Additive manufacturing
(Rapid Prototyping)

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Additive manufacturing

The approved process categories according the standard ISO/ASTM 52900 are presented in the following list:

- material extrusion – an additive manufacturing process in which material is selectively dispensed through a nozzle or orifice
- material jetting – an additive manufacturing process in which droplets of build material are selectively deposited
- binder jetting – an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder material
- sheet lamination – an additive manufacturing process in which sheets of material are bonded to form a part
- vat photo-polymerization – an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization
- powder bed fusion – an additive manufacturing process in which thermal energy selectively fuses regions of powder bed
- directed energy deposition – an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited

Additive manufacturing - summary

Classification by initial material:

Liquid:

- Stereolithography Apparatus (SLA)
- Digital Light Processing (DLP)
- Polyjet printing

Powder:

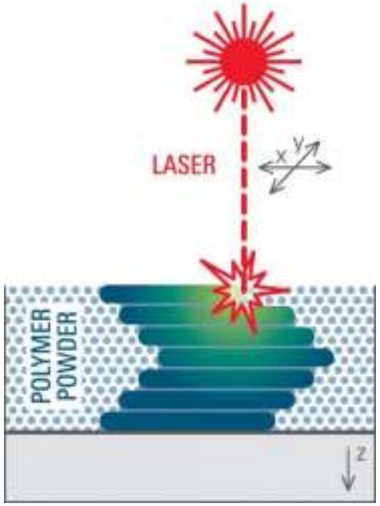
- Selective Laser Sintering (SLS)
- Selective Laser Melting (SLM, DMLS)
- Three Dimensional Printing (3DP)
- Multi Jet Fusion (MJF)
- Directed Energy Deposition (DED, Laser Cladding, MPA,…)

Solid:

- Fused Deposition Modelling (FDM)
- Laminated Object Manufacturing (LOM)
- Thermoplastic Ink Jet (TIJ)
- ARBURG Plastic Freeforming (APF)
- Directed Energy Deposition (DED, MIG/MAG welding)

Additive manufacturing – powder bed fusion

- powder bed fusion – an additive manufacturing process in which thermal energy selectively fuses regions of powder bed



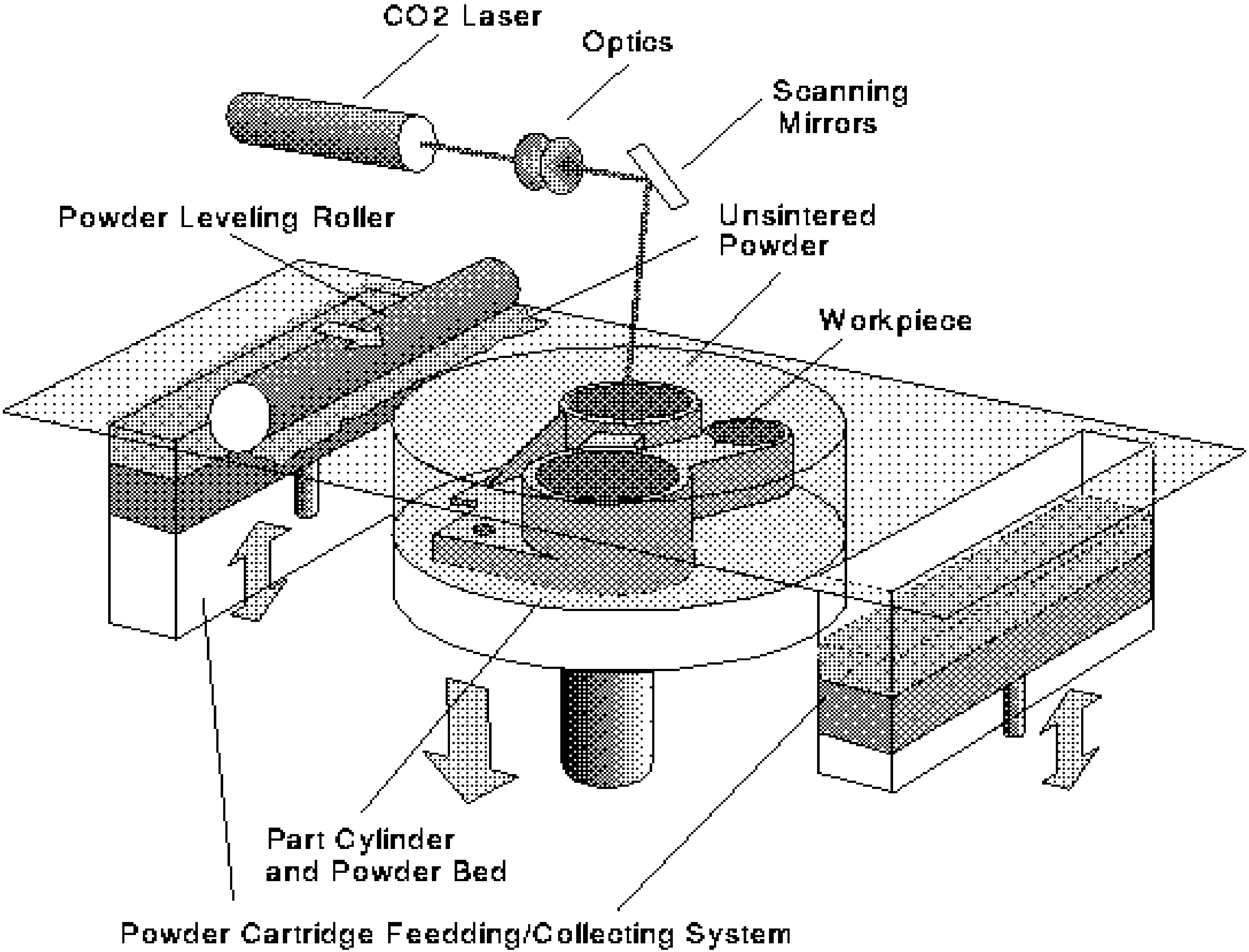
Source: matca.cz/technologie/aditivni-technologie/

Sintering process

- is the process of compacting and forming a solid mass of material by heat and/or pressure without melting it to the point of liquefaction

- the atoms in the materials diffuse across the boundaries of the particles, fusing the particles together and creating one solid piece

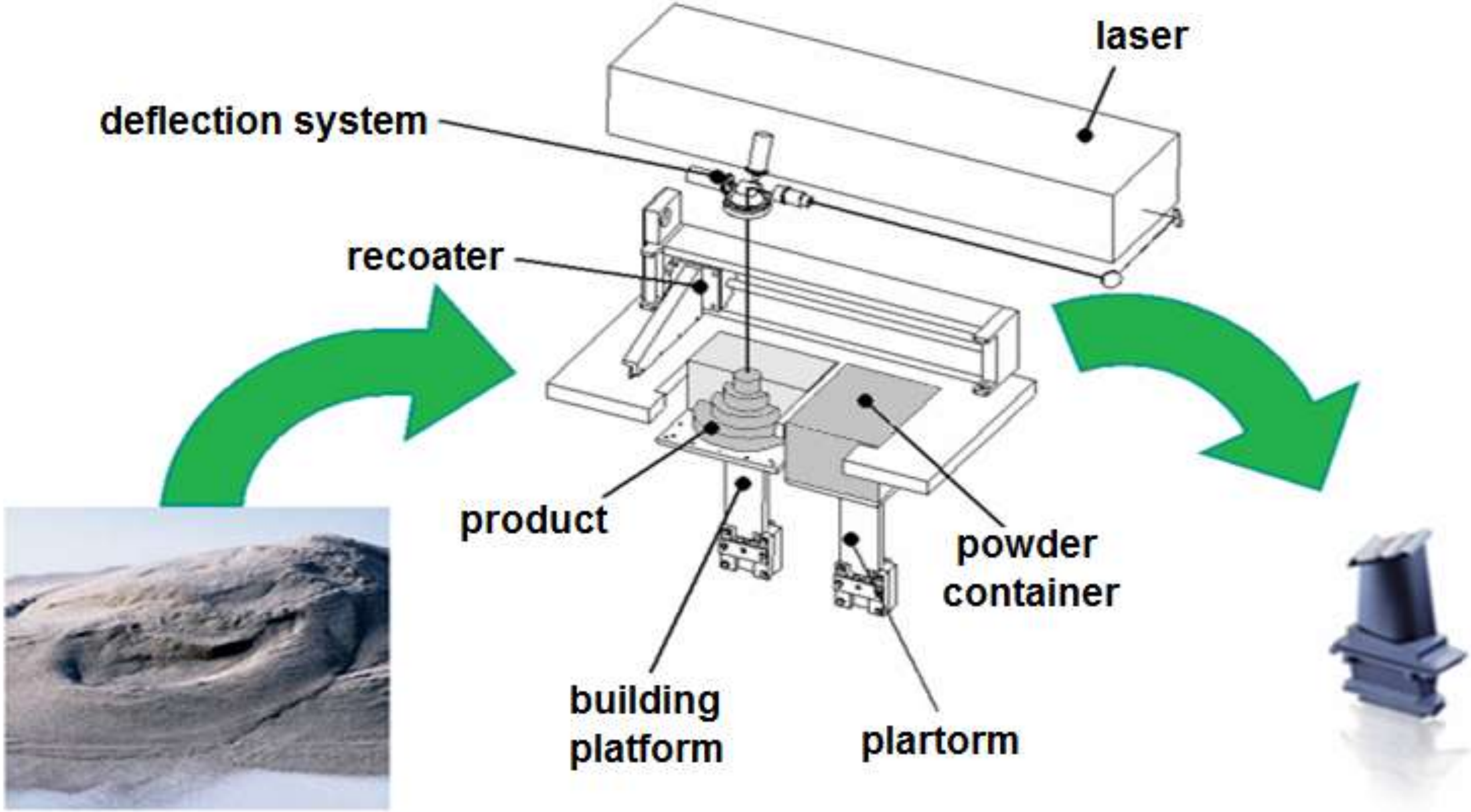
Selective Laser Sintering



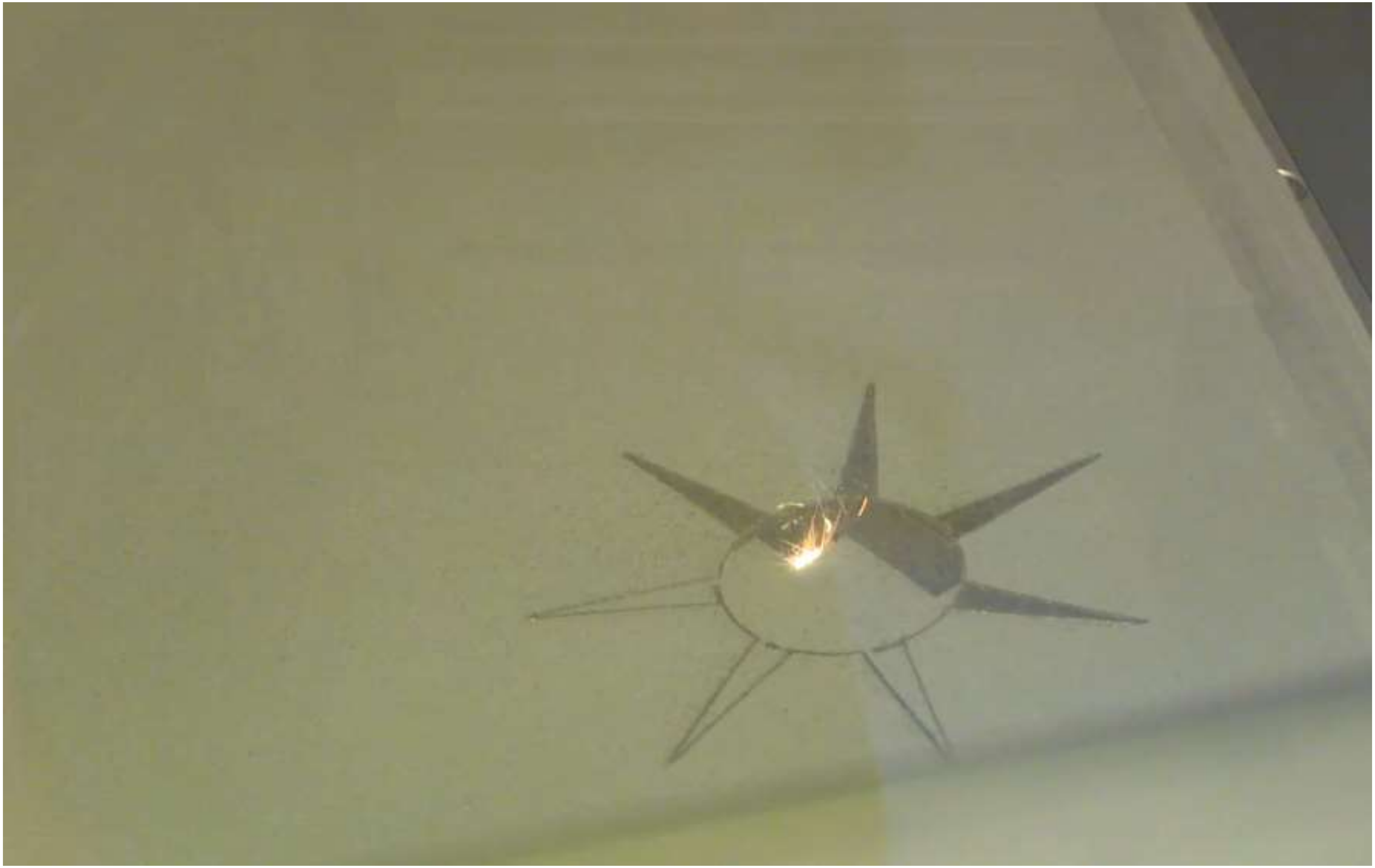
Selective Laser Sintering

	Selective Laser Sintering (SLS)
Applications	Ideal for durable, functional parts with a variety of applications. Capable of producing snap fits and living hinges. Heat and chemically resistant.
Maximum Dimensions	710 x 480 x 480 [mm]
Layer Thickness	Standard Resolution: 0.1 [mm]
Material Options	Nylon, Glass-Filled Nylon, Durable Nylon
Recommended Minimum Feature Size	0.75 - 1.00 [mm]

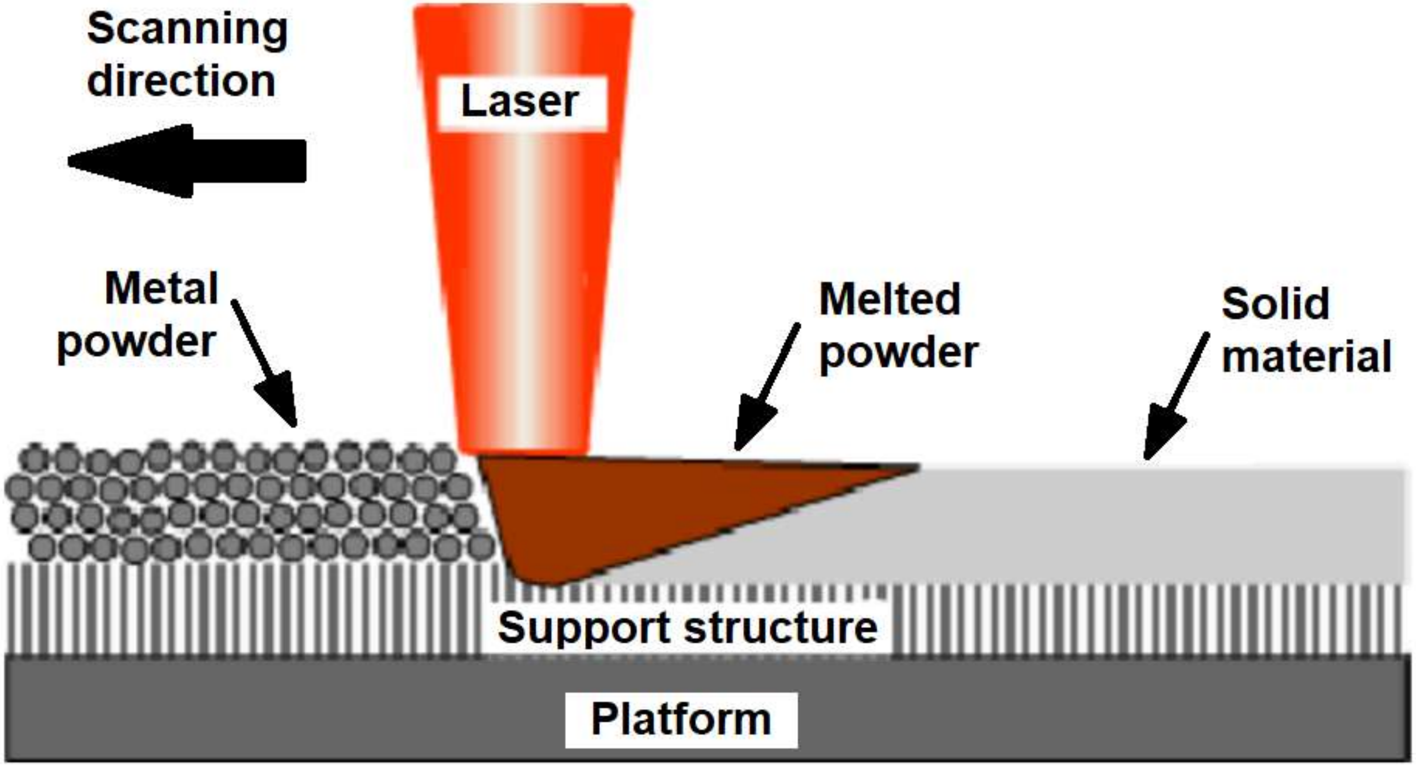
Selective Laser Melting



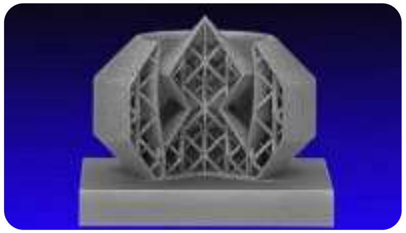
Selective Laser Melting

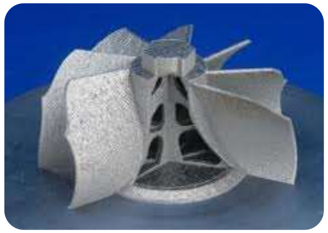


Powder bed fusion – Selective Laser Melting



principle of one layer building



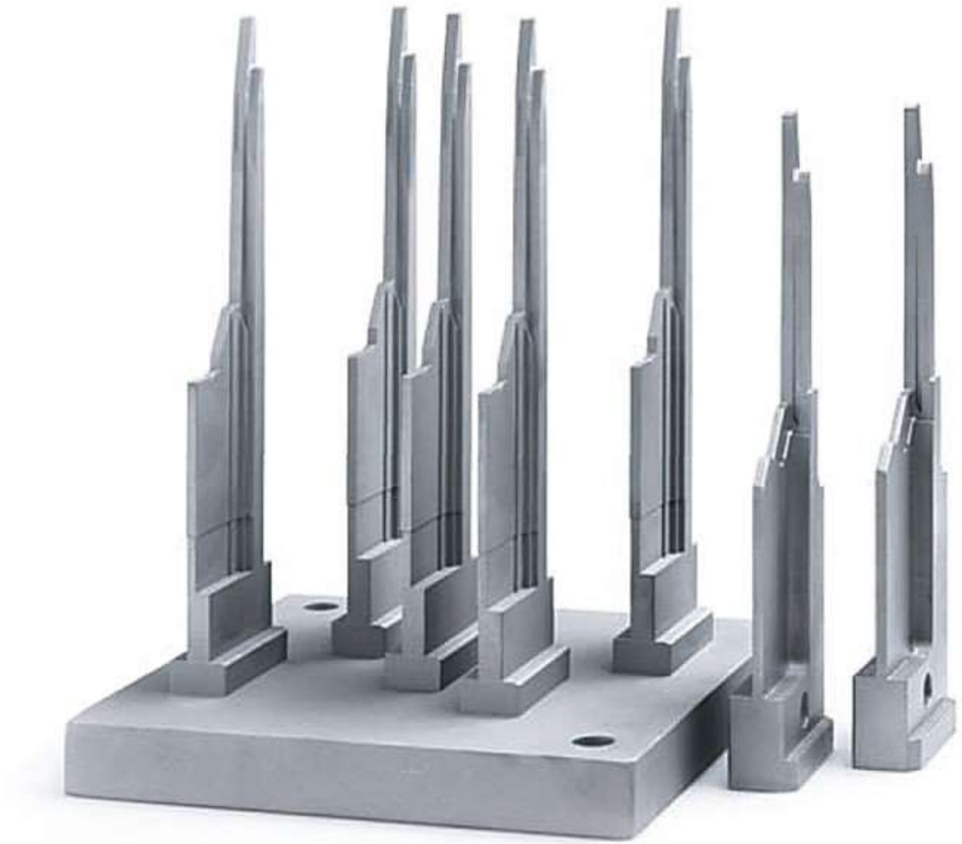


SLM 280

Build Envelope (L x W x H)	**280 x 280 x 365 mm^3 reduced by substrate plate thickness**
3D Optics Configuration, Dual Configuration: with switching unit	Single (1x 400 W), Twin (2x 400 W), Dual (1x 400 W und 1x 1000 W); Single (1x 700 W), Twin (2x 700 W), Dual (1x 700 W und 1x 1000 W) IPG fiber laser
Build Rate	up to 55 cm^3/h
Variable Layer Thickness	20 µm - 75 µm
Min. Feature Size	150 µm
Beam Focus Diameter	80 - 115 µm
Max. Scan Speed	10 m/s
Average Inert Gas Consumption in Process	2,5 l/min (argon)
Average Inert Gas Consumption Purging	70 l /min (argon)

Titanium

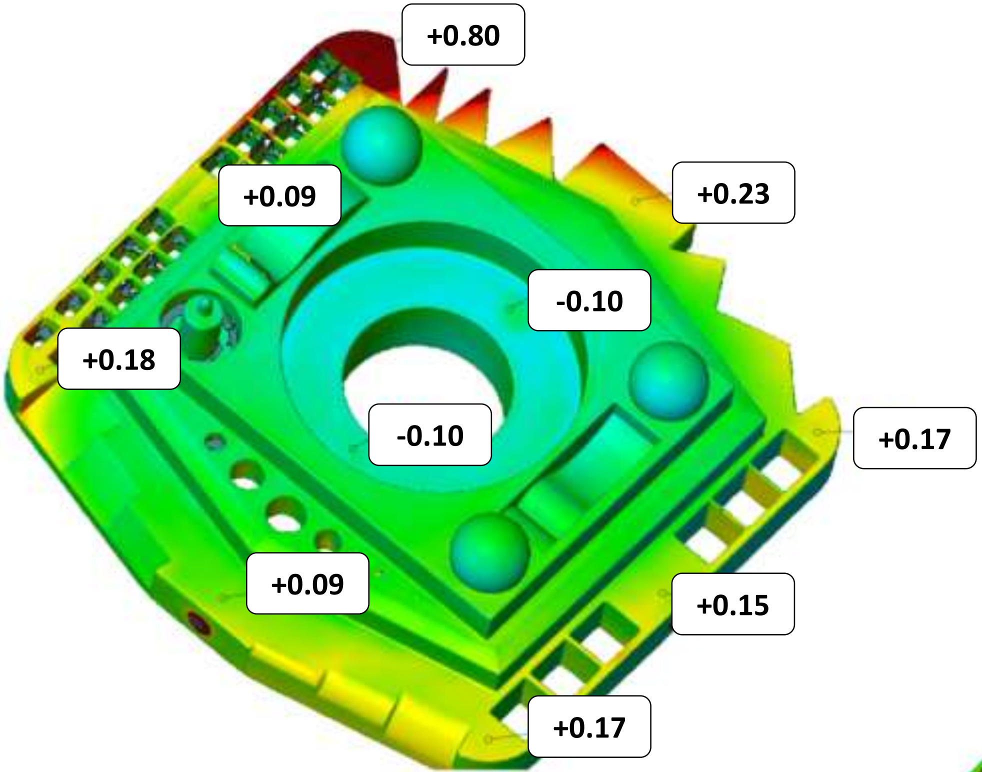
Tool Steel and Stainless Steel



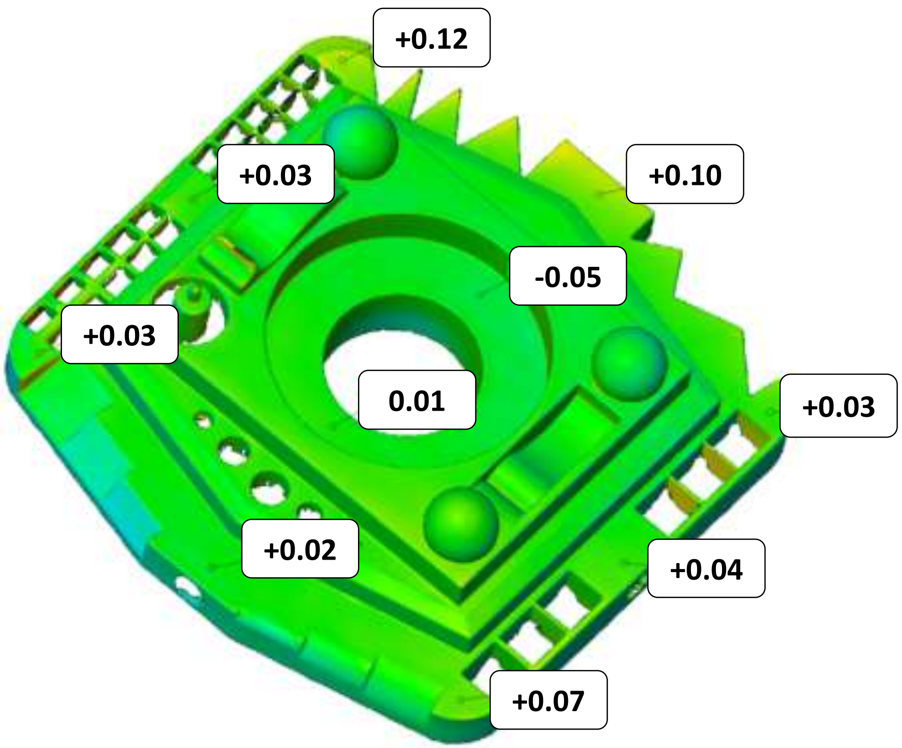
Aluminium

Cobalt-Chrome

Nickel based alloys



After annealing for stress relieving:



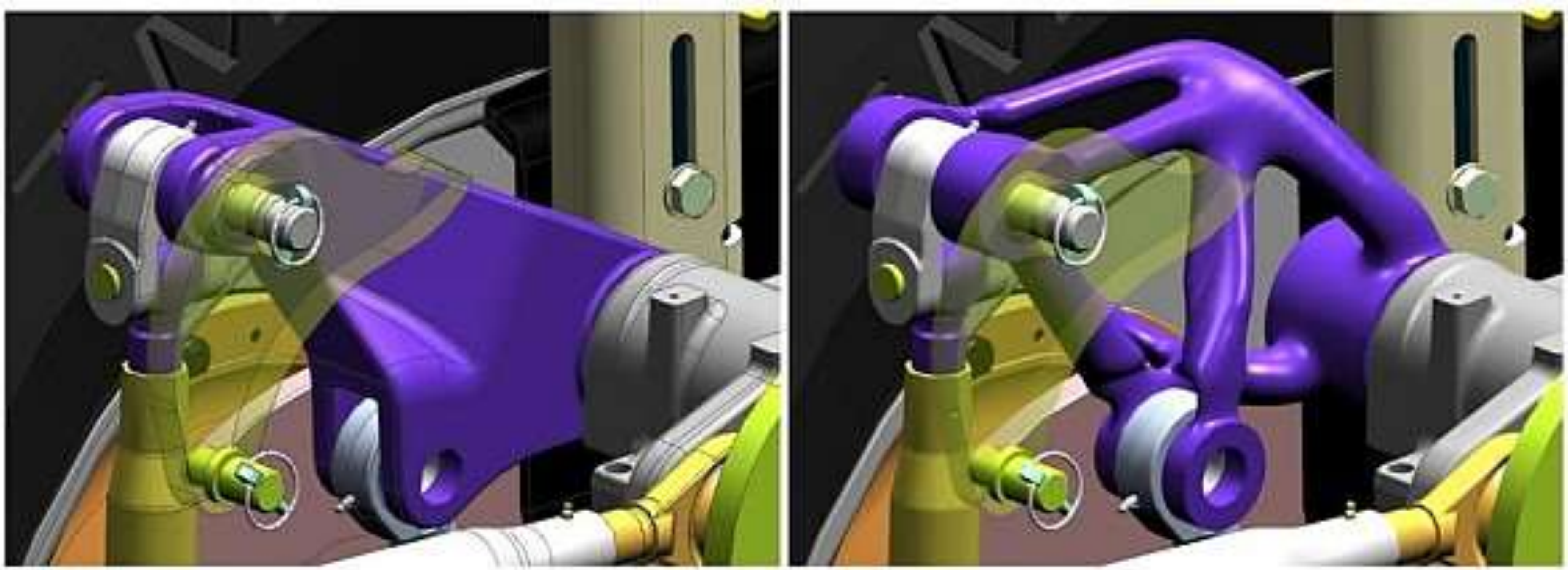
Advantages of SLM

- metal parts
- high quality of the final part, porosity <0.1%
- it is possible to create lightweight structures ↔ topological optimization of parts (new direction of design)

Disadvantages of SLM

- more complex post-processing - the part must be welded to the platform, otherwise it would be deformed due to internal stress → removal of supports is difficult
- annealing necessary to remove internal stress
- the whole process takes place in a protective atmosphere, longer preparation of the print, demands on filtration, etc.
- metal powders are risky from a health point of view, more complicated handling, special equipment required (protective suit, respirator, special vacuum cleaner,…)
- expensive printing

Example of topological optimization



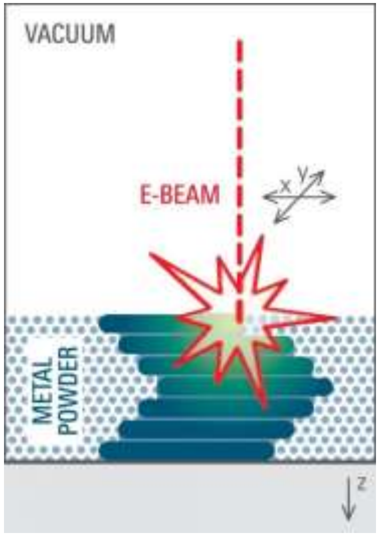
Comparison of a standard design of part and its bionic design with material weight savings of up to 30% (Siemens PLM Software)

Source: https://www.konstrukter.cz/zaciname-s-3d-tiskem-kovu-3-predvyrobni-etapa-topologicka-optimalizace

Example of topological optimization at TUL

Additive manufacturing – powder bed fusion

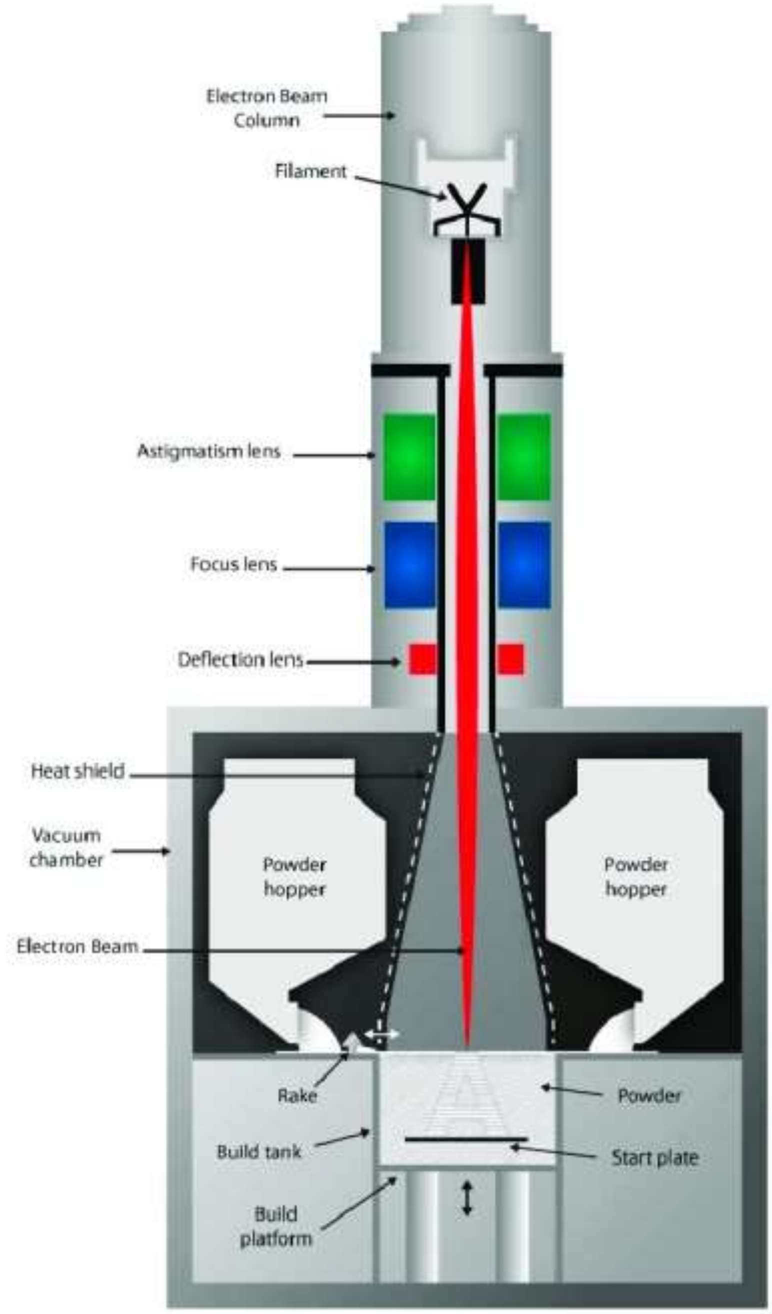
- powder bed fusion – an additive manufacturing process in which thermal energy selectively fuses regions of powder bed



Source: matca.cz/technologie/aditivni-technologie/

Powder Bed Fusion – Electron Beam Melting

The EBM method uses an electron beam as a heat source, which melts the metal powder in individual layers. The part is manufactured in a vacuum chamber to achieve high quality without the need for shielding gas. The advantage of EBM is that the heat source can maintain the annealing temperature during production. As a result, parts produced using EBM do not require subsequent heat treatment to reduce internal stresses compared to SLM. The disadvantage of this method can be the relatively rough surface of the part requiring surface treatments. Despite the higher purchase price of the vacuum system, this method is used, for example, to produce titanium parts in the aerospace industry.



Source: DOI: 10.3390/ma9060470

Additive manufacturing
– powder bed fusion

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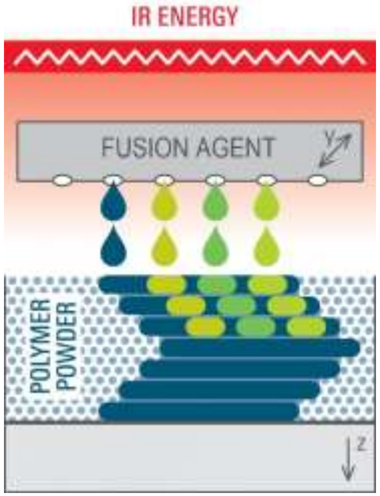
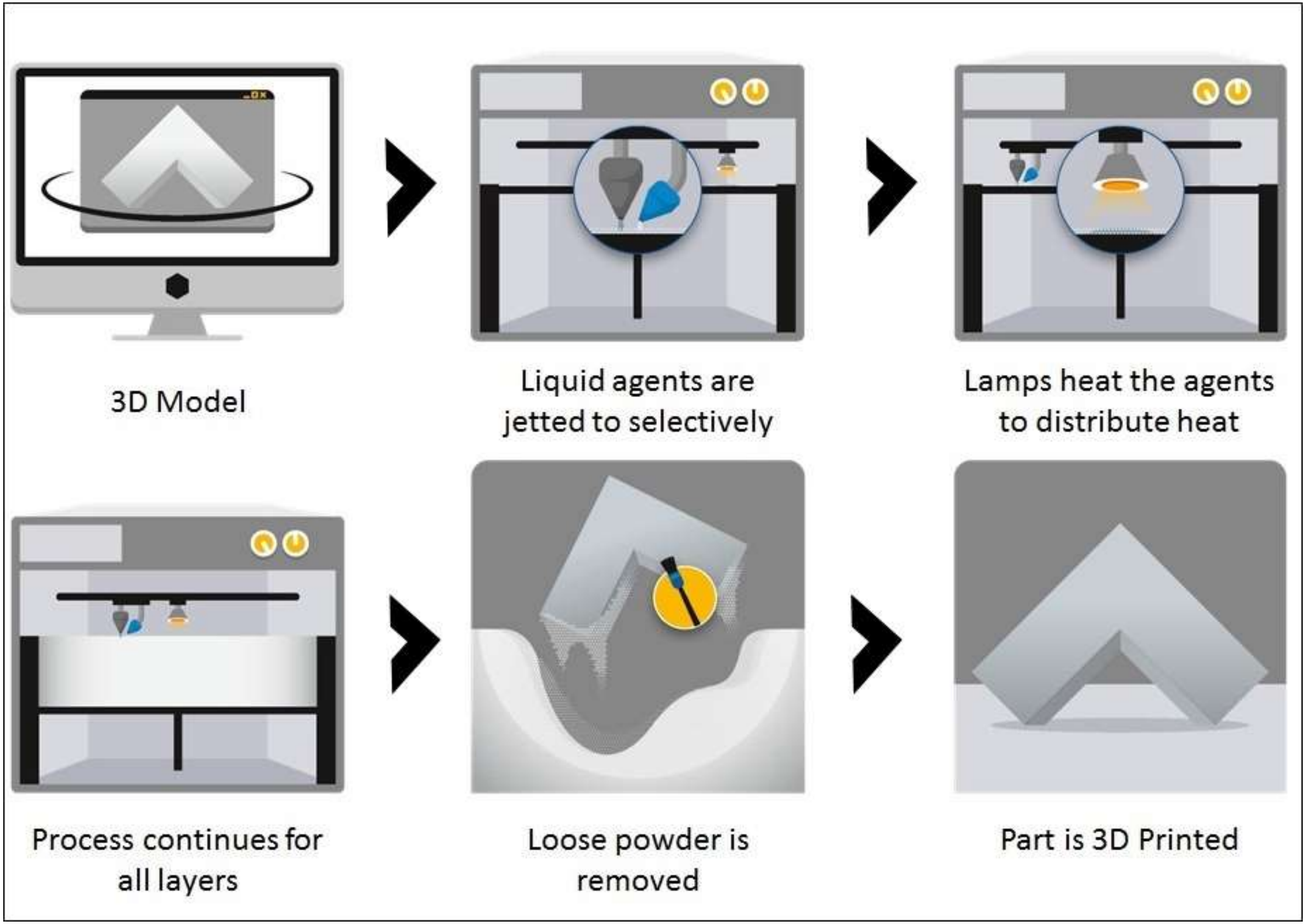


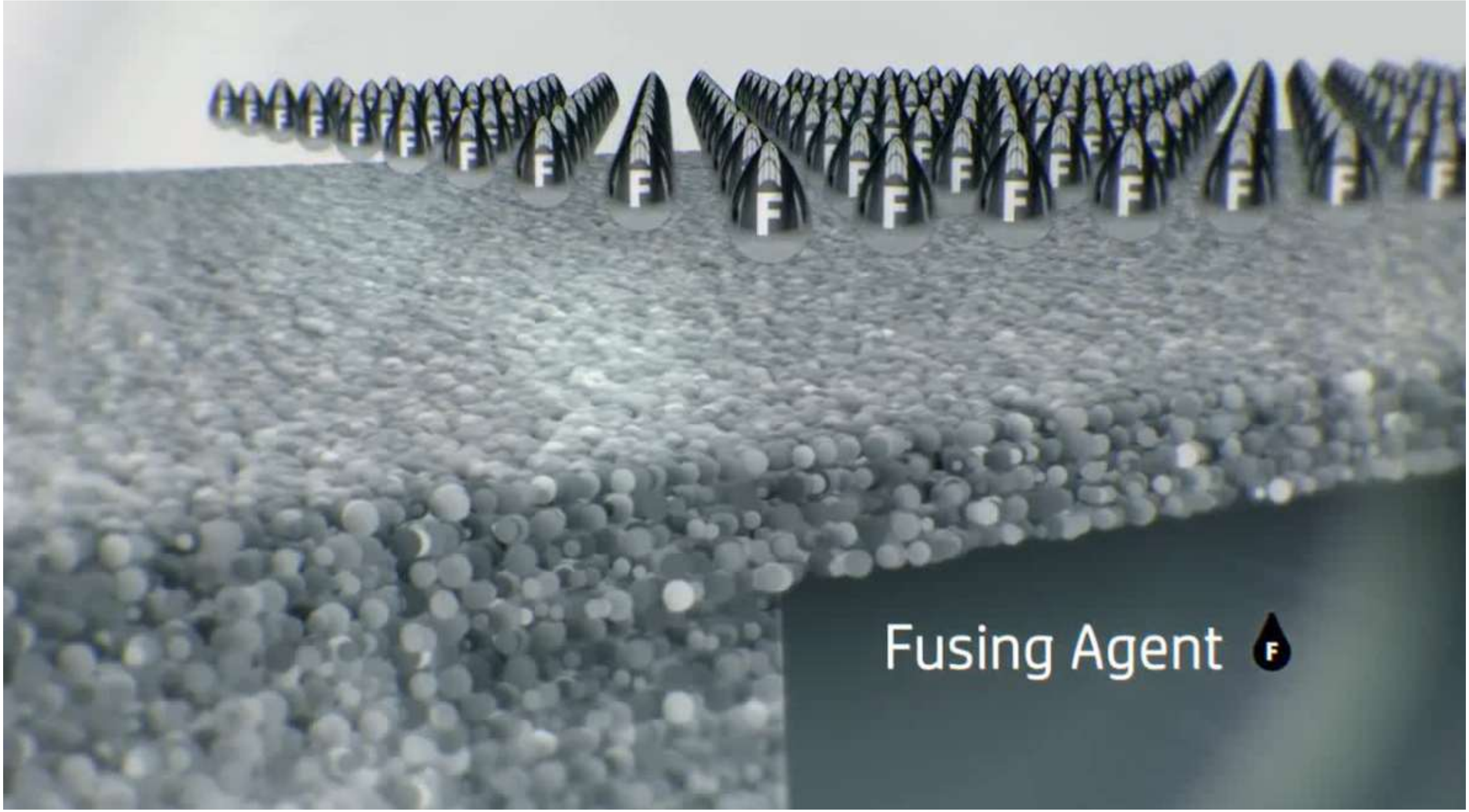
Zdroj: matca.cz/technologie/aditivni-technologie/

HP MultiJet Fusion



3D print from polyamide without the use of a laser

HP MultiJet Fusion



	HP MultiJet Printing
Použití	Functional parts made of PA or TPU with comparable properties as for parts injected into molds.
The size of the workspace	256 x 340 x 360 [mm]
Layer thickness	0.08 [mm]
Standard accuracy	± 0,3 mm
Material options	PA12, TPU
Recommended minimum wall thickness	1.0 mm, u TPU 0,5 mm
Surface structure	Uncoated parts usually have a smooth surface with no visible layers and a stone gray color. Parts made with Multi Jet Fusion technology can be sandblasted and painted or impregnated.

Advantages of MJF

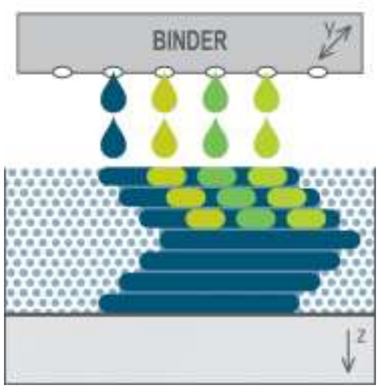
- Short manufacturing time
- Low porosity
- Small internal stress
- Homogeneous parts
- Excellent surface quality
- Parts with mechanical properties comparable to those of injection moulded parts
- A series of small components as a cost-effective alternative to injection moulding

Disadvantages of MJF

- Relatively low accuracy
- Long cooling time of parts after printing, when it is no longer possible to work with them (up to 16 hours when the entire workspace is filled)
- New technology - high prices

Additive manufacturing
– binder jetting

- binder jetting – an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder material



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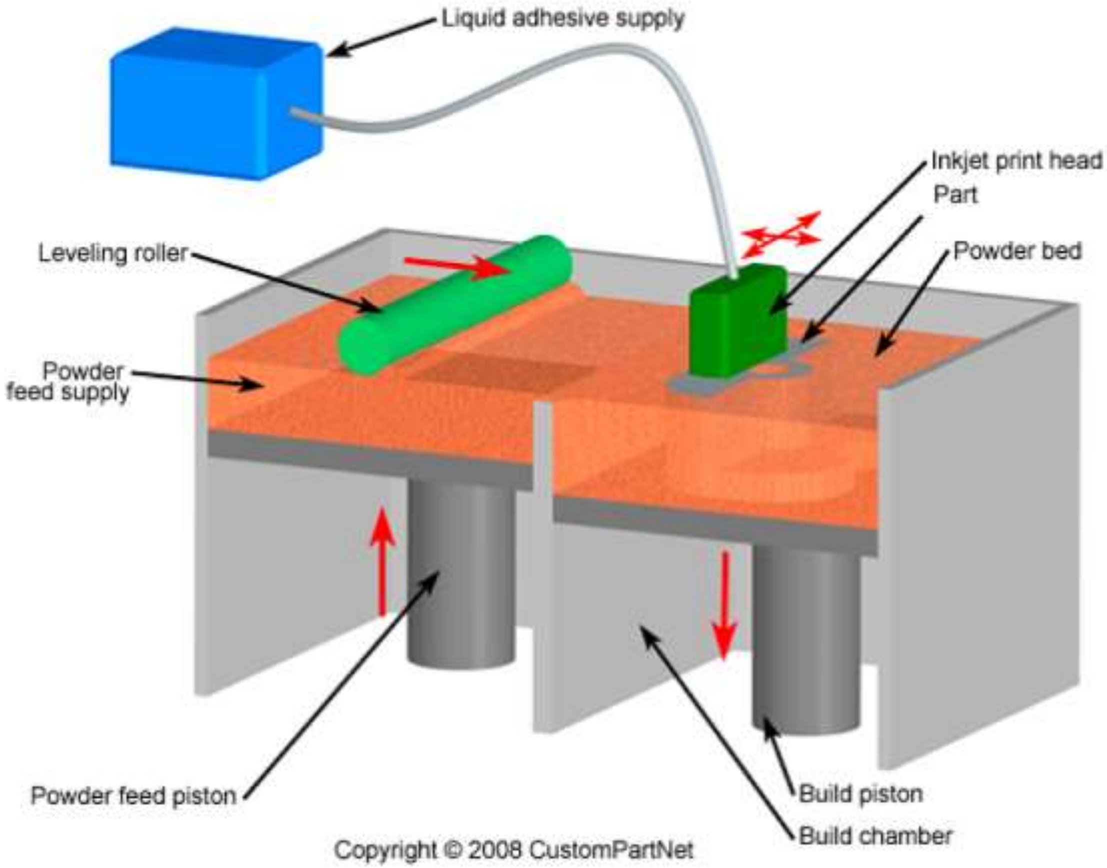
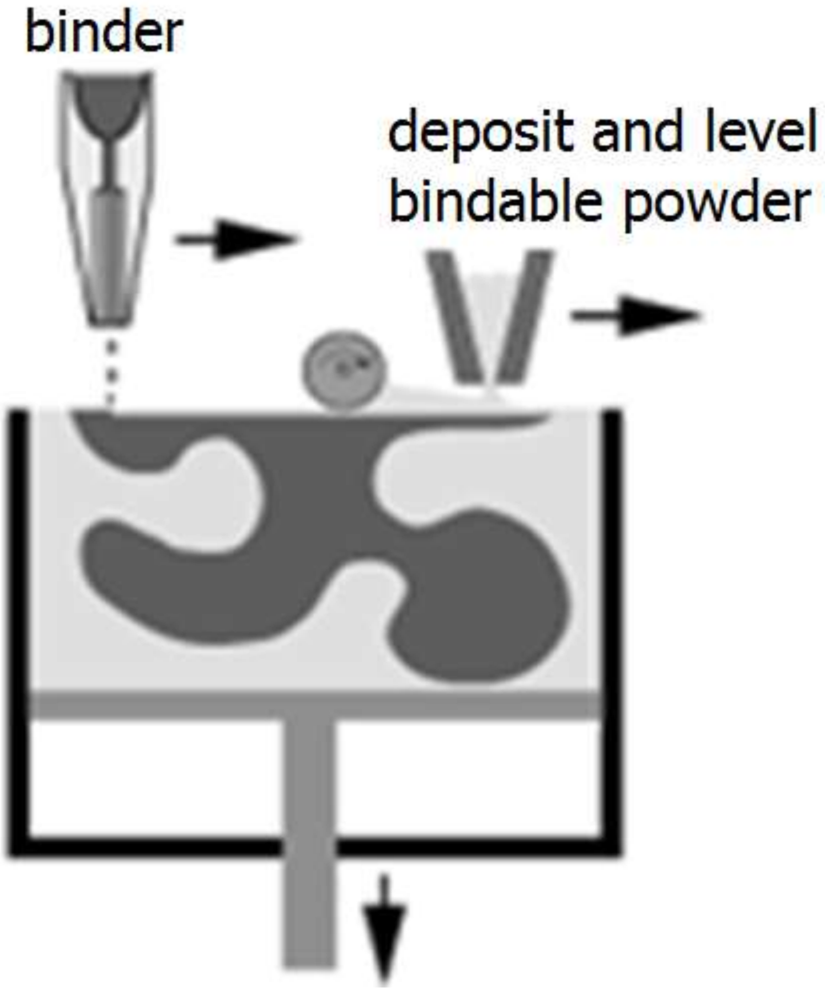
Binder jetting – 3D Printing



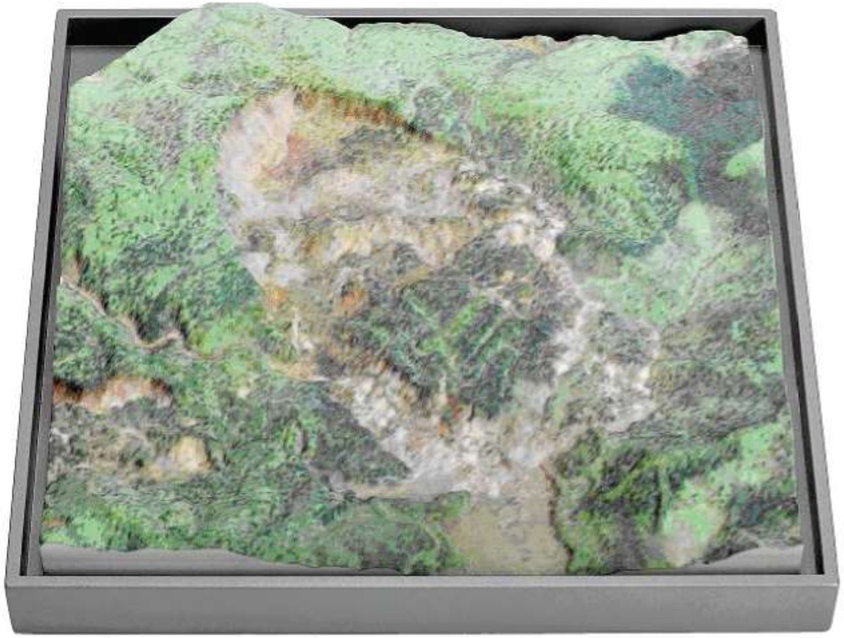
- on a similar principle as an inkjet paper printer
- the material is a powder into which the binder is selectively jetted
- the unprocessed powder remains in the work area and also serves as a support for further layers, it is recycled after printing and reused

3D Printing



Binder jetting – 3D Printing

	ColorJet Printing (CJP - ZPrint)
Applications	Excellent for demonstration models with full color printing. Stiff with good impact strength.
Maximum Dimensions	250 x 380 x 200 [mm]
Layer Thickness	0.089–0.100 [mm]
Material Options	VisiJet PXL
Recommended Minimum Feature Size	1.0 [mm]




SERIES CONTROL VALVE

Advantages of 3DP

- Cheap and relatively fast building
- Suitable for office use
- It is possible to create colour models

Disadvantages of 3DP

- The basic materials used are few and they are not of a technological nature
- Relatively long curing time of the part - immediately after printing it is not possible to manipulate with the part
- The surfaces of the part are rough after finishing, they are not resistant to abrasion, they must be impregnated - extension of the part completion time

Other binder jetting technologies

Sand printing – jetting of resin into silica sand (e.g. for direct printing of moulds for metal casting)

- Max. dimensions 1800 x 1000 x 700 mm, can be glued to larger dimensions
- Very complicated shapes
- Print accuracy ± 0.3 mm
- Sand grain size 0.19 mm
- Breathability 180-300 GP, resp. 300-500 SI

http://www.modelarna-liaz.cz/technologie/44-sandprint-3d-tisk-pisku/

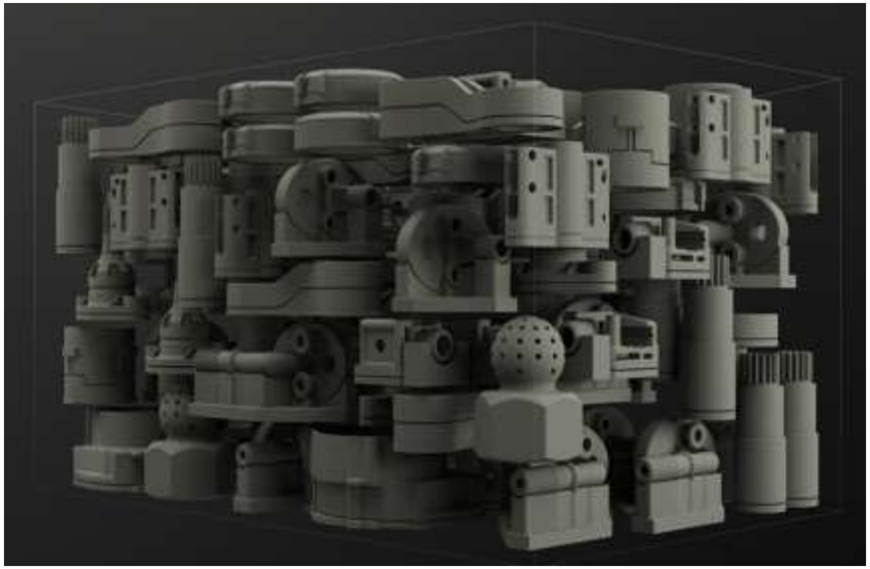
It is possible to cast into printed sand moulds:

- Light non-ferrous metals
- Heavy non-ferrous metals
- Cast iron
- Steel up to a casting temperature of 1500 ° C

Other binder jetting technologies

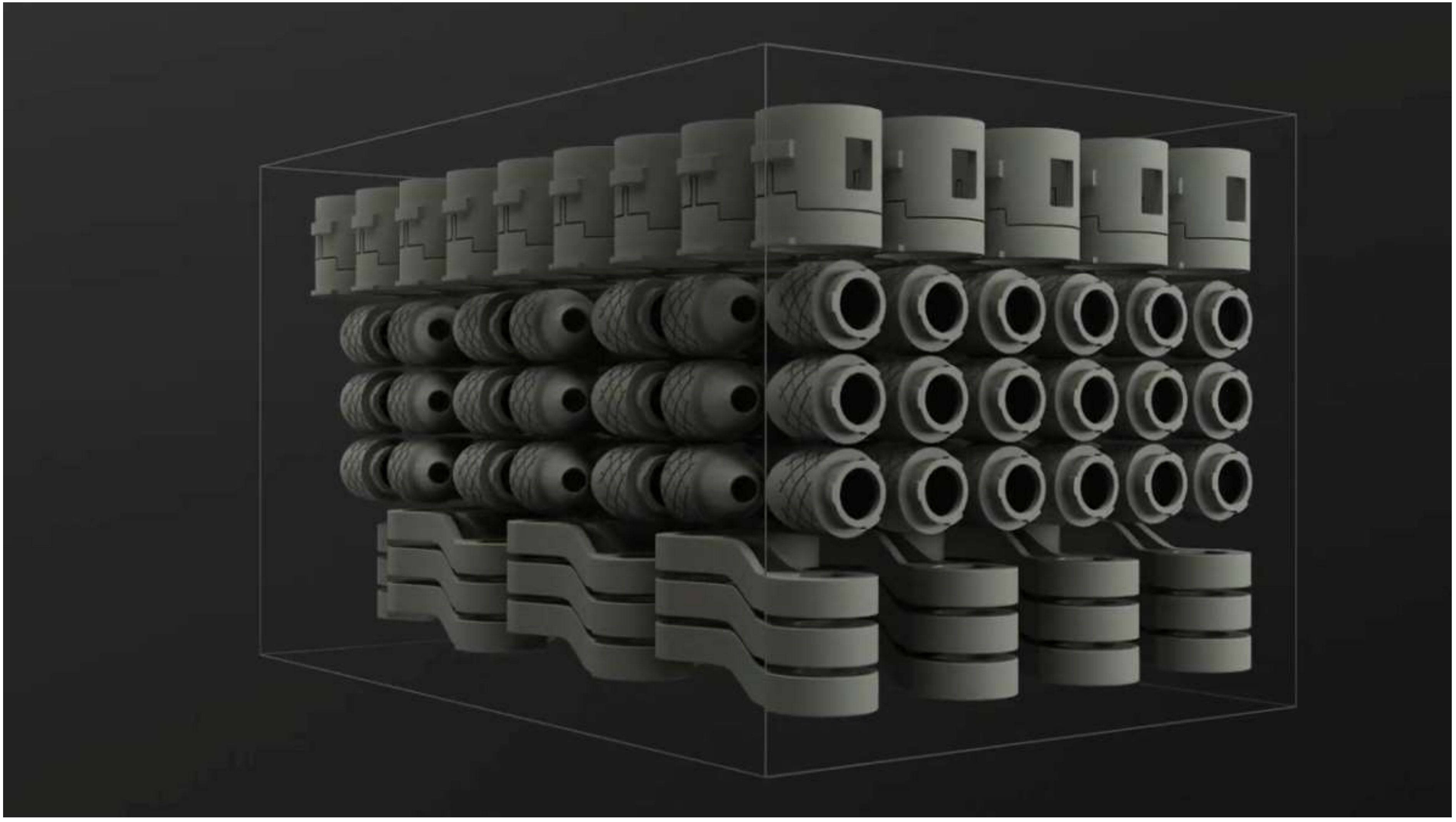
Metal binder jetting – Shop System from the company Desktop Metal

- gluing of metal powder for subsequent production of metal parts (debinding and sintering required)



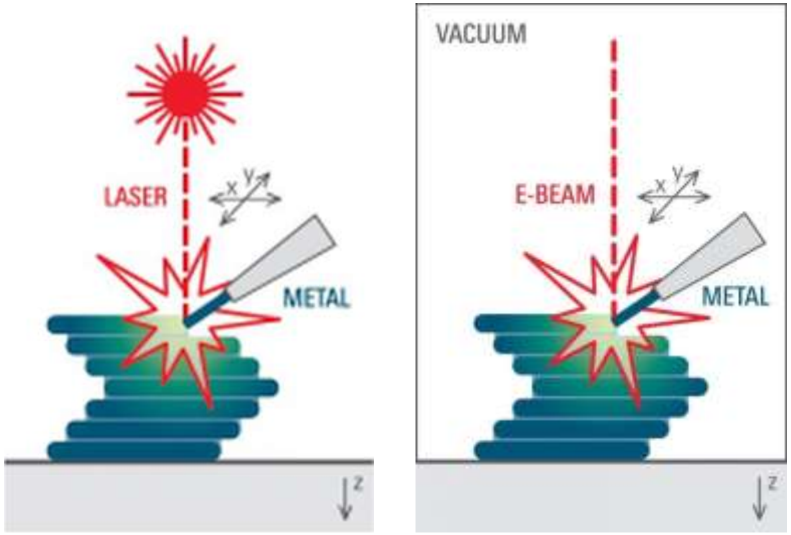
https://www.desktopmetal.com/products/shop

Metal binder jetting



Additive manufacturing
– directed energy deposition

- directed energy deposition – an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited



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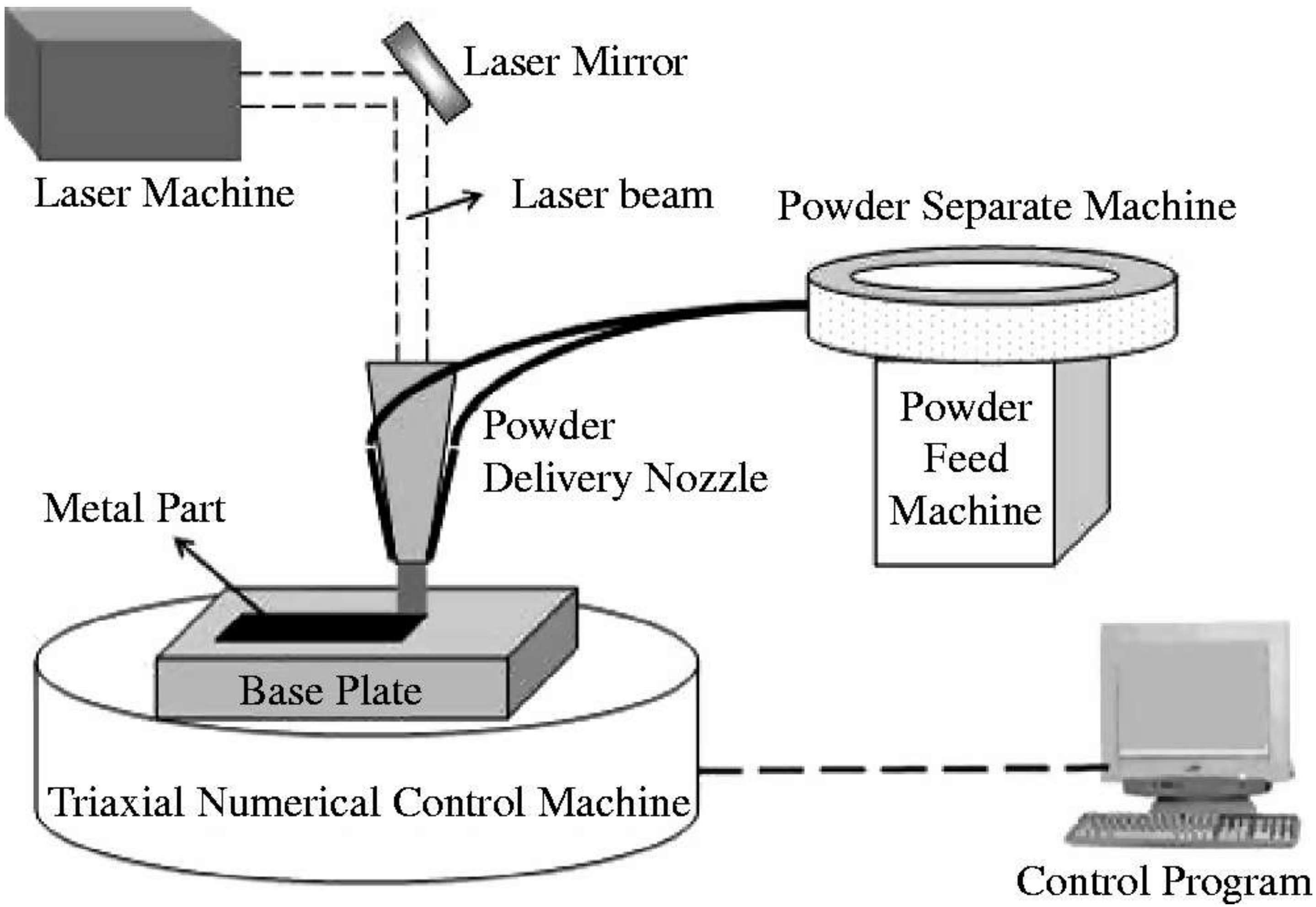
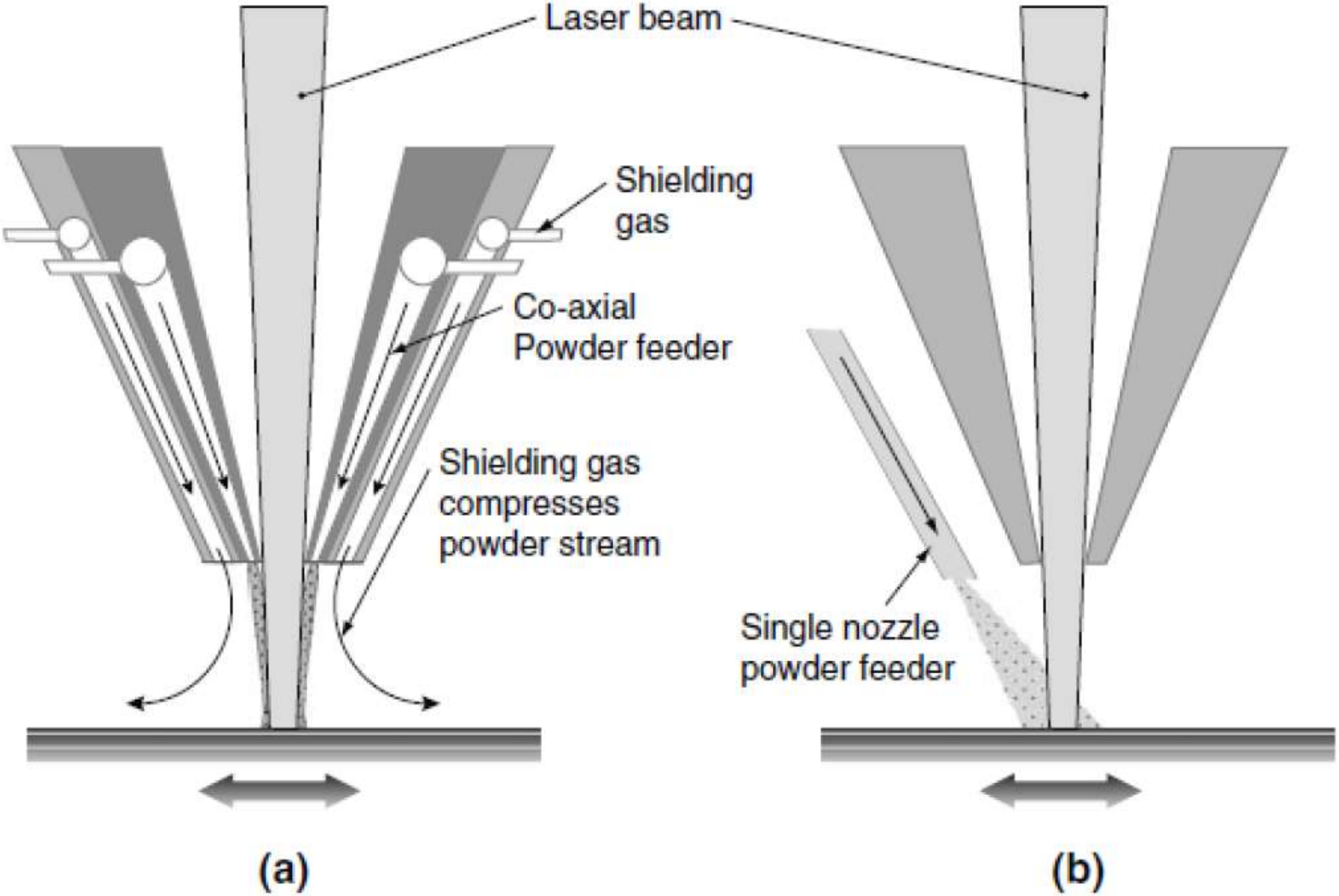
Directed Energy Deposition



Zdroj: http://blog.cafefoundation.org/?p=8410

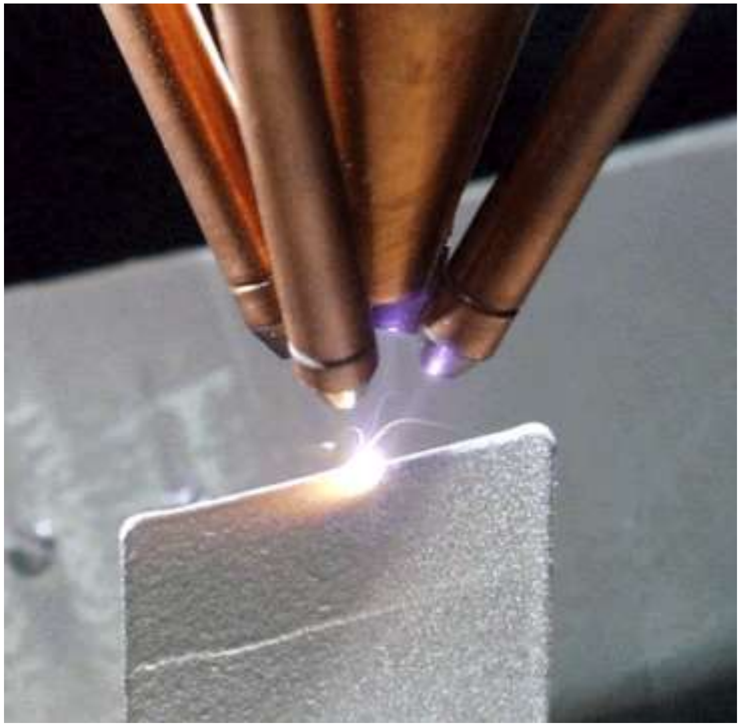
Directed Energy Deposition

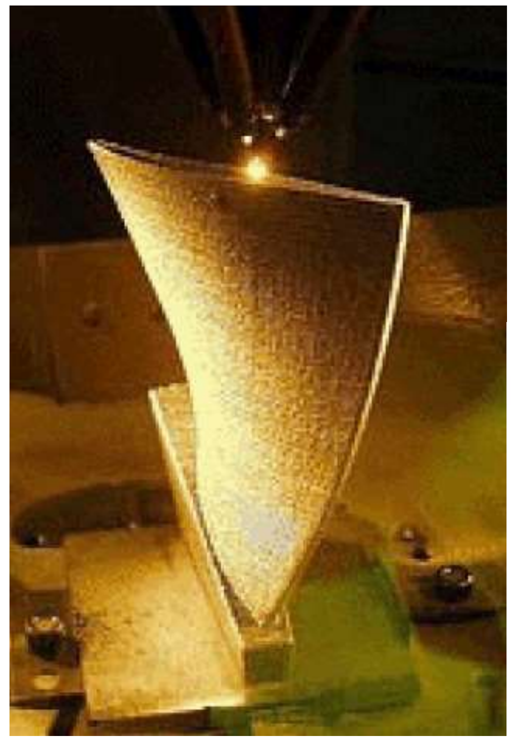


Directed Energy Deposition

LENS technology

Laser Engineered Net Shaping



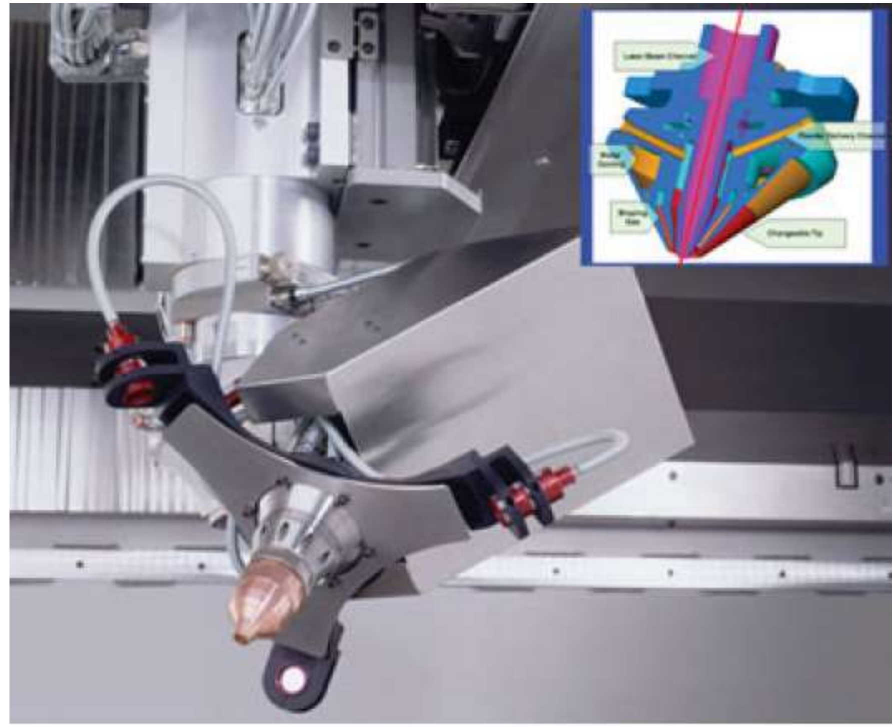


Zdroj: http://www.tms.org/pubs/journals/jom/9907/hofmeister/hofmeister-9907.html

LENS technology

POM Group

- University Of Michigan
- For repair of tools and dies

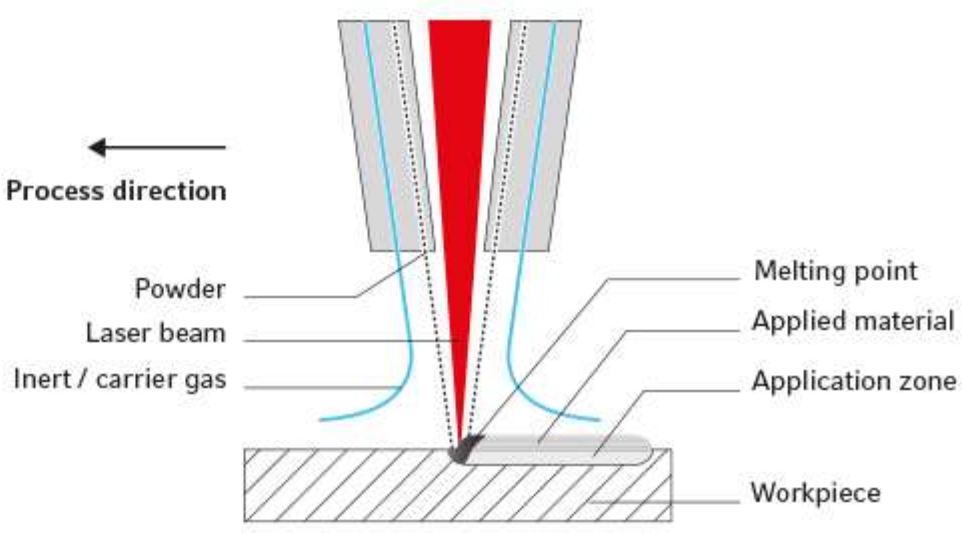


The POM group's patented approach to Direct Metal Deposition (DMD) includes cameras that measure the height of the melt and adjusts laser power to maintain even height.

POM
Precision Optical Manufacturing

Directed energy deposition

Laser welding of metal powder by very powerful laser, even with adaptive control of laser power.



Source: www.dmgmori.com/webspecial/journal_2014_1/en/lasertec-65.htm

Directed energy deposition

Typical technologies:

- **DED** – summary abbreviation (Directed Energy Deposition)
- **Laser Cladding** – DMG Mori
- **MPA** (Metal Powder Application) – Hermle
- **MIG/MAG** welding – Kovosvit MAS (WeldPrint)

see also hybrid technologies at the end of the lectures