

10.09.2026

Photonics4MedTech - Manufacturing & Smart Assembly

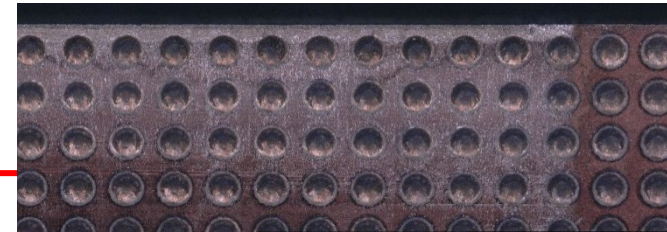
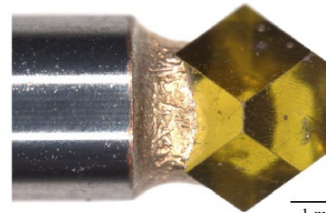
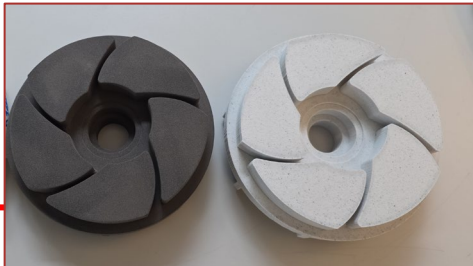
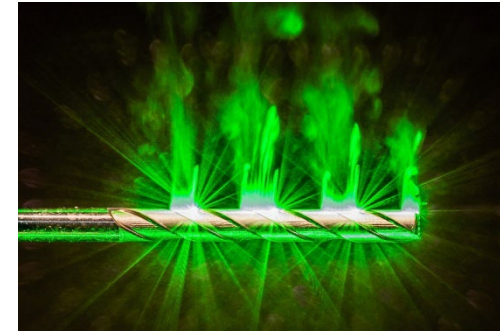
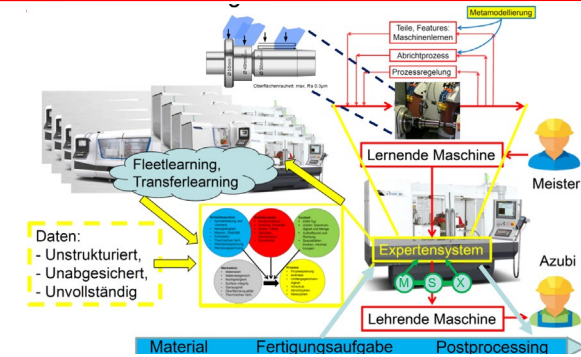
Lasers as an Indispensable Tool in Manufacturing: Ablation, Joining, Forming, and Surface Functionalization

Konrad Wegener

Lasers as an Indispensable Tool in Manufacturing

Content

- inspire: bridge between academia and industry
- It is the system that counts: intelligent machine, digital twin
- Surfaces
- Ablation
- Structuring of tools
- AM (polymer / metall / ceramics)
- Forming
- Conclusion



1 mm

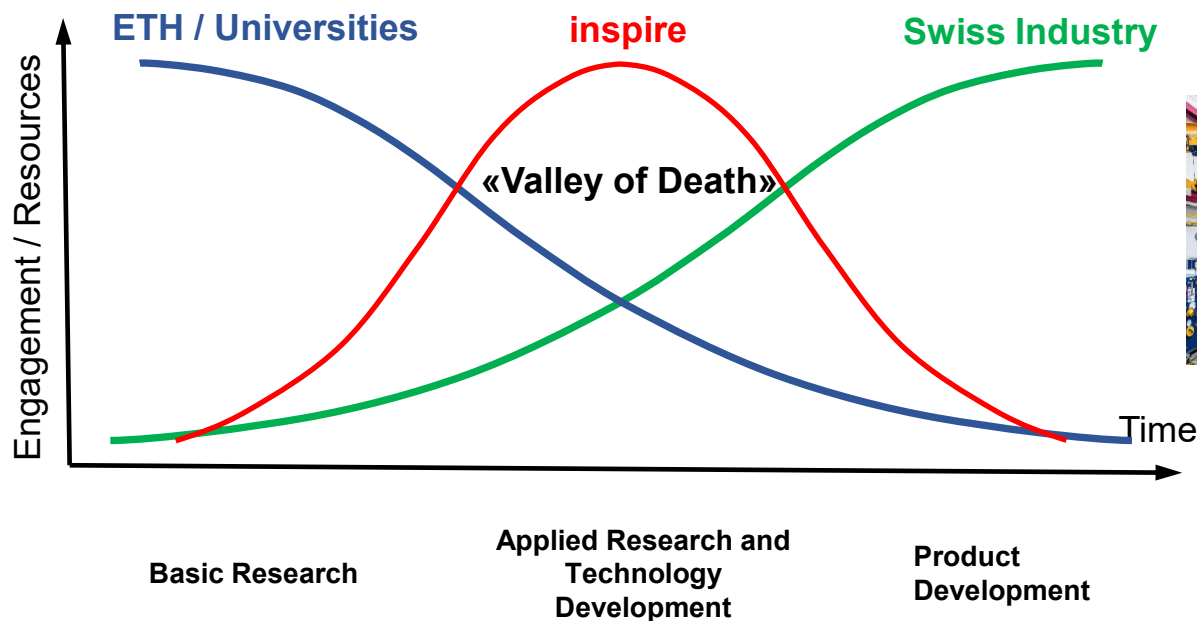
inspire AG

inspire as Bridge between ETH and Industry

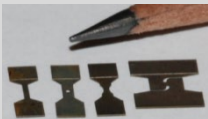
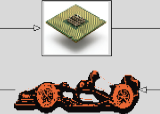
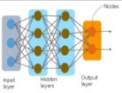
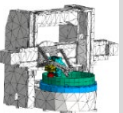
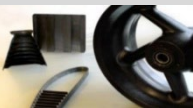
 130 Employees

 18.7 MCHF Turnover

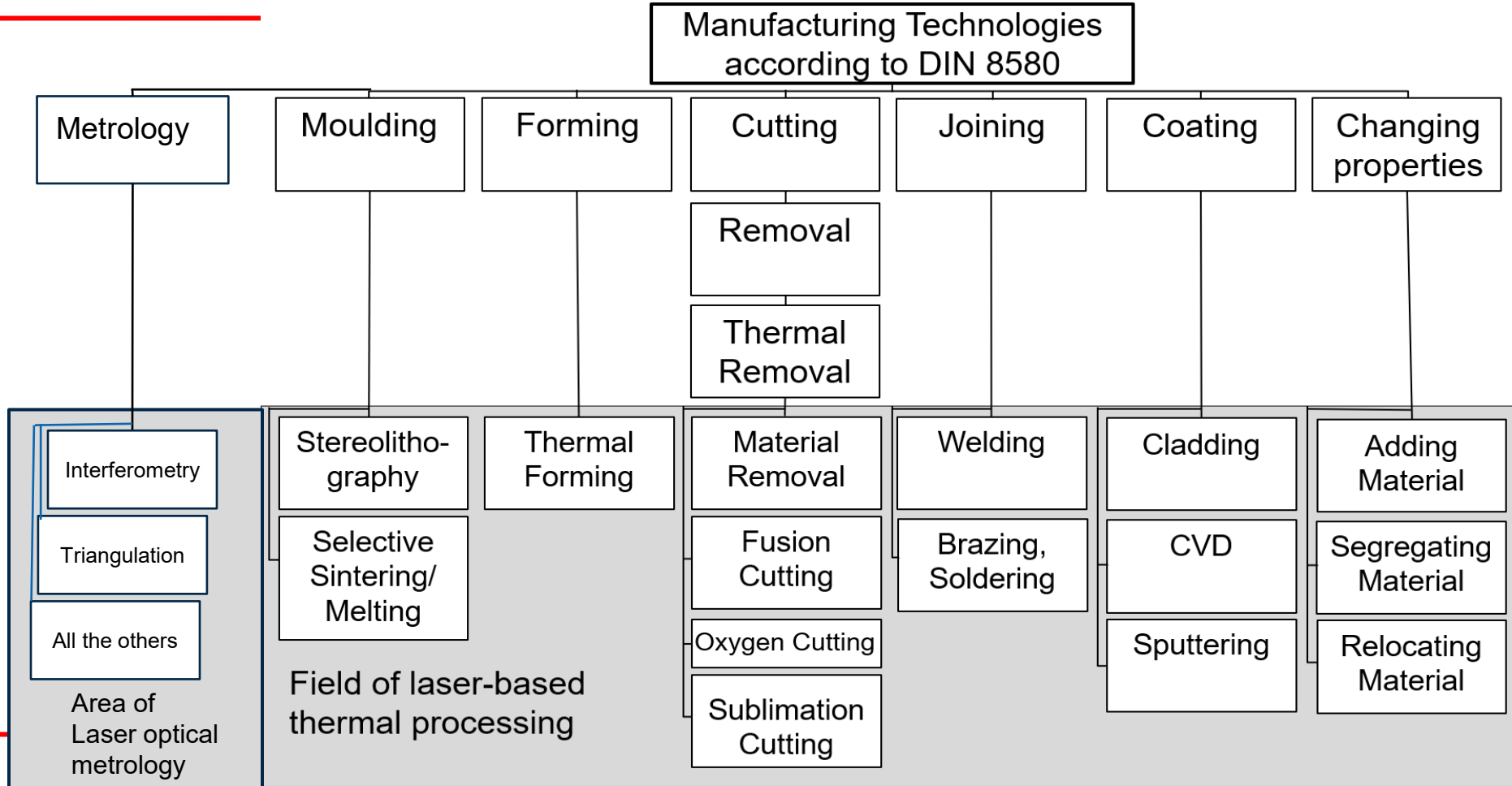
 130 Projects



5 fields of expertise and 14 specialist areas

Materials and Material Mechanics	Design and Simulation	Manufacturing Processes	Automation and Robotics	inspire Academy and Consulting
Materials, Processes and Sustainability Konrad Papis (Prof. Bambach) 	Design for new Technologies Julian Ferchow (Prof. Meboldt) 	Machining and EDM Amir Malakizadi (Prof. Mohr) 	Industrial Robotics Ivo Aschwanden (Prof. Bambach) 	inspire Academy Martin Stöckli 
Material Mechanics Bekim Berisha (Prof. Mohr) 	Machine Concepts Markus Maier (Prof. Mohr) (Prof. Netland) 	Laser Processing Timo Schudeleit (Prof. Bambach) 	Control and Automation Efe Balta (Prof. Lygeros) 	inspire Consulting Markus Maier 
Thermal Analysis Sebastian Lang (Prof. Bambach) 	Additive Manufacturing Daniel Werner (Prof. Bambach) 	Intelligent Production Systems Daniel Knüttel (Prof. Carpanzano) 		
Simulation and Metrology Sascha Weikert (Prof. Mohr) 	Fibre-reinforced Plastics Markus Zogg (Prof. Mohr) 	Virtual and Augmented Reality (Prof. Kunz) 		

Applications of lasers

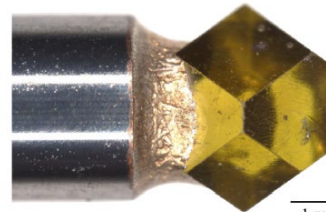
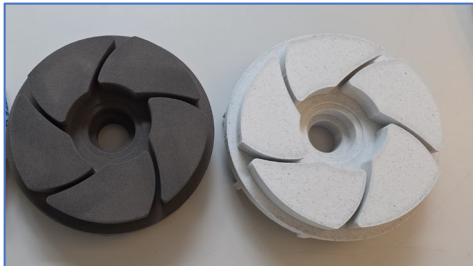
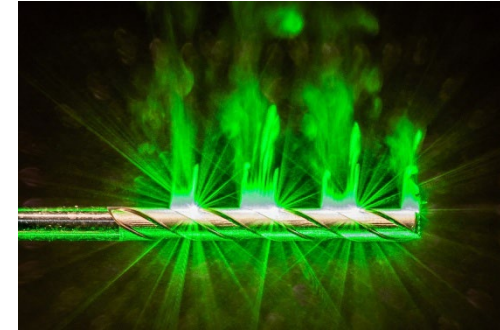
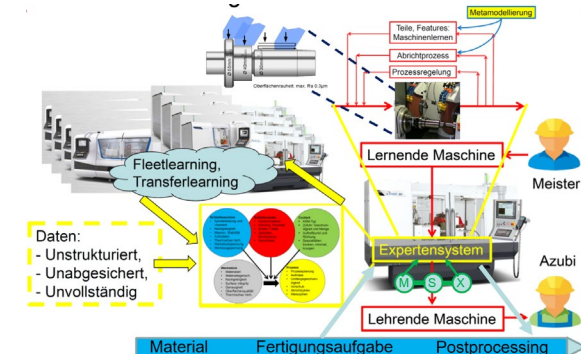


Lasers as an Indispensable Tool in Manufacturing

inspire

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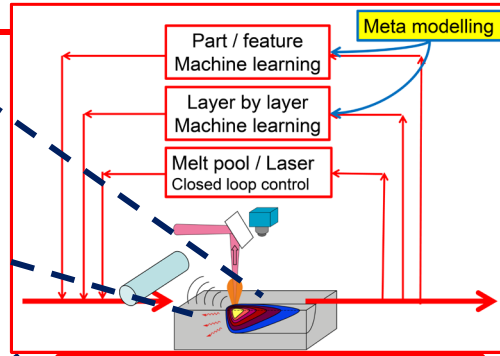
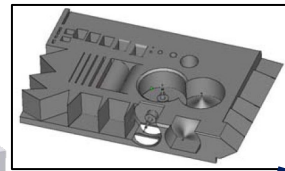
1 mm

Autonomous Machine: Bio-intelligent

Vision:
Operator integrated

Principle 1:
Model-supported

Principle 2:
Task oriented
application of AI

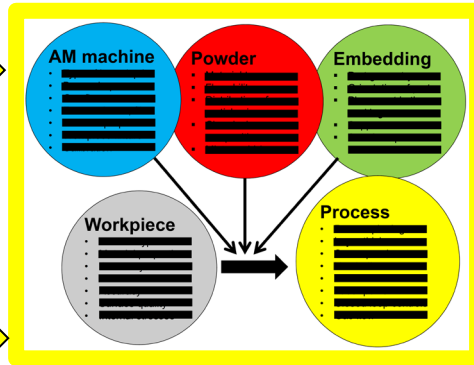


Learning machine



Master

Data:
- unstructured,
- unproven,
- incomplete



Expertsystem

MX, .. S₁, .. C₁...

Teaching machine

Apprentice

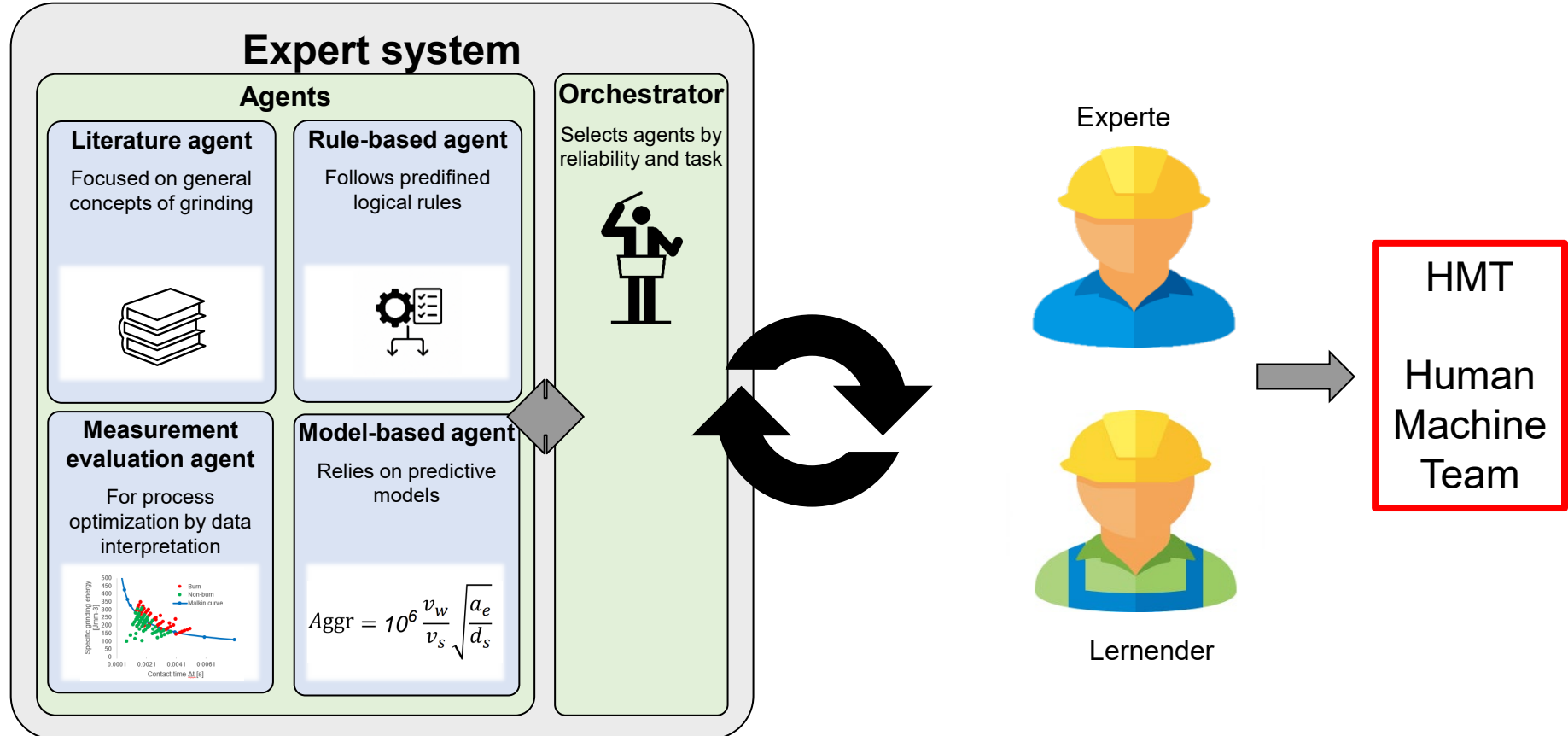


Raw material

Manufacturing task data

Postprocessing

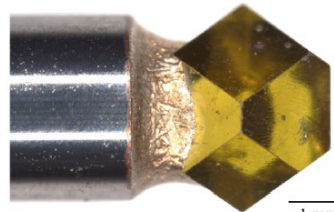
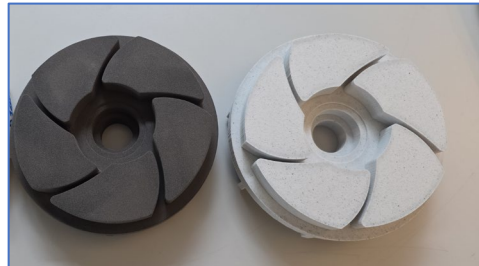
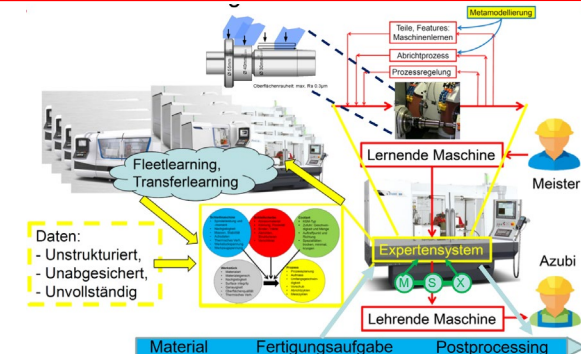
- Stepwise development of functionalities
- Data generation, data analytics strategy generation



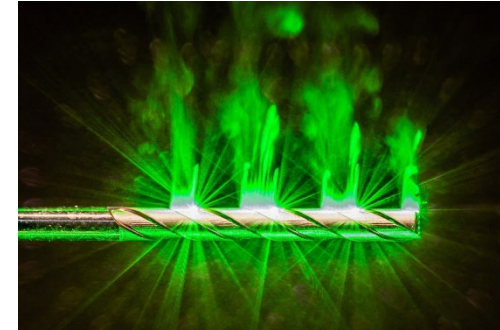
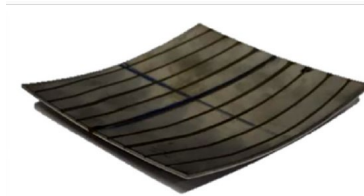
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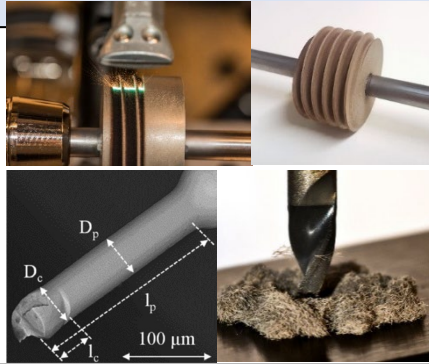


1 mm



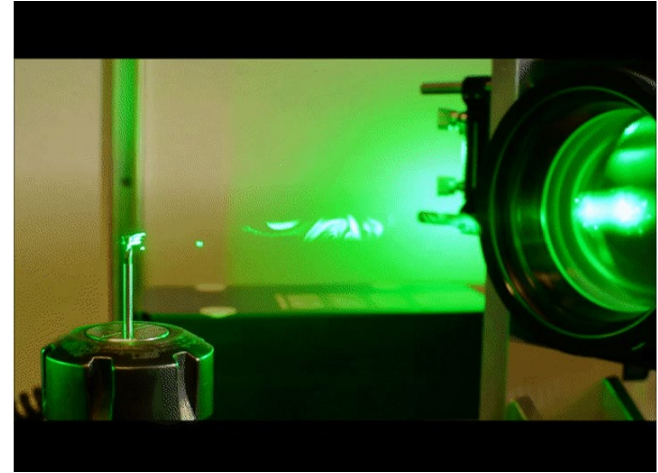
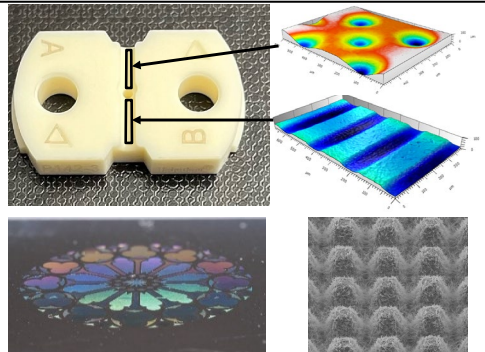
3D

Ultra-hard tool
manufacturing,
modification and
optimization



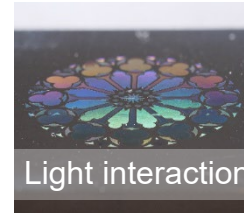
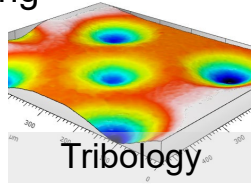
2D

Surface
functionalization and
optimization



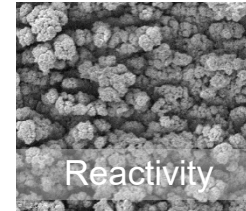
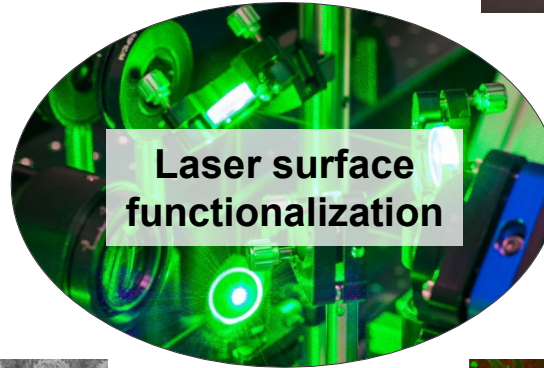
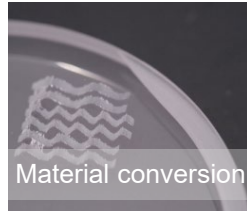
- Ablation: creation of structures and textures
- Deposition: laser deposition on top of the surface
- Embedding: laser alloying

- Wear resistance
- Friction reduction
- Anti-sliding



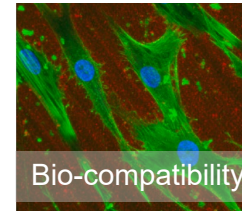
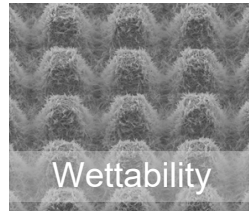
- Coloring (e.g. jewelry)
- Anti-counterfeit (e.g. medical)
- Absorption (e.g. solar panels)

- 3D engraving
- Selective etching
- Micro-fluidics



- Potential of electrodes
- Electrical resistance
- Hydrogen cells

- Corrosion prevention
- Self-cleaning
- Lubrication
- Coating adhesion
- Anti-icing

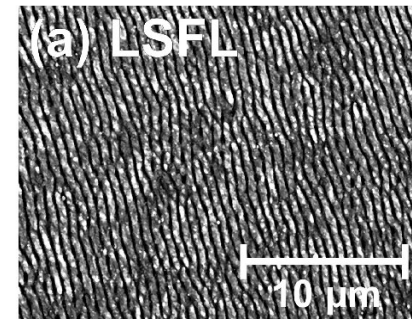


- Cell growth
- Bone attachment (implants)
- Anti-bacterial (dental)

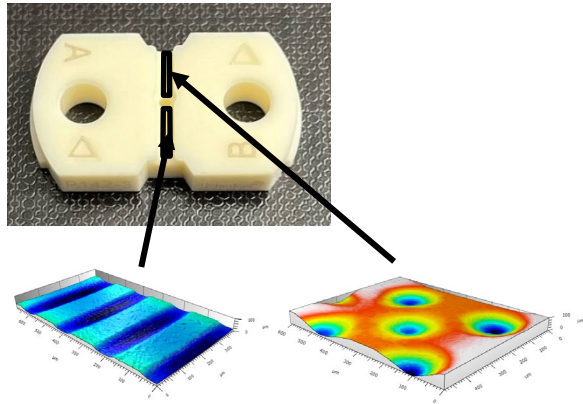
Tailored tribology and adhesion

UKP-Lasers introduce
surface structures: LIPSS

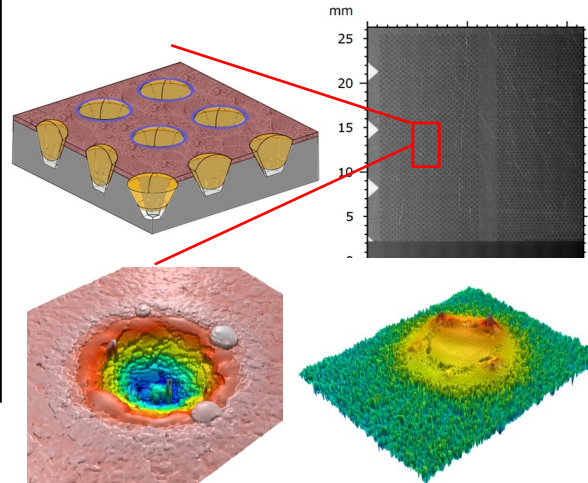
Functional textures range from 100 μm to 100 nm



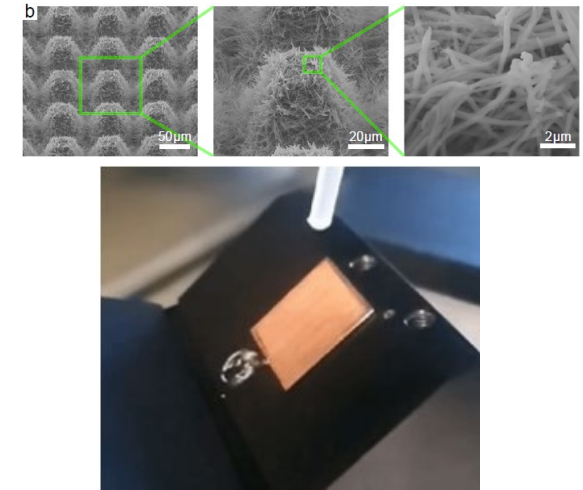
Custom friction (macro-textures)



Improved lubrication (micro-textures)

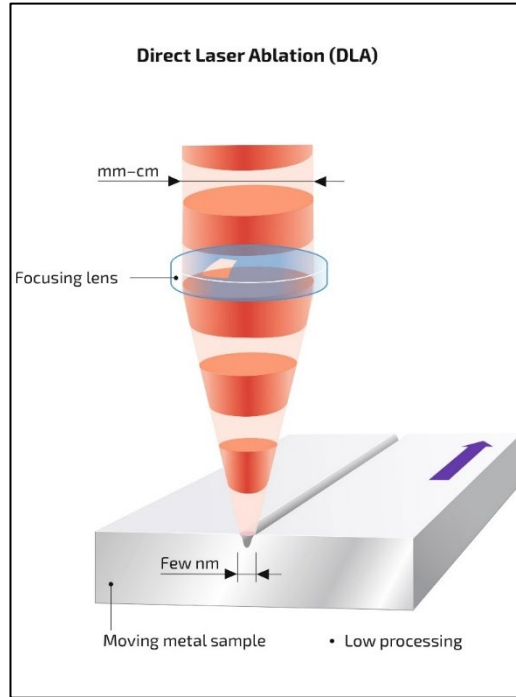


Controlled adhesion (nano-textures)

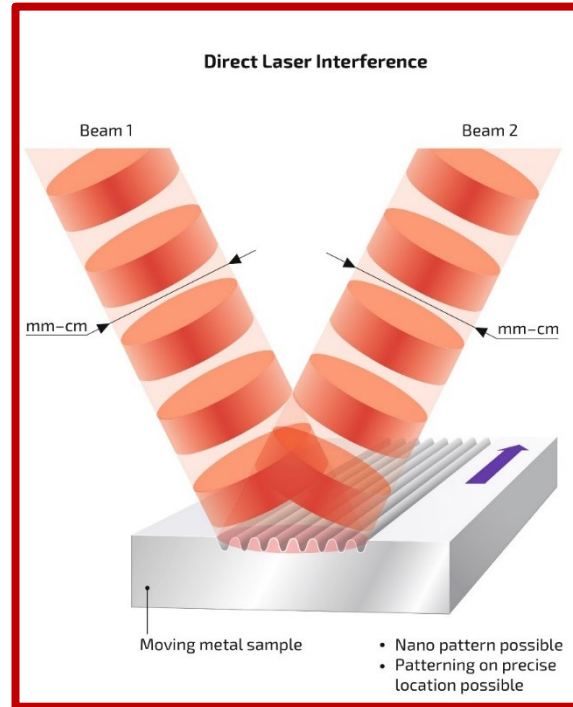


Tribology and adhesion can be tailored according to technical specifications.

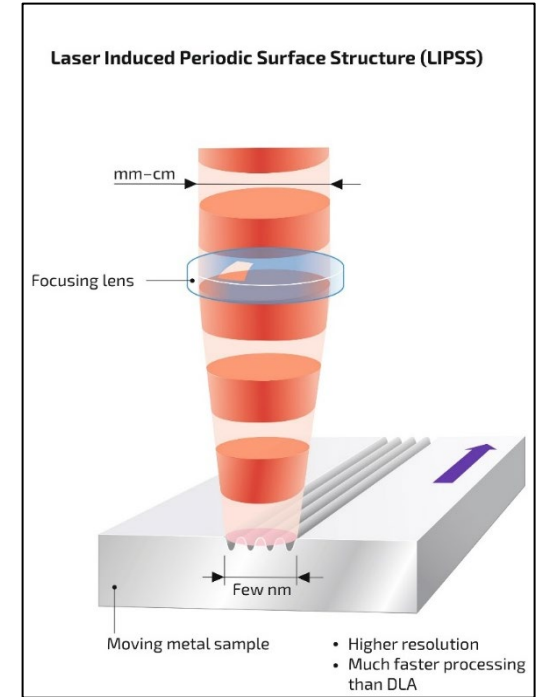
How to manufacture these textures?



100 μm to 10 μm



20 μm to 0.5 μm



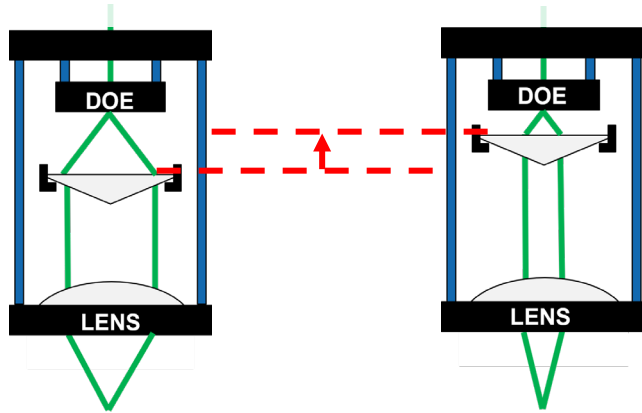
1 μm to 0.05 μm

Resolution

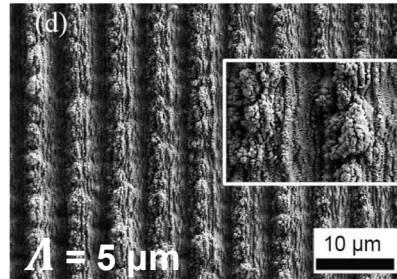
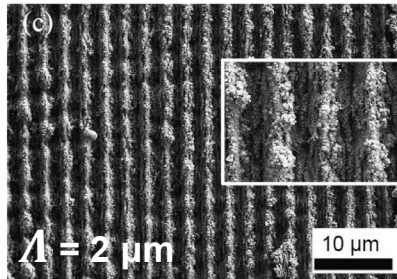
Shape flexibility

DLIP: direct laser interference patterning

Standard DLIP-module

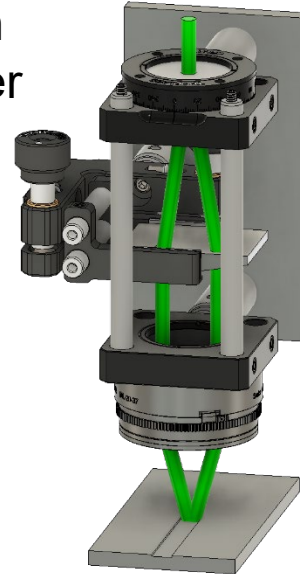


much smaller

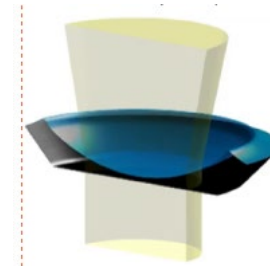


New inspire DLIP-Module

... with a focus variable lense, prism and DOE



© Optotune (Schweiz)



<https://www.clzoptics.com/news/learn-about-fused-silica-and-its-uses.html>

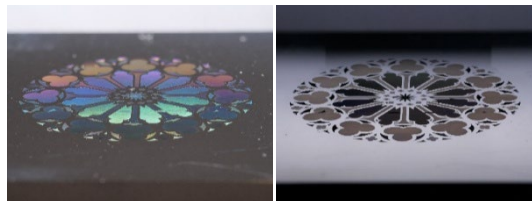
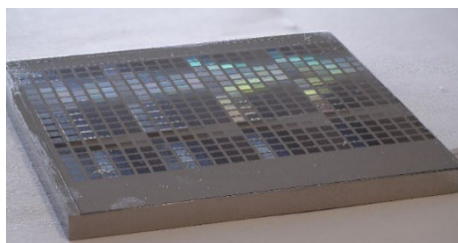
How should the texture look like to possess a functionality?

Oris ProPilot X Calibre 400 Laser

Inspiration in nature



Bio-mimicking



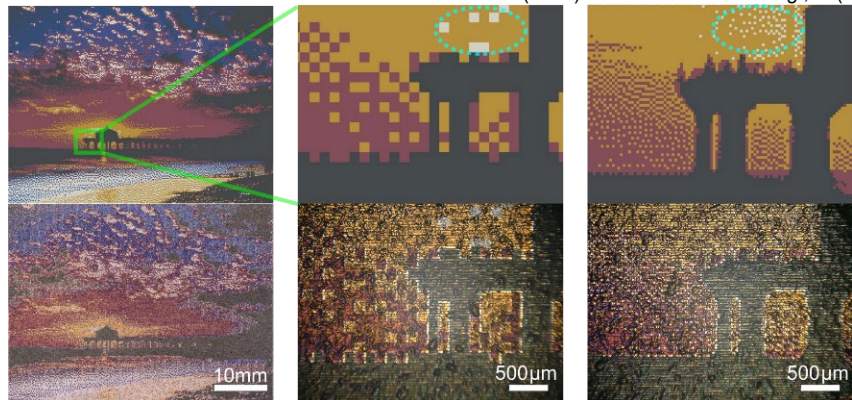
Watches



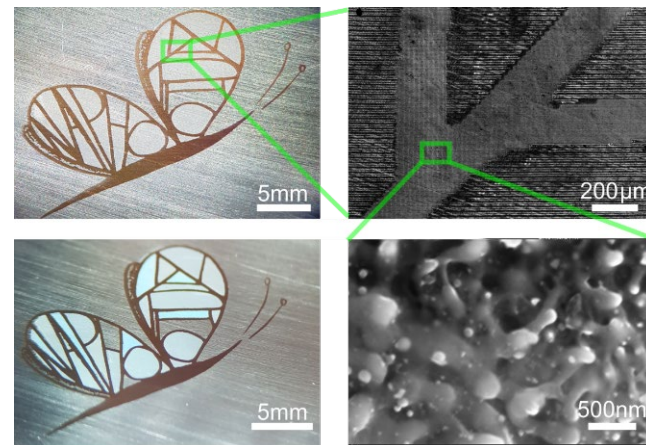
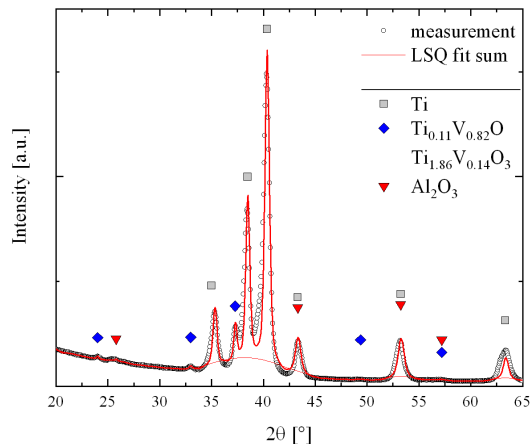
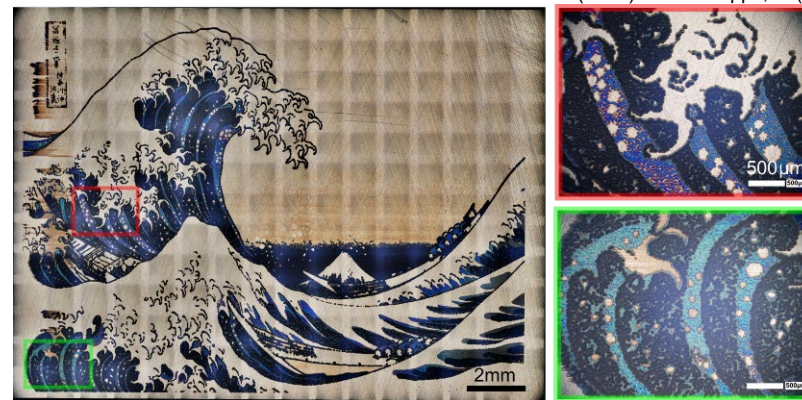
Inspired by nature & shaped by laser

Laser coloration using oxide layers and LIPSS of titanium TiAl6V4

N. Ackert et al. (2020) J. Laser Micro/Nanoeng., 15(1).



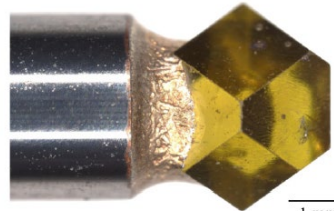
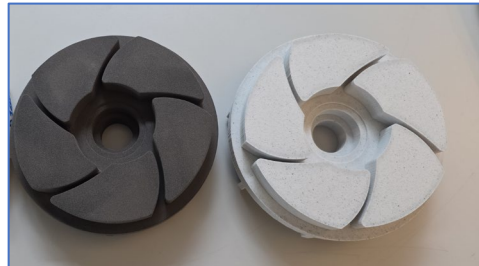
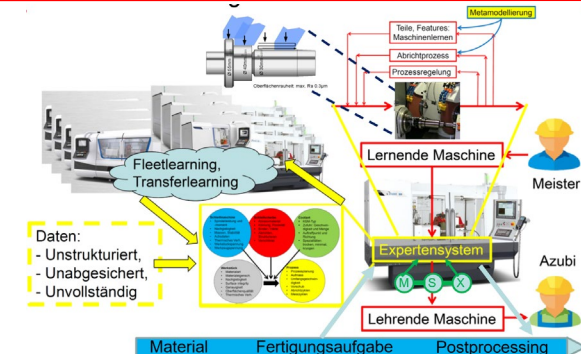
N. Ackert et al. (2020) J. Laser Appl., 32(3)



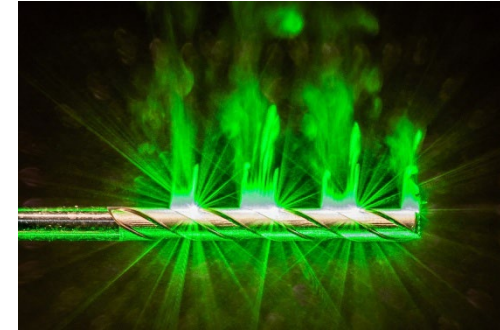
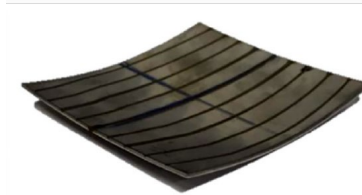
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1 mm



- Material development: harder, more abrasive, tougher, high temperature resistant
- → more performant tool materials → material processing with laser
- Further uniqueness of laser: small, wear free
- USP: Ablation without phase change: The shorter the pulse the lower the heat input
- → Tool is the solution of field differential equations, BC is the workpiece



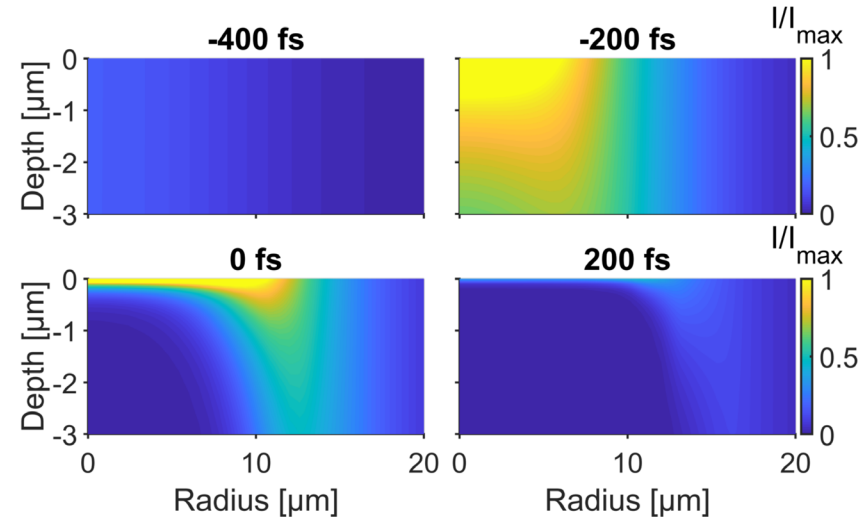
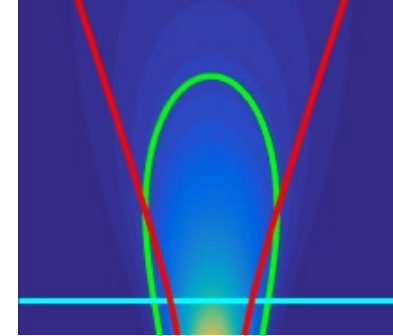
Mechanical Process

- The resulting geometry is the Boolean difference between workpiece and tool
- deviations:
 - displacement
 - wear
 - ...

Transparency / Absorption behavior

Laser process

- Geometry time dependent
- Stationary Geometry



■ Orthogonal

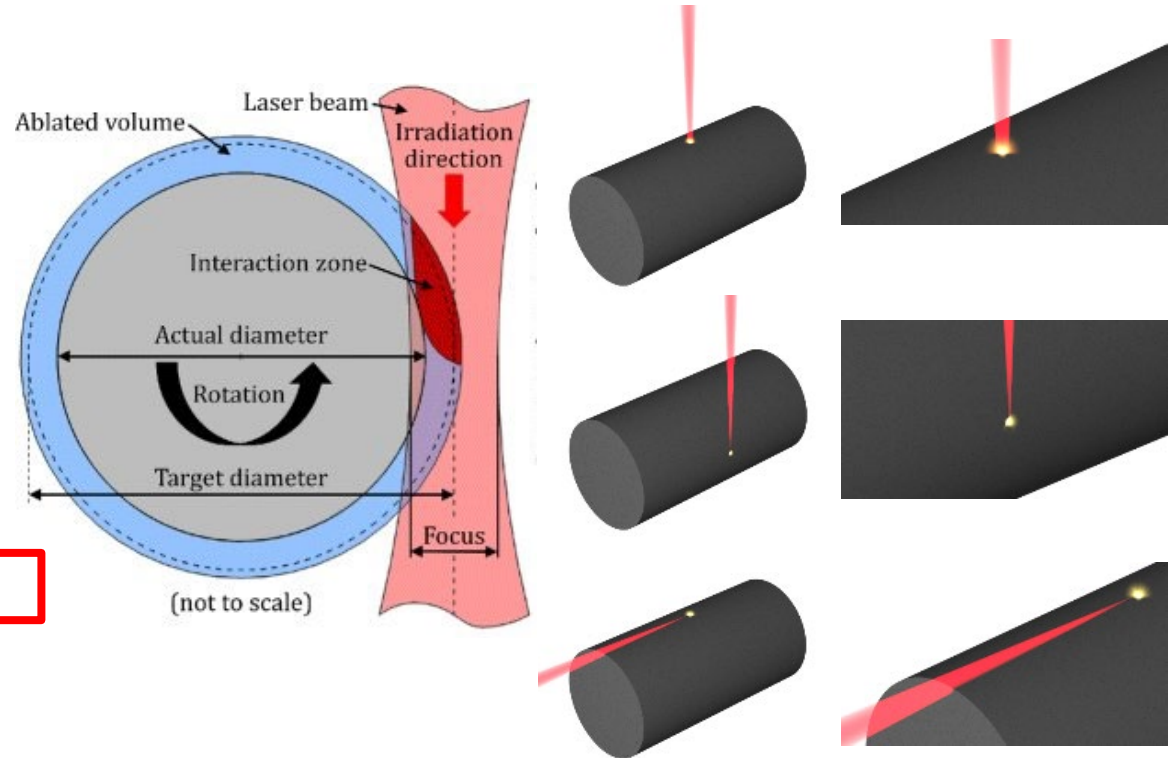
- Gute Zugänglichkeit
- Geometrische Flexibilität
- Hohe Abtragseffizienz
- Modellbasierte Bahnplanung
- Modellkalibrierung erforderlich

■ Tangential

- Flache Einstrahlung
- Präzision / Wiederholgenauigkeit
- Nutzung Ablationsschwelle
- Oberflächenqualität $R_a < 40 \text{ nm}$

■ Axial

- Einfluss der Strahlkaustik



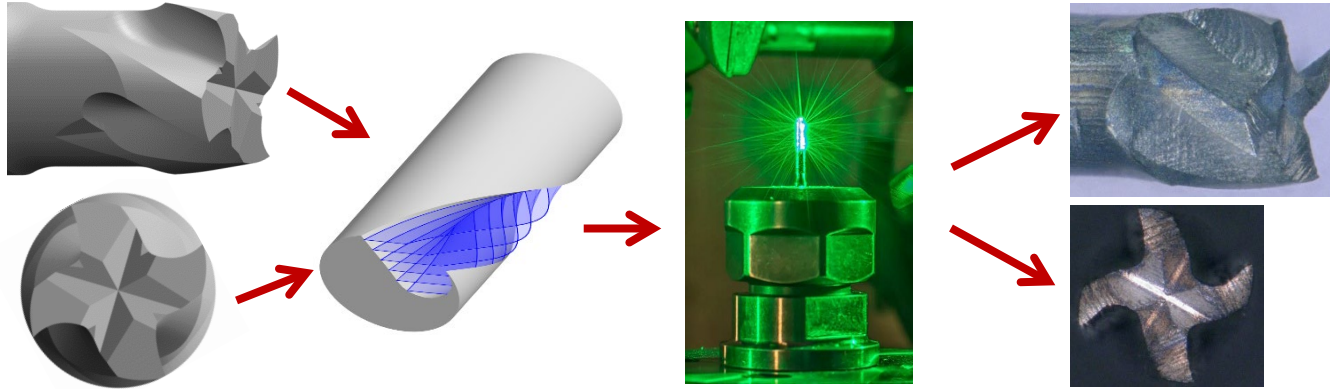
Manufacturing is carried out as follows:

1. CAD modelling

2. Import into CAM

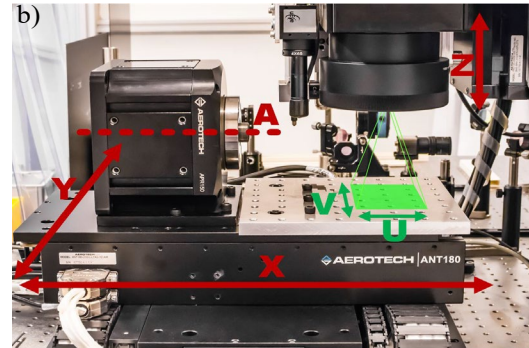
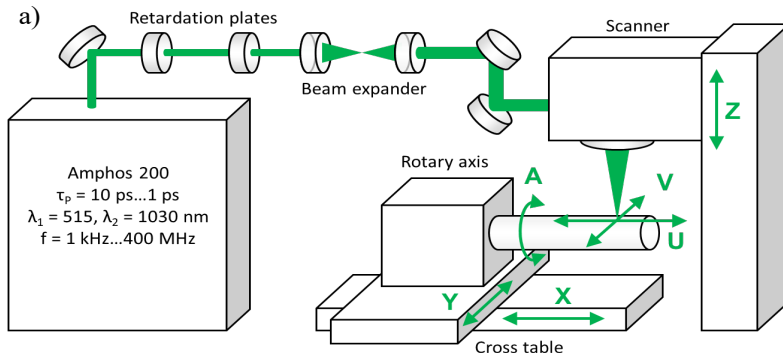
3. Manufacturing

4. Laser-manufactured tools



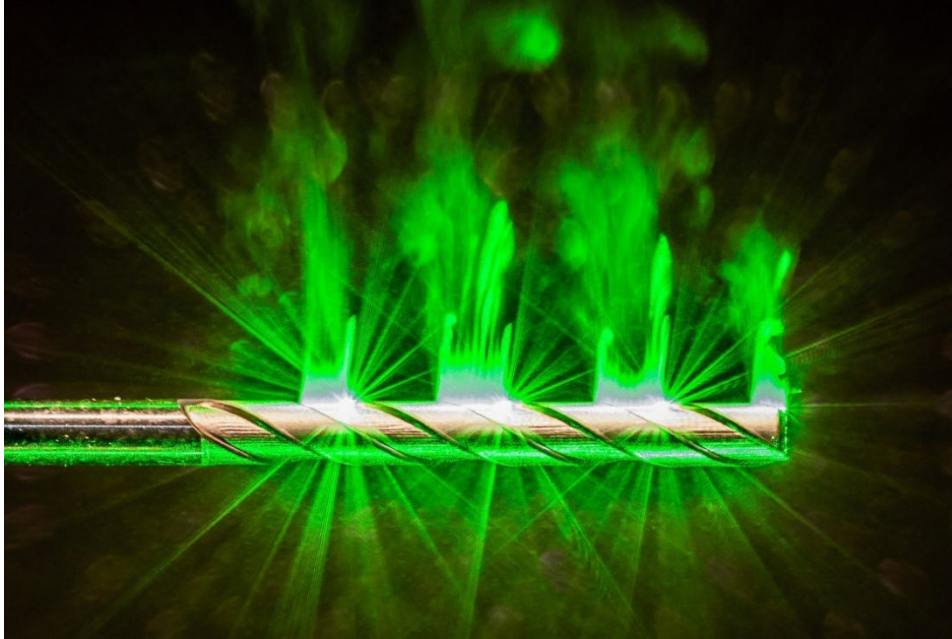
The advantages of laser ablation for the manufacture of micro-tools are:

- "No" process forces that could damage the tool during manufacture.
- High geometric accuracy: with small diameters, 4 or even more cutting edges are possible, as well as different tooth angles and variations in the pitch angle.
- A high aspect ratio is achievable.
- Tool diameters of less than 50 μm are achievable.
- Machining independent of material hardness
- High surface quality with «tangential» irradiation



Tools from PCD

Laser processing of tools, i.e. PCD



- Enabling technology for ceramic machining
- Machining of brittle-hard materials with geometrically defined cutting edges
- Ductile cutting in brittle-hard materials depending on chip thickness
- Machining of cemented carbide, ceramics, cermets, ...

Warhanek 2017



drill



Threading tool



End mill



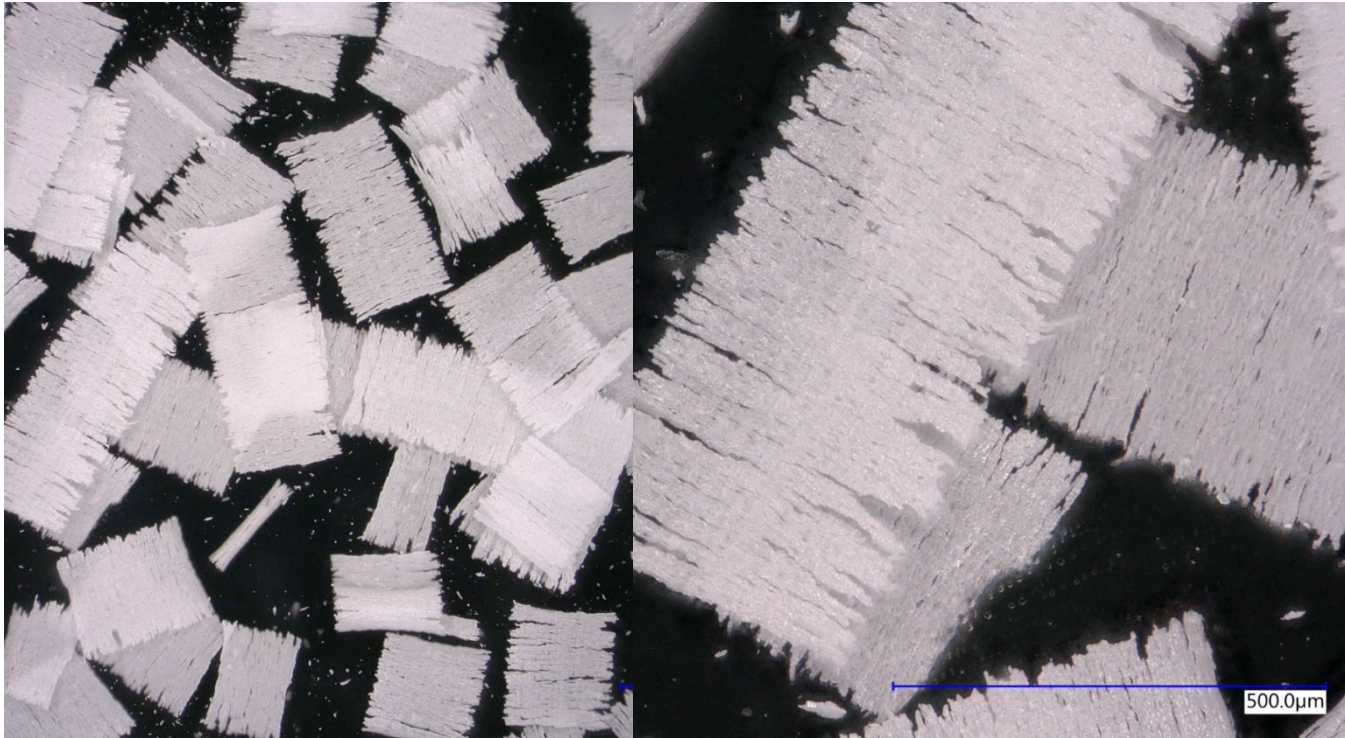
Torus mill

Understanding chip generation in ceramic cutting: ductility

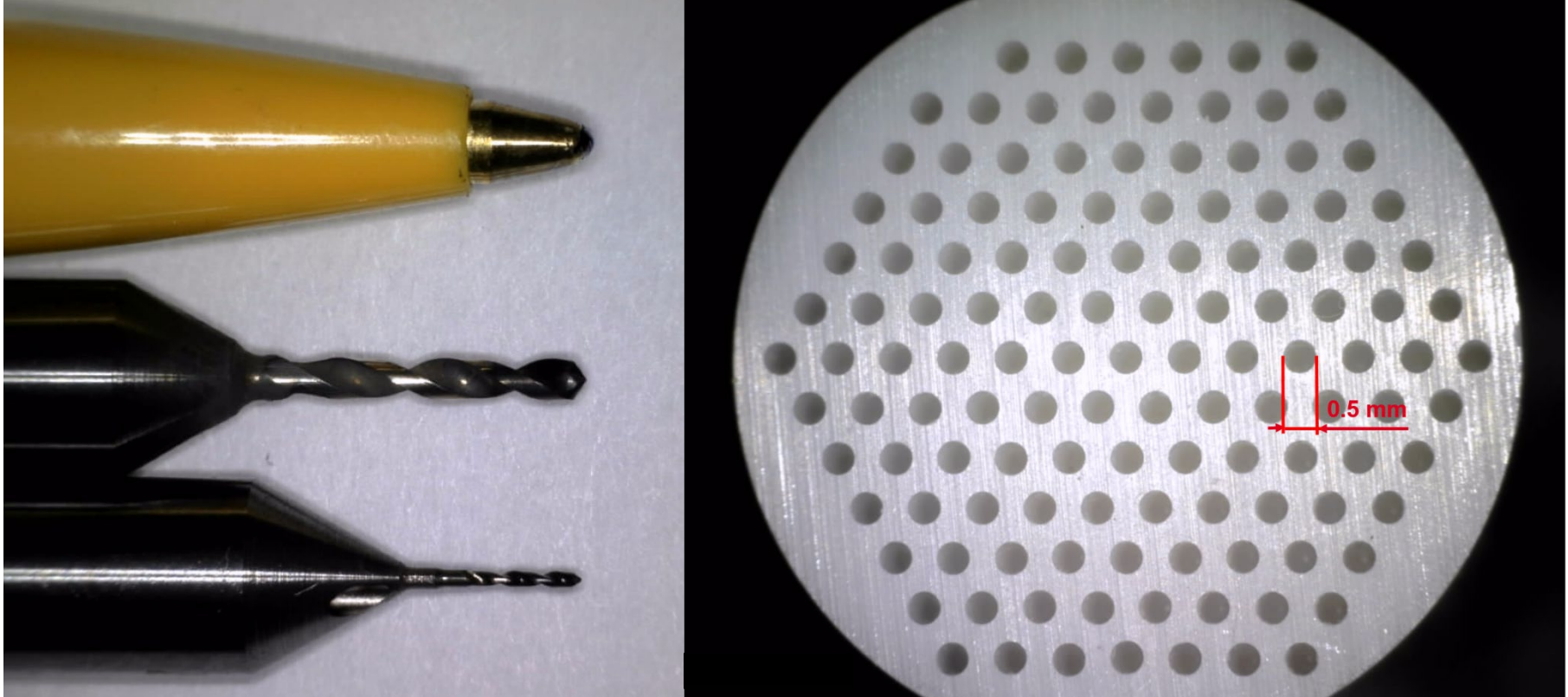
Ductile Chips Obtained During Turning

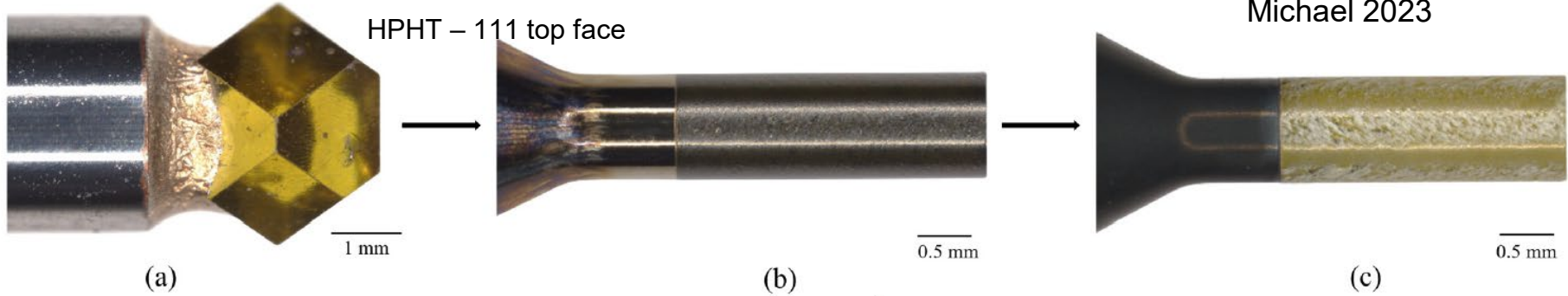
Turning chips from TZP- A: shear chip elements

M2 thread in ATZ



Warhanek 2017

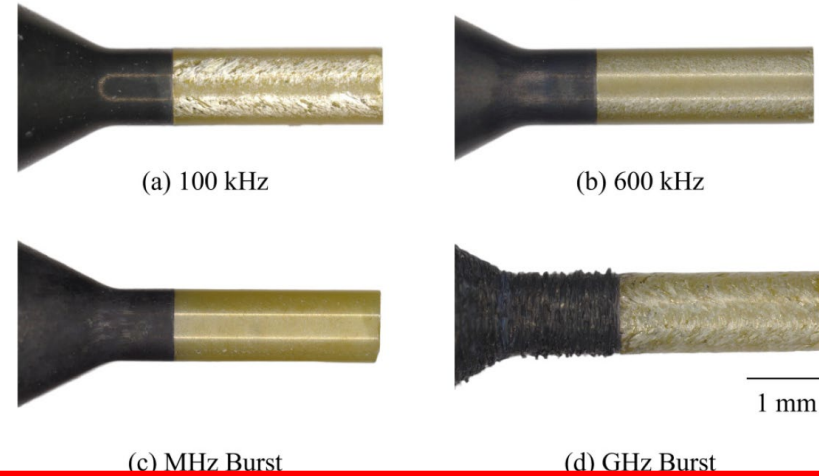
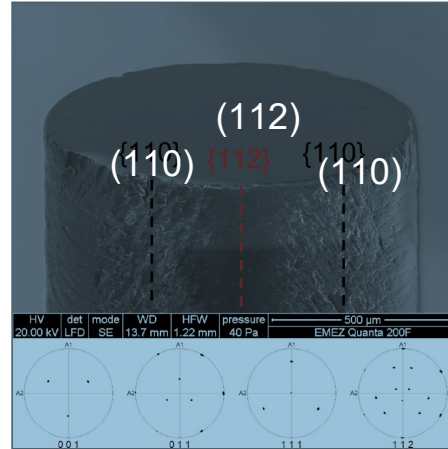




HPHT-100 top face

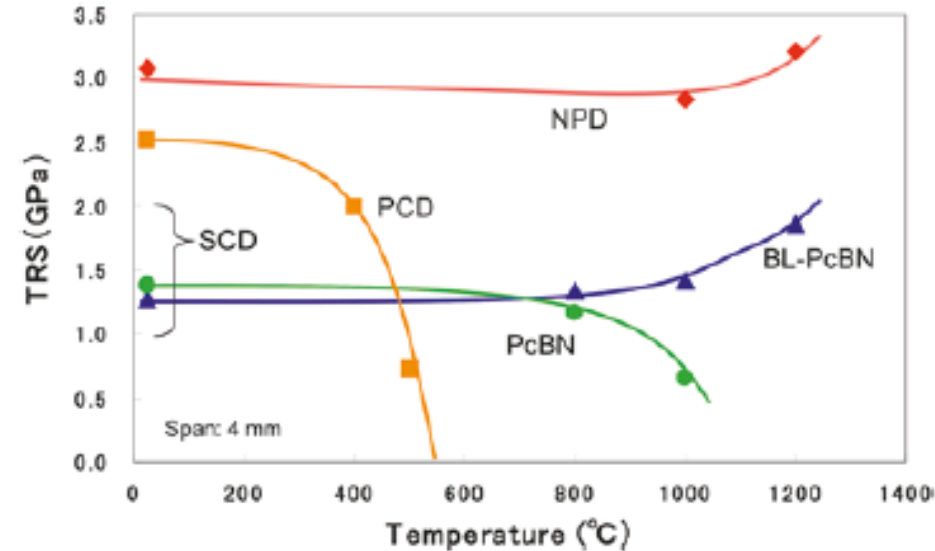


Spaltebenen (111) →
thermische Schäden



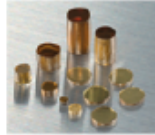
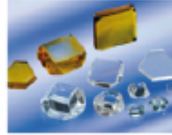
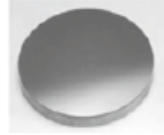
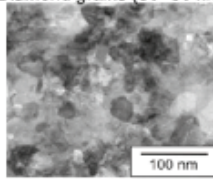
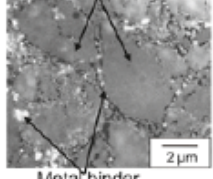
$E = 105 \mu\text{J}$, 100 kHz, MHz Bursts $N=5$ Teilpulse
→ defektfreie Ablation

■ Mechanical properties



Sumiya,
2017

Transverse rupture strength (TRS) of Nanopolycrystalline diamond (NPD) and cBN (BL-PcBN)

	Nanopolycrystalline diamond (NPD)	Single-crystal diamond (SCD)	Sintered diamond (PCD)
			
Microstructure or Image	 Diamond grains (30–50 nm) 100 nm	 Low abrasive wear resistance High abrasive wear resistance ~1mm	 Diamond grains Metal binder 2 μm
Hardness	110–130 GPa	80–120 GPa	50 GPa
Isotropy	Isotropic	Anisotropic	Isotropic
Strength	High	Low (cleavage)	Middle
Thermal stability	1600°C	1600°C	600°C
Edge accuracy	<50 nm	50 nm	~0.5 μm
Transparency	Transparent	Transparent	Opaque

Characteristics of Nano polycrystalline diamond and conventional diamonds

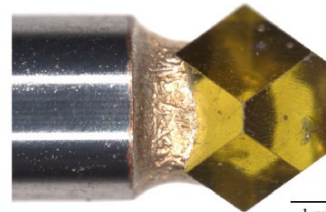
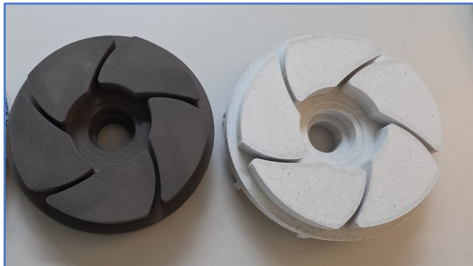
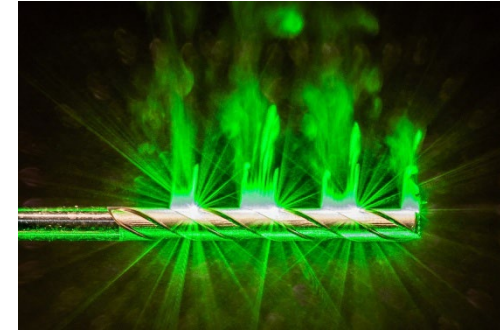
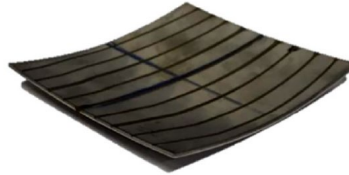
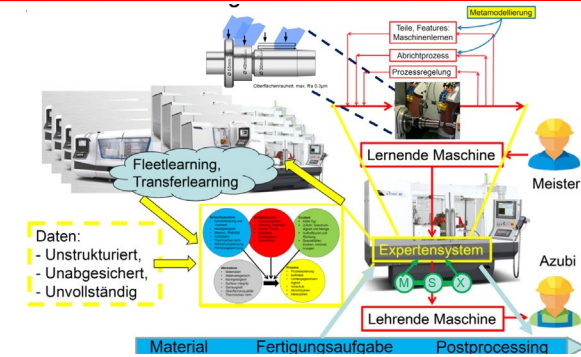
Lasers as an Indispensable Tool in Manufacturing

Content

- inspire: bridge between academia and industry
- It is the system that counts: intelligent machine, digital twin
- Surfaces
- Ablation

■ Structuring of tools

- AM (polymer / metall / ceramics)
- Forming
- Conclusion

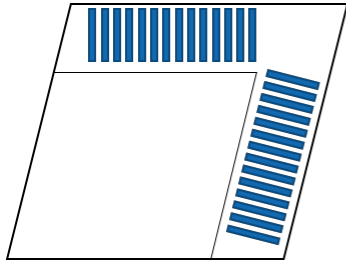
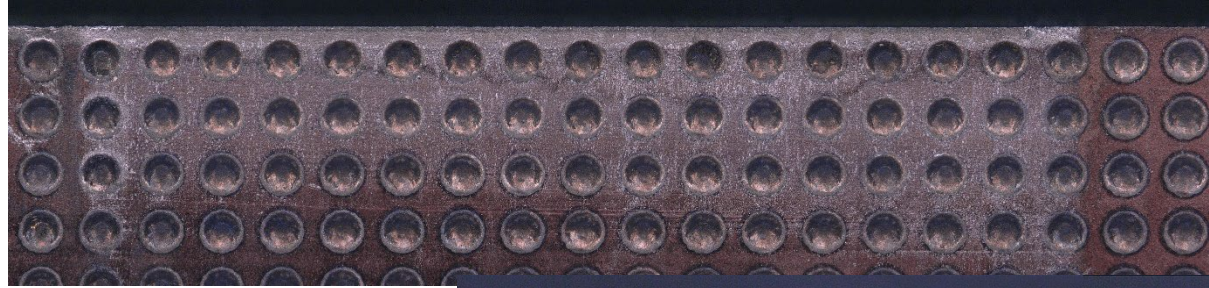


1 mm

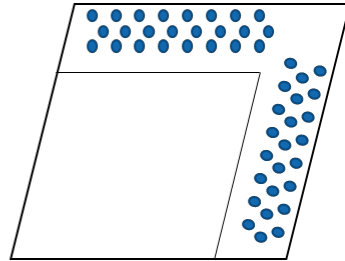
Micro geometry optimisation of macro tools

Laser modification on the rake face

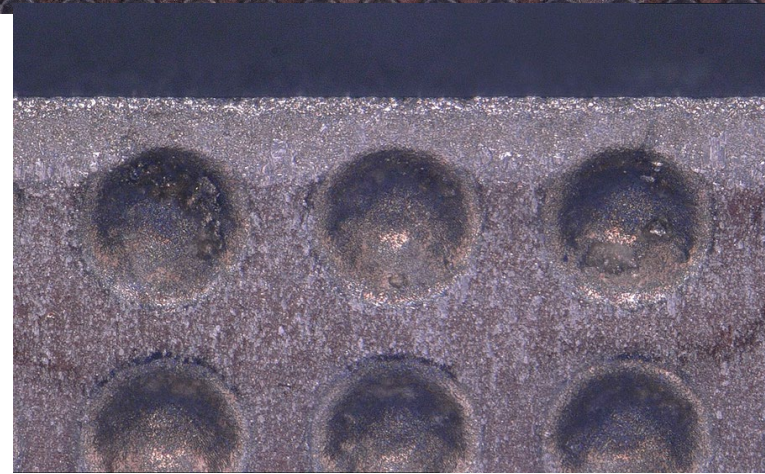
- Rake face modification – experimental analysis:
 - TÄSCHLI (small pockets) und LÖCHLI (small dips)
 - Process conditions: Workpiece: Ti6Al4V, shaping, $v_c=30$ m/min, $f=0.02$ mm, dry
 - Micro geometries:
 - Width/diameter: 20-200 μm



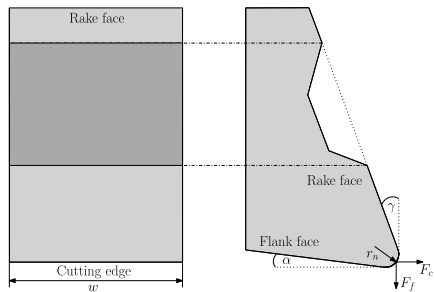
Täschli



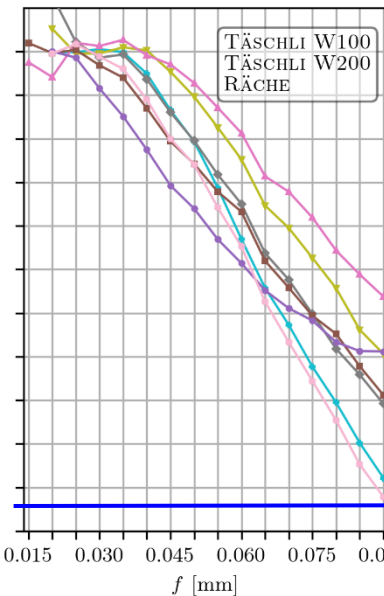
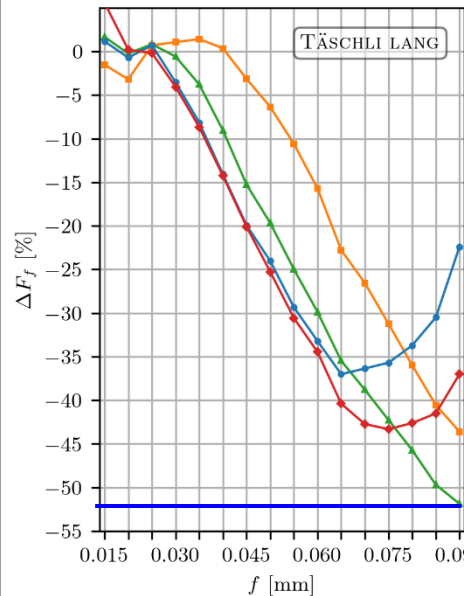
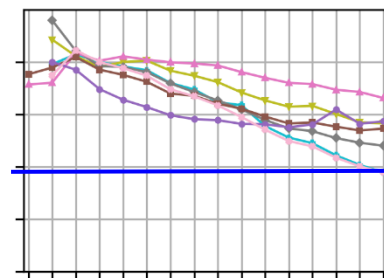
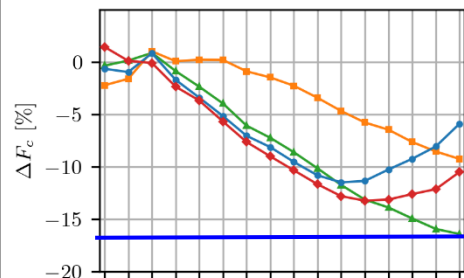
Löchli



Schnittkraftreduktion durch verschiedene Taschenformen



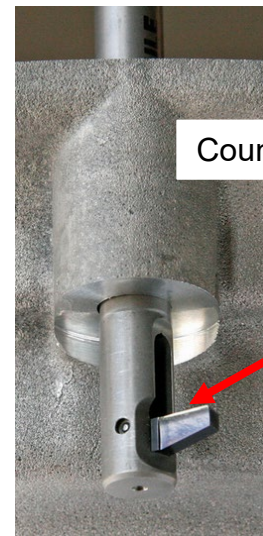
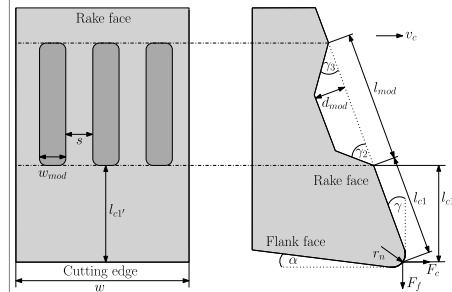
Kraftreduktion etwa proportional zur Kontaktflächenreduktion



572_R1.A 581_R1.A
573_R1.A 581_R1.B

586_R1.B 585_R1.B
574_R1.A 584_R1.A
575_R1.A 584_R1.B
585_R1.A

inspire



Countersinking

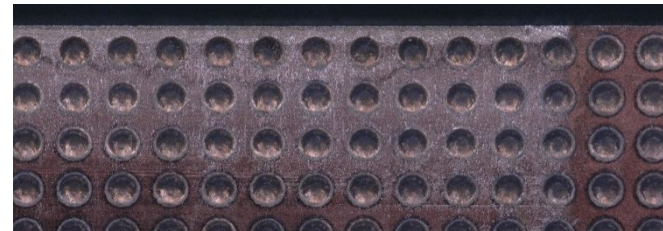
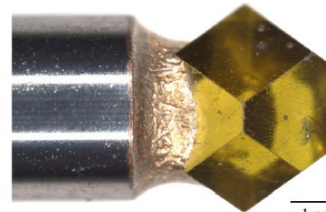
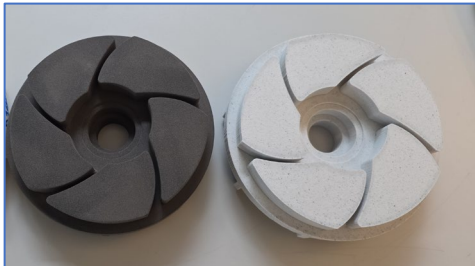
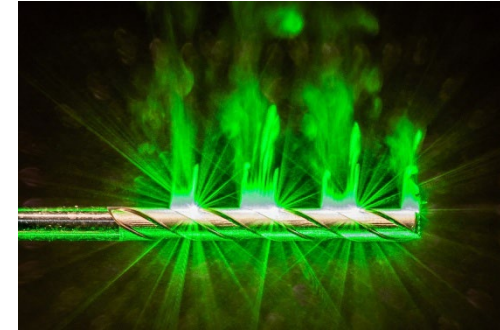
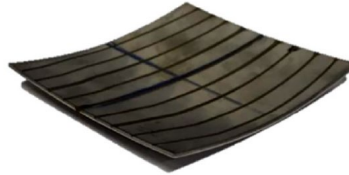
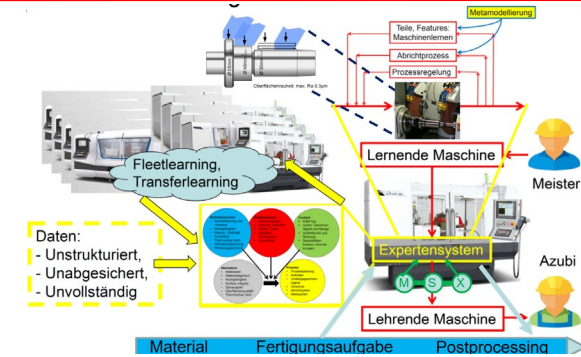
modifiziert

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of ETH Zurich

Lasers as an Indispensable Tool in Manufacturing

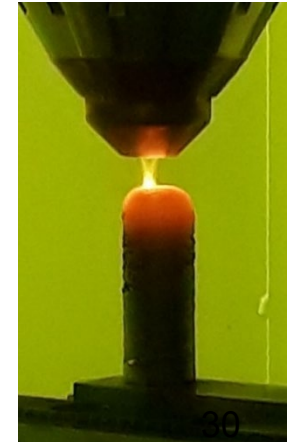
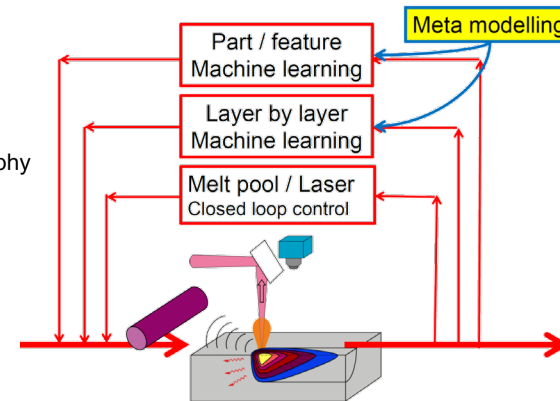
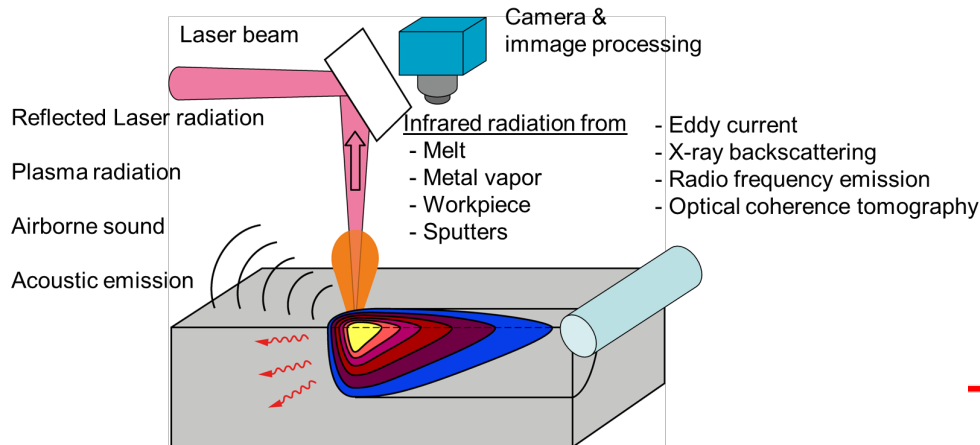
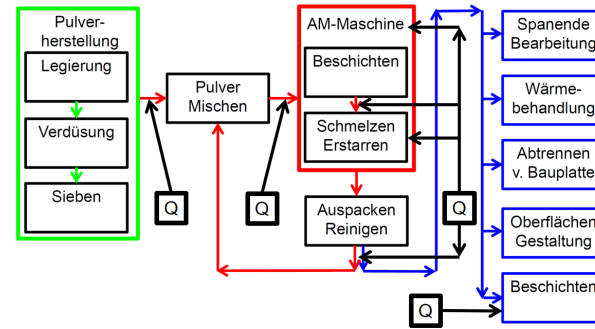
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- Structuring of tools
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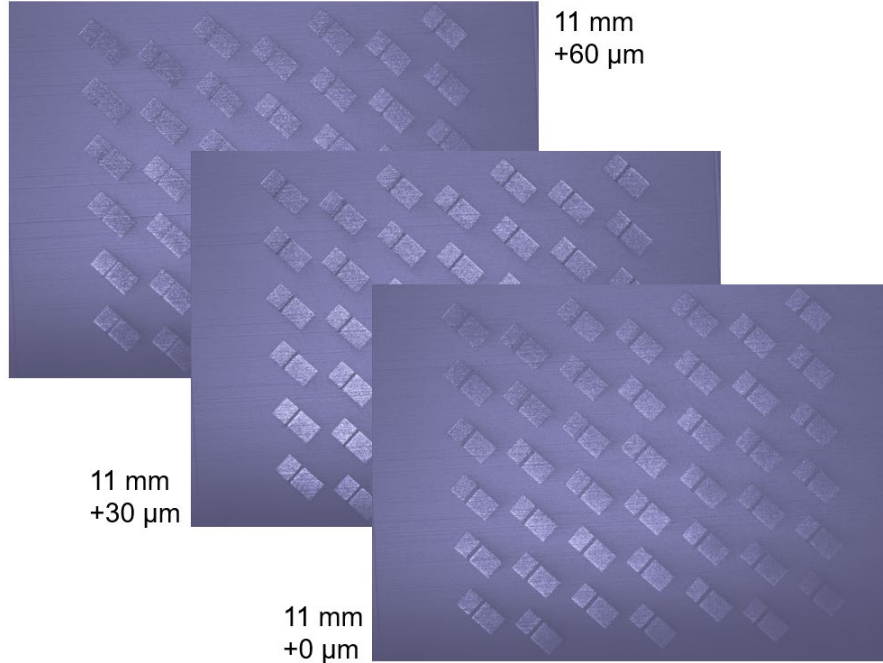
1 mm

- Additive manufacturing
- Design for Additive manufacturing (DFAM)
➔ automatic design
- Increase of buildup rate
- Reduction of material costs
- Process chain approach
- Quality management, Process monitoring
- Error correction: Adaptation, closed loop control, correction, learning



Trends in AM: Monitoring

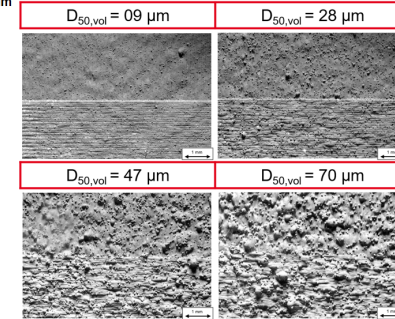
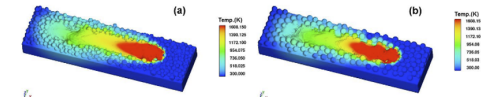
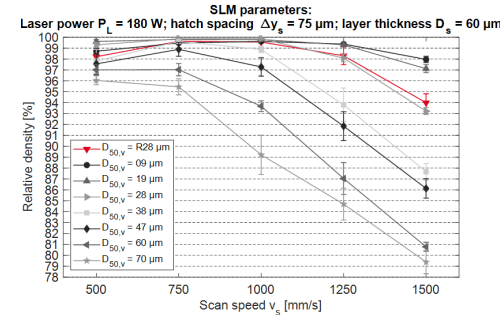
Example sequence of layers



Major challenge:
Detectability of faults and anomalies
Predictability of quality

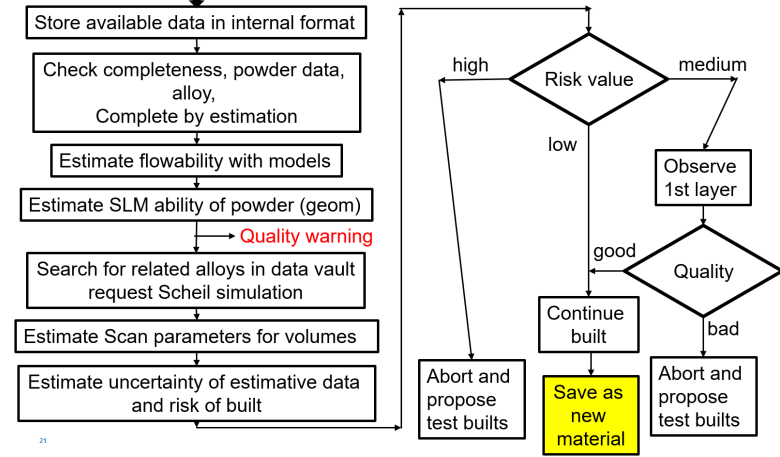
Melt pool dynamics

Haferkamp, Rusch 2019

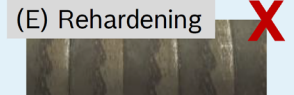
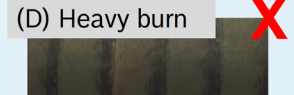
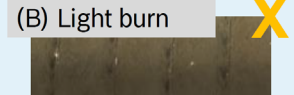
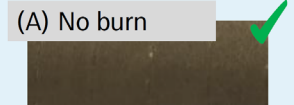
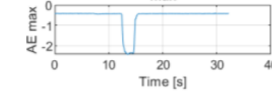
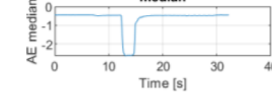
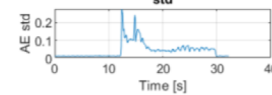
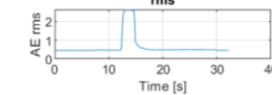
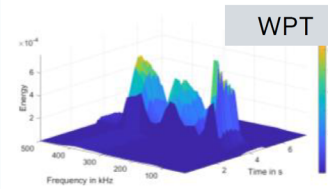
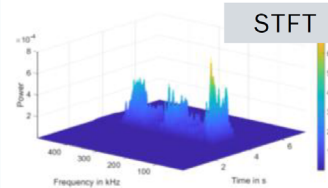
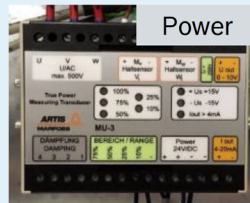
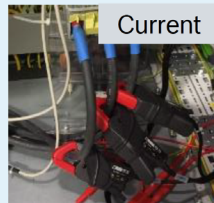
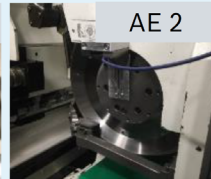
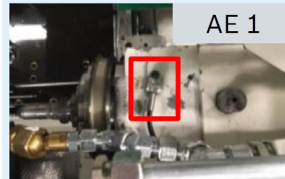
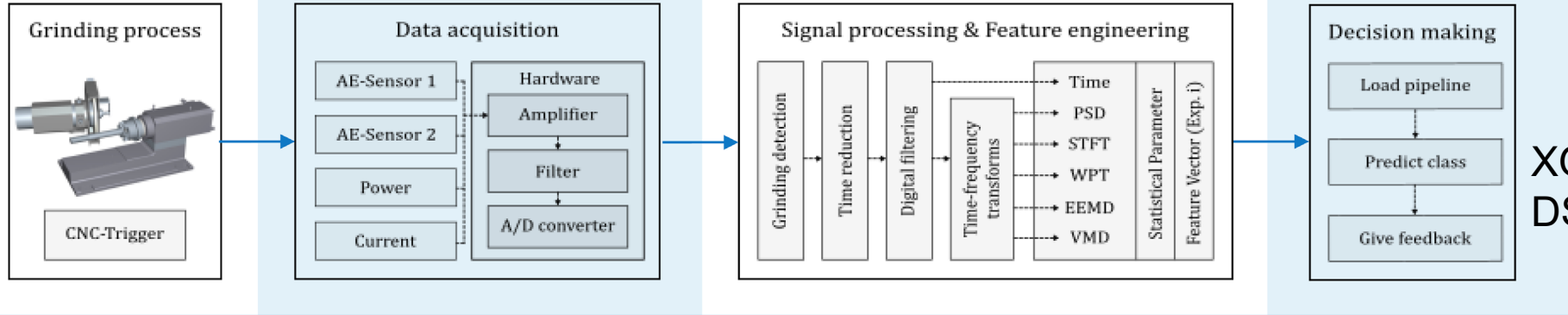


- Consolidated surface roughness reduces the part density and subsequently strength and elongation at break
- Consolidated surface quality can easily be detected by cameras / image processing

Power of powder / materials

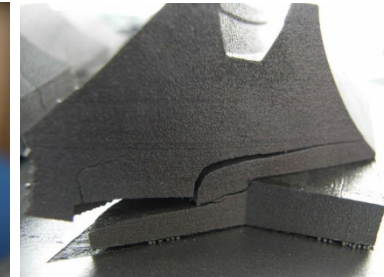
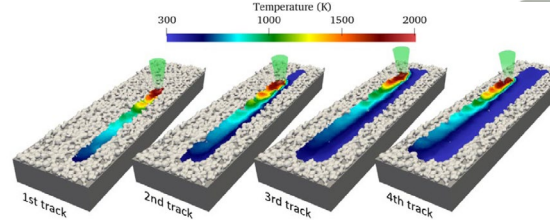
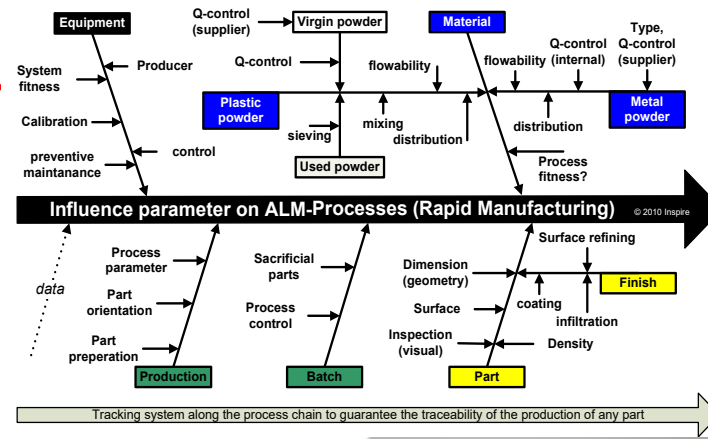


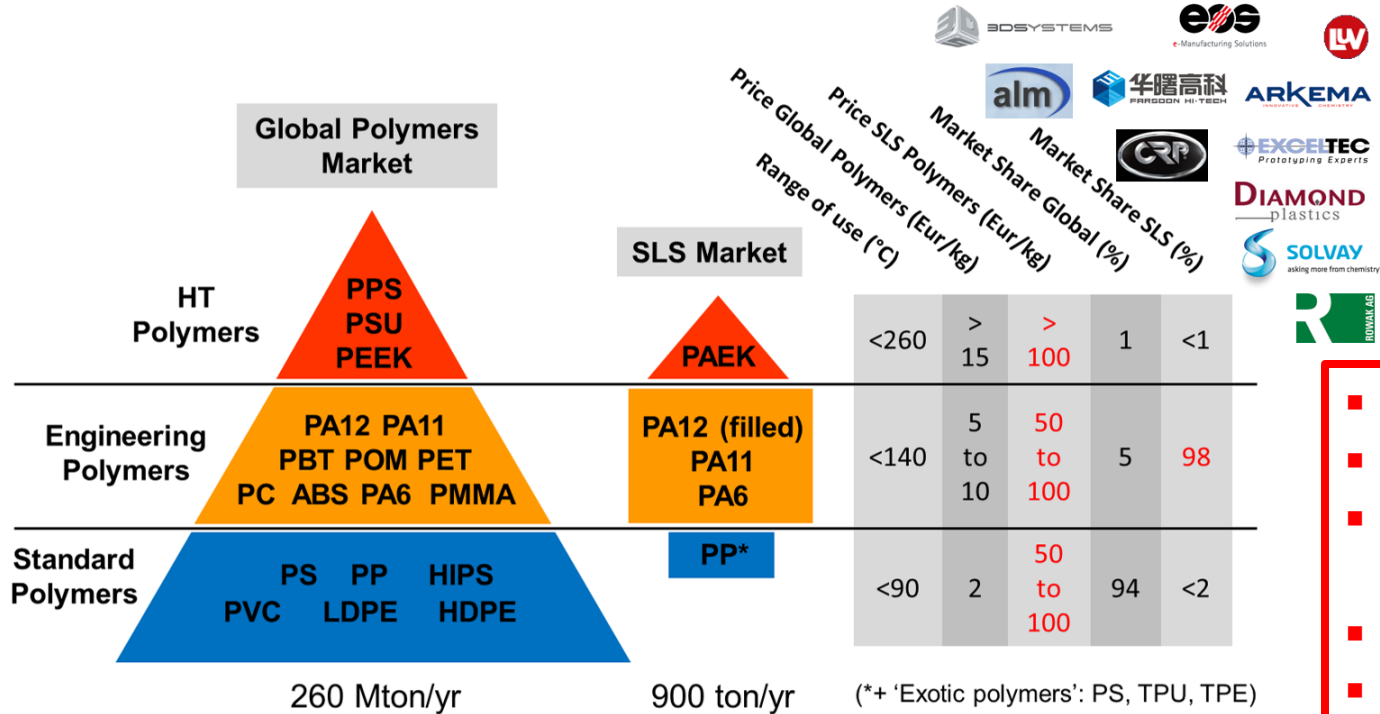
Approach for the feature-based grinding burn detection



Trends in AM

- Process understanding and intelligence
- Simulation techniques, prediction
- Standardisation
- Increase surface quality
- Management of internal stress
- Management of microstructure
- New materials, biomaterials
- Multimaterial, Hybrid built
- Ultimate lightweight
- Individualisation
- Sustainability





- SLS polymers demand is extremely low in comparison to the global polymers market: Higher prices & reduced materials spectrum

- Polymers persist
- Steady growth
- Develop alternative materials for SLS
- Resilient supply
- Environment issues
- Develop process
- Qualification

Company Requests: Grow Business and Reduce Costs in PBF/P

How to reduce cost? Better PA2200?

(KINGS 3D, POWDER Monkeys -
not good enough for 1:1)
Application driven!
Functional materials!

How can we use machine learning

How to repeatedly meet tolerances?
How can we automate processes?
Speed up material adoption?
Google: NMB SLS for Industry 4.0

Applications

Materials

Process

Quality
control &
Automation

Sustainability

How to improve DfAM?

How to stop TM / AM apple
to pineapple comparisons?
Standards/Certification
Check out: www.amable.eu

How can we reduce costs? (faster layer times no quality loss)

Lower print temperatures
(Ideally with PA2200 – Google:
skz.de "PimP my PBF")

Would be nice

Can we estimate
use-Phase for LCA?
How can we **increase
refresh rates?**

What type of New PBF Materials can Bring Value to the Market

Inspires question: Move away from **standard commercial PA12** & find value or new business potential?

Polymer class	Expected gains	Expected Challenges
Lower crystalline materials	✓ Lower printing temperature ✓ Improved blendability	✗ Print settings (non-PA12) ✗ Application development
PA12-Like or “additive free”	✓ Easier to print ✓ Market acceptance ✓ Different chemistries	✗ All market PA12s are additivated (e.g. TiO₂) ✗ Cost constraints
High Temperature PA	✓ Cheaper than PEEK ✓ Increased Sinter window	✗ Unknown stability ✗ Unknown re-fresh rates

MedTech: Lower Melting Polymers

Problem to solve: implantable devices are limited to PEEK (expensive, brittle, difficult to print & non-bio absorbable)

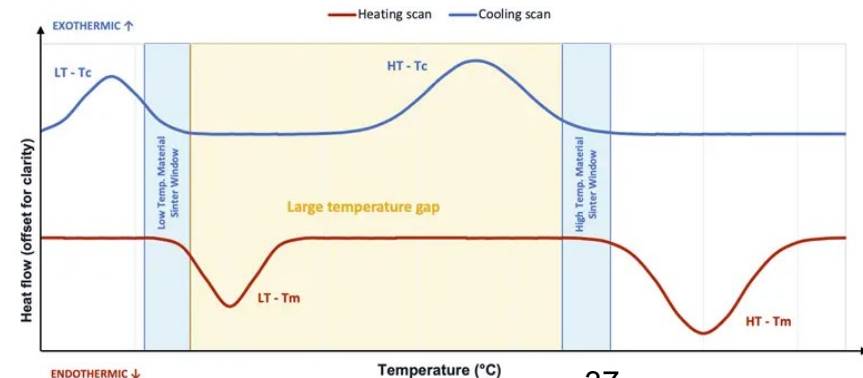
Bio-compatible polymers in PBF have poor properties (brittle or weak), and no surgical visibility (fluoroscopy) limiting utility

LS-122.012: Can we reach the desired mechanical properties by a combination of two non-similar bio-materials (LT / HT →)?

Can we adjust bio-degradation profiles?

Can we make them visible?

Plastics could offer		Current (BA) Plastics weaknesses	
✓	Biodegradability	✗	Mech. Properties
✓	Patient comfort	✗	Weak printability
✓	Lowered weight	✗	Economics
✓	Temperature res.	✗	Stabilizers
✓	Functionalization	✗	Production method
✓	Flexibility	✗	Surgical visibility



MedTech: Lower Melting Polymers

Solution: Through specialized control of printing parameters: Challenging start to project!

Current status:

1. Parts could be printed
2. Fluroscopy additive is identified
3. Complex geometries were obtained
4. Mechanical properties are still not in the desired range (ductility)
5. Initial formulation changes are promising waiting to print!

Next steps: Ongoing / Follow up project for Eureka-Biocall submission – 25th of September.

Initially
– phase separation



Initially
- Extreme curl

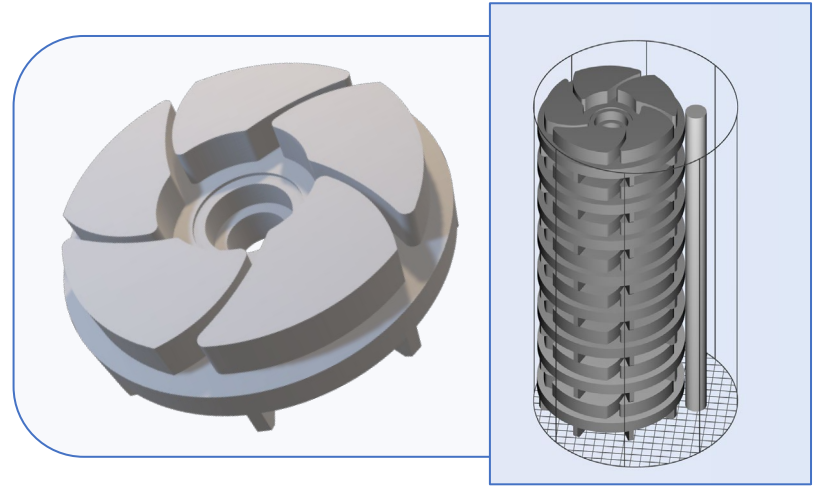


Initially
Mega-Bleeding

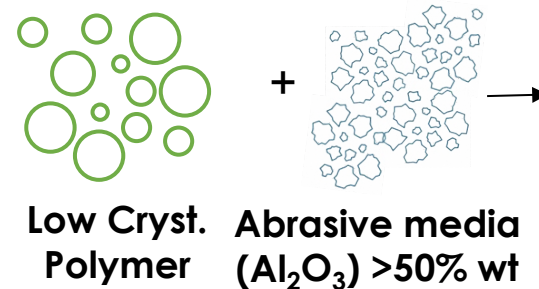


Machining: Can PBF produce better grinding wheels?

Problem to solve: long-lead times for PEI –
Diamond grinding wheels (up to 4 weeks) –
AM could shorten this, but no suitable
material is available (warpage, embrittlement)
PEI: Difficult to form & difficult to recycle!



128.578 INNO-ENG: Next Gen Grinding wheels: Can a low crystalline material handle high abrasive loads while maintaining ductility?
Can it work like PEI or even better without the recycling challenges?



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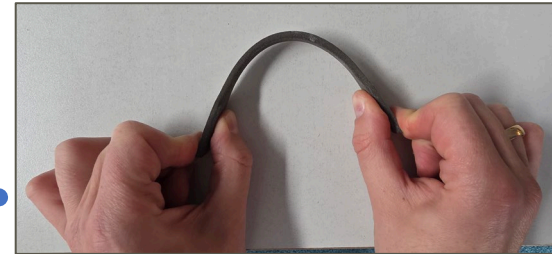
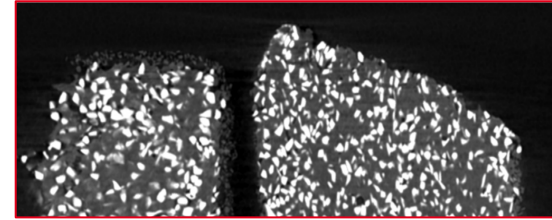
Machining: Can PBF Produce to Better Grinding Wheels?

Solution: Specialized thermoplastics was developed that could handle $>50\%$ wt loading of coarse alumina powder while *maintaining flowability*

Product was printable on Sintratec S3.
Performance *while confidential* – **gave similar performance to PEI-Diamond disks**

Next steps:

Can we optimize surface topography more?
Can we improve beyond PEI-Diamond?
Speak with industry partners for a follow up project
Can we make cool art?



PA12-Like Material Substitutes & Additive Free PA12!

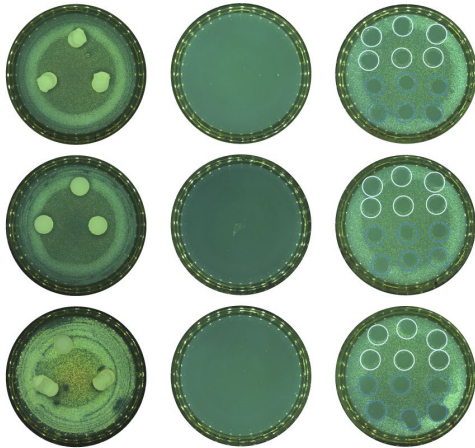
123.400: Anti-Microbial

Enables doping of **non-toxic**/non-dissolvable anti-microbial agents!

diffusion

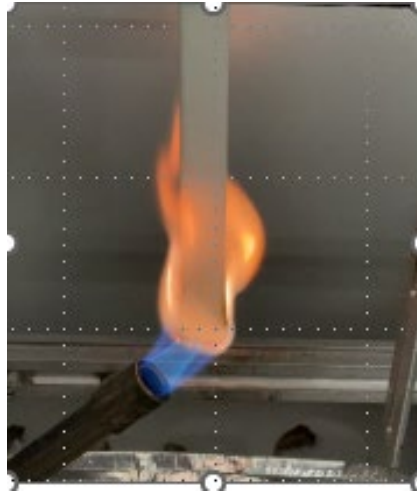
touch

drop



123.834: FR agents

PA12-Like: enables different FR additives @ PA12 print parameters!



SFOE: ELAN

A bio-based PA12 alternative with better chemical resistance & reusability @ PA12 Print.P



High Temperature PA: Feasibility study

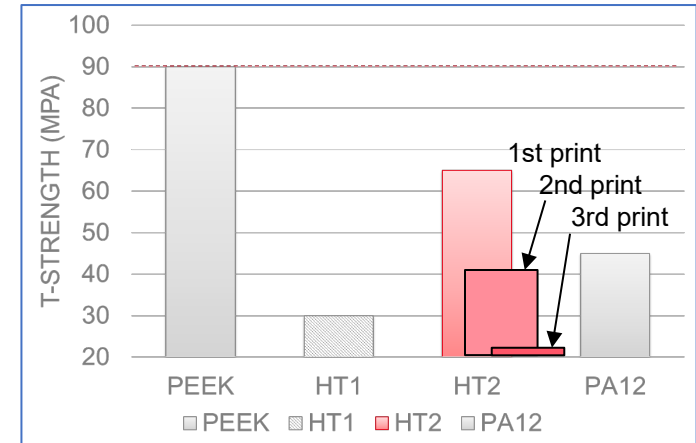
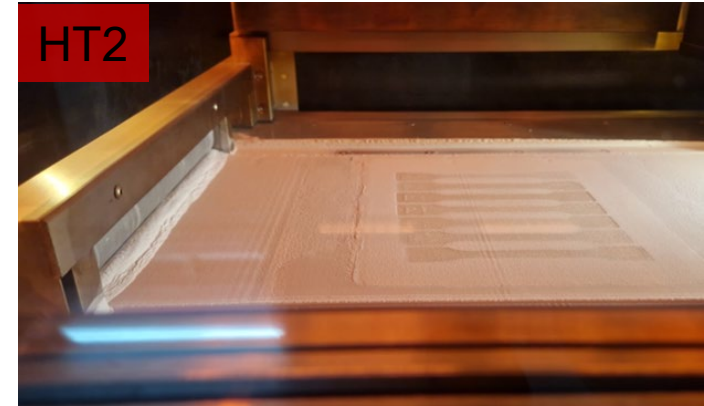
Problem(s) to solve: PEEK is too expensive for engineering based application and series production in PBF

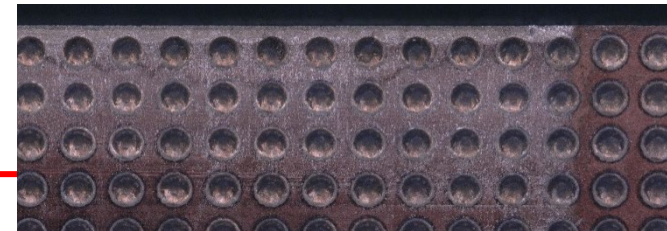
High temperature PA (HT) might be suitable but require process development print temp. 300°C

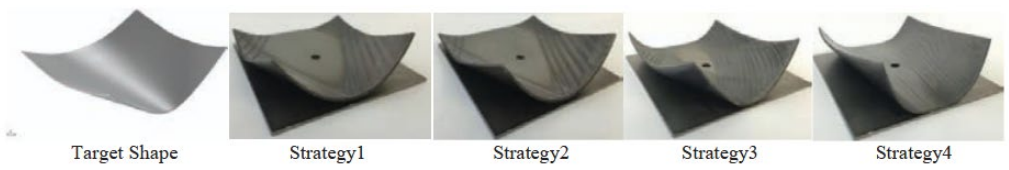
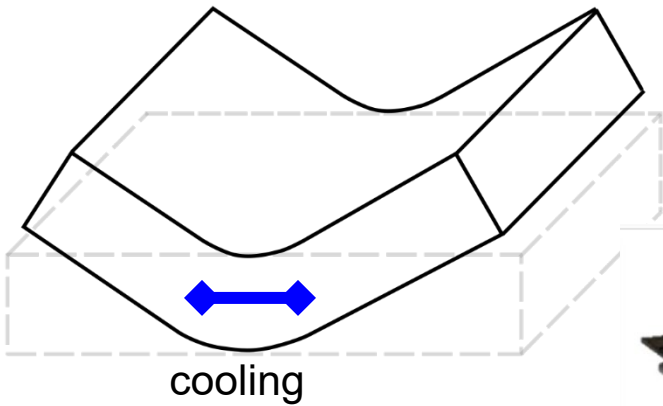
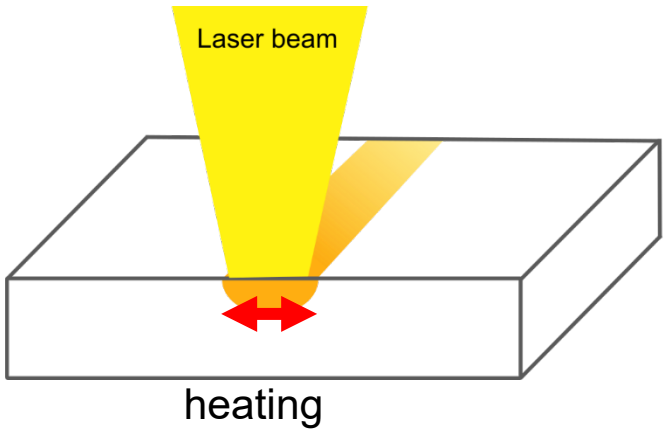
Innovation booster: Determine if material is suitable for use in PBF printer

Results: Printability was good, but thermal aging was evident even in small builds

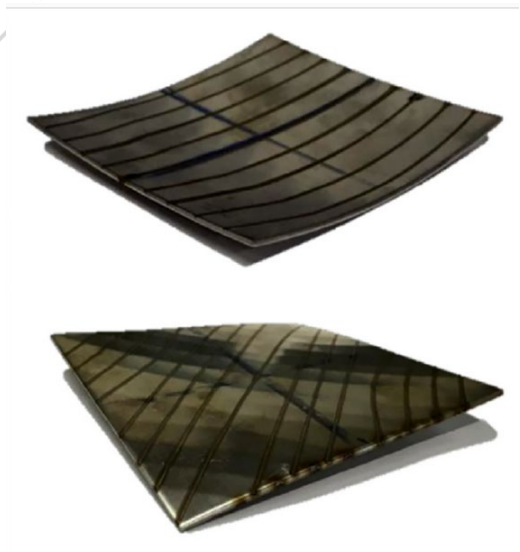
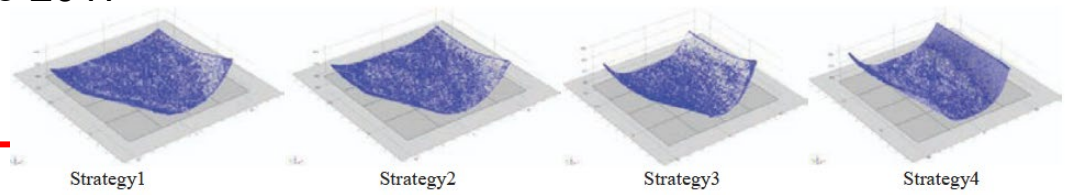
Next steps: Determine stabilizer packages







Gao 2017



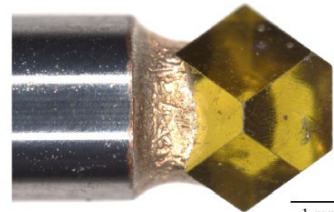
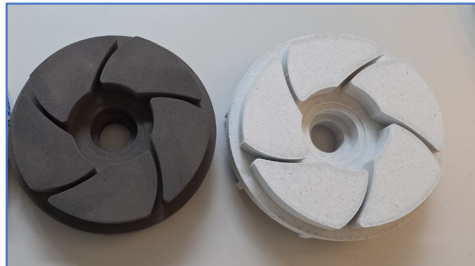
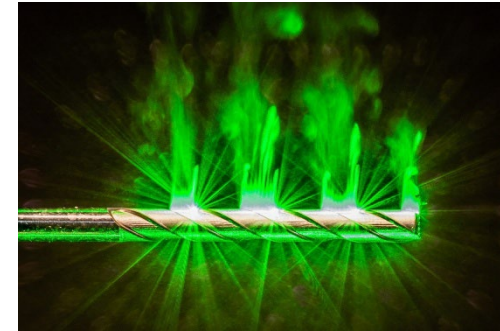
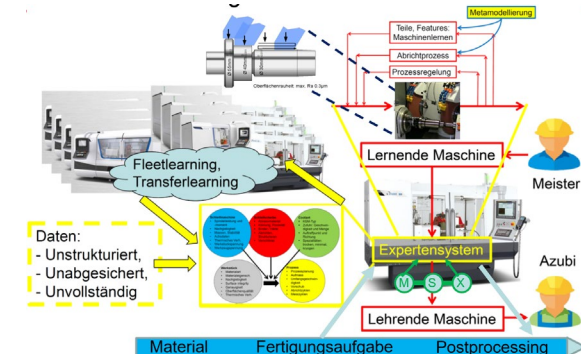
Safari 2020

Lasers as an Indispensable Tool in Manufacturing

inspire

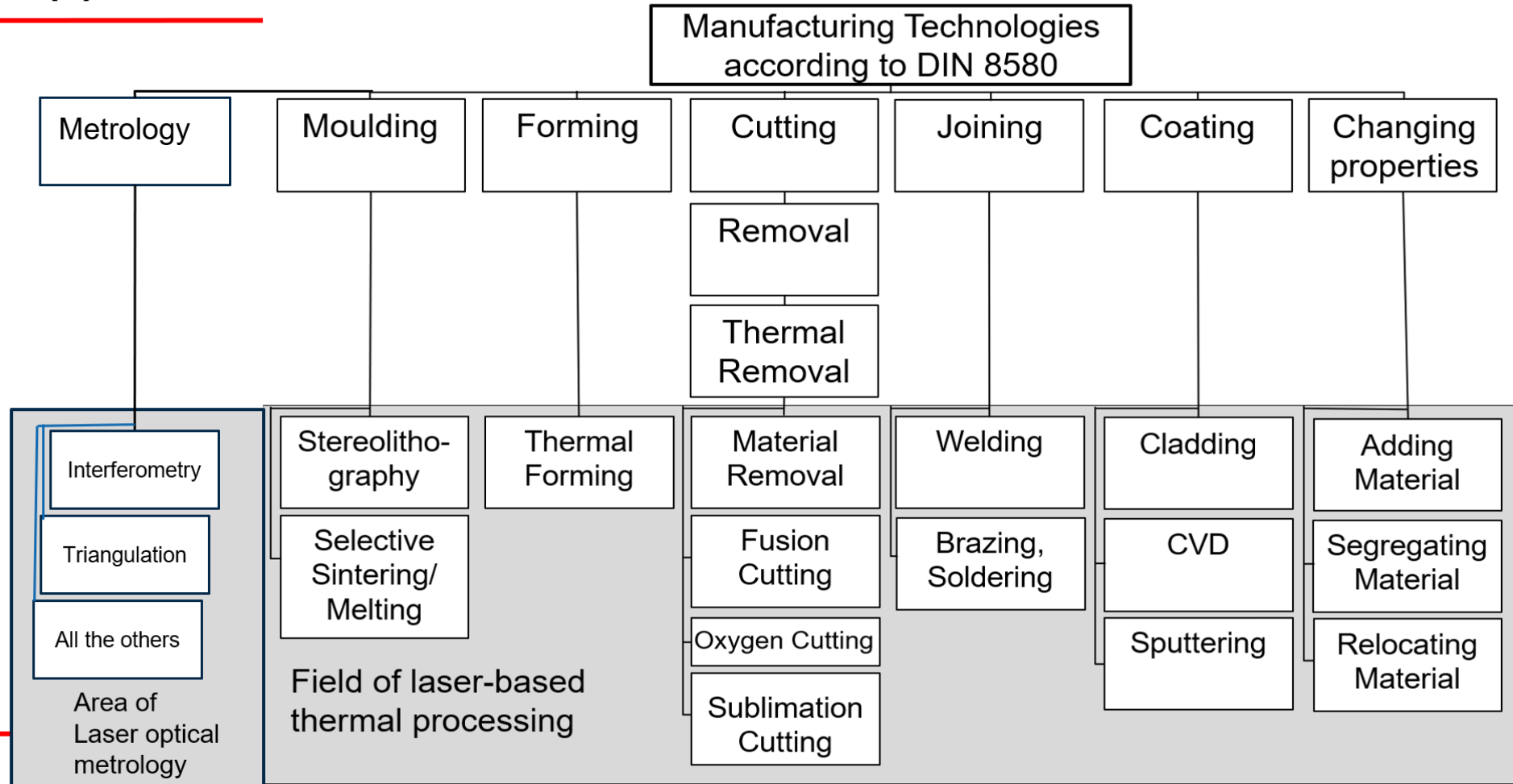
Content

- inspire: bridge between academia and industry
- It is the system that counts: intelligent machine, digital twin
- Surfaces
- Ablation
- Structuring of tools
- AM (polymer / metall / ceramics)
- Forming
- Conclusion



1 mm

Applications of lasers



Laser as indispensable tool for manufacturing

Thank you very much for your kind attention!
<https://www.inspire.ch>

