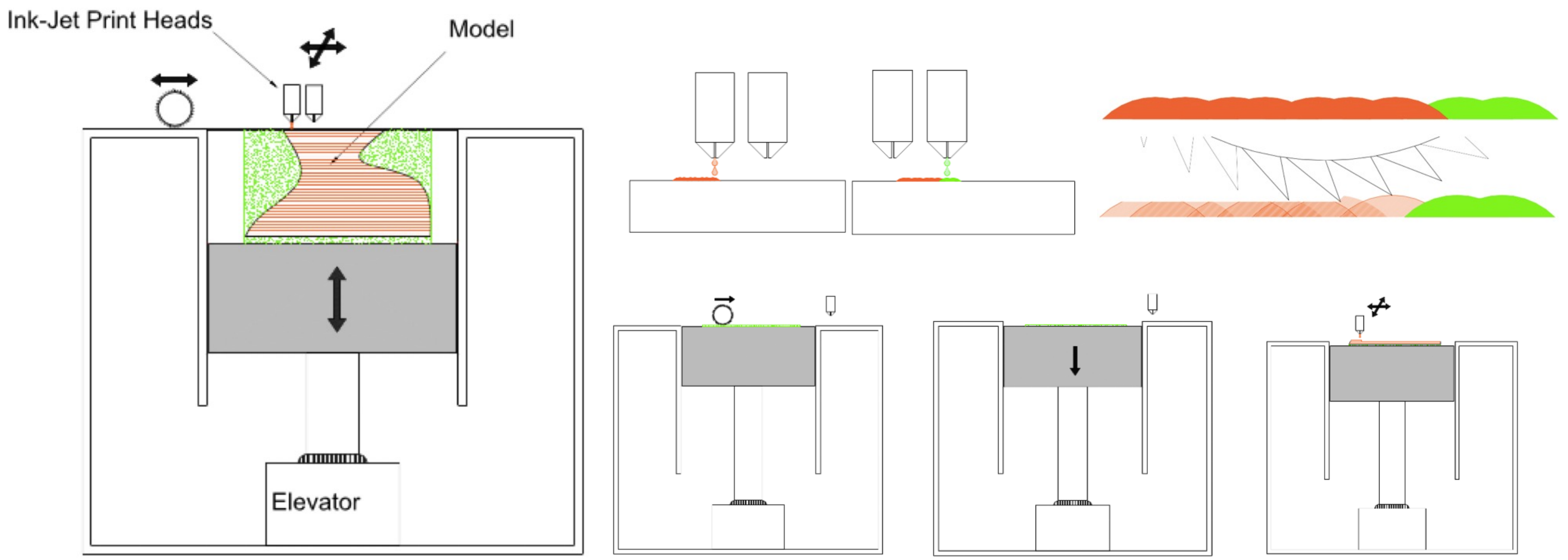


Hybrid

- Support (if needed) created simultaneously with part
- Deposition:
  - Laser Engineered Net Shape (LENS)
  - Thermo and Multi-Jet Printing
  - Shape Deposition Manufacturing (SDM)
- Purpose/Use-case priority
  - Function
  - Feel
  - Aesthetics / Display

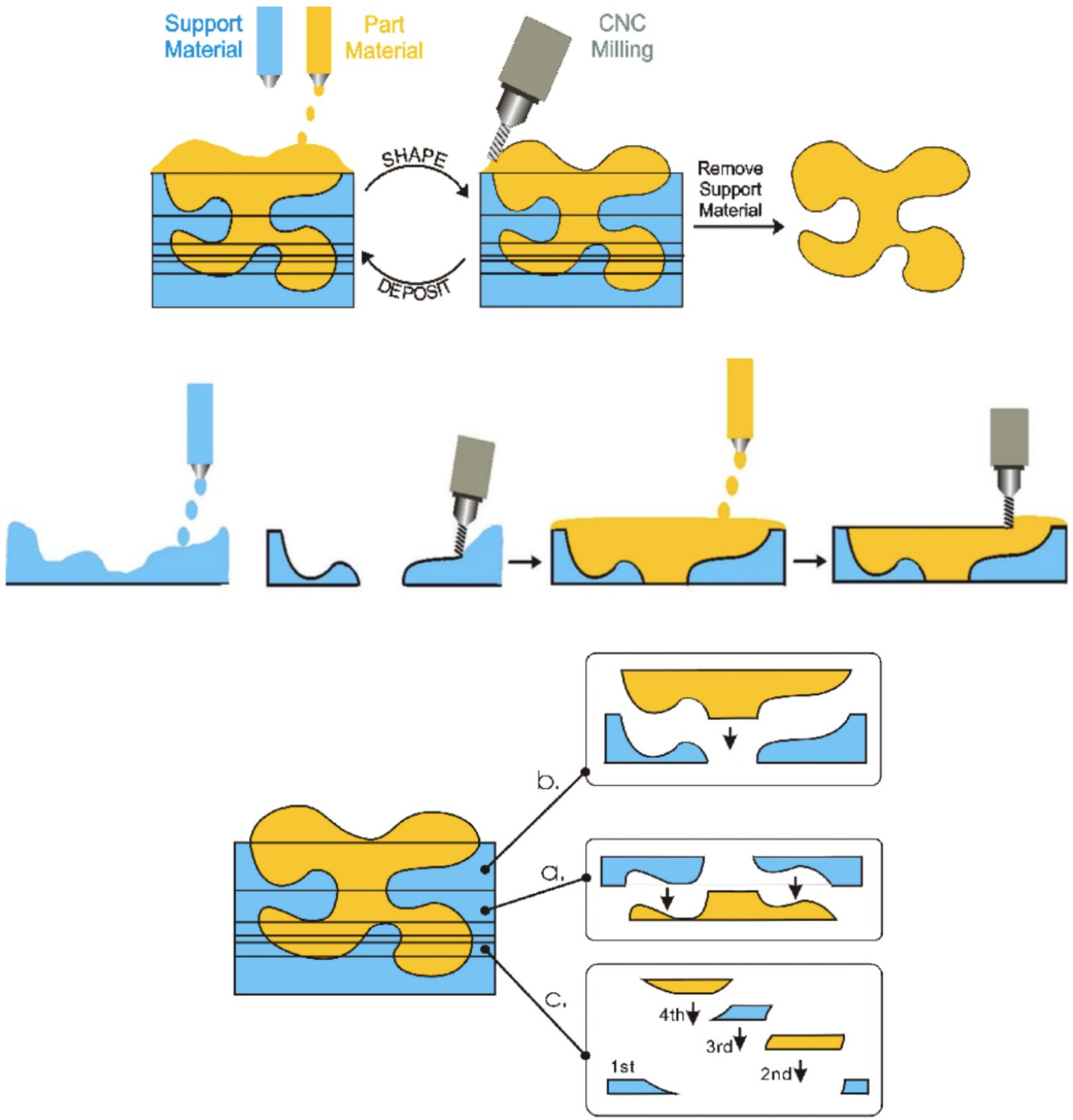
Thermojet / Multi Jet

- Very high accuracy and good surface finish
- Niche application in jewelry making and dental/medical
- Great for investment casting small parts
- Deposits molten material which solidifies on contact
- Low viscosity molten thermoplastic
- Active support structures using different material
- Low melt temperature, low viscosity
- Intended for investment casting
- Support Material: Natural and Synthetic waxes and Fatty Esters
- Melt temp 120°F-158°F



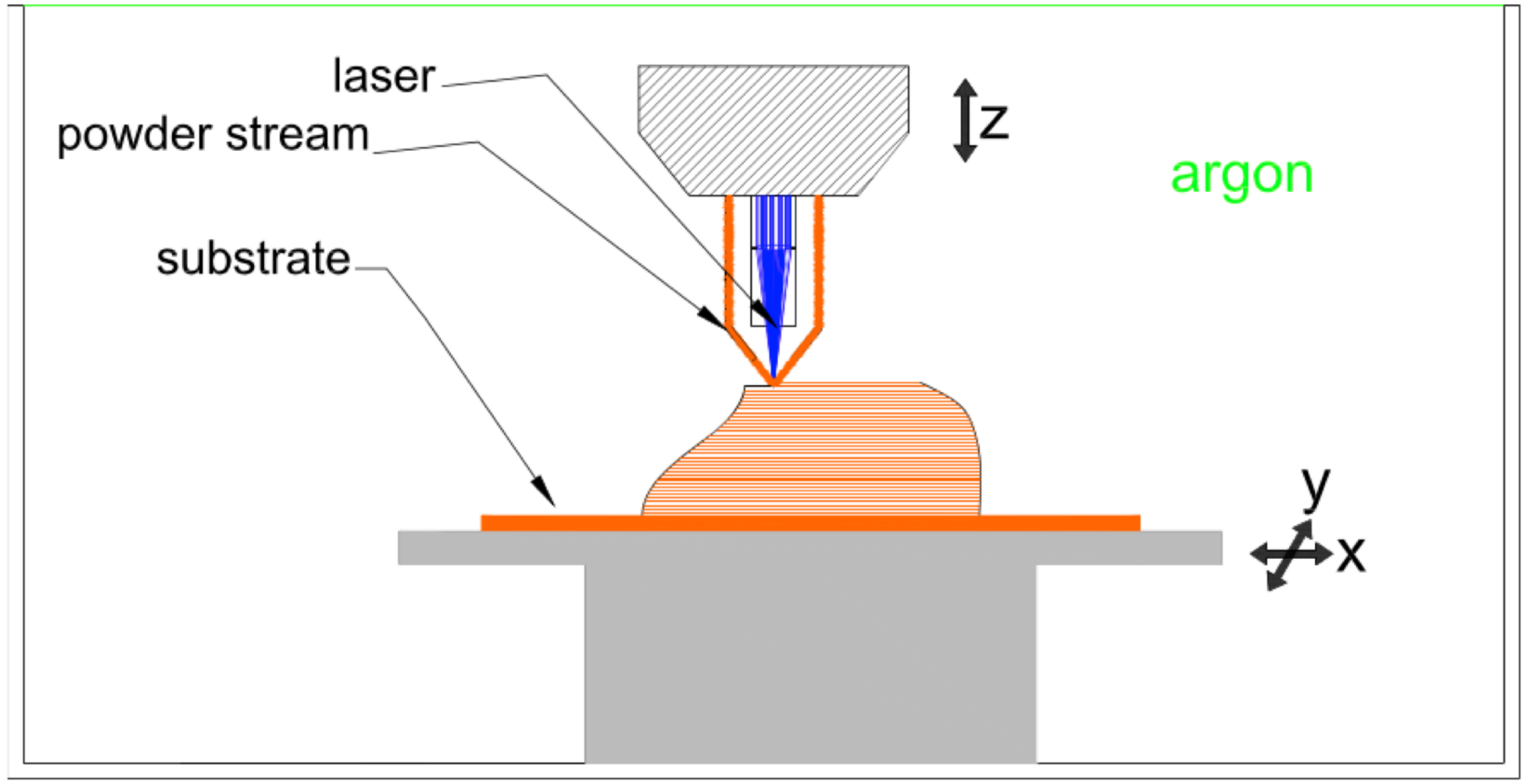
Shape Deposition Manufacturing (SDM)

- A hybrid method using both additive and subtractive manufacturing
- Decompose complex shape into layers (arbitrary depth) such that the part can be made with simple operations
- Either machine a cavity and deposit material, or deposit material and machine the shape



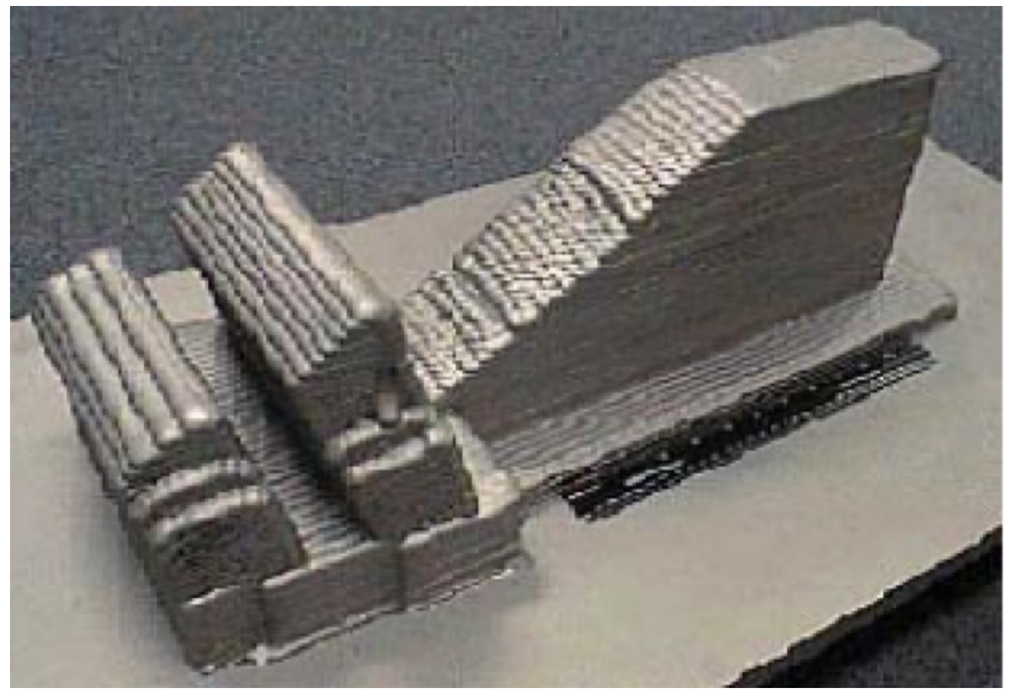
Laser Engineered Net Shape (LENS)

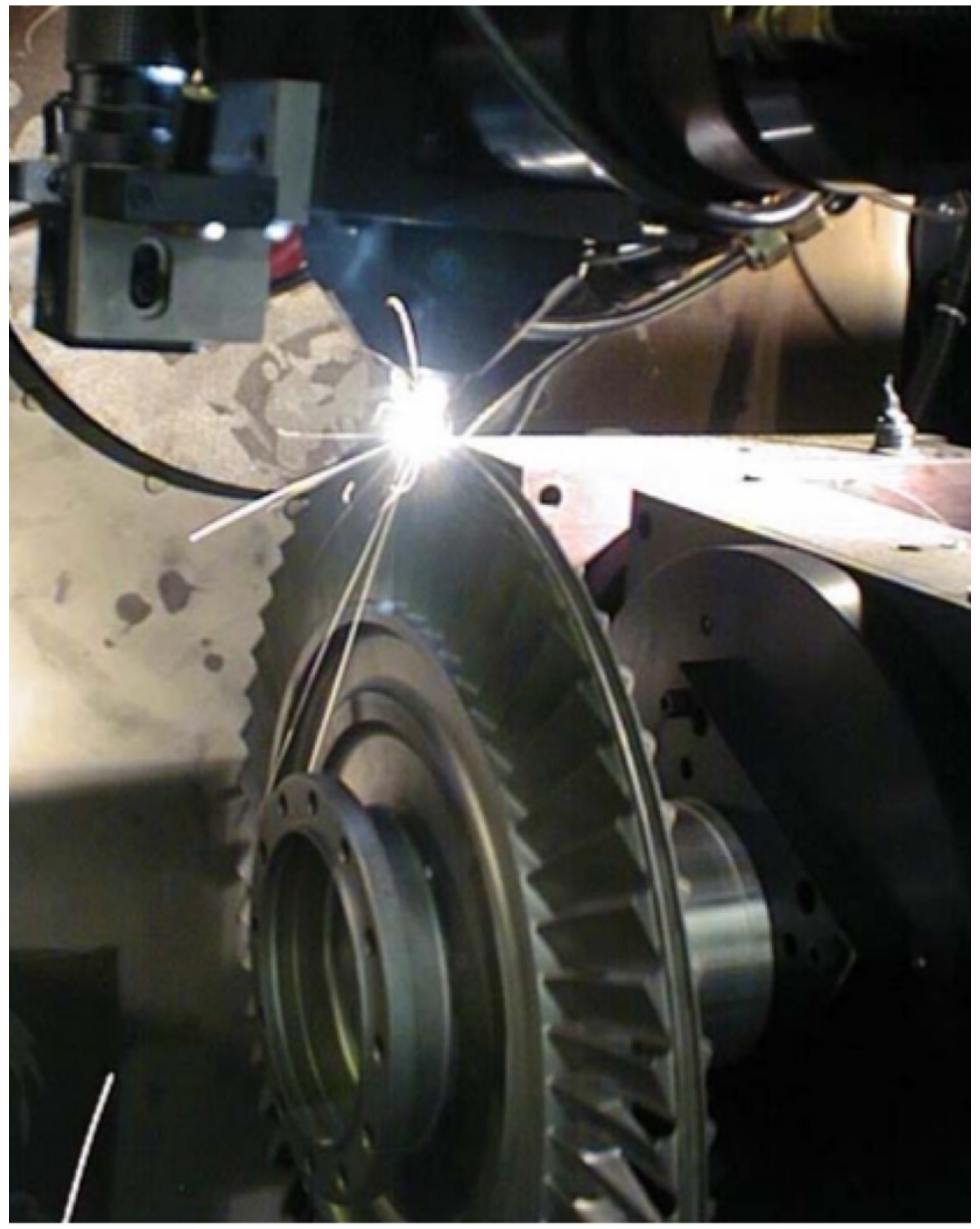
- Uses a focused laser to melt powder and build layers
- Powder is supplied via nozzles around the laser
- Laser, typically Neodymium Yttrium Aluminum Garnet (Nd:YAG) focused with a lens to the build location
- Several nozzles supply metal powders to focal point of laser
- Creates fully dense metal parts and tooling
- Laser power: 500W to 20kW
- Materials
  - Titanium
  - Stainless Steel – Inconel
- Can process reactive materials because of inert environment
- LENS process is good for depositing expensive and/or difficult to machine metals



Laser Engineered Net Shape (LENS) cont…

- It is expected that LENS parts/tooling will be machined
- Extra material purposely deposited for this reason
- Substrate may need to be removed
- Post processing alone could exclude LENS from “rapid” category...
- Large use of the LENS process is repair of existing parts
- Cracked/Brokenparts filled with metal in selective regions using LENS process
- Saves costly replacements
- Repair is as strong or stronger than original material





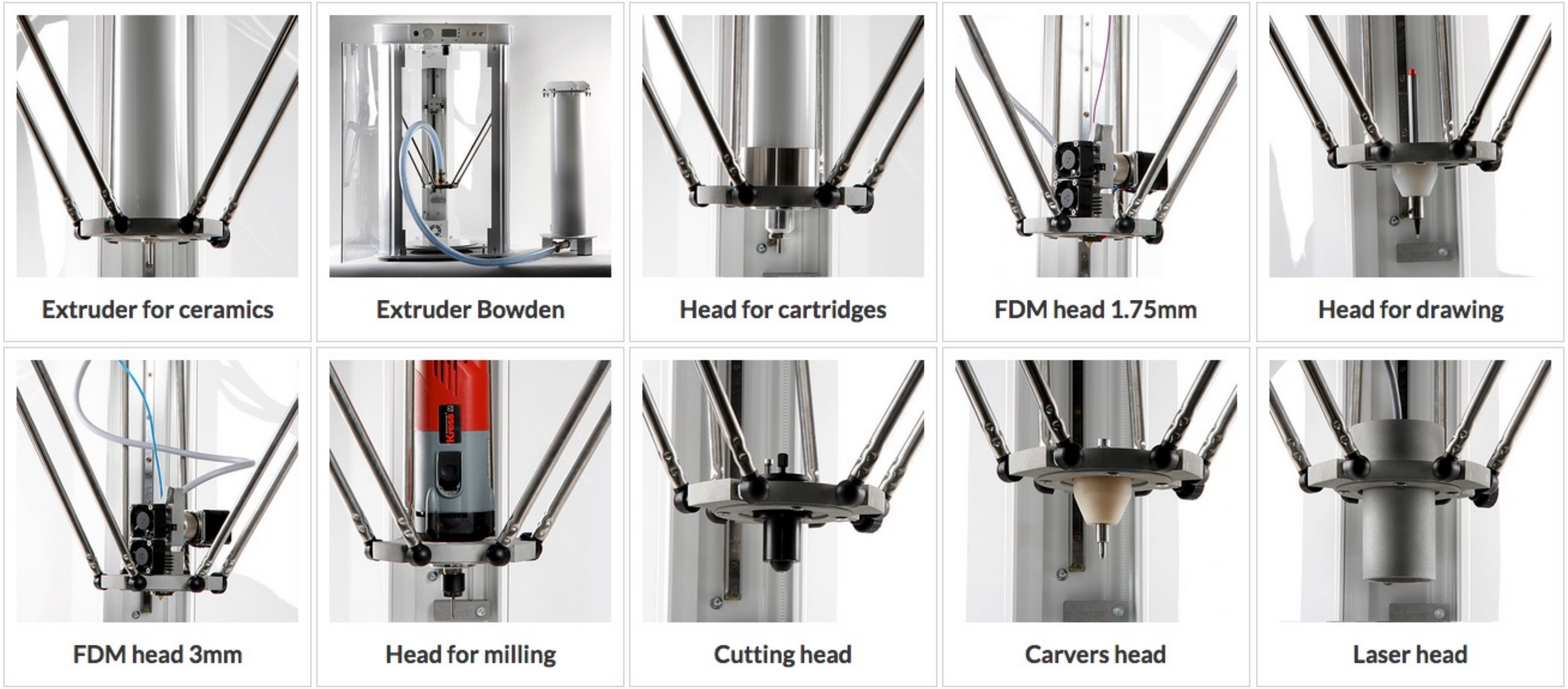
Post Processing, Maintenance, & Quality Assurance

- ***"I'm melting"***: water soluble supports
- ***"I'm not melting but I am feeling a bit hygroscopic"***: help control the wet filament population, have your filament stored and adsorbed
- ***"I think I'm melting"***: FDM vs. FFF (why your extruder is probably clogged)
- ***"I wish I was melting"***: you can't "print metal" but you can sinter it
- ***"I overcooked it"***: laser power and angle of incidence in a heated build chamber
- ***"I wasn't roughhousing"***: post-processing steps non-AM quality assurance inspection standards applied to AM parts
- ***"I'm not done with it, but it printed"***: the often forgotten but beneficial post-processing steps
- ***"I'm for sure melting"***: how to make fully dense metal parts using AM processes/techniques

Post Processing: Sintering

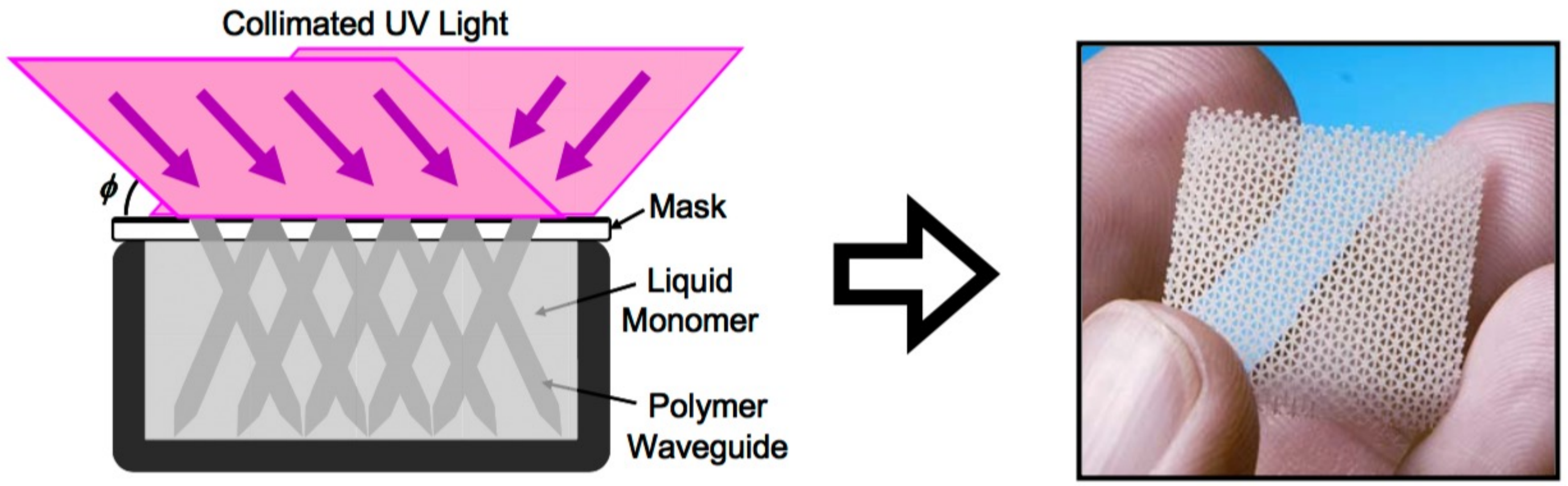
- Parts must be extracted from contents of the build chamber, parts must be found in a “block” of material and cleaned
- Cost increases with part complexity and quantity of parts (very little material can be recycled)
- “The Shapeways Factory is a Modern Santa Klaus’ FabLab”

That’s not a multi-tool! This is a multi-tool

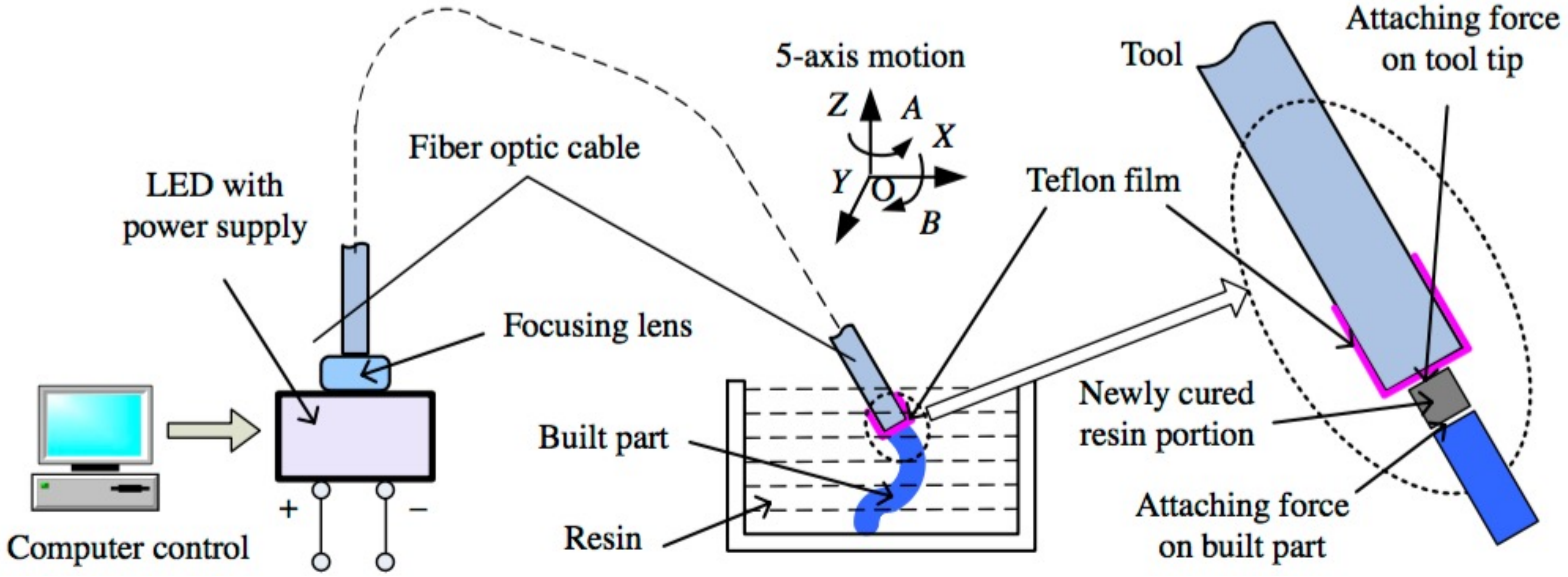


Emerging AM Methods

- Self-Propagating Photopolymer Waveguides (SPPW)
  - Lattice-based open-cellular materials
  - shorter manufacturing time vs. SLA



- Layer-Less AM processes
  - Could be applied to multiple AM system types
  - Borrows concepts from CNC machining



Emerging AM Methods

- In-situ FFF painting
- CMYKW FDM