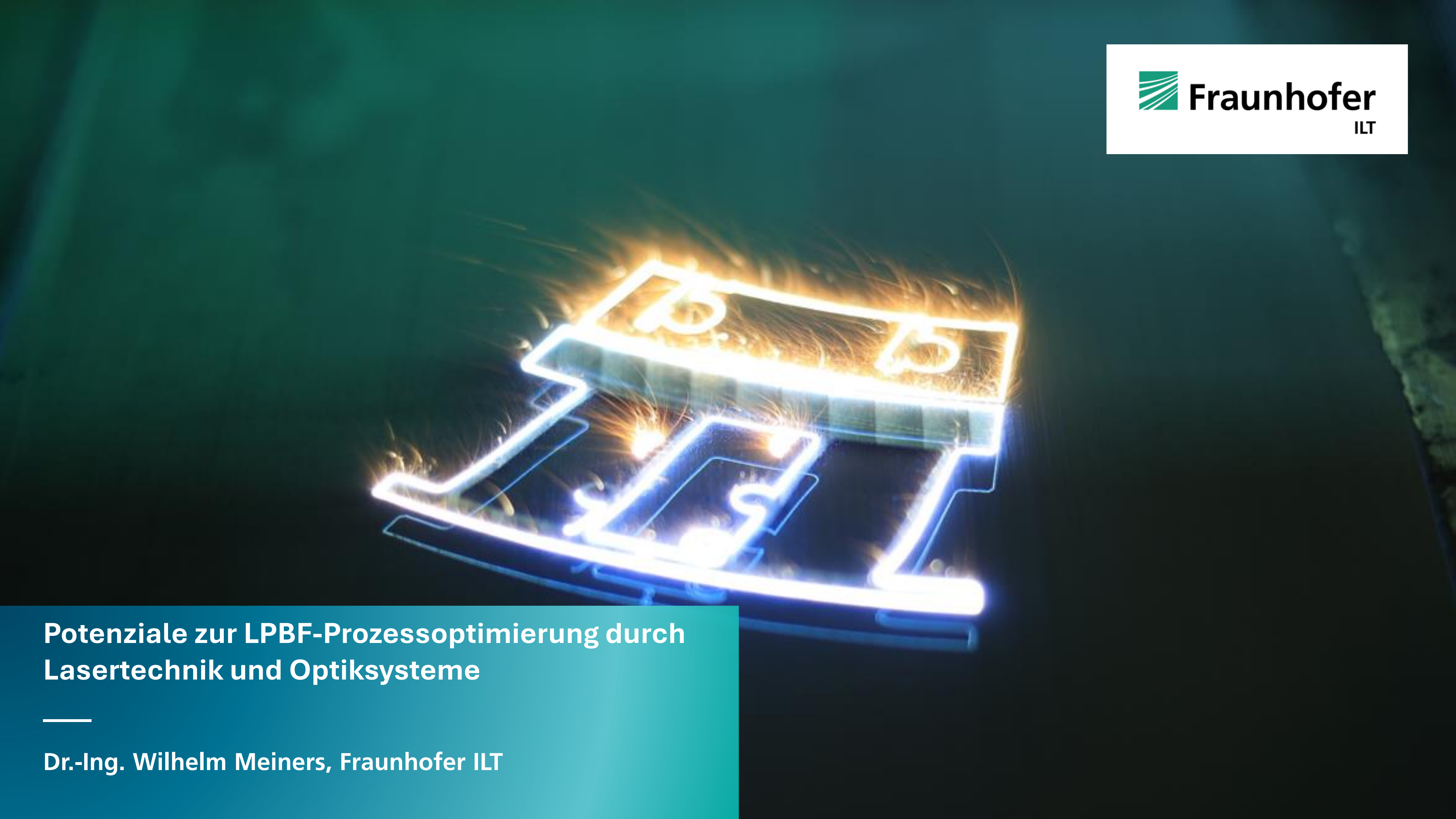
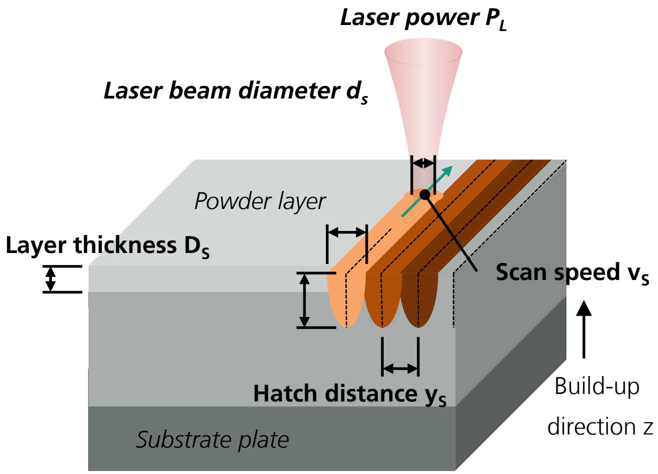


Potenziale zur LPBF-Prozessoptimierung durch Lasertechnik und Optiksysteme

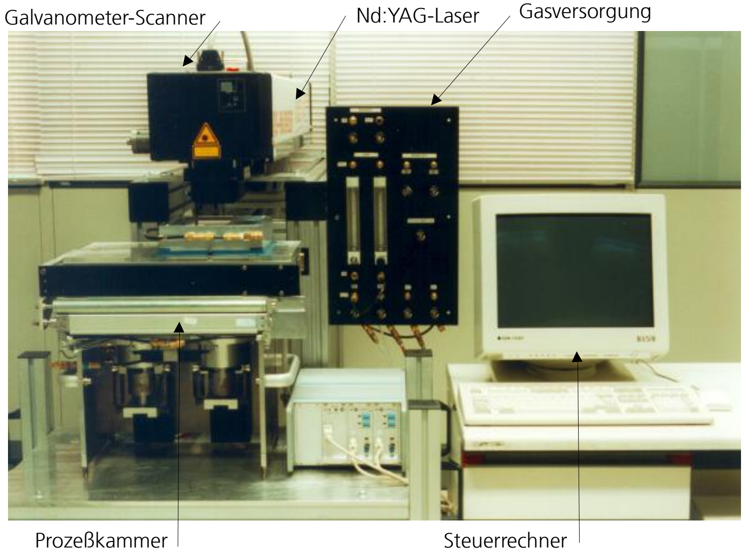
Dr.-Ing. Wilhelm Meiners, Fraunhofer ILT

Laser powder bed fusion (PBF-LB/M)

Basic principle



- basic principle and laser-optic setup unchanged for 30 years
- key enabling component: single mode fibre laser
- focused gaussian beam profile
- vector scanning with 2-axis galvo scanner



PBF-LB/M systems

Scaling of PBF-LB/M systems

Large-format multilaser machine portfolio Europe, US and China (Examples)

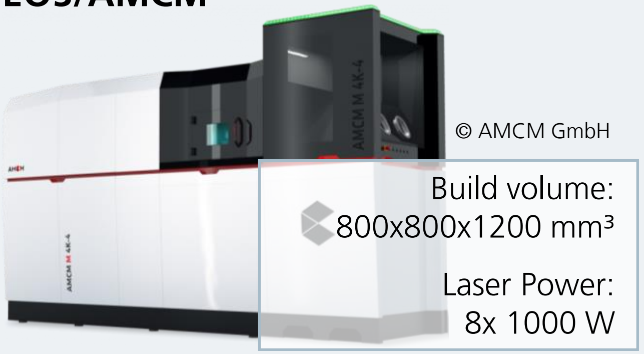
Restricted

Nikon SLM Solutions

Build volume:
600x600x1500 mm³

Laser Power:
12x 1000 W

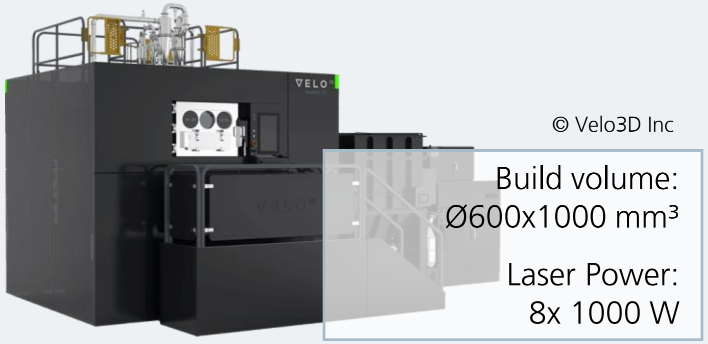
EOS/AMCM



Build volume:
800x800x1200 mm³

Laser Power:
8x 1000 W

Velo3D



Build volume:
Ø600x1000 mm³

Laser Power:
8x 1000 W

Farsoon

Build volume:
840x840x960 mm³

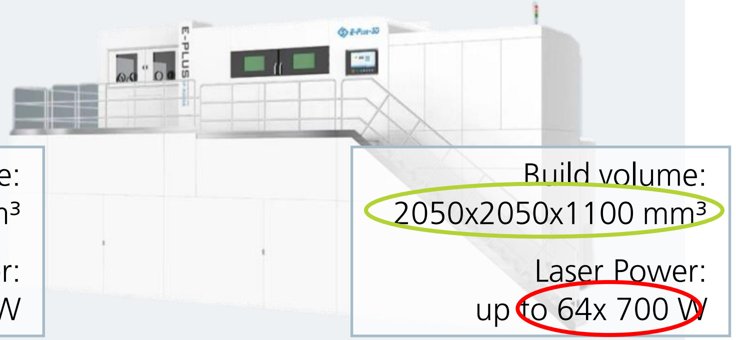
Laser Power:
12x 500 W

Bright Laser Technologies

Build volume:
1500x1500x1200 mm³

Laser Power:
26x 500 W

EPlus 3D



Build volume:
2050x2050x1100 mm³

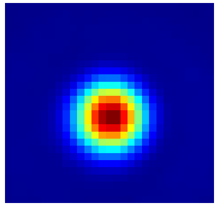
Laser Power:
up to 64x 700 W

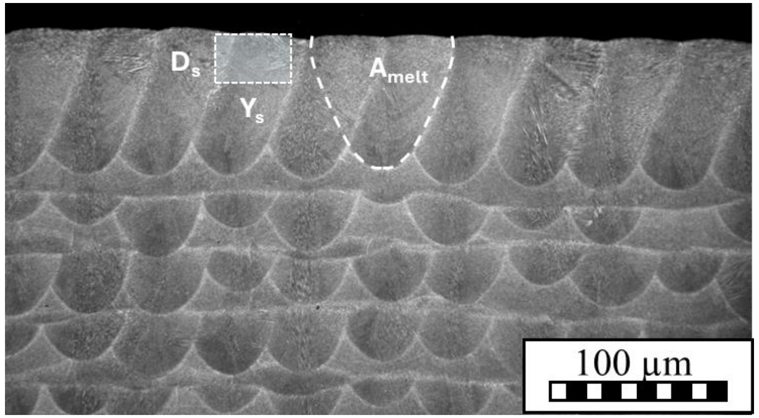
Laser powder bed fusion (PBF-LB/M)

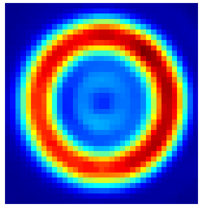
Process efficiency

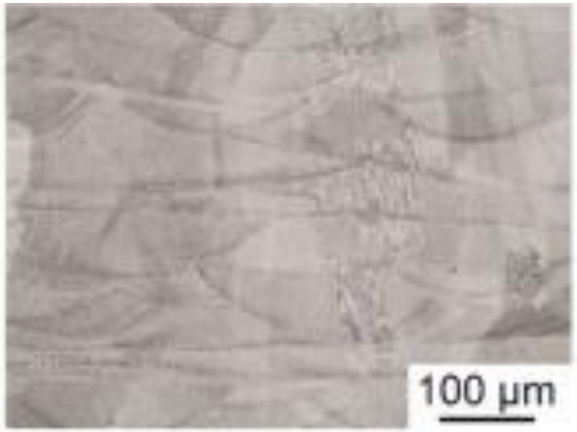
- Standard process:
- gaussian beam shape Ø ≈ 80-100µm
- transition mode welding
- Laser power and build rate limited by keyhole formation
- Efficiency µ limited by large overlap ($\mu = D_s \cdot Y_s / A_{melt} \approx 0{,}4$)

- new approaches: new beam shapes
- Example: ring mode, Ø > 200 µm
- Heat conduction mode
- Shallower melt track
- Higher laser power applicable









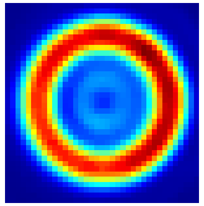
[Wudy et.al.:Tailored microstructures in laser-based powder bed fusion of 316L using beam shaping: From microstructure formation in individual specimens to their transition in segmented parts. Additive Manufacturing, Volume 113, 5 September 2025]

Laser powder bed fusion (PBF-LB/M)

Ring mode laser

Example: Demonstrator part out of TiAl6V4

- Ring mode laser
- Beam diameter: 220 µm
- Laser power: 1kW



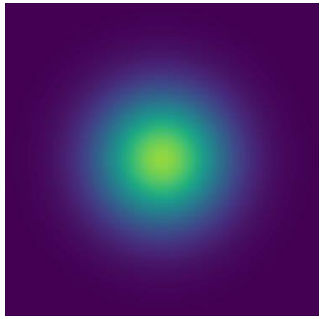
- Layer thickness: 60µm
- Build rate: 20 mm^3/s
- Volume energy: 50 J/mm^3

- Standard process for TiAl6V4:
  P_{Lmax} = 350 W, build rate ≈ 9 mm^3/s
  Volume energy: 44 J/mm^3

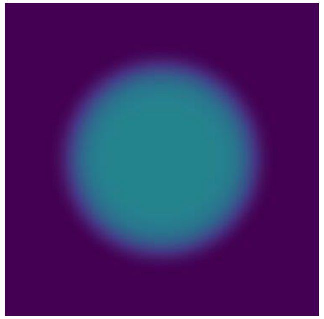
Laser powder bed fusion (PBF-LB/M)

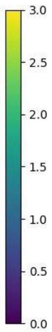
Beam shape comparison @ ILT

- gaussian

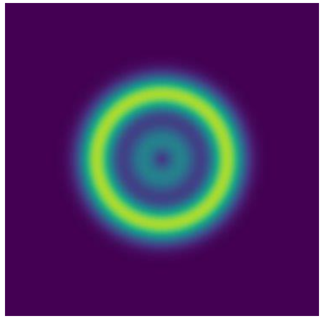


- top hat

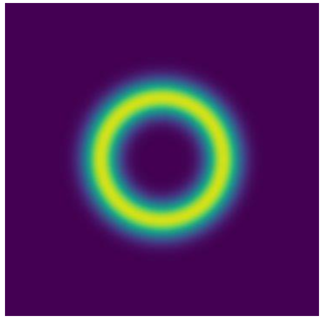




- Ring/gaussian



- pure ring



identical boundary conditions

- same beam diameter
- identical equipment and procedure (powder, machine, parameter, scan strategy, etc.)

comprehensive analysis

- spatter formation and layer topology
- density
- melt pool shape
- surface roughness
- microstructure and mechanical properties
- accuracy and detail resolution
- build rate and efficiency

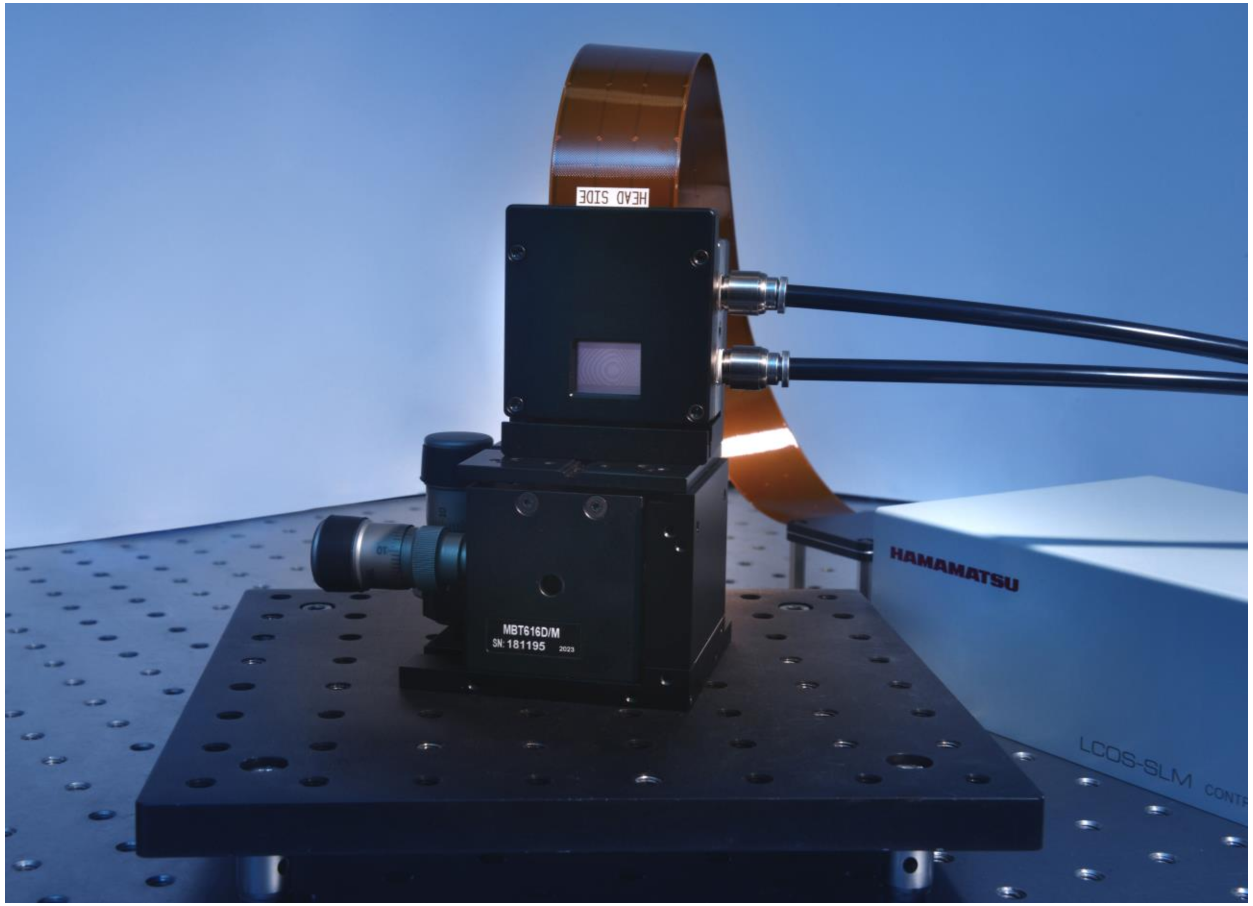
➢ **Result: knowledge about impact of beam shape only**

High Power Beam Shaping for PBF-LB/M

Flexible development platform for complex, process-adapted beam shapes

- The flexibility of the LCoS-SLM enables an in-depth investigation into how intensity distribution affects melt pool formation, aiming to achieve a variety of goals:
  - ➢ less spatter formation
  - ➢ controlled melt pool dynamics
  - ➢ smoothened melt track surface
  - ➢ adapted melt track geometry
  - ➢ adapted temperature field for less crack formation

- latest LCoS generation allows for P_{Lmax} of 2 kW
- high flexibility requires systematic approach



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High Power Beam Shaping for PBF-LB/M

Flexible development platform for complex, process-adapted beam shapes

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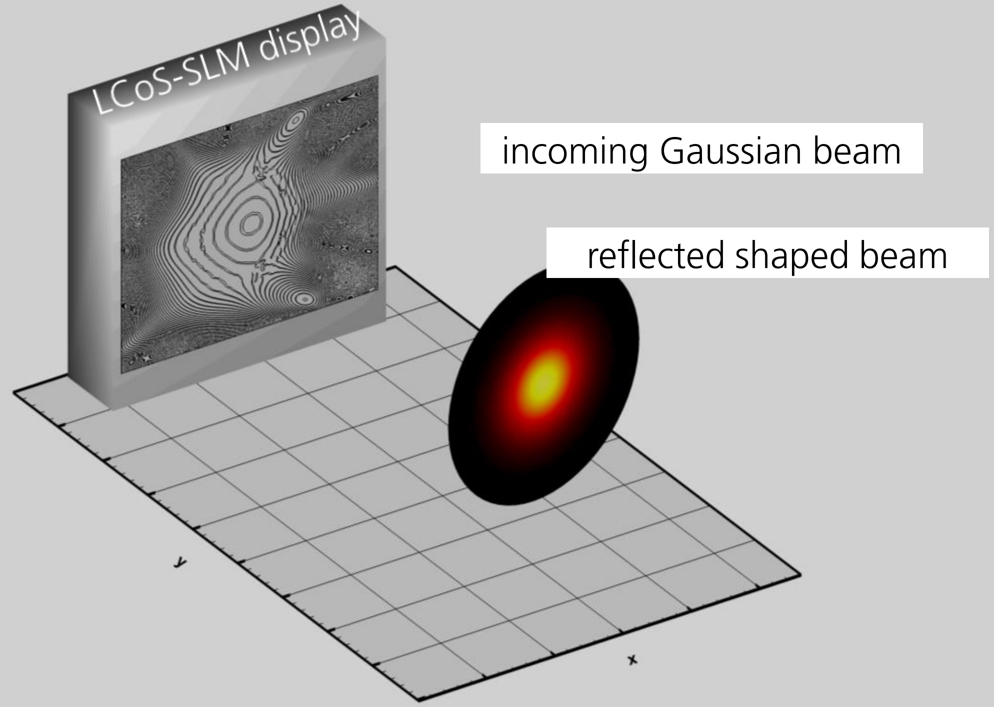


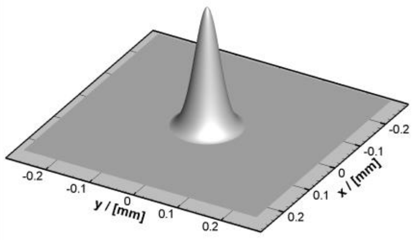
Change of the laser beam intensity distribution after reflection on the phase mask of the LCoS-SLM

Impact of different beam shapes on melt pool shape

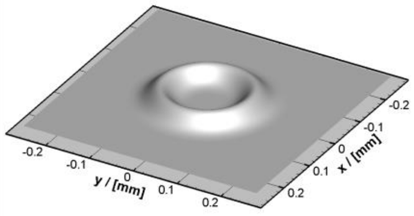
Simulation approach

beam shape

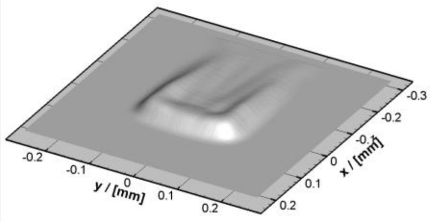
focussed gaussian



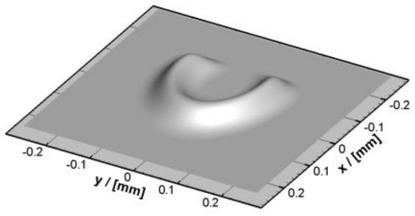
ring-shaped



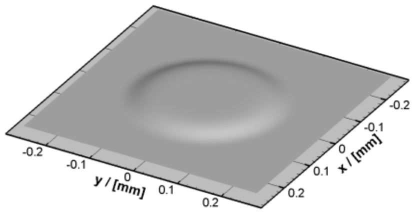
seat-shaped



u-shaped

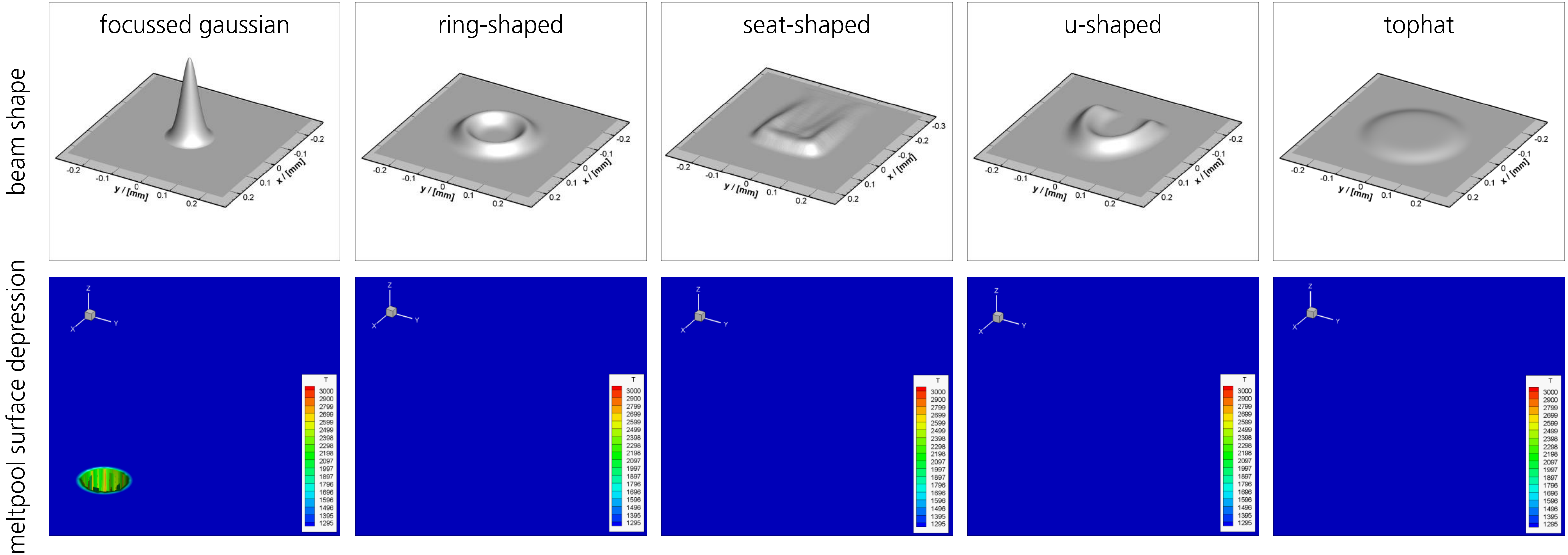


tophat



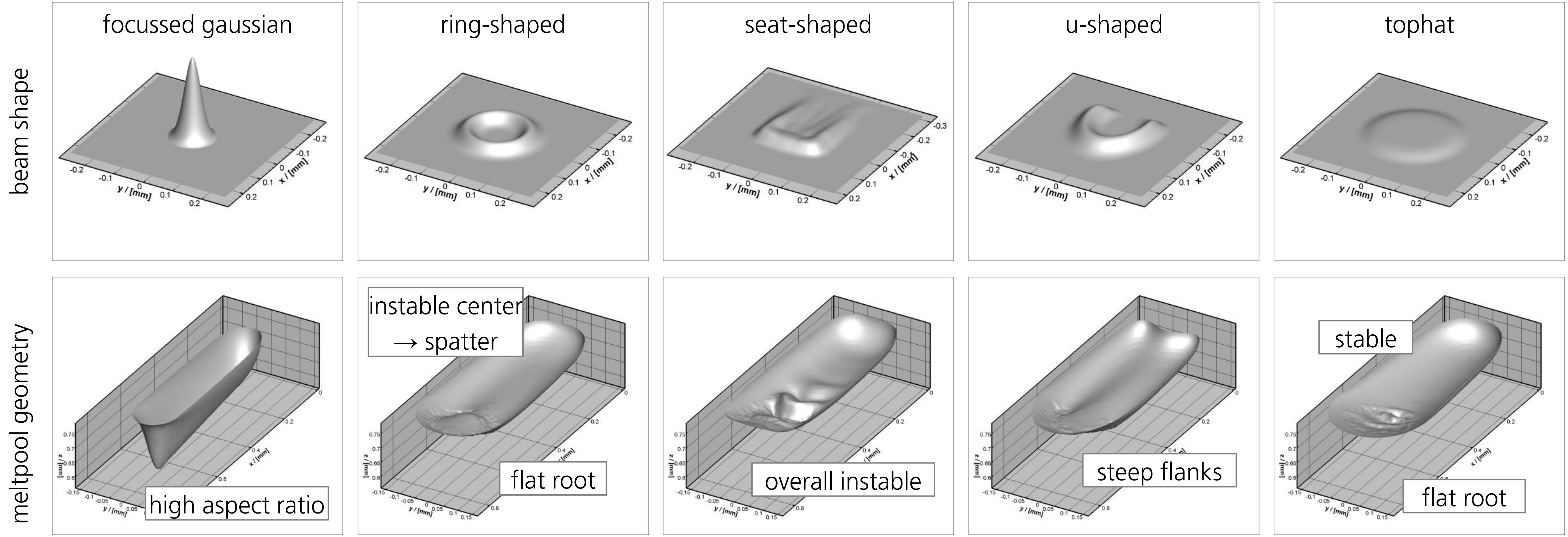
Impact of different beam shapes on melt pool shape

Simulation approach



Impact of different beam shapes on melt pool shape

Simulation approach



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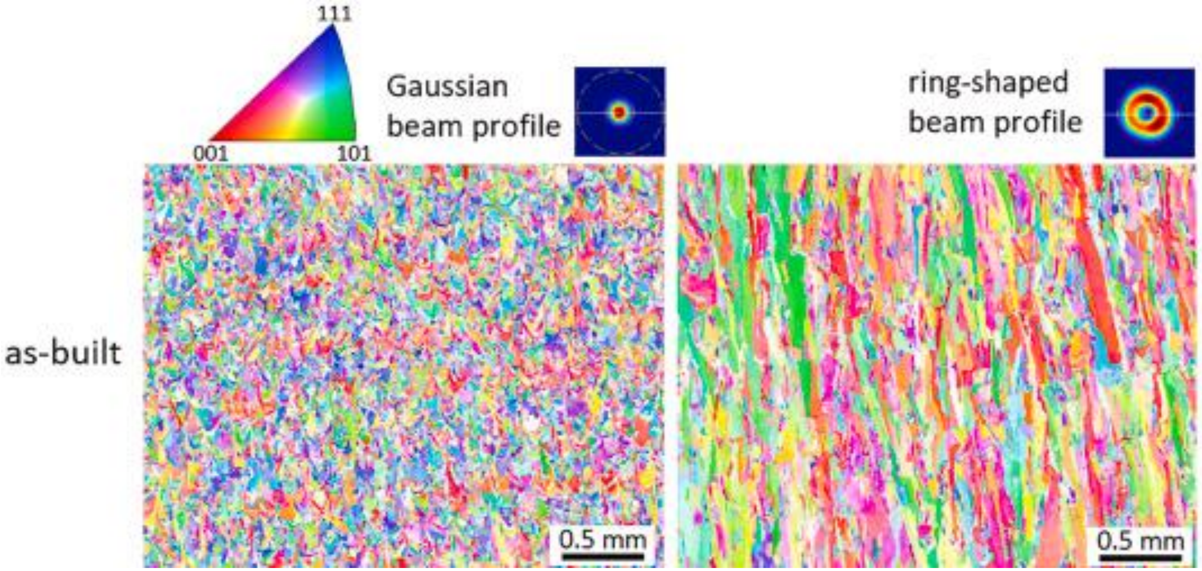
Impact of different beam shapes on melt pool shape

Limitations

- higher laser power with adapted beam shape will generate larger melt pools with impact on:
  - ➢ surface quality
  - ➢ detail resolution
  - ➢ microstructure
  - ➢ mechanical properties

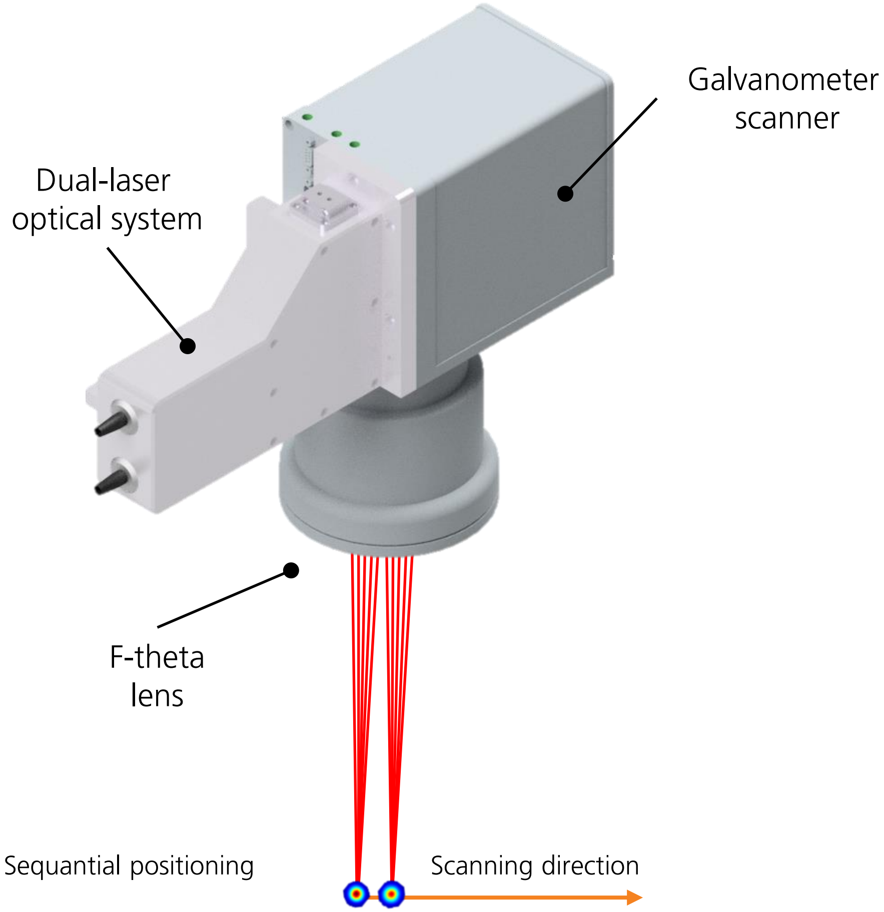
- Example for IN718



[Wudy et.al., Influence of laser beam shape and post heat-treatment on the microstructure and mechanical properties of nickel-based alloy IN718 manufactured by laser powder bed fusion
Journal of Materials Research and Technology, Volume 37, July–August 2025, Pages 1970-1986]

Beam shaping approach @ ILT

Multi spot (double spot)



- Standard process (single spot)

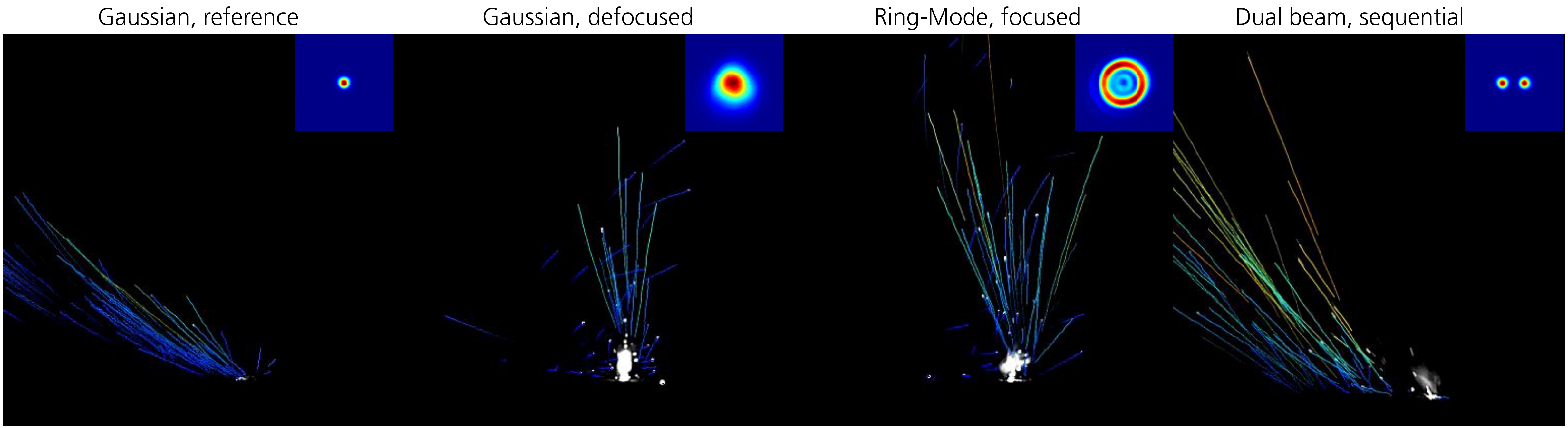
  P_L, V_{scan}

- Double spot process

  P_L x2, V_{scan} x 2

Beam shaping approach @ ILT

Spatter formation

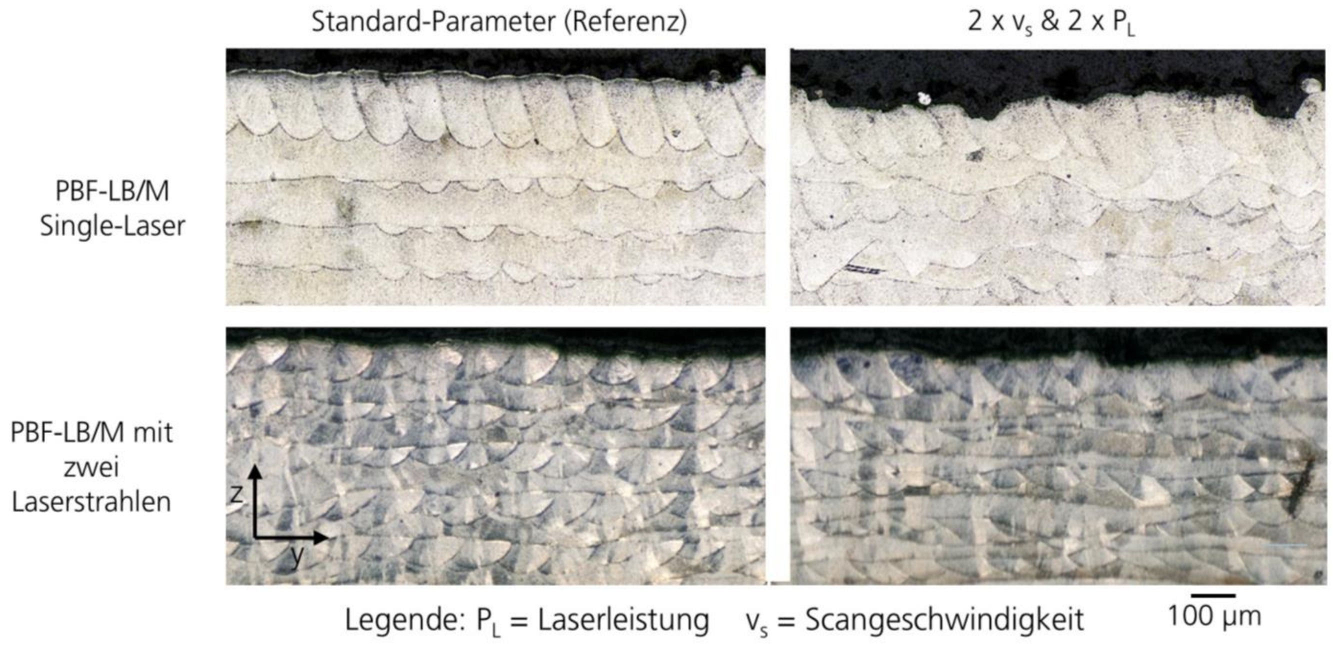


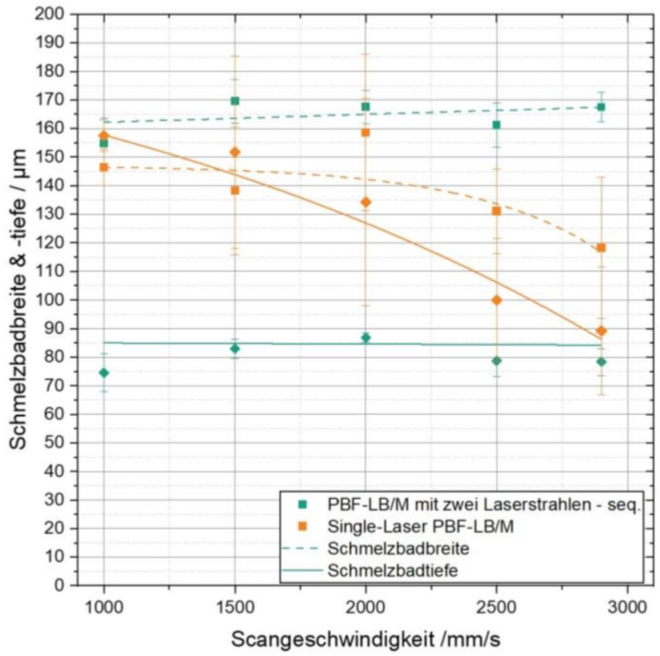
- typical spatter formation for standard process (single spot, gaussian, Ø ≈ 90 µm)
- different (not less) spatter formation for large spot size (ring and gaussian)
- similar spatter formation for double spot process

Beam shaping approach @ ILT

Multi spot (double spot)

- instable weld track formation for single spot process at higher laser power and higher scan speed
- consistent weld track formation (depth, width) for double spot process at higher laser power and higher scan speed
- Example for IN 625

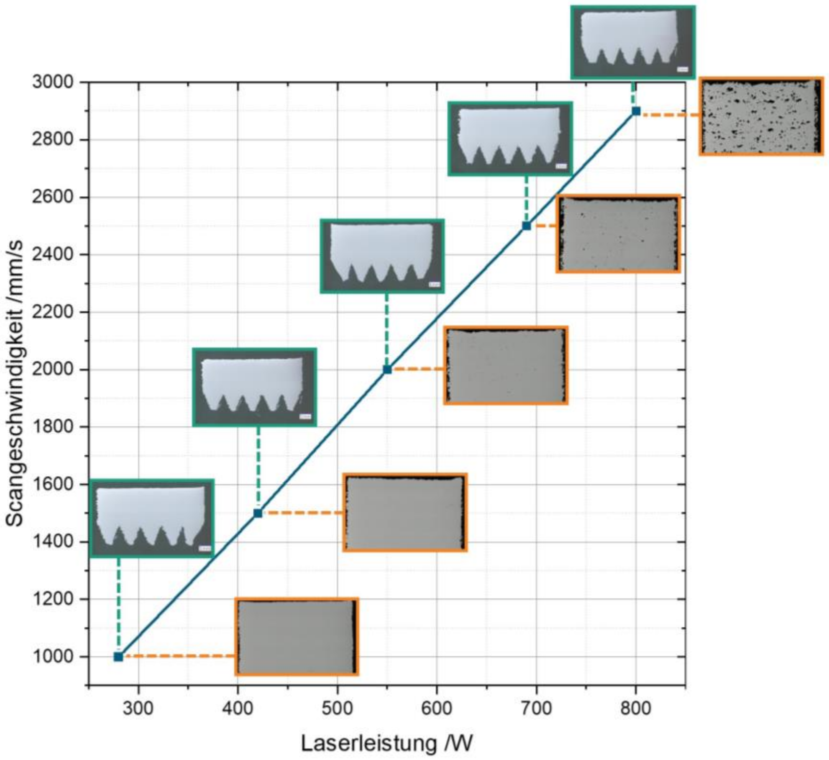


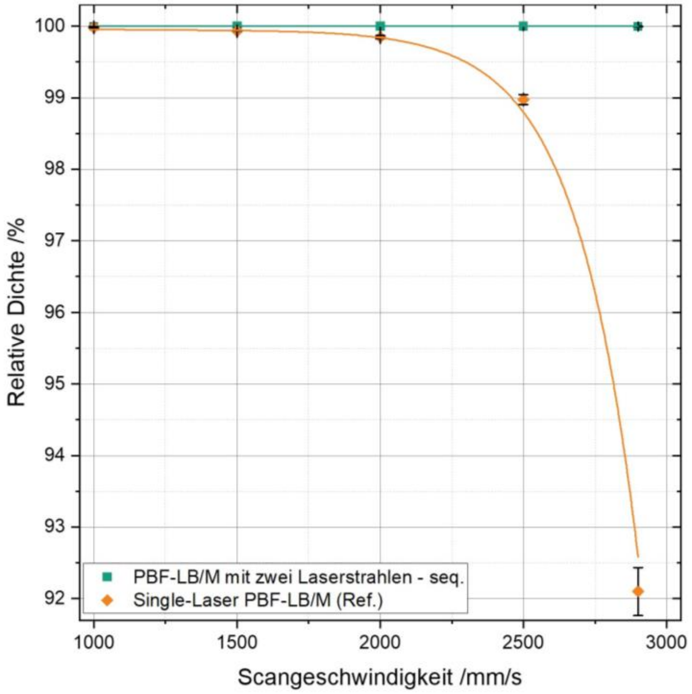


Beam shaping approach @ ILT

Multi spot (double spot)

- density drop for single spot process at higher laser power and higher scan speed
- consistently high density
- for double spot process at higher laser power and higher scan speed
- Example for IN625

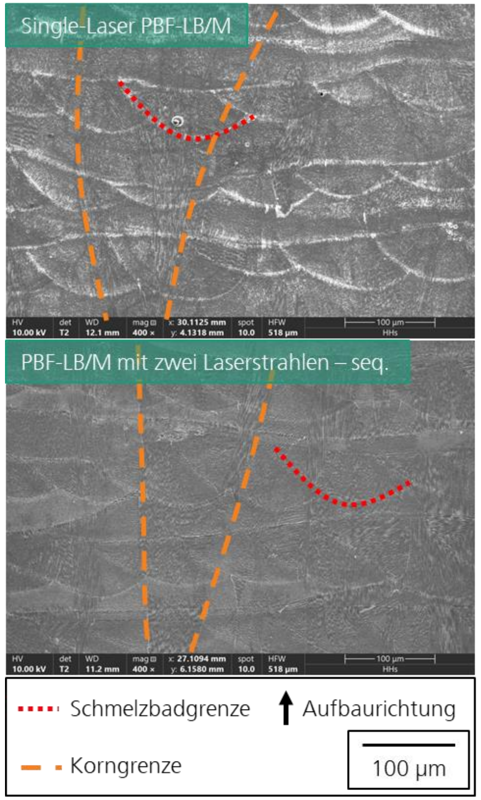


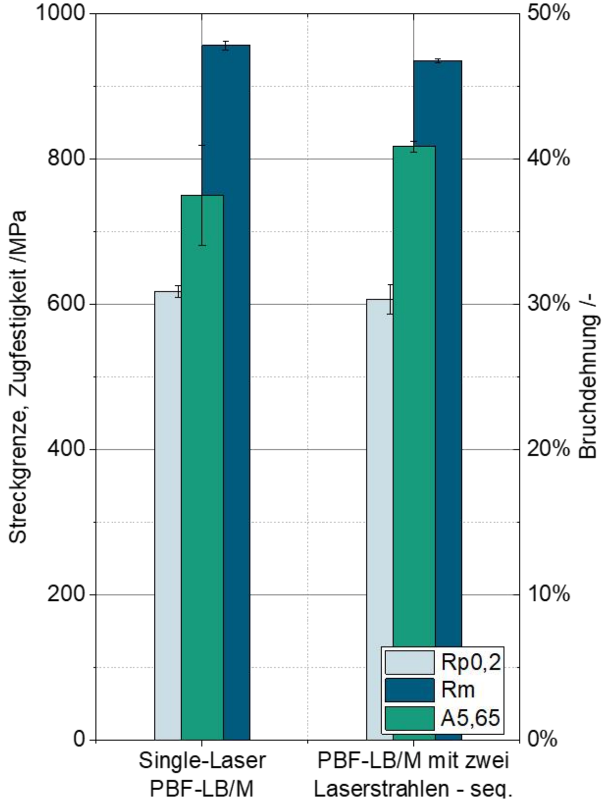


Beam shaping approach @ ILT

Multi spot (double spot)

- Same microstructure for single spot standard process and double spot process with doubled build rate (IN 718)
- Same mechanical properies for single spot standard process and double spot process with doubled build rate
- Example for IN625



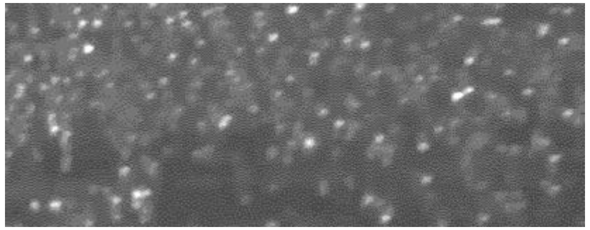


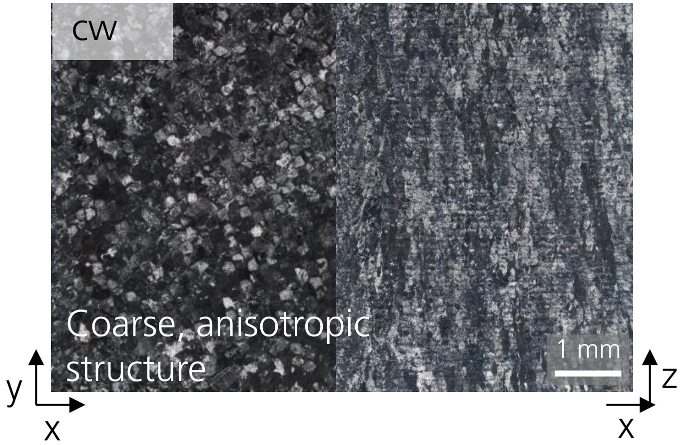
New exposure strategy for PBF-LB/M

Fast pulse distribution

Conventional "cw" exposure

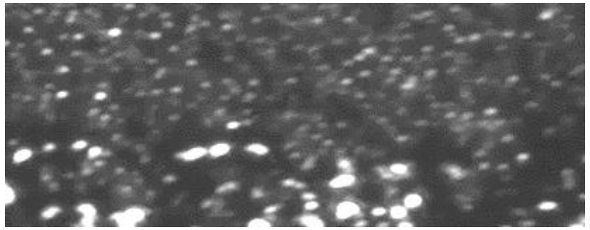
- Continuous energy input
- Larger heat-affected zones and heat accumulation
- continuous and directed solidification
- Typical grain growth in z-direction, coarse and anisotropic grain structure

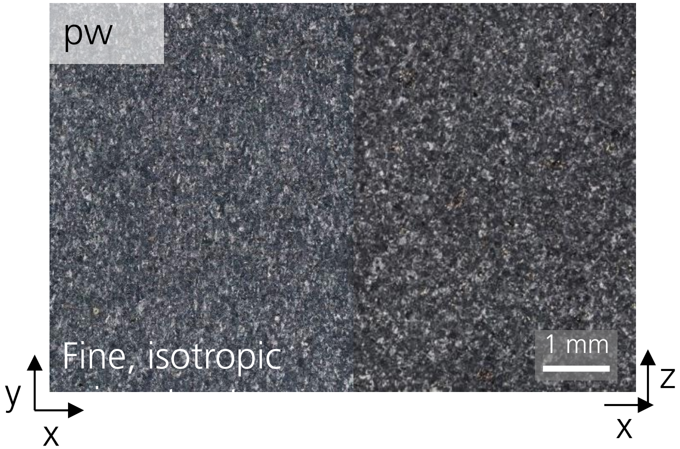




Pulsed modulated "pw" exposure

- Discontinuous energy input
- Smaller heat-affected zones
- Less overheating
- discrete solidification during pulse pause
- Fine and isotropic grain structure





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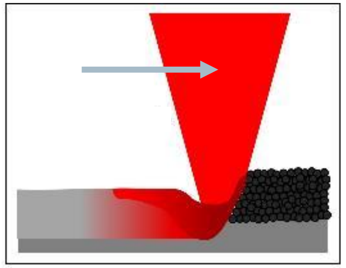
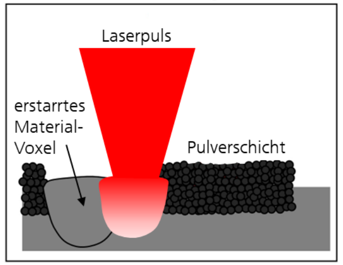
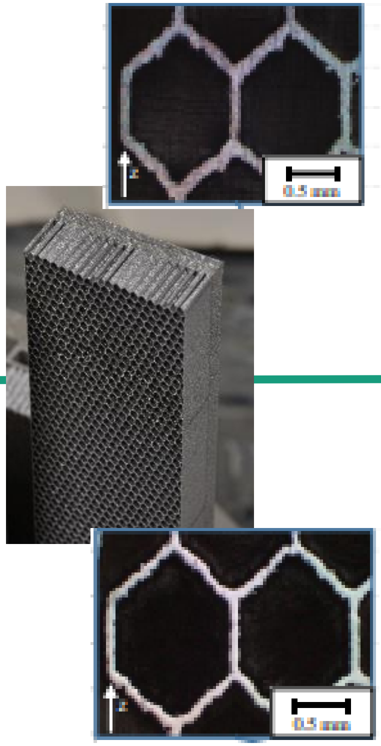
New exposure strategy for PBF-LB/M

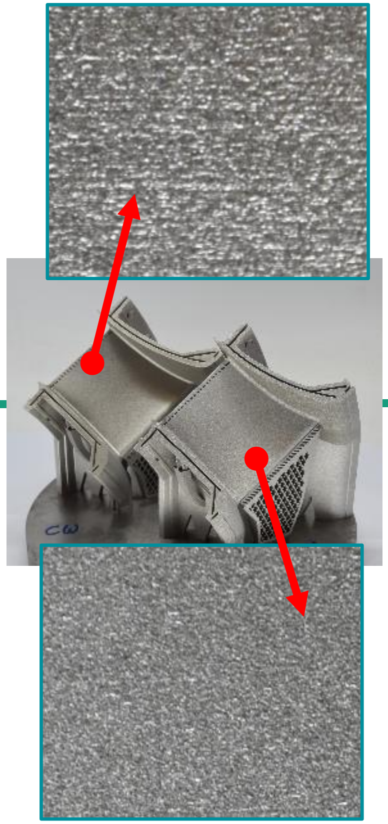
Fast pulse distribution

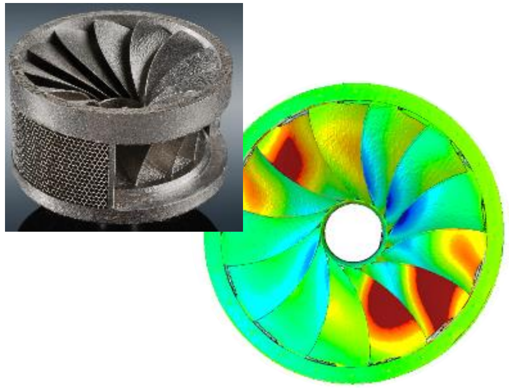
	Precision/Detail resolution	Surface quality	Distortion	Microstructure
Standard PBF-LB/M	d_{min} = 126µm			anisotrop, grobkörnig
Pulsed modulated PBF-LB/M	d_{min} = 83µm			isotrop, feinkörnig

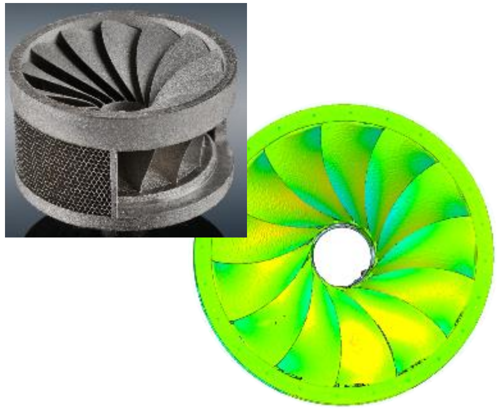


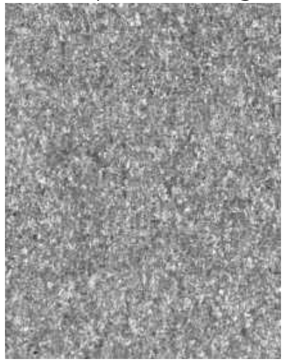








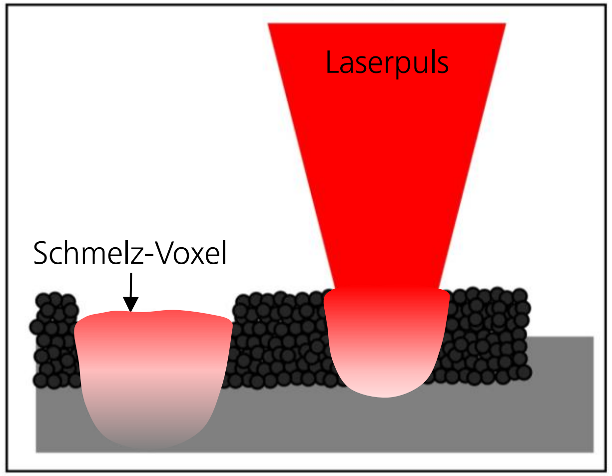




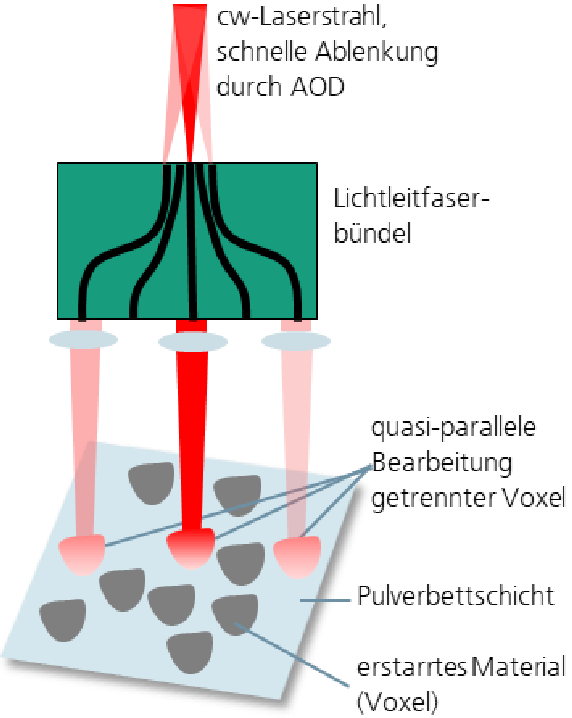
New exposure strategy for PBF-LB/M

Fast pulse distribution

- quasi-parallel pulse exposure
- extremely fast beam deflection over long distances
- use of a cw laser beam source
- pulse processing without pulse pause



- Basic process principle



- Basic optic setup

INLEAP PHOTONICS LASER IN MOTION

INLEAP® FASTLIGHT®

- Commercial component

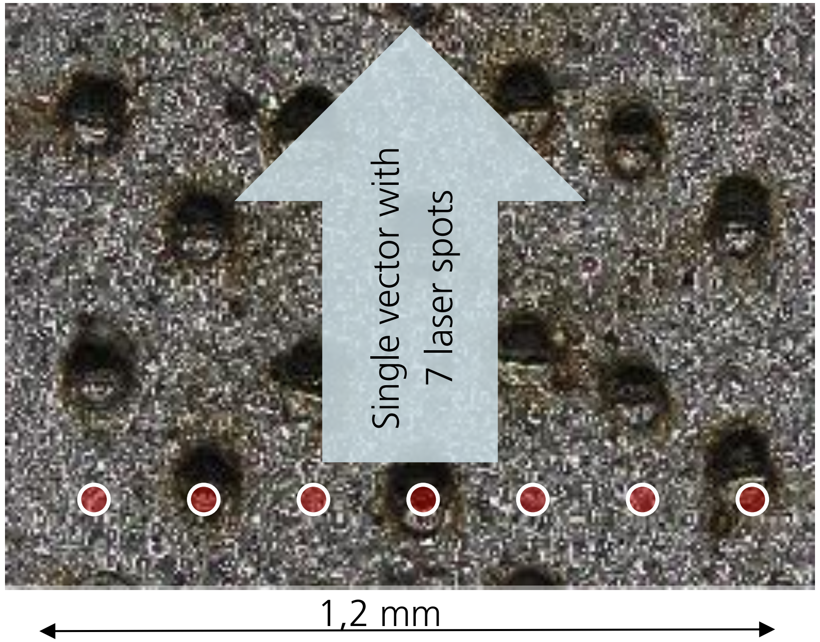
Fraunhofer ILT

New exposure strategy for PBF-LB/M

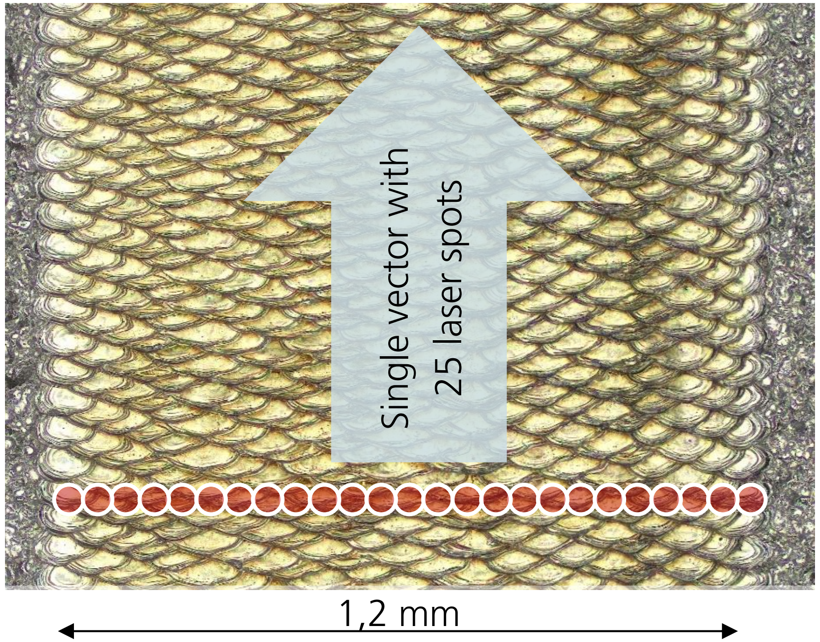
Fast pulse distribution

- Feasibility study for filling strategy

- Fast pulse distribution



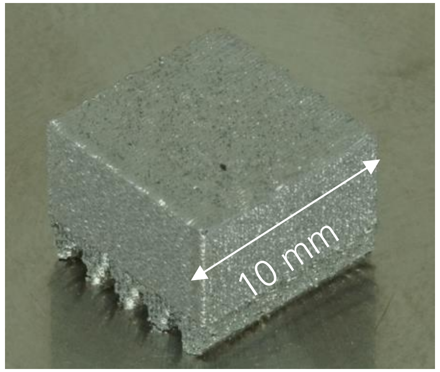
- Quasi-line exposure



New exposure strategy for PBF-LB/M

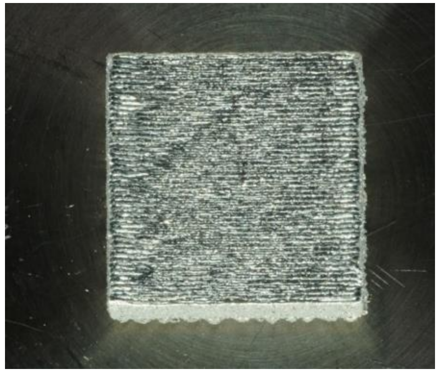
Fast pulse distribution, Volume build up, stainless steel 316L

- Feasibility study for volume build up (stainless steel 316L)
- High density at same build rate achieved

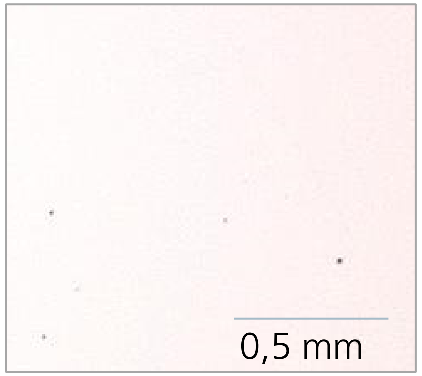


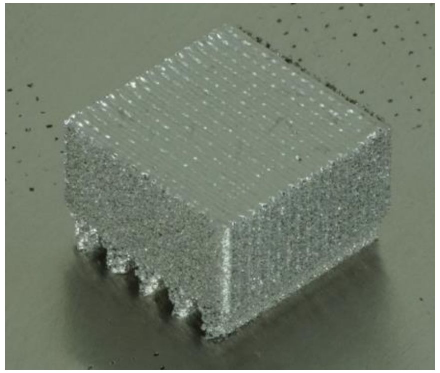
Reference

- Conventional strategy
- P_L = 300 W
- Single Spot
- build rate 3,5 mm^3/s



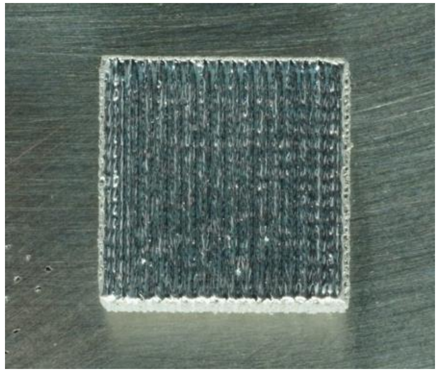
Density: 99.95%



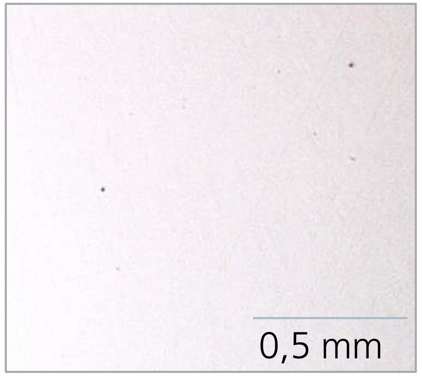


New approach

- 3 Pixel
- 75 kHz
- PL = 300 W
- build rate 3,5 mm^3/s



Density: 99.98%



Fraunhofer ILT

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