3D Printing

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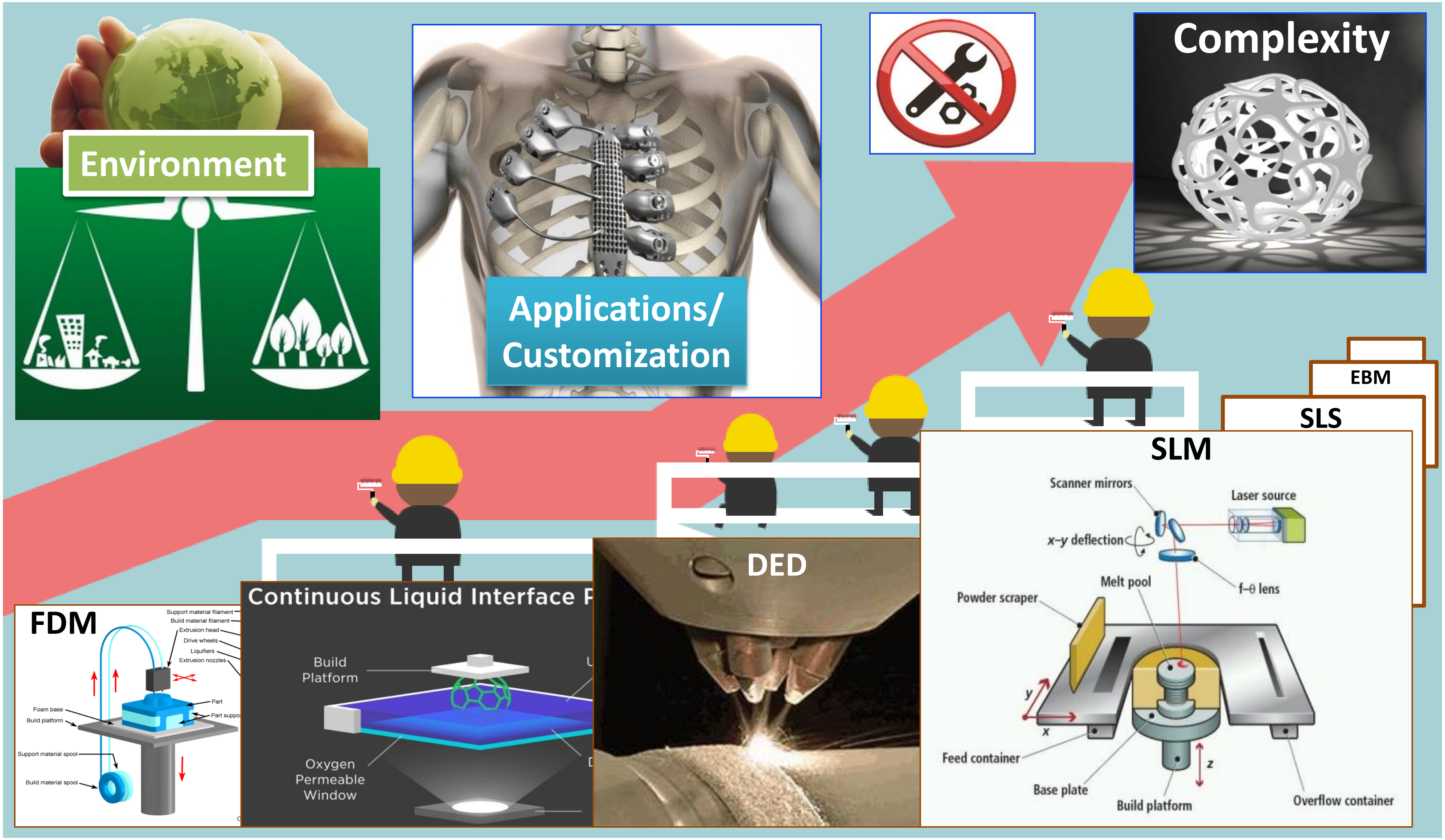
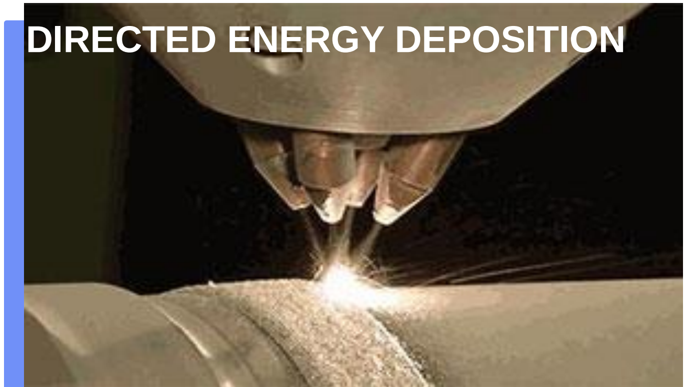
Why Do We Need 3d Printing ?



Type of 3D Printing Technology

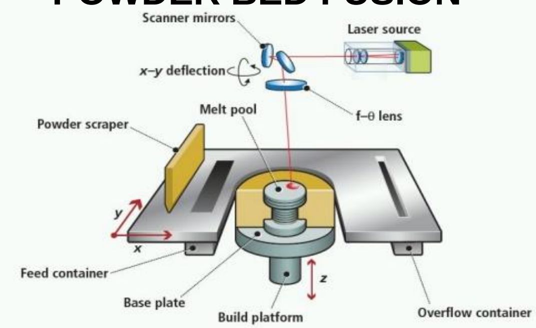
- Stereo lithography(SLA)
- Digital light processing(DLP)
- Fused deposition modeling (FDM)
- Selective laser sintering (SLS)
- Selective laser melting (SLM)
- Electronic beam melting (EBM)
- Laminated object manufacturing (LOM)

DED – PBF Comparation

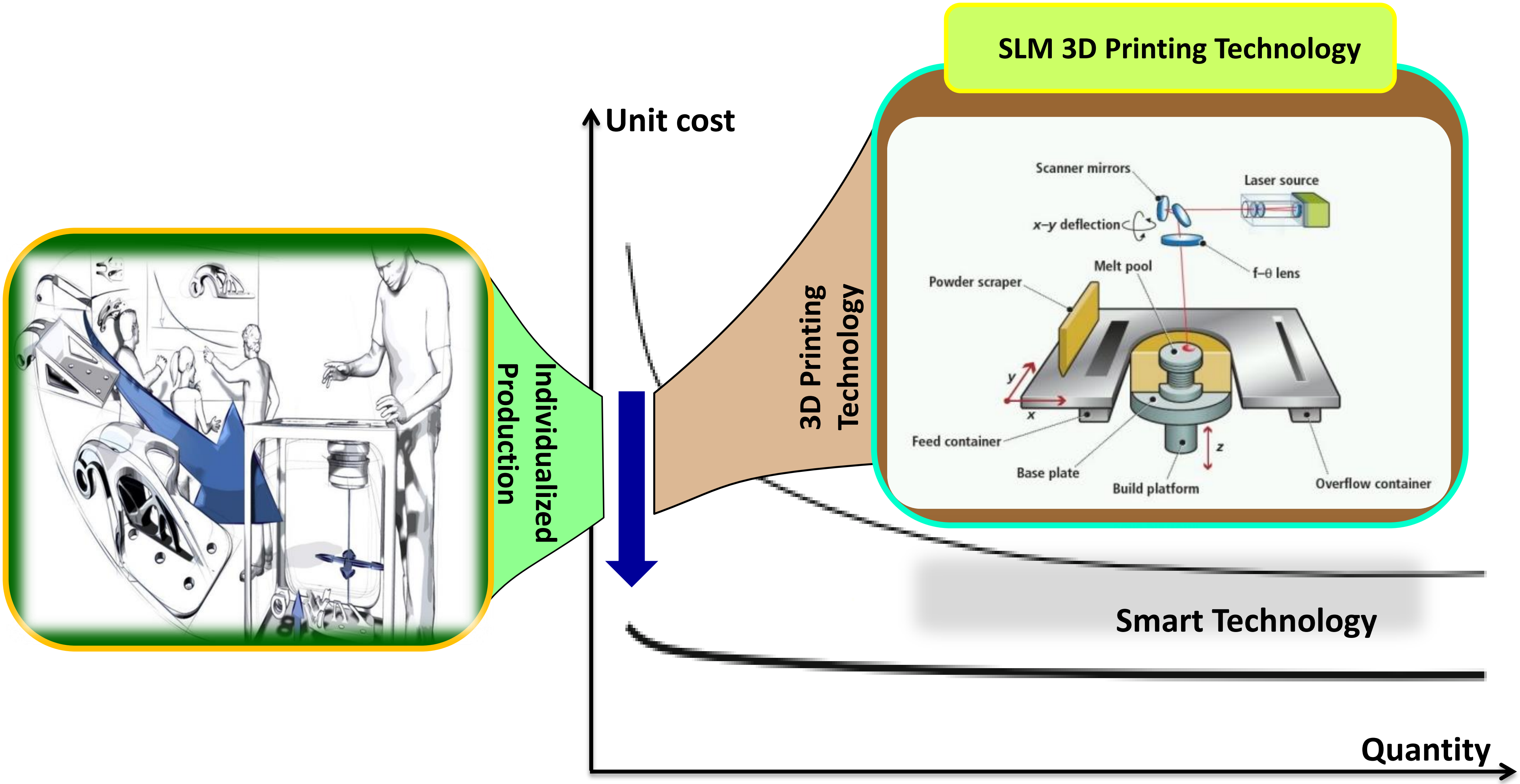


	DED	PBF
Part complexity	Limited	Almost unlimited
Build-up rate, *cm^3/h*	~70	5~20
Build-up on	3D surfaces	Flat surfaces
Layer thickness , *μm*	100~1000	20~100
Material types	Powders, wires	Powders
Operating environment	Open air	Protected air
Roughness, *Ra, μm*	7~20	4~10
Post finishing	Machining required	Not often
Multiple materials	Can be used	Single material

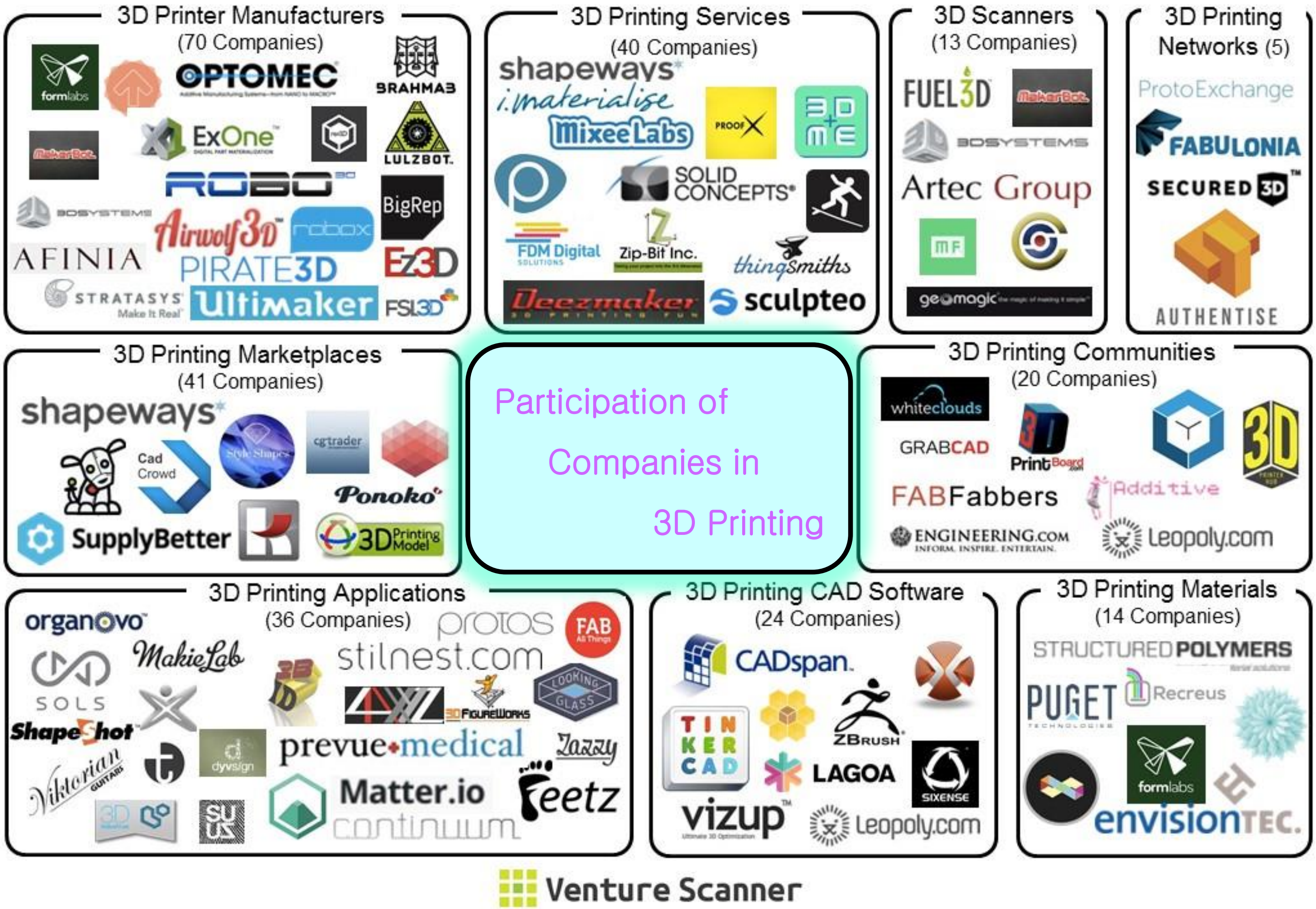
POWDER BED FUSION



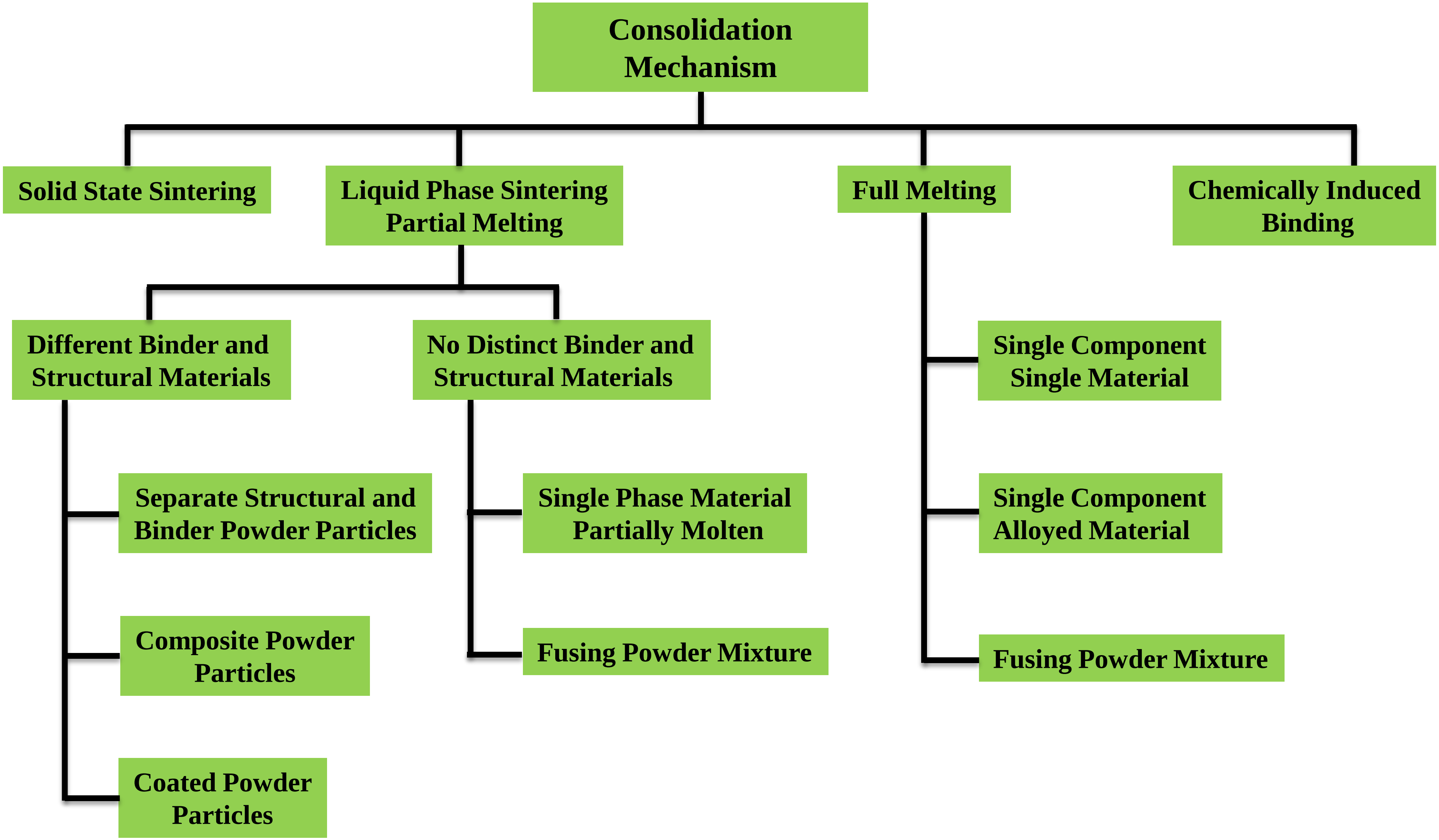
SLM 3D Printing Technology



Companies in 3D Printing



Classification of Laser based Powder Consolidation Mechanism



Consolidation mechanisms versus materials

	Solid State Sintering	Liquid Phase Sintering	Full Melting	Chemical
Polymers	NO	Yes	Yes	Seldom
Metals	Seldom	Yes	Yes	Yes
Cermets	No	Yes	No	Yes
Ceramics	Yes	Yes	Yes	Yes
Other composites	No	Yes	No	Yes

Solid State Sintering

- Occur below the material's melting temperature
- Rarely used due to slow mechanism
- Not economically viable
- Early testing on Steel
- Produced Ti teeth with dense core and porous shell

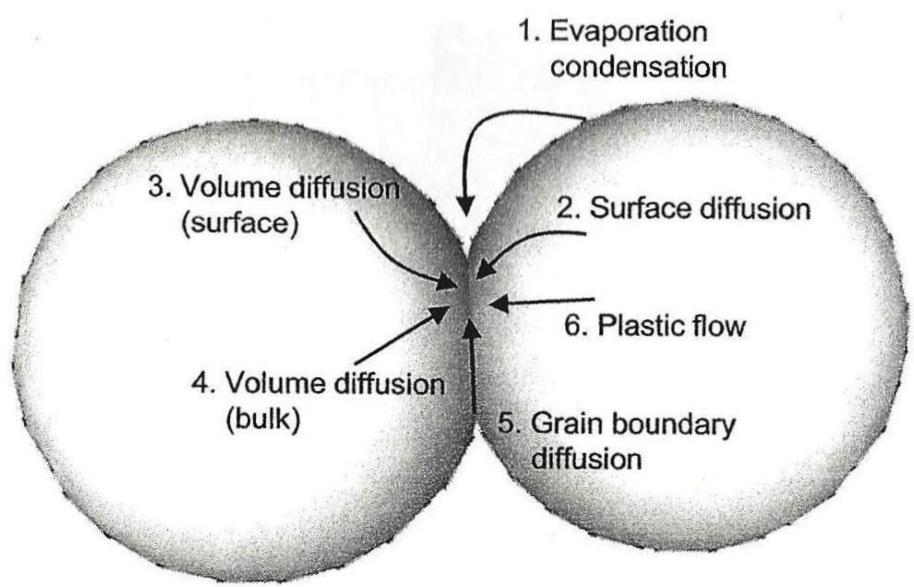
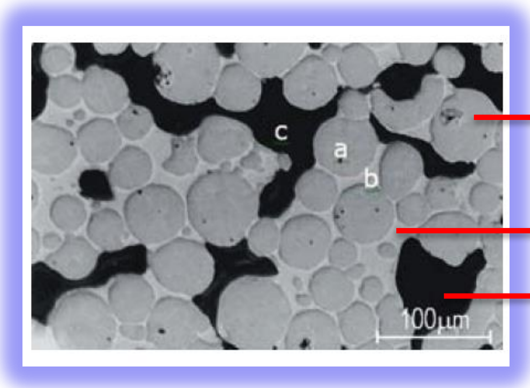


Figure : Schematic illustration of the six sintering mechanism during solid state sintering (SSS)

Liquid Phase Sintering / Partial Melting

A. Different Binder and Structural Materials

I. Separate Structural and Binder Particles

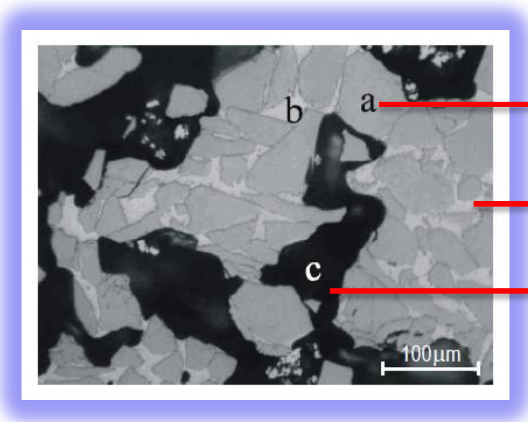


Nonmolten steel particle

Molten Cu

Porosity

Figure: LPS of stainless Steel-Cu powder mixture

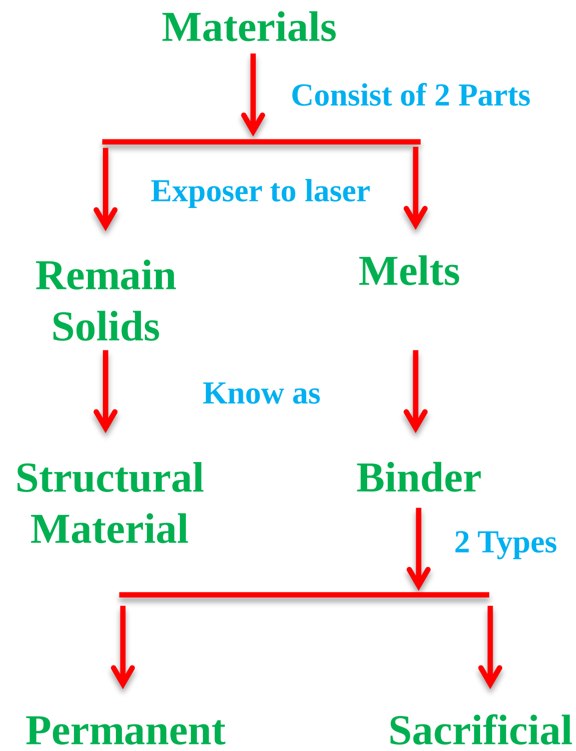


Nonmolten steel particle

Molten Cu

Porosity

Figure: LPS of WC-Co powder mixture



Liquid Phase Sintering / Partial Melting

II.Composite Particles :

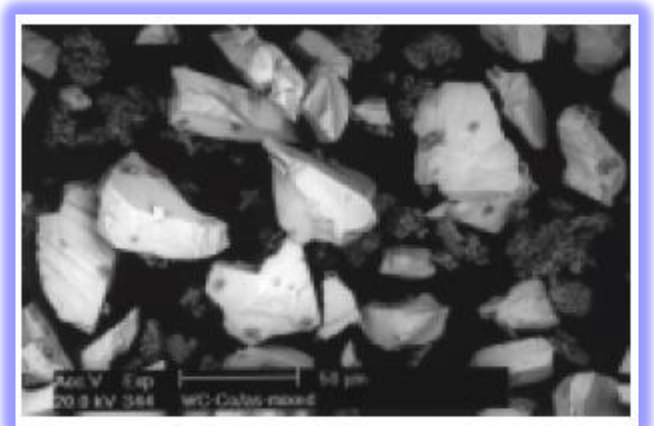


Figure: WC-Co powder Mixture

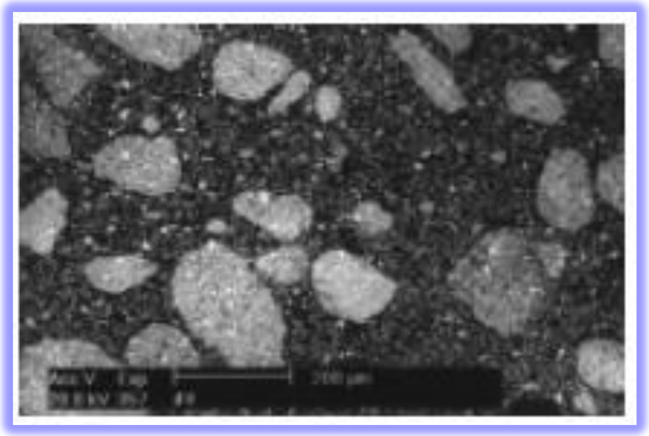


Figure: Mechanically alloying WC-Co powder

- In composite each individual powder grain contains both binder and structural materials.

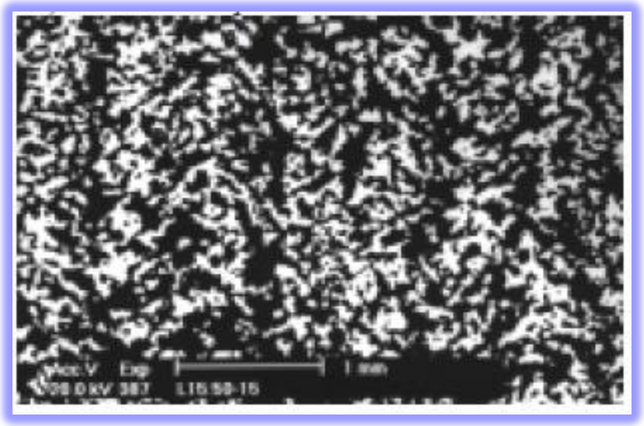


Figure: Sintered WC-Co powder Mixture

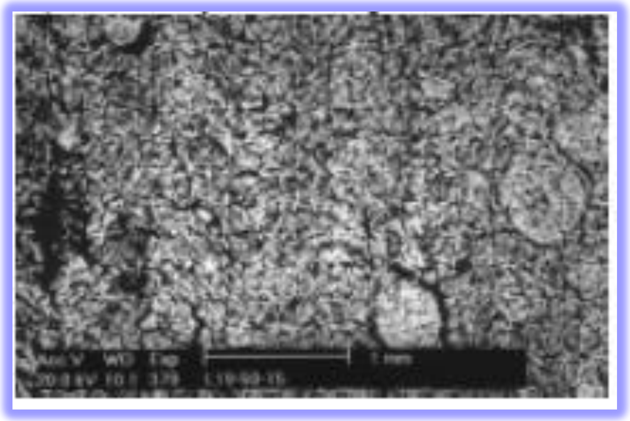
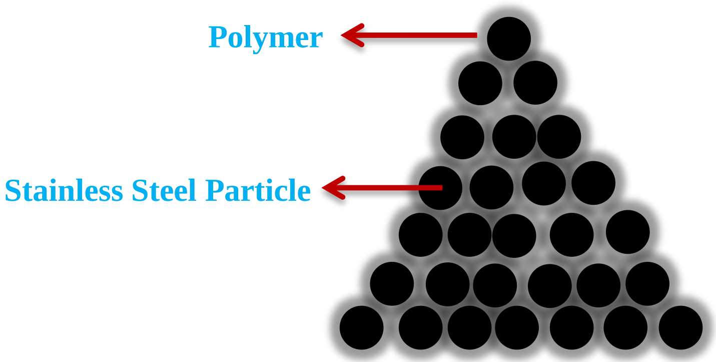


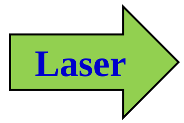
Figure: Sintered mechanically alloying WC-Co powder

- Composite yields higher density and better surface roughness than powder mixture.

Liquid Phase Sintering / Partial Melting

III. Coated Powder Particles: Coated structural martial with binder





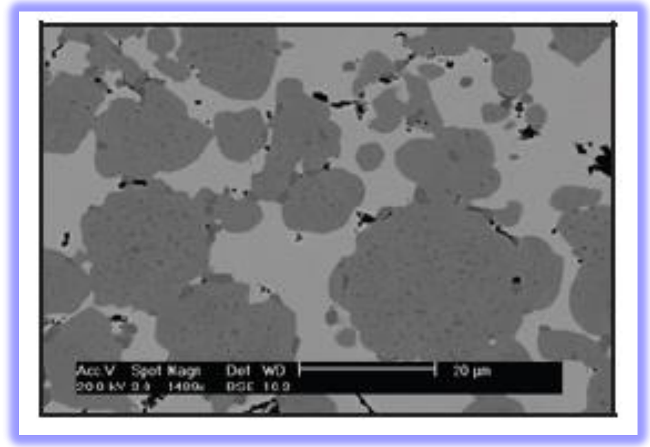
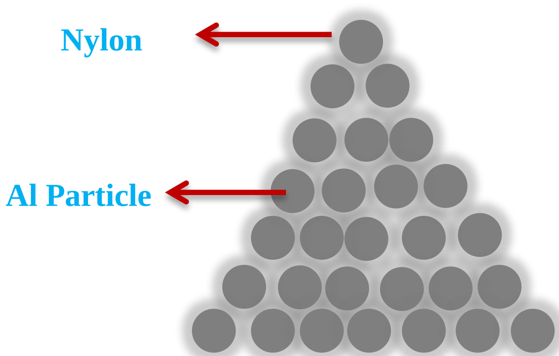
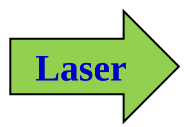


Figure: Polymer Coated Stainless Steel Powder

Figure: Bronze infiltered Laserform ST 100 part





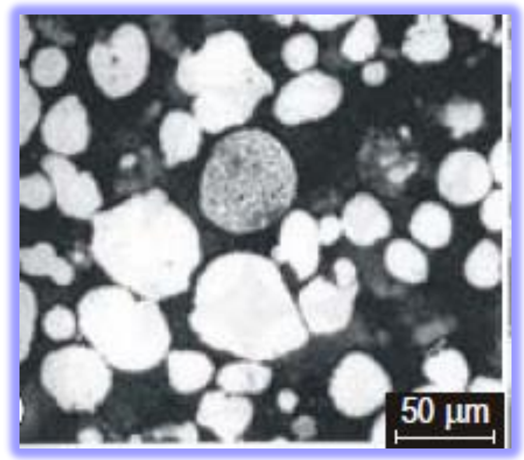


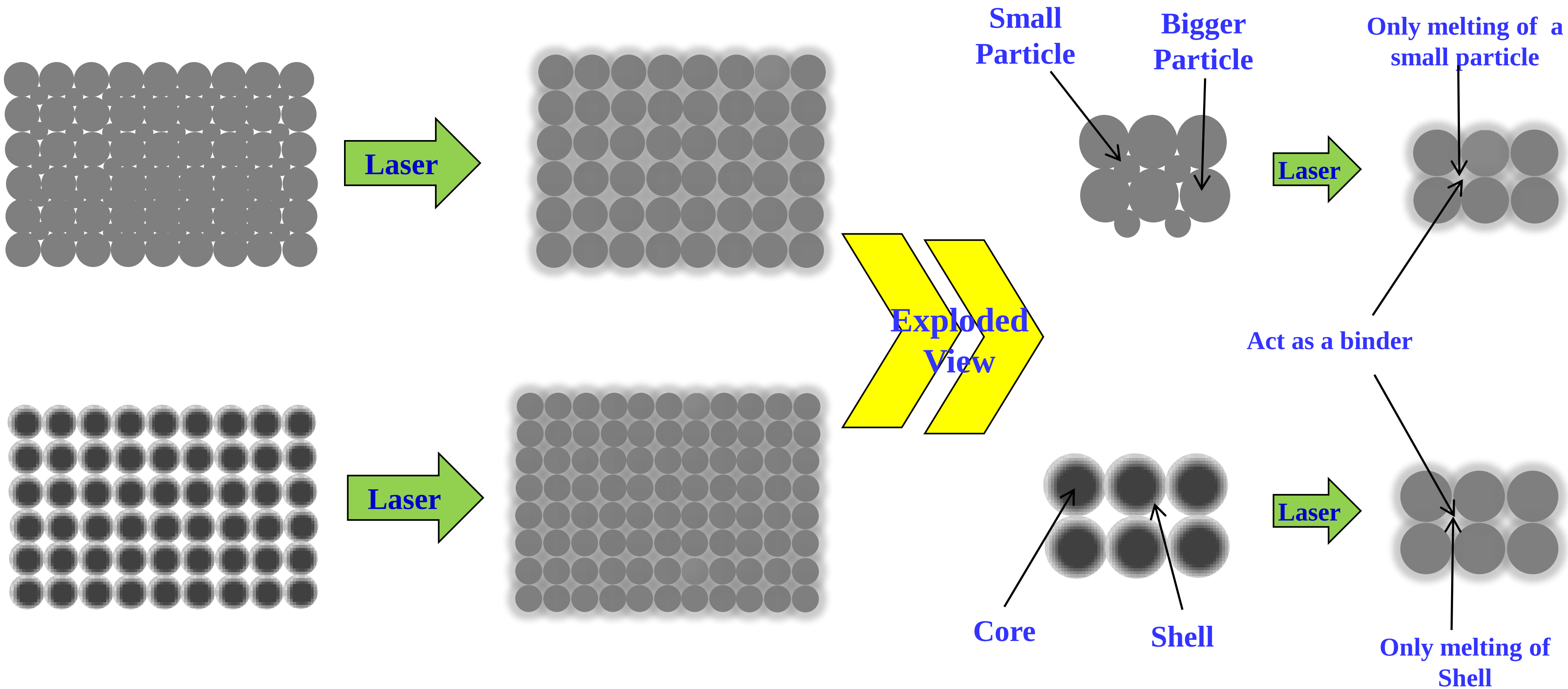
Figure: Nylon coated Al Powder

Figure: Green Part made from nylon coated Al

Liquid Phase Sintering / Partial Melting

B. No Distinct Binder and Structural Materials

I. Single Phase:



Liquid Phase Sintering / Partial Melting

II. Fusing a Powder Mixture :

- Consisting of multiple kinds of powder particles

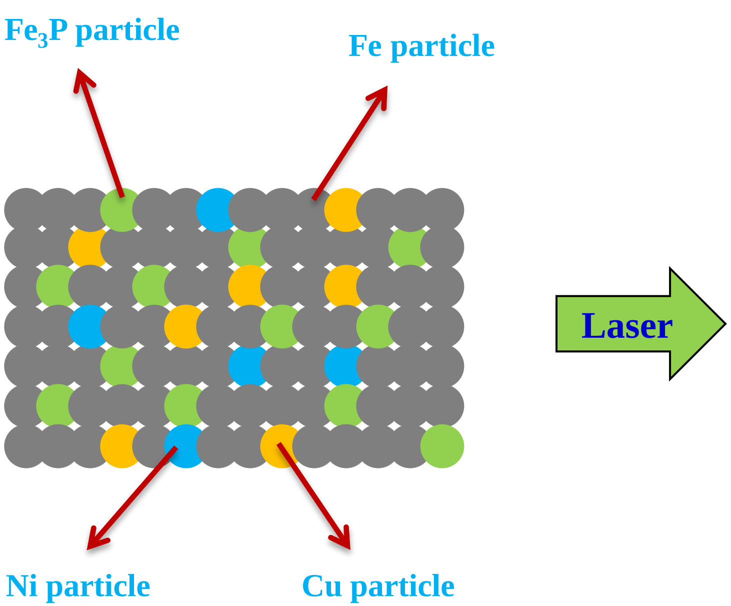


Figure: Powder mixture of Fe-Fe_3P-Ni-Cu

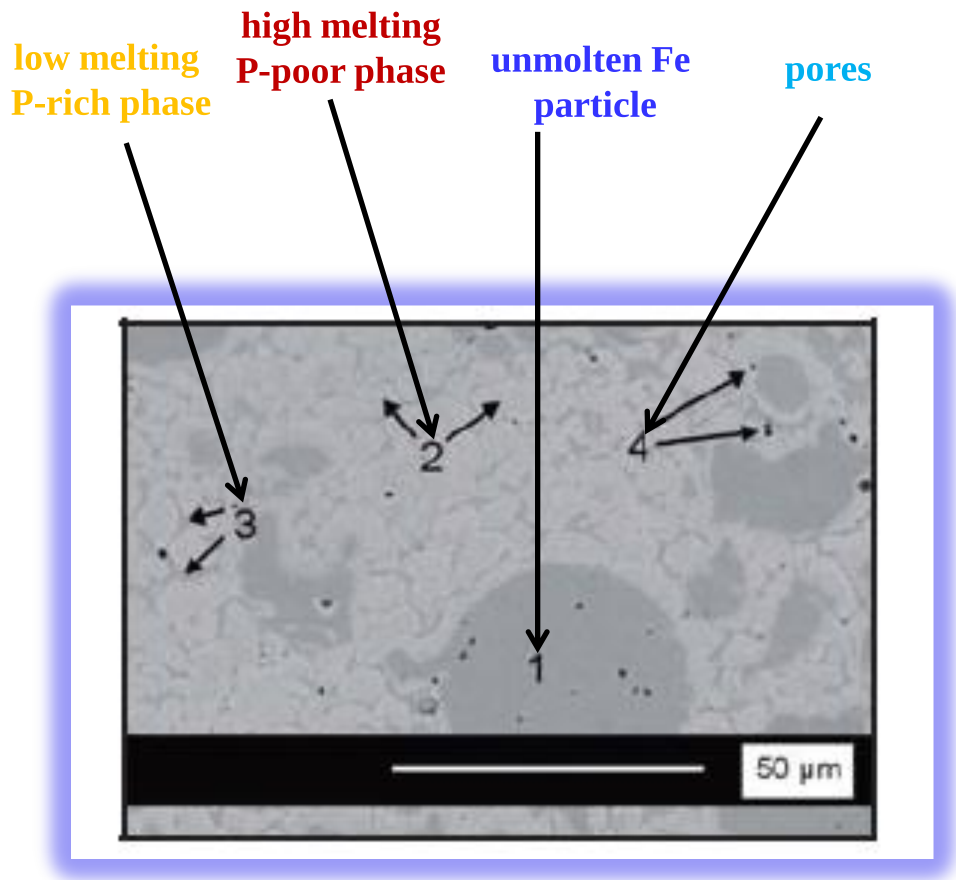


Figure: Micrograph of multiphase steel powder

Chemical Induced Binding

- Not commonly used
- Feasible for Metals
- Binding through laser induced chemical reaction process
- Use of low laser power
- Possible to achieve product with higher accuracy

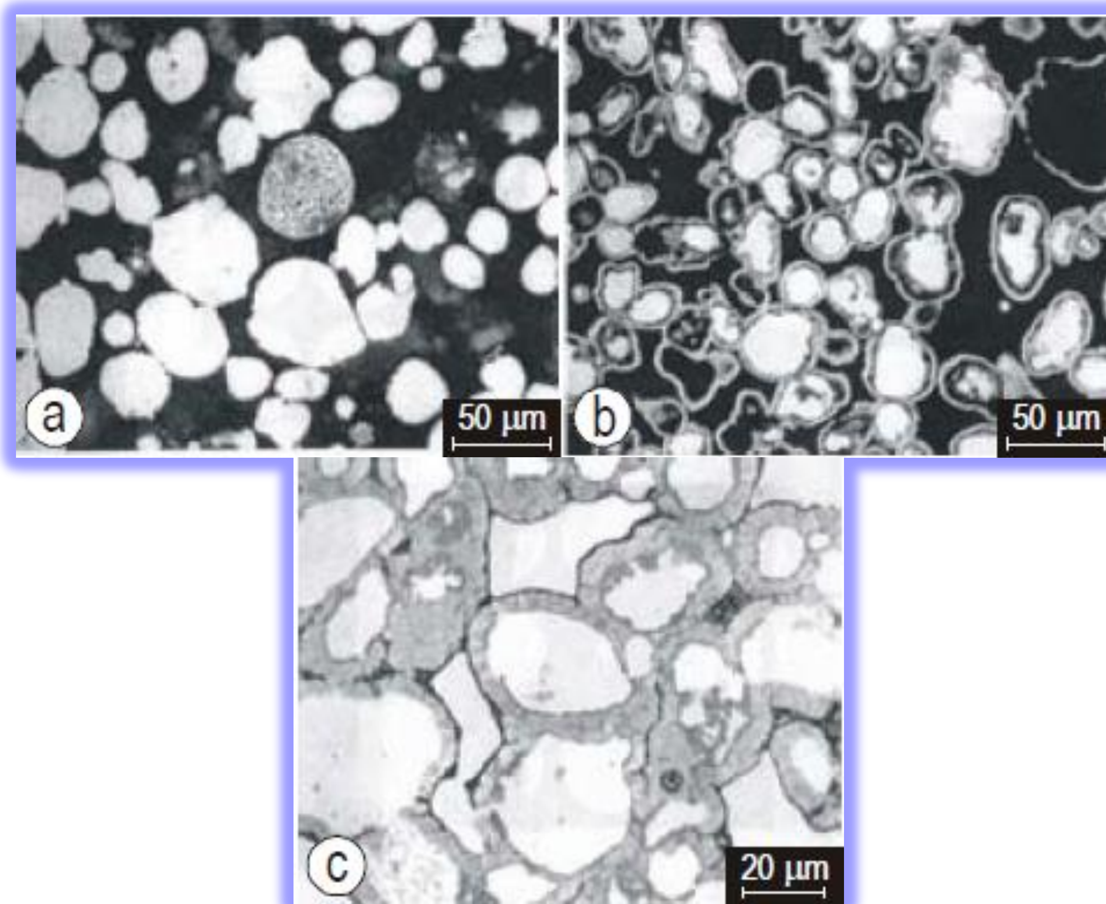


Figure: (a) Green part (nylon binder in black) (b) Aluminium nitride skeleton surrounding the aluminium grains (c) infiltrated part

Full Melting (Selective Laser Melting)

❖ Mechanism of Consolidation

- **Full melting of metal powders applying modern laser sources and optics**

- **Achieved fully dense part without any post-process densification**

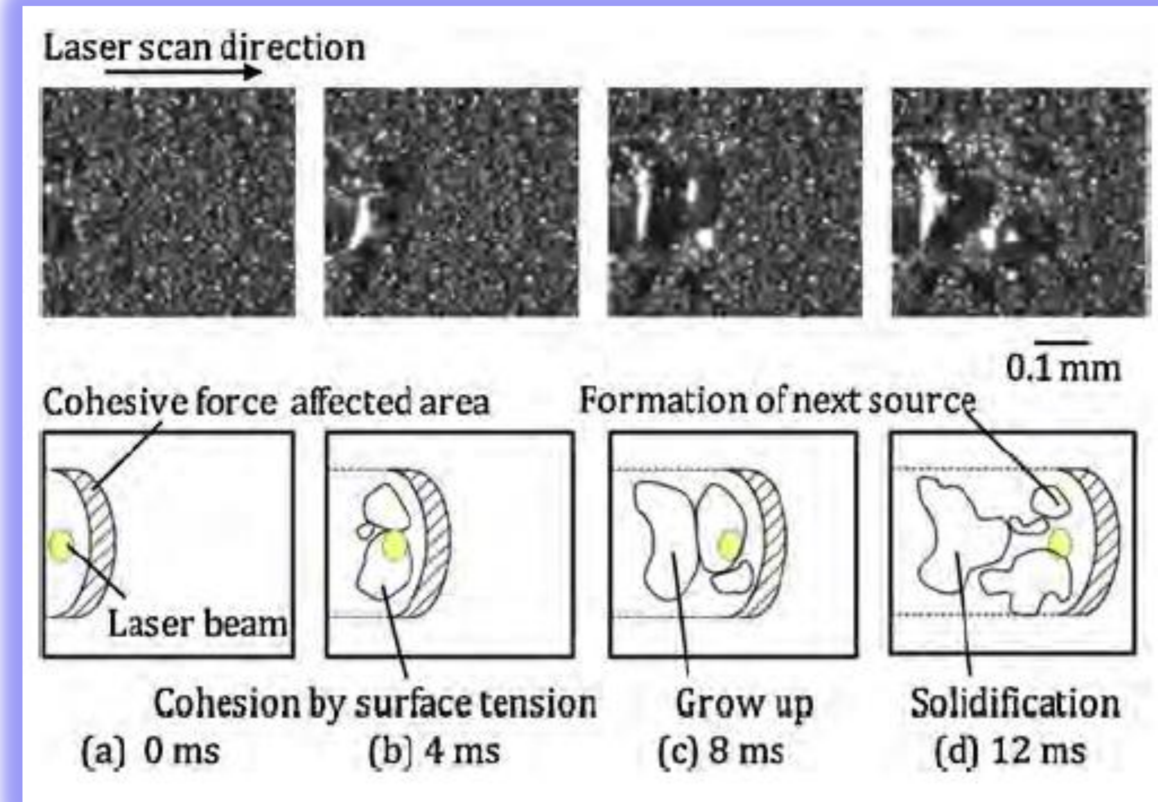


Figure: Consolidation aspect of metal powder in Selective lase Melting (SLM)

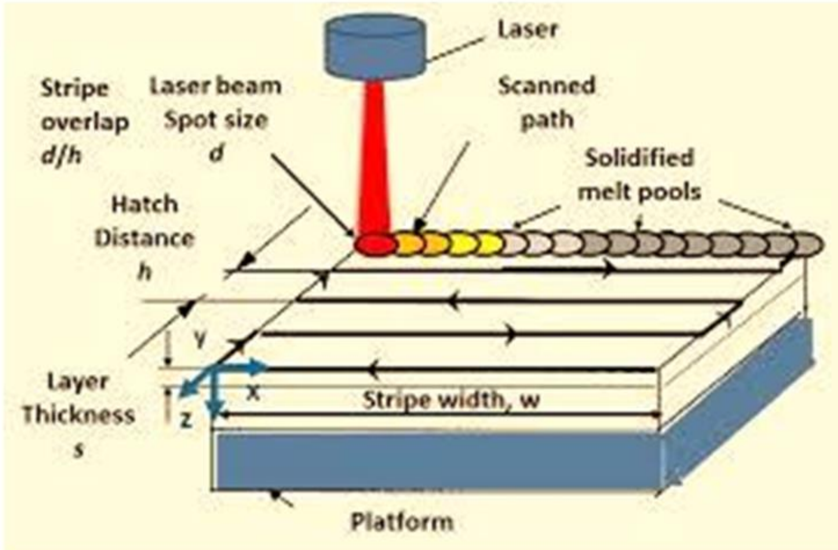
Factor Effecting the Binding Mechanism in Selective Laser Melting (SLM)

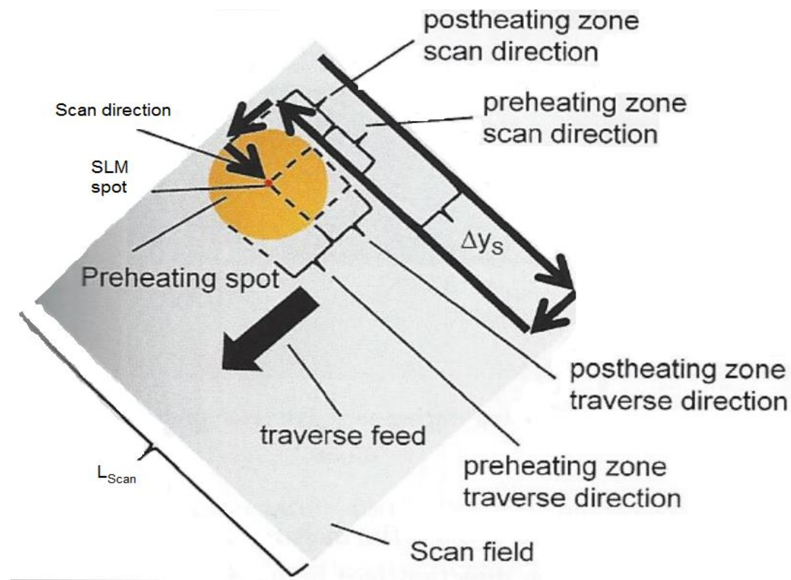
- **Surface Tension (a/o Raleigh instabilities)**
- **Viscosity**
- **Wetting**
- **Thermocapillary Effect**
- **Evaporation**
- **Oxidation**

Benefits and Drawbacks of SLM

	Benefits	Drawbacks
Material choice	No distinct binder and melt phases ⇩ Single material parts	Not appropriate for controlled composite materials
Time and cost	Elimination of furnace post process ⇩ Less time and cost	Higher energy level ⇨ High laser power Good beam quality ⇨ More expensive laser Smaller scan velocity ⇨ Longer built time
Part quality	Dense parts without post infiltration and sintering or HIPing	Melt pool instabilities ⇨ Low quality of lower surface, higher roughness of upper surface, risk of internal pores Higher residual stress ⇨ Need to build and anchor part on solid base plate, risk of delamination, distortion when removing base plate

Process Parameters in SLM





❑ Process Parameters

- Laser power, *P*
- Laser scan speed, V_s
- Laser beam diameter, *d*
- Powder bed thickness, *s*
- Hatch distance, *h*
- Stripe width, *w*
- Hatch overlap, *d/h*

❑ Process Variables

- Temperature
- Melt pool geometry
- Heating Time
- Time at "melt zone"
- Cooling Time

❑ Process outputs

- Residual stress deformation
- Porosity & density
- Yield strength
- Micro-hardness
- Growth direction
- Grain size

Surface Temperature During Laser Irradiation

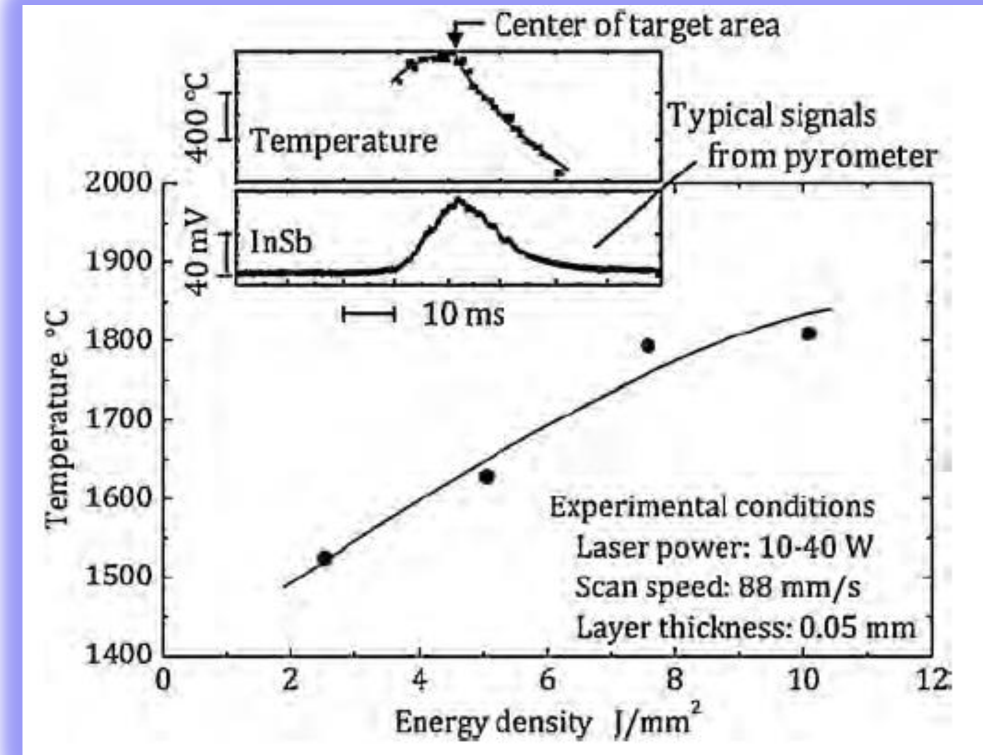


Figure: Variation of temperature with energy density

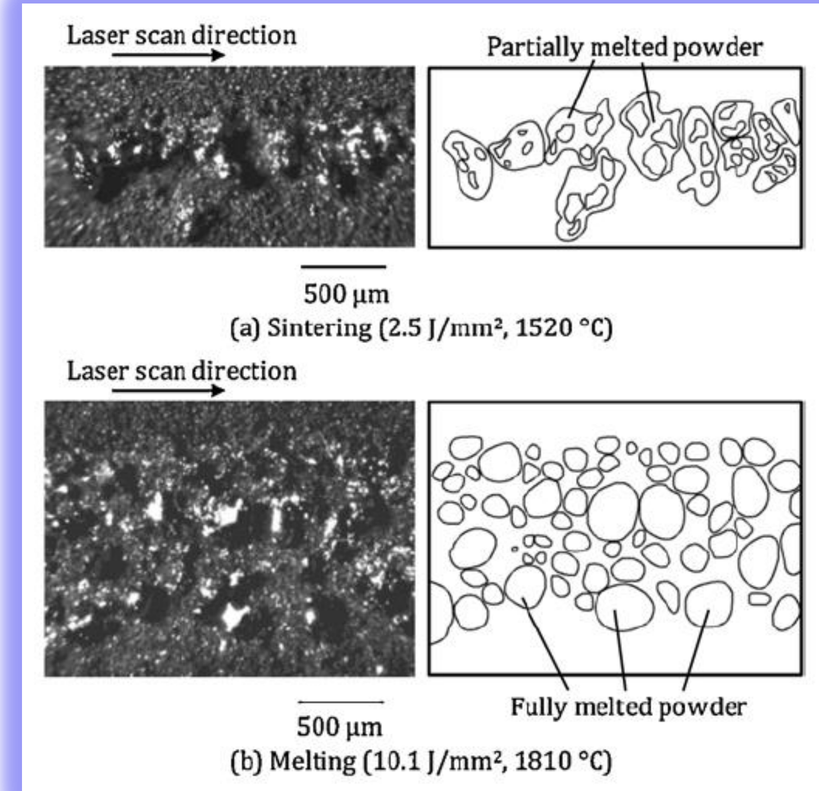


Figure: Comparison of influence of energy density on consolidation

Visualization of the Source of Residual Stress on Metal Powder

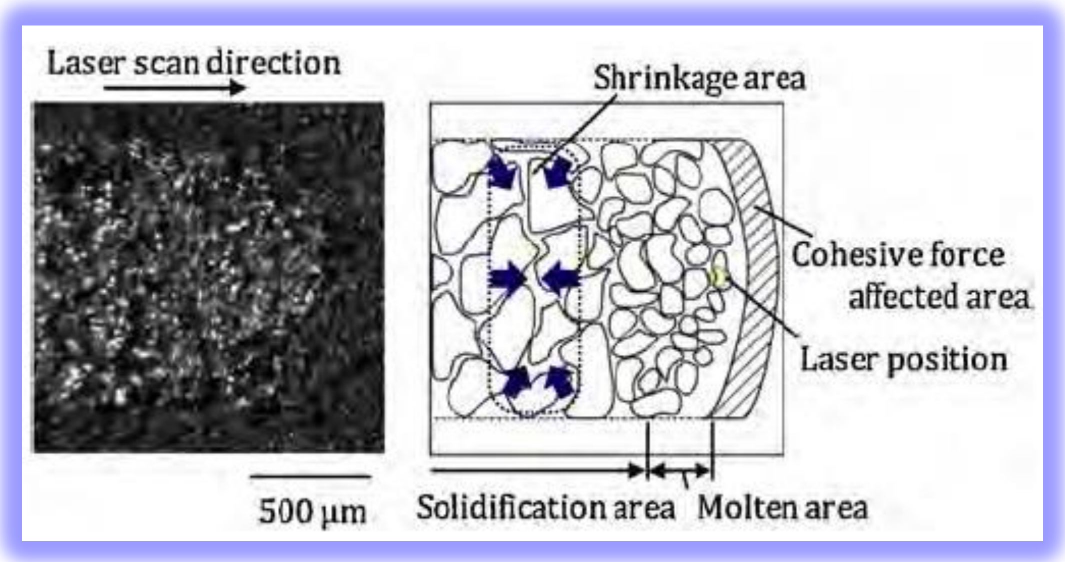


Figure: Image and schematic representation of consolidation

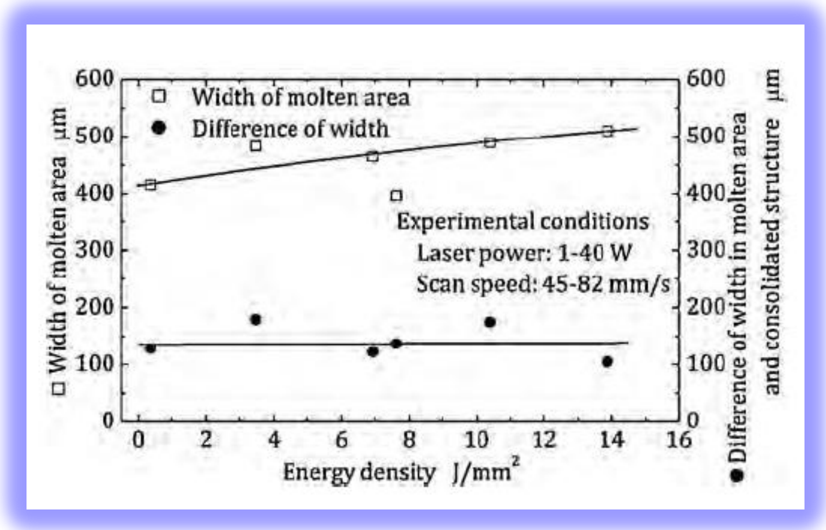
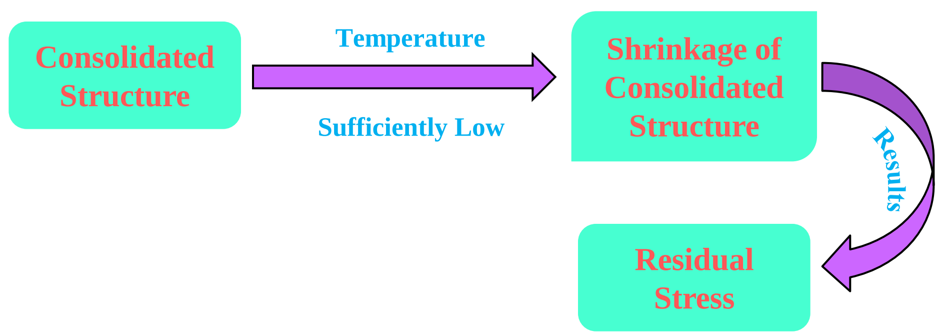
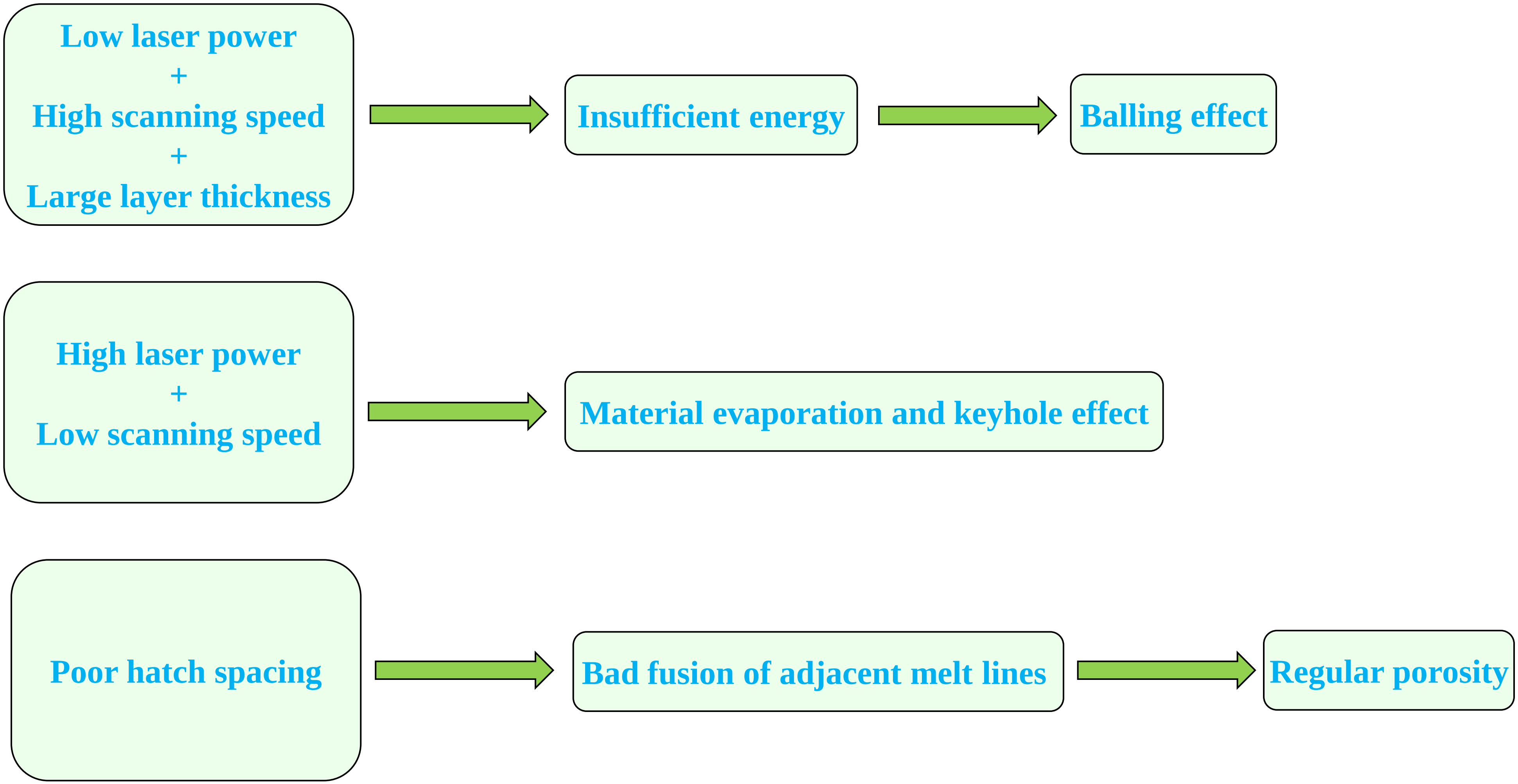


Figure: Variation of molten width and shrunk distance with energy density



Effects of Process Parameters in SLM



Balling Effects in SLM

- Formation of spheroidal beads

Consequences:

- Hinders the formation of continuous melt pool lines
- Jams the powder coating mechanism

Remedies:

- By keeping oxygen level at 0.1%
- Applying a combination of high laser power and low scanning speed
- Appling rescanning of laser

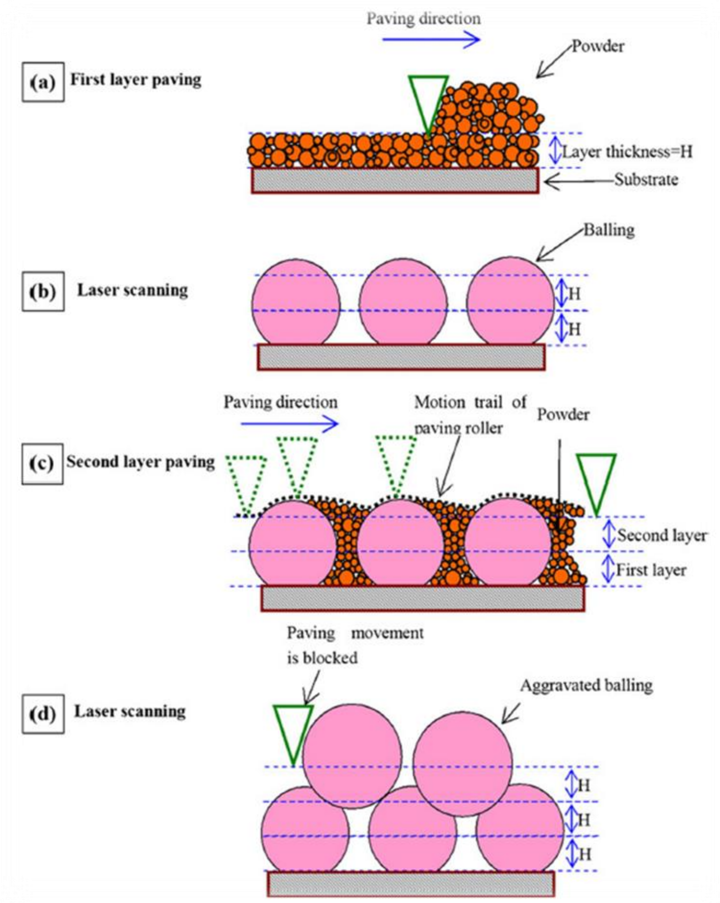


Figure: Aggravation of balling that jams the powder coating mechanism in SLM

Thermal Fluctuation in SLM

Consequences:

- Generation of residual stress in component built
- Crack formation and delamination of parts

Remedies:

- Heat treatment of SLM components
- Rescanning of laser
- Appling chessboard strategy
- Preheating of lower surface

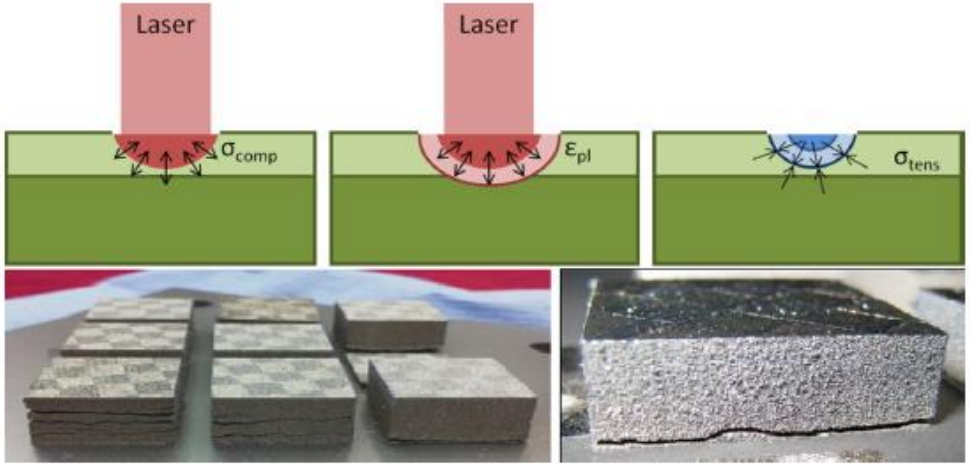


Figure: Temperature gradient mechanism (top) leading to crack formation and delamination (bottom)

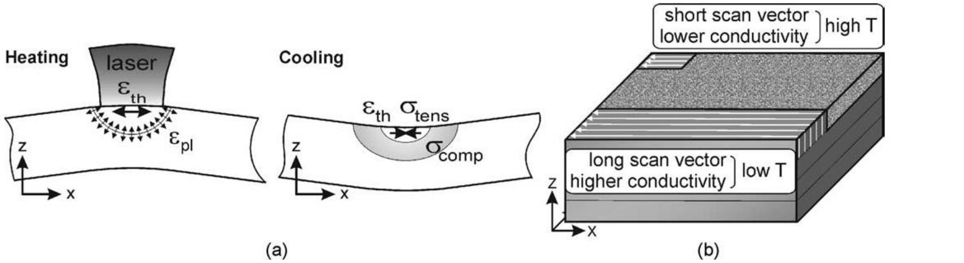
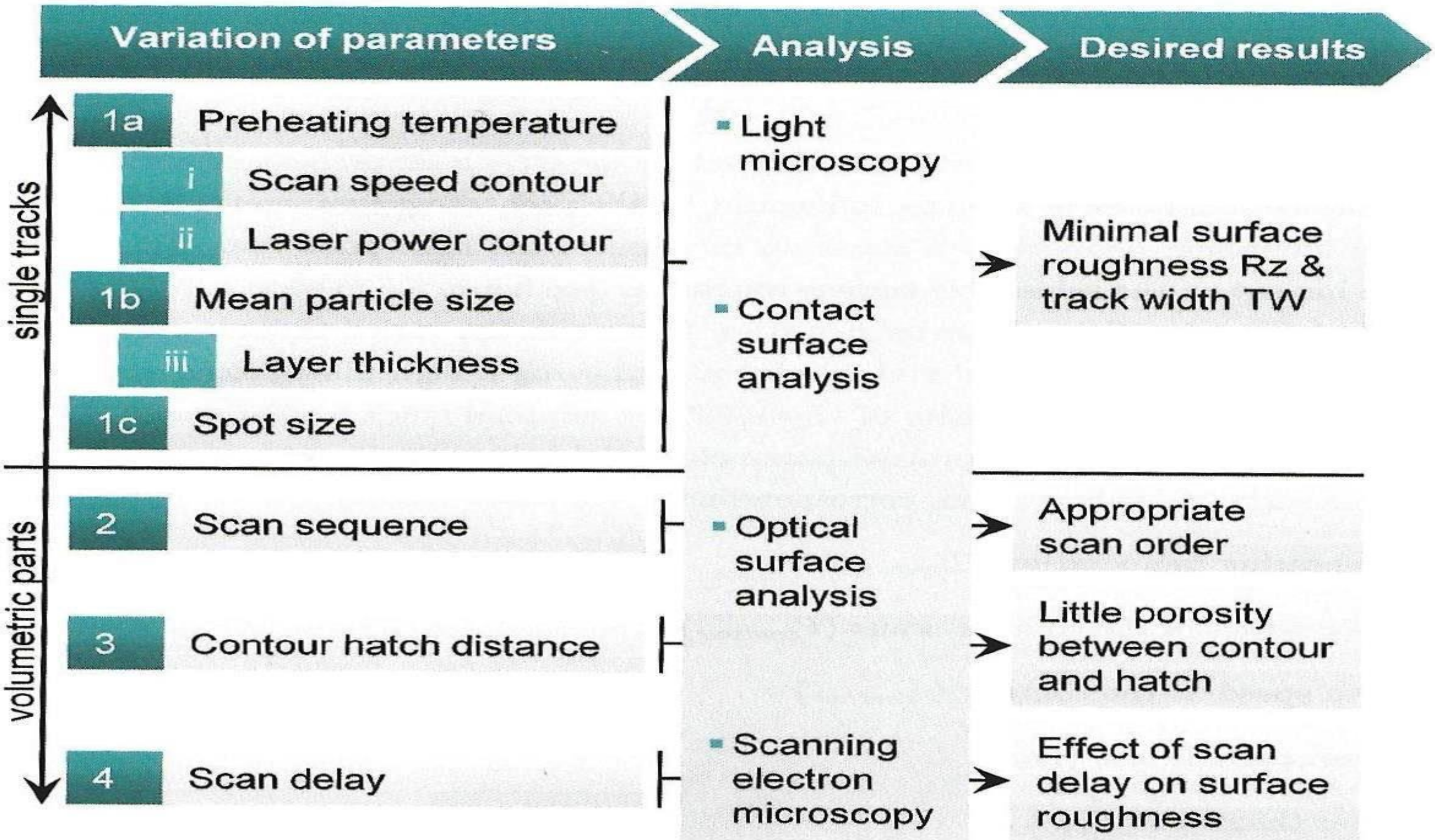
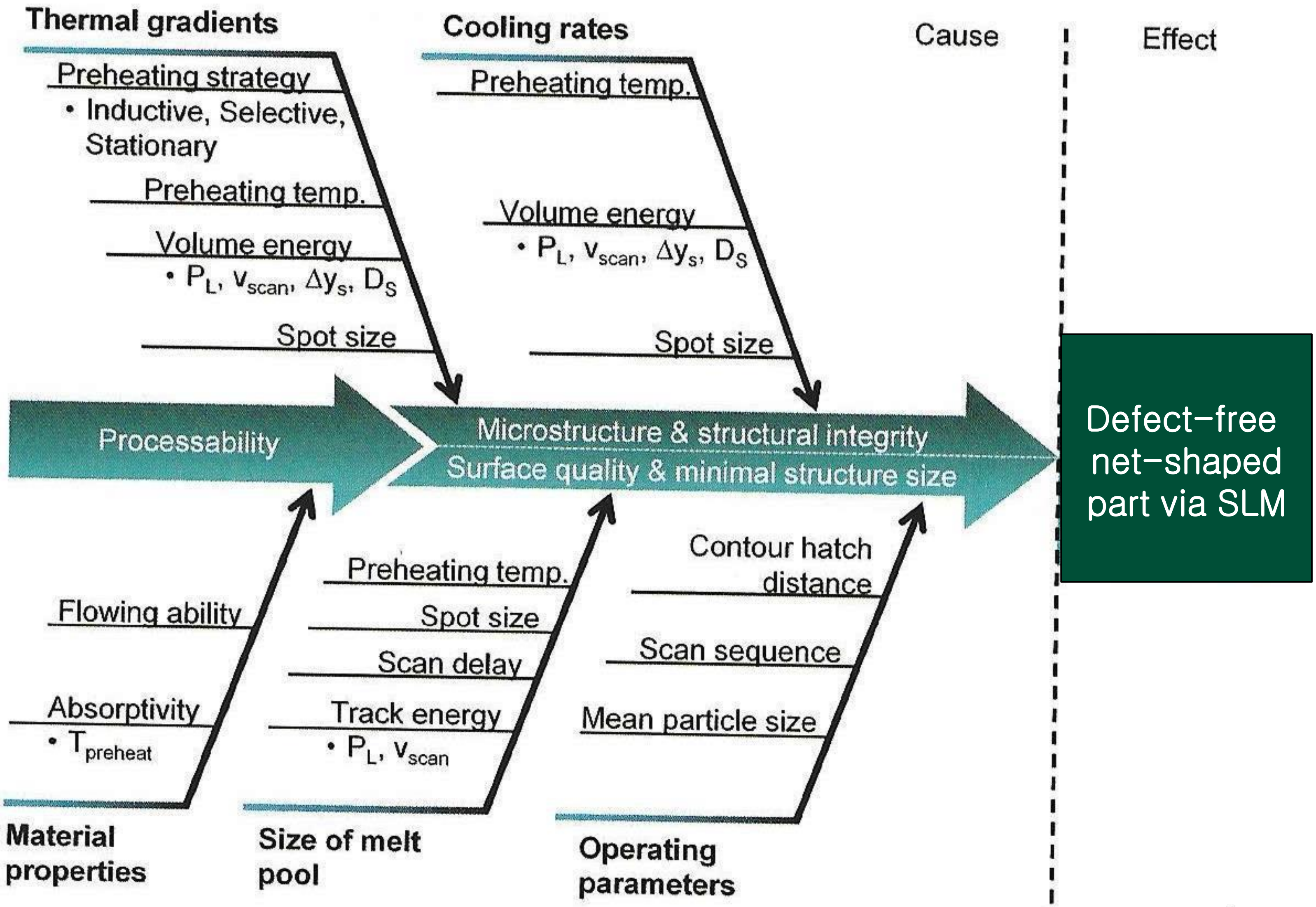


Figure: (a) Temperature gradient mechanism (b) different temperature through different scan vector lengths

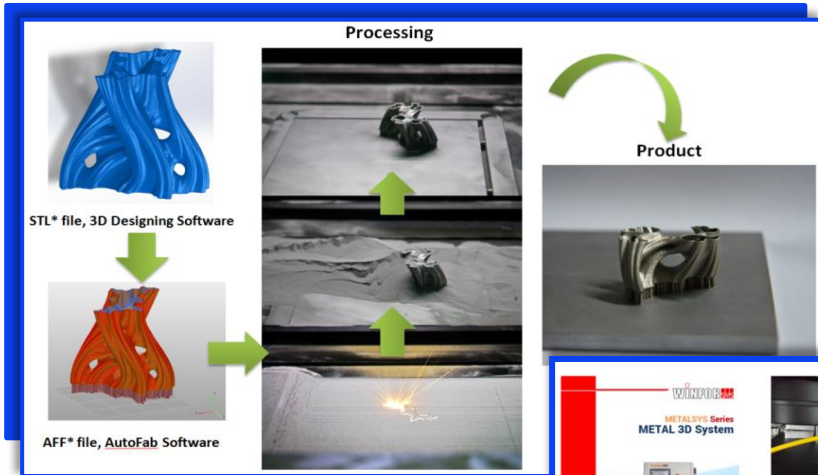
Process Development For Improved Surface Quality

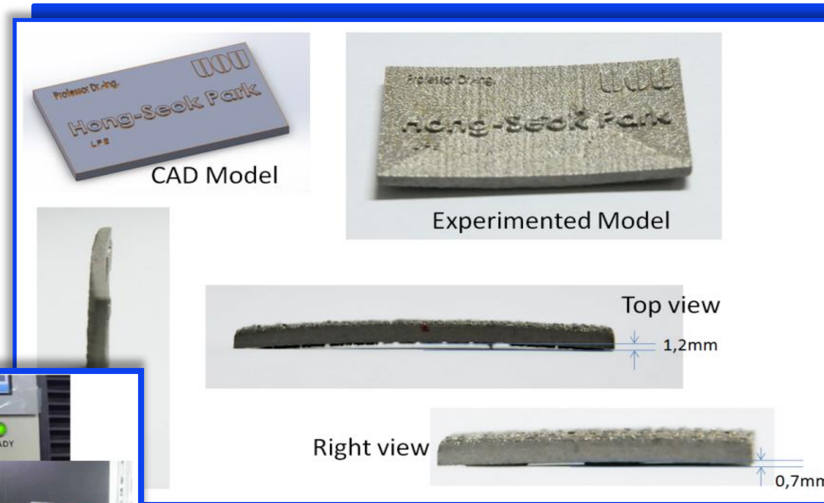


Cause-Effect Diagram for Manufacturing Parts Via SLM

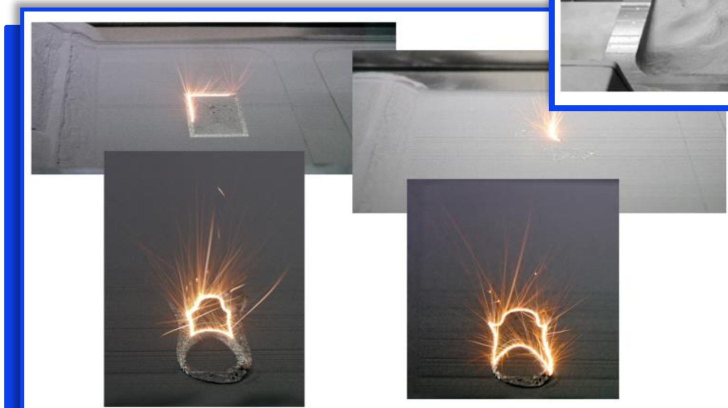


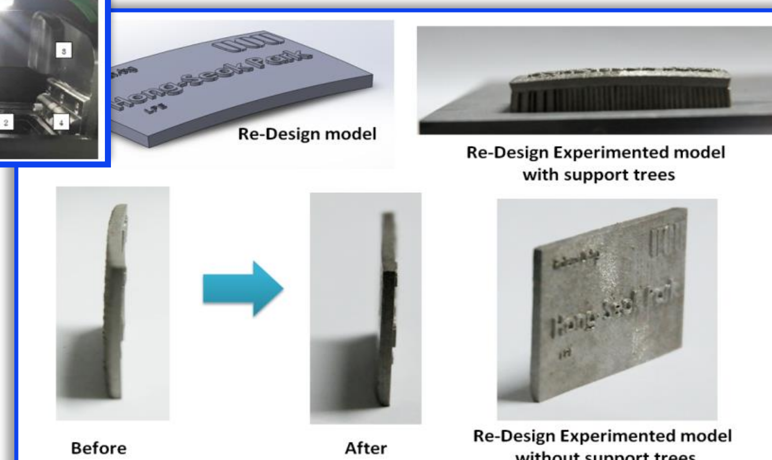
Experiment


Processing
Product
STL* file, 3D Designing Software
AFF* file, AutoFab Software


CAD Model
Experimented Model
Top view
1,2mm
Right view
0,7mm


METALSYS Series
METAL 3D System
Emission
READY




Re-Design model
Re-Design Experimented model
with support trees
Before
After
Re-Design Experimented model
without support trees

EXPERIMENTAL RESULTS

Deformation

CAD Model

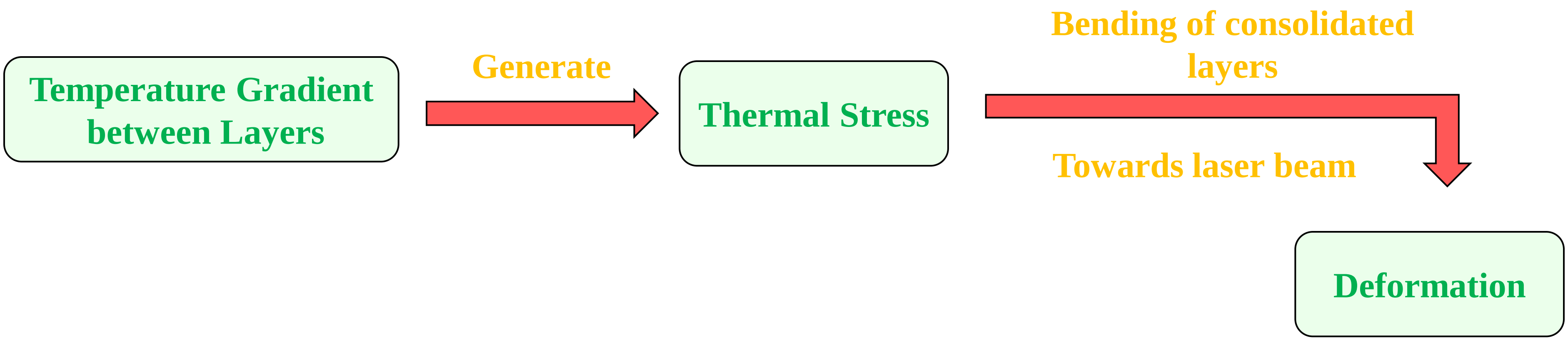
SLM Product

Top View

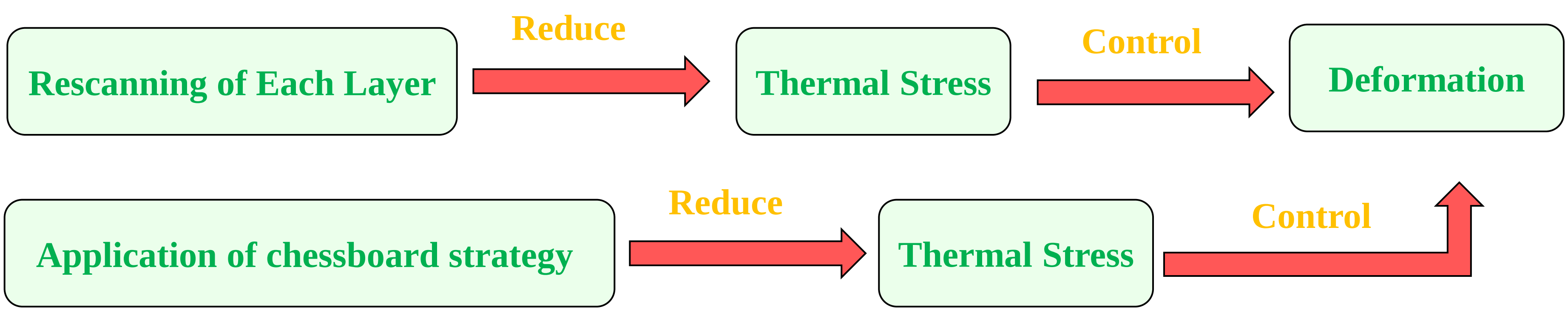
Side View

Reason of the deformation and its solution

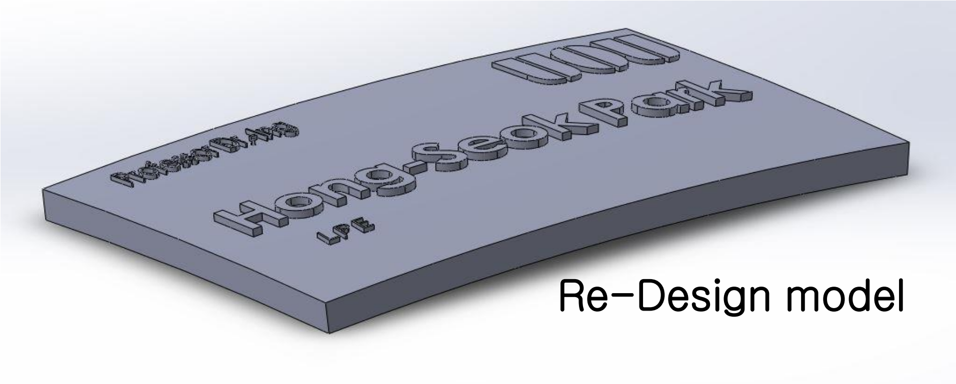
- **Possible reason**



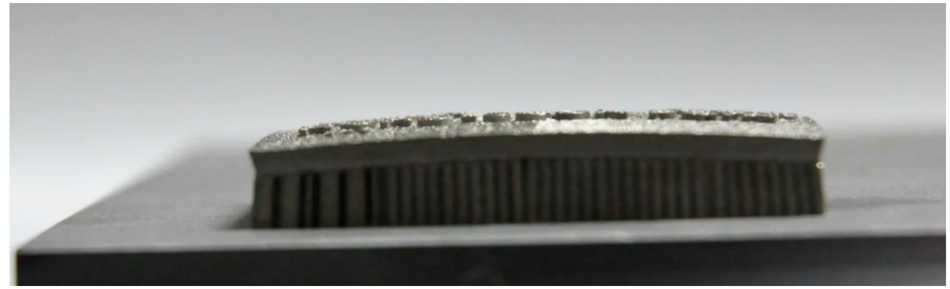
- **Possible solution**



Re-designing of CAD Model to Get Net-shaped Parts



Re-Design model



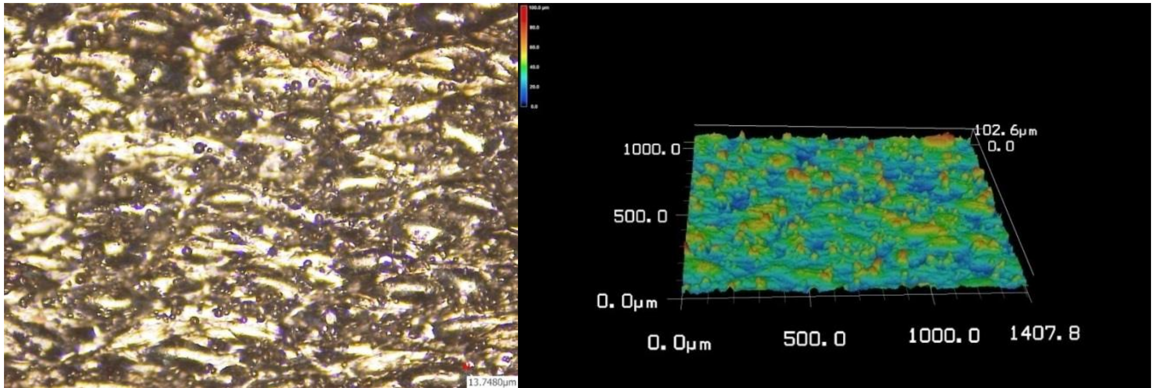
Re-Design Experimented model
with support trees

Before

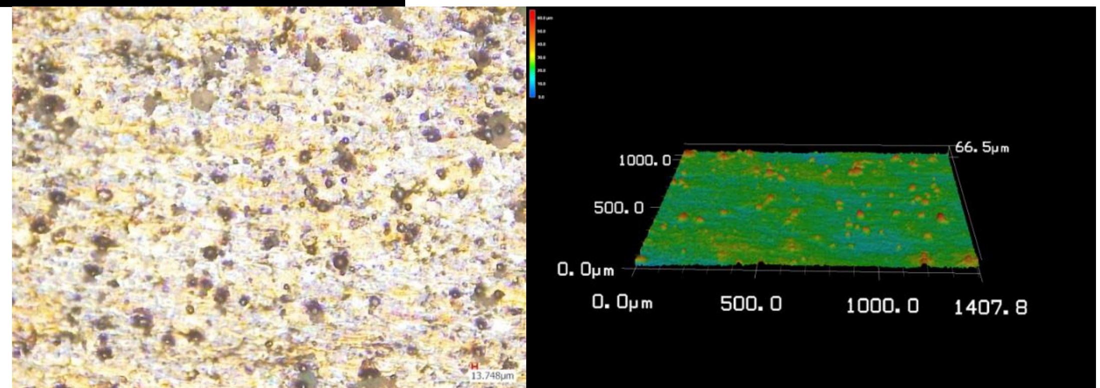
After

Re-Design Experimented model
without support trees

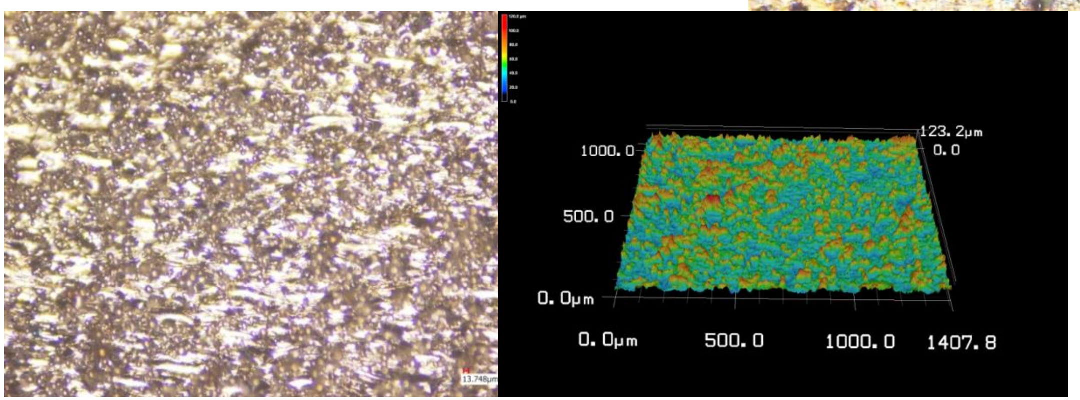
Surface Roughness



Sample 1
Laser Power: 150 W
Scan Speed: 1000 mm/sec
R_a:9.1361 μm

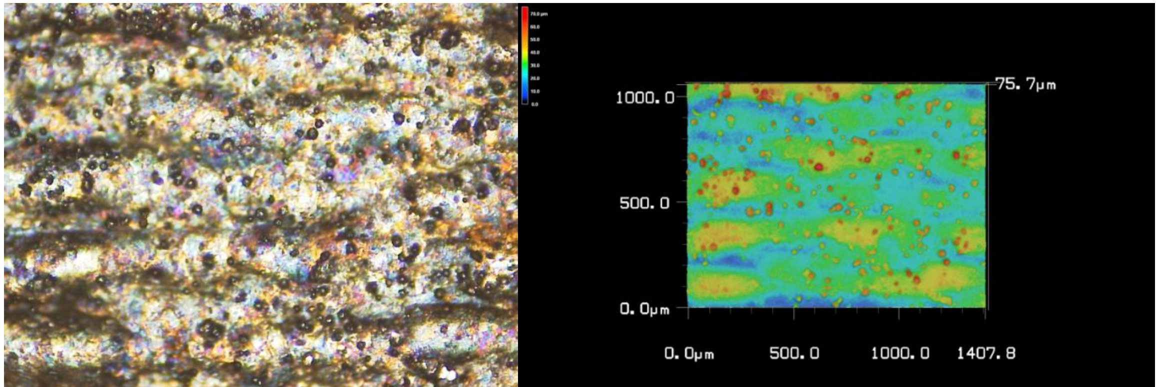


Sample 2
Laser Power: 150 W
Scan Speed: 600 mm/sec
R_a:3.452 μm

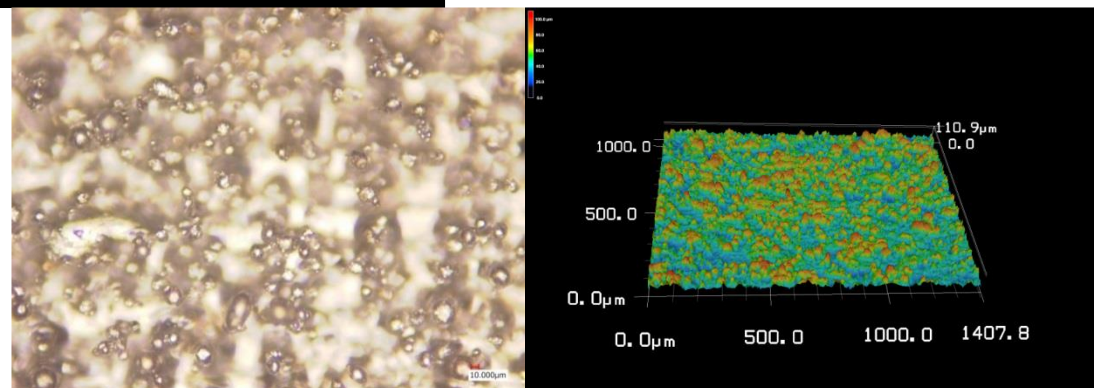


Sample 3
Laser Power: 150 W
Scan Speed: 300 mm/sec
R_a:10.524

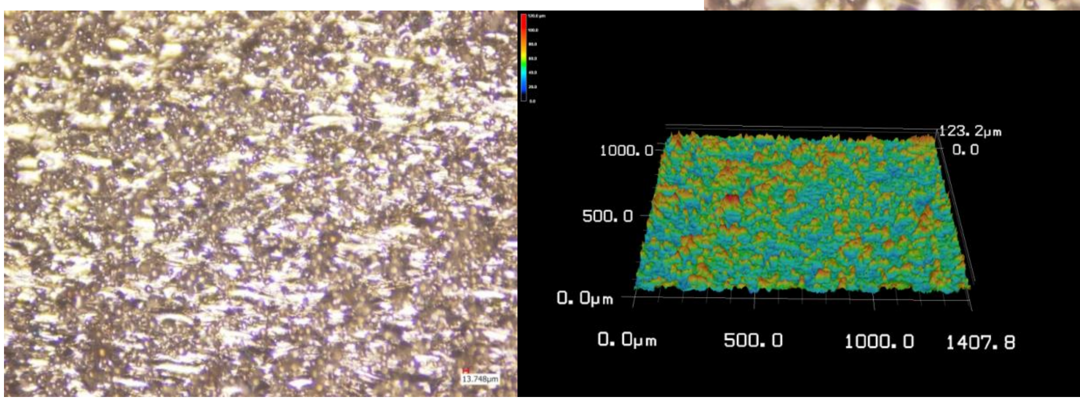
Surface Roughness



Sample 4
Laser Power: 80 W
Scan Speed: 300 mm/sec
R_a: 6.3905 μm

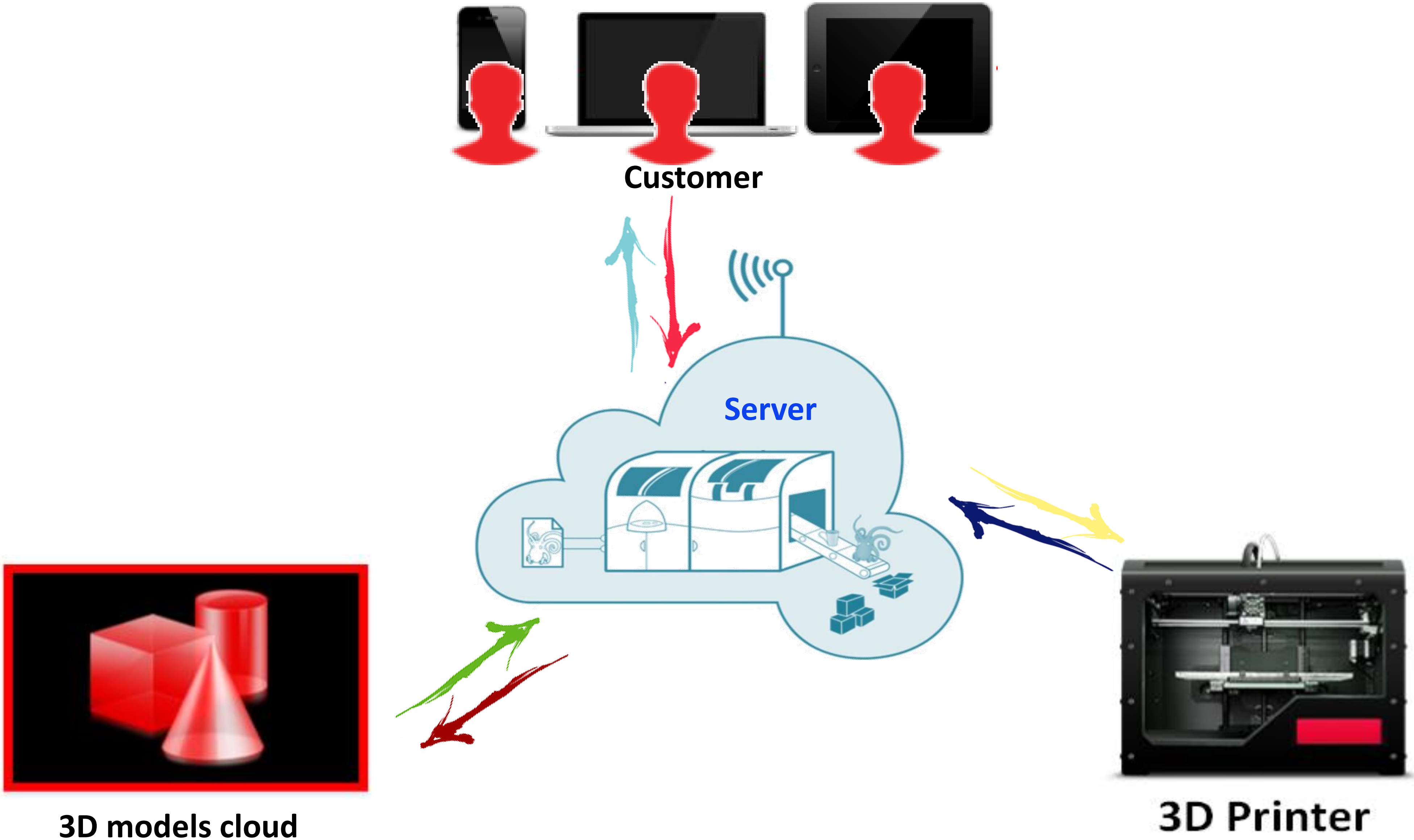


Sample 5
Laser Power: 100 W
Scan Speed: 300 mm/sec
R_a: 10.970 μm



Sample 6
Laser Power: 150 W
Scan Speed: 300 mm/sec
R_a: 10.524μm

CLOUD – 3D PRINTING SERVICE

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