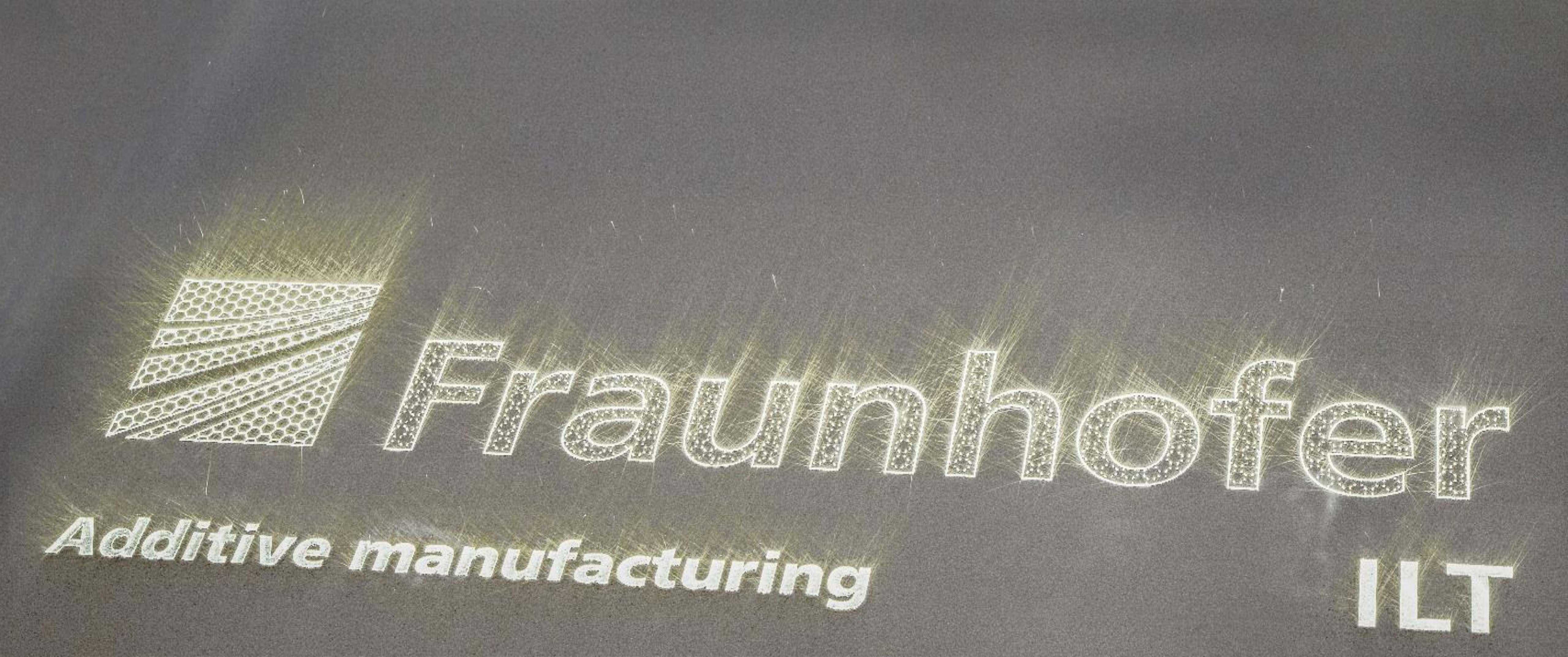


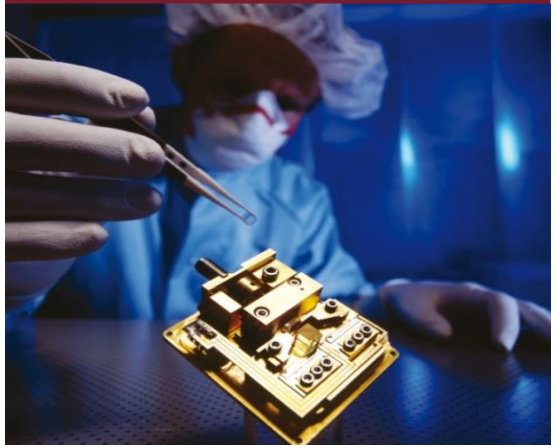
Laser Powder Bed Fusion at ILT

Tim Lantzsch / Simon Vervoort

The Fraunhofer Institute for Laser Technology ILT

Technology Focus

LASER AND OPTICS



LASERMATERIAL PROCESSING

MEDICAL TECHNOLOGY AND BIOPHOTONICS

LASER MEASUREMENT TECHNOLOGY

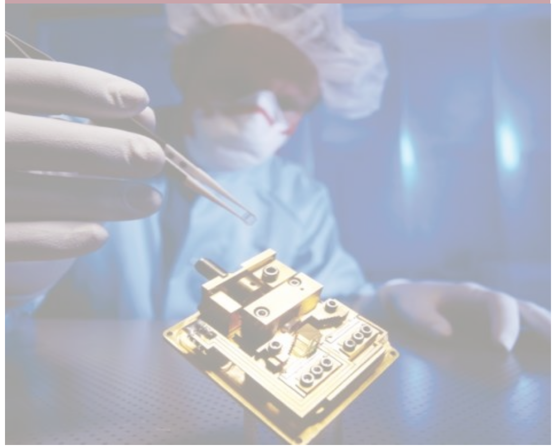
DIGITALIZATION

QUANTUM TECHNOLOGY

The Fraunhofer Institute for Laser Technology ILT

Technology Focus

LASER AND OPTICS



LASERMATERIAL PROCESSING

MEDICAL TECHNOLOGY AND BIOPHOTONICS

LASER MEASUREMENT TECHNOLOGY

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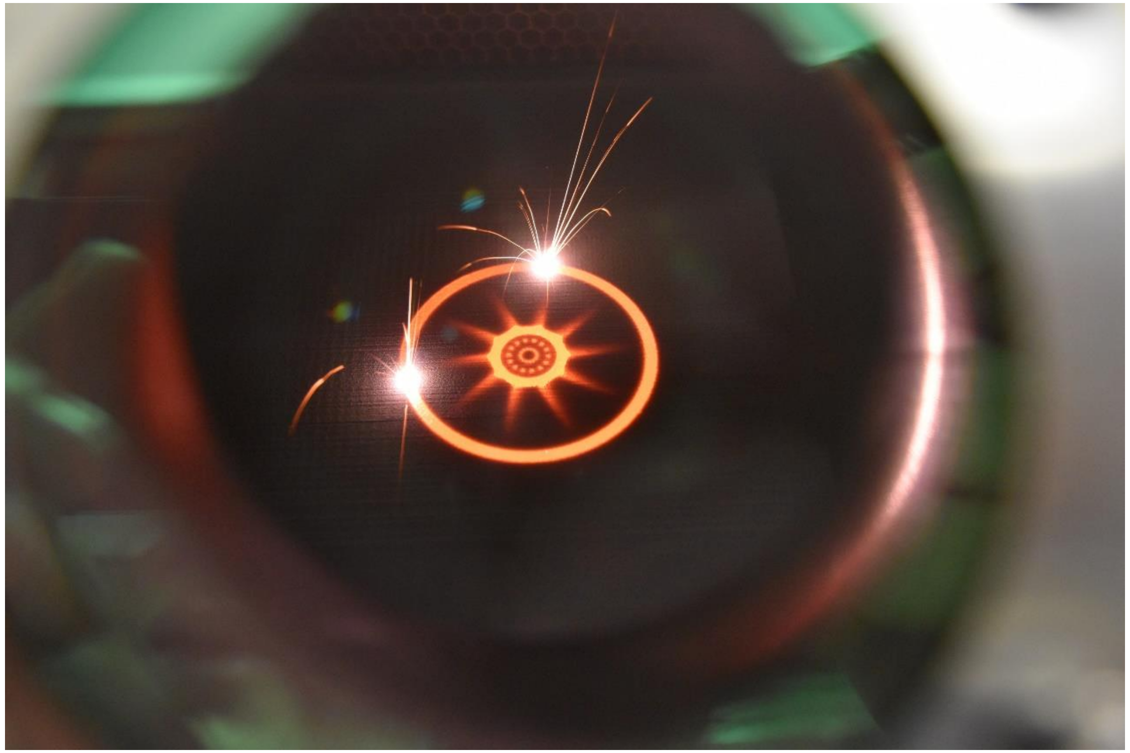
QUANTUM TECHNOLOGY

The Fraunhofer Institute for Laser Technology ILT

Lasermaterial Processing: Additive Manufacturing

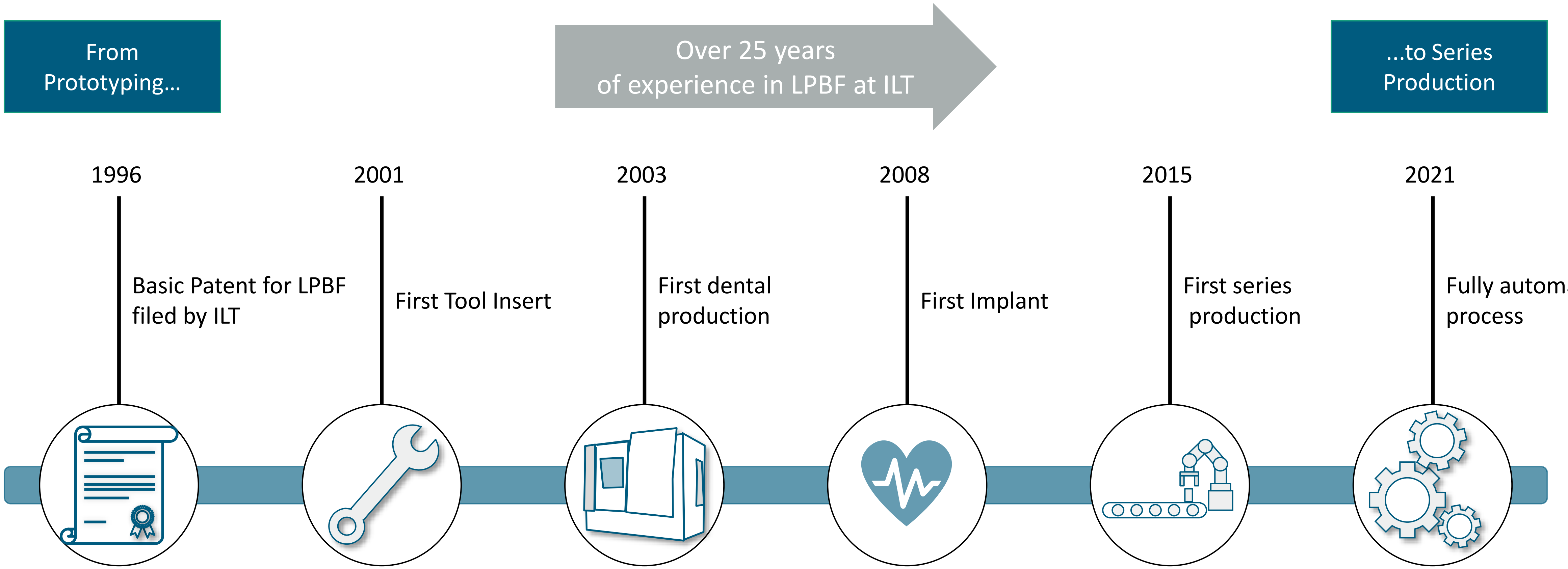
LASER MATERIAL DEPOSITION

LASER POWDER BED FUSION



The AM History at ILT

LPBF as a key enabler of AM



Fraunhofer ILT

More than 20 machines enable research and implementation of a wide variety of applications

Commercial machines

EOS M290 1kW
P = 1000W — 250x250x300 mm^3

Trumpf TruPrint 5000
P = 3 x 500W — Preheating 500°C — Ø300x400 mm^3

SLM Solutions 280 HL Twin
P = 500W — 280x280x365 mm^3

Concept X-Line 2000 R
P = 2x1000W — 800x400x400 mm^3

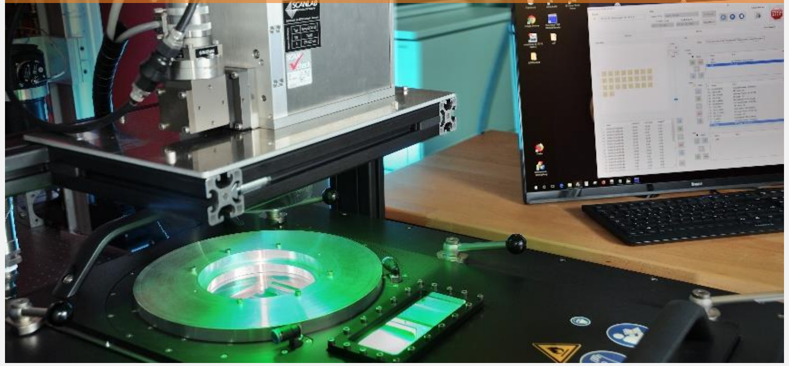
EOS M270
P = 200W — 250x250x215 mm^3

Trumpf Trumaform
P = 1000W — Ø250x160 mm^3

EOS Formiga (SLS)
P = 30W — 200x250x330 mm^3

Laboratory machines

Inhouse enhancements



Aconity Midi – Hazard. Mat.
P = 1kW — Preheating 1200°C — Ø170 x 150 mm^3

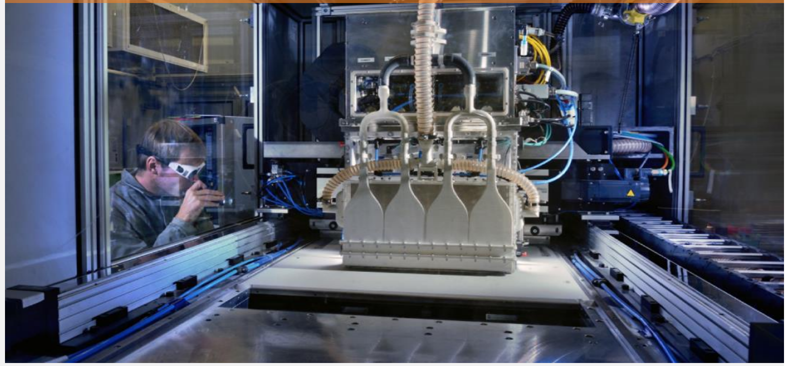
LMI Alpha
P = 400W — Ø140 x 200 mm^3

Aconity Mini – Mikro LPBF
P = 200W — Ø140 x 190 mm^3

Aconity Midi – green
P = 1 kW (515 nm) — Ø170 x 150 mm^3

Aconity Midi
P = 400W — Preheating 800°C — Ø170 x 150 mm^3

Inhouse developments



LPBF-ScalAR
P = 400 W x 5 — 800x1000x400 mm^3

Hybrid Machine
LPBF und Wire-LMD

3x Laboratory Systems
Adaptive process control and laser & optics integrations

1x Laboratory System
Preheating concepts and reactive materials

1x Laboratory System
Process monitoring

1x Laboratory System - SLS
Flexible setup for laser & optics integrations

Fraunhofer ILT

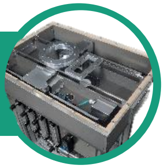
LPBF department pursues a holistic, process-, system-, application and polymer-technical and digital approach for various industries

Laser Powder Bed Fusion

M. Sc. Tim Lantzsch
Head of Department Laser Powder Bed Fusion LPBF

Tel +49 241 8906-193
tim.lantzsch@ilt.fraunhofer.de

+ 20 LPBF machines incl. commercial and laboratory equipment



+ Approx. 30 student assistants and 20 Bachelor/Master candidates

Process & Systems Engineering

M. Sc. Niklas Prätzsch
Group Manager
Process and Systems Engineering LPBF

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niklas.praetzsch@ilt.fraunhofer.de

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Dipl.-Ing. Simon Vervoort
Group Manager
Application Development LPBF

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AM Polymers

Prof. Dr.-Ing. Dipl.-Wirt.-Ing.
Sebastian Bremen
Group Manager
AM Polymers

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Sebastian.bremen@ilt.fraunhofer.de

Research Associates

Fraunhofer ILT

Infrastructure at Fraunhofer ILT

Materials and key branches

Al Aluminium base

- AlSi10Mg
- AlSi7Mg
- AlSi9Cu3
- AlSi12
- AlMgSc

Fe Iron base

- Stainless steels (316L, 17-4PH)
- Tool steels (H13, Maraging steel)

Ni Nickel base

- Inconel 718
- Inconel 625
- Inconel 738
- Inconel 939
- Hastelloy X

… Other materials

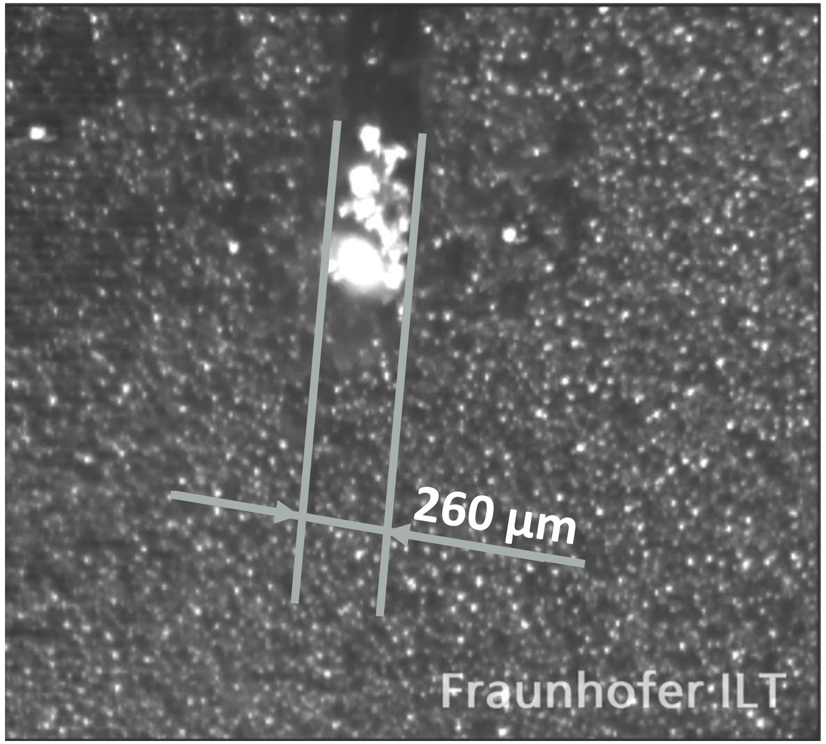
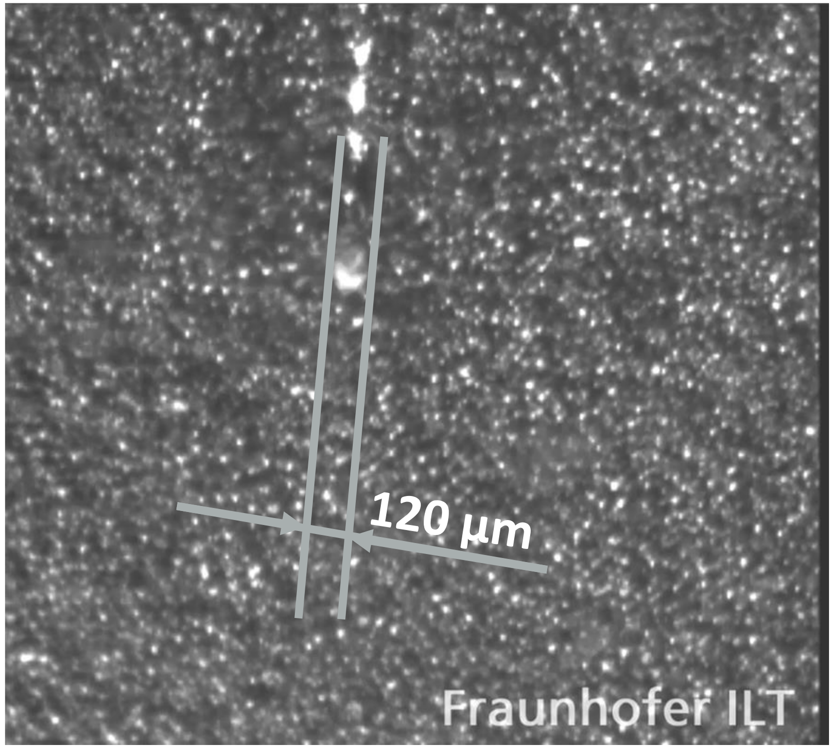
Ti	Titanium alloys
Cu	Copper alloys
Co Cr	Cobalt chrome alloys
Mg	Magnesium alloys
Pd Ag Au	Precious metals
W Mo	Refractory metals

Additional expertise in alloy development at ILT

Fraunhofer ILT

LPBF with modulated laser radiation

Comparison cw vs. ps

Continuous Wave Mode	Pulsed-modulated Mode
	

Macro Laser Powder Bed Fusion with pulsed-modulated laser radiation

Geometric accuracy and detail resolution can be increased for large scale parts

Goal

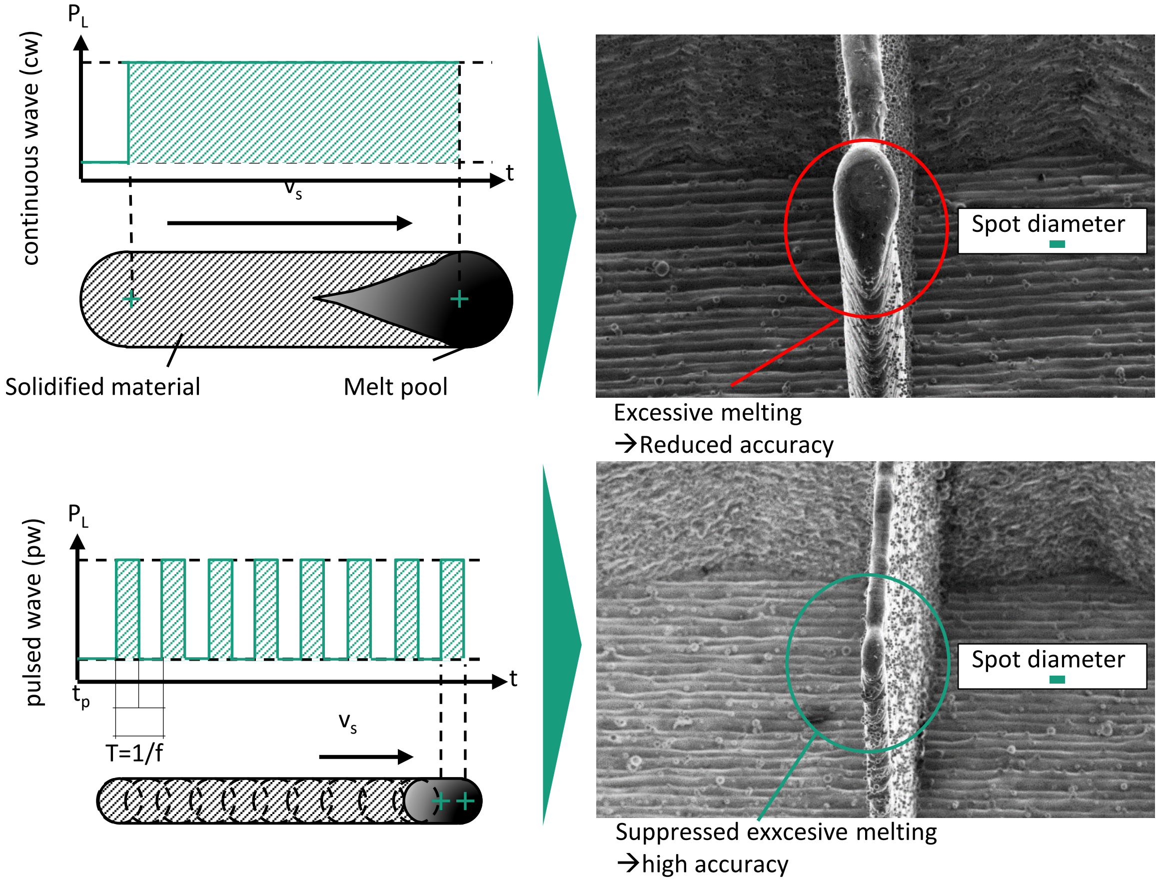
Increasing as-built geometric accuracy and detail resolution for industrial scale applications, e.g. for filigree structures to increase part quality and to reduce post processing effort.

Approach

Adjustment of processing parameters such as scanning speed, pulse overlap and pulse frequency so that discretely solidifying melt pools are generated within the build part contour. Limiting melt pool volume prevents overheating phenomena such as excessive melting and hence, geometric deviations are reduced.

Benefits

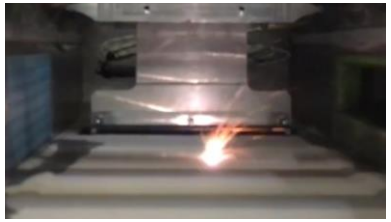
Due to reduced geometric deviations, subtractive post processing effort is reduced. Increased detail resolution in functional part areas leverage build part performance (e.g. turbomachinery parts).



Fraunhofer ILT

Geometry-controlled Energy Input for LPBF

LPBF Challenges



Spatter

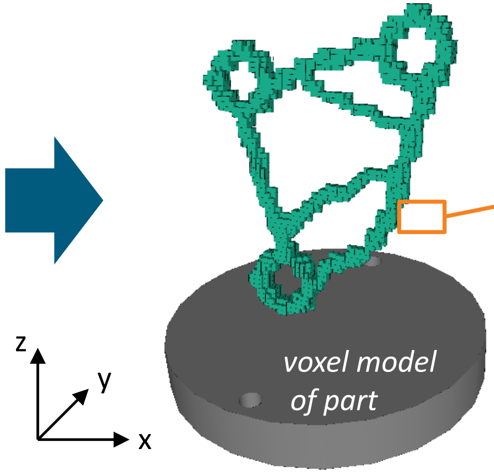
Overheating

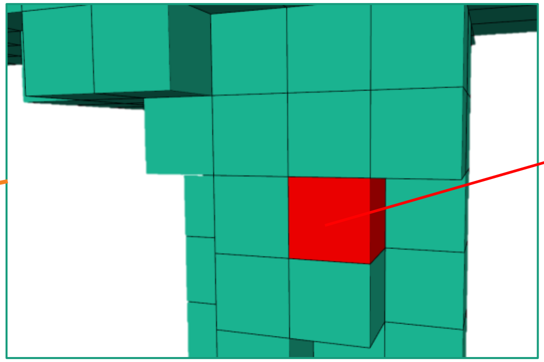
Process failure

Process duration

? **Dynamic adaption of LPBF Process parameters**

Approach: Representation of the (geometrical) part properties by **voxel (volumetric pixel) model**





Exemplary **properties of each voxel**

Z distance to powder

2D distance to component contour

„**Voxel density**“ in specific regions of the part

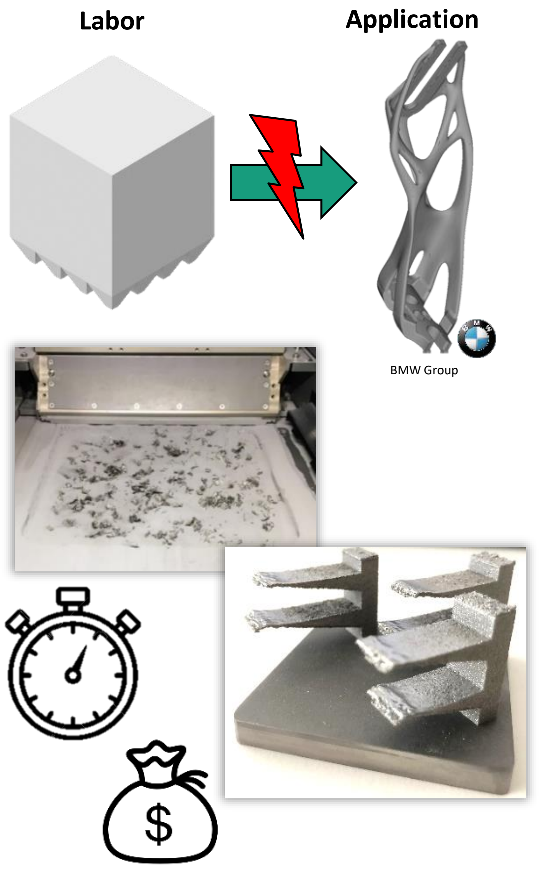
! **Process parameters as function of voxel properties**

Fraunhofer ILT

Geometry-controlled Energy Input for LPBF

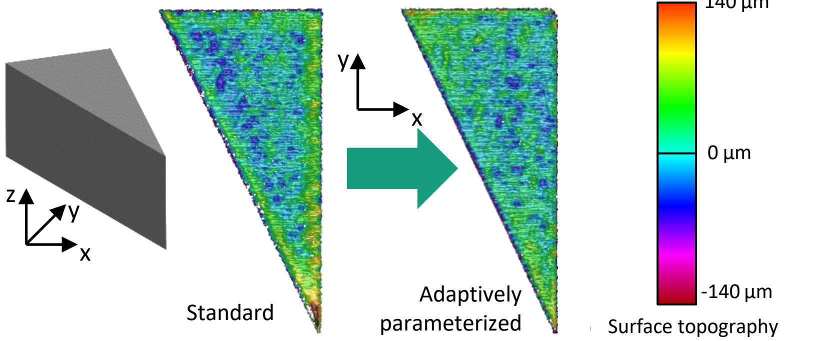
Idea and Approach

Challenges

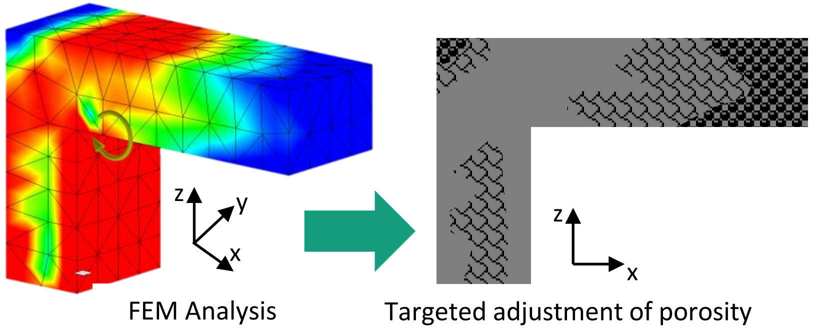


Approach of ILT

Geometry-adapted process control

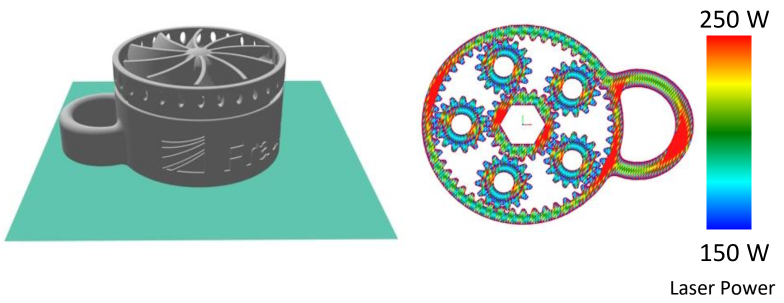


Application adapted process control

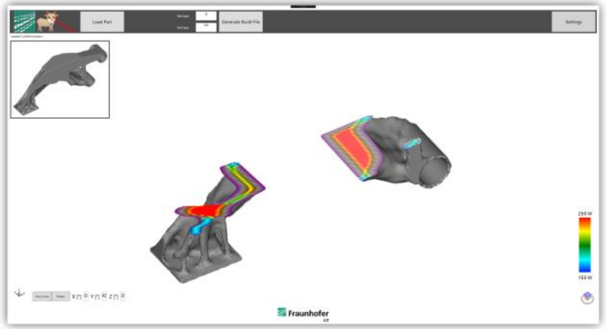


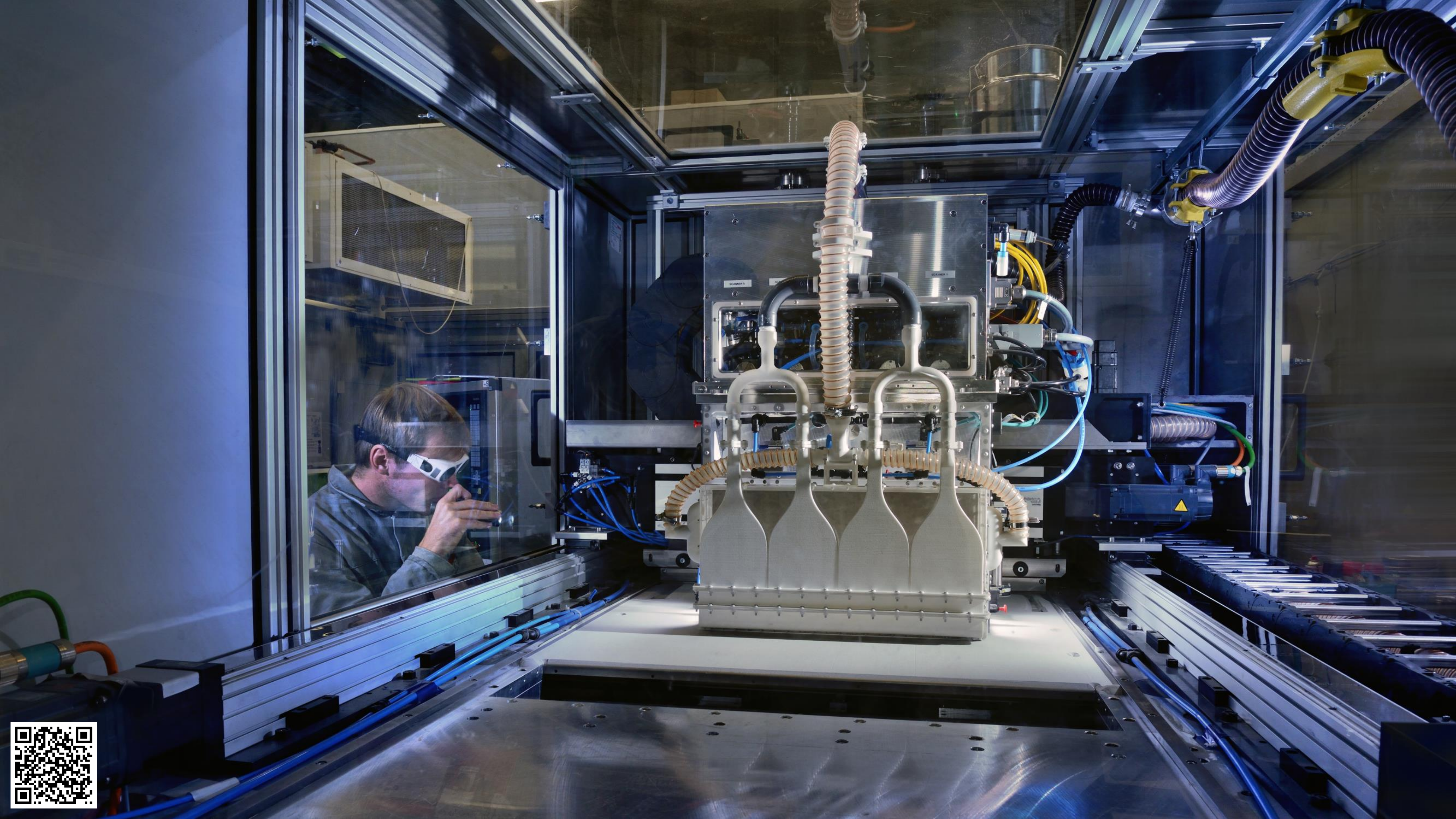
Expertise of ILT

Proprietary software for laser & scanner control



Proprietary software for data preparation





Beam shaping for LPBF

Scaling of productivity by high laser powers

Principle

Goal: Increase of productivity by LPBF processing with high laser powers

Challenges:

- For Gaussian laser intensity distribution high laser powers result in high peak intensities
- Strong evaporation due to excessive energy input
- Risk of keyhole induced defects and process instabilities

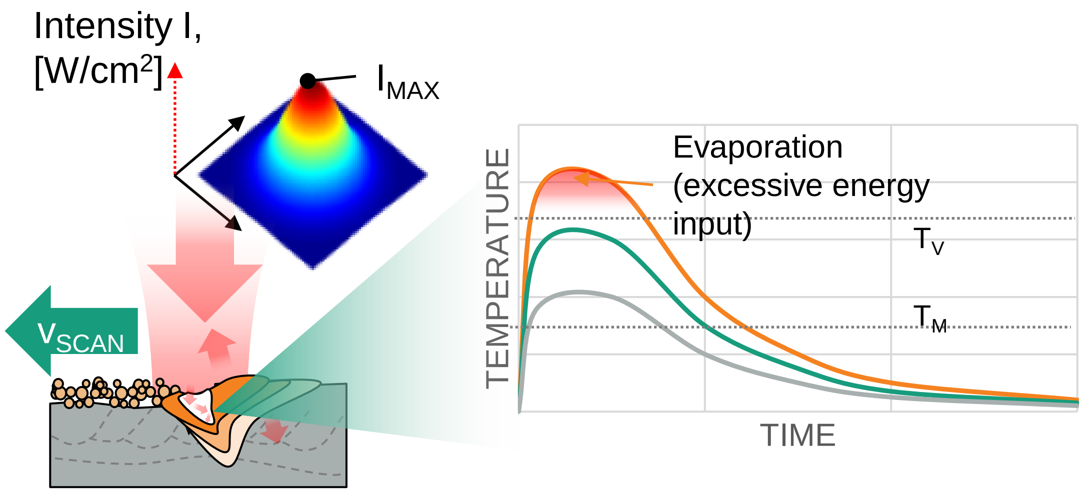
Approach:

- Variation of laser beam diameter d_s
- Variation of laser intensity distribution

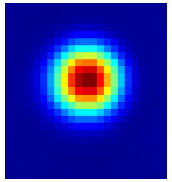
Benefits

➢ Robust high-power LPBF processing

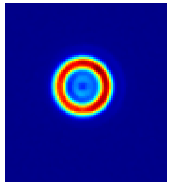
Approach



Control of local energy input



Laser beam diameter d_s



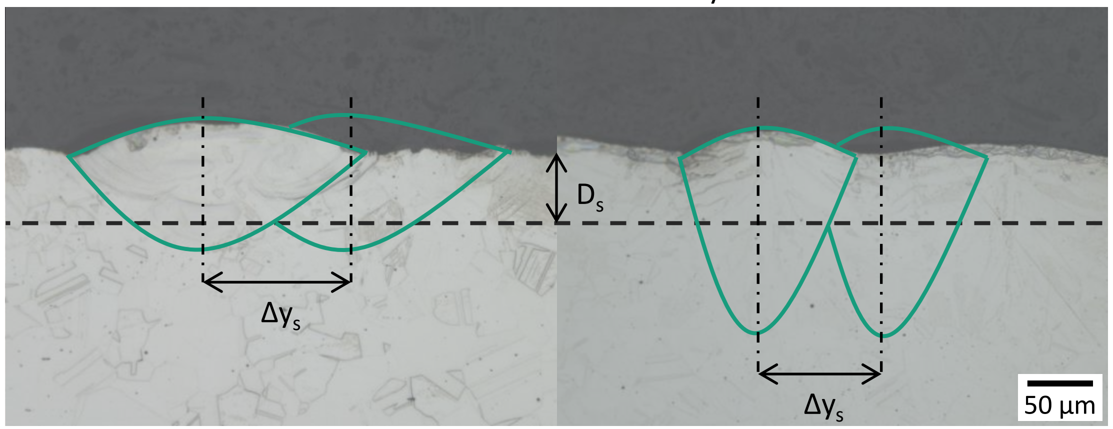
Laser intensity distribution

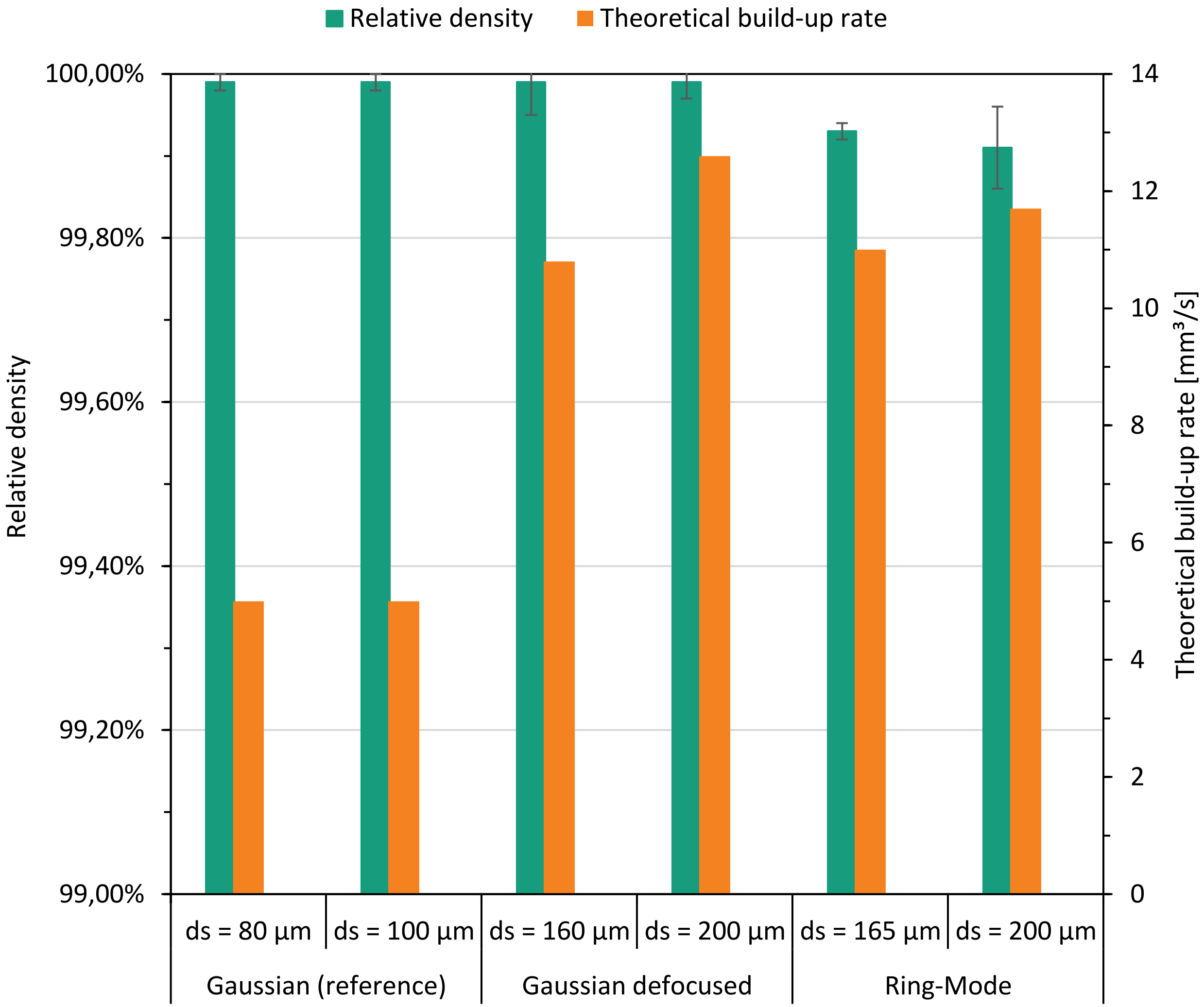
Fraunhofer ILT

Beam shaping for LPBF

Combined process and systems engineering for high-productivity LPBF

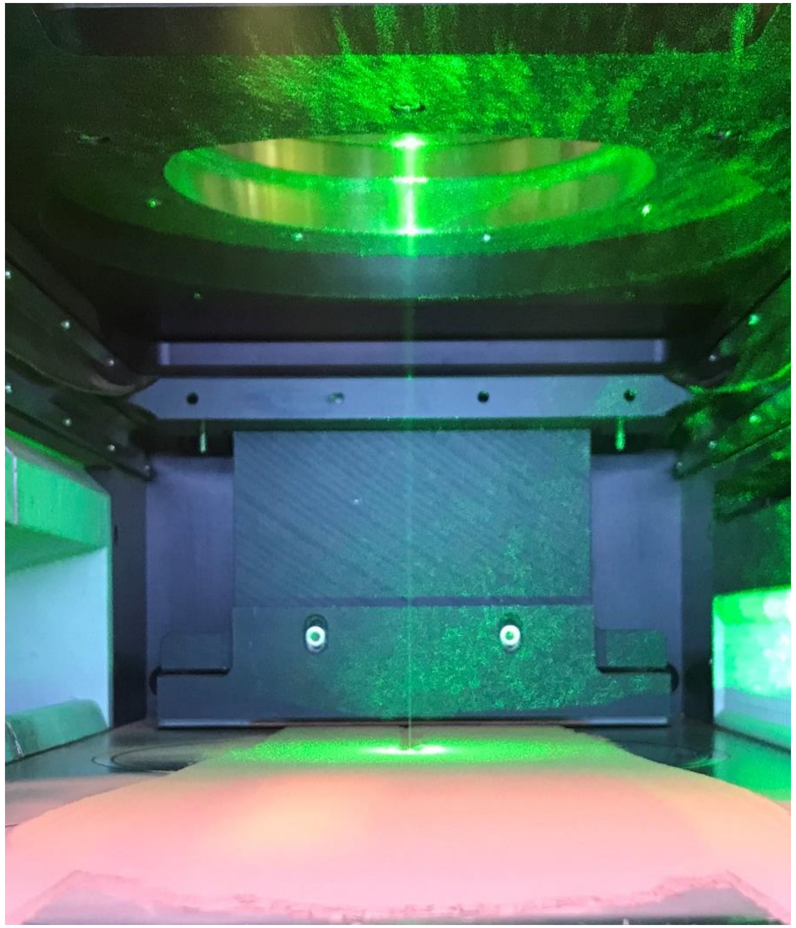
- Beam shaping for control of LPBF processing regime
- Relative densities of $\rho_{rel} \geq 99{,}9\%$
- Increase of theoretical build-up rate by up to 150% compared to Gaussian reference for IN625



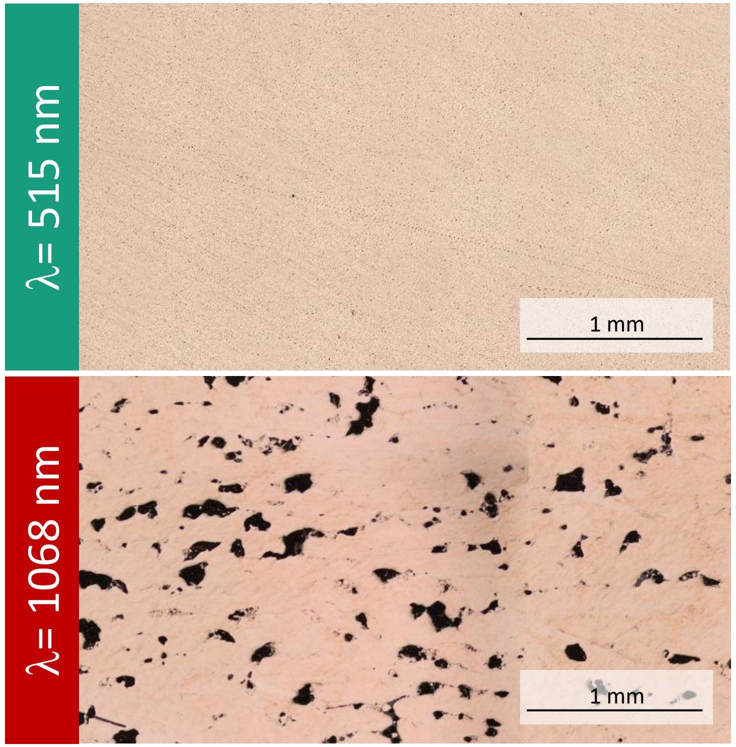


LPBF with green laser wavelength

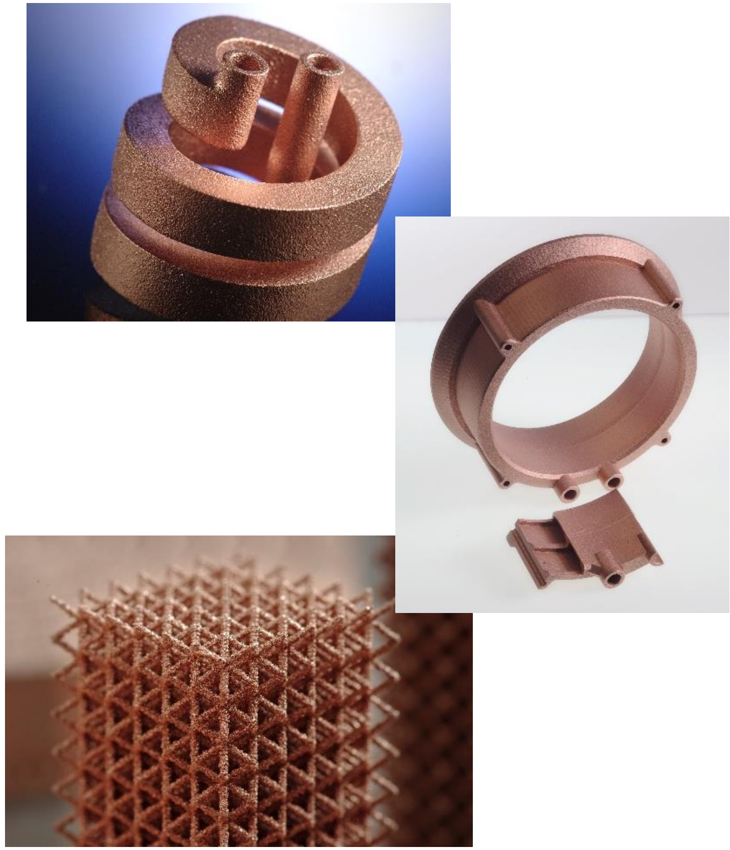
Extension of process boundaries for highly-reflective materials



P_L= 800W, v_{SCAN}= 800 mm/s



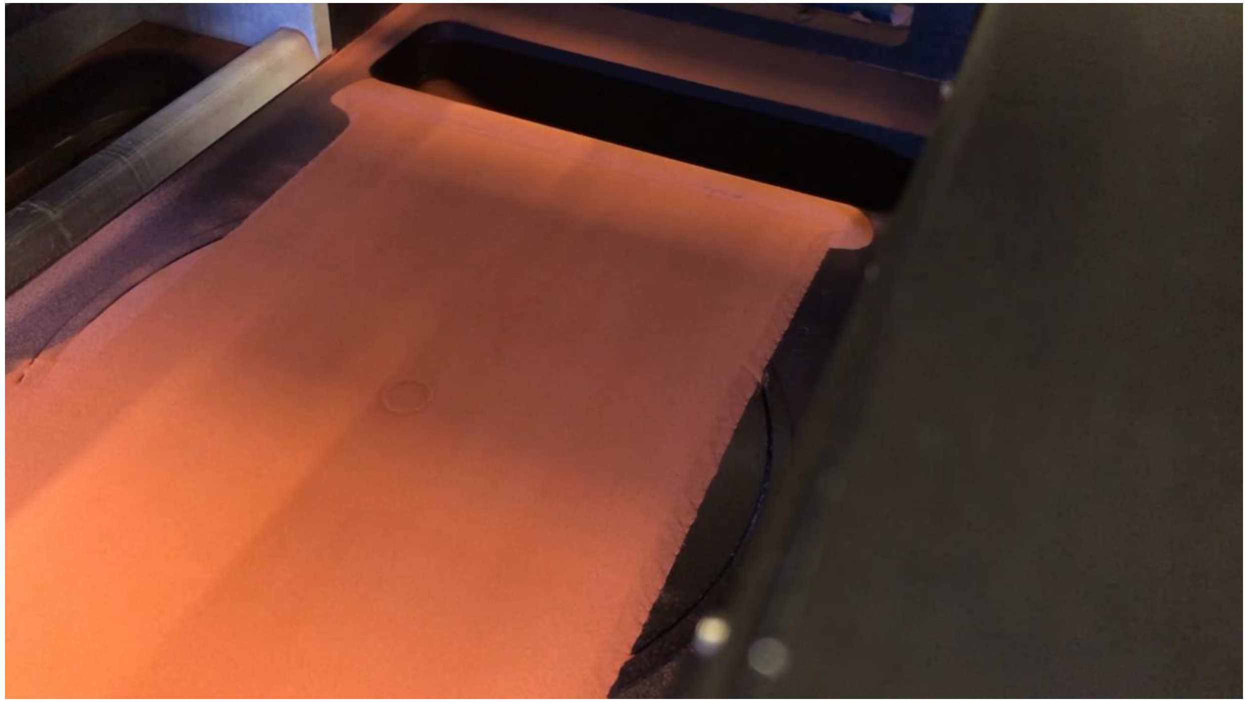
LPBF process or pure copper (Cu-ETP), Laser beam diameter: 160 µm (TopHat)



LPBF with green laser wavelength enables stable and reproducible processing of pure copper

Demonstrator part – LPBF with green laser wavelength

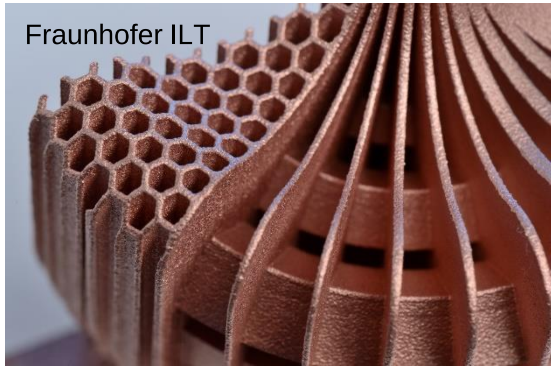
- LPBF lab machine at ILT
- Laser beam diameter d_s = 160 µm
- Layer thickness D_s = 30 µm
- Build job duration: approx. 26 h

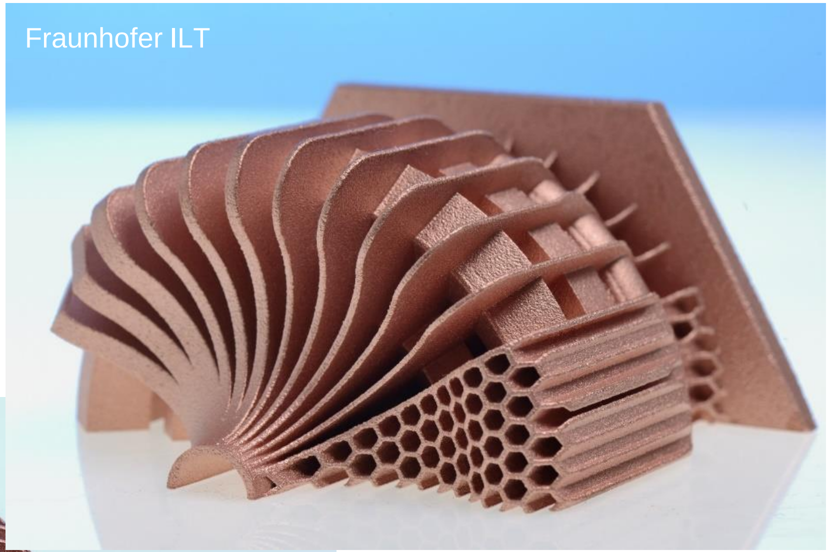


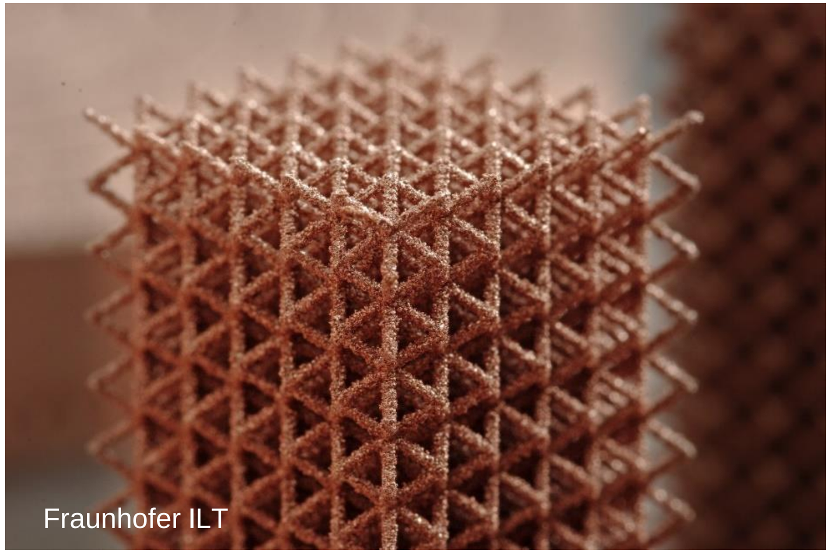
Fraunhofer ILT

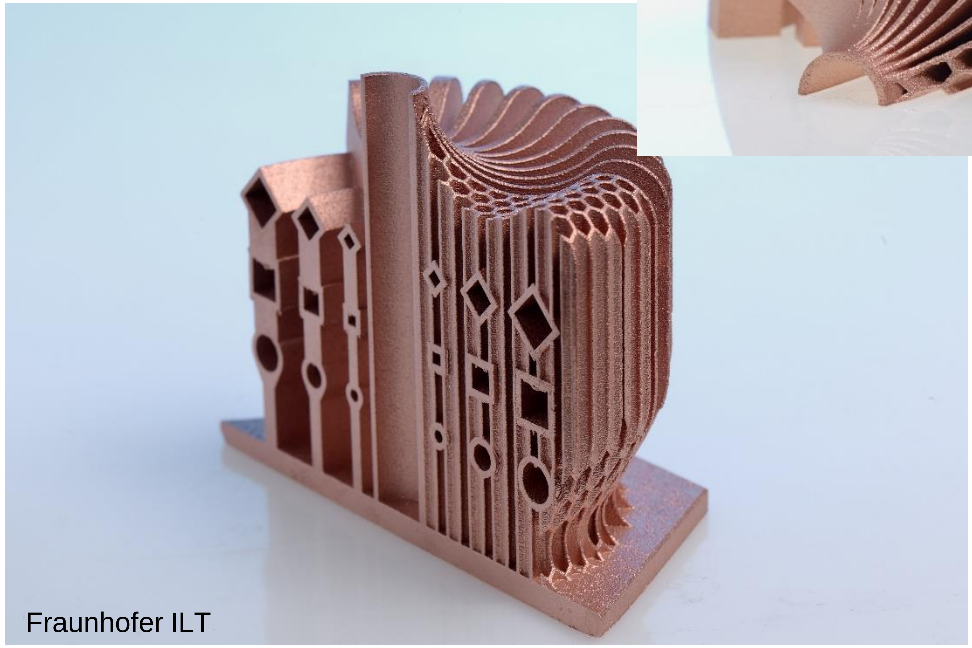
LPBF of copper and copper alloys

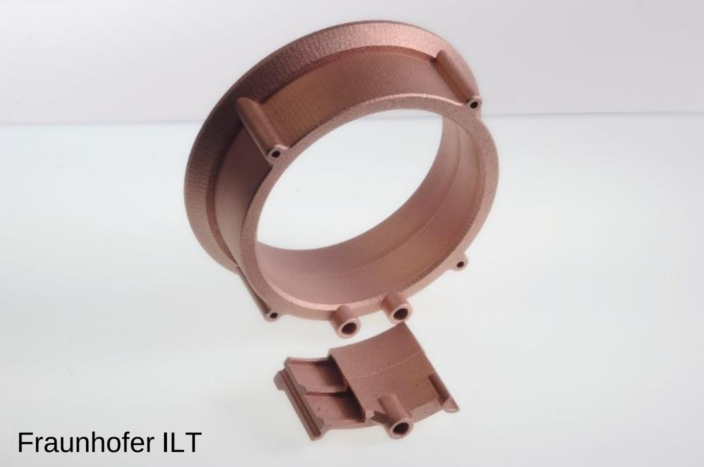
Design and application demonstrators











Direct Preheating of the Melt Pool Layer for Laser Powder Bed Fusion

Constant preheating independent of build height

Results

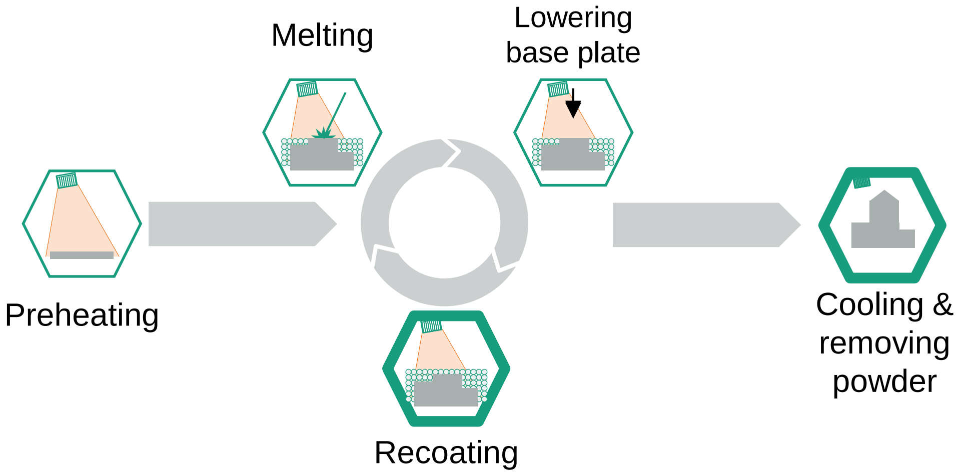
Integration of a VCSEL laser module from TRUMPF photonic components into a LPBF laboratory machine

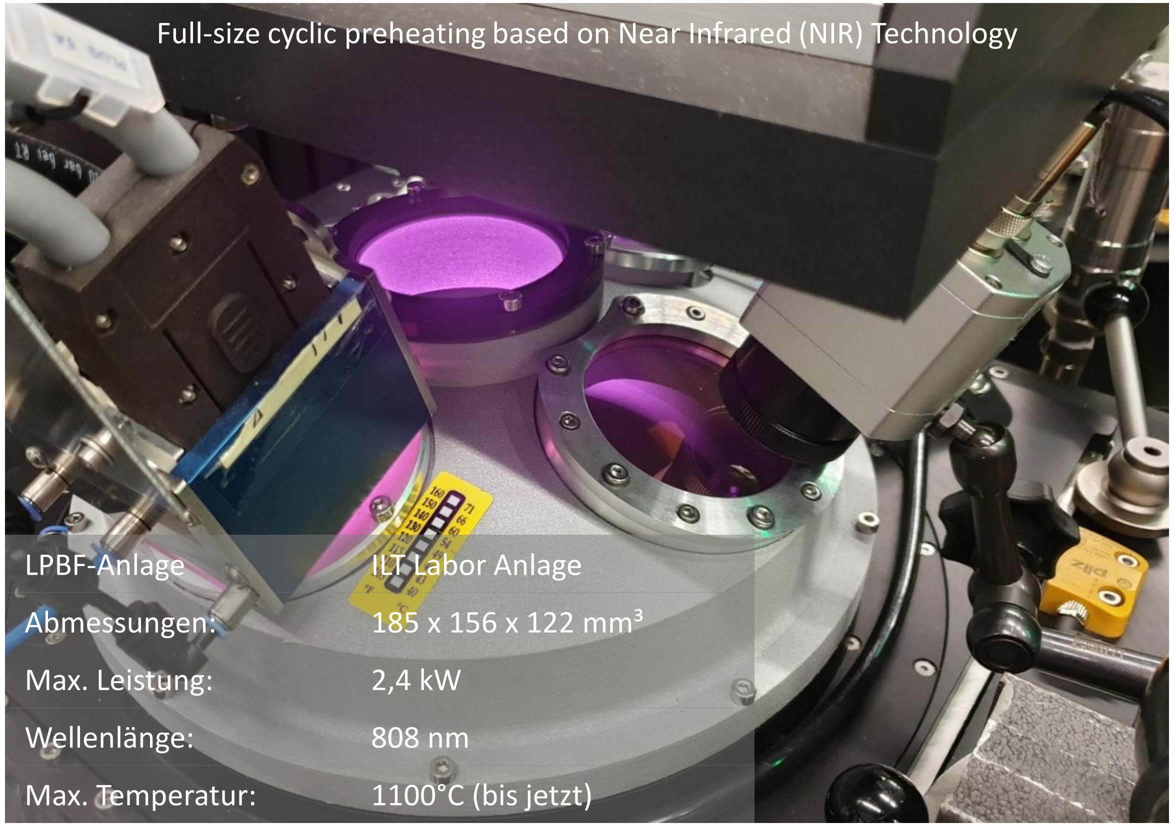
Successful applications:

Reduced deformation for IN718 and TiAl6V4 (> 500°C)

Crack free processing of IN738 (> 1000°C)

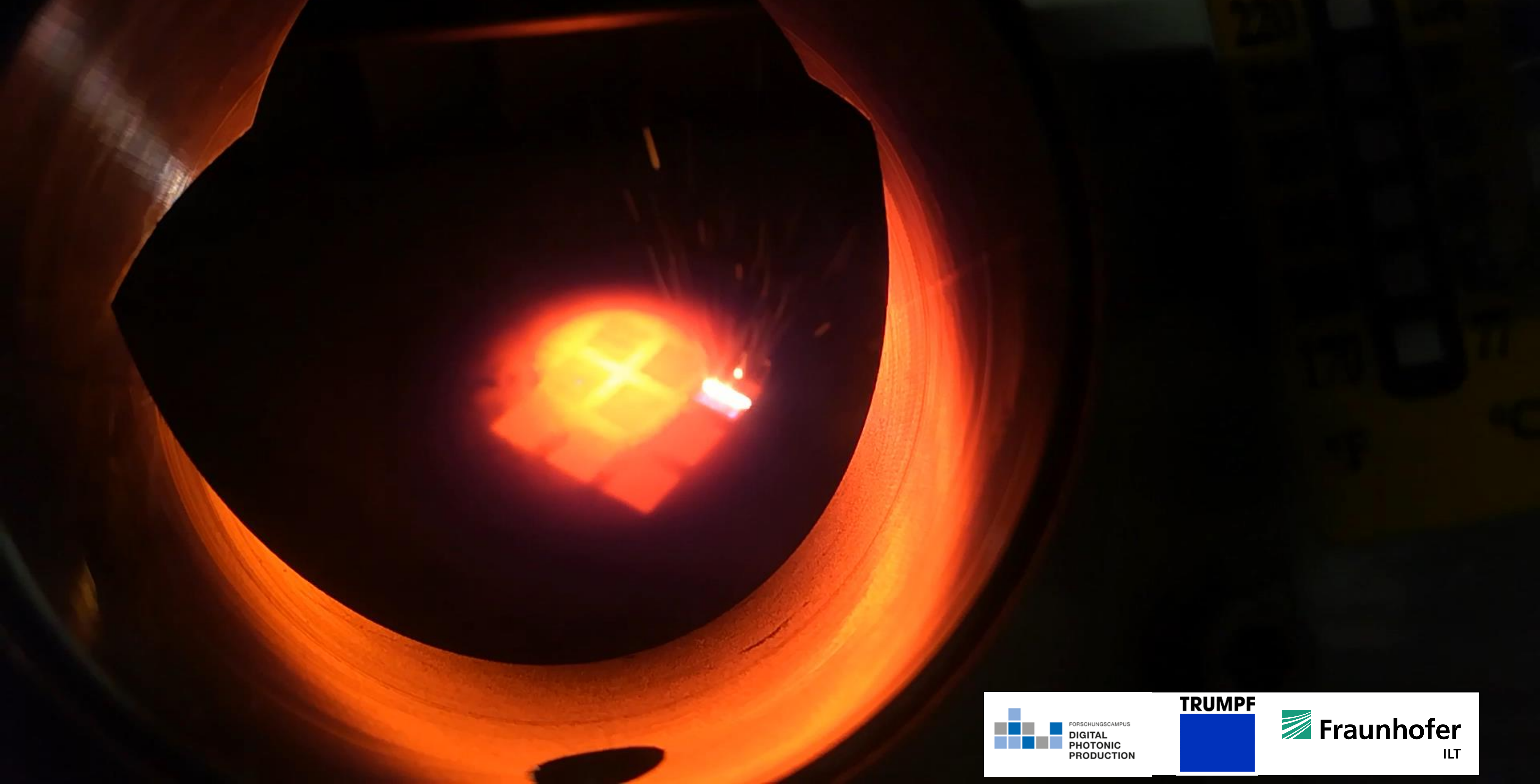
Current research: Processing of titanium aluminides (TNM-B1) at > 900°C





Fraunhofer ILT

Continuous Preheating based on Vertical Cavity Surface Emitting Laser (VCSEL)

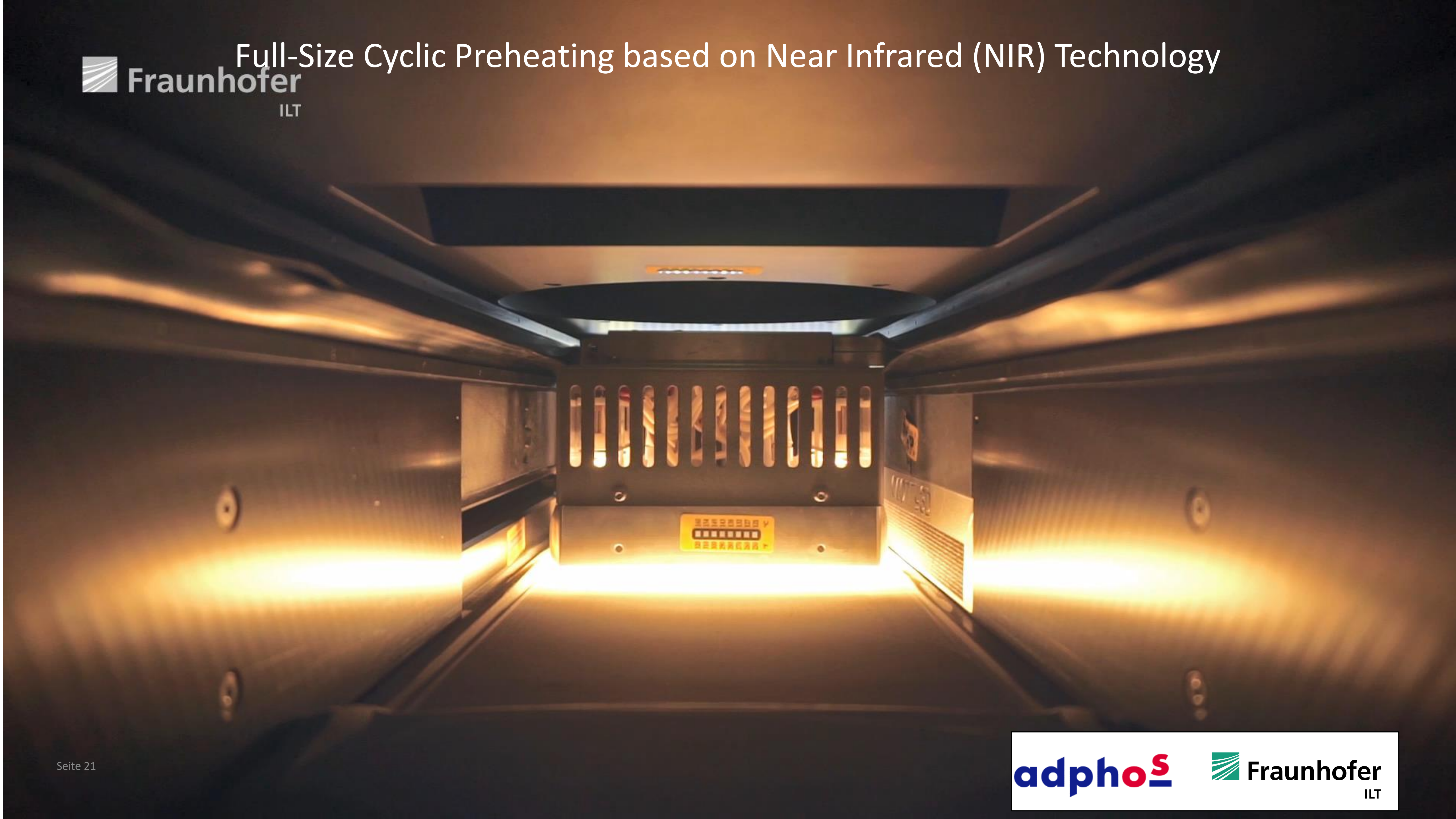


FORSCHUNGSCAMPUS DIGITAL PHOTONIC PRODUCTION

TRUMPF

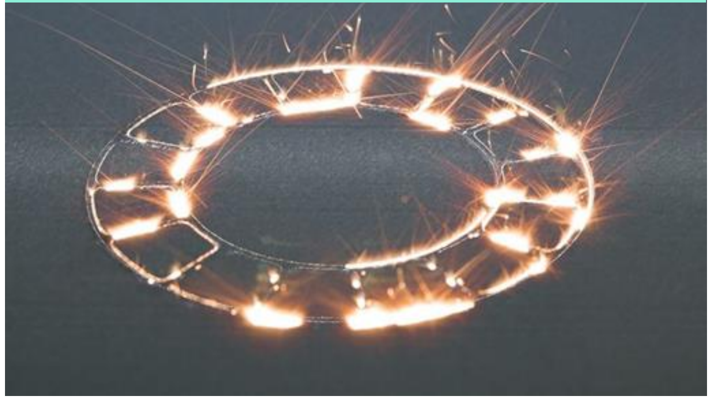
Fraunhofer ILT

Full-Size Cyclic Preheating based on Near Infrared (NIR) Technology



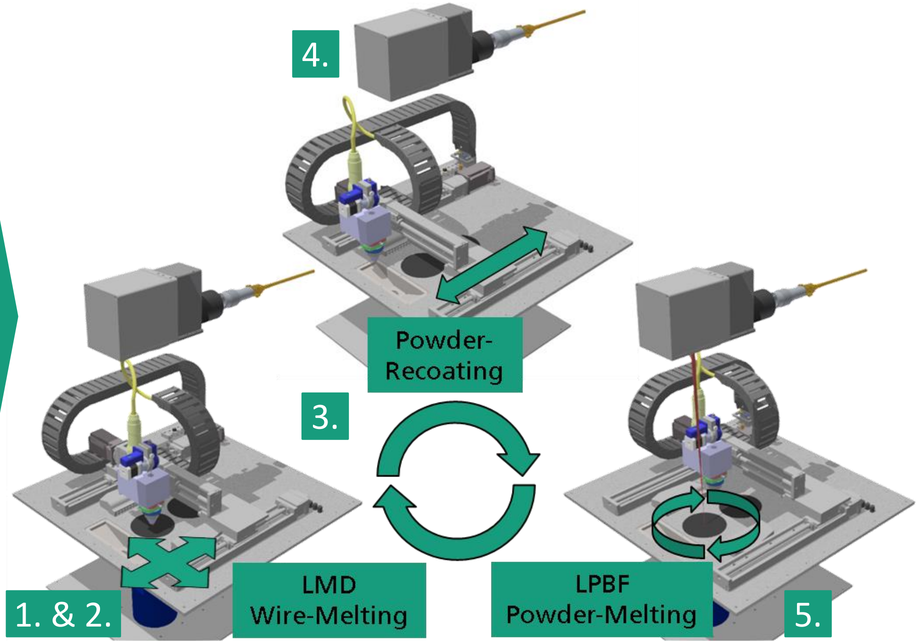
Hybrid-additive Prozessführung mittels LPBF und LMD

LPBF



W-LMD

Bearbeitungsschritte bei kombinierter Prozessführung



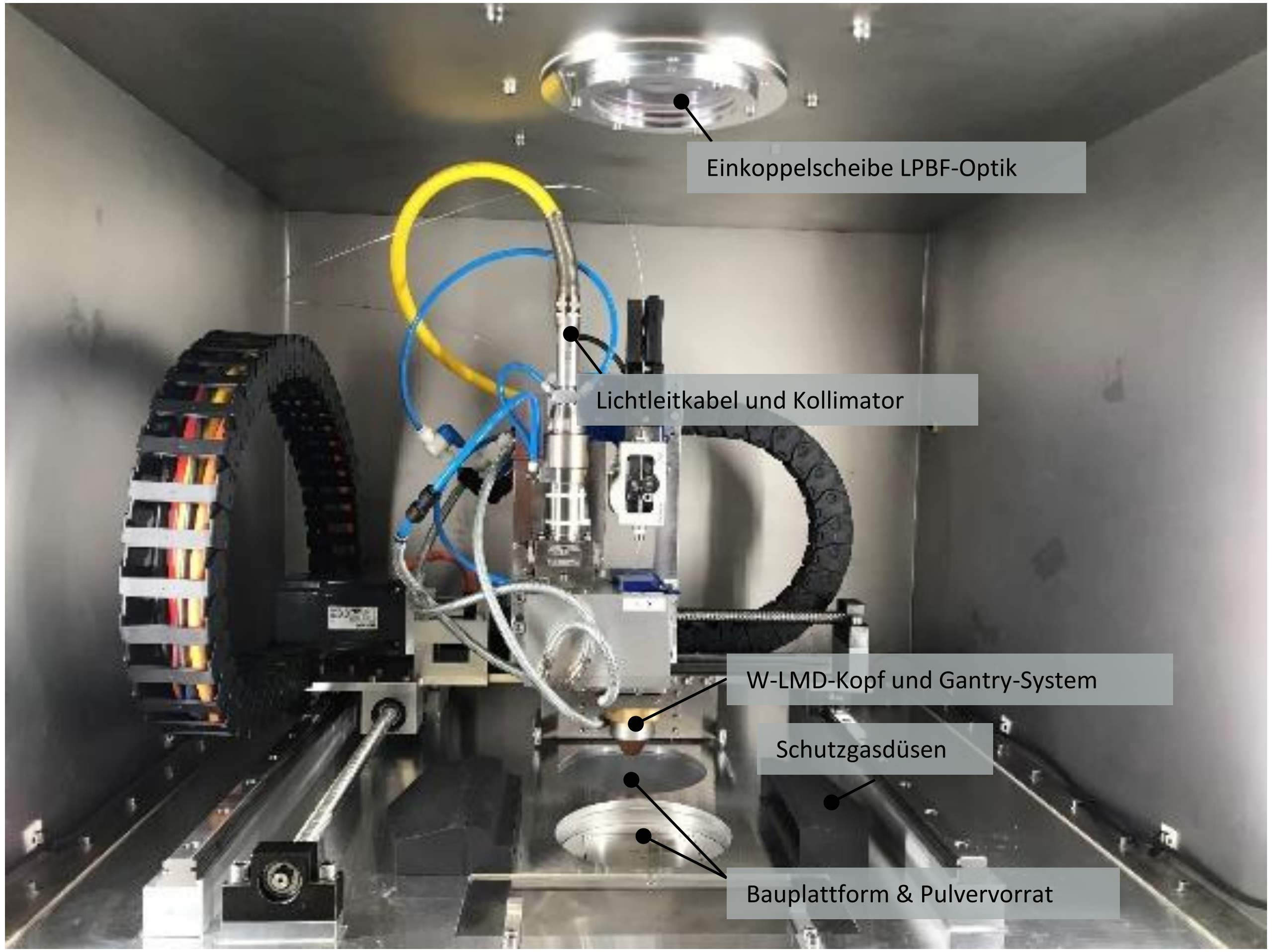
Prozessablauf:

1. Start G-Code LMD
2. W-LMD Bearbeitung
3. Verfahren der Bauplattform nach unten
4. Pulverauftrag
5. LPBF-Prozess

n-mal*

* n = Anzahl LPBF-Lagen bis zur nächsten LMD-Lage, aufgrund der unterschiedlichen Schichtdicken ca. 10

Kombinierte Systemtechnik am Fraunhofer ILT



Entwicklung eines kompakten LMD-Kopfes mit koaxialer Drahtzufuhr

Nachgerüstete LPBF-Laboranlage mit kombinierter Prozesstechnik

Durchgängiges Datenformat für die Bahnplanung mittels LMD und LPBF

Langjährige Erfahrung in der Prozessentwicklung der jeweiligen Verfahren für div. Materialien

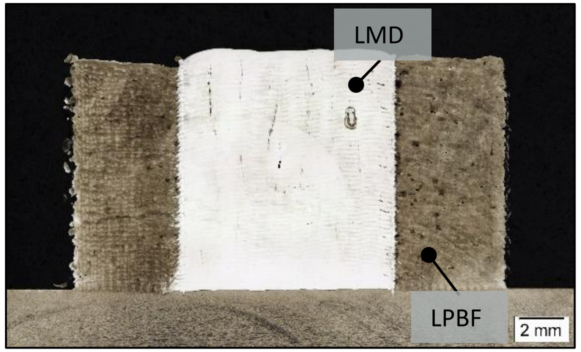
Prozessparameter für den Werkstoff Ti6Al4V für LMD- und LPBF-Einzelprozesse

Durchmesser Bauplattform: 200 mm

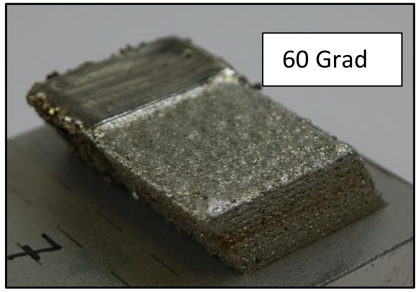
Vorarbeiten am Fraunhofer ILT: Kombinierte Prozessführung

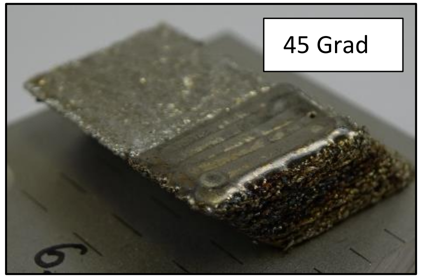
Kombinierte Prozessführung für IN718 (W-LMD) und 316L (LPBF):

Übergangsbereiche

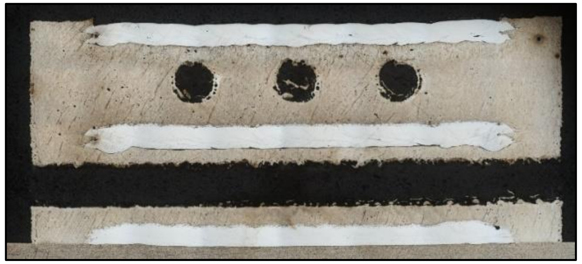


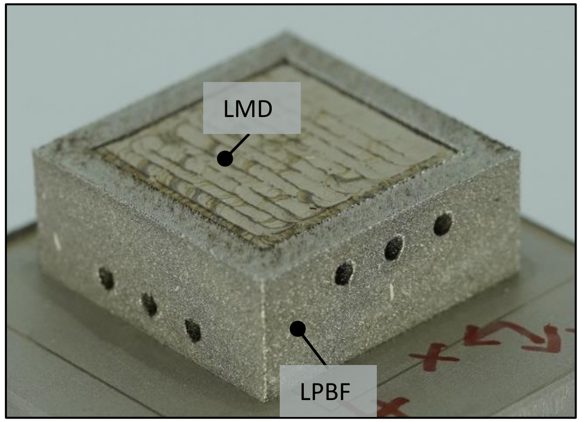
Überhänge





Innenliegende Strukturen





- Kombinierte Prozessführung von LPBF und W-LMD exemplarisch für Werkstoffkombination IN718 und 316L demonstriert

Fraunhofer ILT

LPBF with modulated laser radiation (µ-LPBF)

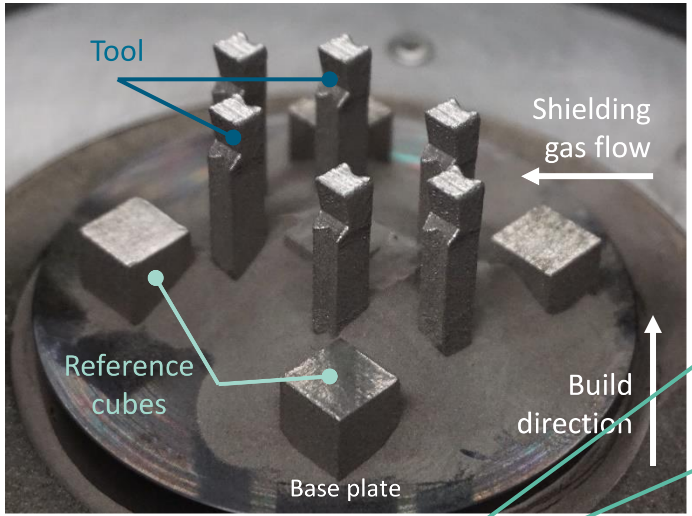
Demonstrators

Photograph	SEM	SEM Detail

LPBF for Engineering Steels

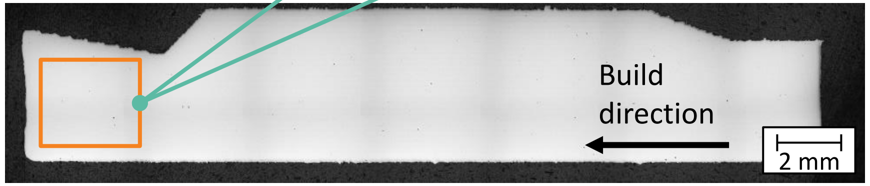
Additive manufacturing of cutting tools with high-speed steel

Additive manufacturing of high-speed tool



Hardness (as built) > 62 HRC

Part density > 99,96%



Material: High-speed steel HS 6-5-3-8 (ASP2030) with 1,3 wt.-% C

Volume energy density E_V = 80 J/mm³

Preheating temperature T_H = 500°C

Source: WZL RWTH Aachen University, Fraunhofer Institut für Lasertechnik (ILT)

Application of additive tool

Processed material: Inconel 718

Cutting speed.: v_c = 5 m/min

Chip thickness: h = 0,2 mm

Cuttign edge radius: r_b = 20 µm

Coolant: trocken

Miniaturized Process Chamber Module for LPBF

Improving material development for LPBF

Goal

Improving experimental investigations for new LPBF alloys

Approach

Miniaturized LPBF process chamber integratable into a standard LPBF (laboratory) machine

Very low powder demand, fast and easy establishing of process readiness

Benefits

Open Software

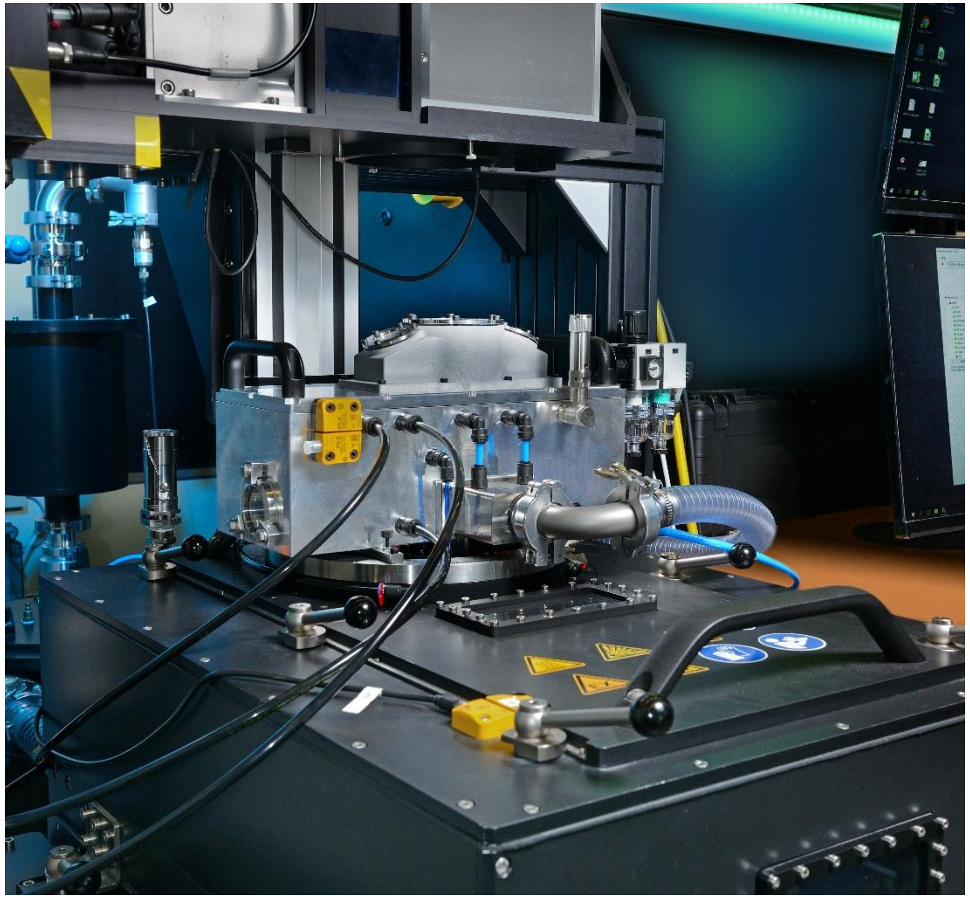
Powder demand of approx. 2 cl

Shared utilization of key machine components (Laser system, optical alignment)

Full inert gas atmosphere in < 10 min (O_2 < 50 ppm)

Integrated shieling gas system

Compact design (easy material change)



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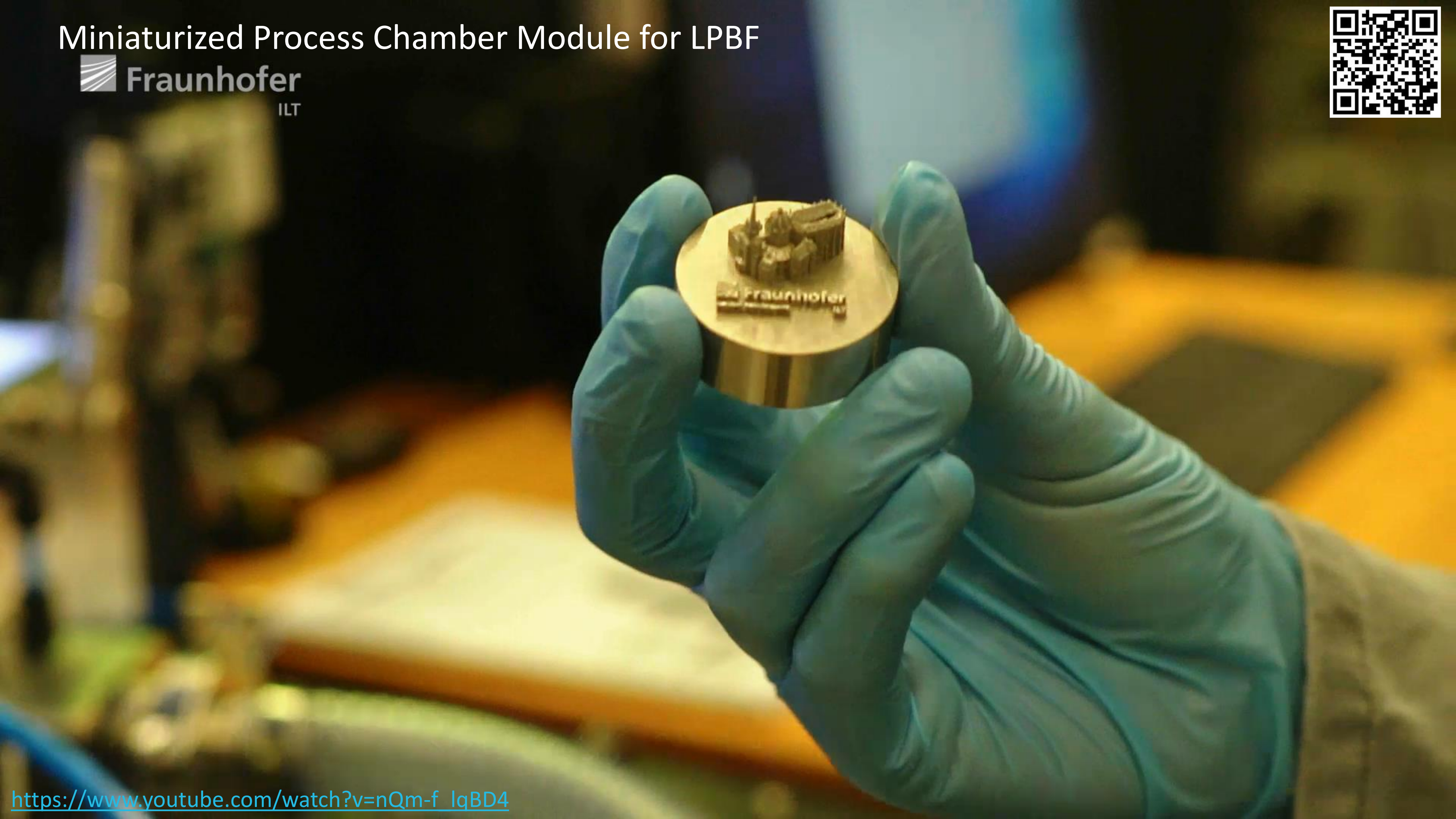
Miniaturized Process Chamber Module for LPBF



https://www.youtube.com/watch?v=nQm-f_lqBD4

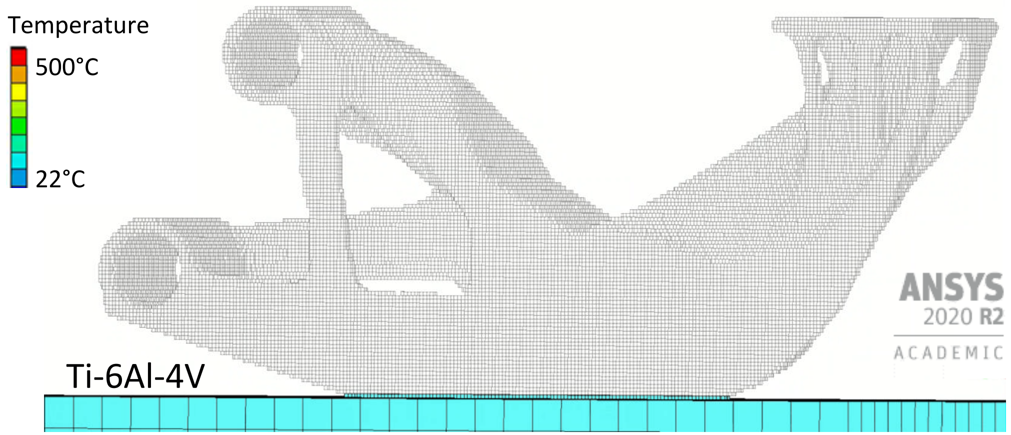
Part geometry effect on material properties

Complex part geometries lead to **inhomogeneous thermal history** in LPBF process

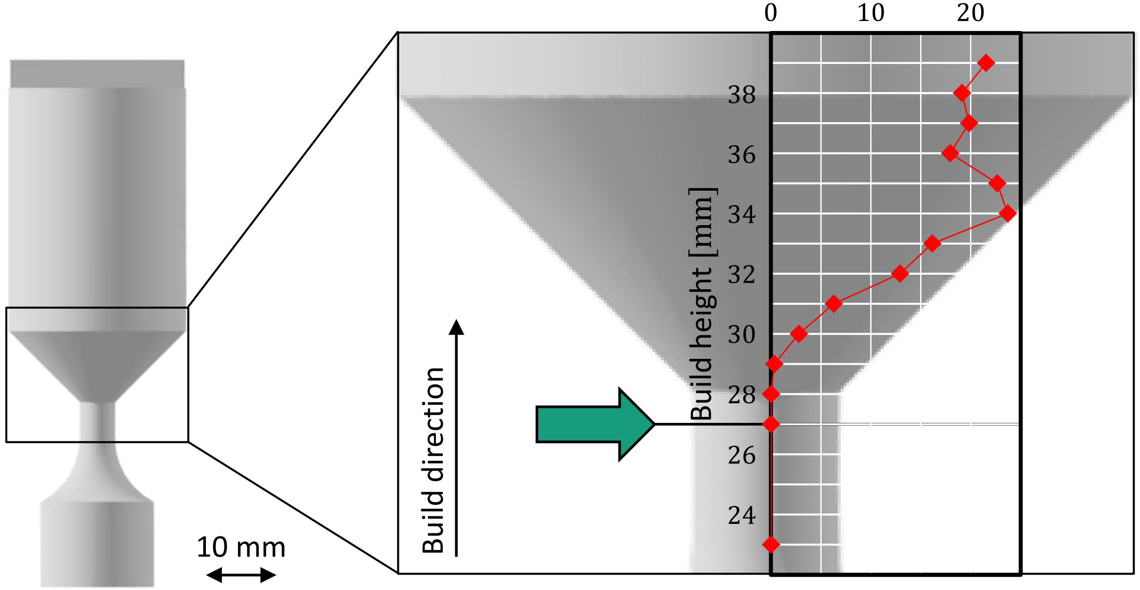
LPBF of Ti-6Al-4V: Overheating leads to intrinsic heat treatment and higher β-phase fraction

Part scale **prediction model** under development

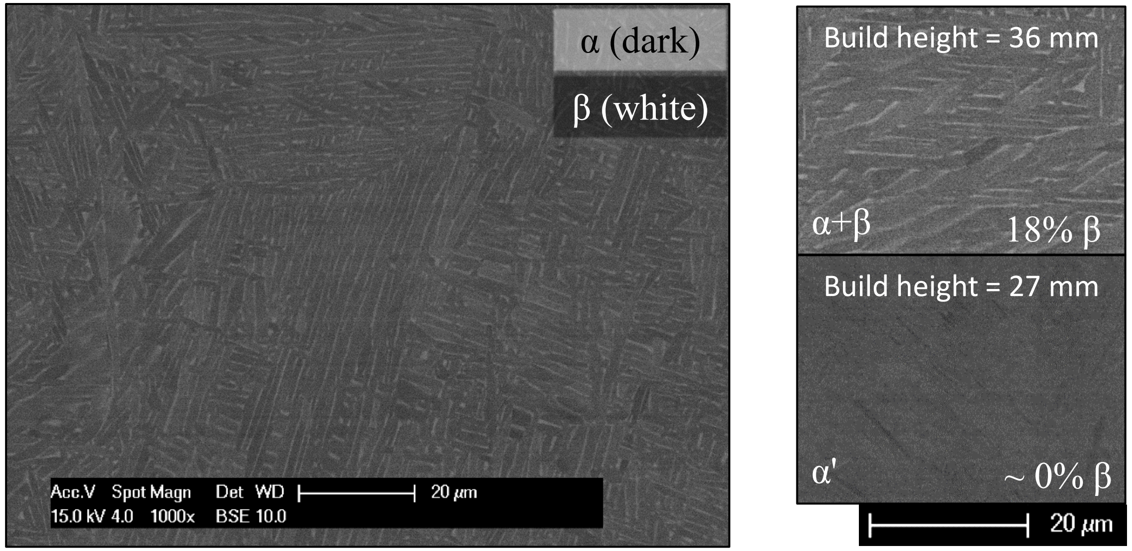
Transient thermal LPBF simulation of topology optimized part



Ti-6Al-4V β-phase fraction [%]

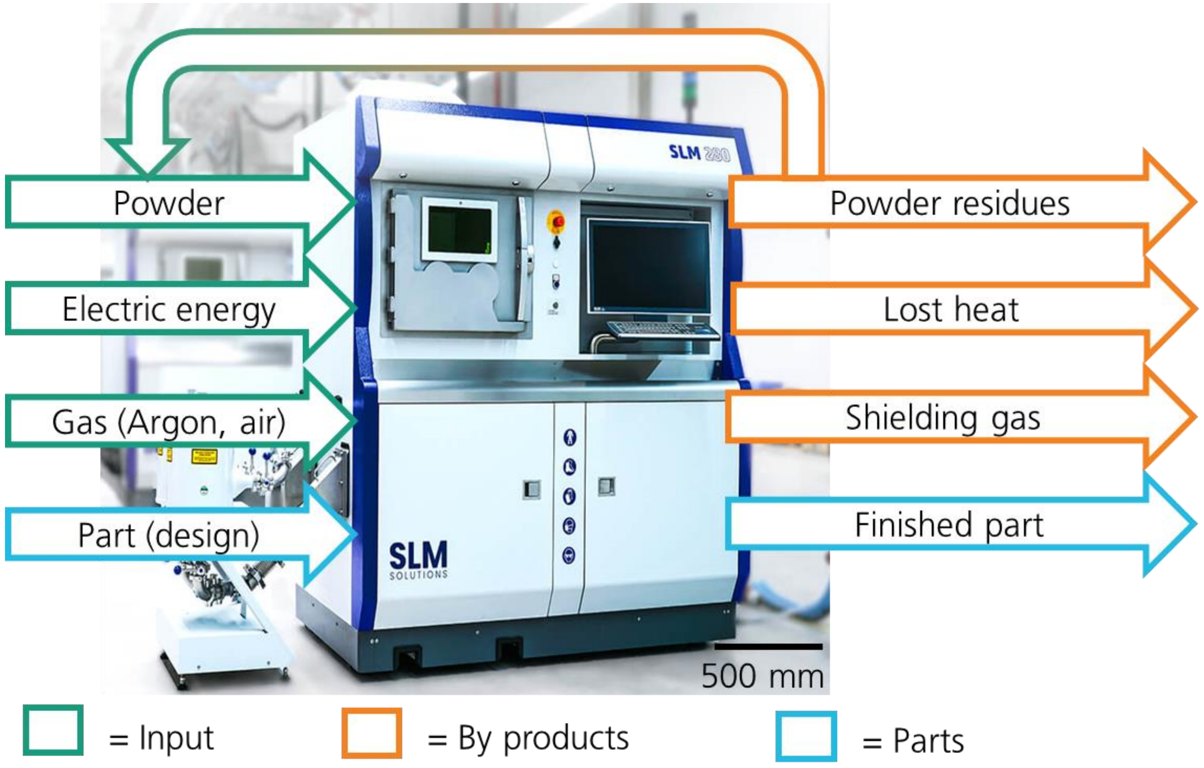


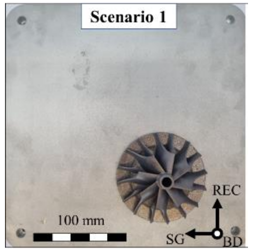
SEM imaging (BSE mode)

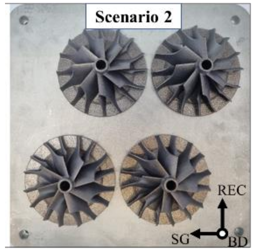


Life cycle assessment in the LPBF process

Gate-to-Gate Analysis of the LPBF Process







Process step	Scenario 1 Share [%]	Scenario 1 Mass [kg CO_2.eq.]	Scenario 2 Share [%]	Scenario 2 Mass [kg CO_2.eq.]
LPBF process	35.63 %	86.023,52	31.18 %	94.874,81
Electr. energy	└ 30.78 %	74.299,50	└ 27.08 %	82.402,80
Argon	└ 03.89 %	9.401,73	└ 03.33 %	10.144,20
Substrate plate	└ 00.86 %	2.064,58	└ 00.68 %	2.064,58
Silicon recoater	└ 00.06 %	152,42	└ 00.05 %	152,42
Transportation	└ 00.05 %	105,26	└ 00.03 %	110,69
Powder reconditioning	01.55 %	3.730,54	1,23%	3.730,54
Electr. energy	└ 01.49 %	3.594,12	└ 1,18%	3.594,12
Rubber gloves	└ 00.06 %	136,43	└ 0,04%	136,43
Cleaning	00.30 %	715,14	00.25 %	768,85
Heat treatment	03.57 %	8.625,26	02.83 %	8.625,26
Electr. energy	└ 03.57 %	8.624,60	└ 02.83 %	8.624,60
Water	└ 00.00 %	0,64	└ 00.00 %	0,63
Milling	00.69 %	1.656,11	02.18 %	6.623,86
Total	**100.00%**	**241.396,00**	**100.00%**	**304.309,00**
Mass per part		**131.19**		**41.35**
Mass per kg molten powder material		**940.45**		**296.39**

CO_2 Footprint per part

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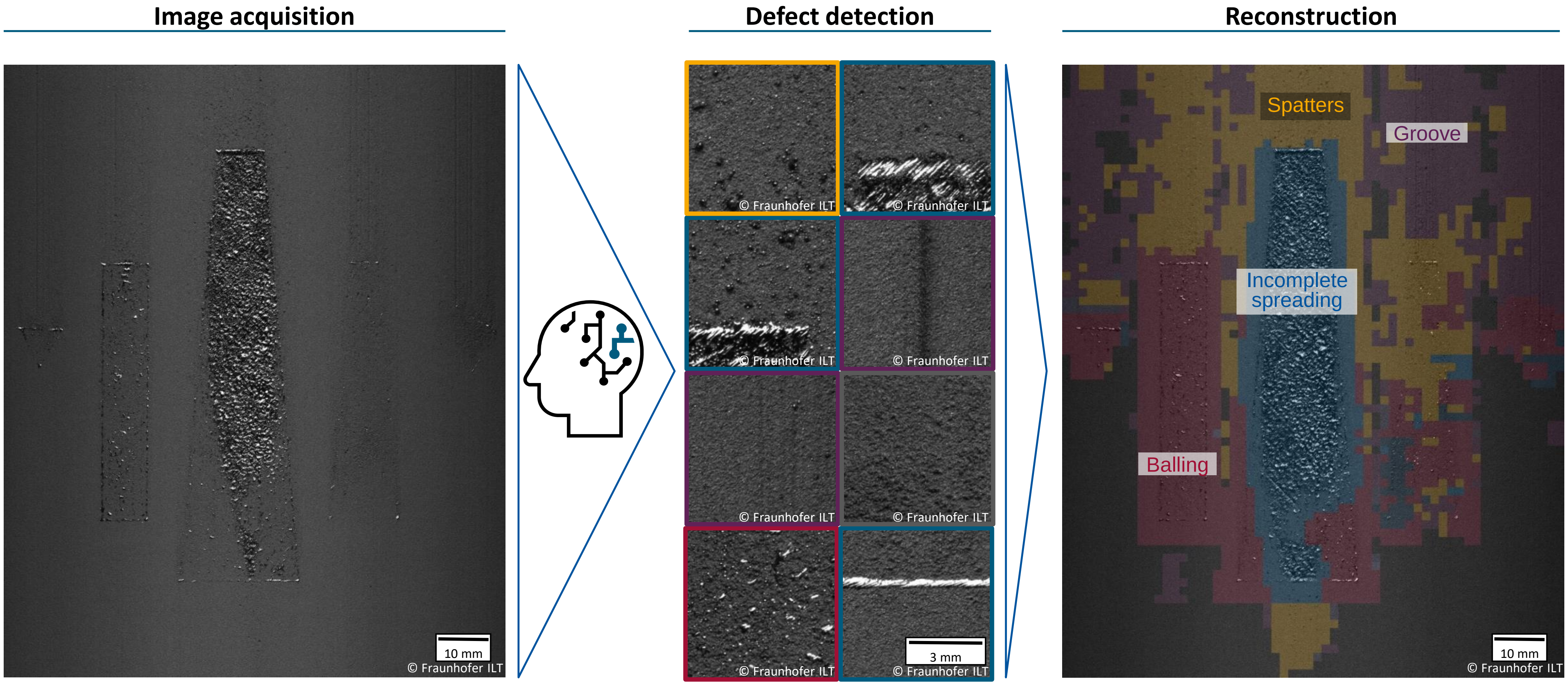
Pretrained deep CNNs to detect many different powder bed anomalies



Source: Fischer et al. (2022). Monitoring of the powder bed quality in metal additive manufacturing using deep transfer learning. *Materials & Design*, *222*, 111029.

Smart LPBF parts

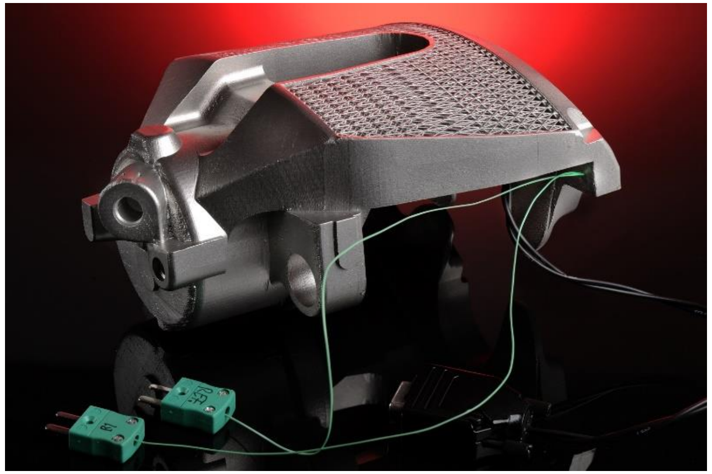
LPBF parts with integrated sensors and electronics

Milling head

- Integrated sensors for radial and tangential force measurement
- Strain gauges printed via thin film processing
- Wireless data transmission
- Internal coolant supply

Break caliper

- Integrated strain gauges for break force measurement
- Internal break temperature measurement
- Internal beak fluid temperature measurement
- Lightweight design



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