



University of Stuttgart
Institut für Strahlwerkzeuge



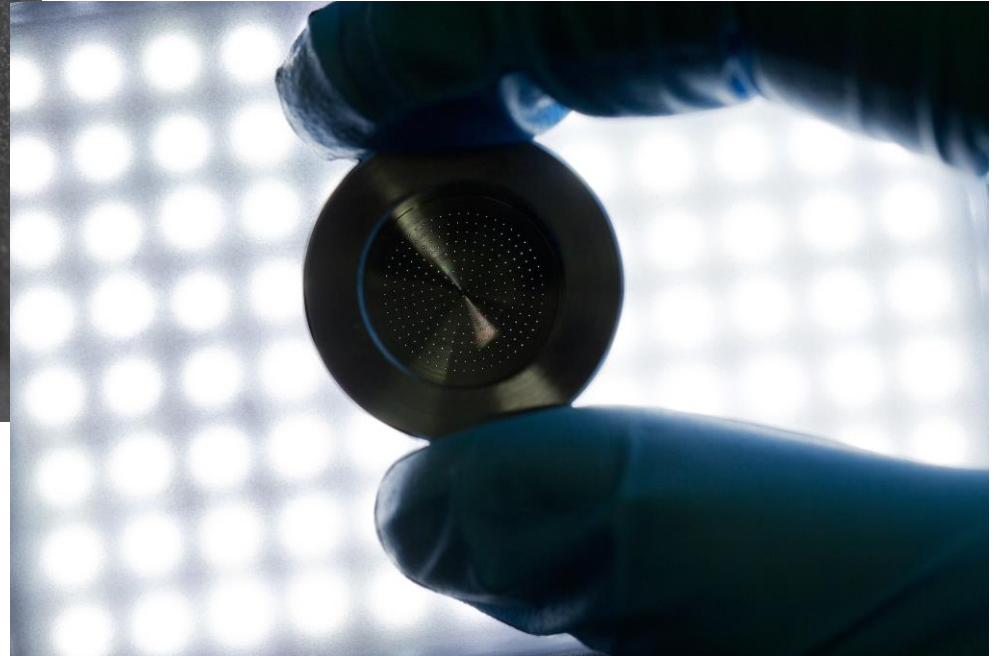
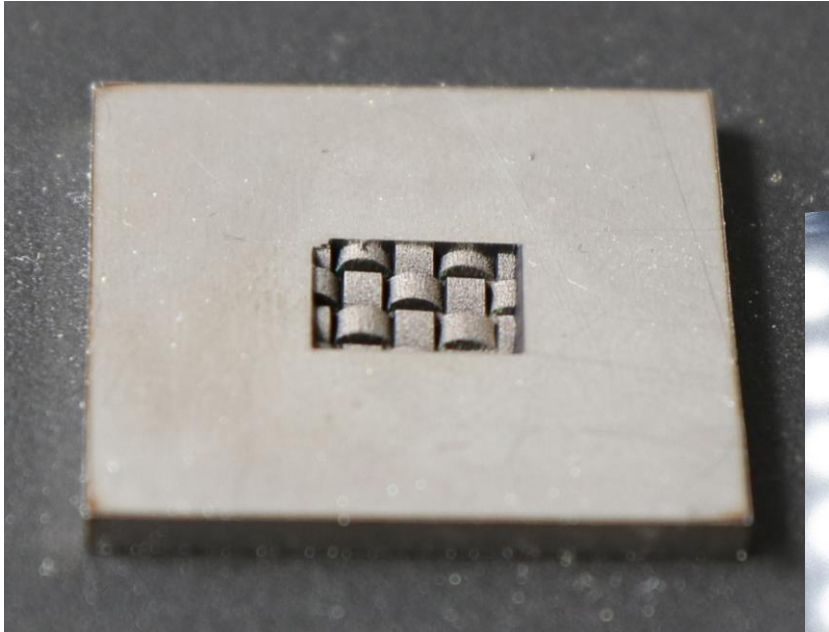
IFSW

Controlled ultra-short pulse ablation using optical coherence tomography

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Matthias Buser, Steffen Boley,
Dr. Rudolf Weber, Prof. Dr. Thomas Graf**

Ablation of materials with ultra-short pulsed lasers

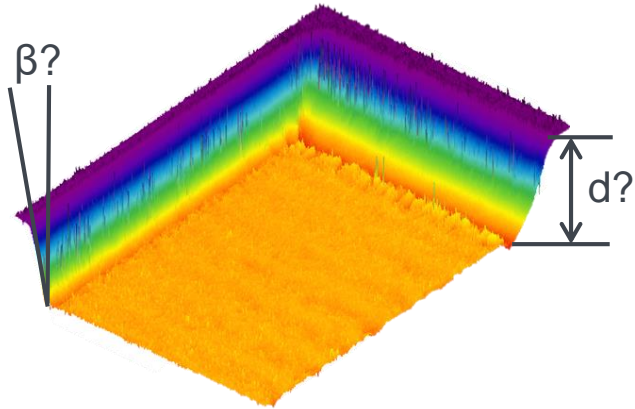
High quality and high precision



Motivation

Why do we want control?

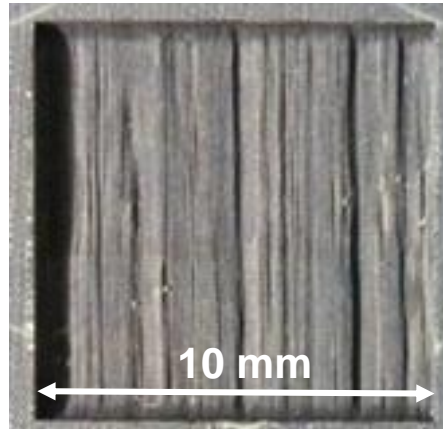
Quality assurance



Repeatability?

→ Post-process measurement

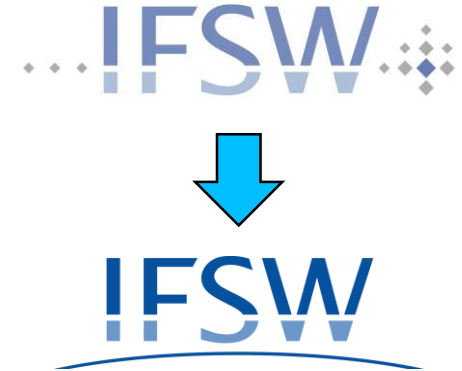
Inhomogeneous materials



Irregular ablation

→ Very rough surface

Customization

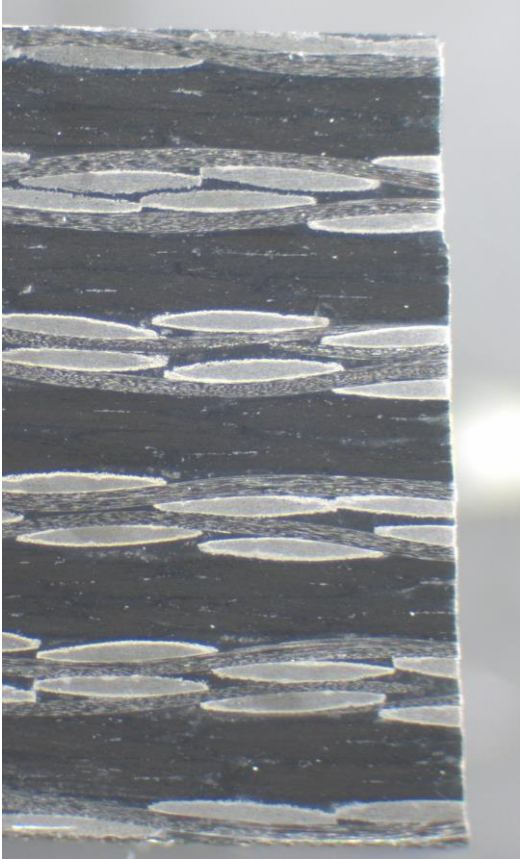


Customized geometries

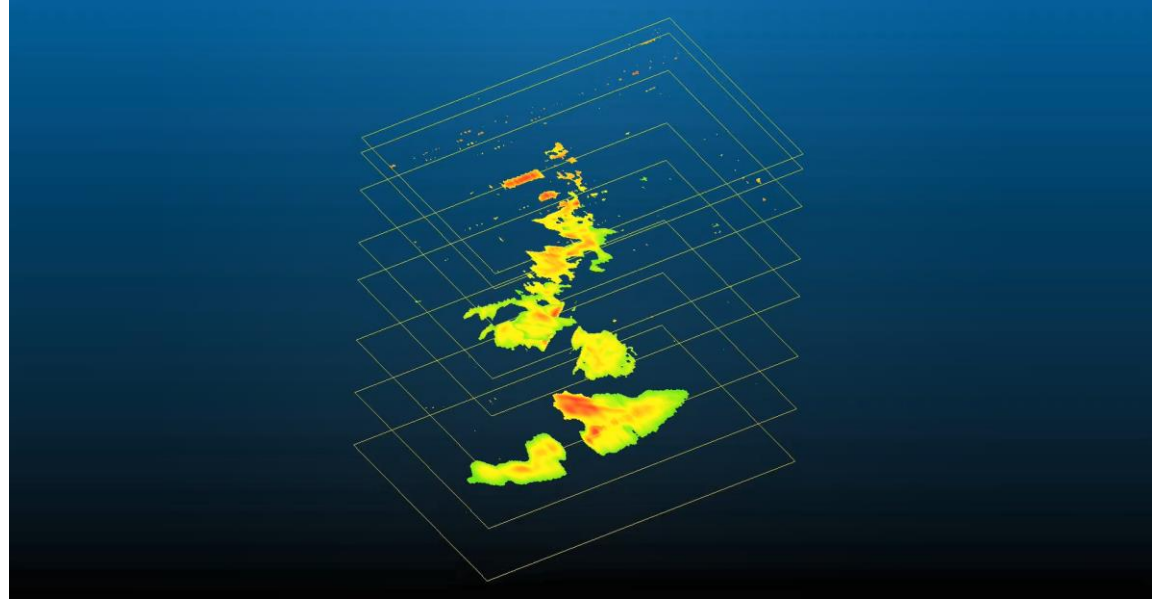
→ Time consuming adjustment of the process

Application example

Repair process for parts made from carbon fiber reinforced plastics (CFRP)



Cross section through a 10 mm thick CFRP workpiece (laser cut)



Impact damage in CFRP. Film provided by edevis.

Application example

Repair process for parts made from carbon fiber reinforced plastics (CFRP)

Concept to repair parts made from CFRP

Damage analysis



Calculation of optimum repair geometry



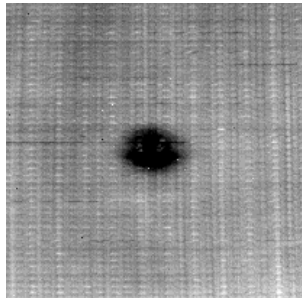
Laser ablation of CFRP



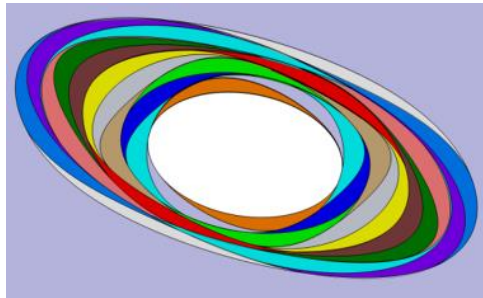
Repair



Quality assurance



edevis



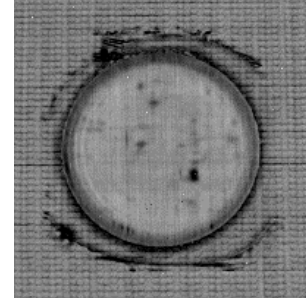
DLR



IFSW



DLR



edevis

Ablation of CFRP with lasers

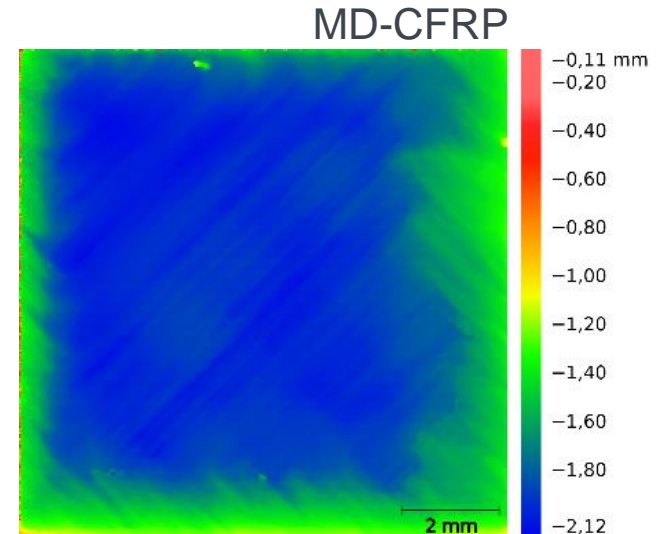
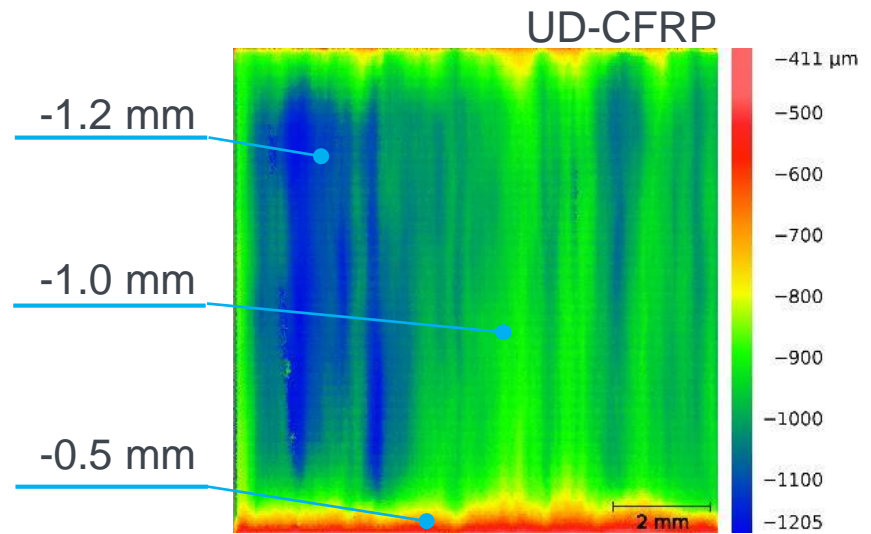
Uncontrolled process

Uncontrolled ablation process:

- Irregular surface
- Increasing surface roughness with ablation depth
- Average roughness Sa of up to 350 μm !

Layer-exact ablation of CFRP impossible with an uncontrolled process.

 **Process control**



Controlled ablation of CFRP

Setup

Distance measurement

PRECITEC CHRocodile2

Wavelength **1080 ± 20 nm**

Measurement frequency 70 kHz

Measuring range **<6 mm**

Vertical accuracy **±1 μm**

Spot size 15 μm

Processing laser

TRUMPF TL 20-1 FQ

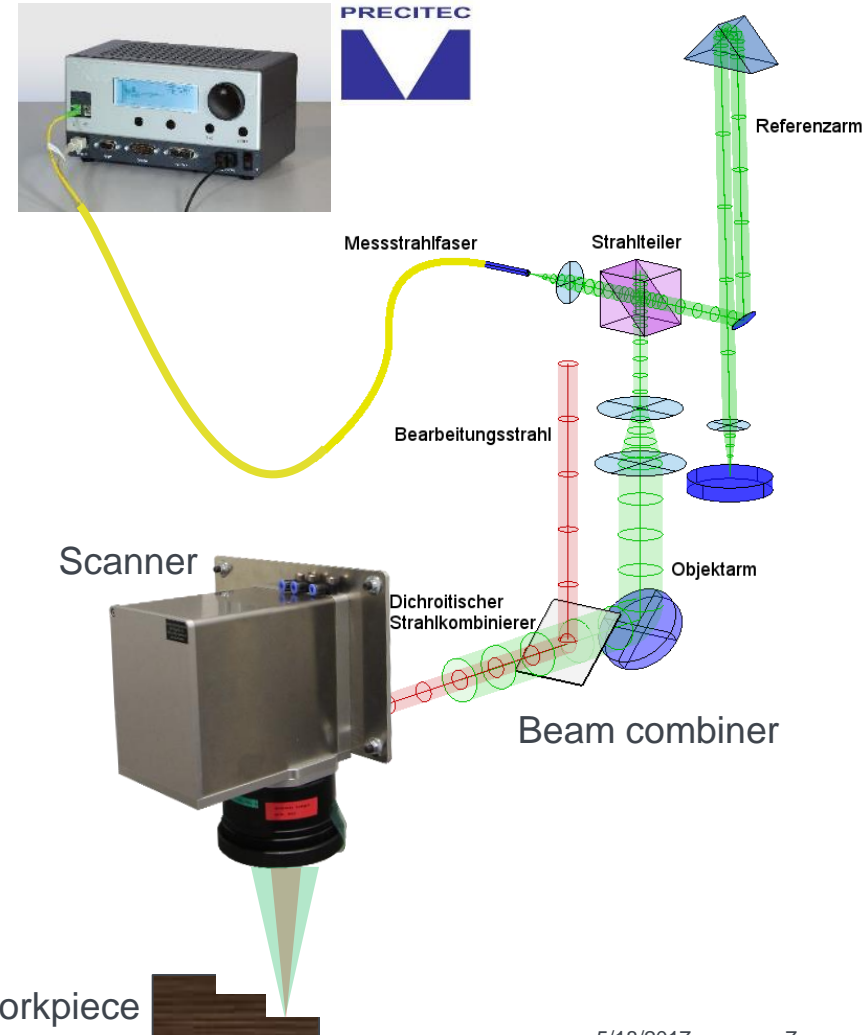
Wavelength **1047 nm**

Pulse duration 60 ns

M² <1,2

Average power 21 W

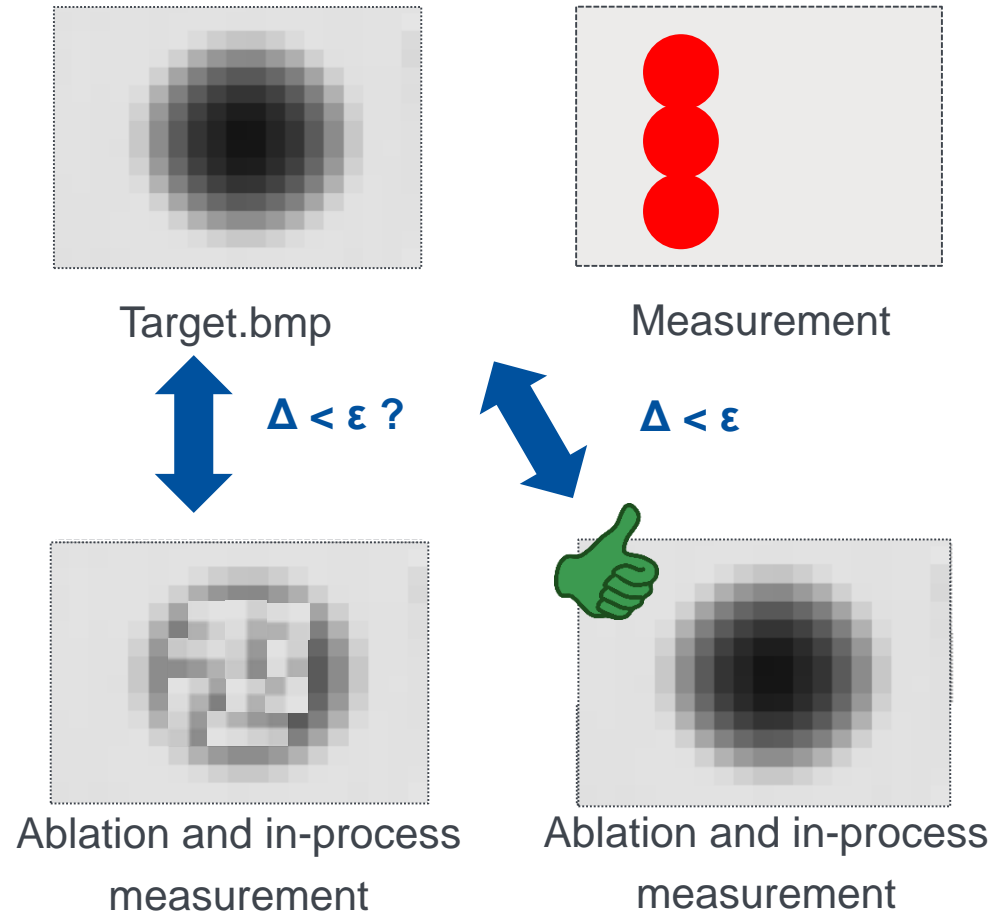
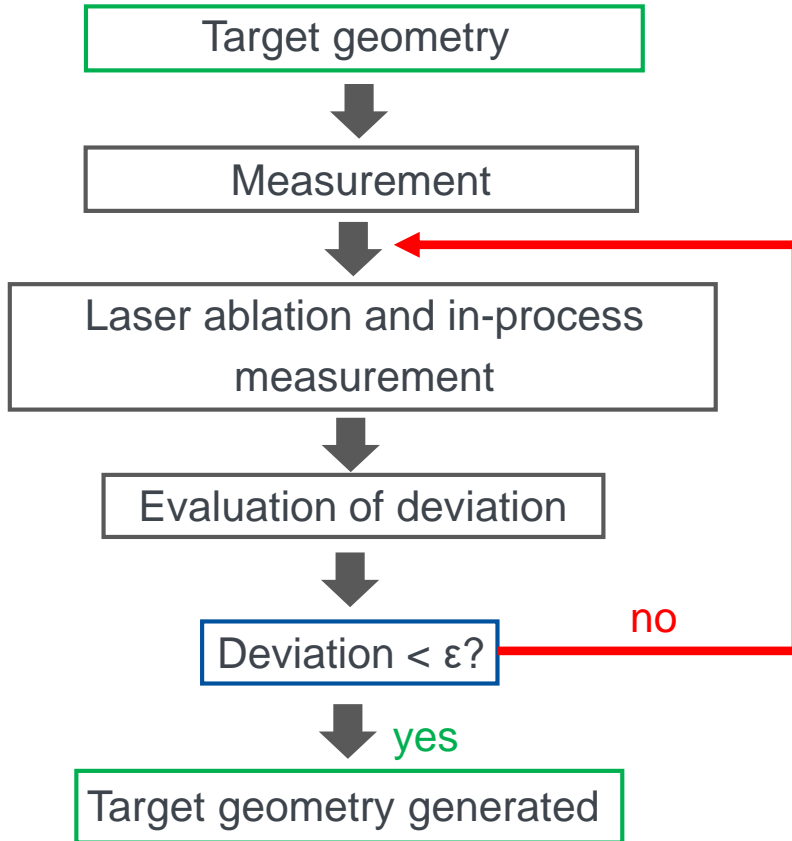
Repetition rate 15 kHz



CFRP workpiece

Controlled ablation of CFRP

Principle



Controlled ablation of CFRP

Example



Controlled ablation of CFRP

Generation of a complex geometry

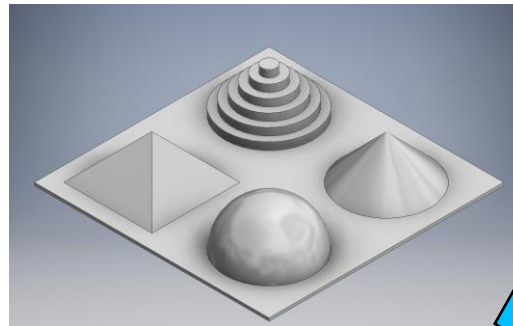
- Field size: 25 mm x 25 mm
- Ablation depth: 5 mm (black) and 50 μm (white); linear grey scale values
- Processing time: 3.5 h

400 x ff

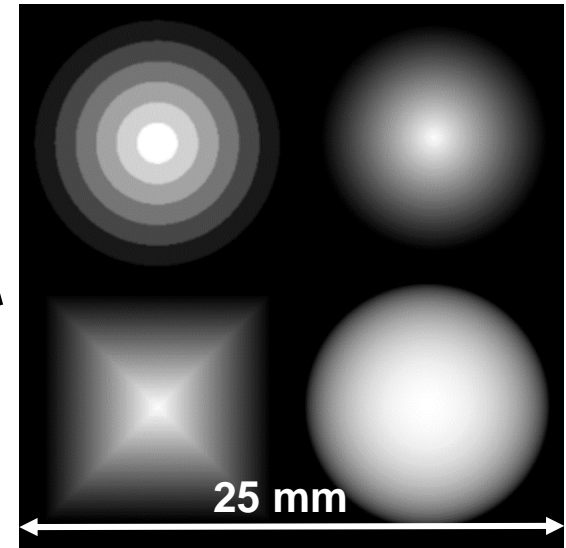


Processing parameters:

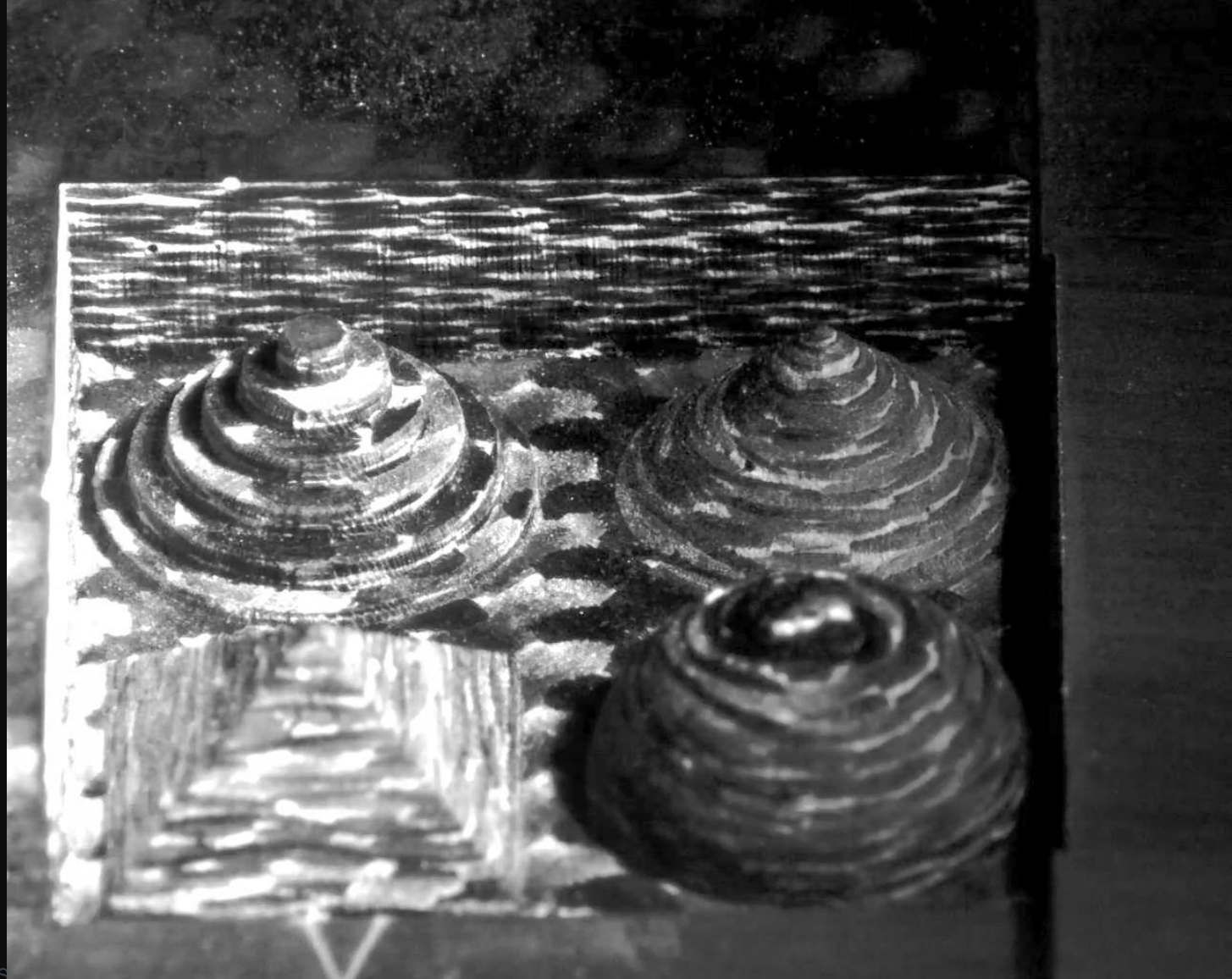
- Spot size: 90 μm
- Pulse energy: 1.4 mJ
- Repetition rate: 15 kHz
- Pulse duration: 60 ns
- Feed rate: 600 mm/s
- Hatch distance: 80 μm



CAD

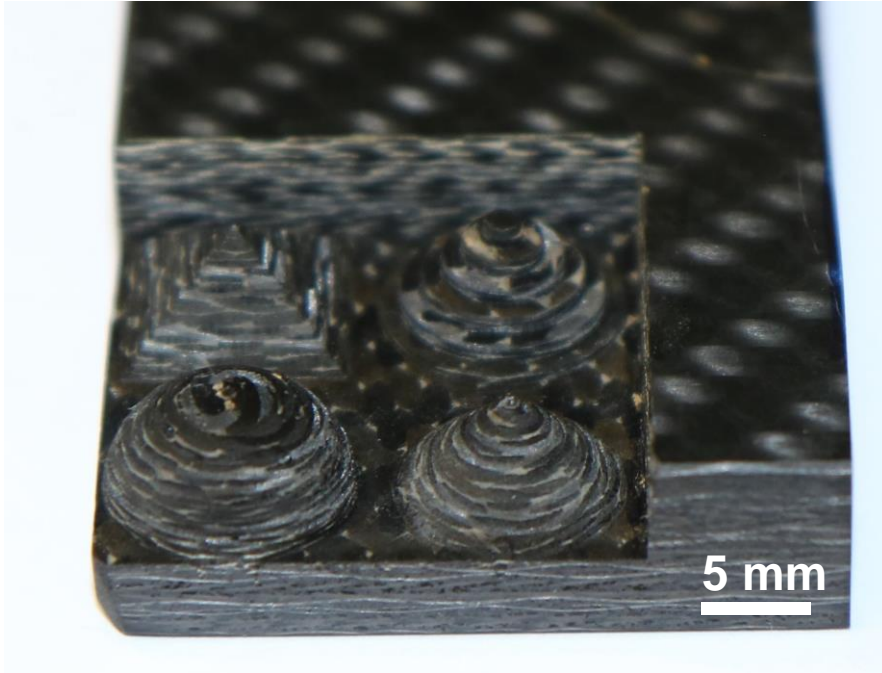


Bitmap with grey values

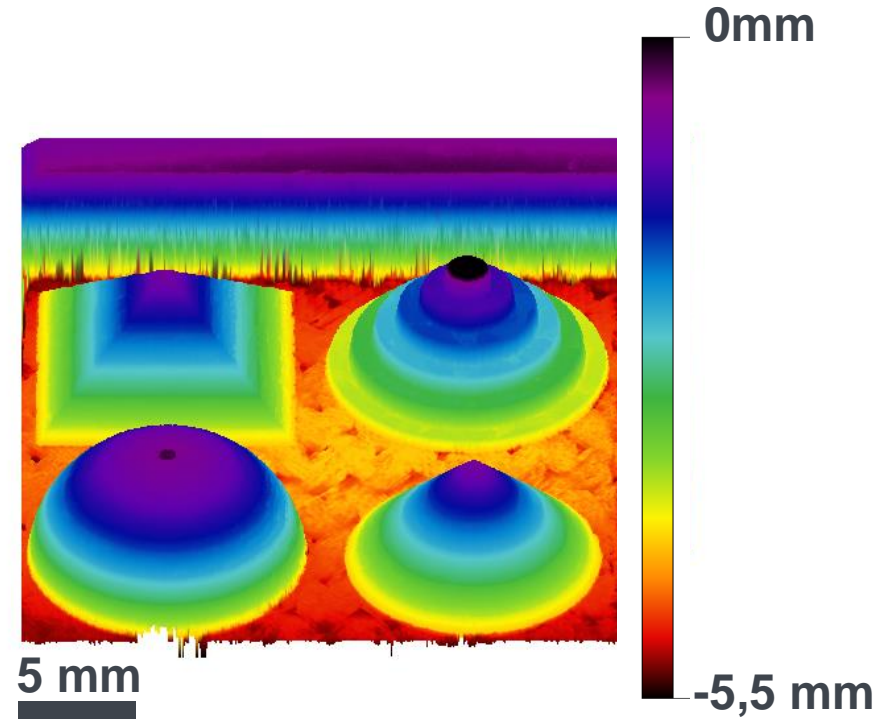


Controlled ablation of CFRP

Result



Photography

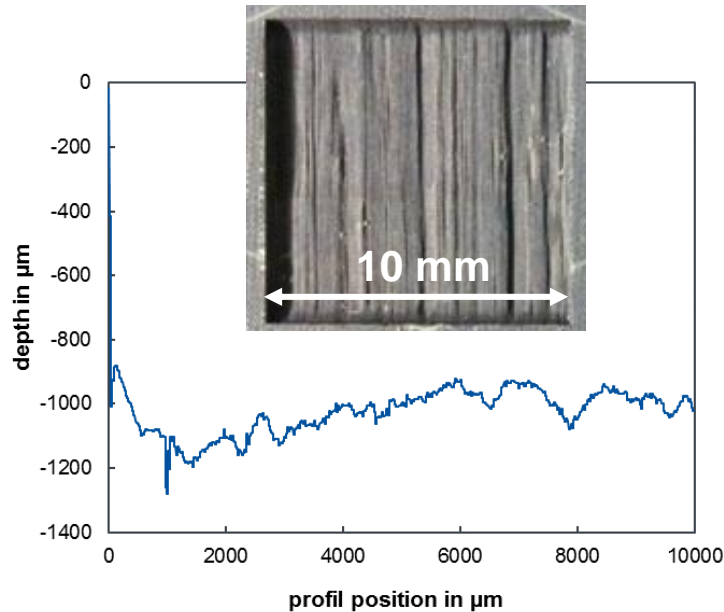


Measured geometry

Controlled ablation of CFRP

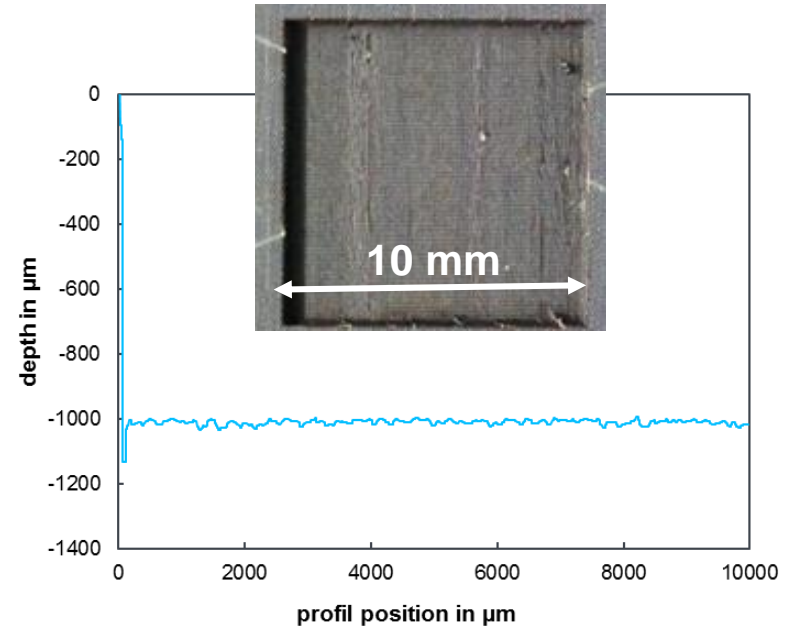
Improvement through process control

Uncontrolled



- Deviation in depth up to $\pm 200 \mu\text{m}$
- $S_a = 60 \mu\text{m}$

Controlled

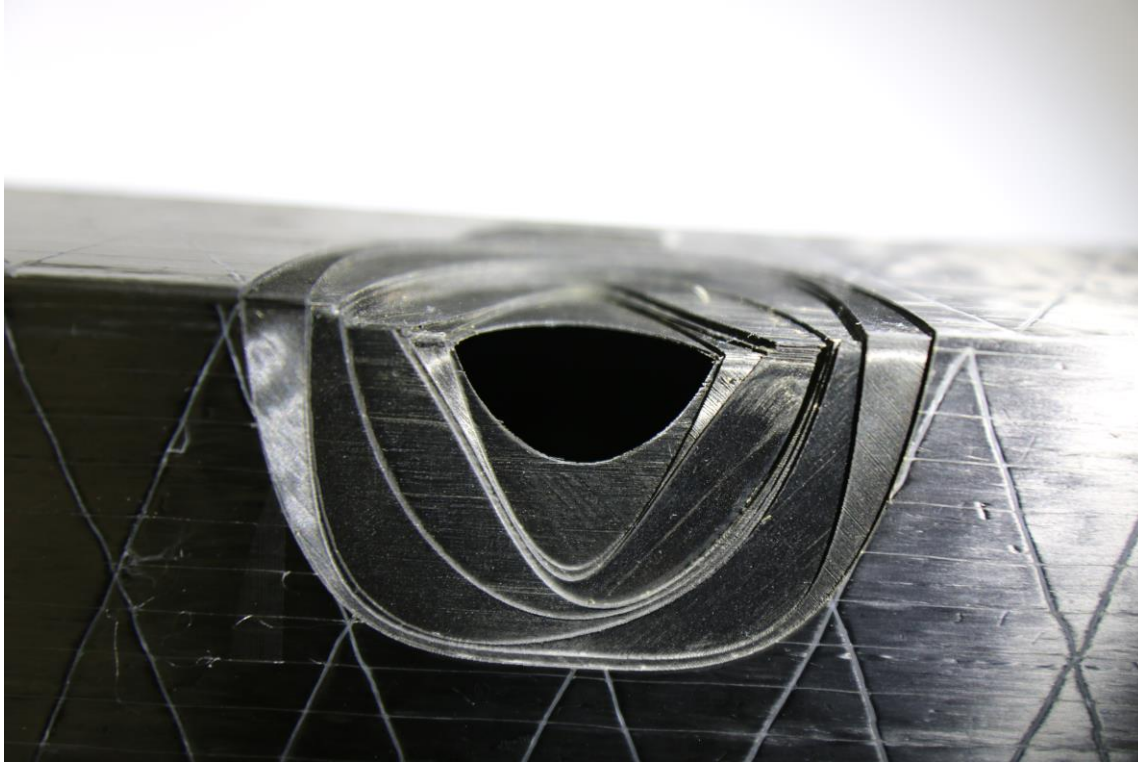


- Deviation in depth **smaller $\pm 20 \mu\text{m}$**
- **$S_a = 7 \mu\text{m}$**

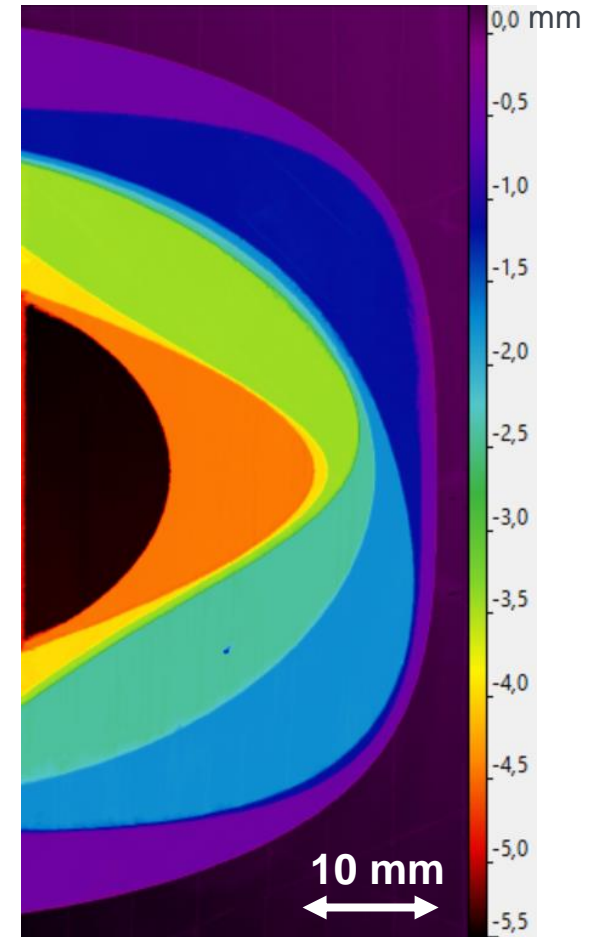
Faktor 10

Controlled ablation of CFRP

Repairment of a side arm



Multi-directional 4.8 mm thick CFRP



Controlled ablation of steel

Upscaling to high average powers

Target geometry:

- Field size: 10 mm x 10 mm
- Depth: 2 mm (black) and 0 mm (white)

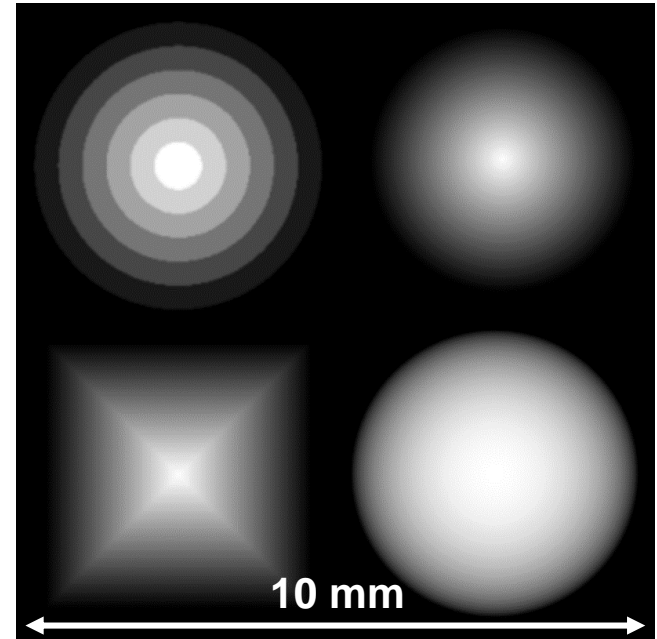
Processing parameters:

- **Average power:** 410 W
- Repetition rate: 300 kHz
- Pulse duration: 8 ps
- Spot size: 85 μm
- Feed rate: 5 m/s
- Hatching distance: 20 μm
- Fluence: 48 J/cm²

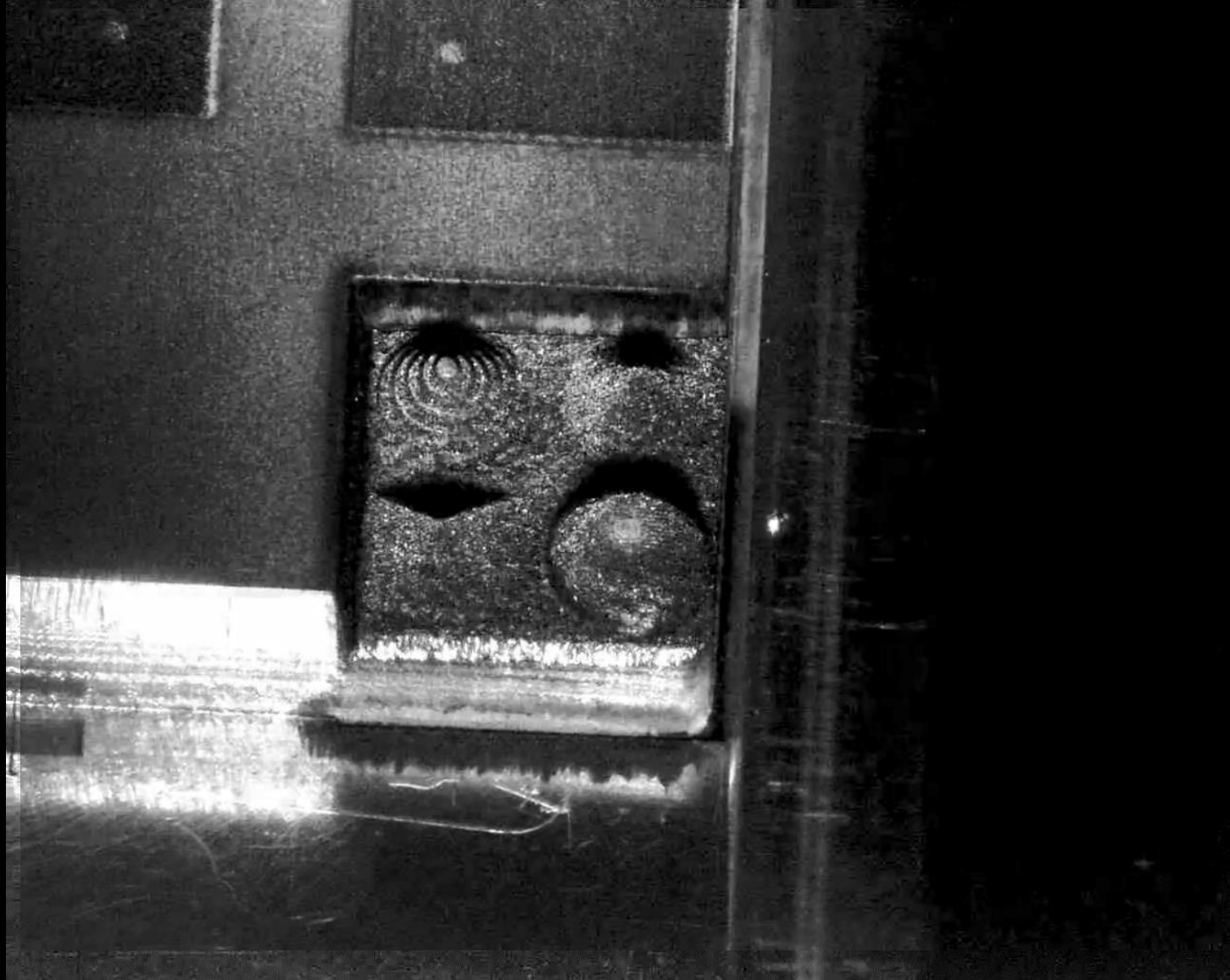
Processing time: ~ 5 h

Video:

1800 x ff 



Target geometry

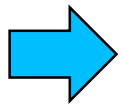


0:00:00

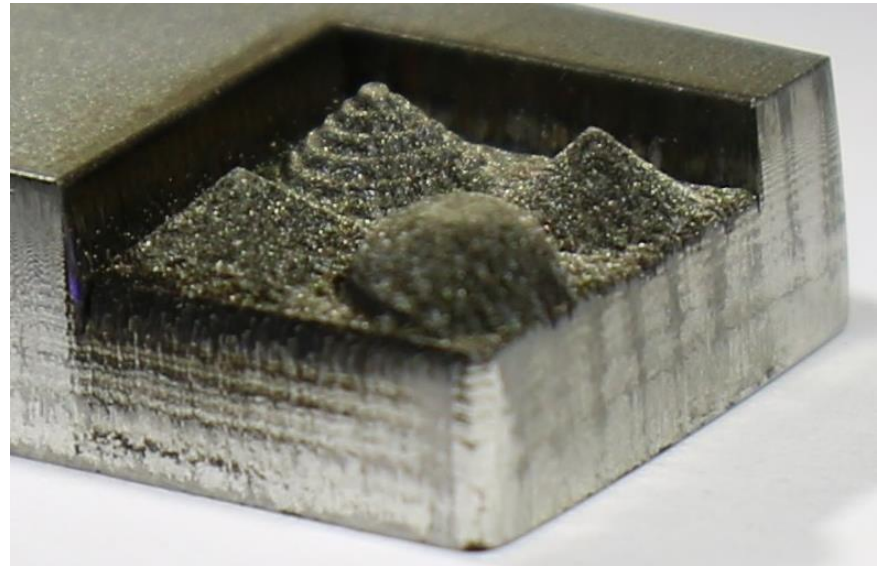
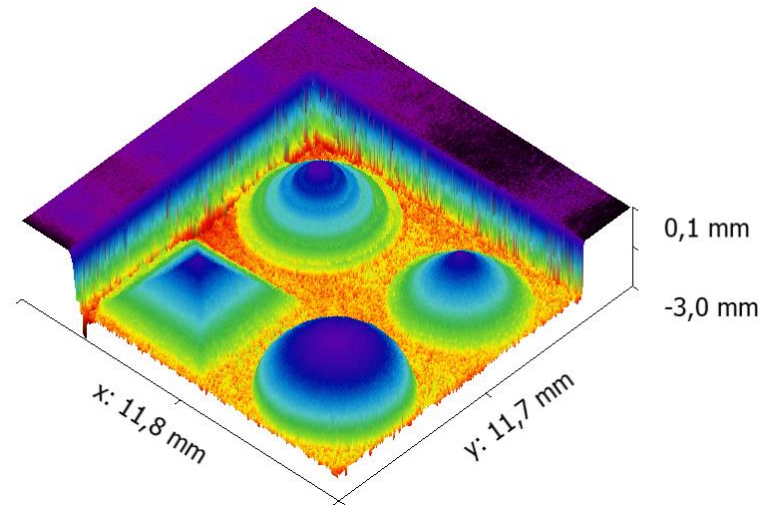
Controlled ablation of steel

High-power result

- Number of scans: 1474
- Energy specific volume: 0.34 mm³/kJ
- Ablation rate: 0.55 mm³/min
- Average deviation: 100 μm
- Roughness S_a : 54 μm



Laser processing with high average power needs adapted strategies.

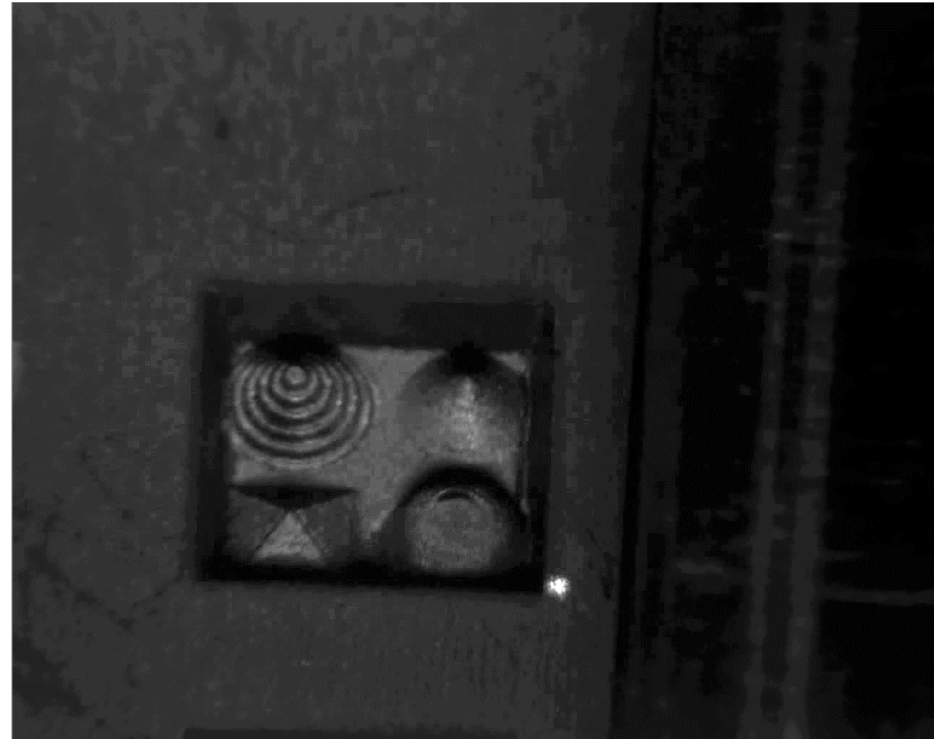


Controlled ablation of steel

2-step process for higher processing speed

1. Rough-machining (12.1 J/cm^2) to a depth of $750 \text{ }\mu\text{m}$

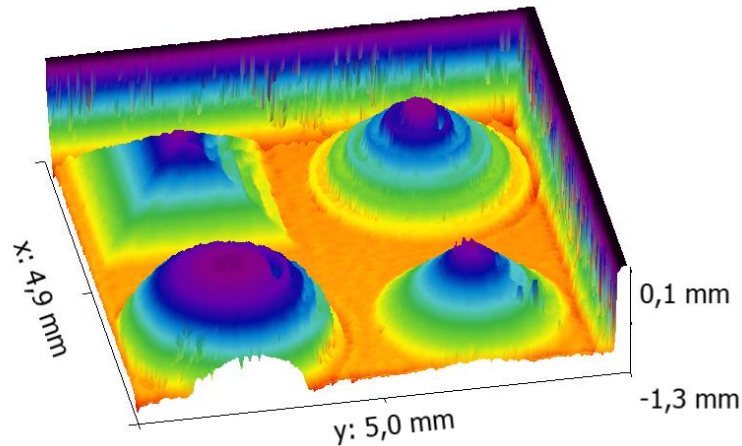
2. Fine machining (2.2 J/cm^2) to a depth of $1150 \text{ }\mu\text{m}$



Controlled ablation of steel

2-step process result

- Rough machining: 250 scans
- Fine machining: 300 scans
- Average deviation: **50 μm (2x better)**
- Roughness S_a : **6.2 μm (9x better)**



Summary

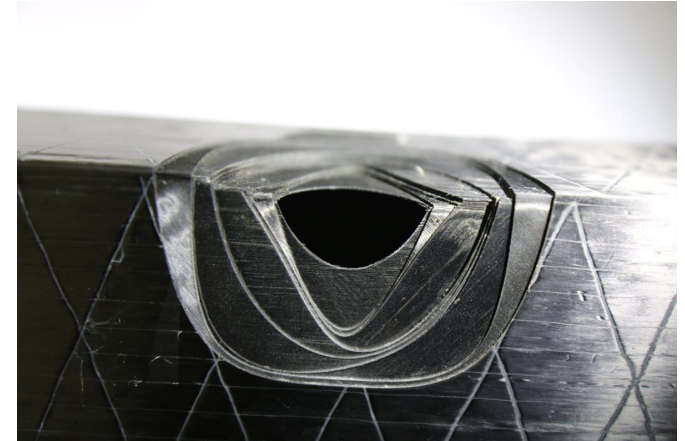
Controlled ultra-short pulse ablation using optical coherence tomography

System for a controlled ablation process established.

Controlled ablation **enables precise processing** of inhomogeneous materials like **CFRP**.

Improvement in **geometric accuracy** and **surface roughness** by a **factor of 10!**

Controlled ablation enables **new, faster strategies** for **high quality processing** of homogeneous materials like **steel**.

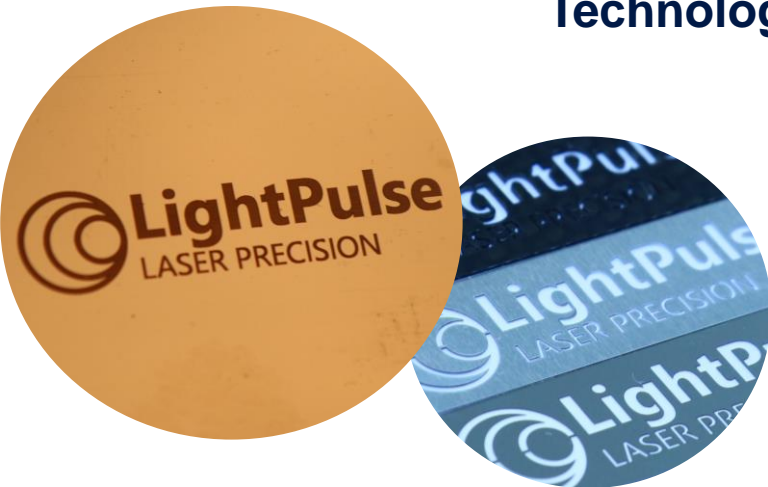
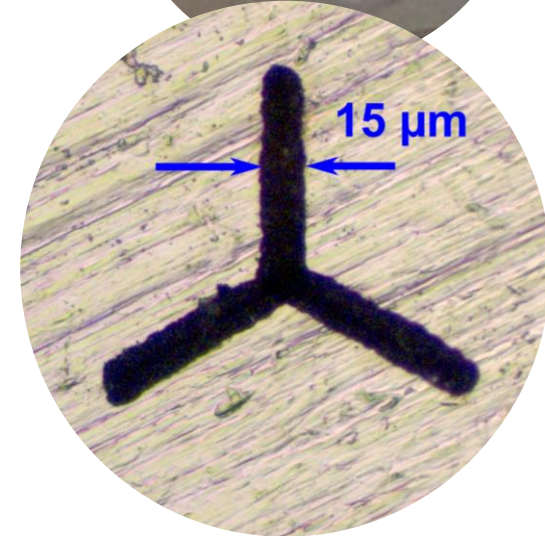


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Thank you!



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