Lecture 3 - Polymer Physics and 3D Printing Techniques

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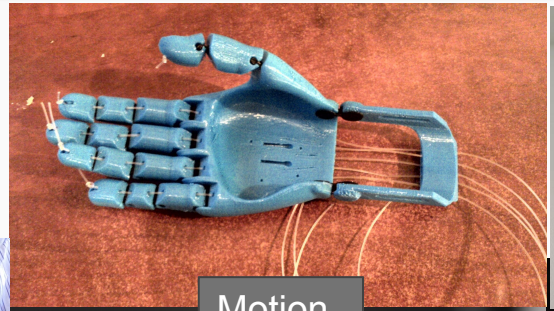
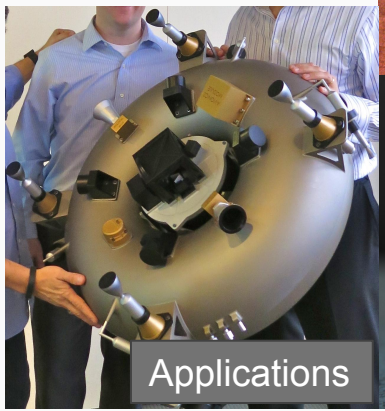
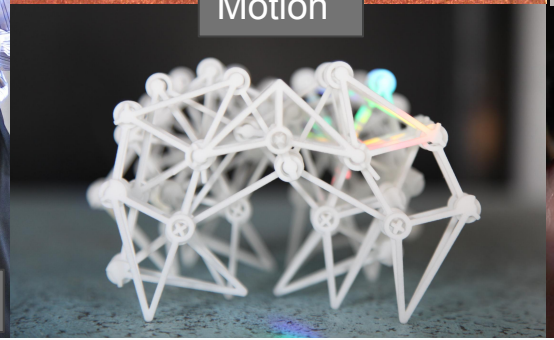


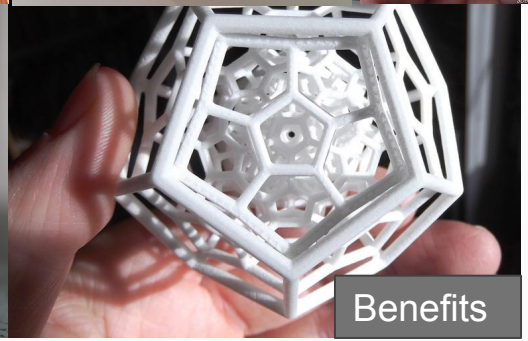
Motion

Limitations



Applications





Benefits

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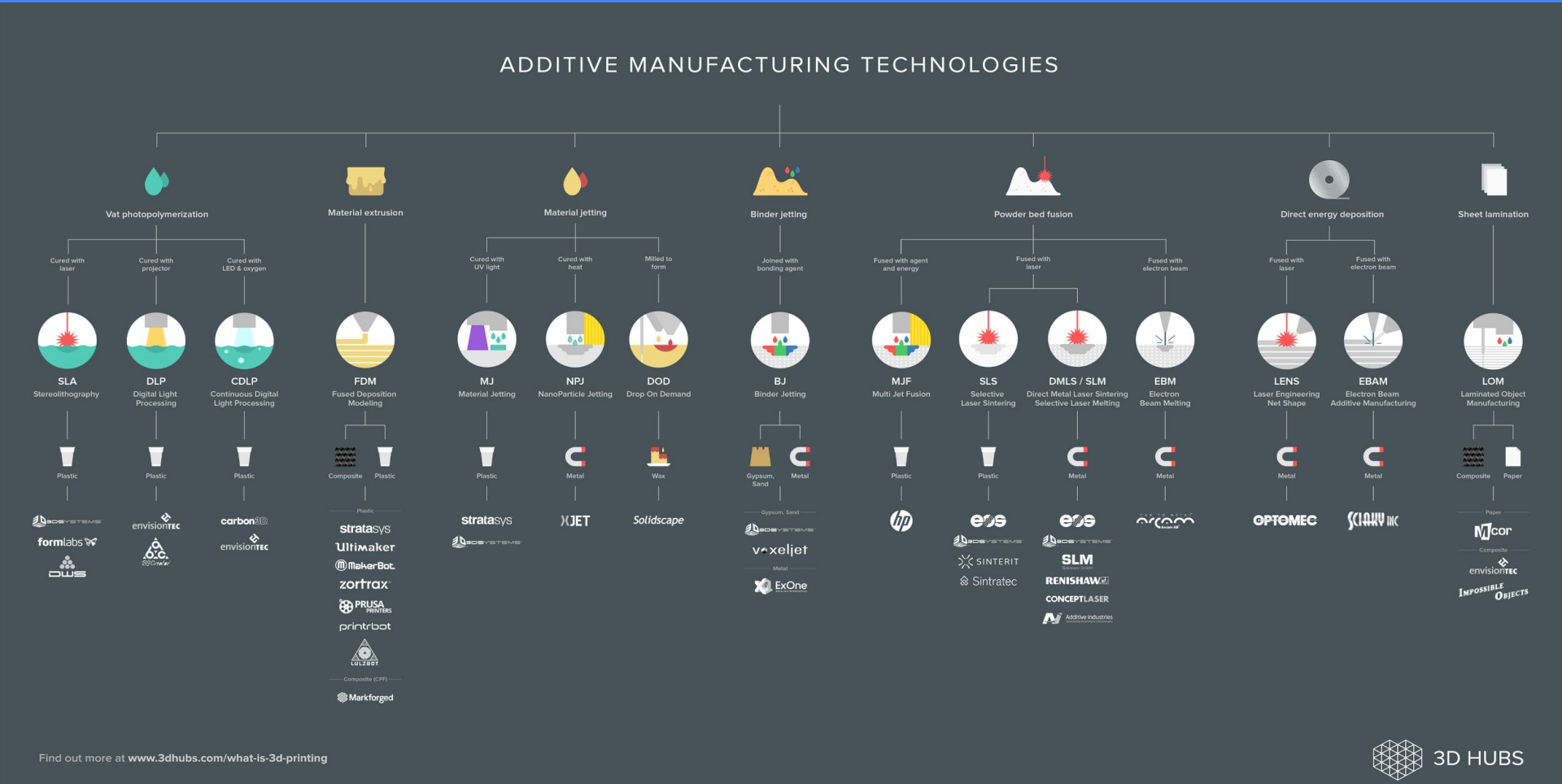
Overview

www.thingiverse.com/thing:6291

- Overview of ***all*** 3D printing techniques
- Techniques and processes

Many different ways to print in layers…



Find out more at **www.3dhubs.com/what-is-3d-printing**

3D HUBS

- Raw material feed :
  - Plastic of metal filament
  - Polymer resin
  - Powder bed
  - Material droplets
  - Sheet

- Solidification in layer using
  - Curing / photopolymerisation
  - Melting - material flowing
  - Sintering - fusing of powder grain boundaries
  - Binder - activated with energy or not

- All 3D printing techniques combine a particular feed and solidification method
  - Plastic filament + melting = **Fused Filament Fabrication / Fused Deposition Modelling**
  - Powder bed + melting = **Selective Laser Melting**
  - Polymer resin + curing = **Stereolithography**
  - Sheet + binder = **Sheet lamination**

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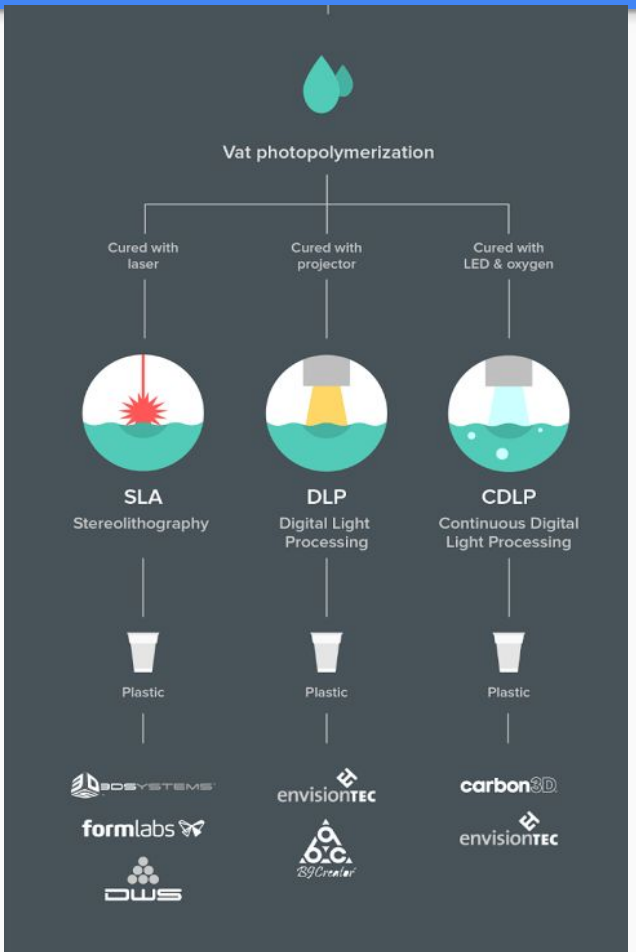
3D Printing : Polymer UV Curing

Curing techniques



- Curing is a process applied to materials in order to make them change state
- **Photopolymerization** uses light to cause a change in polymer structure from soft to hard
- Resin reservoir and light penetrates near surface to cause curing

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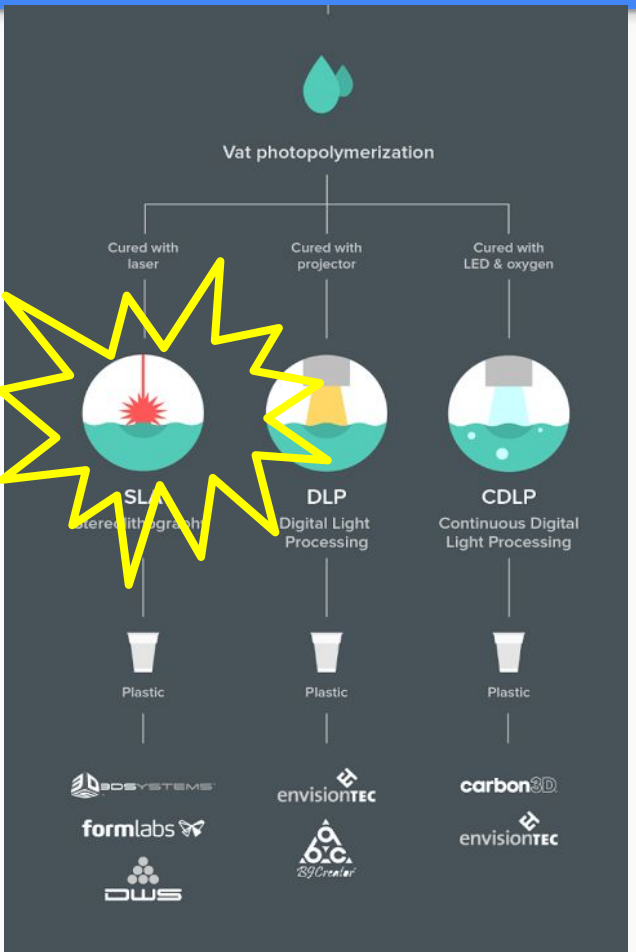
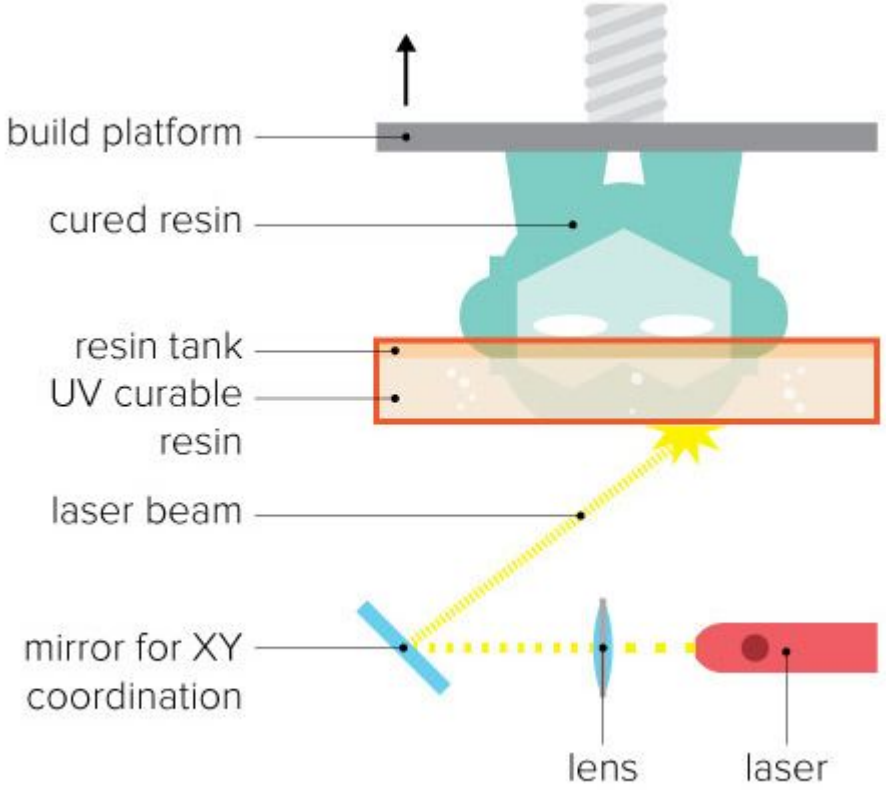
Stereolithography

See SL Modelling in Lecture 4 and 5





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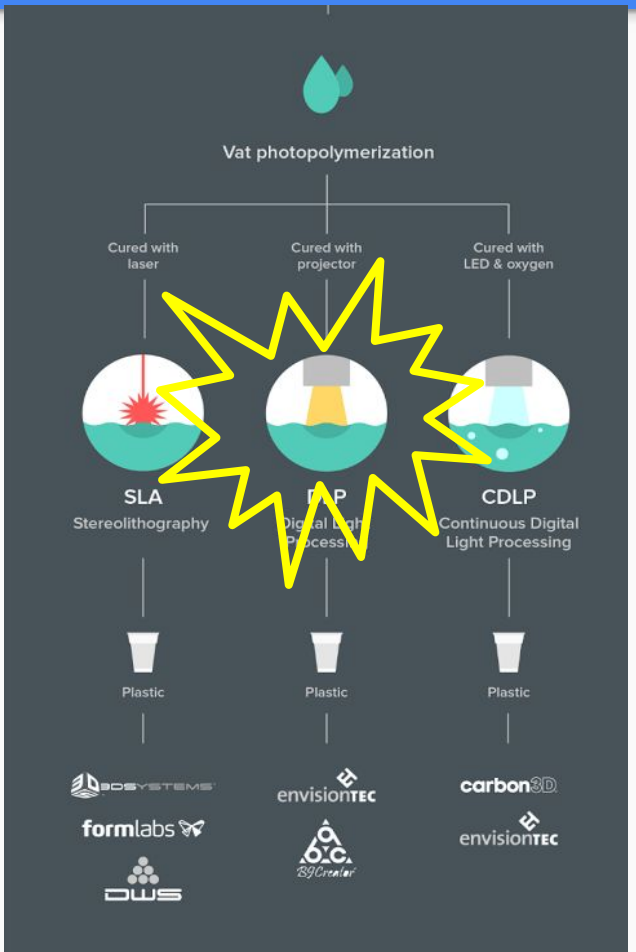
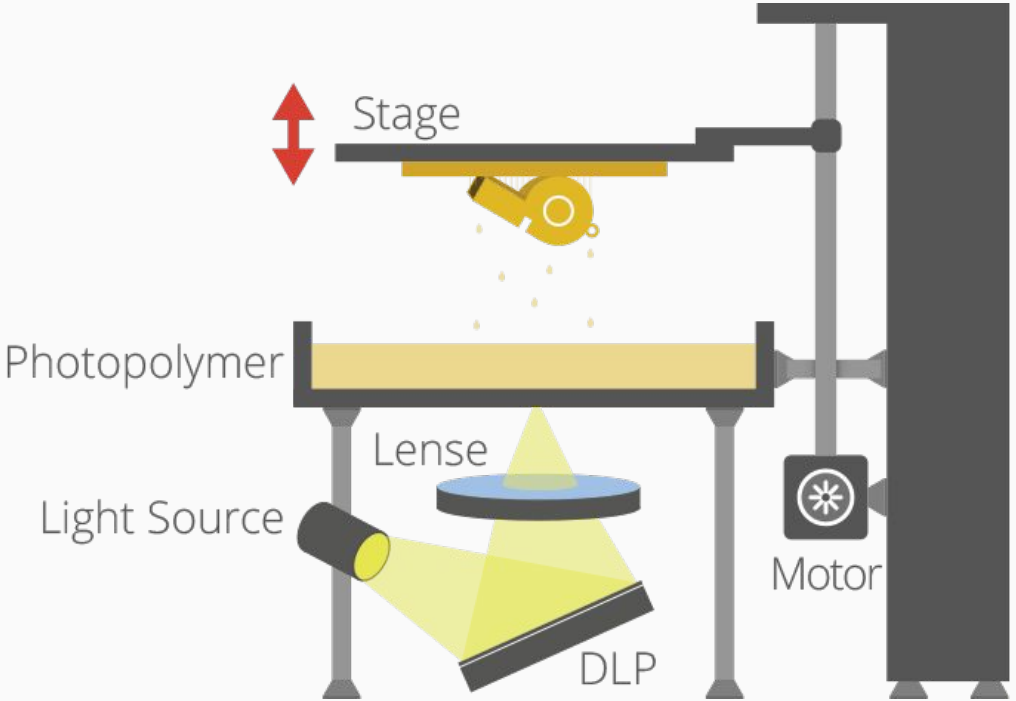
Digital Light Printing





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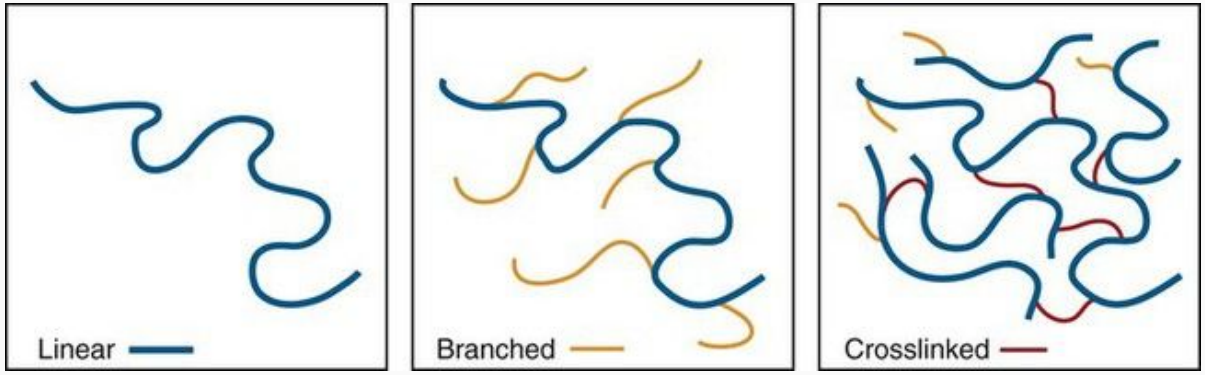
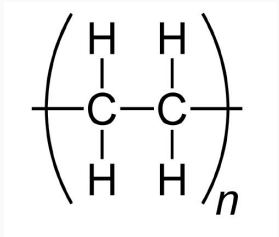
Polymers : Introduction 1

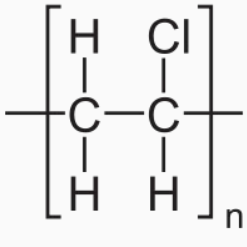
Polymers have a carbon-carbon backbone

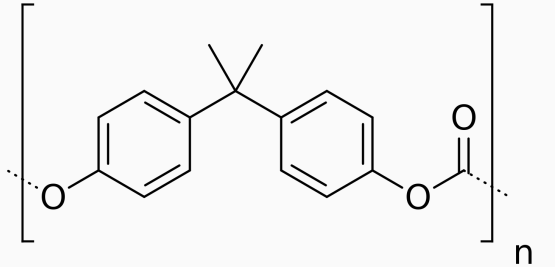
Repeating *monomer* unit

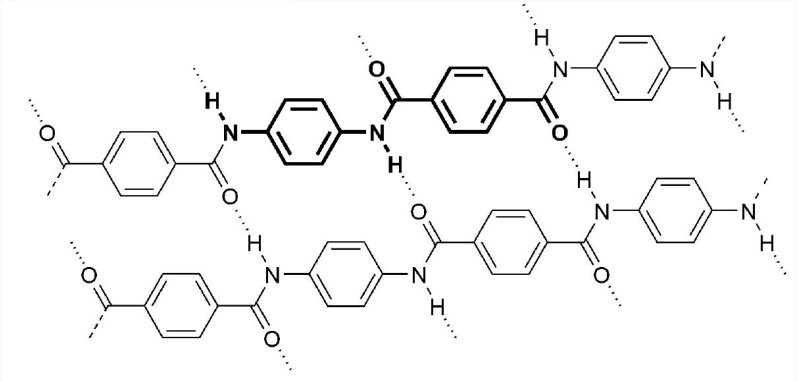
Properties dependent on side groups / inter-chain interactions











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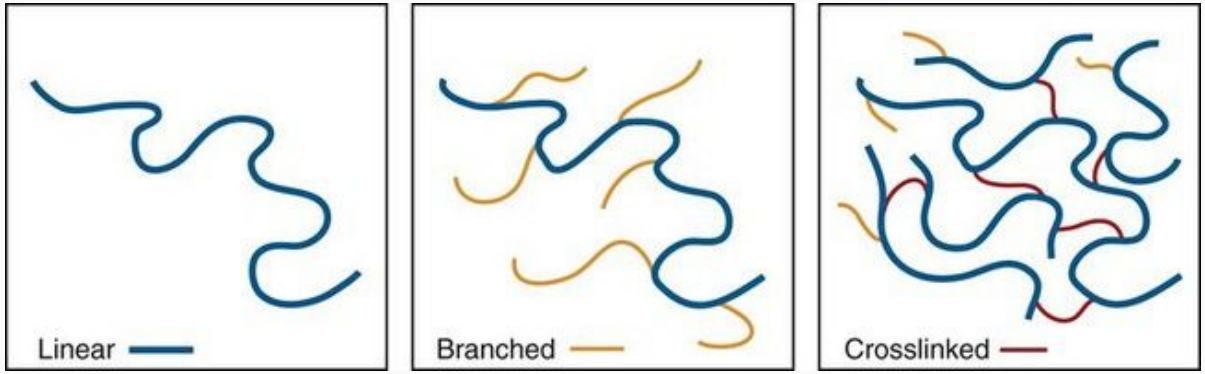
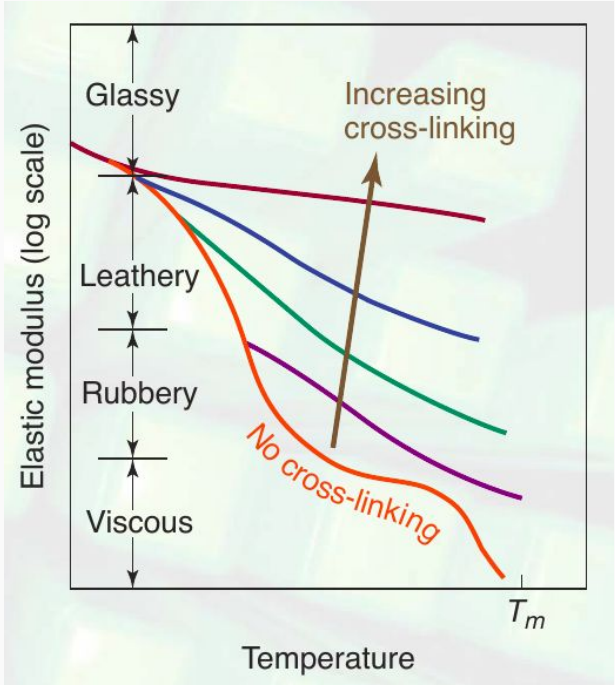
Polymers : Introduction 2

Glass transition: thermal fluctuations overcome interchain bonds

Curing is the process of hardening polymer resin through a chemical reaction that produces **cross-linking** between polymer chains





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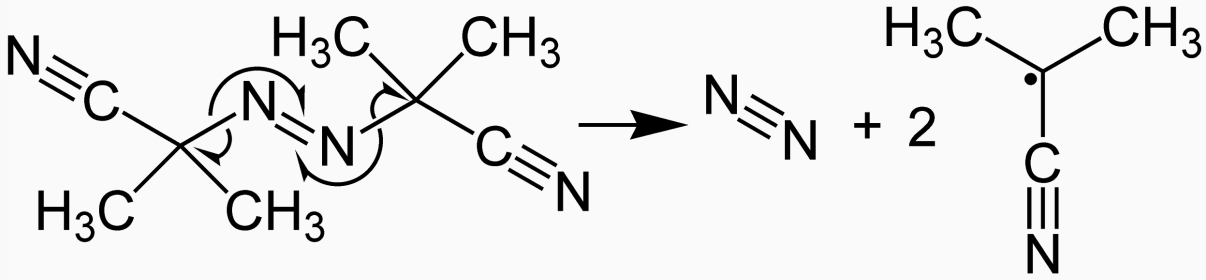
Curing Steps

Step 1: Free radical formation
Step 2: Initiation
Step 3: Chain propagation
Step 4: Termination

Key:

R• : Radical
M : Polymer molecule

Step 1 : Example free radical production



Steps 2-4 : Example initiation, propagation and termination

Initiation:

$$R\bullet + M \longrightarrow RM\bullet$$

Propagation:

$$RM\bullet + M_n \longrightarrow RM_{n+1}$$

Termination:

$$RM_{n+1} + RM\bullet \longrightarrow RM_{n+1}MR$$

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Questions

1. Find YouTube videos of Stereolithography and DLP printing systems

2. Why use UV photons rather than IR for the curing process?

3. Find examples of linear, branched and cross-linked polymers.

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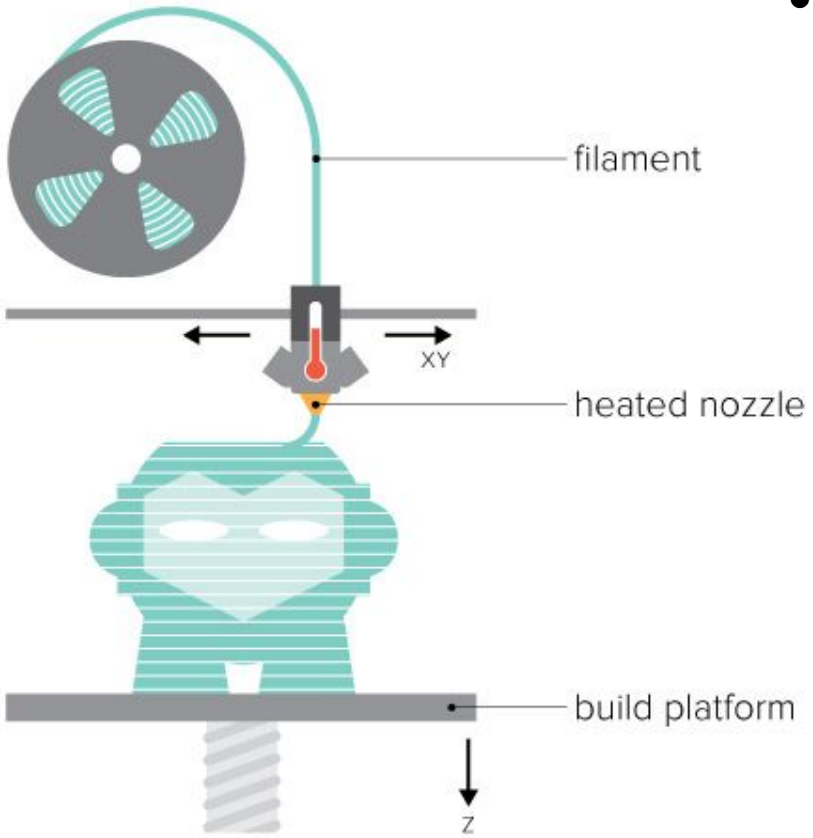
3D Printing : Filament techniques

Extrusion techniques



- Known as:
  - Fused filament fabrication (FFF)
  - Fused deposition modelleing (FDM)

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Material Properties

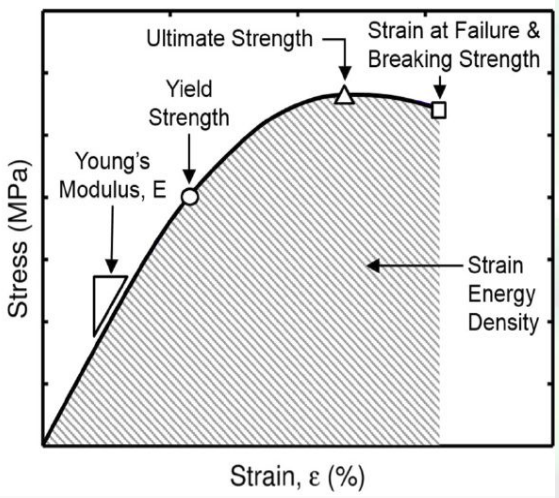
Thermosoftening polymers typically exhibit two transitions with increasing temperature

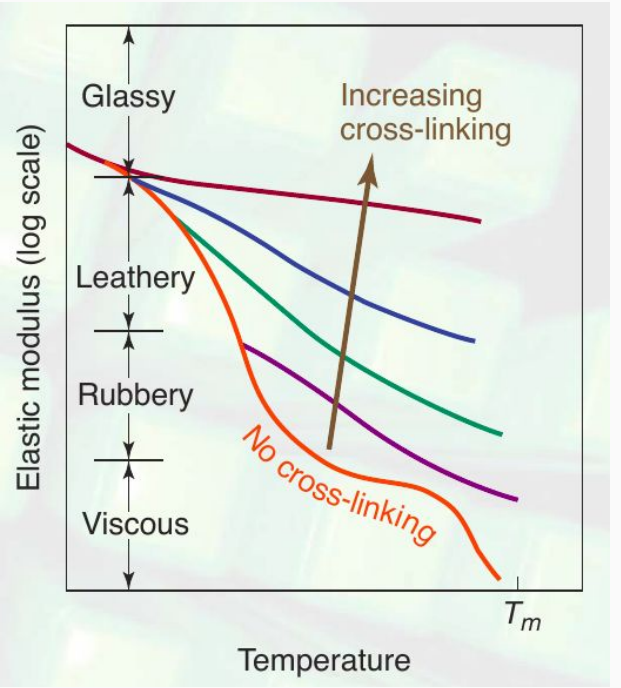
- Glass transition
- Melting transition

N.b. More materials physics in Lecture 9 and 10

- **Glass transition** occurs when thermal energy overcomes interchain attractive forces
  - Polymer can more freely move past each other
  - Softening of material

- **Melting transition** is a transition to amorphous, viscous phase





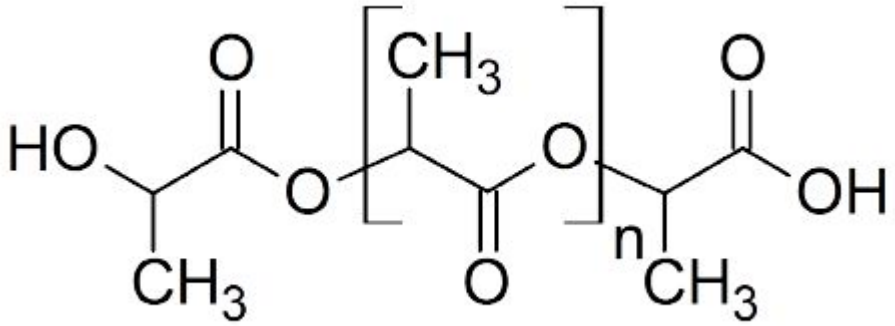
Polylactide Acid (PLA) Material Properties

An extremely common FFF/FDM material

Biodegradeable and produced from corn and molasses

Thermosoftening

- PLA



Mechanical properties

- Density = 1.2 g/cm^3
- Young's/Elastic Modulus = 2GPa
- Tensile Strength = 60 MPa
- Compressive Strength = 20 MPa

Thermal properties:

- Glass transition at 50 to 60 ^oC
- Specific heat capacity = 1800 J kg^{-1} K^{-1}
- Thermal conductivity = 0.13 W m^{-1} K^{-1}

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Questions

1. What's the mass of material in an extruder whose molten region is 0.4mm diameter, 1mm high?

2. How much energy does it take to raise this material's temperature from 20 ºC to 200 ºC? (assume that the specific heat capacity does not change with temperature)

3. What is the effect on the material of a heated bed that holds the lowest FFF layer at 50 ºC?

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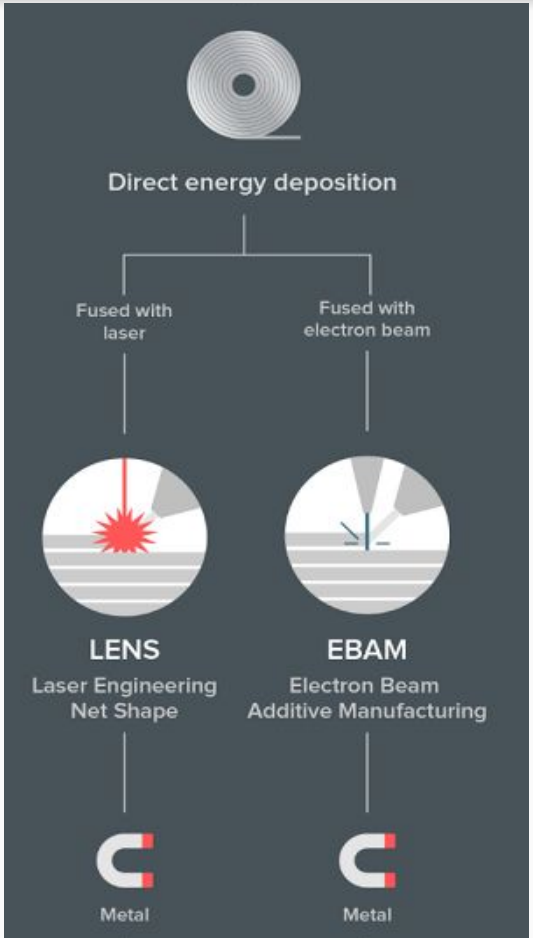
Direct energy deposition : Melting of metallic filament



- Laser Engineering Net Shape
  - Metal powder supplied coaxially to beam
  - Molten pool maintained under beam

- Electron Beam Additive Manufacturing
  - Metal wire supplied into molten

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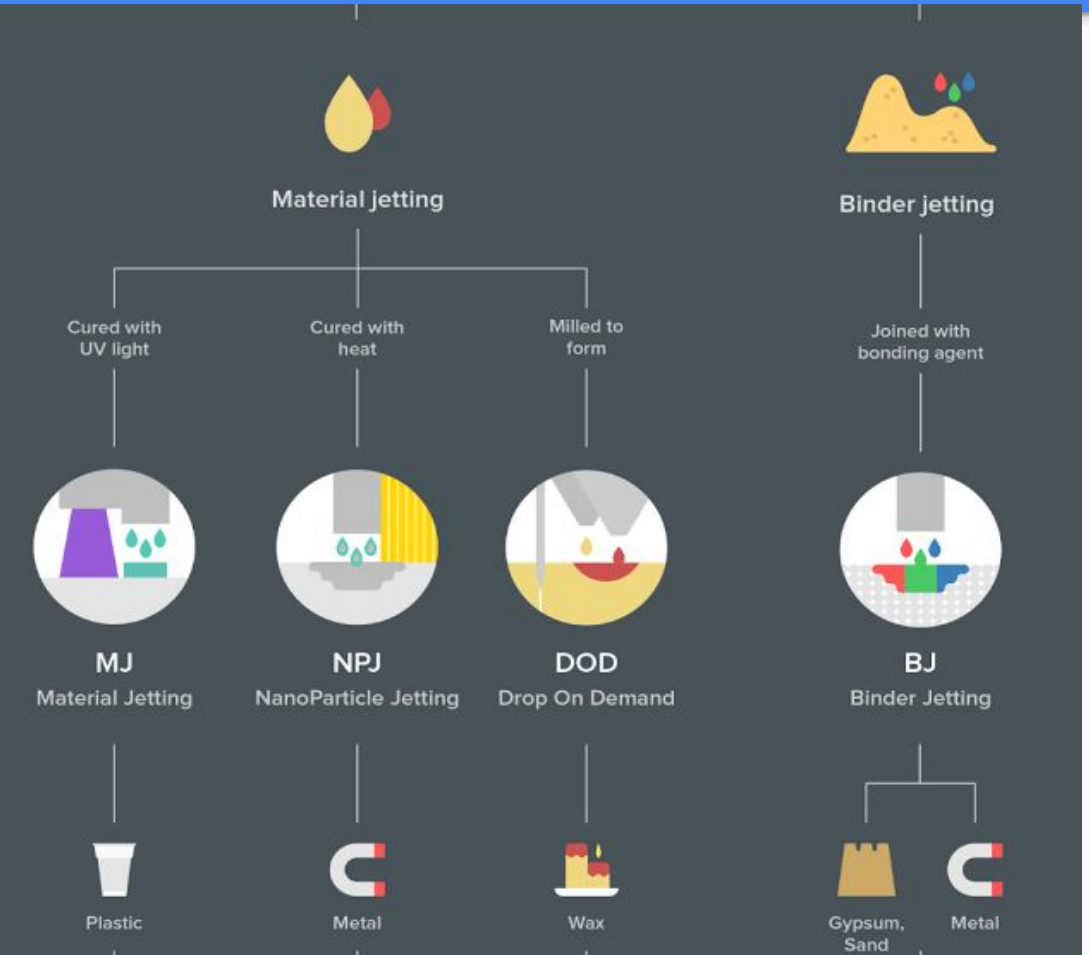
3D Printing : Jetting techniques

Material/Binder jetting techniques



- Material jetting/binding:

1. Places drops of material on the build platform

2. Solidification using either
    a. UV light and photopolymer resin (MJ)
    b. Heat acting on binder in powder bed (NPJ)
    c. Wax drop and milling (DOD)
    d. Binder mixed with material drops (BJ)

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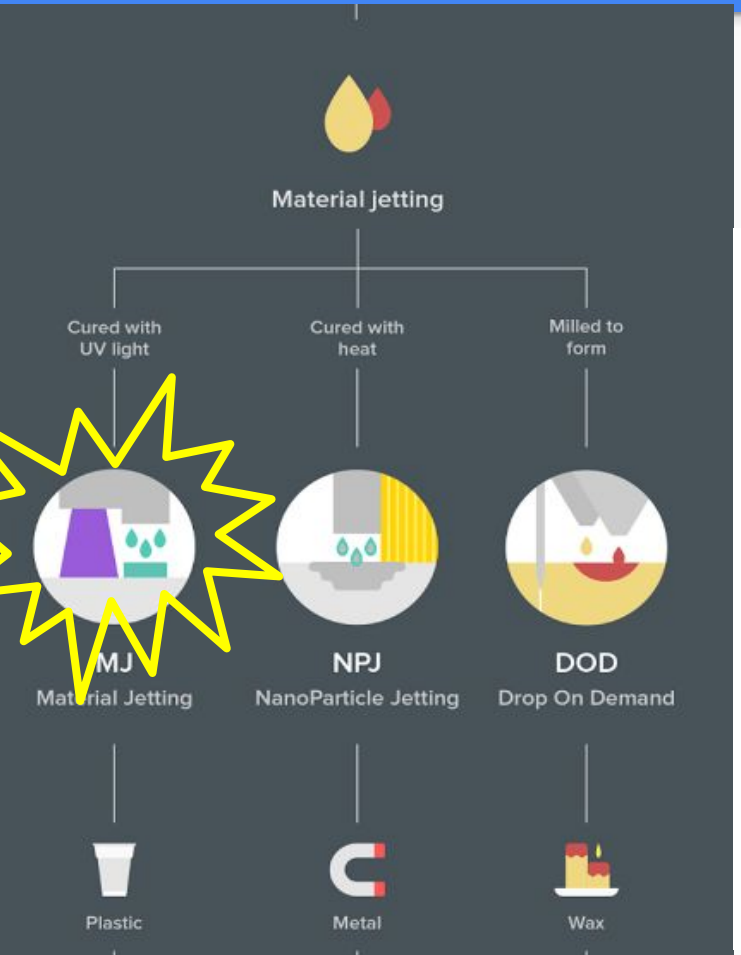
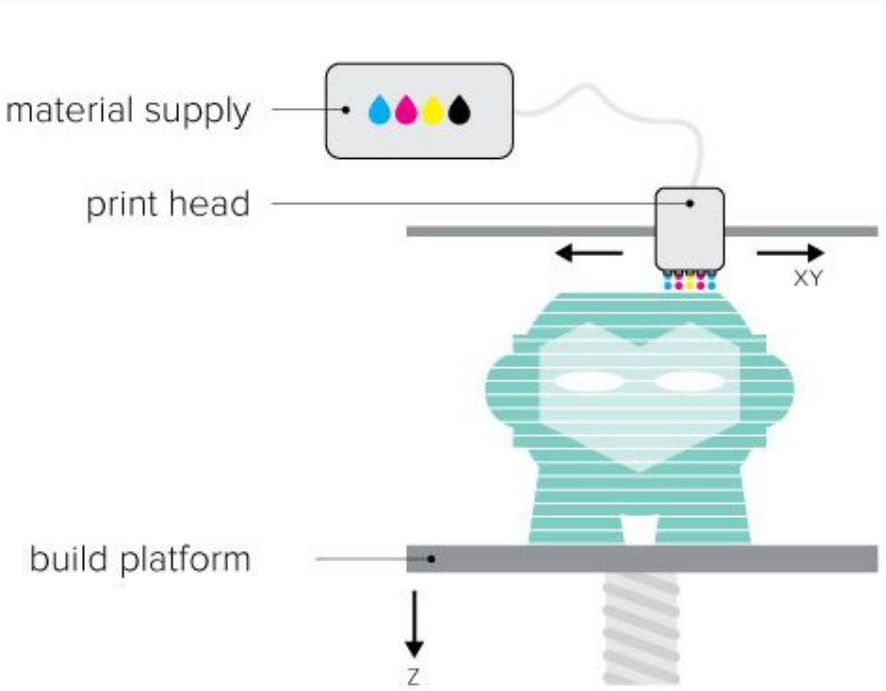
Material jetting techniques



- Print head can jet droplets of many materials, incluing dissolvable support material
- Printhead also cures or mills the resulting materials



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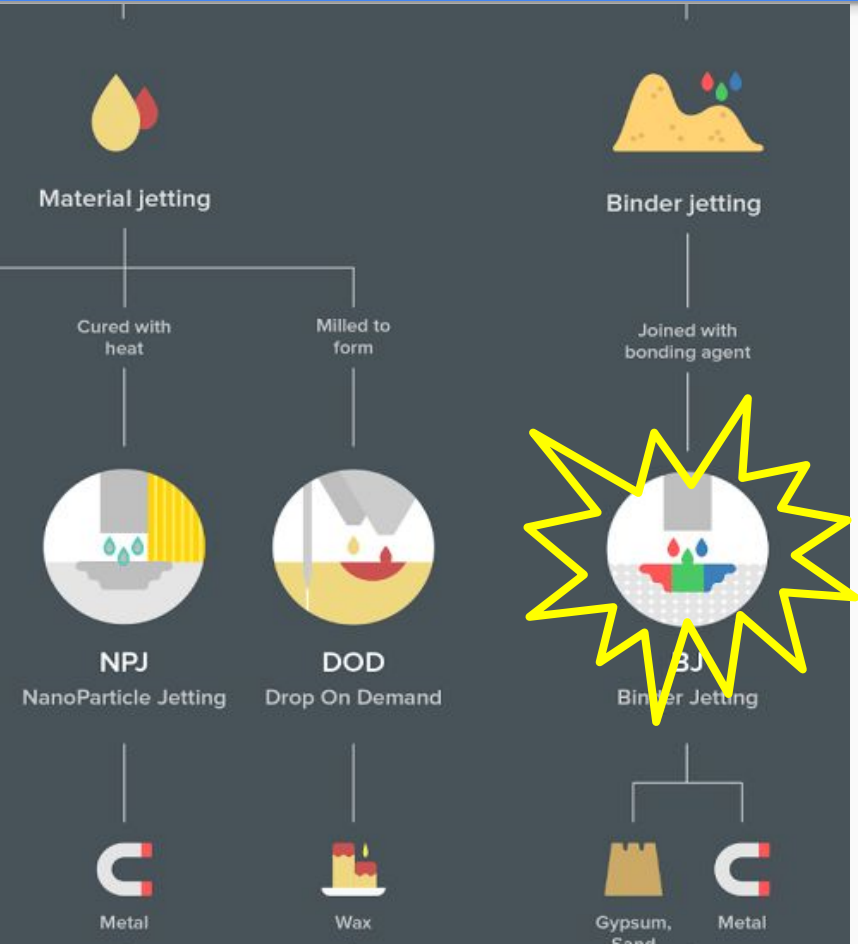
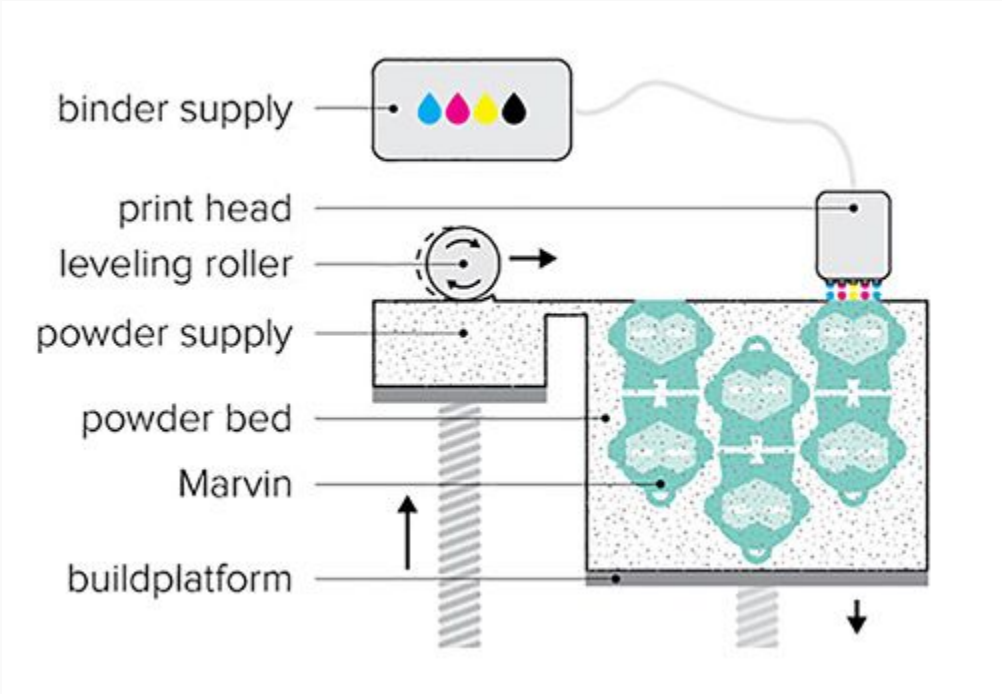
Binder Jetting





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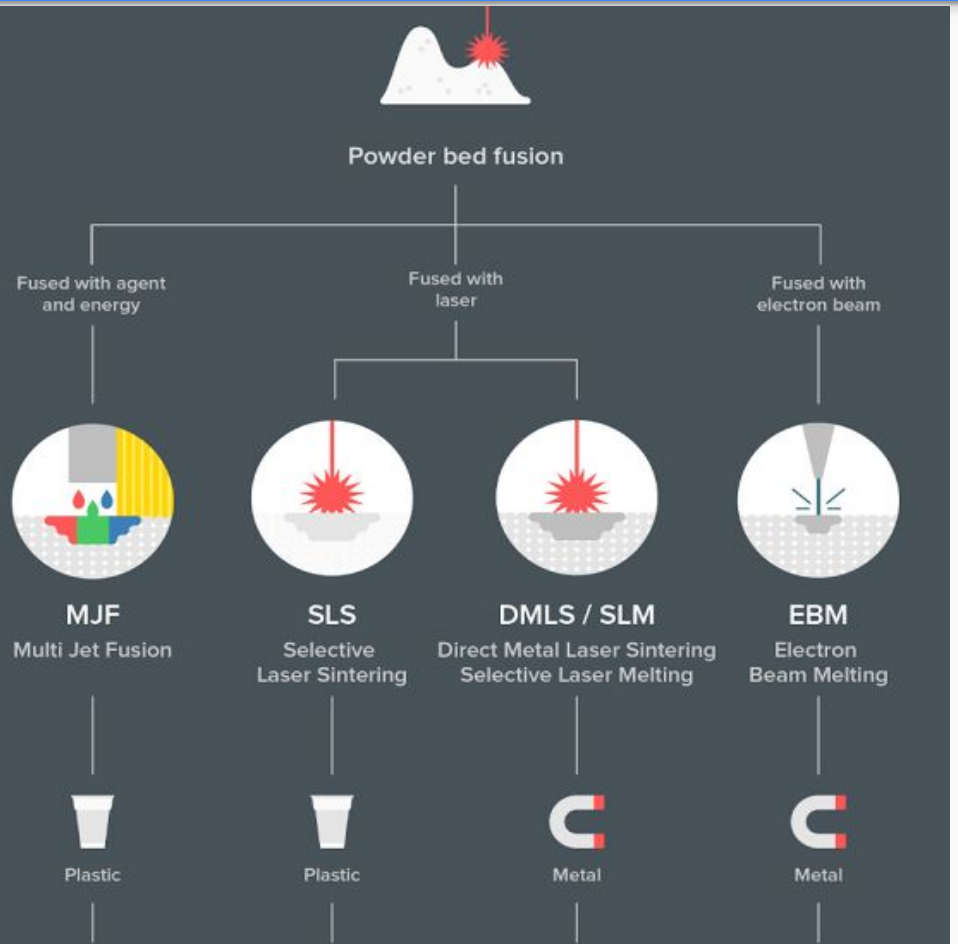
3D Printing : Powder bed fusion

Powder bed fusion techniques



- Raw material is a smooth powder layer
- Solidification in the layer is produced by
  - Binding agent activated by light/heat (MJF)
  - Laser sintering/melting (SLS/SLM/DMLS)
  - Electron beam melting (EBM)

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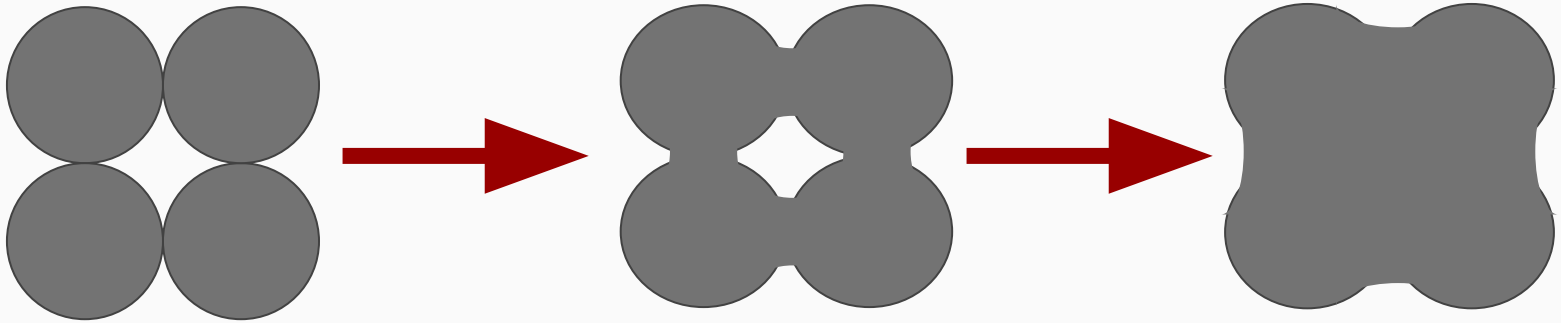
Sintering Process

- **Sintering :** Increases the density and reduces the porosity of powders without melting
- Atomic diffusion reduces surface area and (free) energy of the powder



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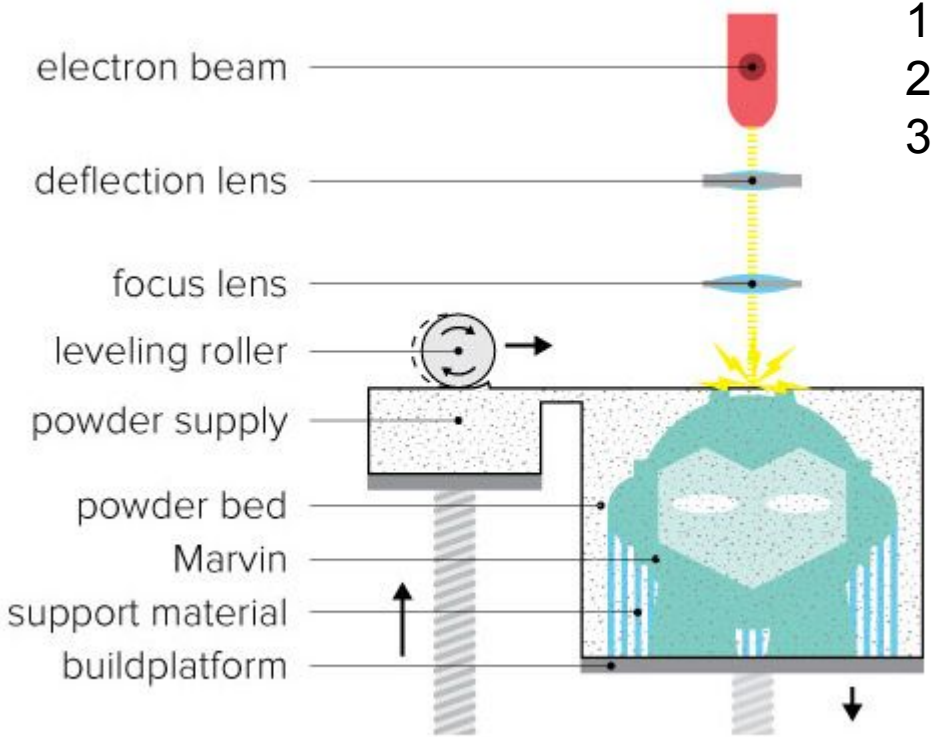
Selective laser melting and electron beam melting

- Either **laser** or **electron** beam melting of powder layer



1. Laser melts layer
2. Printbed drops down
3. Roller smooths over a new powder layer

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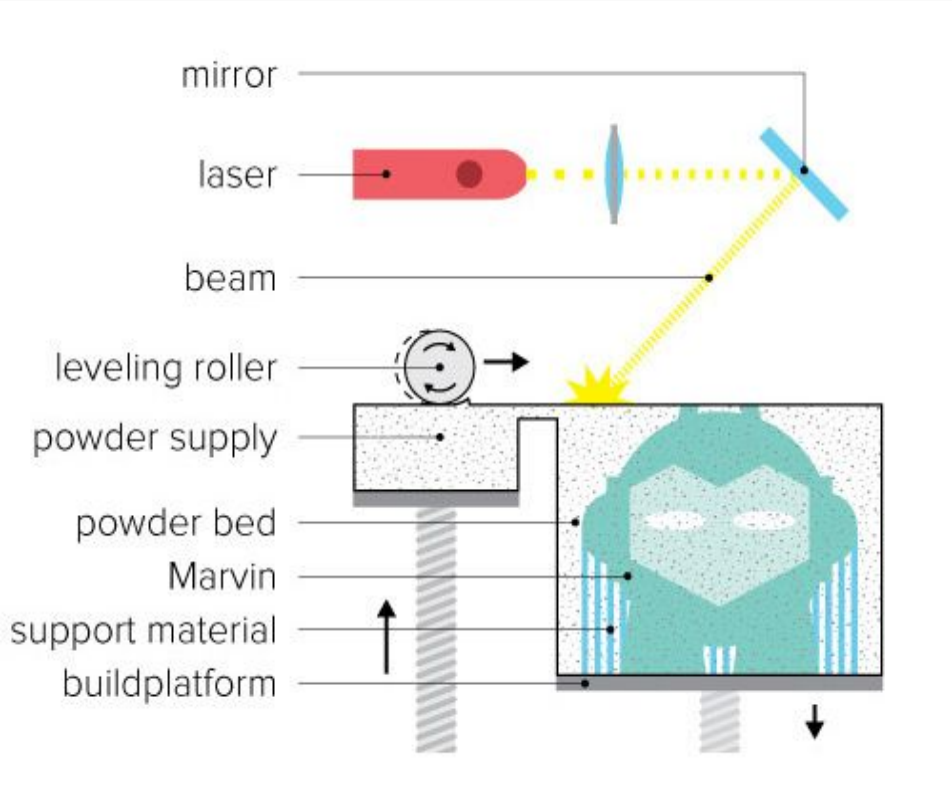
Selective laser melting and electron beam melting

- Techniques are very similar either **laser** or **electron** beam melting of powder layer



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Summary

Summary

- Covered variety of printing techniques which differ in feedstock delivery and solidification method
  - SL and FFF are two in-depth techniques in this course
- Feedstock delivery can be filament (plastic or metal), powder (bed or delivery)
- Solidification methods include curing, sintering, binding, jetting, and lamination
- Polymer physics used in FDM/FFF and Stereolithography
  - Polymer structure
  - UV curing process
  - Introduced the polymer glass transition

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