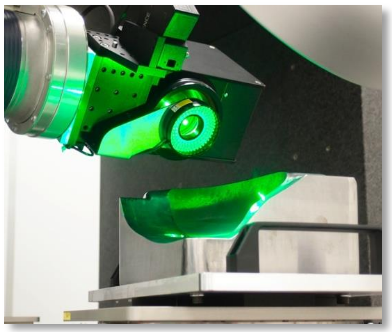

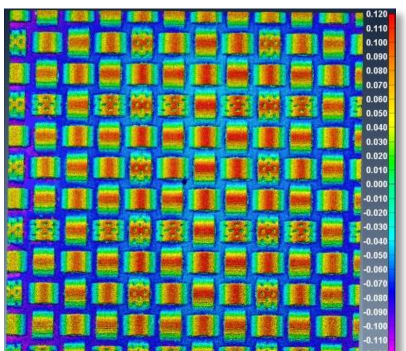

Sensor based adaptive laser micromachining using ultrashort pulse lasers for zero-failure manufacturing

Fraunhofer Institute for Production Technology, Aachen

M. Sc. Guilherme Mallmann

Prof. Dr.-Ing. Robert Schmitt

04.11.2015, Burgdorf, Switzerland

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Outline

1 **Process monitoring in laser material processing - brief overview**

Process monitoring, challenge

2 **High-precision optical inline measurement technology for distance measurement**

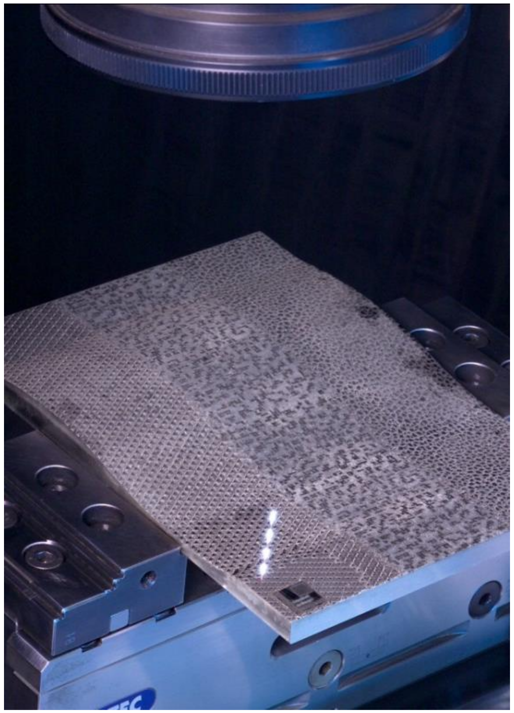
Solution concept, measuring principle, applications

3 **Laser process monitoring with Inline distance measurement technology**

Machine integration, automatic parameterization and control processes

4 **Outlook / Summary**

Process monitoring in laser material processing
Brief overview



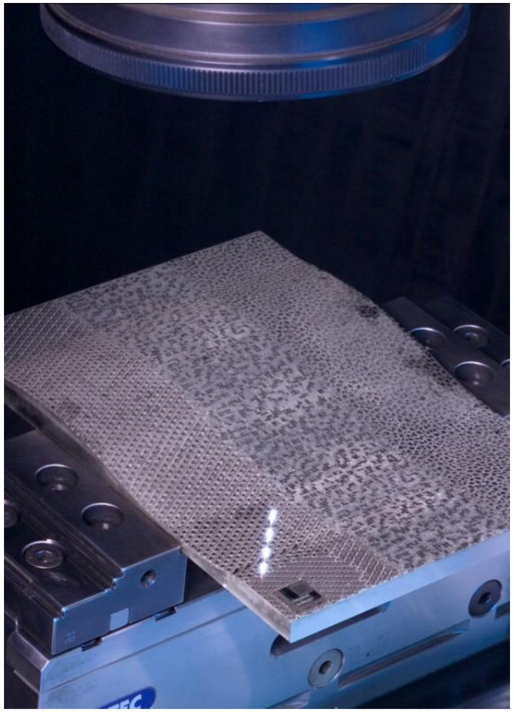
- Laser processes are dependent on machine, workpiece and environmental related parameters
- … which influence the process stability and product quality
- Particularly in the manufacturing of precision components is the process window, i.e. the range of allowable parameter variations, extremely tight.
- For this reason, process monitoring and its consequent control are essential in laser micro machining

State of the art on Process monitoring and control:

- Data acquisition
  - Acoustic and electromagnetic process emission (e.g. Pyrometer, Photodiode, 2D cameras)
  - *In situ* capacitive, confocal chromatic and triangulation sensors
- Monitoring or control variables
  - Direct monitoring of the focal position, removal depth or melting bath (diameter, temperature, etc.)
  - Shape of lasered component (e.g., weld seam's shape and position)

Quelle: Ion , J. C.: "Laser Processing of Engineering Materials"

Current challenges in laser material processing



- **Time-consuming determination of process parameters**
  - Machining results are dependent on material, laser, surface properties, optical beam path, environment-related factors
- **Characterization of the actual component shape and position**
  - Form deviations resulting from previous process steps can lead to process failures (e.g. removal deviations)
  - Deviation of the component position due to clamping variations can lead to process failures (e.g. removal deviations)
- **Process control**
  - No feedback of current laser machined depth
  - Strong material and process dependency of methods for process monitoring and control (High calibration and modeling effort)
  - Monitoring and control of laser processes with new materials (e.g. composites, plastics) are very limited
- **Quality control**
  - Workpiece inspection after the processing
  - Increased risk of rejects at the end of the value chain
  - Insufficient vertical or lateral accuracy of current measurement techniques

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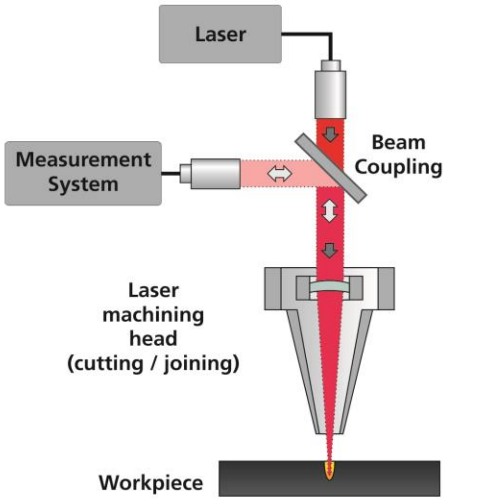
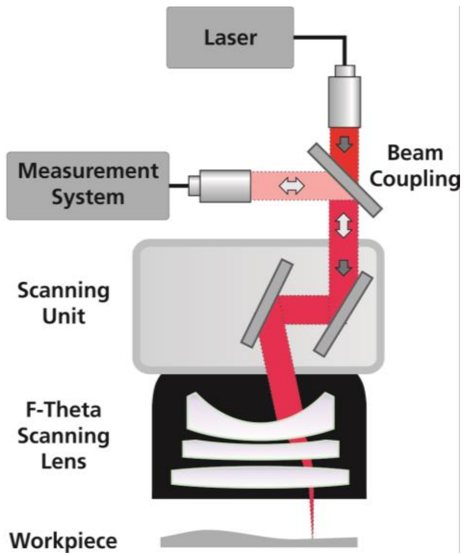
Laser process monitoring using inline distance measurement

High precision optical inline distance measurement





Objective

- Monitoring and optimization of laser structuring processes
- Integration of an in-process measurement technique for performing a feedback control of laser structuring processes

Principle

- Modular measurement technology based on low coherence interferometry
- Measurement system integrated in the machine's laser beam optical path
- Feedback of the measured data to the process control

Results

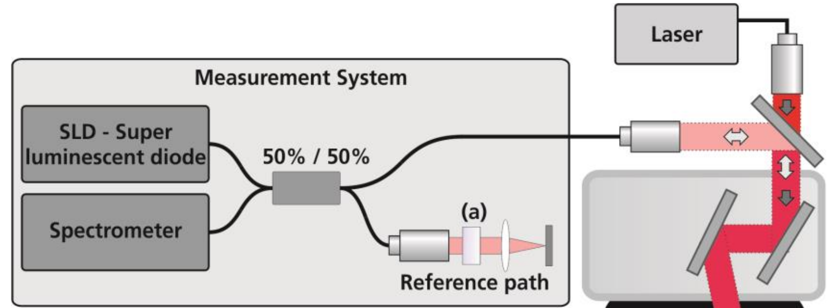
- Automatic optimization of process parameters
- Improvement of process quality
- Enhancement of process automation

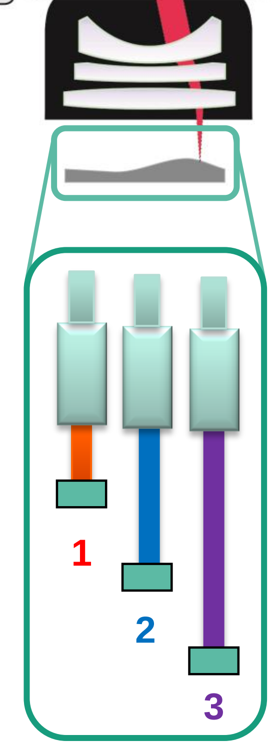
Laser process monitoring using inline distance measurement

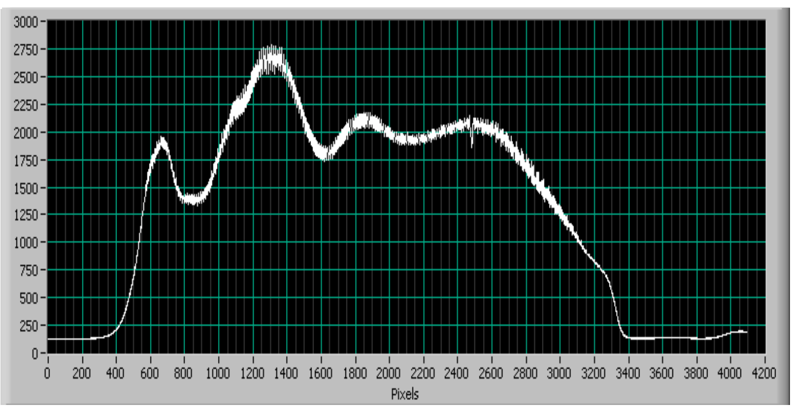
Measurement principle (reflective surface)

Approach with reflective materials

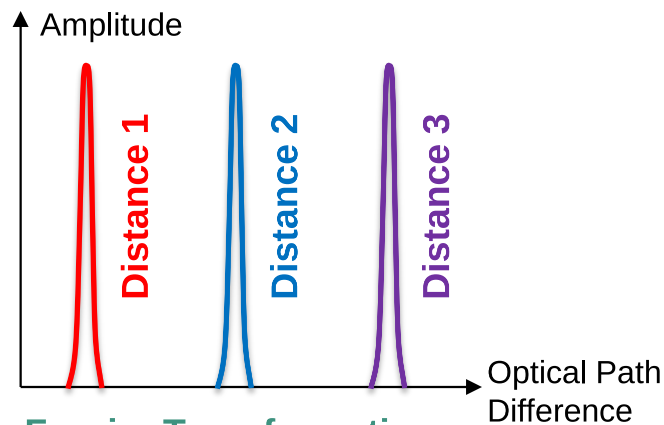
- Measuring principle: low coherence interferometry
- Vertical height information is obtained in the spectrum of the interferogram generated
- Fourier transform of this spectrum provides distance-dependent peak
- Measurement systems able to be implemented with different wavelengths (from 450 to 2300 nm) and therefore of being integrated in different laser system configurations







Intensity distribution of the spectrometer



Fourier Transformation

Source: Brezinski, M., [Optical coherence tomography – Principles and Applications]

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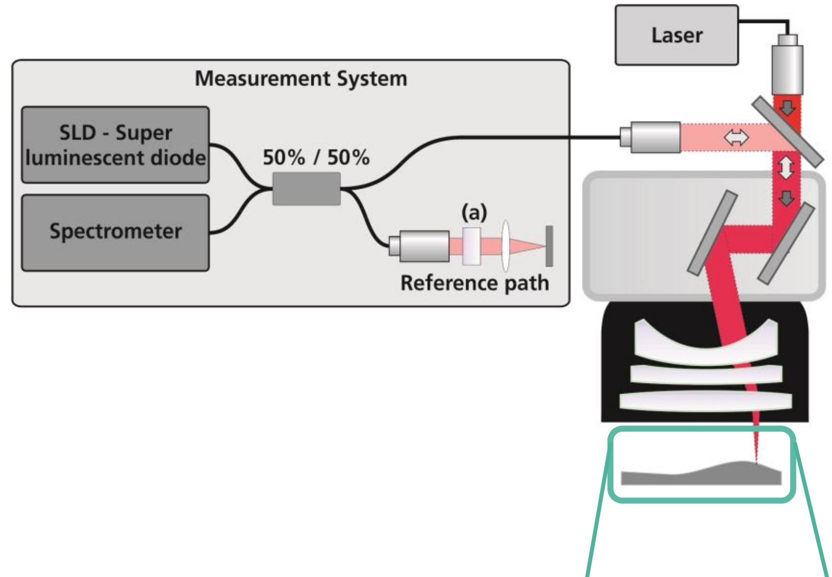
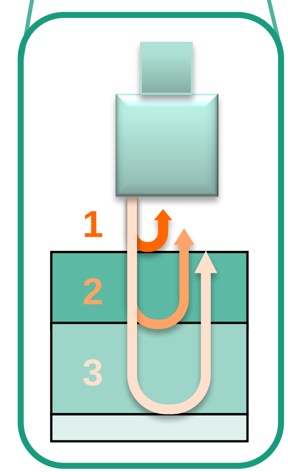
Laser process monitoring using inline distance measurement

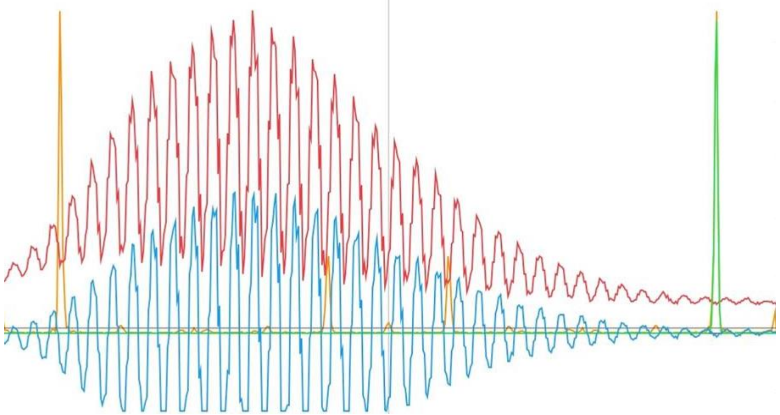
Measurement principle (part transparent materials)

Approach part transparent materials

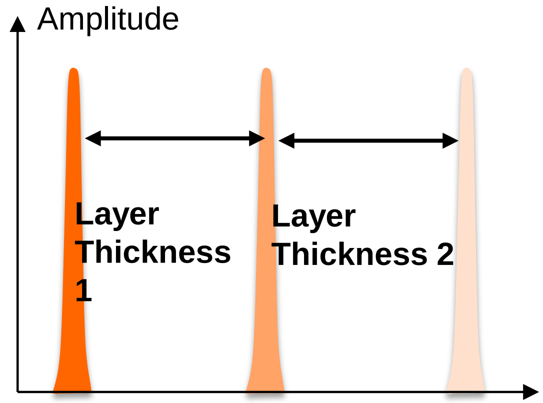
- Measuring principle: low coherence interferometry (Optical coherence tomography)
- Vertical height information is obtained in the spectrum of the interferogram generated
- Fourier transform of this spectrum provides distance-dependent peak
- Measurement systems able to be implemented with different wavelengths (from 450 to 2300 nm) and therefore of being integrated in different laser system configurations







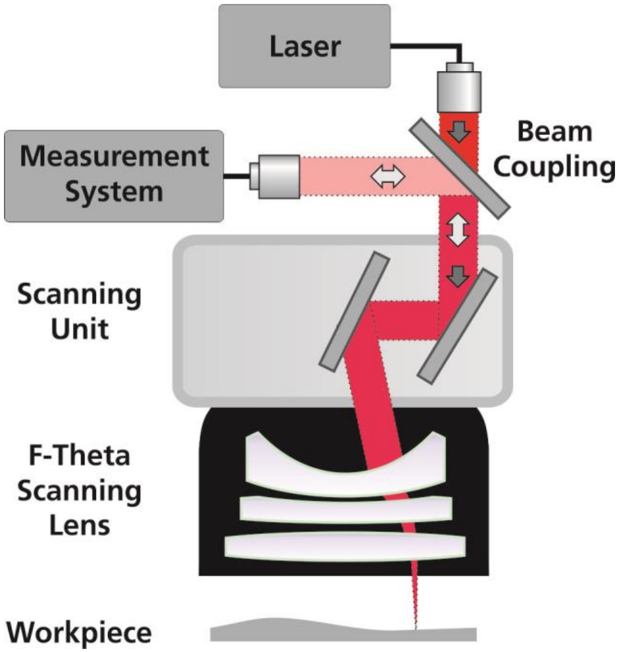
Intensity distribution of the spectrometer



Fourier Transformation

Source: Brezinski, M., [Optical coherence tomography – Principles and Applications]

Laser process monitoring using inline distance measurement
Technical possibilities



Before machining

- Characterization of the workpiece's position and topography for machine aligning as well as adjustment of the machining strategy / CNC code
- Automatic process initialization (laser parameter setting)

During the machining

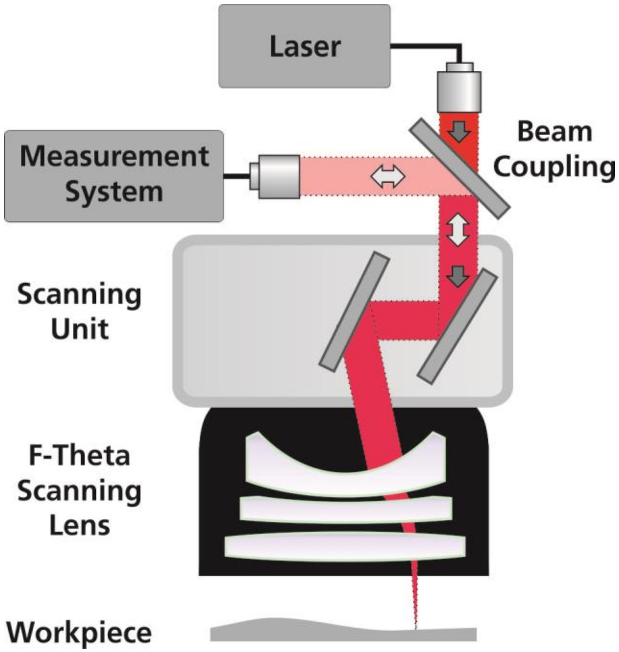
- Inline measurement of ablation depth
- Detection of process deviations and control
- Inline monitoring the focus position
- Early identification and correction of manufacturing defects

After the machining

- Quality assurance directly in the machine (using machine coordinates)

Laser process monitoring using inline distance measurement

Application possibilities



Material independence

- Inline measurement system / process monitoring can be used with:
  - Metals
  - Glass
  - Plastics
  - Fiber-reinforced composites (CFRP, GFRP)
  - Multilayer systems (OLEDs, solar cells)
  - Ceramics

Integrability

- Evaluation system adjustable on the machine configuration (laser wavelength scanning optics, solid optics) and thus flexibly integrated and applicable
- Integrable with continuous wave (CW), short-pulse / ultra-short pulsed laser systems

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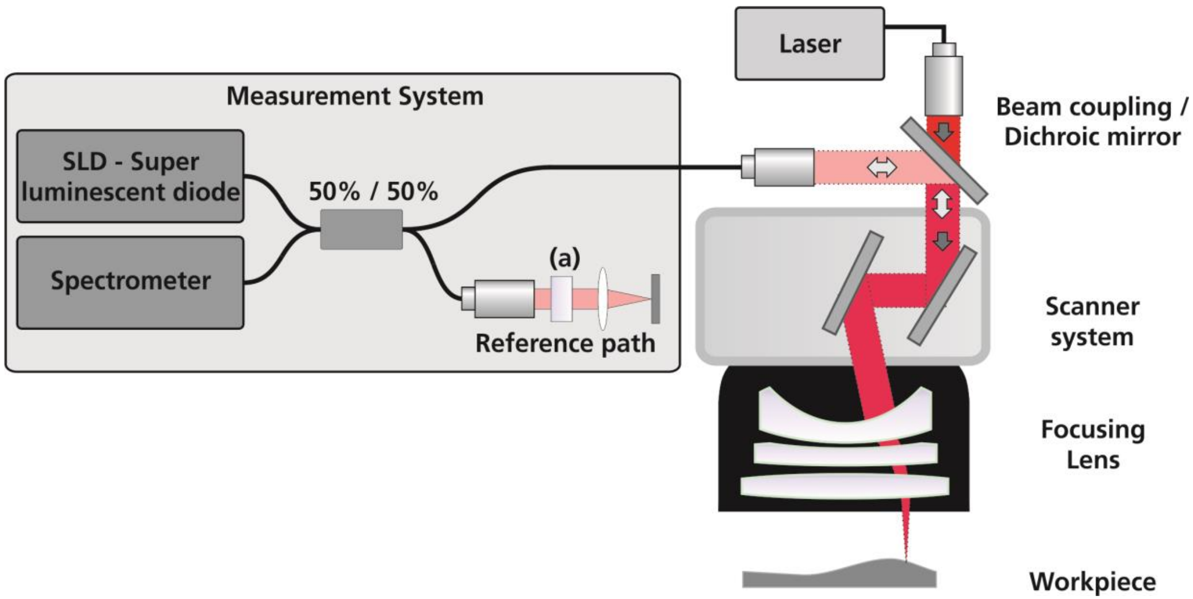
4 Outlook / Summary

Laser process monitoring using inline distance measurement
High precision inline metrology for the Laser micro processing



Before machining

- Acquisition of the workpiece topography for machine alignment
- Automatic process initialization (laser parameter setting)

During machining

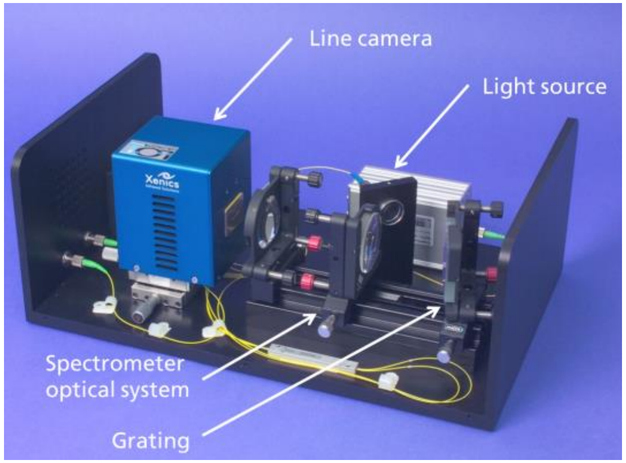
- Inline measurement of removal depth
- Detection of process deviations and control
- In-line monitoring of the focal position
- Early identification and correction of manufacturing defects

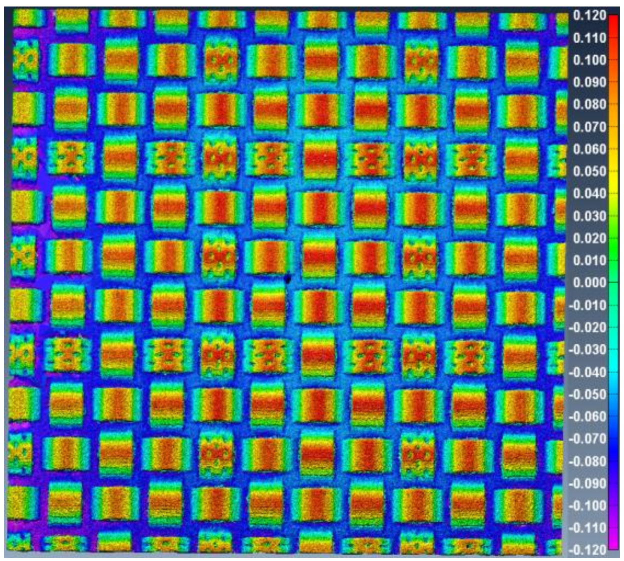
After machining

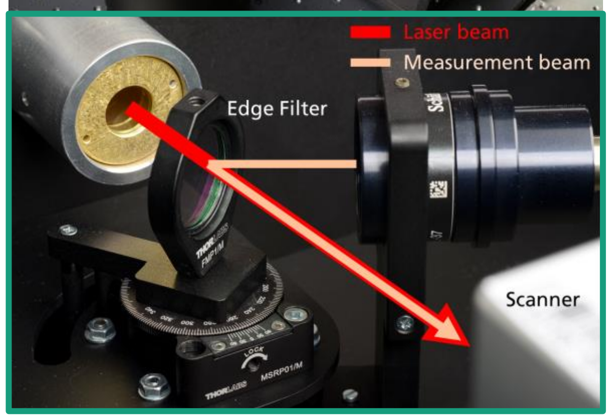
- Quality assurance directly in the machine

High precision inline metrology for the Laser micro processing

First generation system – IR Laser applications







Measurement system

- Measurement wavelength range: 1017 nm ± 50 nm
- Measurement range: 1,3 mm
- Measuring system repeatability: 200 nm (Standard deviation)
- Measuring frequency: max. 2kHz

Prototype – Laser micro machining

- Nano second pulsed fiber laser (central wavelength: 1064 nm)
- Scanning System (analog based)
- Telecentric F-theta objective with focal distance of 80 mm
- Measurement area: 30 mm x 30 mm
- Beam coupling: Edge Filter

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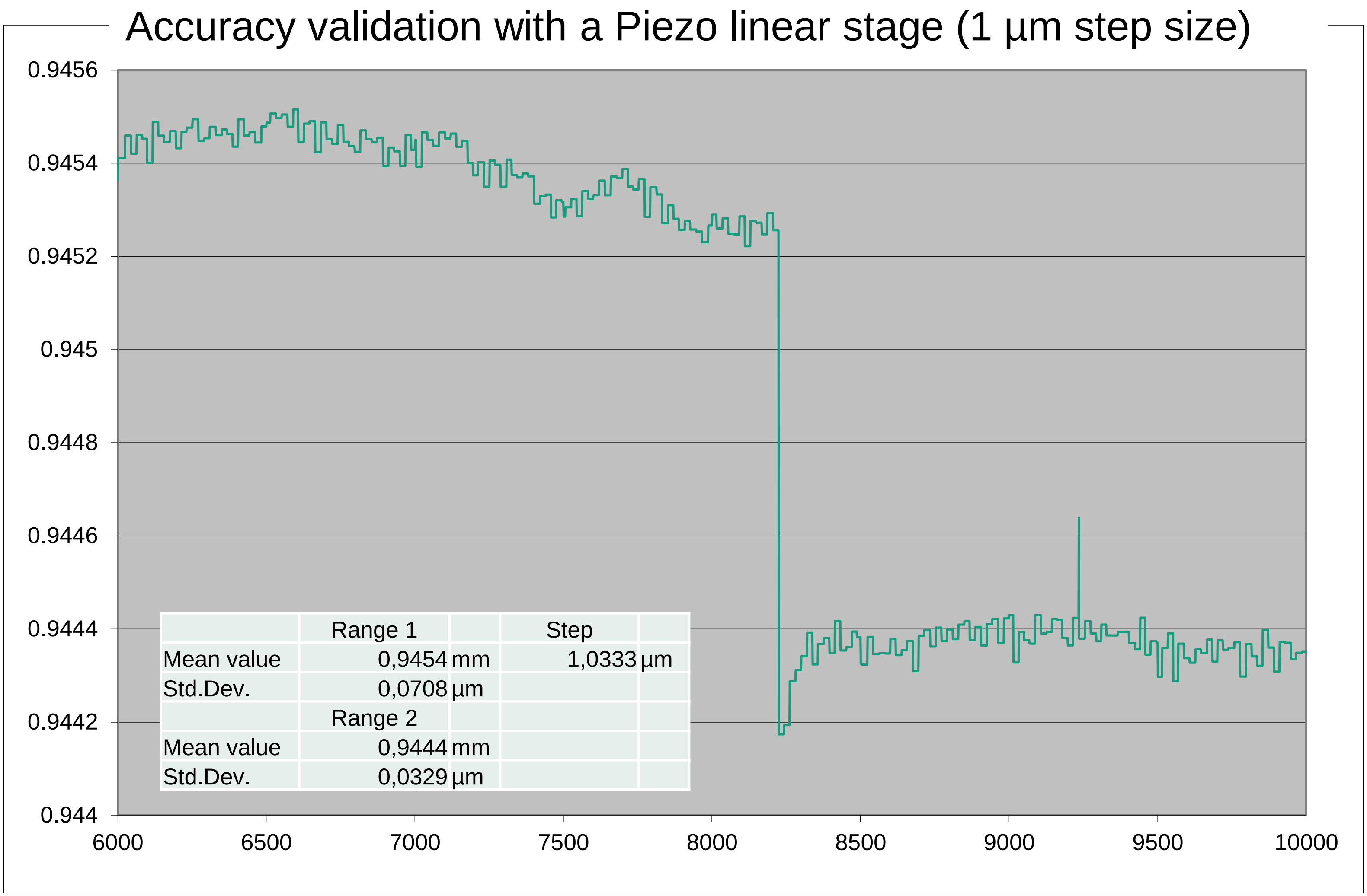
System characterization
Z Accuracy

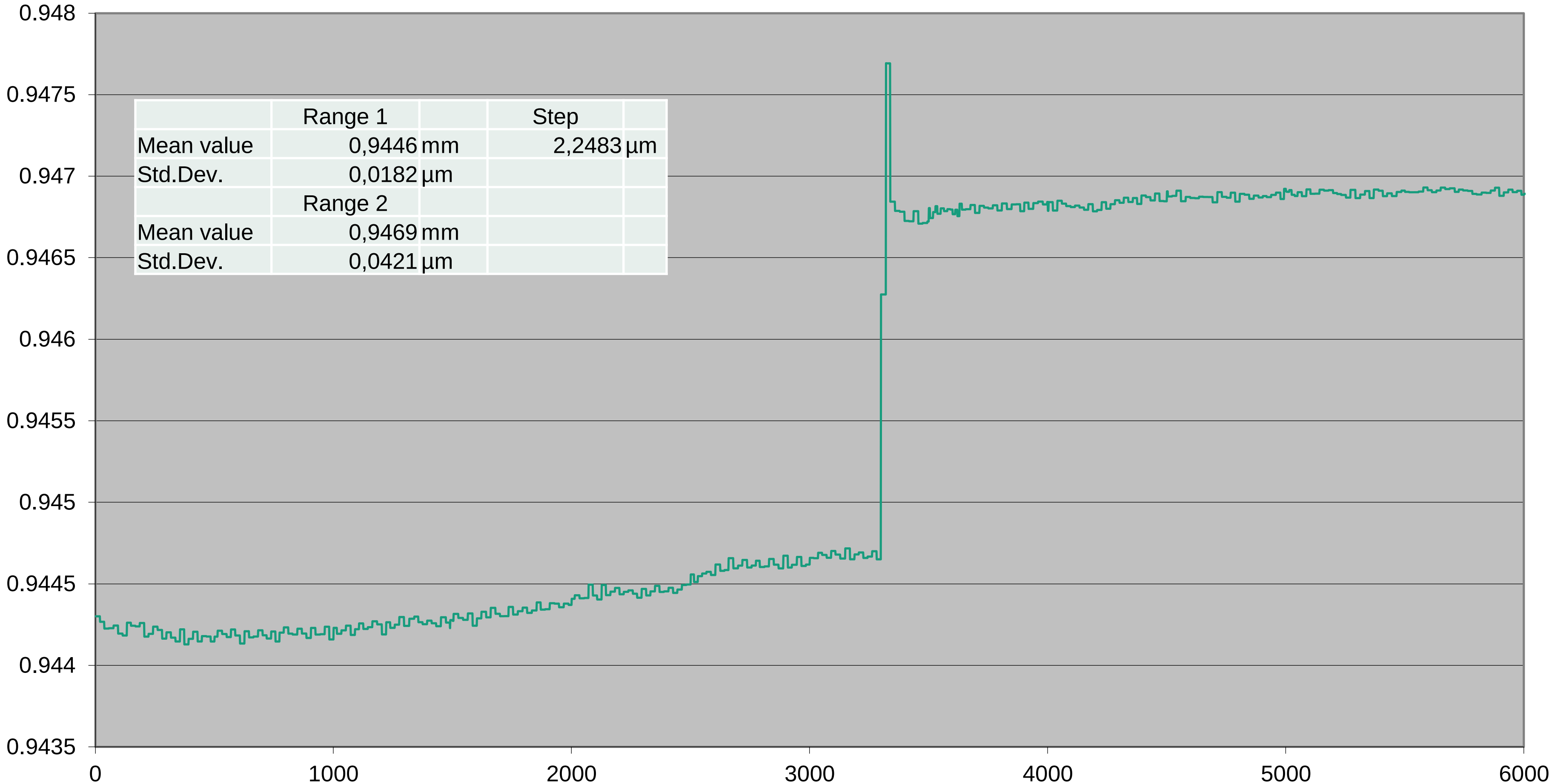


	Range 1		Step	
Mean value	0,9454	mm	1,0333	µm
Std.Dev.	0,0708	µm		
	Range 2			
Mean value	0,9444	mm		
Std.Dev.	0,0329	µm		

System characterization

Z Accuracy

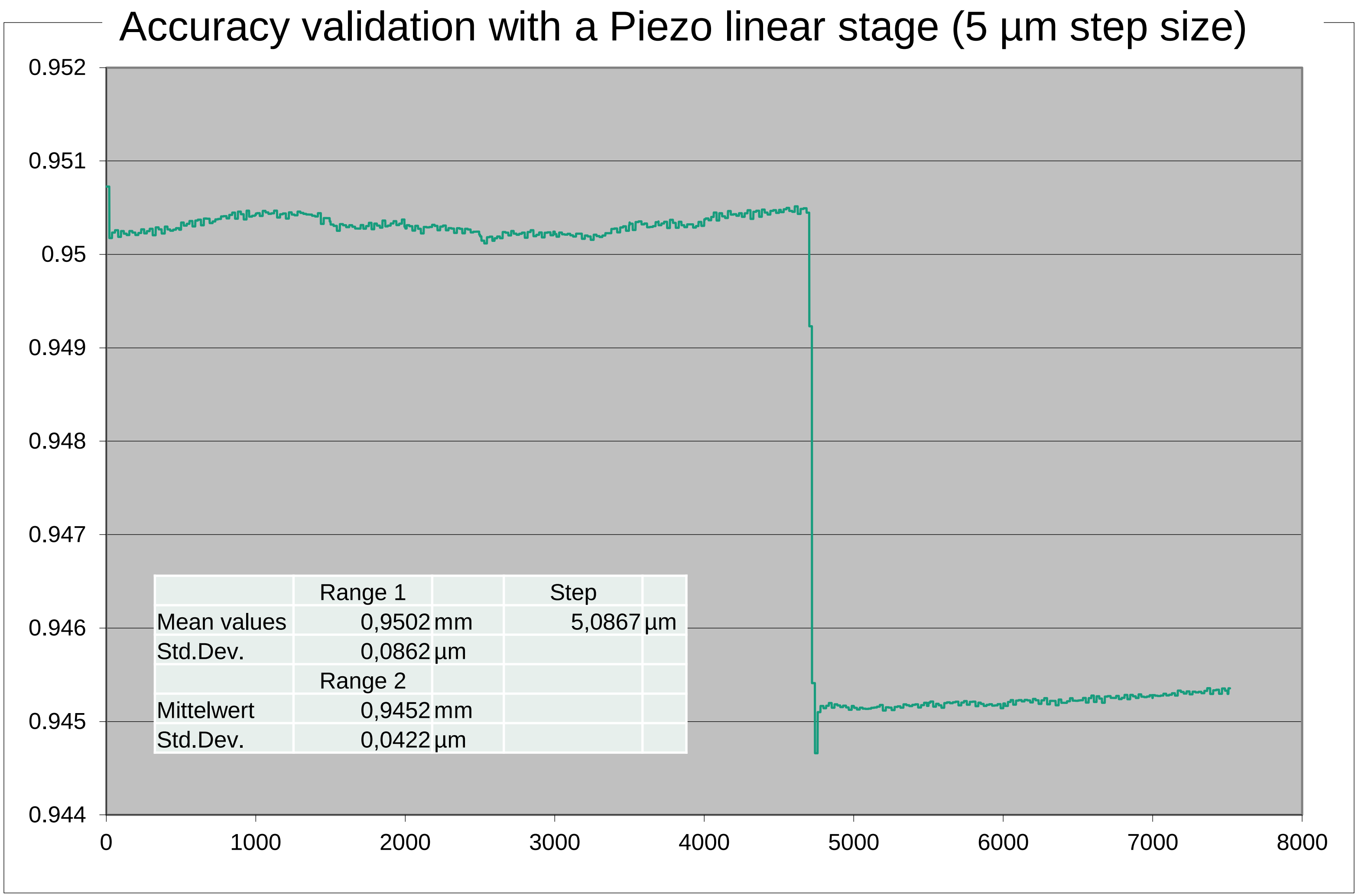
Accuracy validation with a Piezo linear stage (2 µm step size)



	Range 1		Step	
Mean value	0,9446	mm	2,2483	µm
Std.Dev.	0,0182	µm		
	Range 2			
Mean value	0,9469	mm		
Std.Dev.	0,0421	µm		

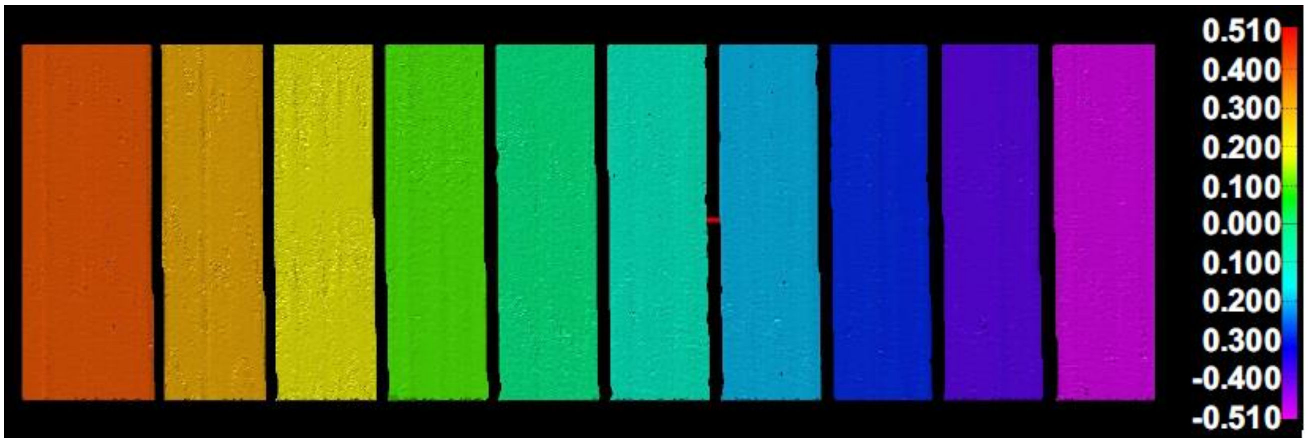
System characterization

Z Accuracy



	Range 1		Step	
Mean values	0,9502	mm	5,0867	µm
Std.Dev.	0,0862	µm		
	Range 2			
Mittelwert	0,9452	mm		
Std.Dev.	0,0422	µm		

Measurement range and Linearity

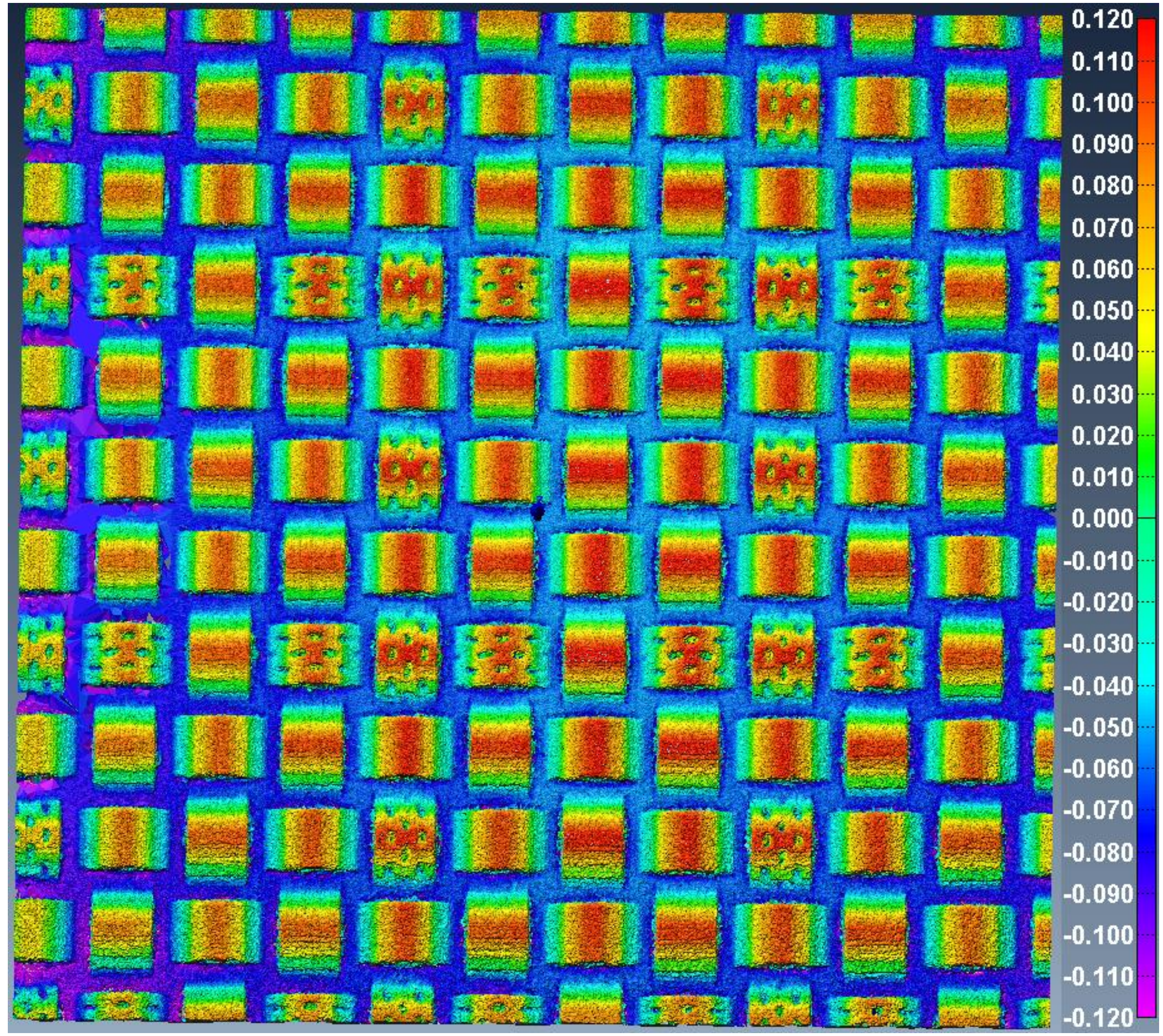


- Step standard for the evaluation of the measurement range
  - Measurement values in millimeters
  - Scanning area of 6.5 mm x 2 mm
- The deviation between the developed and a reference measurement system is of a maximum of 9.053 µm, which represents 0.79% of the measurement range

High precision inline metrology for the Laser micro processing

Measurement of laser structured surfaces

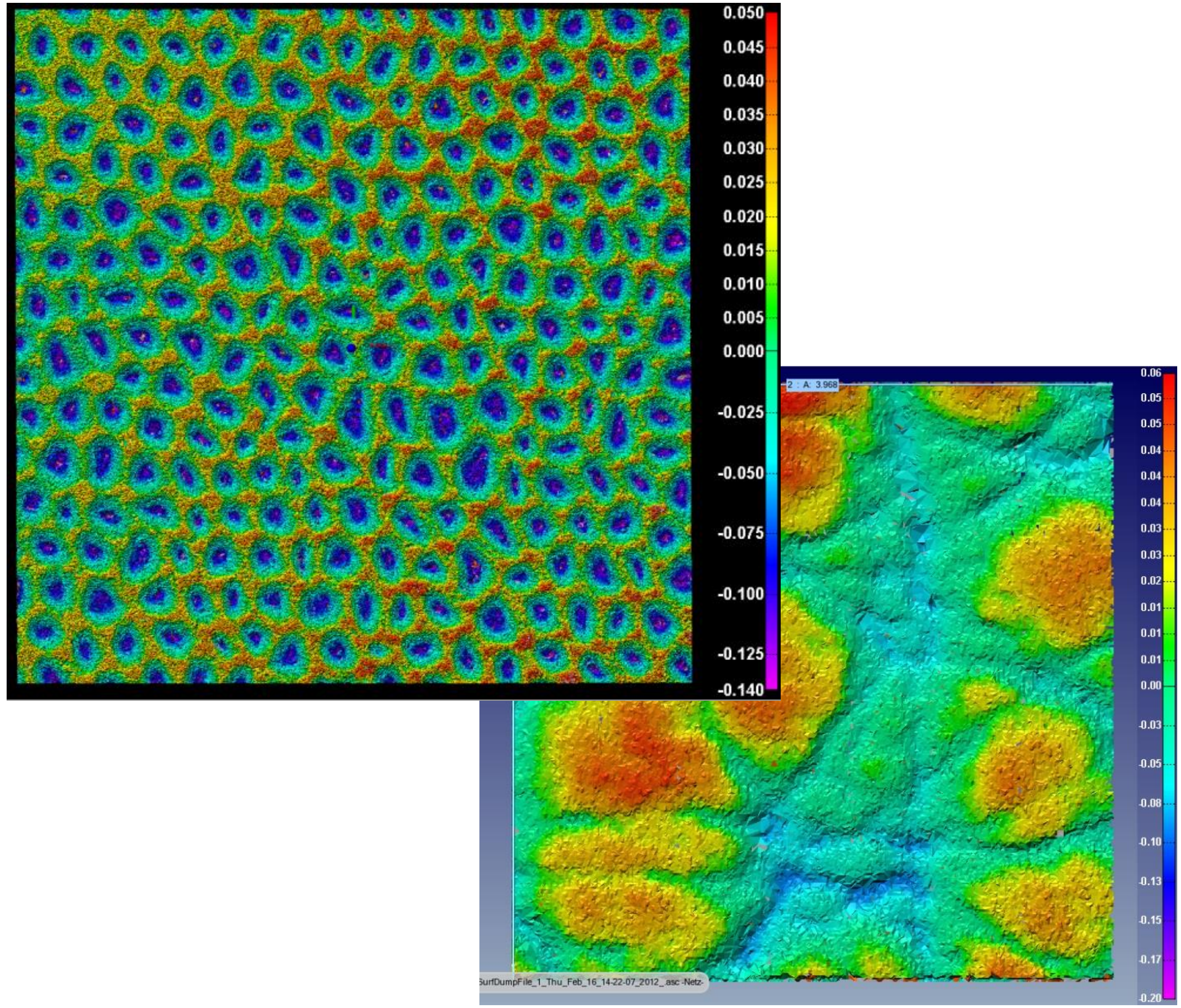
Measurement of
laser structured surface:
textile structure



High precision inline metrology for the Laser micro processing

Measurement of laser structured surfaces

Measurement of
laser structured surface:
leather structure



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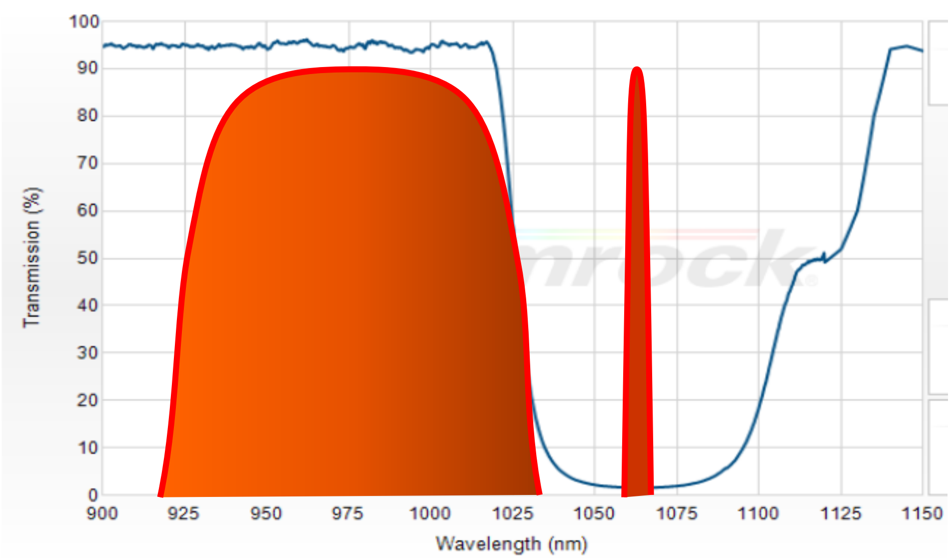
High precision inline metrology for the Laser micro processing

Second generation system – IR Laser applications

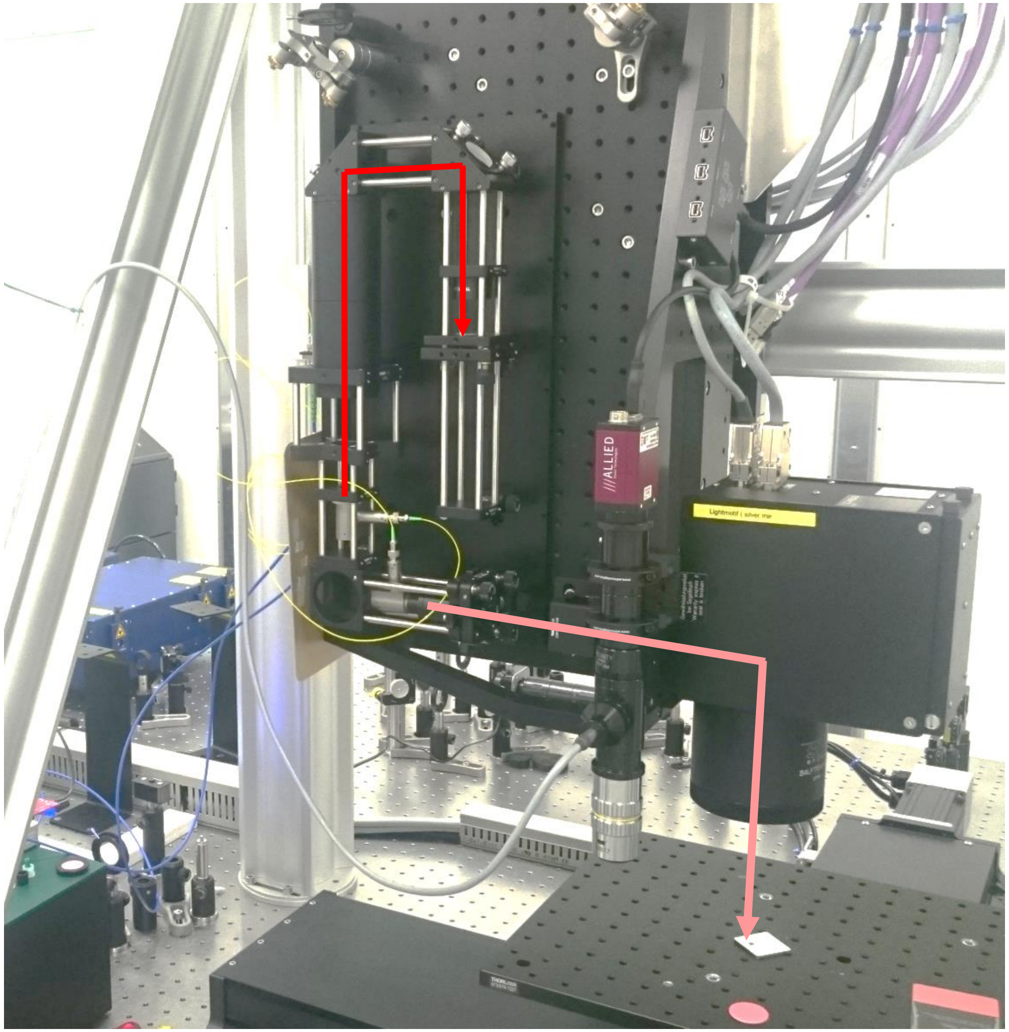


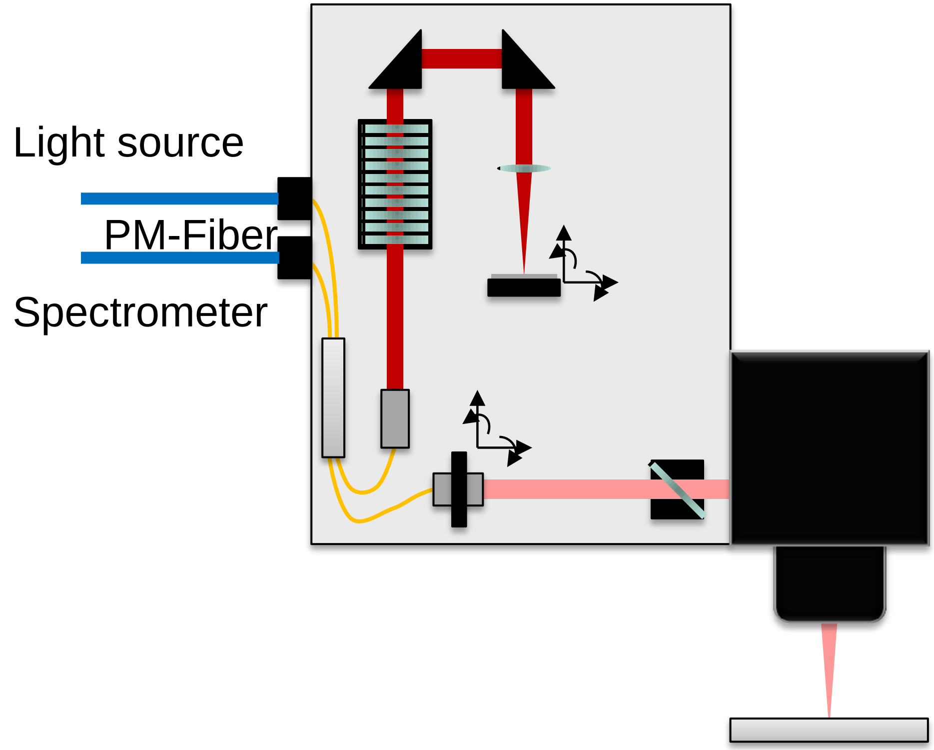
Measurement system

- Measurement wavelength range:
  980 nm ± 50 nm
- Measurement range:
  4,9 mm
- Measuring system repeatability:
  200 nm
  (Standard deviation)
- Measuring frequency:
  max. 10kHz
- Optimized telecentric F-theta for perfect laser and measurement beam coaxiality as well as spot and focal match

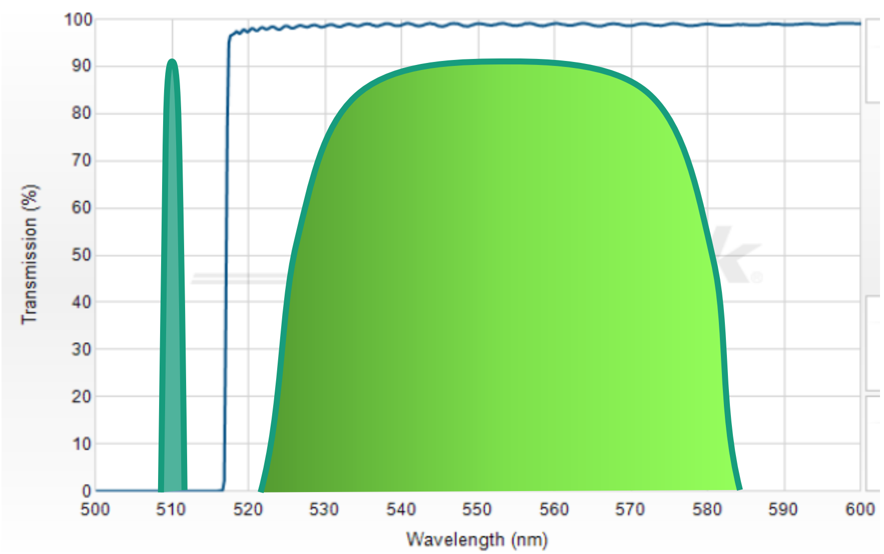
High precision inline metrology for the Laser micro processing

Second generation system – IR Laser applications – First integration





First generation system – Green laser applications (Work in Progress)



A·D·A·L·A·M·

Measurement system

- Measurement wavelength range:
  557nm ± 31 nm
- Measurement range:
  2,5 mm
- Measuring system repeatability:
  200 nm
  (Standard deviation)
- Measuring frequency:
  max. 10kHz
- Optimized telecentric F-theta for perfect laser and measurement beam coaxiality as well as spot and focal match

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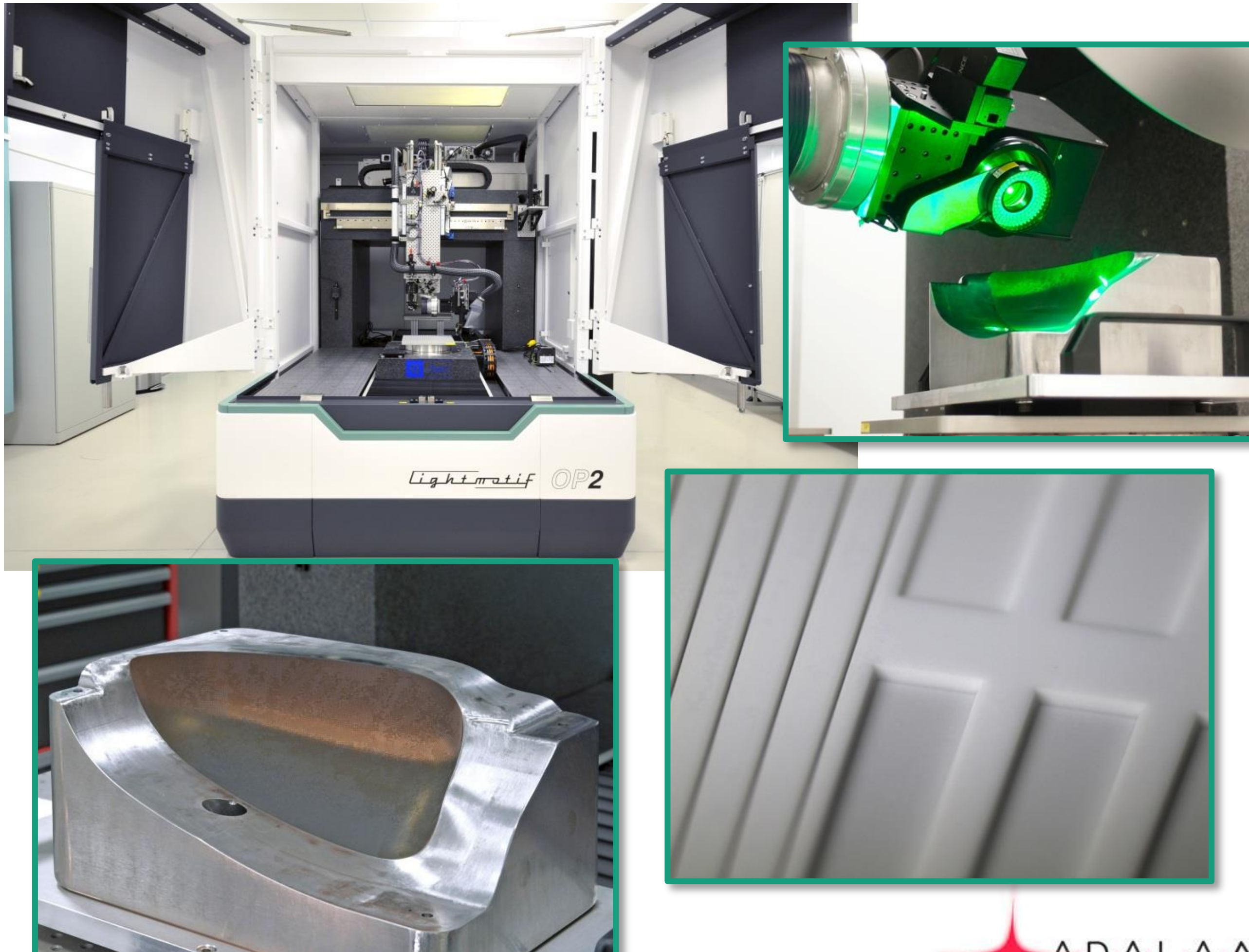
High precision inline metrology for the Laser micro processing
Test and validation



- Lightmotif OP2
  - 5-axis laser micromachining system
  - Picosecond pulsed laser
  - High accuracy galvo-scanner (digital based)
  - Air bearing direct-drive stages, sub micrometer repeatability
  - 600 x 600 mm
  - 300 kg load

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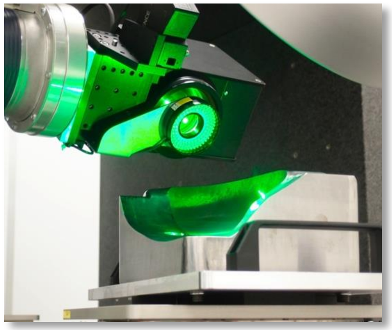
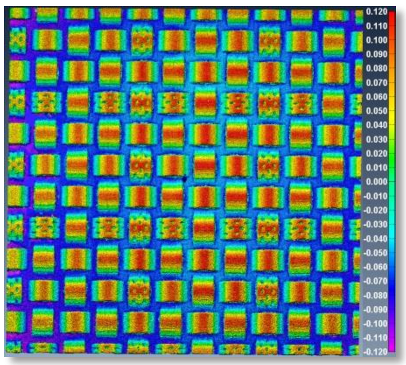
Summary





- Current challenges in laser material processing involving process monitoring
  - Time-consuming determination of process parameters
  - Characterization of the actual component shape and position
  - Process control based on feedback of the current laser machined depth
  - Strong material and process dependency of methods for process monitoring and control (High calibration and modeling effort)
  - Inline quality control

- High-precision optical inline measurement technology for distance measurement
  - Measuring principle: low coherence interferometry
  - Vertical height information is obtained directly in axis
  - Measurement systems able to be implemented with different wavelengths (from 450 to 2300 nm) and therefore of being integrated in different laser system configurations

- Laser process monitoring with Inline distance measurement technology
  - Measurement system for IR-Range
    - Measurement wavelength range: 980 nm ± 50 nm
    - Measurement range: 4,9 mm
  - Measurement system for Green-Range
    - Measurement wavelength range: 557nm ± 31 nm
    - Measurement range: 2,5 mm
  - Measuring system repeatability: 200 nm (Standard deviation)
  - Measuring frequency: max. 10kHz