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University of Applied Sciences

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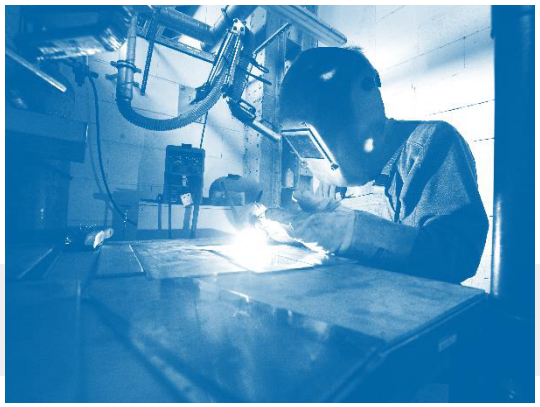
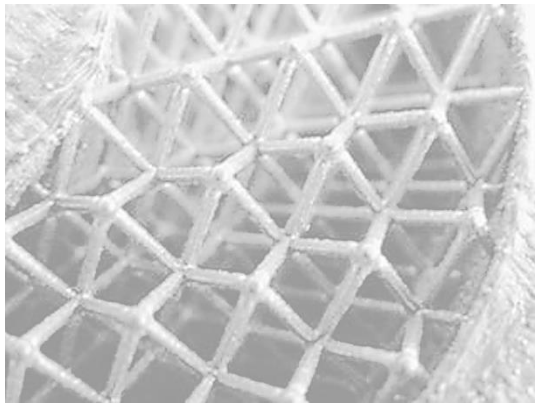




Investigation of parameter influences on the laser processing of ceramics with ultra-short pulses

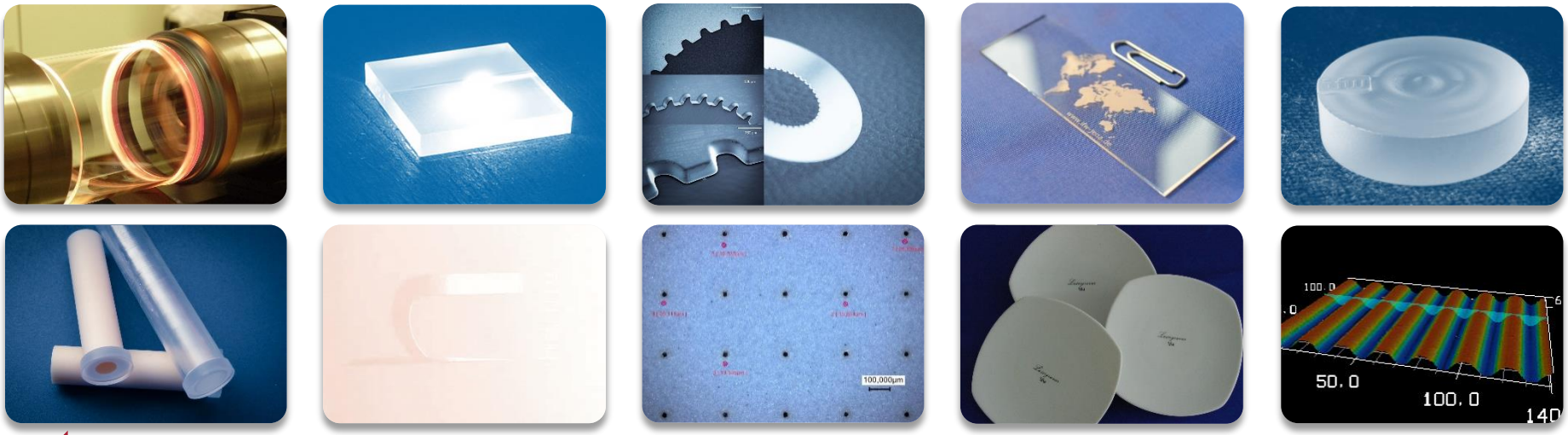
Maria Friedrich*, Sebastian Wächter*, Kristina Völlm,** Jens Bliedtner**

*ifw Günter-Köhler-Institut für Fügetechnik und Werkstoffprüfung, Jena

** Ernst-Abbe-Hochschule, Jena

Laser processing of glass and ceramics

Joining | Polishing | Cutting | Marking | Structuring



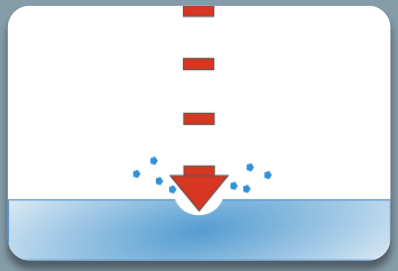
High thermal influence

High resolution / precision

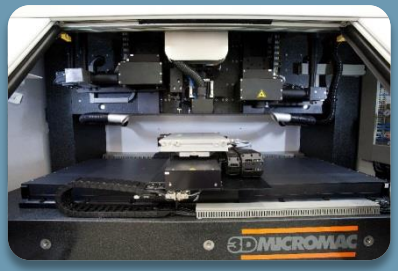
CO_2 laser → Solid state laser → Fiber laser → USP laser

Outline

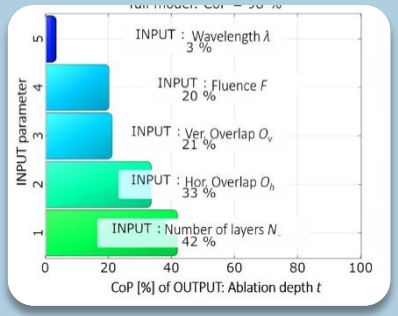
1. USP laser ablation



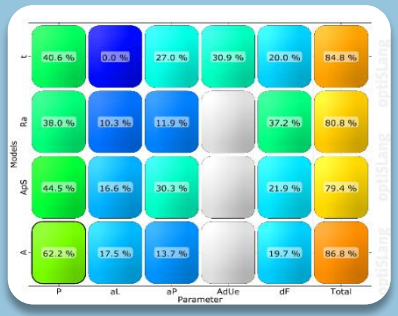
2. Experimental Approach



4. Current activities

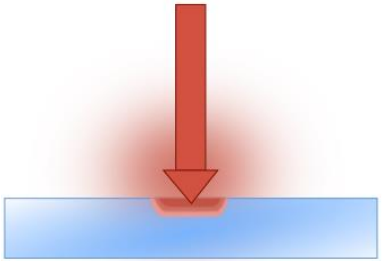
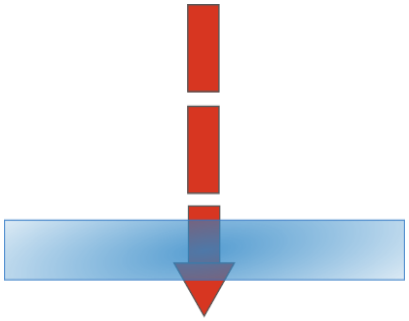
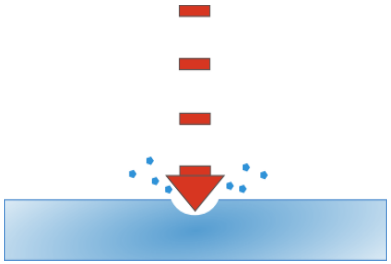


3. Sensitivity Analysis



1. USP laser ablation

CO_2 laser → Solid state laser → Fiber laser → **USP laser**

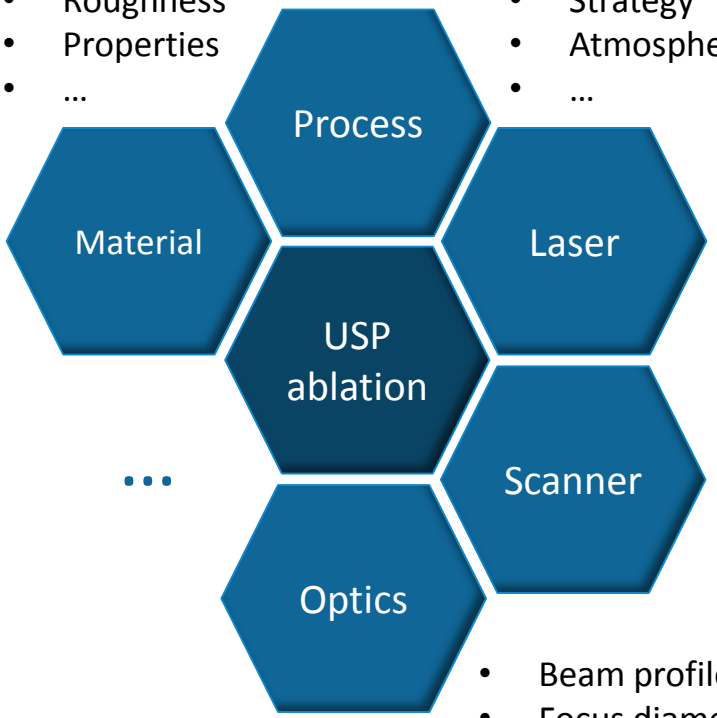
λ = 10,6 µm	λ = 1064 nm	λ = 1064 nm, τ_p < 10 ps
		
• Thermally affected process • Melting of material	• Redeposited material, cracks • OR: material transparent	• Non-linear absorption • Thermal conduction negligible • Precise material removal
		

1. USP laser ablation

Multitude of process parameters …

- Roughness
- Properties
- …

- Strategy
- Atmosphere
- …

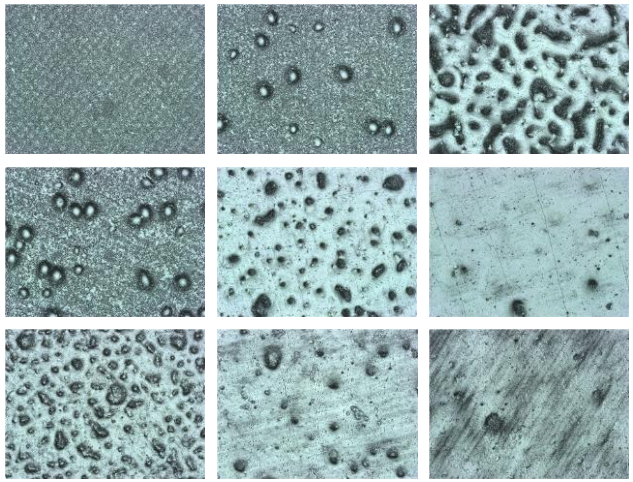


- Wavelength
- Pulse duration
- Pulse energy
- Repetition rate
- …

- Marking speed
- Line distance
- Pulse overlap
- Number of layers
- …

- Beam profile
- Focus diameter
- Divergence
- …

… results in various surface qualities



2. Experimental Approach

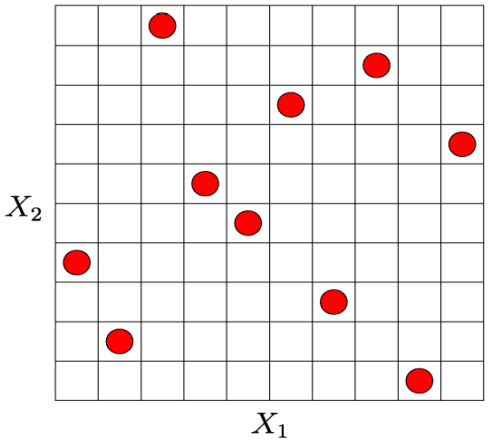
Multi-dimensional parameter space

→ Sensitivity analysis, meta model, optimization
→ Identification of main parameters and non-linear effects

dynardo optiSLang®

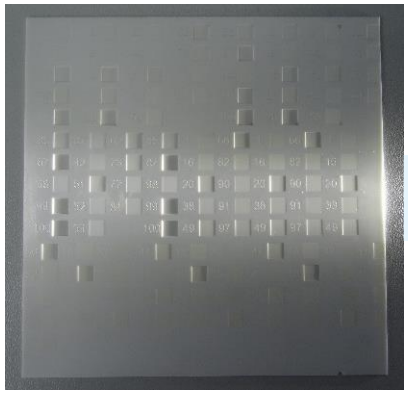
DoE

- Latin Hypercube Sampling



Experiments

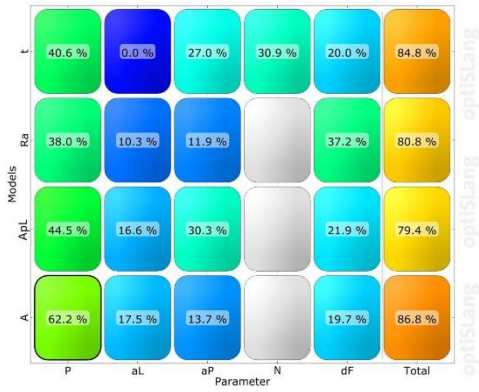
- USP ablation of alumina (Al_2O_3)



Excel Add-In

Analysis

- Sensitivity analysis based on MOP



2. Experimental Approach

Parameter Ranges

Input Parameters				Output Parameters	
actuating variables		**controlled variables**			
Power P [W]:	0.3 … 20	**Fluence** F [J/cm²]:	0.1 … 32	**Roughness** Ra [µm]:	0.42 … 3.8
Wavelength λ [nm]:	355; 532; 1064	**Pulse distance** a_P [µm]:	1 … 15	**Ablation rate** A [mm³/min]:	0 … 7.8
Scanning speed v_S [mm/s]:	200 … 3000	**Horizontal overlap** O_h [%]:	-33 … 99	**Ablation depth** t [µm]:	0.24 … 543
Line distance a_L [µm]:	1 … 15	**Vertical overlap** O_v [%]:	-33 … 99	**Ablation/layer** ApL [µm]:	0.018 … 31.5
Focal length f [mm]:	40; 80; 100; 250	**Focus diameter** d_F [µm]:	12 … 100		
Number of layers N:	1 … 20				

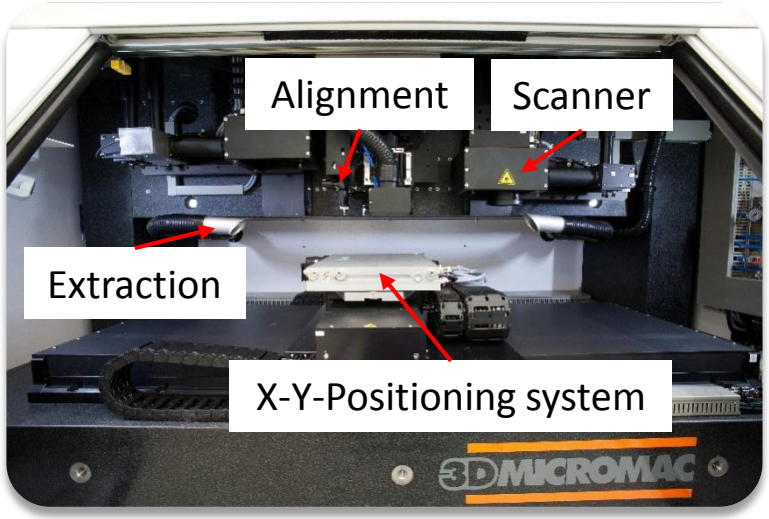
DoE

Sensitivity Analysis

2. Experimental Approach

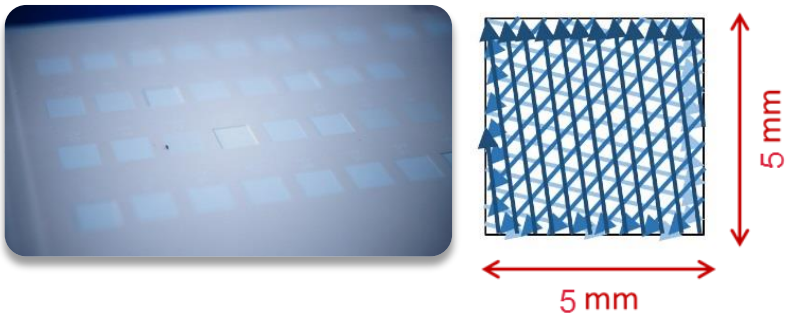
Experimental Setup

Machinery: „microSTRUCT vario“ (3D Micromac)
Laser: „HYPER RAPID 25“ (Lumera Laser)
„Pharos“ (Light Conversion)



- Wavelength: 1064 nm, 532 nm, 355 nm
- Pulse duration: 230 fs – 10 ps
- Repetition rate: < 1 MHz
- Max. power: 25 W

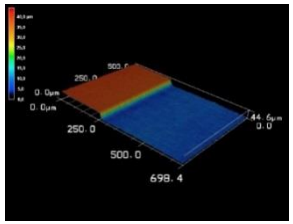
Investigation of surface ablation:



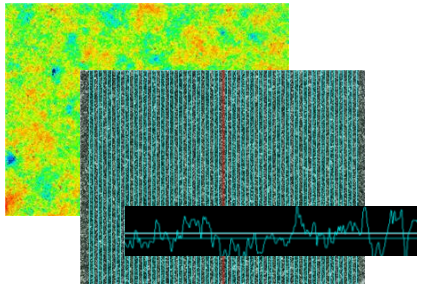
Laser Scanning Microscope:

(Keyence, VK-X100)

Depth:



Roughness:

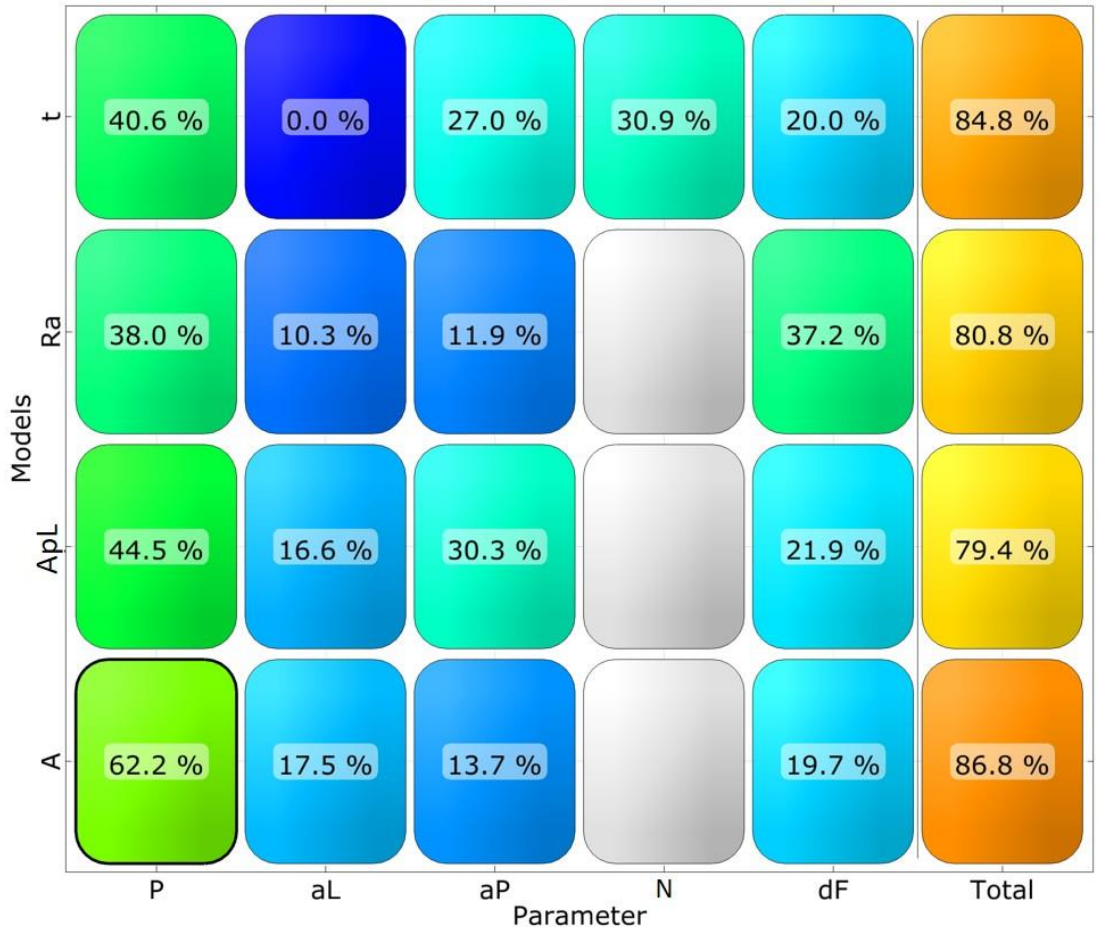


3. Sensitivity Analysis

CoP Matrix

Best achieved CoP-Matrix:

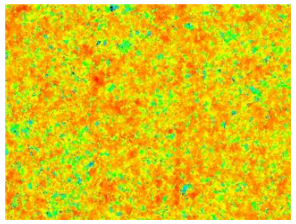
- Manual filtering to avoid input correlations
- Main parameters: P, a_L, $a_P + d_F \rightarrow F$, O_h, O_v
- λ has no significance
- Number of layers N only important for depth t → process continues homogeneously into depth



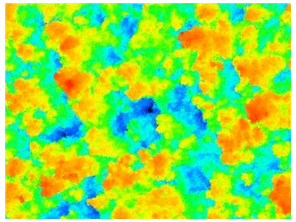
3. Sensitivity Analysis

- Roughness increases with fluence
- Optimal pulse distance depends on fluence
- With increasing fluence, minimum shifts to smaller values

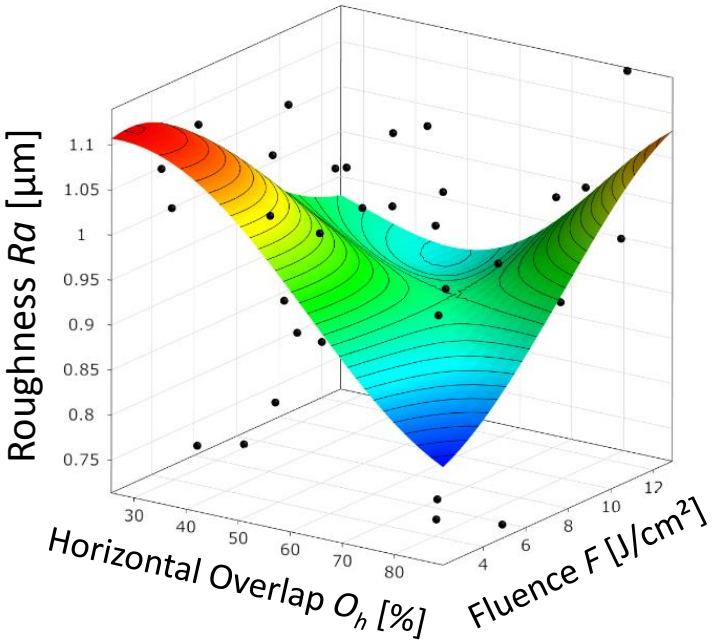
Al_2O_3:

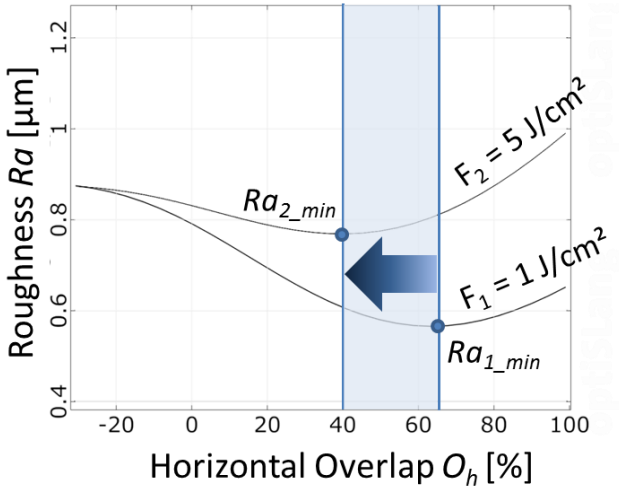


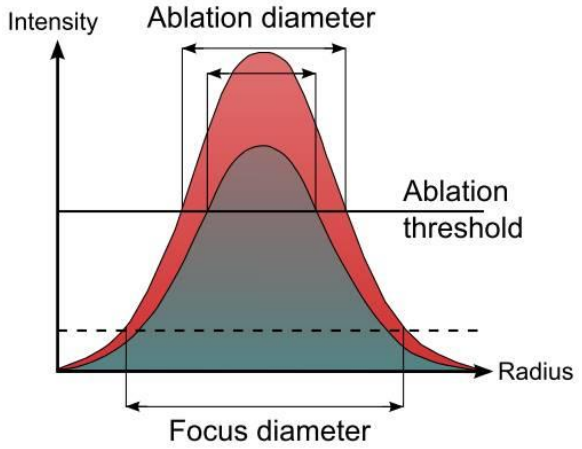
Ra_{min} = 0,42 µm



Ra_{max} = 3,8 µm





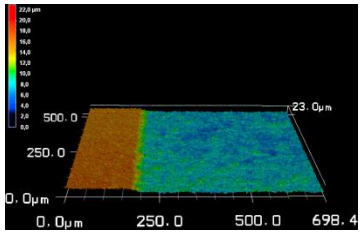


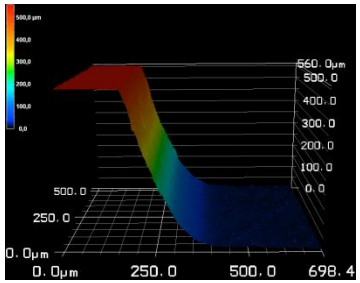
3. Sensitivity Analysis

Ablation rate

- Ablation rate increases with power
- Line distance and pulse distance interact
  → High values: high speed
  → Small values: high material removal

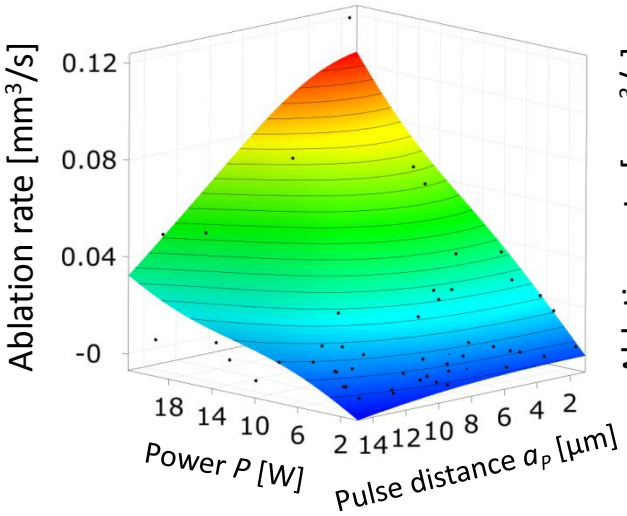
Al_2O_3:



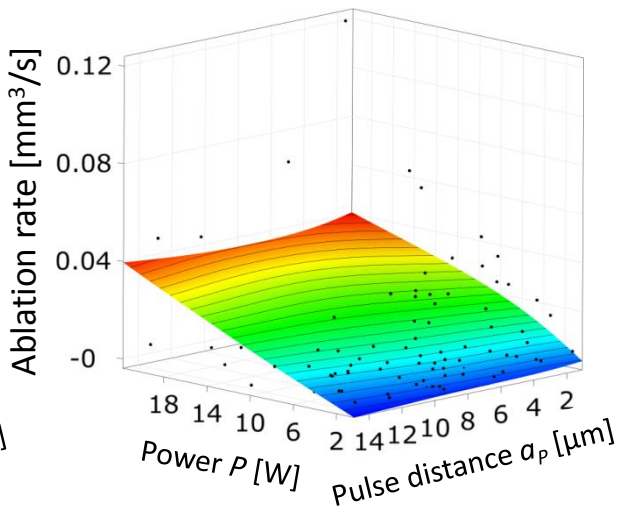


$r_{min} \approx 0$ mm³/min

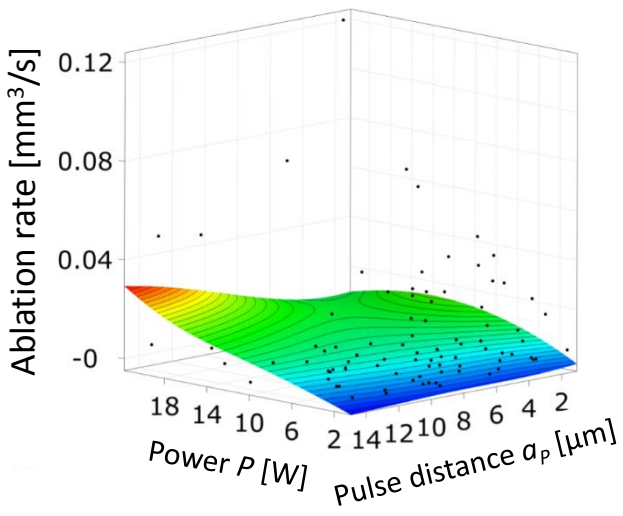
$r_{max} = 7.8$ mm³/min



$a_L = 15$ µm



$a_L = 4.4$ µm



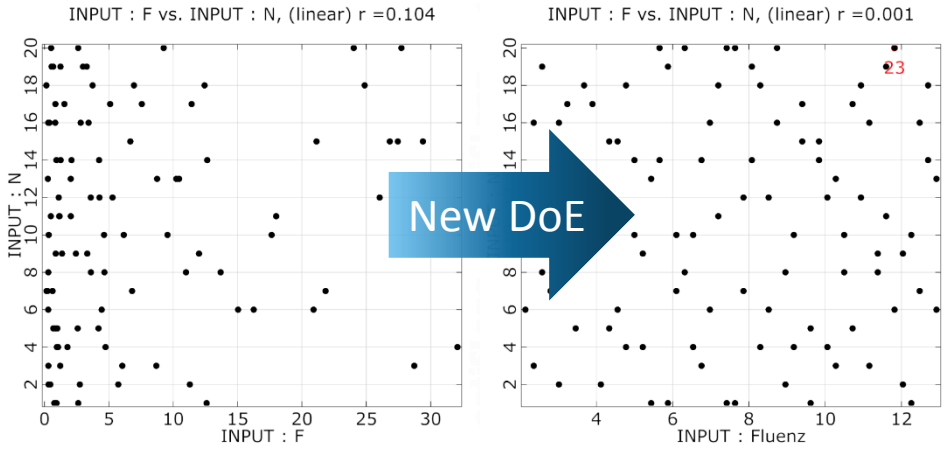
$a_L = 1$ µm

4. Current Activities

Improvement of DoE

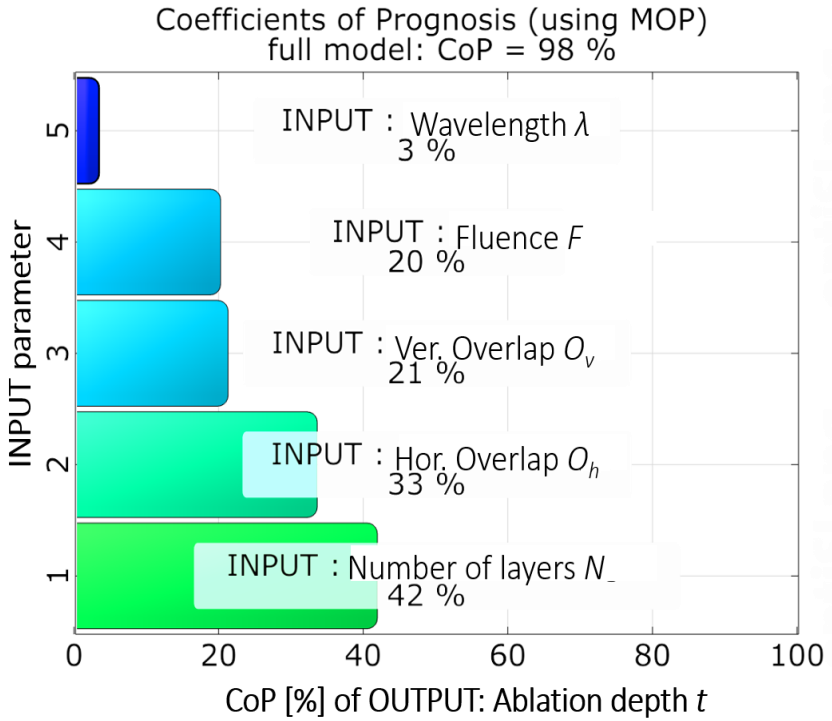
Problems with first attempt:

- Asymmetrical distribution of data points due to machine settings
- DoE based on actuating variables, but controlled parameters more significant



- New DoE based on controlled parameters

CoP (t) = 84.8 % → New DoE → CoP (t) = 98 %



4. Current Activities

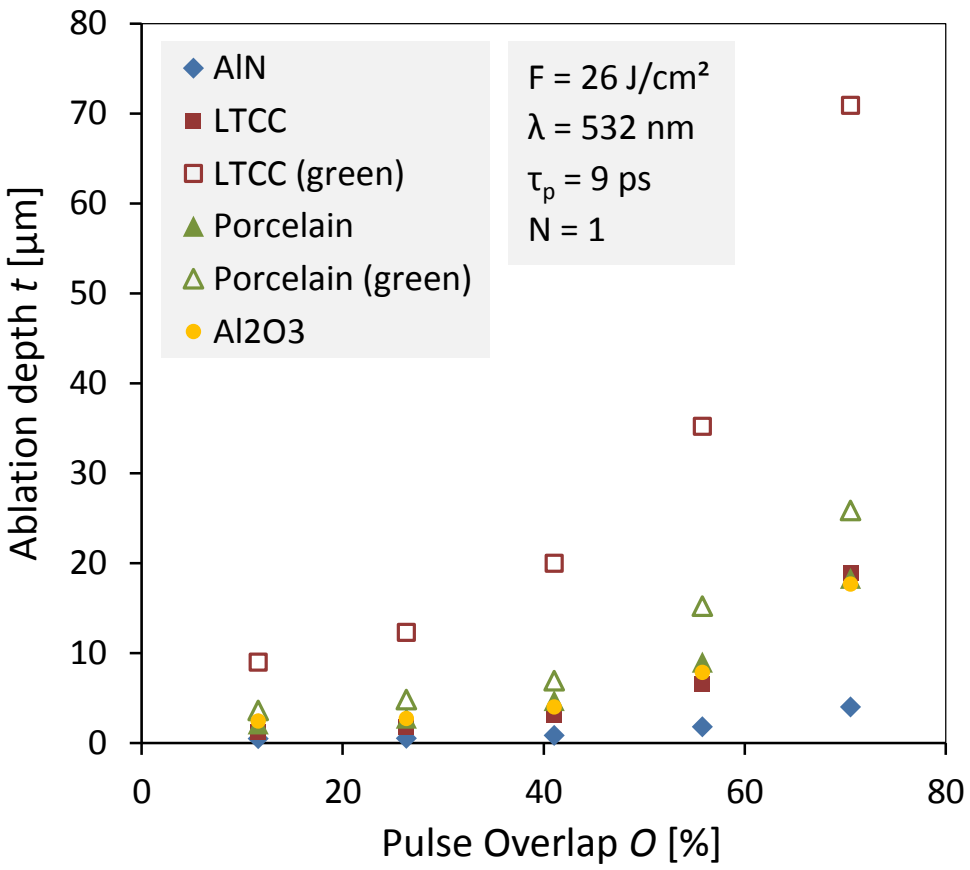
Examination of various ceramic materials:

- Principle behavior stays the same → ablation depth increases non-linearly with pulse overlap
- Exact values differ strongly

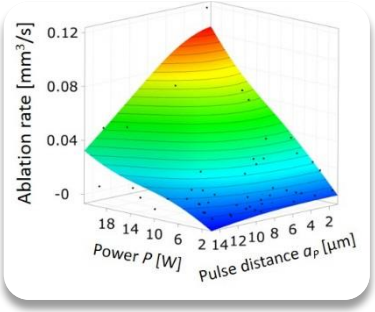
Al_2O_3 values calculated with Excel Add-In

MOP solver

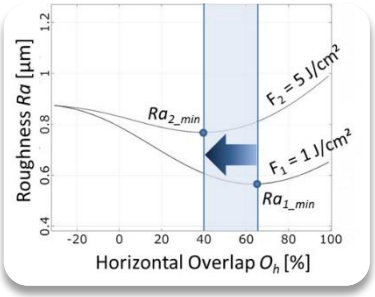
optiSLang MOP solver version 6.0.1									
Meta model database was imported from:									
D:\Ablage\0_Untersuchungen\0_Versuchsplan\0_Auswertung\OptiSlang_Auswertung\!Mittelwerte_OptiS									
Extrapolate	0								
	F	P	Uev	Ueh	aL	aP	AdUe	WL	dF	Full model
ApL		45.44%			17.12%	29.57%			22.27%	79.41%
A		62.25%			19.28%	13.20%			18.79%	86.85%
t		38.90%			0.00%	24.46%	29.04%		19.80%	84.82%
Ra		37.14%			9.14%	3.48%			33.87%	80.79%



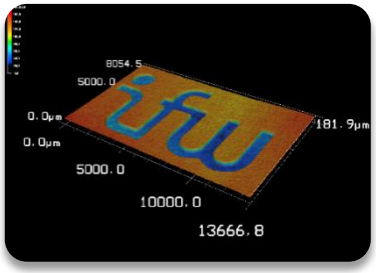
Summary



- optiSLang can be used to create physically meaningful metamodels based on experimental data
- Avoidance of input correlations necessary



- USP laser processing of ceramics can be optimized with regard to quality (surface roughness) and quantity (ablation rate)



OUTLOOK

- Extension of investigations to further materials
- Optimization of industrial applications:
  3D structuring + functionalization

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LLT APPLIKATION
Laser- und Lichtstrahl-Technologie

LUST HYBRID-TECHNIK

Reichenbach
PORZELLANMANUFAKTUR

VIA ELECTRONIC

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