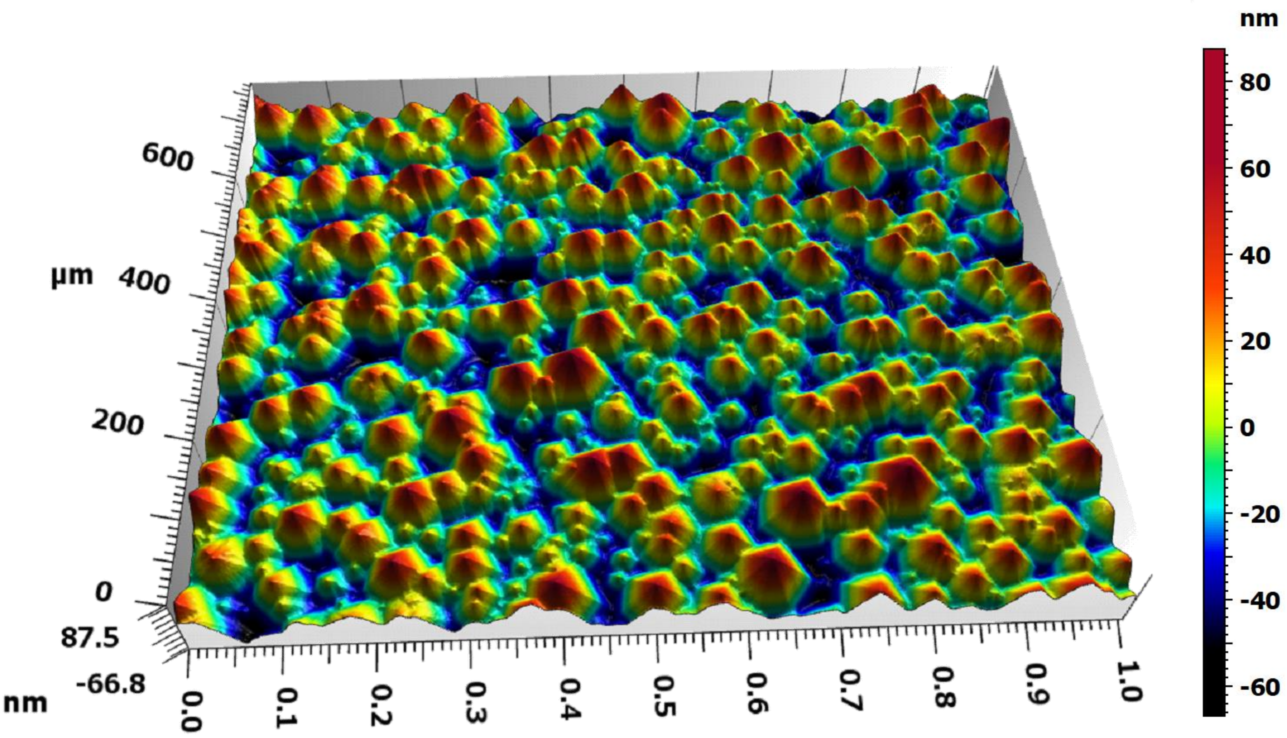
optical measurement of functional surfaces



with super resolution

smart WLI

short introduction of the GBS

founded 1997 as a subsidiary of the ZBS
with roots in universitary research

quality assurance systems
based on massively parallel image processing

2008 installation of the first smartWLI
(high performance white-light interferometer)

focus on the smartWLI measuring devices Germany, USA, Japan, France, China, Korea, Taiwan, Sweden, UK, Switzerland, Israel, Austria, Spain, Norway, Italy...

head quarter

company extension in 2019

GBS – continous product development


2008


2009

2010

2011


2012

2013

2014

2015


2016

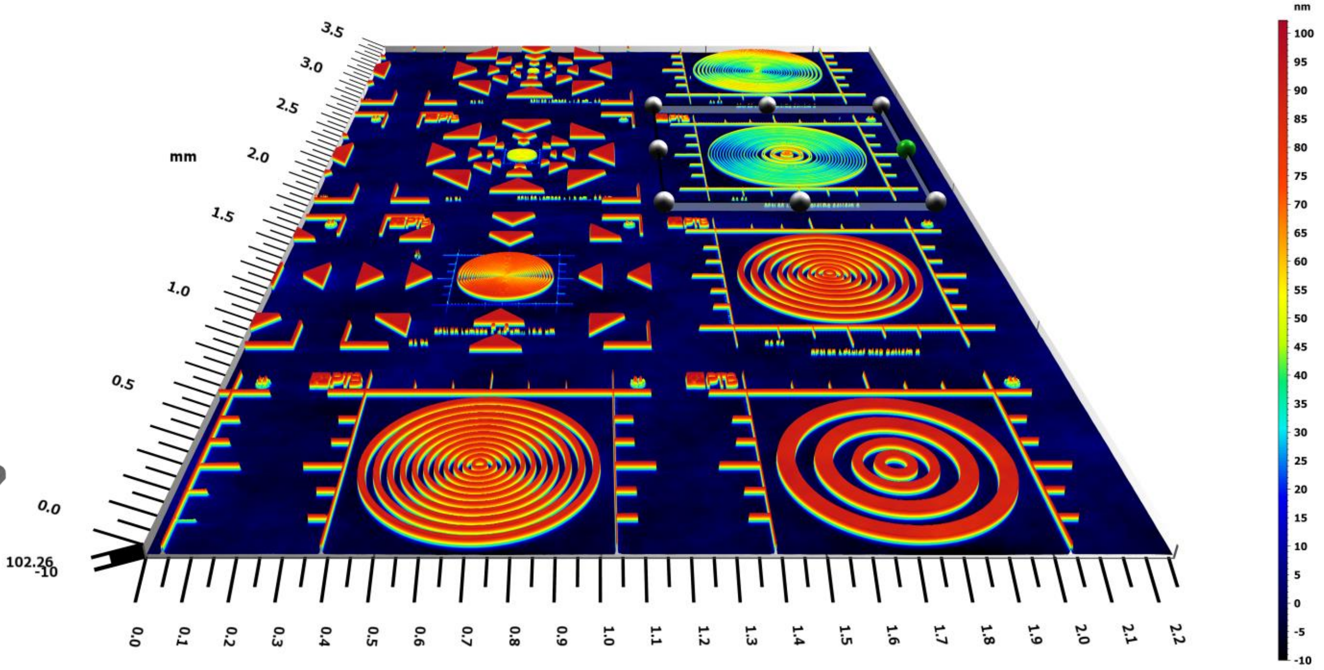
2017

2018

2019

smartWLI next – now available since June 2020!

universal lab measuring system
with up to 4 objectives and motorized turret



massively parallel data processing

high resolution camera

more than10 TFLOPS with 3.000 cores

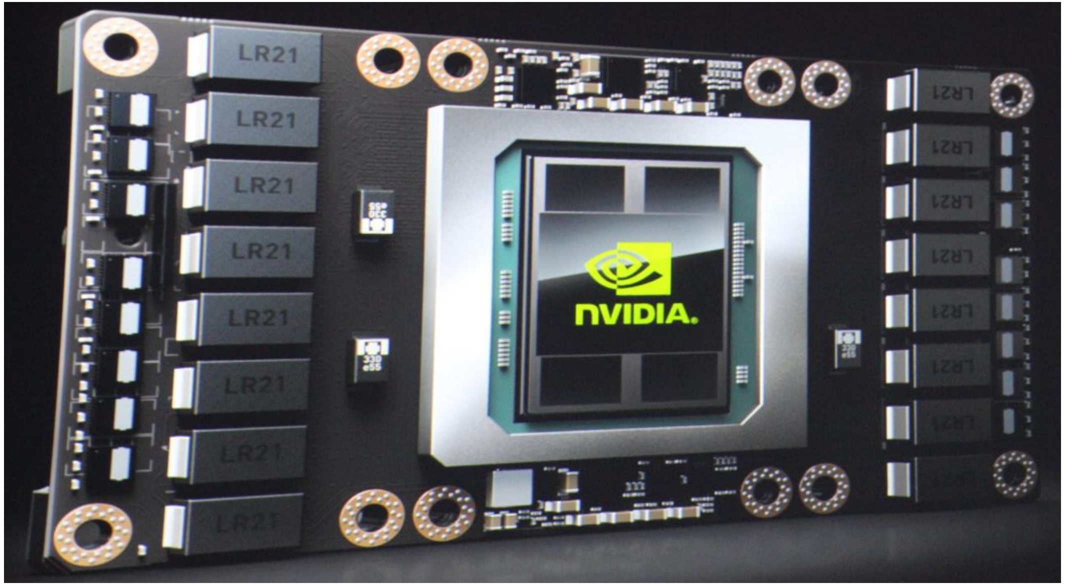
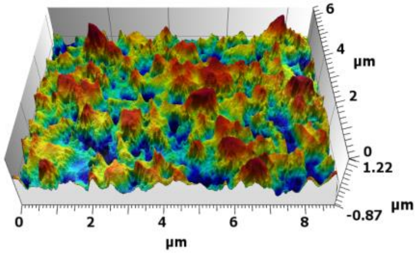


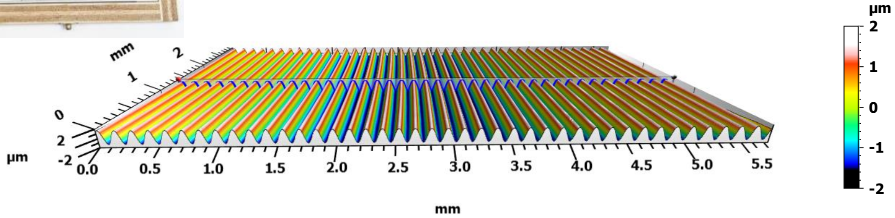
image correction, contrast enhancement
3D calculation in real time!

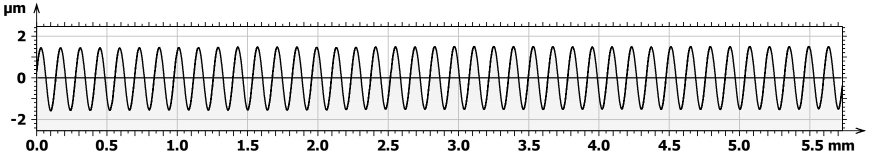


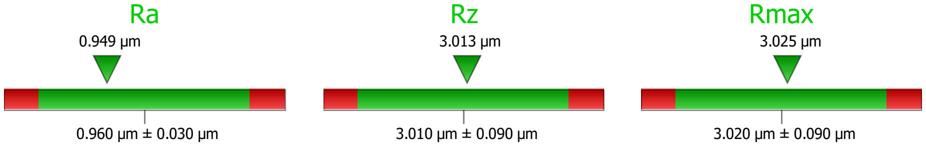
high resolution 3d data

tracible surface roughness standards

Mahr MSS-3
certified surface and step standard





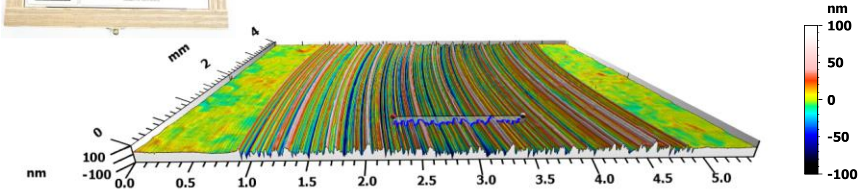


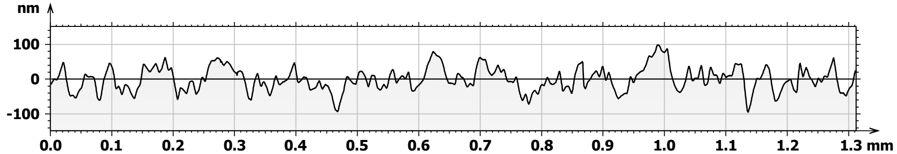
Ra
0.949 µm
0.960 µm ± 0.030 µm

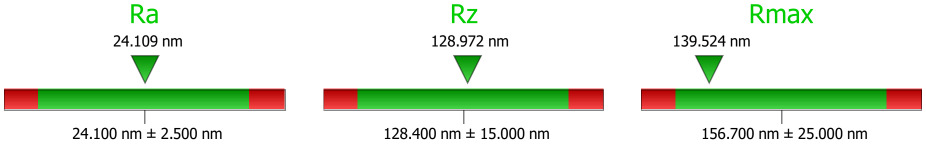
Rz
3.013 µm
3.010 µm ± 0.090 µm

Rmax
3.025 µm
3.020 µm ± 0.090 µm

Halle – super fine
certified surface roughness standard







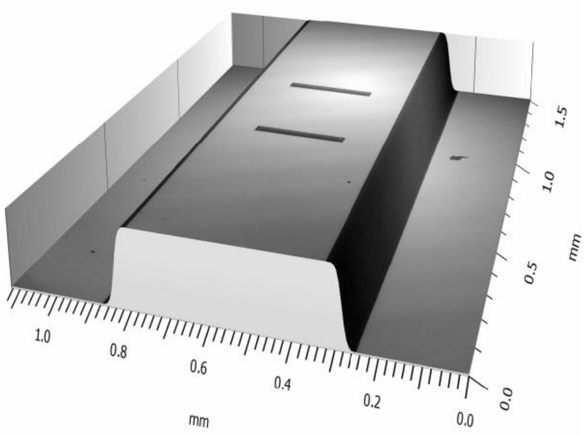
Ra
24.109 nm
24.100 nm ± 2.500 nm

Rz
128.972 nm
128.400 nm ± 15.000 nm

Rmax
139.524 nm
156.700 nm ± 25.000 nm

deviation smaller 30 nm / 100 µm step height

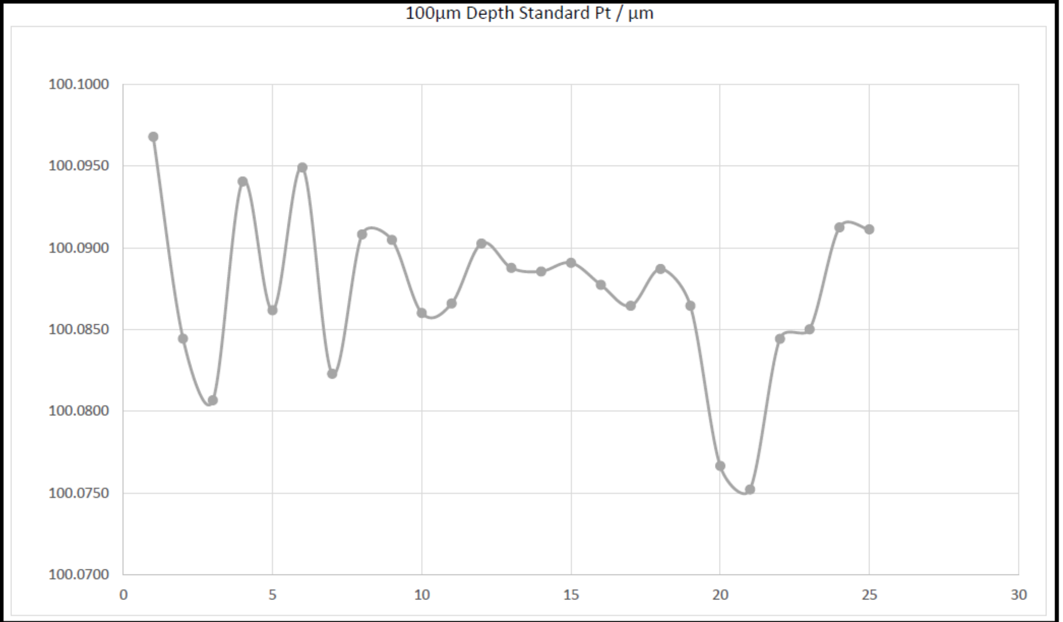
SiMetricS – step height standard
optional with PTB - Zertifikat



Factory Calibration Certificate

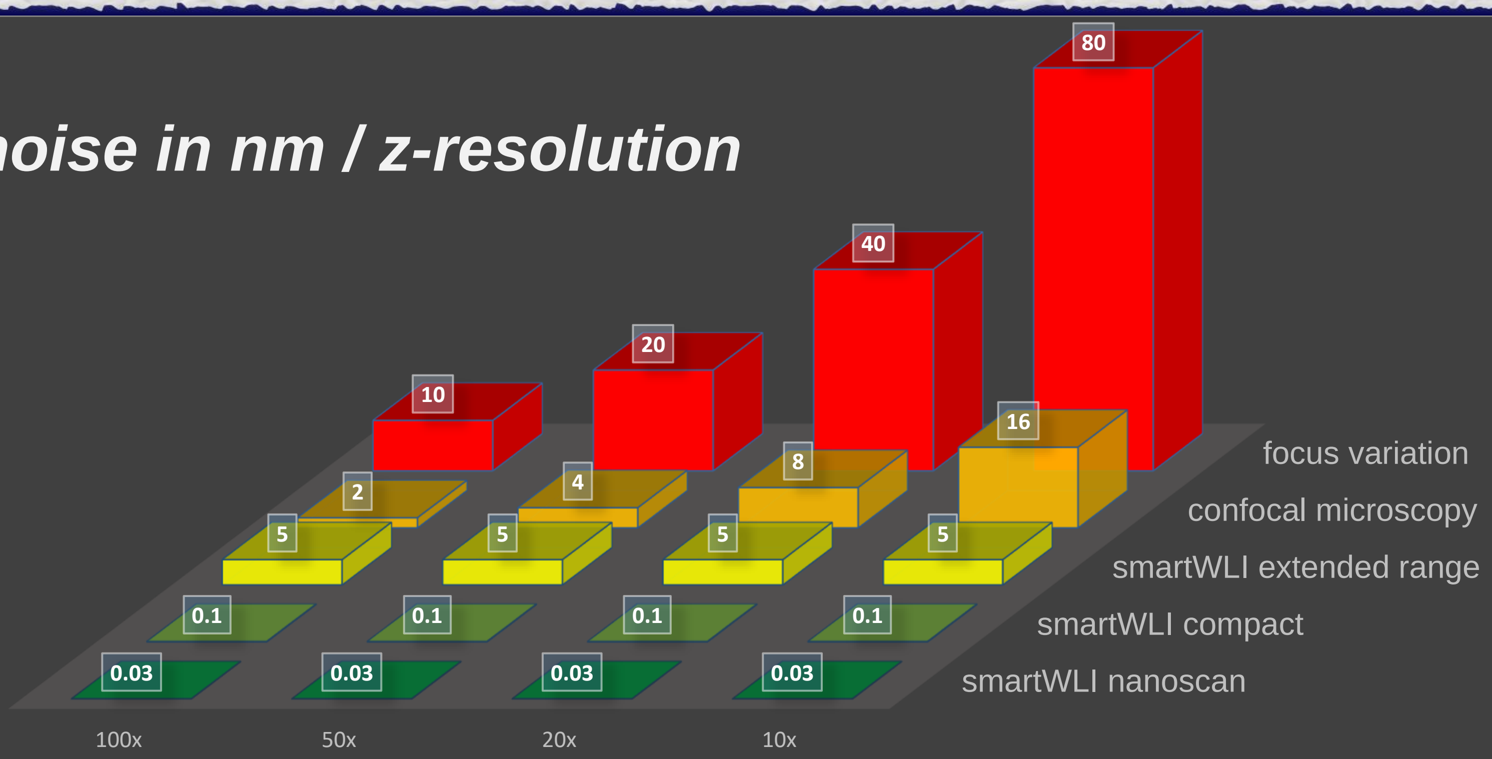
System:	smartWLI compact		**Sensor No.:**	xxx
Objective:	Nikon CF IC EPI Plan DI 10xA MUL40101		**Serial No.:**	xxx
Feature:	100µm Depth Standard	**Pt / µm**	**Software:**	smartVIS3D 2.1.0.37
Standard:	SiMetricS Serial Type A1		**Mode:**	VSI smooth
Nominal Value / µm:	100.07		**Uncertainty / ± µm:**	0.030

Nr.	Pt / µm
1	100.0968
2	100.0844
3	100.0807
4	100.0941
5	100.0862
6	100.0949
7	100.0823
8	100.0908
9	100.0905
10	100.0860
11	100.0866
12	100.0903
13	100.0888
14	100.0886
15	100.0891
16	100.0877
17	100.0865
18	100.0887
19	100.0865
20	100.0767
21	100.0752
22	100.0844
23	100.0850
24	100.0913
25	100.0911


100µm Depth Standard Pt / µm

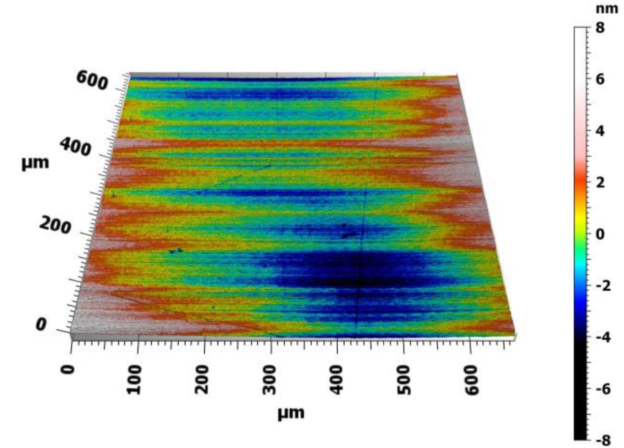
Min:	**100.0752**	**System Deviation / µm:**	**0.017**	**Date**	**xxx**
Max:	**100.0968**	**Reproducibility 1-σ / µm:**	**0.005**	**Inspector**	**n.n**

comparison to optical measuring principles

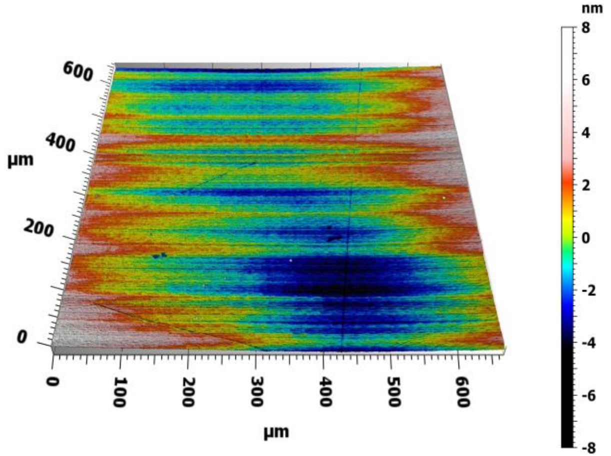


- *the smartWLI nanoscan provide a sub-atomic height resolution*
- *the improvement of the lateral resolution is very important*

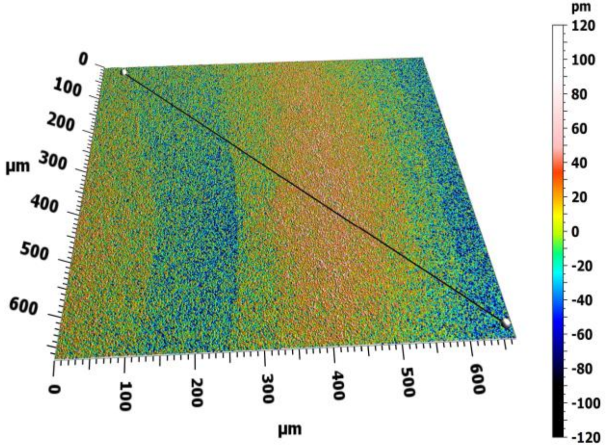
ISO 25178-604 2.1.11 system noise / single scan



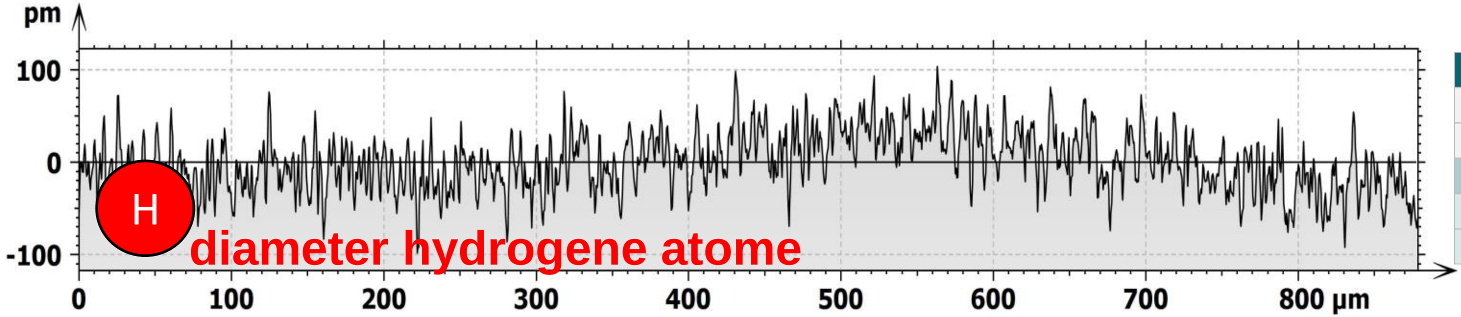
scan 1



scan 2



difference 1 - 2



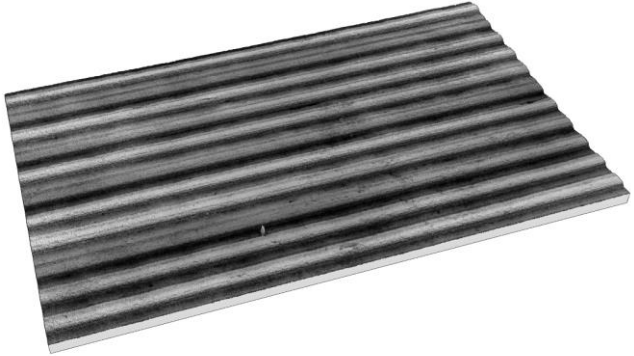
diameter hydrogene atome

ISO 25178 - Primary surface		
F: None		
λs Filter: No λs-filtering		
Height parameters		
Sq	33.9	pm
Sa	27.2	pm

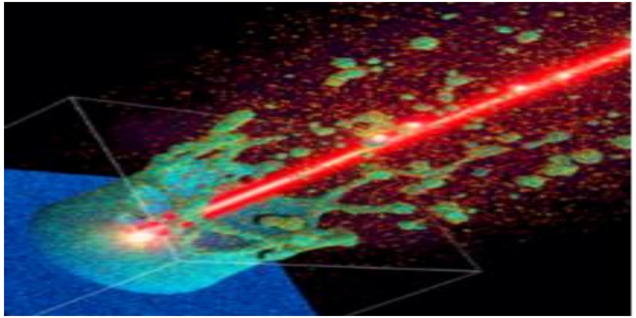
laser structuring for automotive application

connecting rod

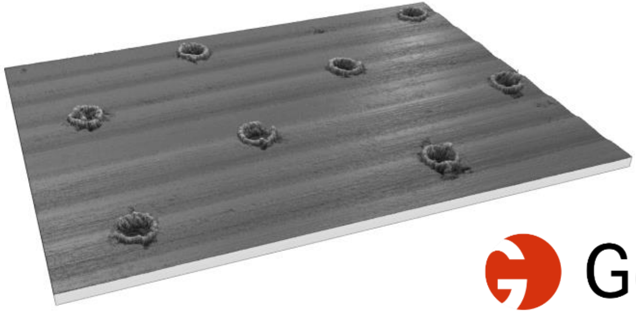
original surface



laser structuring

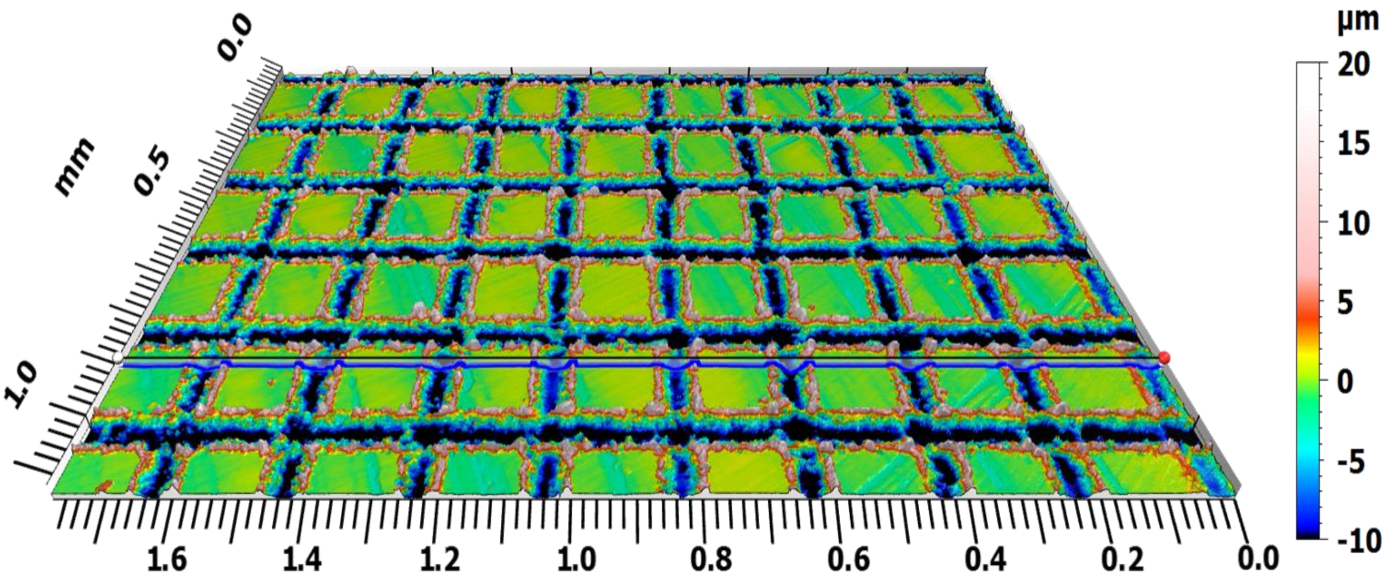


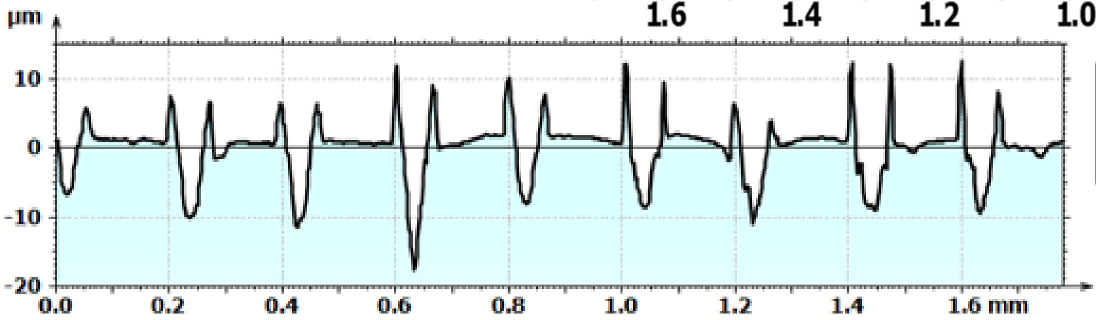
after laser structuring



Gehring

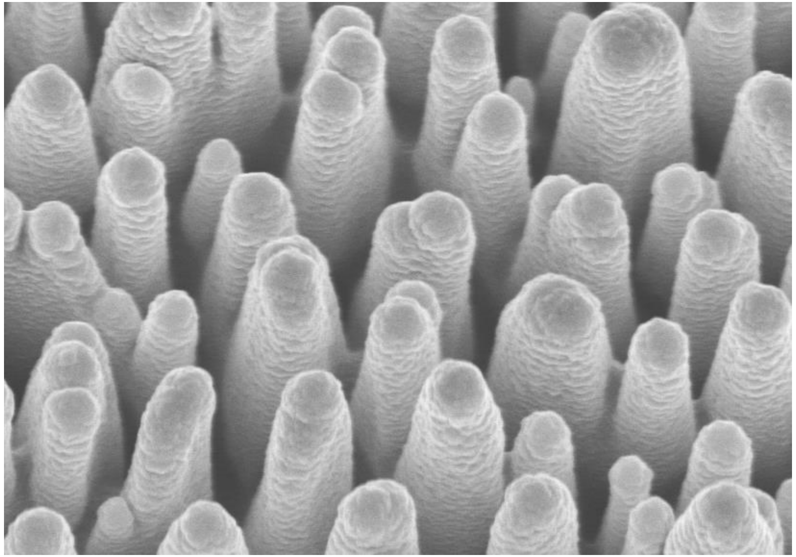
surfaces with defined functions





The laser grate increase the friction and enable the reduction of the friction area as well as the complete part.

the challenge to measure nano structures 3d



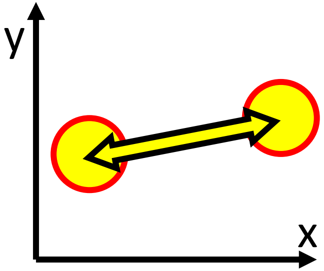
SEM image
functional “black silicon” structure

AFM:
- ➢ structures could not be reached
- ➢ and potentially break the tip

SEM stereoscopic reconstruction:
- ➢ getting pictures of the same spot with different slopes is difficult
- ➢ the aspect ratio allowed limited slope variations which limits the z-resolution
- ➢ the necessary autocorrelation reduce the lateral resolution significant

smartWLI:
- ➢ is it possible to measure such structures?
- ➢ what are the smallest structures which can be measured?

aperture and optical resolution for 2d pictures



Rayleigh – criterion light intensity has to drop of 73.5 % of the max. intensities

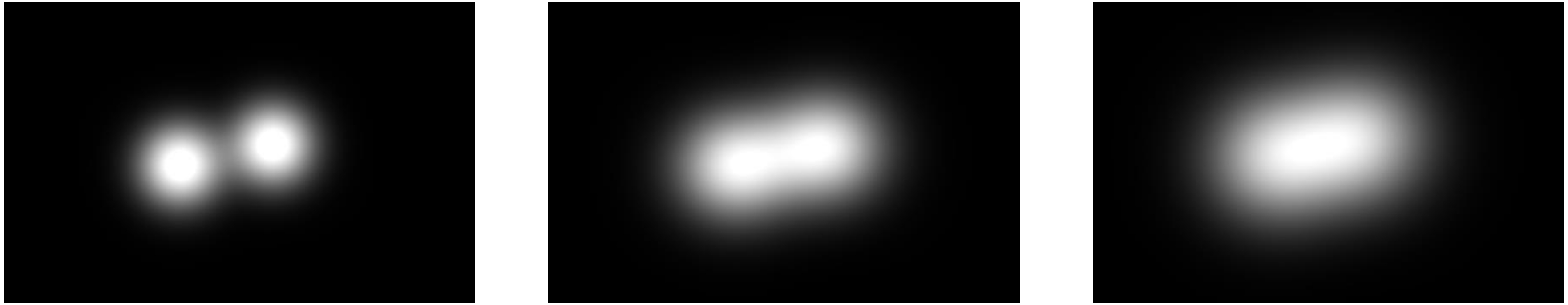
$$d = \frac{0.61 * \lambda}{NA}$$

d – distance between the light sources
λ – wavelength of the light source
NA – numerical aperture of the objective

Sparrow's – criterion light intensity doesn't drop between max. intensities

$$d = \frac{0.47 * \lambda}{NA}$$

d – distance between the light sources
λ – wavelength of the light source
NA – numerical aperture of the objective

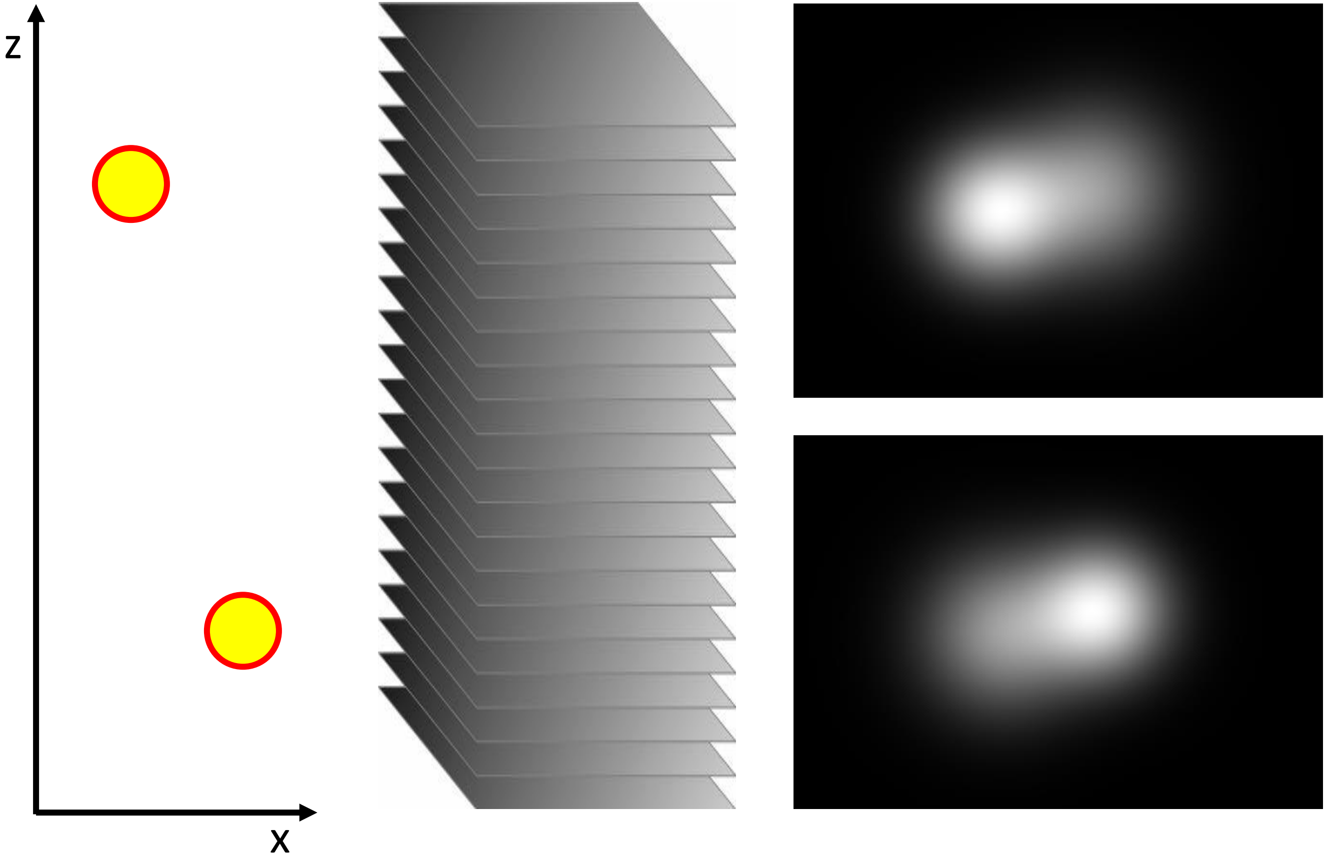


separation possible

separation limit

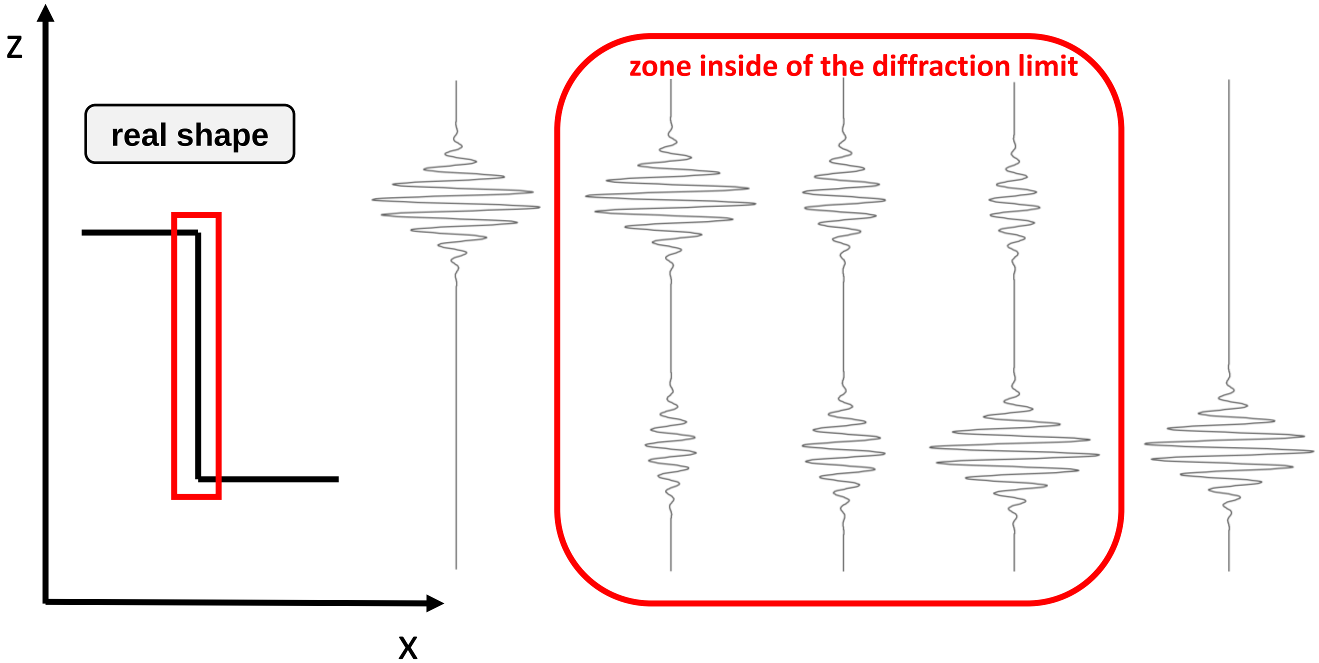
separation impossible

3d scanning, distance below optical resolution

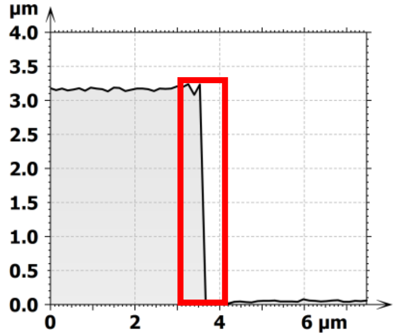


- ➢ height differences simplify the signal separation
- ➢ the light source in optimal sharpness can better separated from the other light source at a different height level
- ➢ aperture and optical resolution still have a big influence on the system resolution of optical area scanning systems but based on the evaluation of image stacks the limit depends from the height differences of the structures
- ➢ instead of an optical image of both light sources at the same height level the separation is possible

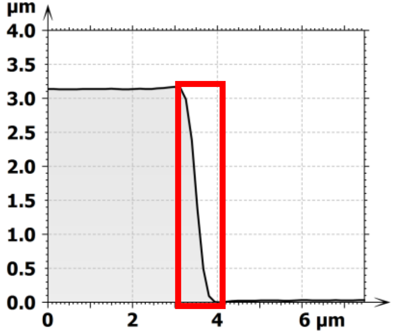
interferometric signal on a step



measuring result with advances algorithm

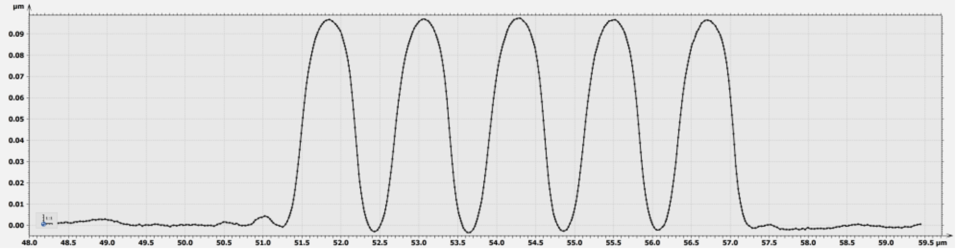


measuring result with simple algorithm

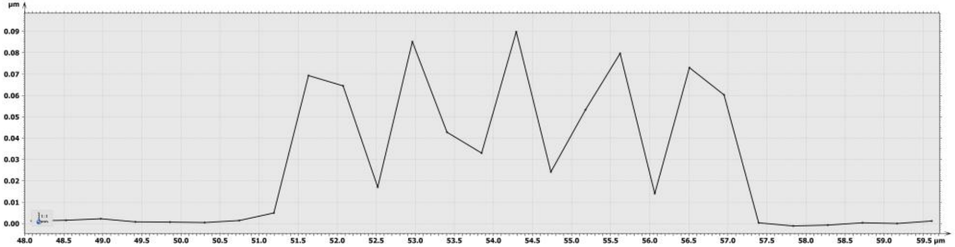


- the diffraction limit is the reason of an mixed signal of upper and lower level
- interferometry isn't based on the light intensity and advanced algorithms can separate both signals depending on the height differences, hardware components and used algorithm

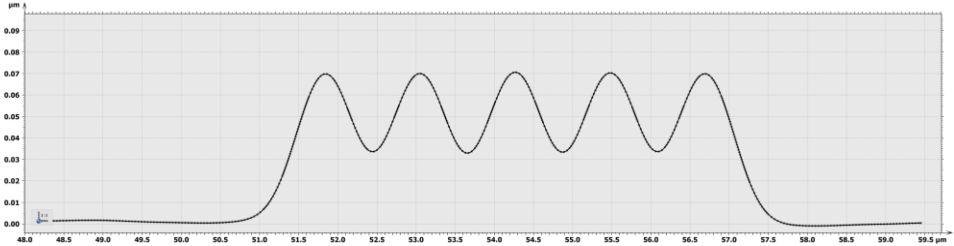
ISO 25178-604 2.1.17 – D_{LIM} for objective tests



sufficient point density
sufficient system resolution



insufficient point density
(amplitude below 50% of the real structure)

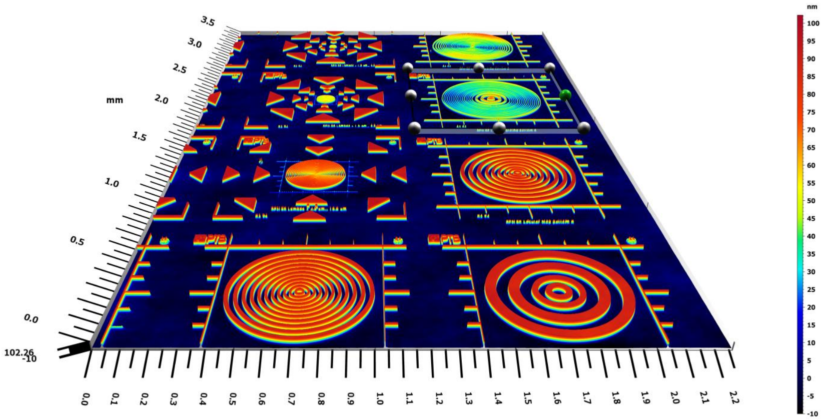


insufficient system resolution
(amplitude below 50% of the real structure)

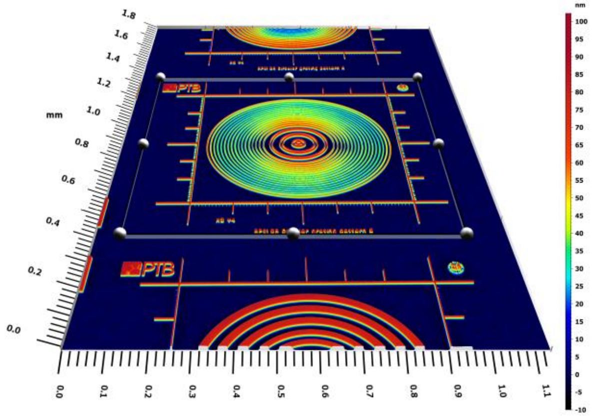
- *ISO 25178 specifies the scale limitations for the surface texture by areal methods*
- *the lateral period limit D_{LIM} is the spatial period of a sinusoidal profile at which the measured height falls to 50% of the real height*

target with sinus structures for resolution tests

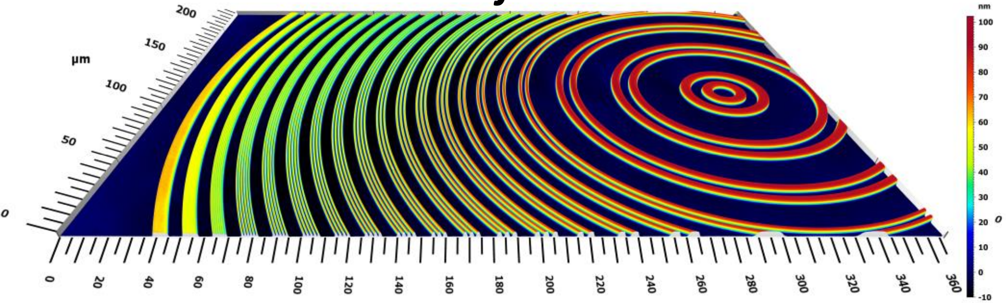
5x objective



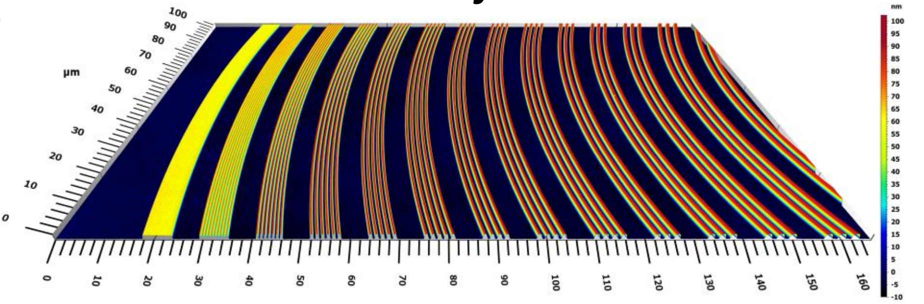
10x objective



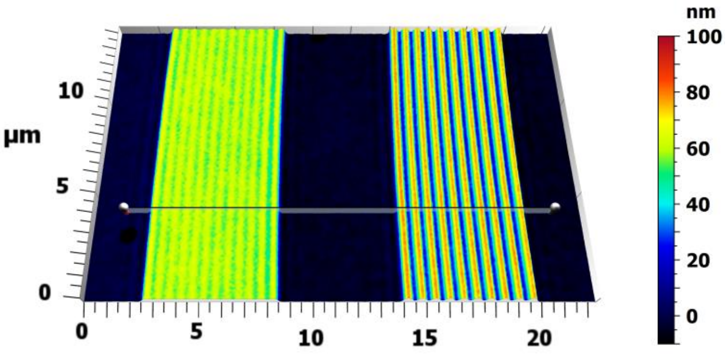
50x objective

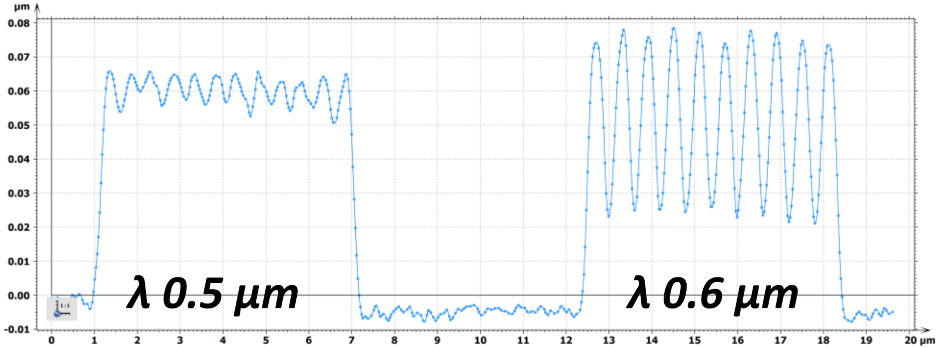


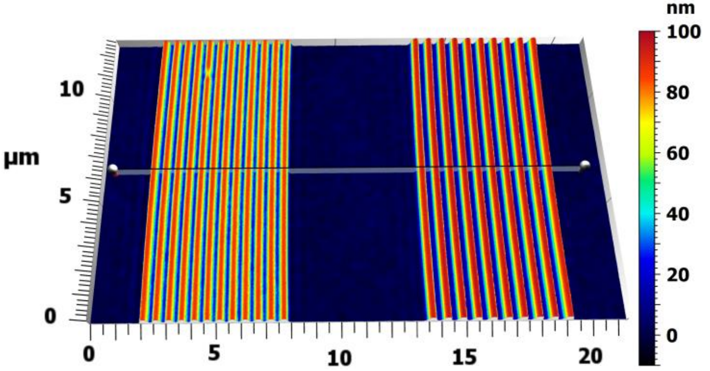
115x objective

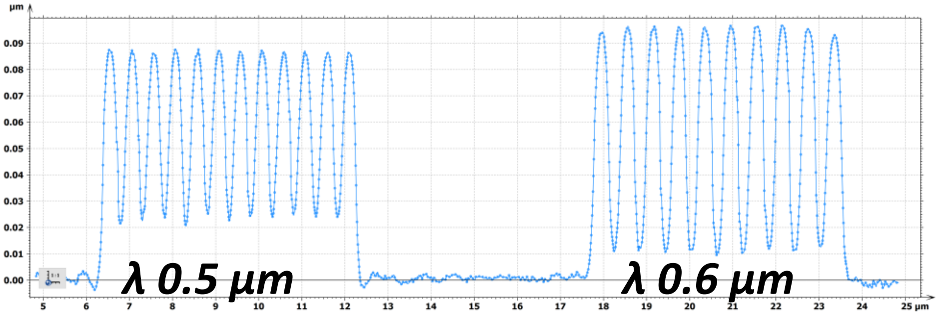


smartWLI nanoscan for highest resolution









The analysis proves that smartWLI nanoscan has not only a much better point density but also a 50% higher system resolution: D_{LIM} smartWLI compact 115x app. 0.6 µm / D_{LIM} smartWLI nanoscan 115x app. 0.4 µm.

comparison of data processing strategies

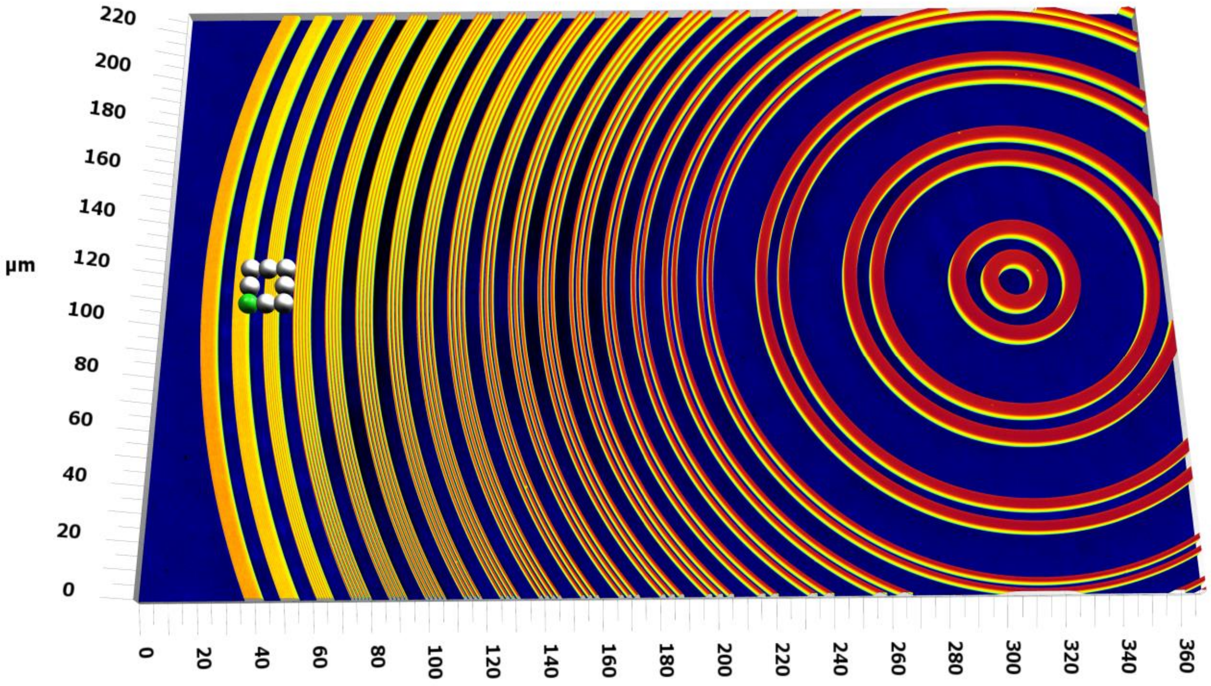
PTB resolution target, sinus structures with a wavelength of app. 0.8 µm and an height of app. 0.08 ... 0.1 µm

50x objective, point density 0.19 µm, optical resolution app. 0.6 µm, partial area out of 0.34 x 0.28 mm²

The point density is already far below the resolution limit. Can I really use filters to reduce the noise without loosing significant height information?

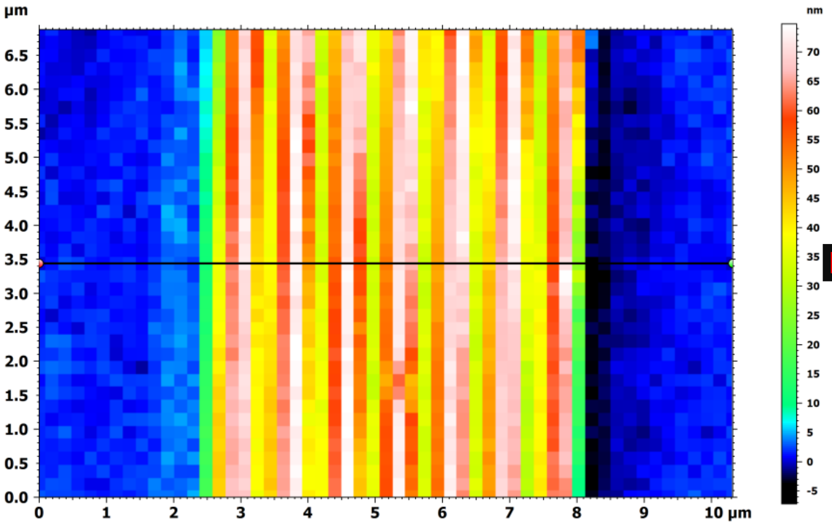
Is it possible to reduce the noise with phase averaging?

Is it possible to get better results with super resolution algorithms?



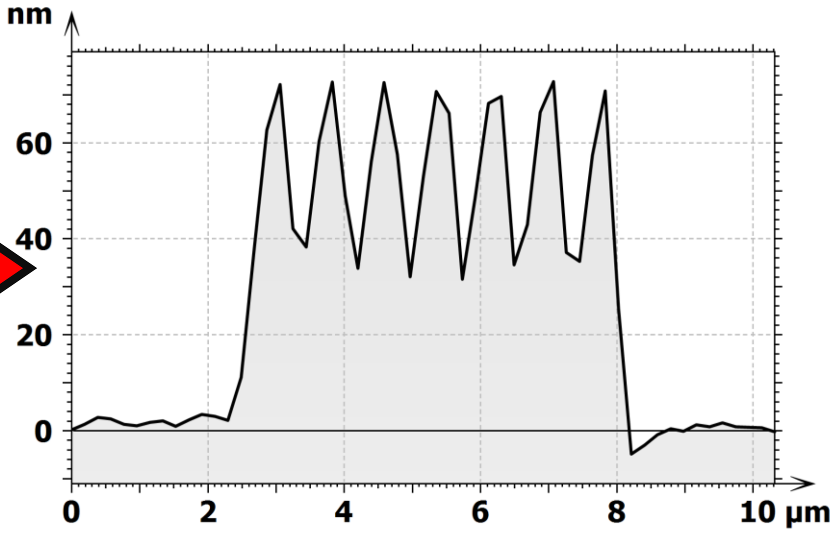
can the data processing be improved?

color coded 3d plot



unfiltered raw data

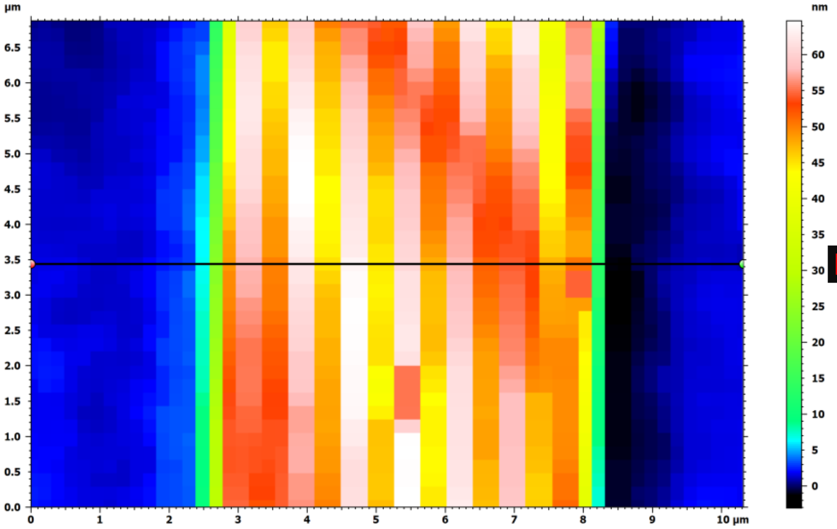
profile



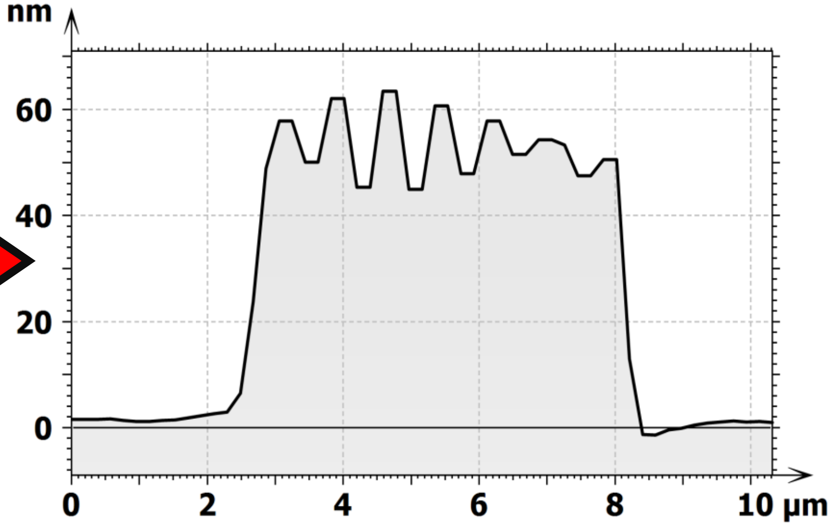
modulation below 50% of the real structure height

profile averaging, 3x3 median filter

color coded 3d plot



profile

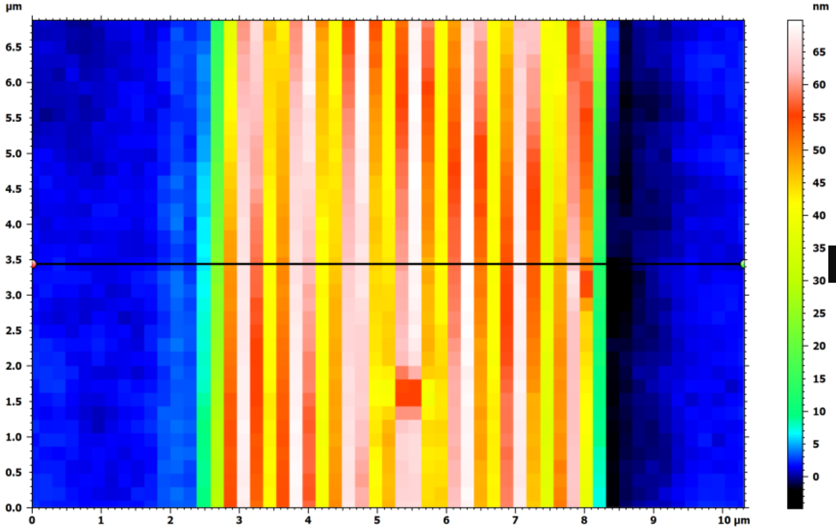


strong noise reduction

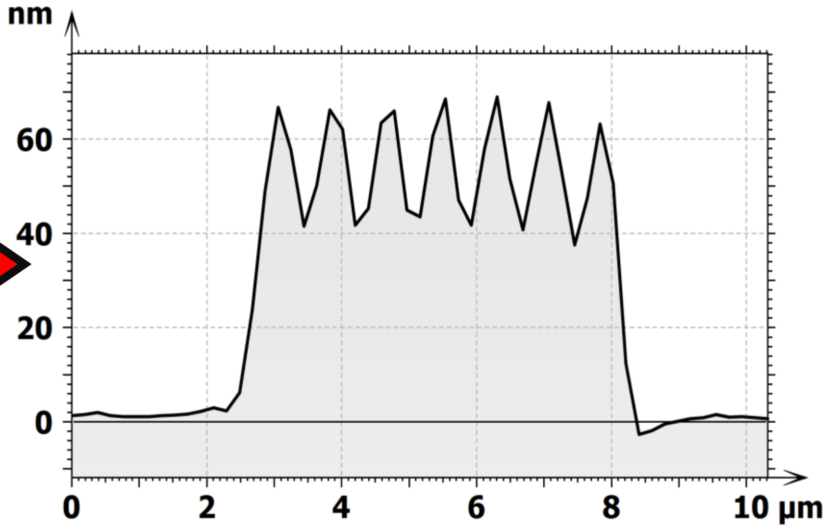
strong reduction of the height signal

profile averaging only

color coded 3d plot



profile

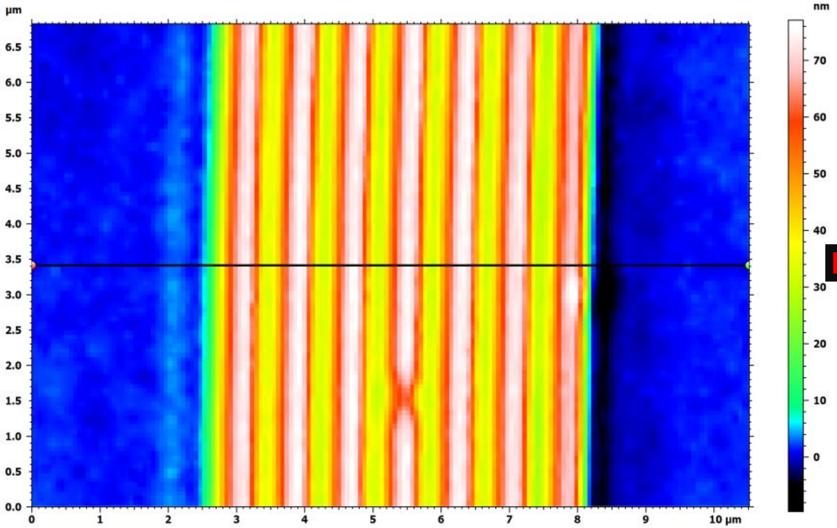


noise reduction

reduction of the height signal

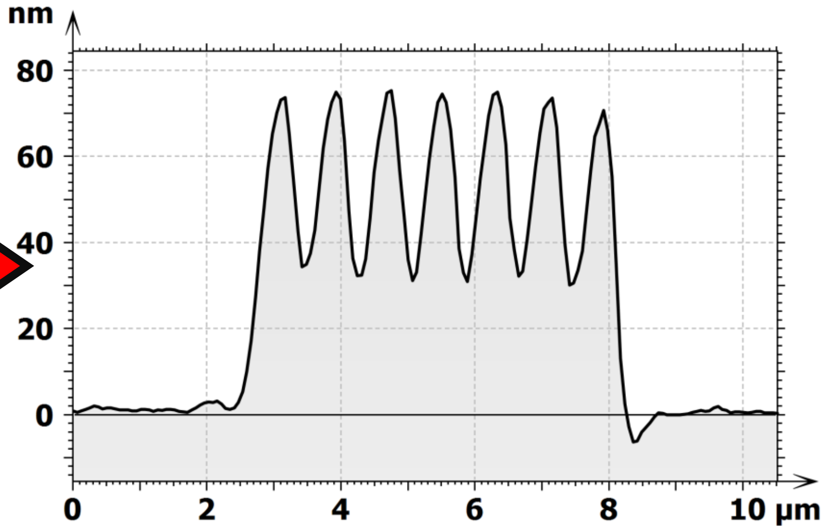
advanced data processing with super resolution

color coded 3d plot



noise reduction, increased resolution

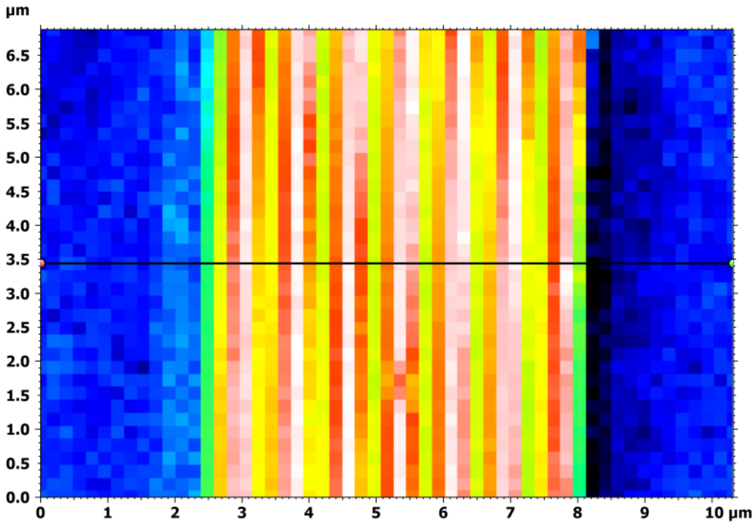
profile



improved height signal

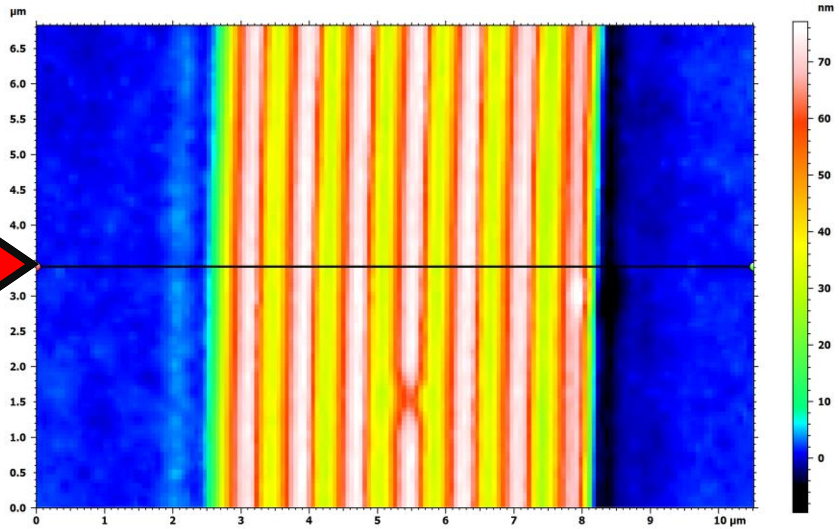
comparison of the 3d data

standard resolution



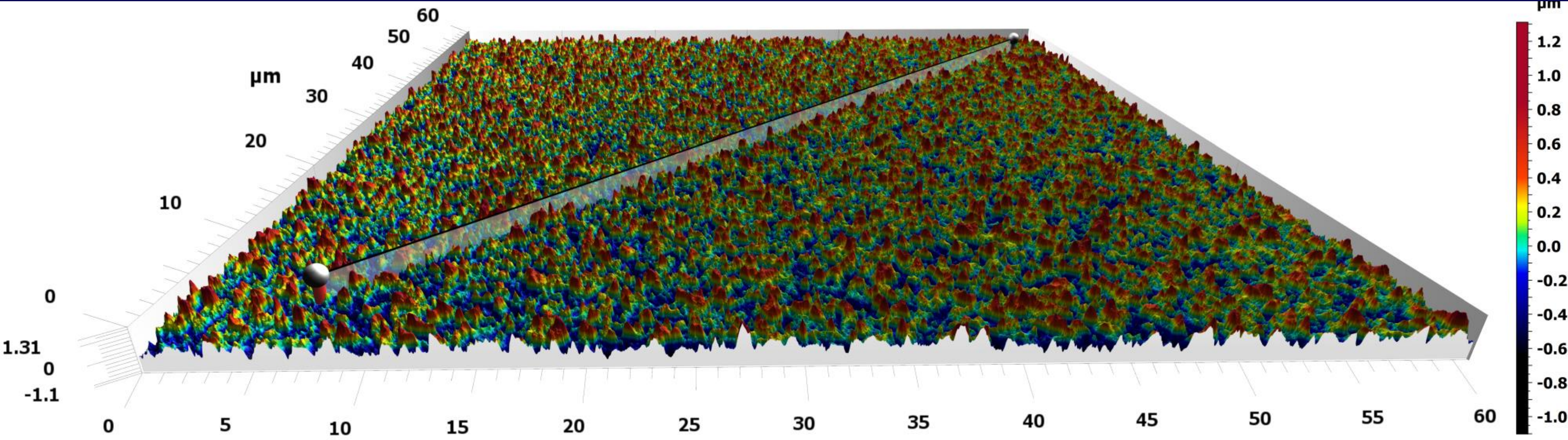
moiré effects, zones with reduced amplitude

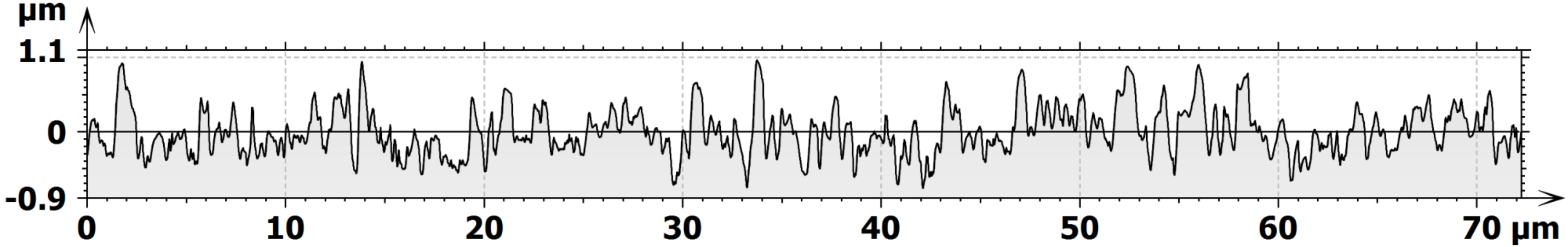
super resolution



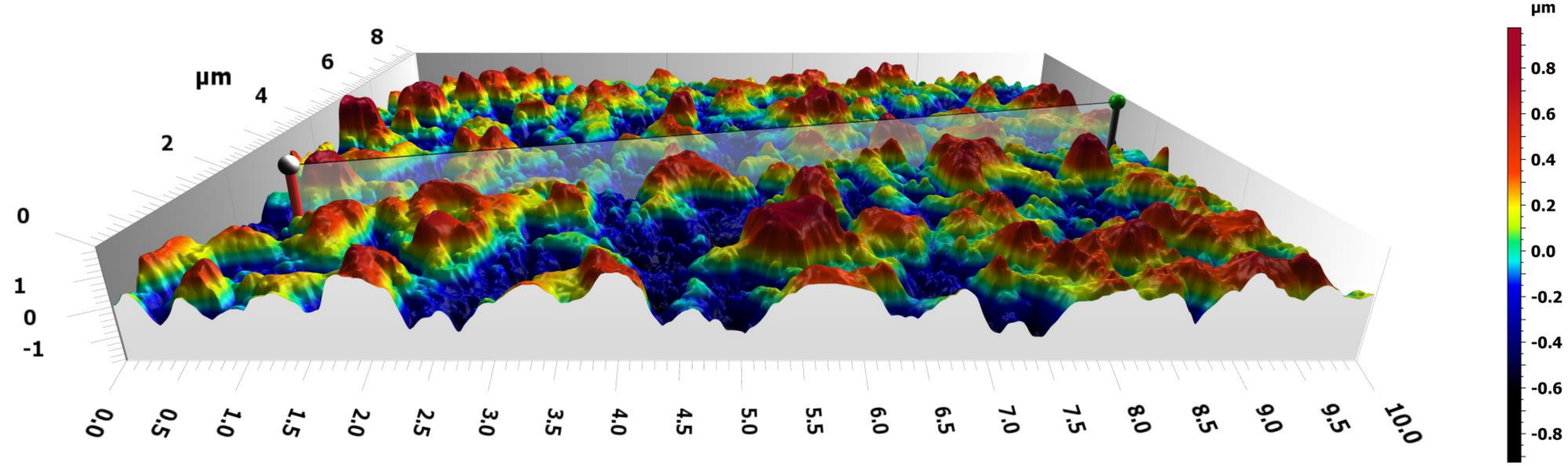
significant closer to the real 3d structures

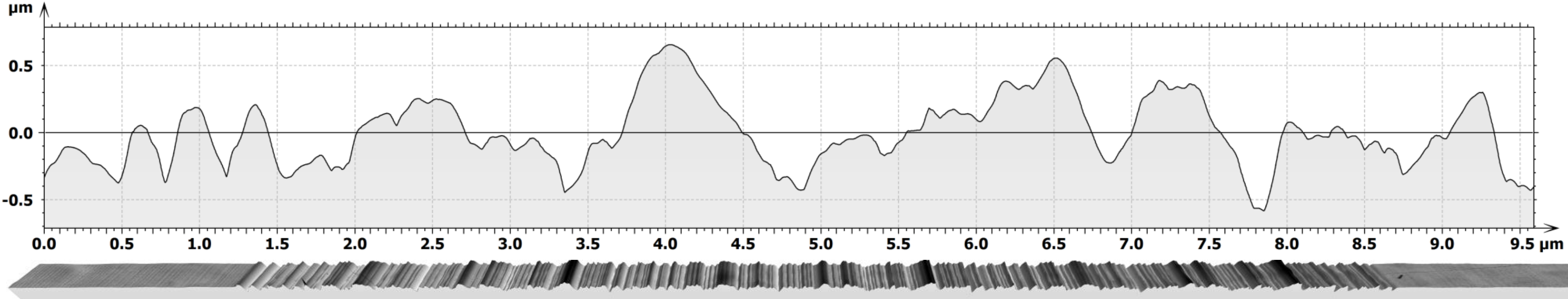
smartWLI nanoscan: “black silicon” structures



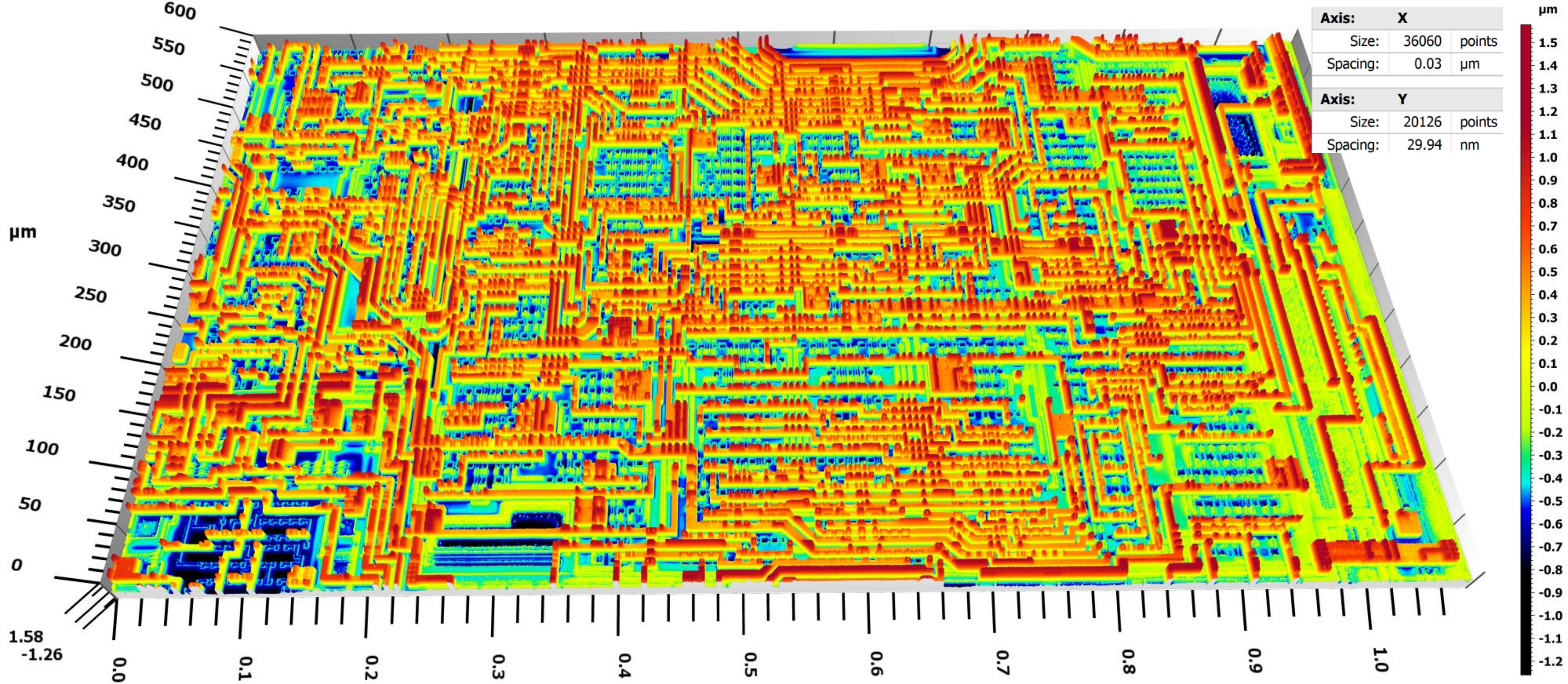


“black silicon” structures – partial area





more details in a shorter measuring time



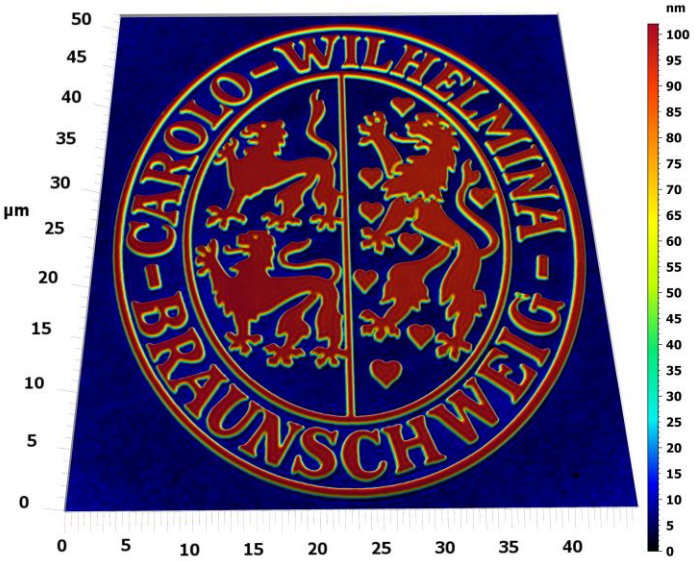
Axis:	**X**	
Size:	36060	points
Spacing:	0.03	µm
Axis:	**Y**	
Size:	20126	points
Spacing:	29.94	nm

smartWLI nanoscan, 115x objective: 180 single scans, 10 min.

conclusion

- ***the systems can be used to measure functional surfaces with a seize below 1 µm***
- ***the algorithms used for the data evaluation have a strong influence to the practical achieved lateral resolution***
- ***super resolution can improve the measuring results even if the original measuring point density of the camera is already significant below the optical resolution of the used objective***
- ***structured height, material and geometry have a significant influence of the lateral resolution which the system can achieve***
- ***the D_{LIM} parameter is a suitable tool to check the lateral resolution of the system***

Thank you for the support!



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The sinus structures from the PTB are a great help for resolution tests and further improvements. My greetings to Braunschweig! Last but not least I would like to thank for the support of the TU Ilmenau giving us a better understanding of such surfaces and SEM reference data.