Laser Aided Additive Manufacturing

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Subtractive vs Additive manufacturing

CAD model → Work piece → Subtractive tool path → Machine piece by piece → Retrieve, clean up & assemble → Ready to ship

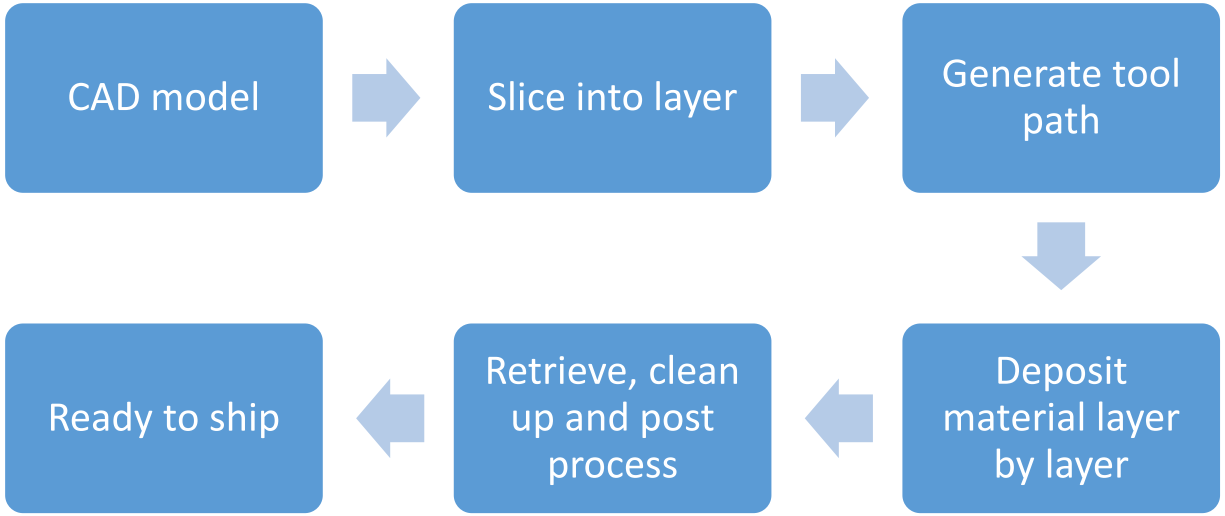
CAD model → Slice into layer → Generate tool path → Deposit material layer by layer → Retrieve, clean up & post process → Ready to ship

additive manufacturing (AM), *n*—a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication.

UNE-EN ISO/ASTM 52900:2017 Additive manufacturing - General principles - Terminology (ISO/ASTM 52900:2015). ; , 2017. doi: https://www.astm.org/cgi-bin/resolver.cgi?3PC+UNE+UNE-EN ISO/ASTM 52900:2017+en-US

https://en.wikipedia.org/wiki/Egyptian_pyramids

Why additive manufacturing?



- Design freedom
- Improved quality
- Flexibility in capability
- Eco-friendly
- One stop shop
- Time to market
- Cost savings

Additive manufacturing materials

Metals

https://www.metal-am.com/gkn-reports-development-new-metal-powder-additive-manufacturing/

https://www.grainger.com/product/20YE02

- Al alloys
- Fe alloys
- Ni alloys
- Cu alloys
- Co alloys
- Ti alloys

- SAMs’
- HEAs
- MMCs’
- Etc.

Non-metals

https://www.spilasers.com/application-additive-manufacturing/additive-manufacturing-materials/

https://www.kennametal.com/fr/fr/products/sintec-ceramics/ceramic-powders.html

- Thermo plastics
  - PLA
  - ABS
  - Nylon
  - TPE

- WAX etc.
- Photo polymers
- Ceramics

Additive manufacturing components

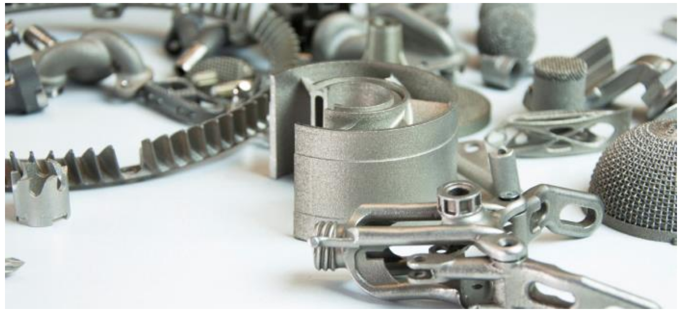
https://www.metal-am.com/gkn-reports-development-new-metal-powder-additive-manufacturing/

https://www.grainger.com/product/20YE02

https://www.spilasers.com/application-additive-manufacturing/additive-manufacturing-materials/

https://www.kennametal.com/fr/fr/products/sintec-ceramics/ceramic-powders.html

https://www.wevolver.com/article/additive.manufacturing.a.stepping.stone.to.future.technologies



https://3dprintingindustry.com/news/beamit-and-bercella-to-develop-rd-projects-for-additive-manufacturing-and-carbon-fiber-parts-170827/

https://additive.lincolnelectric.com/

https://www.3dnatives.com/en/optimizing-projects-with-fdm-and-sla-3d-printing-211120194/#!

https://www.3dnatives.com/en/ceramic-3d-printing-170420194/

Metal AM, who makes it ? Who uses it ?

OEMs

GE
Desktop Metal
eos
SLM Solutions GmbH
TRUMPF
OPTOMEC
RENISHAW apply innovation™
3D SYSTEMS
hp
VELO 3D
ExOne
NORSK TITANIUM
MELTIO
InssTek DMT® Metal 3D Printing Specialist
MELD MANUFACTURING
LINCOLN ELECTRIC
xerox
GEFERTEC
Arcam EBM A GE Additive Company
CONCEPTLASER a GE Additive company
COHERENT

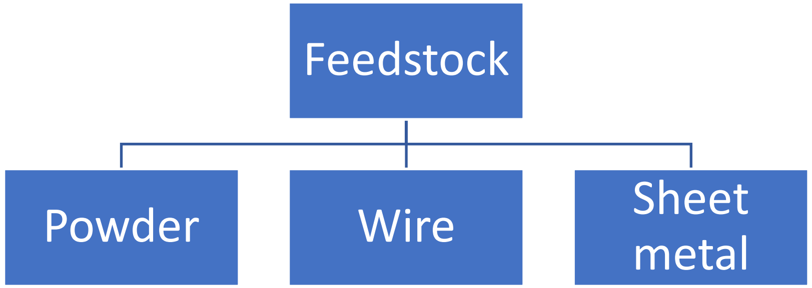
...... and many more

Customers

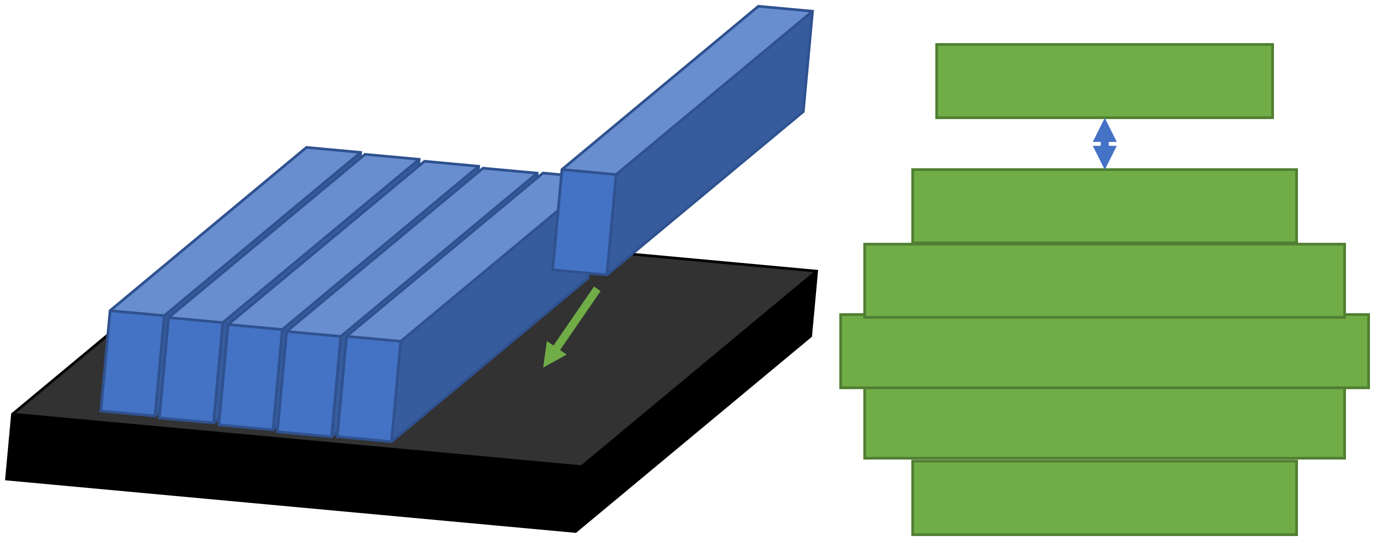
GE
AIRBUS
GKN AEROSPACE
BOEING
Pratt & Whitney A United Technologies Company
SPIRIT AEROSYSTEMS
LOCKHEED MARTIN
United States Army
United States Navy
United States Air Force
United States Space Force Department of the Air Force MMXIX
Relativity
BLUE ORIGIN
NASA
ARCONIC
BMW
CATERPILLAR
SAMSUNG
Baker Hughes
Ford

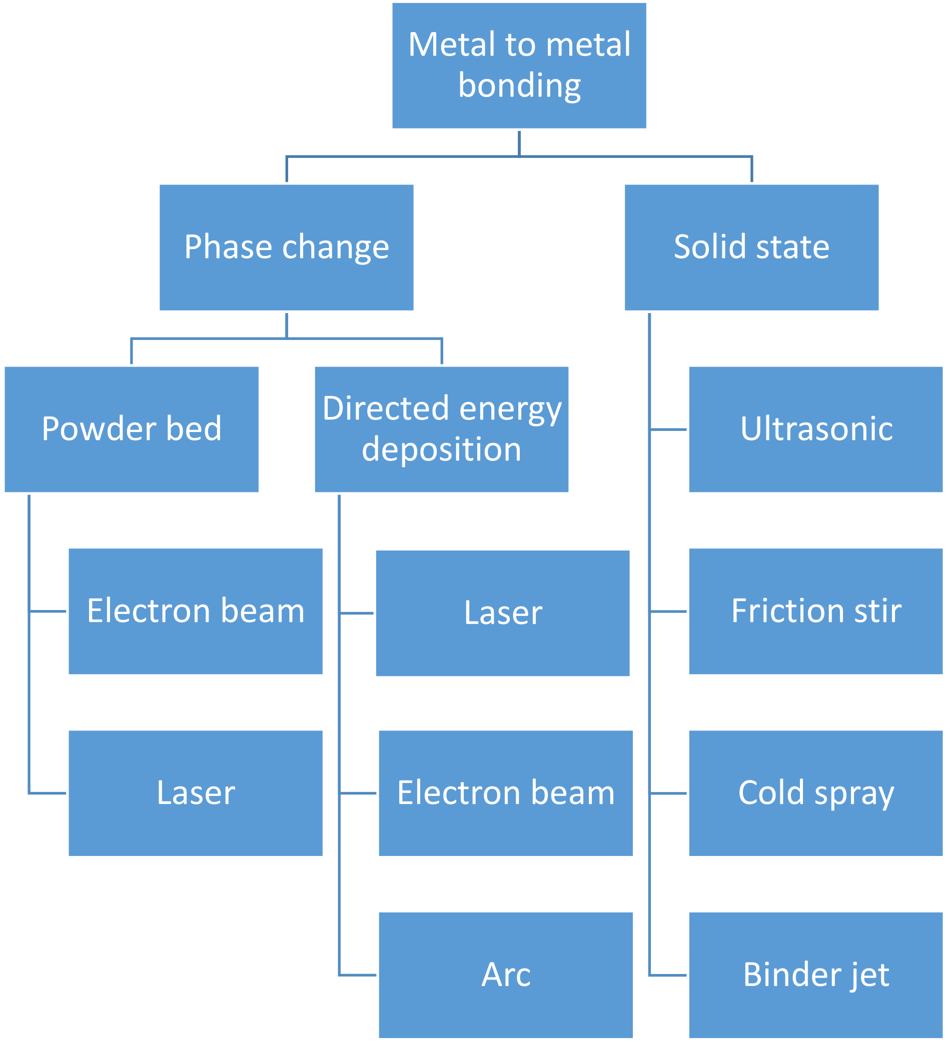
...... and many more

Metal fusion



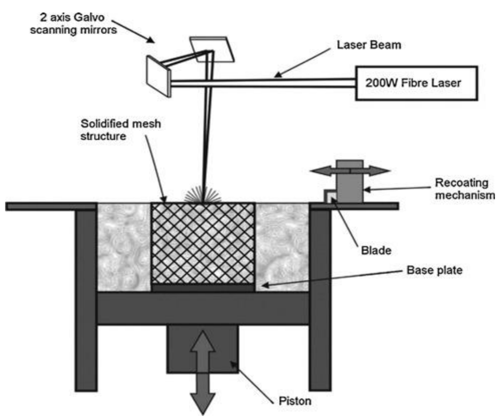
Bead to bead & layer to layer bonding





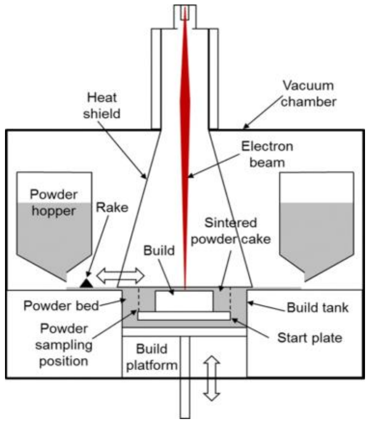
Metal additive manufacturing

Laser powder bed fusion



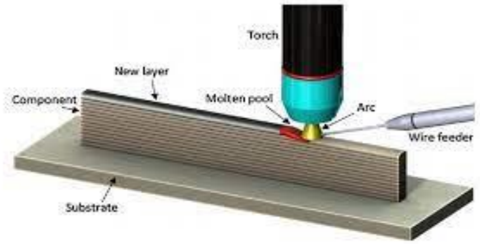
Xin Zhou, et. Aa.. Textures formed in a CoCrMo alloy by selective laser melting, Journal of Alloys and Compounds, Volume 631, 2015, Pages 153-164, ISSN 0925-8388,

E-beam powder bed fusion



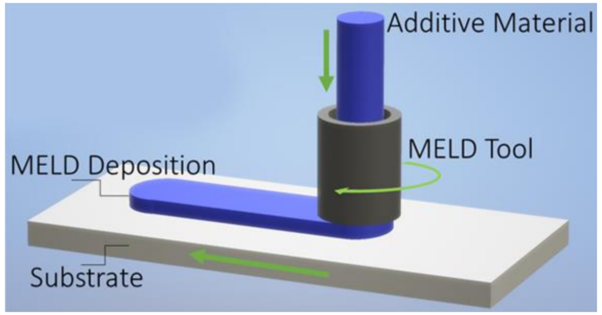
Gruber, H., Henriksson, M., Hryha, E. *et al.* Effect of Powder Recycling in Electron Beam Melting on the Surface Chemistry of Alloy 718 Powder. *Metall Mater Trans A* **50,** 4410–4422

Wire arc deposition



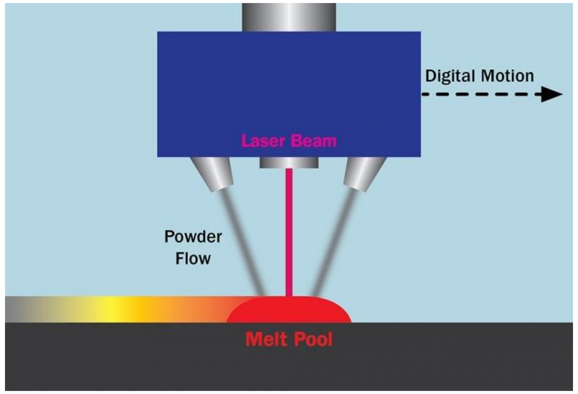
Hamedi, Azarakhsh. (2019). Bayesian networks in additive manufacturing and reliability engineering. 10.13140/RG.2.2.23981.54248.

Friction stir deposition



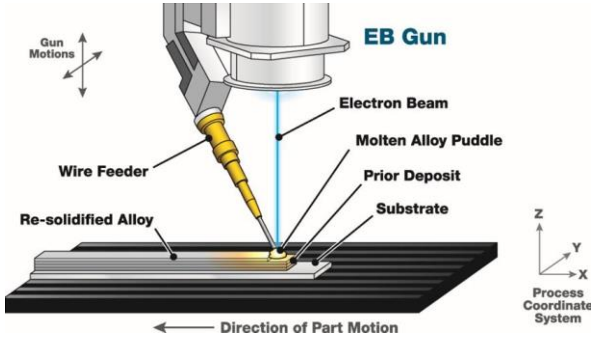
https://www.metal-am.com/meld-to-offer-unique-metal-additive-manufacturing-process/

Laser blown powder deposition



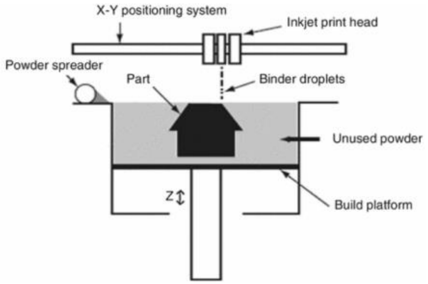
https://optomec.com/optomec-improves-additive-repair-technique/

E-beam wire deposition



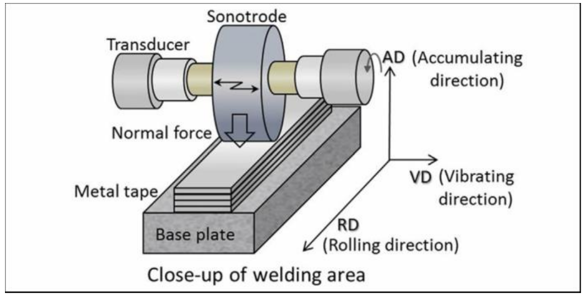
https://www.additivemanufacturing.media/articles/the-possibilities-of-electron-beam-additive-manufacturing

Binder jet



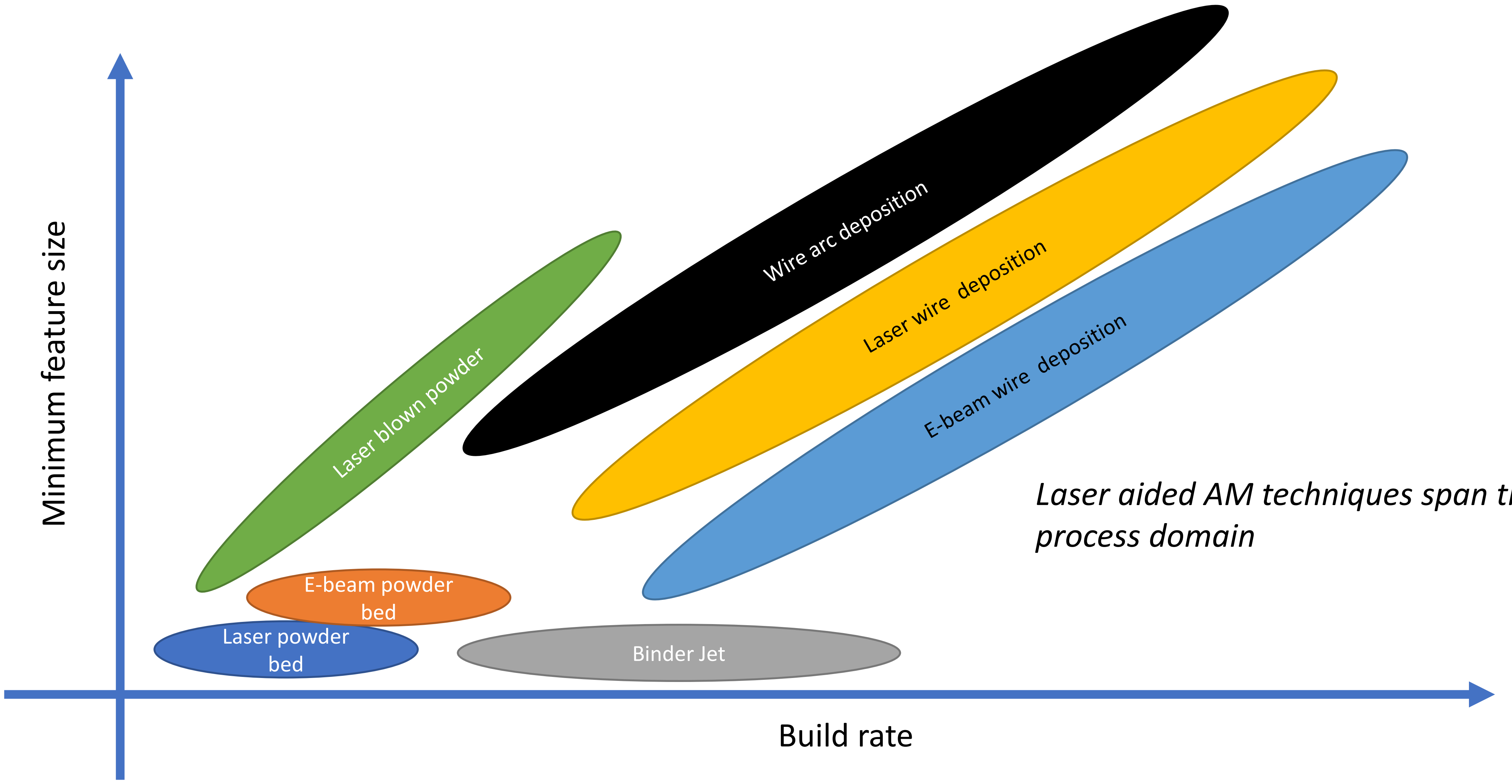
http://canadamakes.ca/what-is-binder-jetting/

Ultrasonic deposition



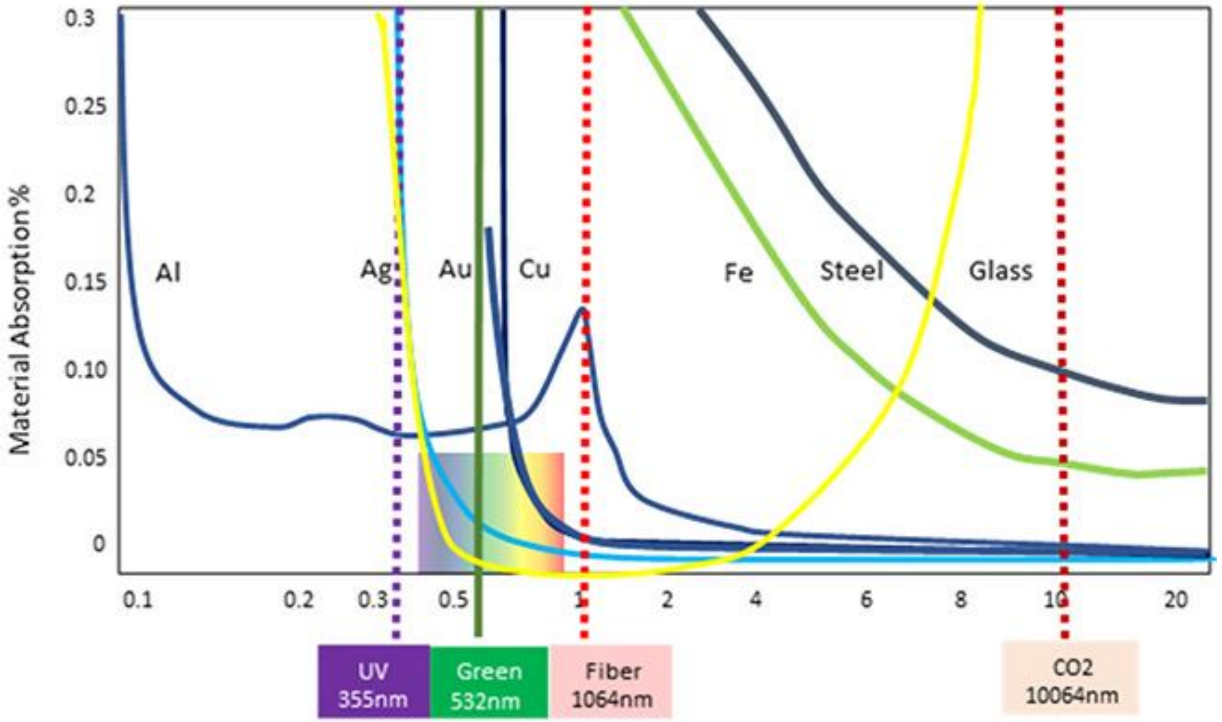
https://www.insidemetaladditivemanufacturing.com/blog/ultrasonic-additive-manufacturing

Comparing modalities



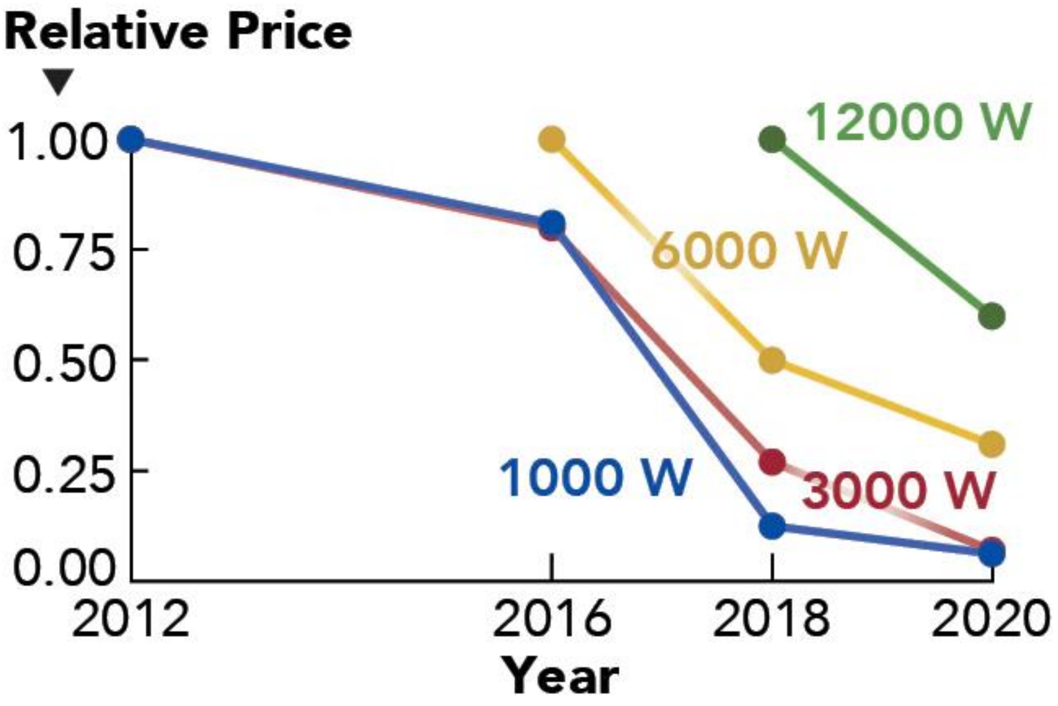
Laser aided AM techniques span the largest process domain

Lasers



https://www.controllaser.com/blog/2018/11/22/how-can-i-select-the-right-laser-source-for-my-application/

Prices of Fiber lasers in China



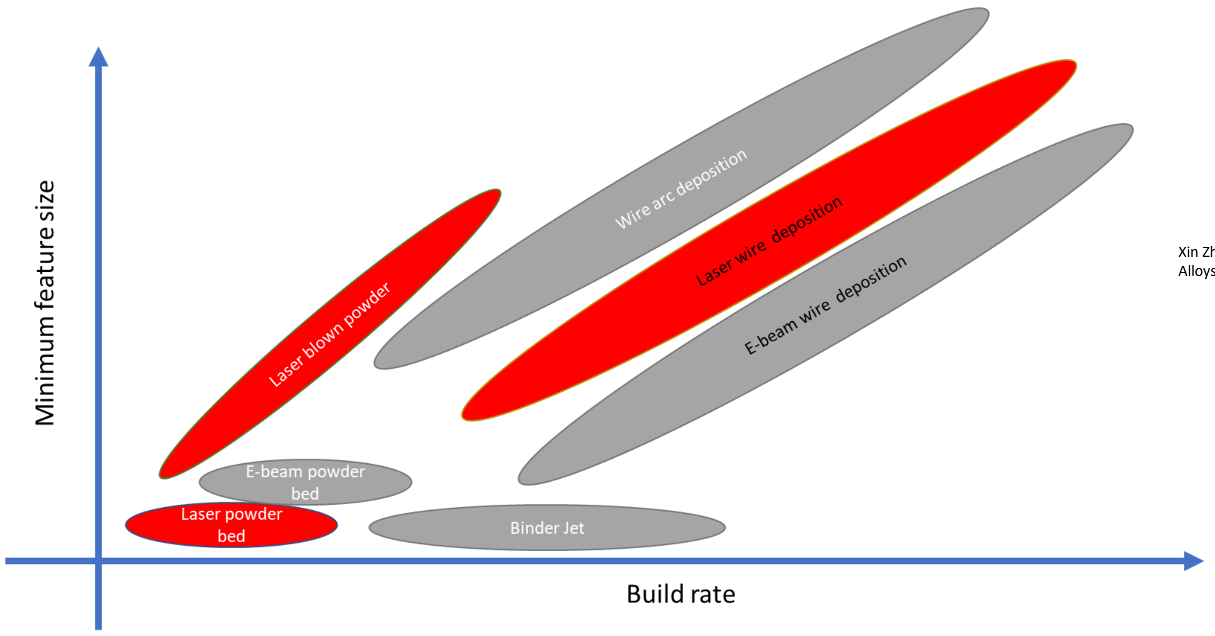
https://www.industrial-lasers.com/home/article/14068621/the-status-of-industrial-lasers-in-china

- Visible lasers
- IR lasers
  - Fiber lasers
  - CO2 lasers
  - Diode lasers

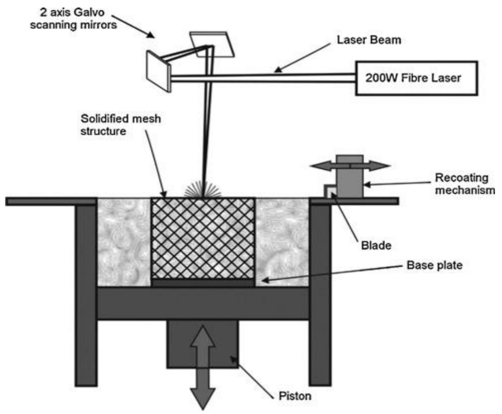
- Al alloys
- Fe alloys
- Ni alloys
- Cu alloys
- Co alloys

- Ti alloys
- SAMs'
- HEAs
- MMCs'
- Etc.

Laser aided additive manufacturing



Laser powder bed fusion



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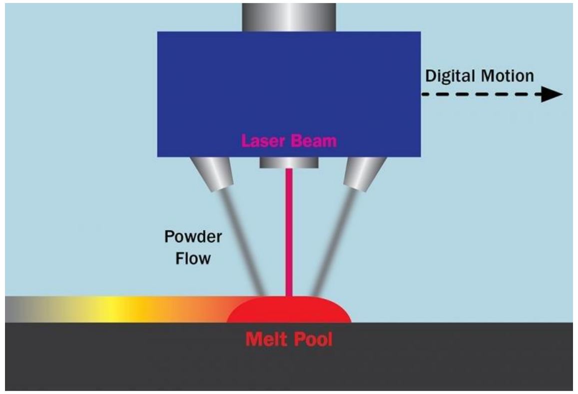
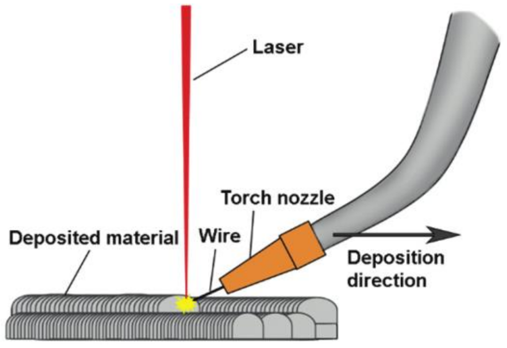
Laser blown powder deposition



https://optomec.com/optomec-improves-additive-repair-technique/

Laser wire deposition

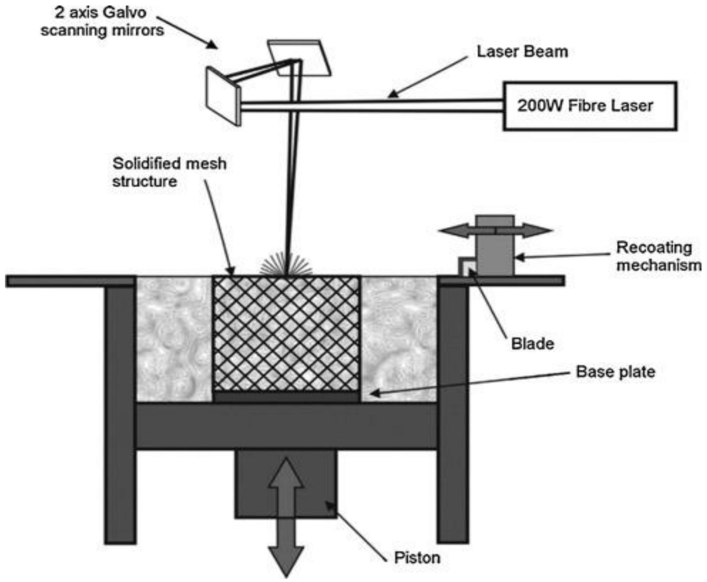


Segerstark, Andreas. (2017). Laser Metal Deposition using Alloy 718 Powder: Influence of Process Parameters on Material Characteristics.

Laser powder bed fusion

- Very fine spot size (50-150micron diameter)
- Powder size distribution 15 to 45 micron
- Very fast scan speeds
  - Galvo mirrors
- Support structures

Laser powder bed fusion



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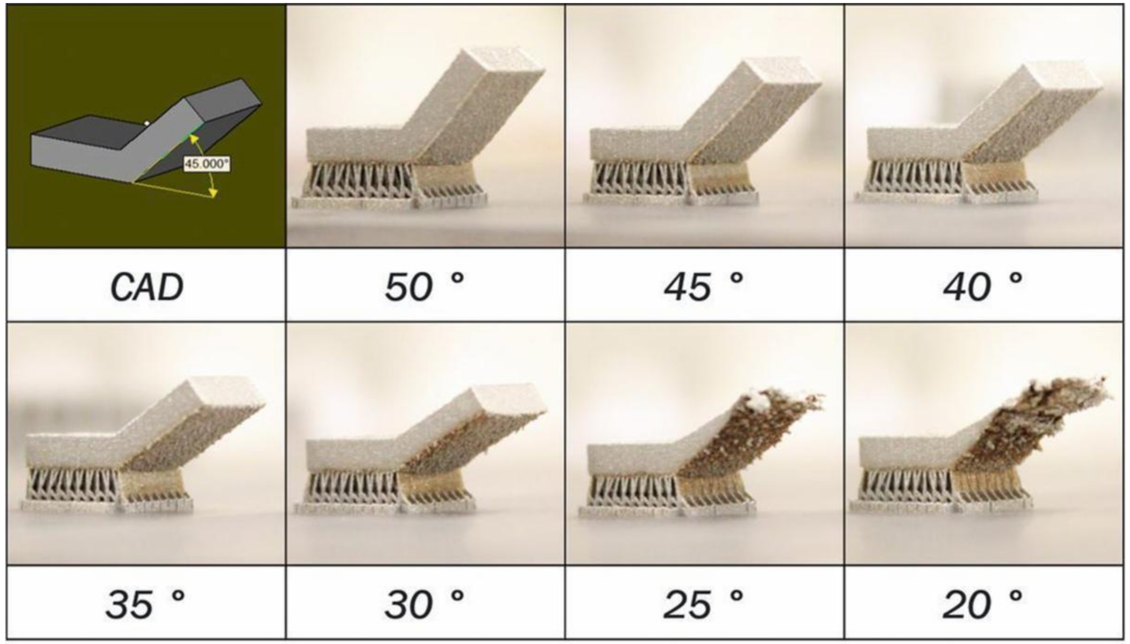
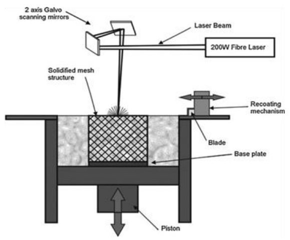


https://www.cadalyst.com/design-related-technologies/3d-printers/am-support-structures-need-impact-and-elimination-strategies

Laser powder bed fusion



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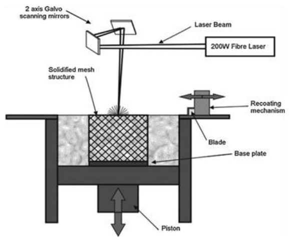

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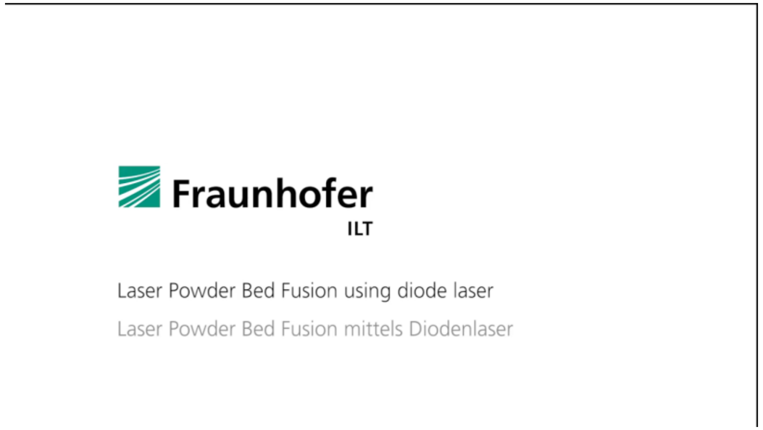
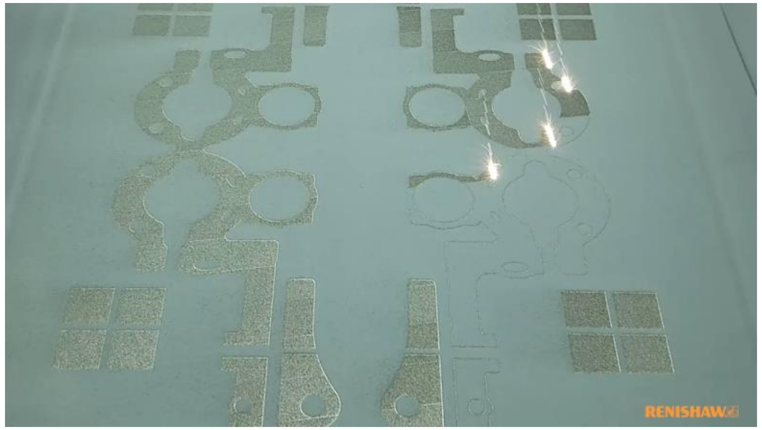


https://www.youtube.com/watch?v=Wrxef_4DL_g

https://www.youtube.com/watch?v=Mjf6oaMVWr8



https://www.youtube.com/watch?v=XTXwTBup-co

https://www.youtube.com/watch?v=v9iWMiblRrI

- Several commercial machines available
- Maximum part dimensions dependent on the build chamber dimensions
- 10s of process parameters
- Multiple lasers could be working synchronously
- Fiber lasers
  - Continuous
  - PWM
- Wattages up to 500W

RENISHAW apply innovation™

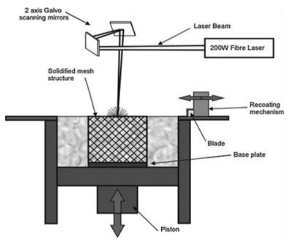
SLM Solutions GmbH

VELO 3D

CONCEPTLASER a GE Additive company

Typical workflow

Laser powder bed fusion



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Material and machine setup

Acquire and characterize powder → Setup a process DOE for process domain eval. → Run experiments and optimize for density → Identify viable process domain → Optimize parameters for performance

Identify secondary process parameters → Setup a process DOE for process domain eval. → Optimize for supports, roughness, overhangs etc. → Identify viable process domain → Further optimize for productivity

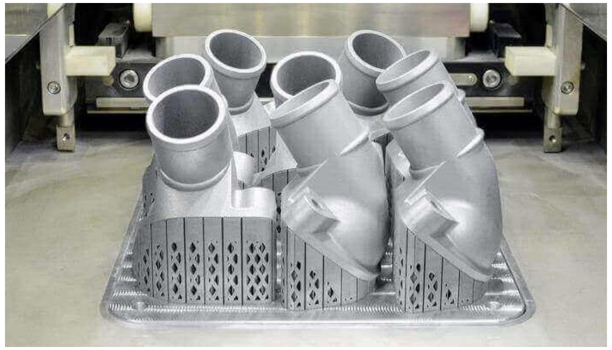
Part build

Identify part geometry → Design build layout, support structures → Evaluate buildability, stress evolution and optimize → Build part, pass/ fail → Post process

Applications

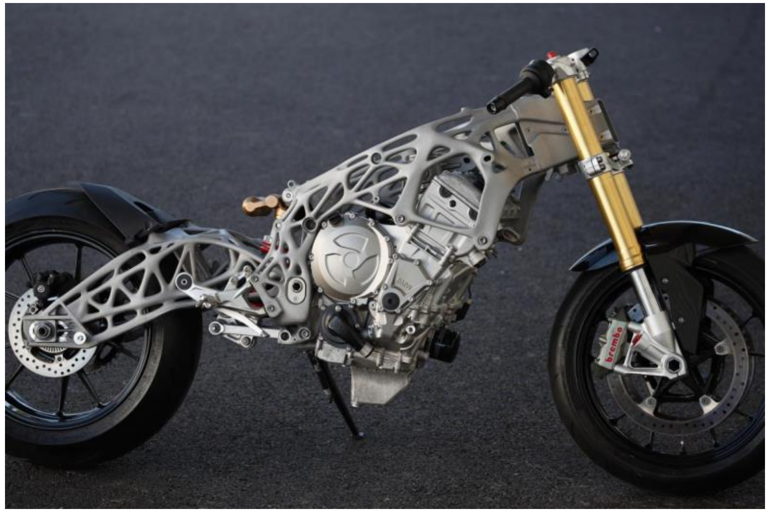
- Aerospace industry
- Automobile industry
- Bio-medical industry
- Manufacturing industry
- Space exploration industry
- Several more

https://additive-manufacturing-report.com/technology/metal/laser-beam-powder-bed-fusion/



https://www.3dnatives.com/en/direct-metal-laser-sintering100420174-2/

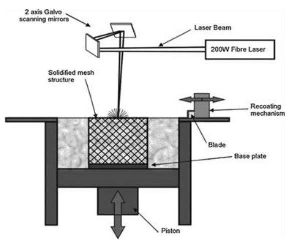
https://www.ge.com/additive/stories/new-manufacturing-milestone-30000-additive-fuel-nozzles



https://www.visordown.com/features/general/bmw-tech-day-3d-printing-technology

Advantages and challenges

Laser powder bed fusion



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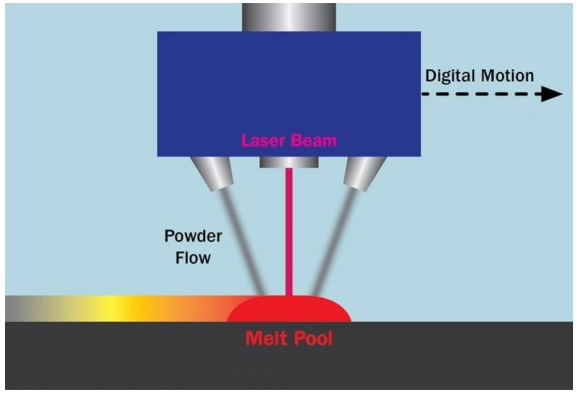
- Small feature resolution
- Large number of alloys being developed
- Design flexibility
- Free form fabrication
- Multiple parts in a single build
- Turnkey solutions
- Powder reusability
- Assemblies →Monolithic components

- Relatively low build speed
- Large setup and process costs
- Monolithic material printing
- Part size bound by build chamber
- New component fabrication only
- Post processing challenges
- Support material removal
- Process control challenges

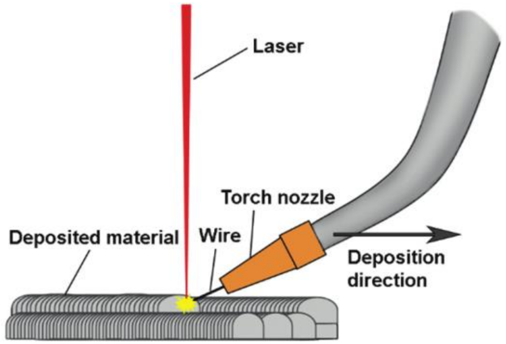
Laser Directed Energy Deposition (DED)

Laser blown powder deposition



https://optomec.com/optomec-improves-additive-repair-technique/

Laser wire deposition



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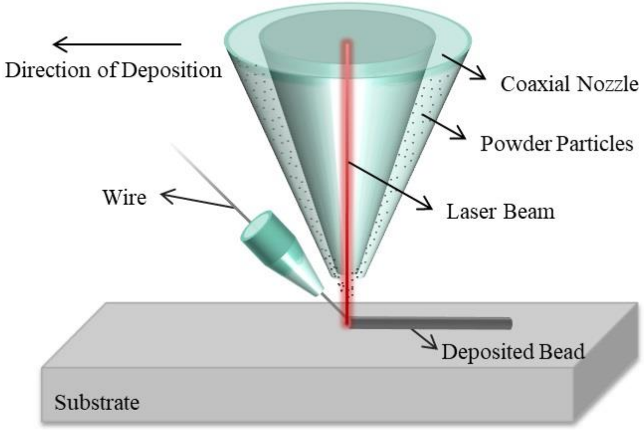
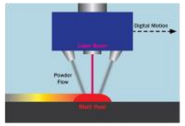
Laser wire and powder deposition



- Technique varies by feed stock
- Relatively larger spot size (250 micron to 3000 micron)
- 45 to 200micron powder size distribution

- Several implementations available
- Scalable, flexible and fast
- Relatively higher deposition rate
- Relatively lower feature resolution

Laser blown powder deposition



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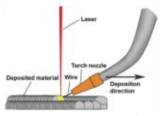

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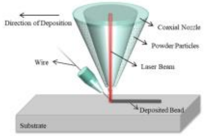
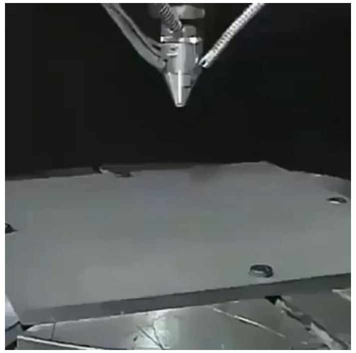


Laser DED



https://www.youtube.com/watch?v=OMw-bAXiL2c

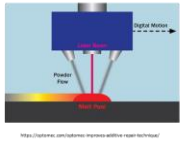
https://www.youtube.com/watch?v=dFRvmVF0wU0

https://www.youtube.com/watch?v=_JHqdVU9Ebo

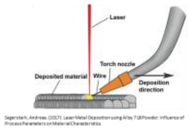
- Several commercial machines available
- Multiple system architectures
  - CNC machine
  - Robotic systems
  - Gantry systems
- Open air vs Controlled atmosphere
- Wattages up to 20kW
- Multi-material deposition
- Support less printing
  - 5 axis deposition
- Scalable deposition methdology

TRUMPF OPTOMEC MELTIC CONCEPTLASER a GE Additive company GEFERTEC InssTek DMT® Metal 3D Printing Specialist 3D SYSTEMS

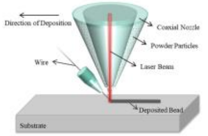
Laser blown powder deposition



Laser wire deposition



Laser wire and powder deposition



Workflow

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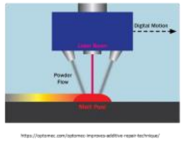
Part build

Part Design *CAD Model Parasolid, igs, stl* → **Decompose Model Into DED features** → **3D Slicing and tool path generation** → **Distortion Modeling** *physics based* → **Motion system programming** → **Build the Part** *Execute the Toolpath* → **Post Process** *Heat Treat, Machine, etc.*

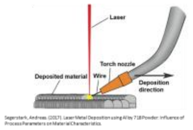
Distortion Modeling → Part Design

Applications

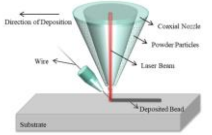
Laser blown powder deposition



Laser wire deposition



Laser wire and powder deposition



https://www.oilfieldtechnology.com/drilling-and-production/06082014/metallisation-has-launched-a-new-laser-cladding-system-for-the-oil-and-gas-industry/

https://www.metal-am.com/nasa-looks-to-large-scale-ded-additive-manufacturing-for-future-rocket-engines/

https://www.openmind-tech.com/en/cam/additive-manufacturing/directed-energy-deposition.html

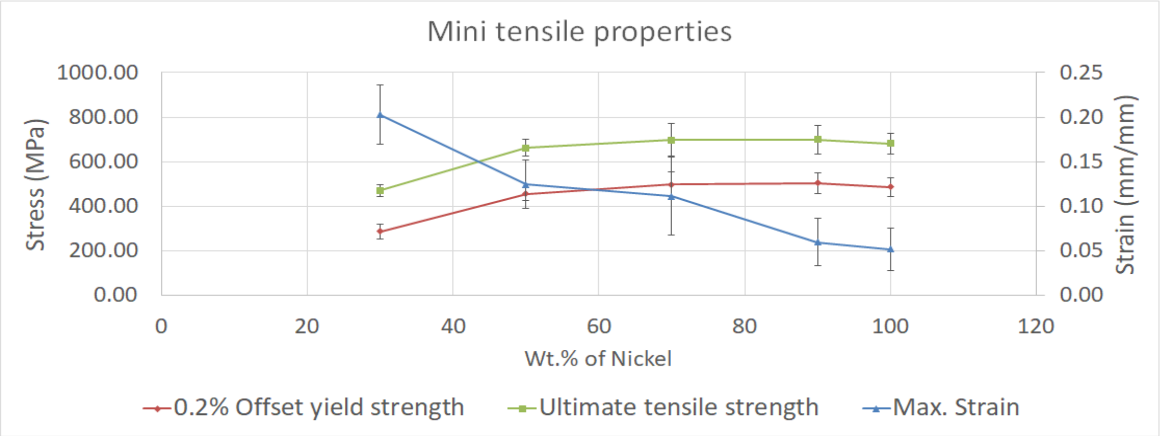
https://engineeringproductdesign.com/knowledge-base/direct-energy-deposition/

Broken Gear Teeth | After LENS Printed Repair | Machined to Spec

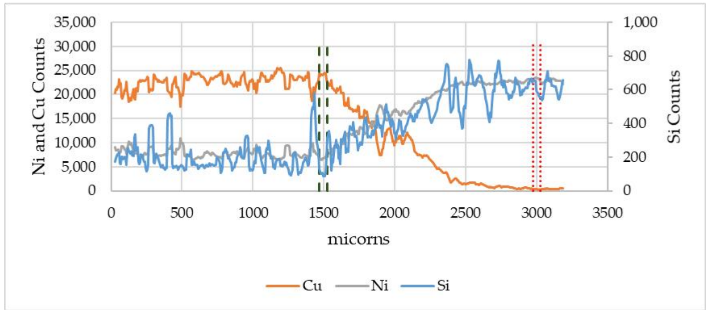
https://optomec.com/how-3d-metal-printing-saves-time-and-lowers-costs-ded-for-repair-of-industrial-components/

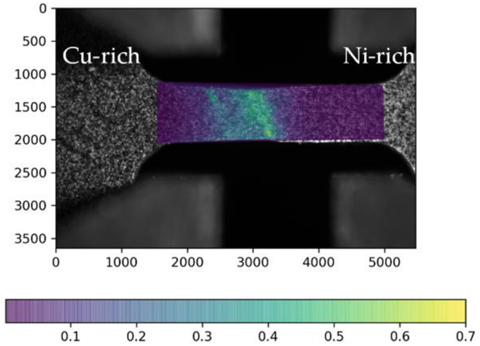
In-situ alloy fabrication

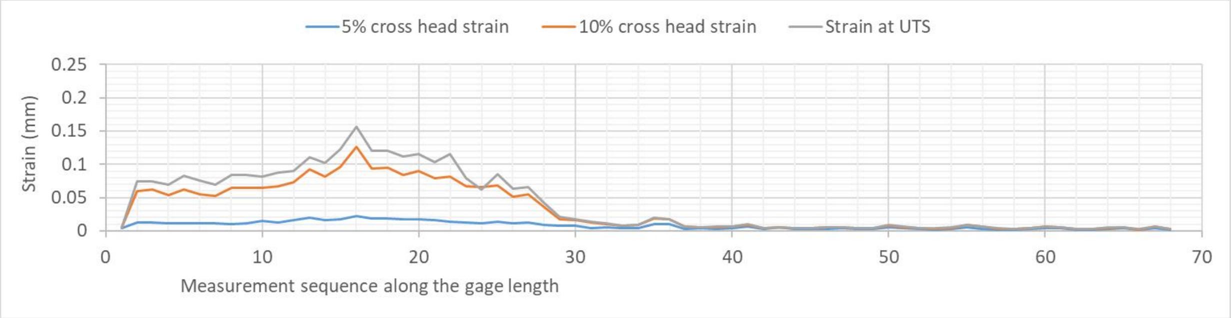
Cu + Ni blended powders



Karnati, Sreekar & Liou, Frank & Newkirk, Joseph. (2019). Characterization of copper–nickel alloys fabricated using laser metal deposition and blended powder feedstocks. The International Journal of Advanced Manufacturing Technology. 103. 1-12. 10.1007/s00170-019-03553-0.

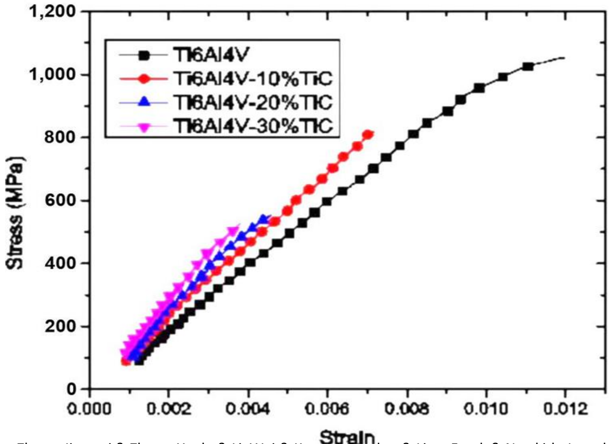


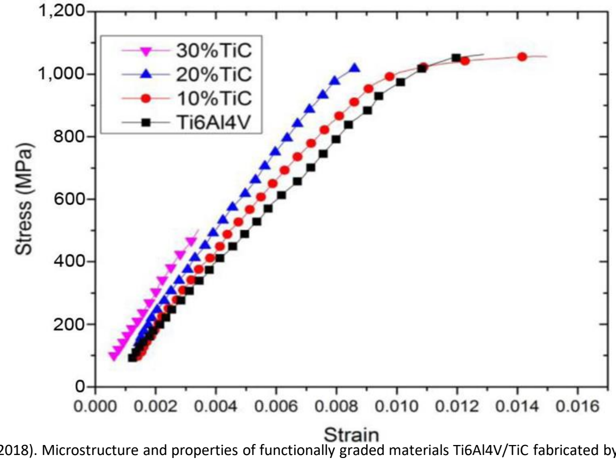




Karnati, Sreekar & Zhang, Yunlu & Liou, Frank & Newkirk, Joseph. (2019). On the Feasibility of Tailoring Copper–Nickel Functionally Graded Materials Fabricated through Laser Metal Deposition. Metals. 9. 287. 10.3390/met9030287.

Ti + TiC blended powders





Zhang, Jingwei & Zhang, Yunlu & Li, Wei & Karnati, Sreekar & Liou, Frank & Newkirk, Joseph. (2018). Microstructure and properties of functionally graded materials Ti6Al4V/TiC fabricated by direct laser deposition. Rapid Prototyping Journal. 24. 00-00. 10.1108/RPJ-12-2016-0215.

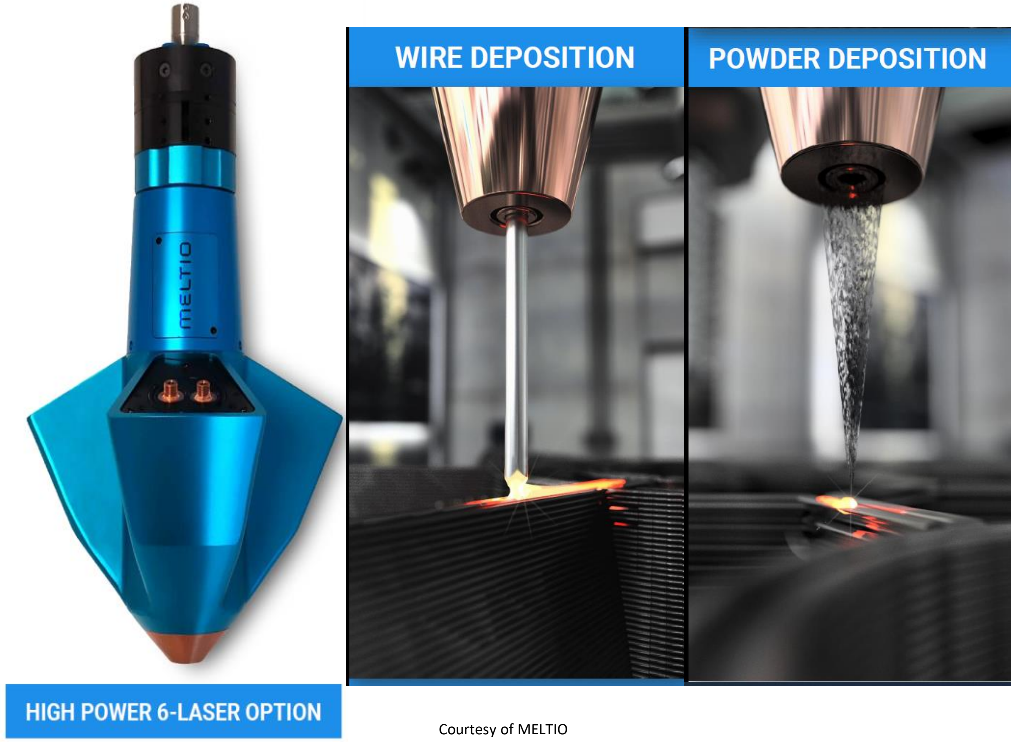
- On demand alloy fabrication
- Functionally graded materials
- Metal matrix composites

Laser DED

Hybrid DED

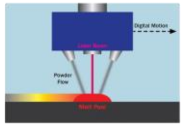
https://en.dmgmori.com/products/machines/additive-manufacturing/powder-nozzle/lasertec-65-ded-hybrid

Multi laser, multi material/ dual feed stock DED



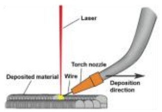
Courtesy of MELTIO

Laser blown powder deposition



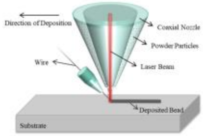
https://optomec.com/optomec-improves-additive-repair-technique/

Laser wire deposition



Segerstark, Andreas. (2017). Laser Metal Deposition using Alloy 718 Powder: Influence of Process Parameters on Material Characteristics.

Laser wire and powder deposition



Advantages and challenges

- Relatively higher build speed
- Large number of alloys being developed
- Design flexibility
- Free form fabrication
- Multi material deposition
- Scalable infrastructure
- Assemblies →Monolithic components

- Relatively lower feature resolution
- Long process development lead time
- One part at a time
- New component fabrication only
- Post processing challenges
- Support material removal
- Process control challenges

Conclusion

- One stop shop
- Cost and/or lead time saver
- Not a solve all manufacturing solution
- Complexity for free
- Immense commercial and social impact and potential