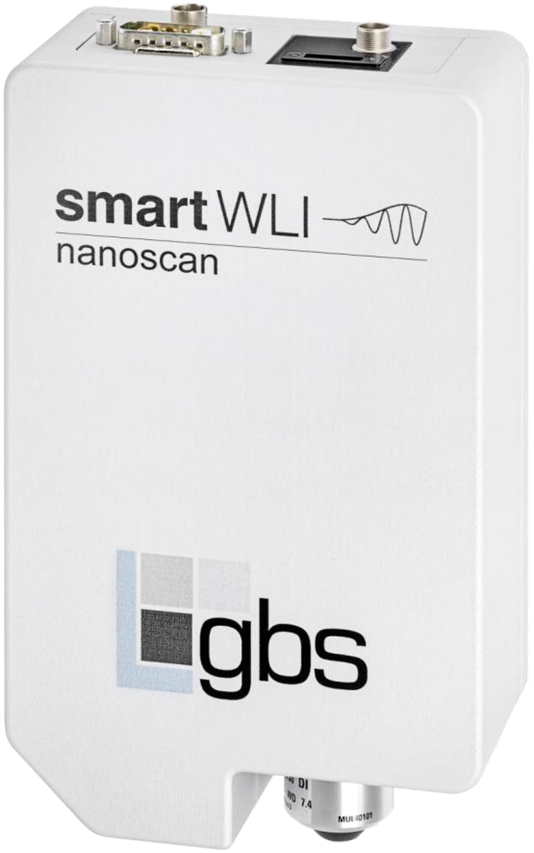
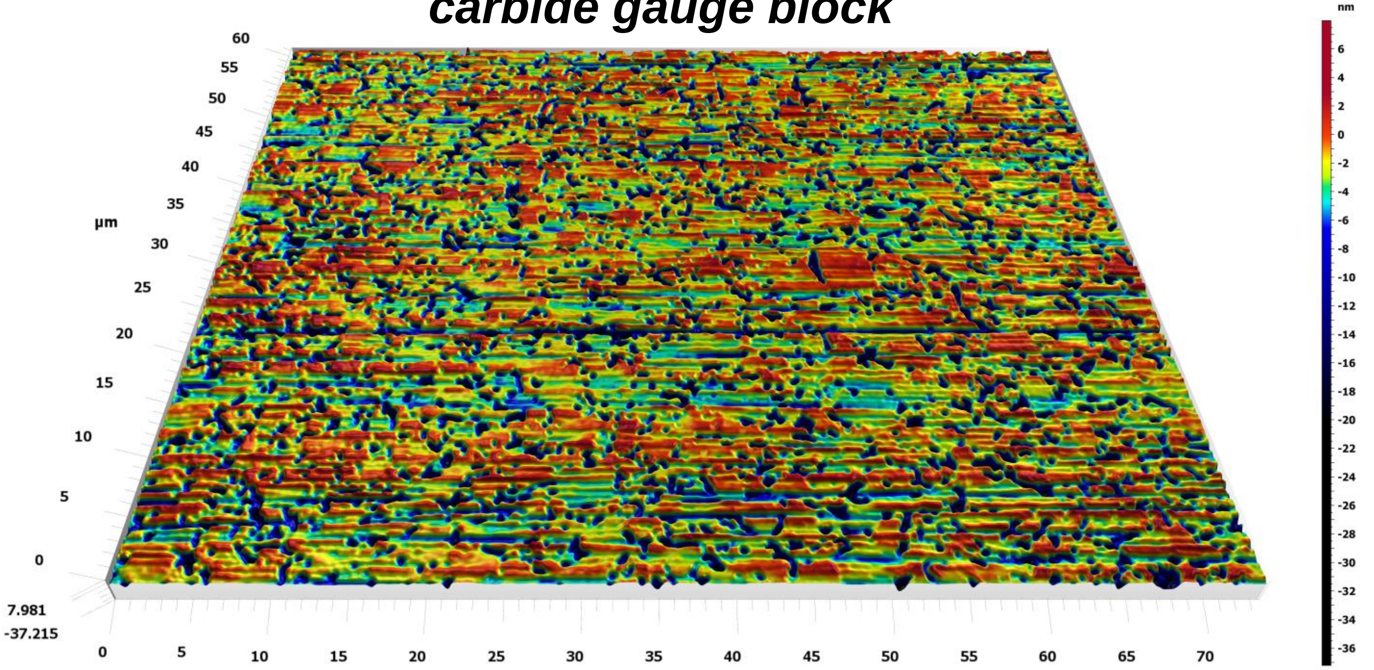
super resolution for coherence scanning interferometry



carbide gauge block



based on advanced image processing strategies

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

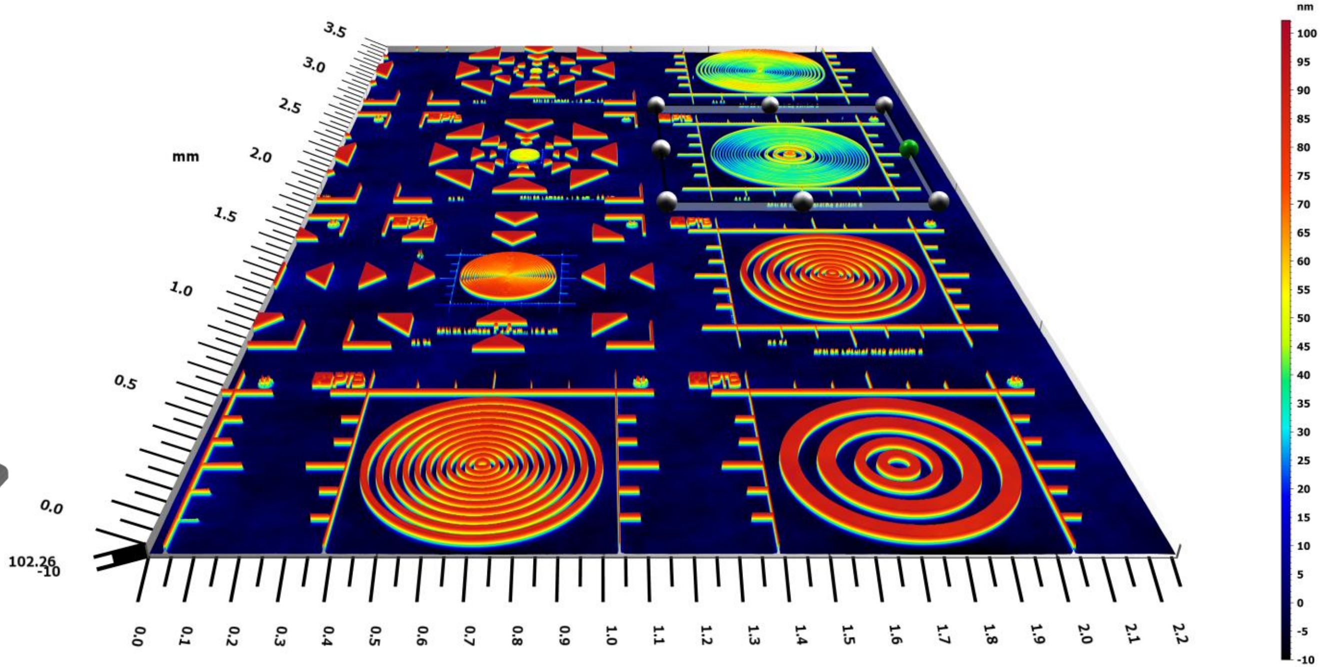
2017

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

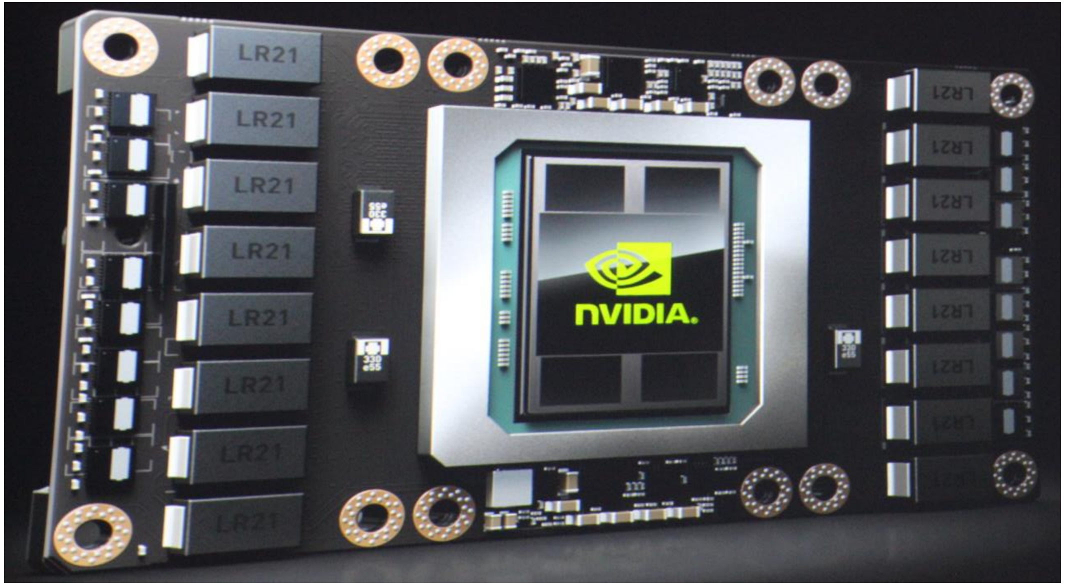
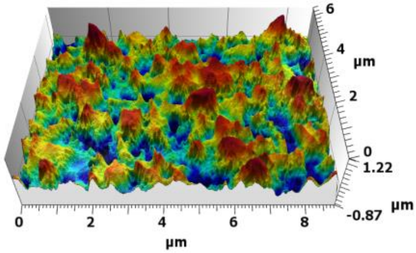
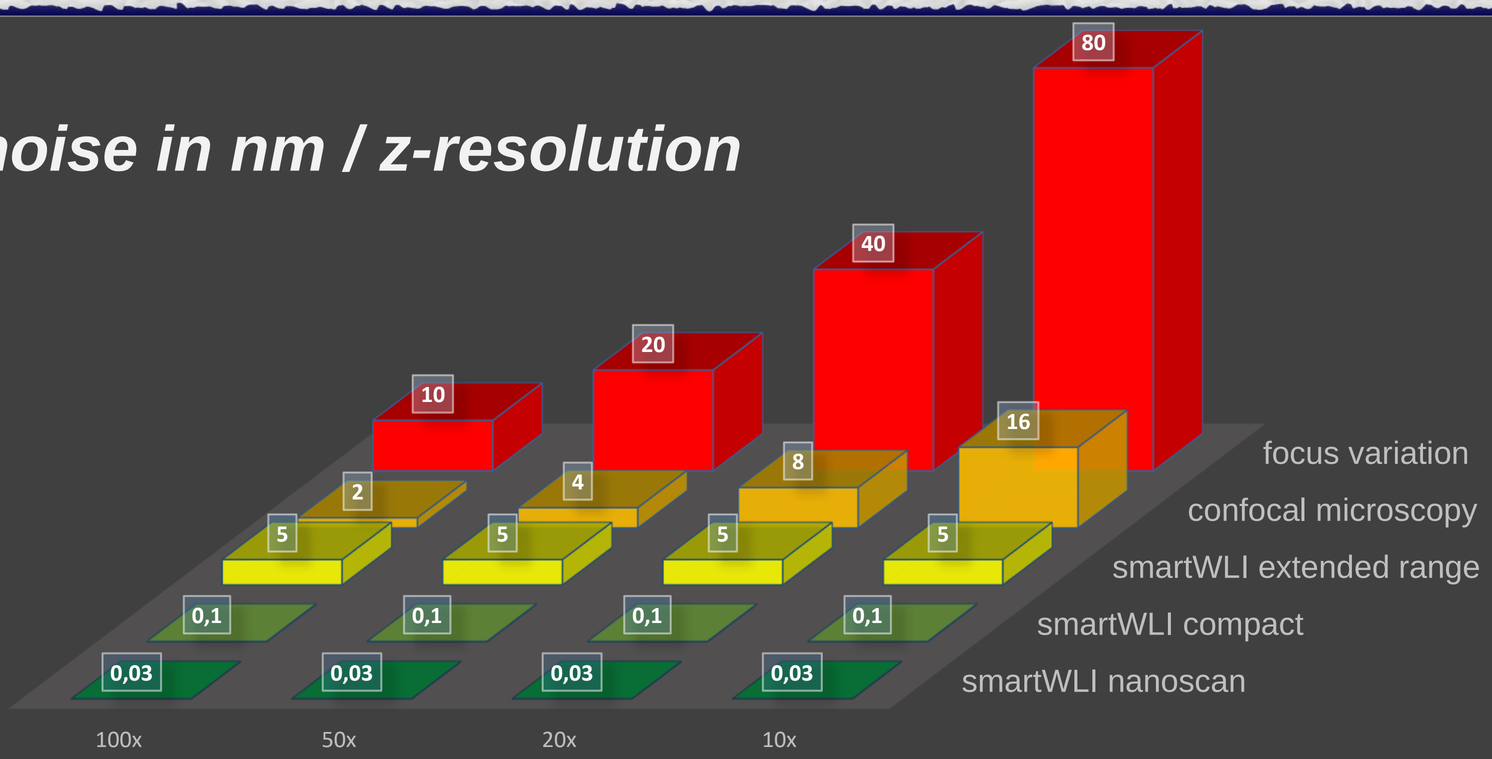


image correction, contrast enhancement
3D calculation in real time!



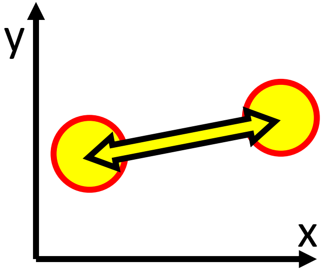
high resolution 3d data

comparison to optical measuring principles



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

aperture and optical resolution for 2d pictures



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

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

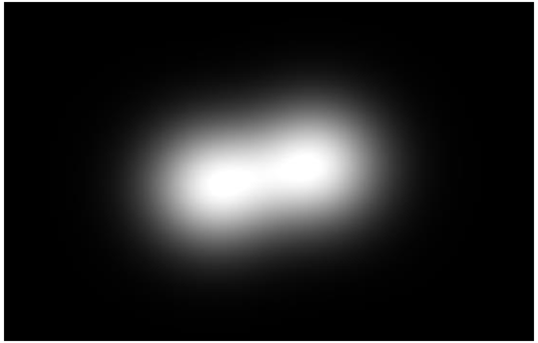
d – distance between the light sources
λ – wavelength of the light source
NA – numerical aperture of the objective

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

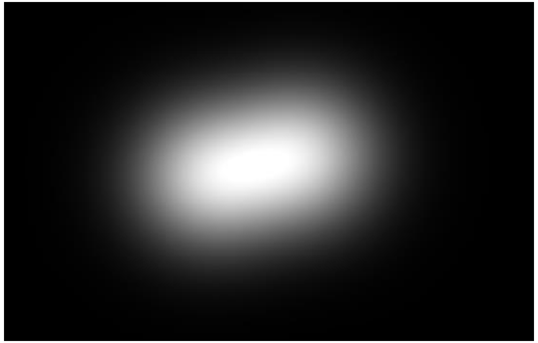
$$d = \frac{0.47 * \lambda}{NA}$$

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

separation possible

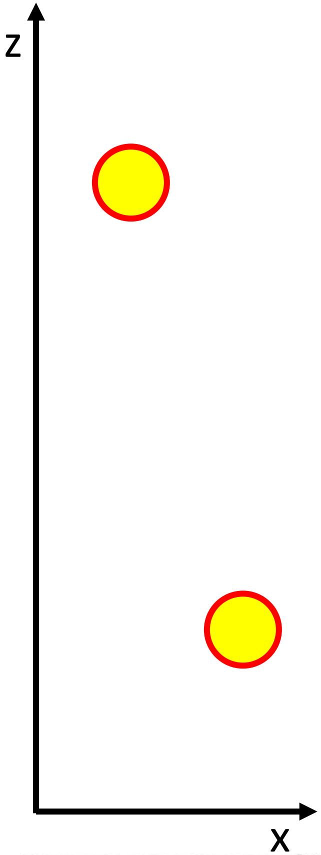


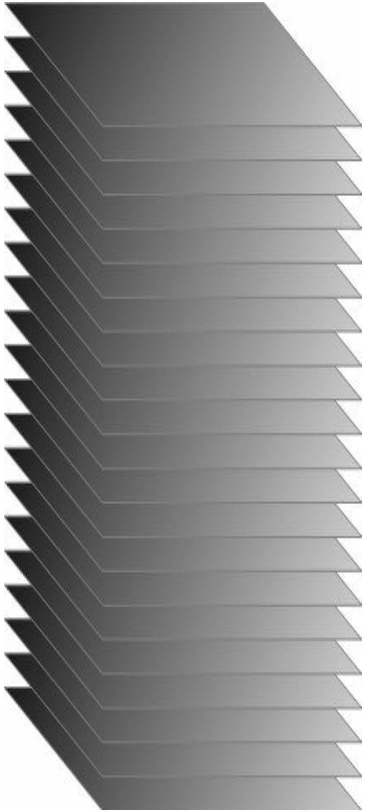
separation limit

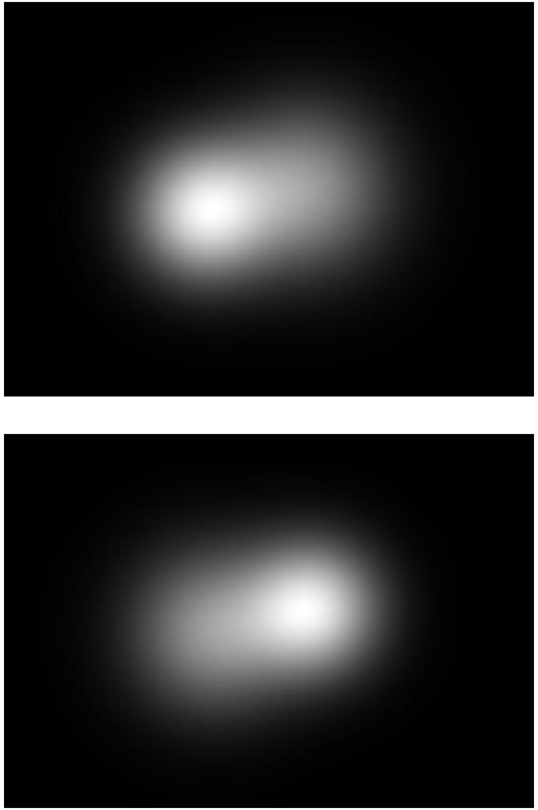


separation impossible

3d scanning, distance below optical resolution

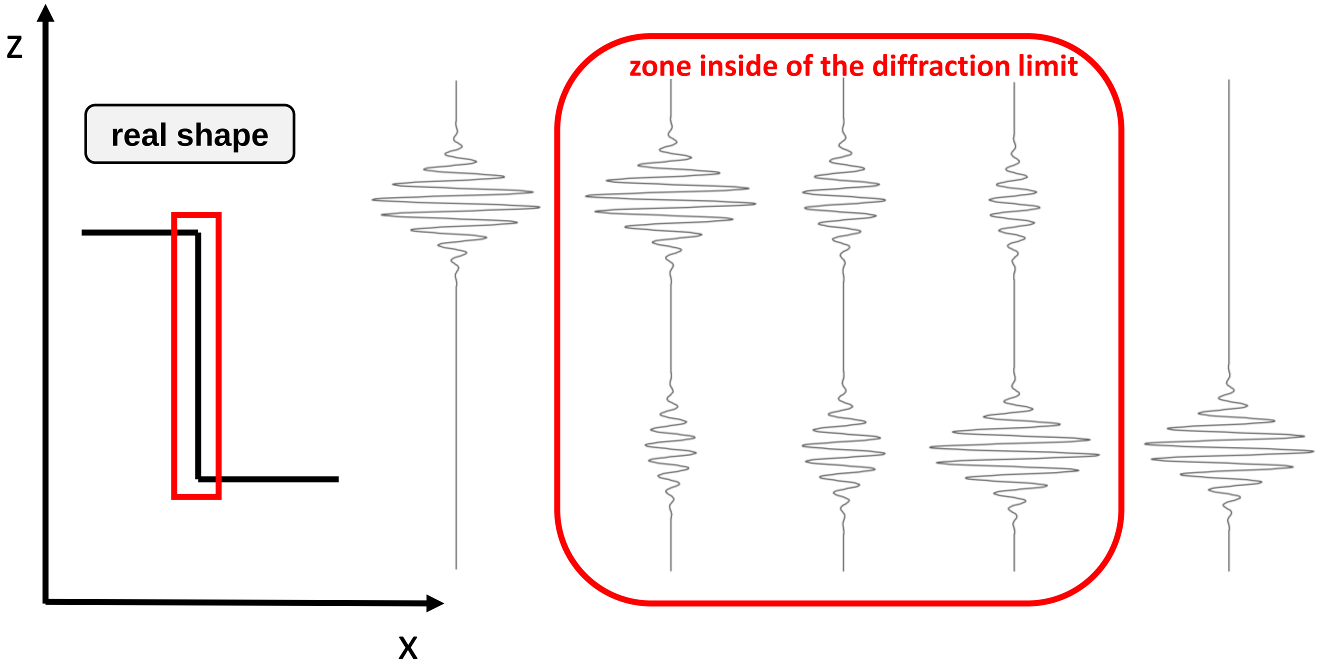




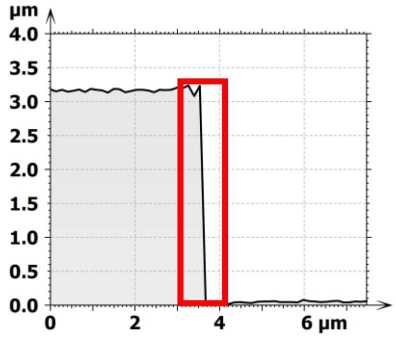


- height differences simplify the signal separation
- the light source in optimal sharpness can better separated from the other light source at a different height level
- aperture and optical resolution still have a big influence on the system resolution of optical area scanning systems but based on 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

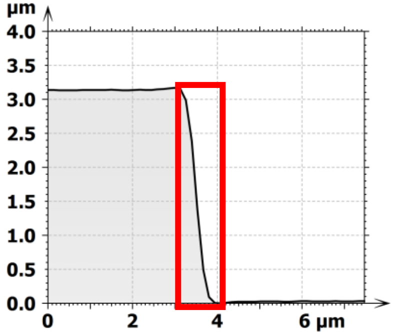
interferometric signal on a step



measuring result with advances algorithm

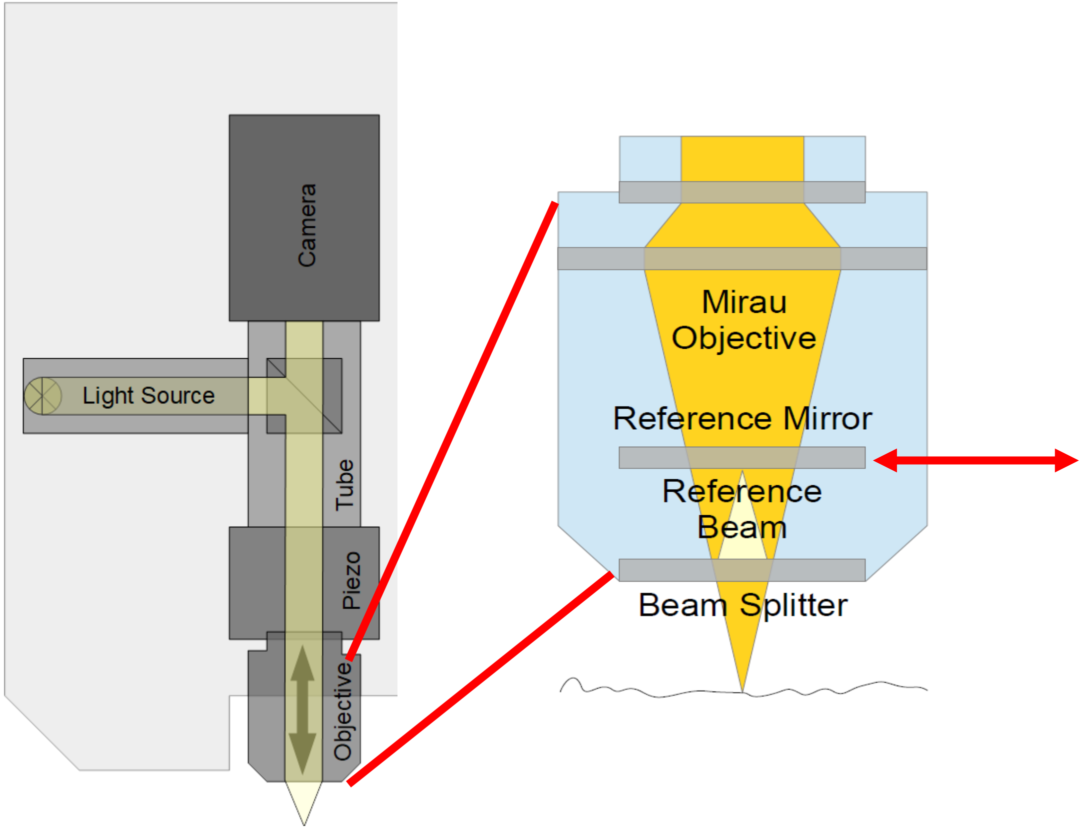


measuring result with simple algorithm



- 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

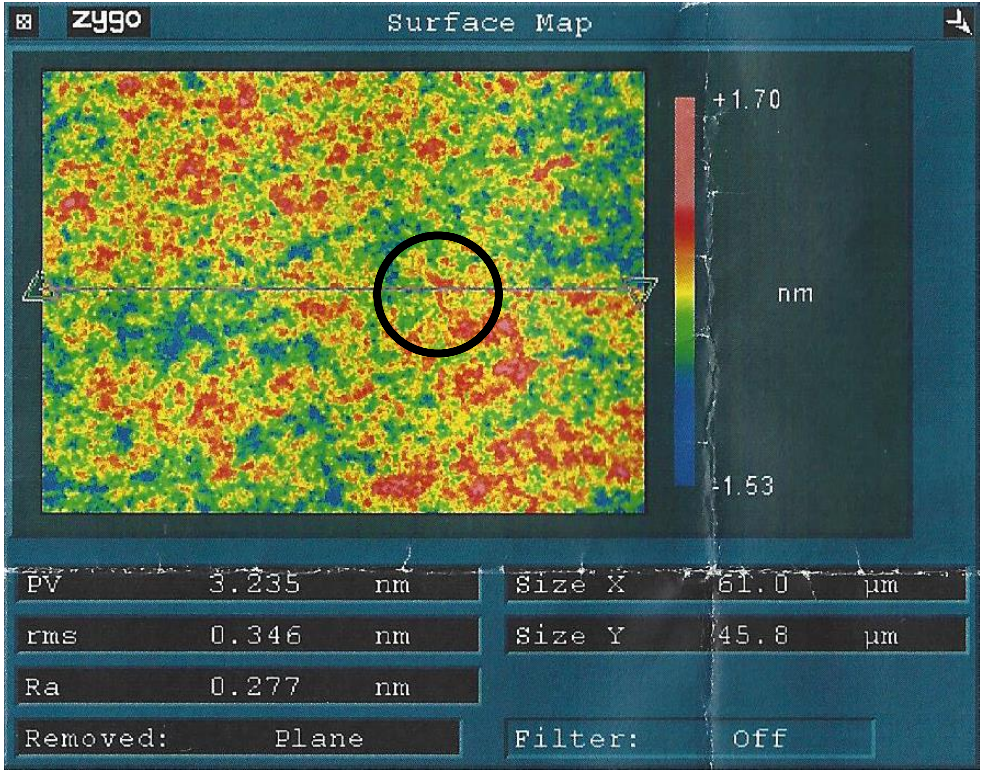
calibration of the reference mirror



According the intention of structure measurement with subatomic height resolution, the already smooth appealing structures are “extreme rough and crocked” in reality .

For measurements with subatomic height resolution, accurate measurement and subtraction of the reference mirror topography are essential.

quality control of the mirror surface



PV 3.235 nm

rms 0.346 nm

Ra 0.277 nm

Removed: Plane

Size X 61.0 µm

Size Y 45.8 µm

Filter: Off

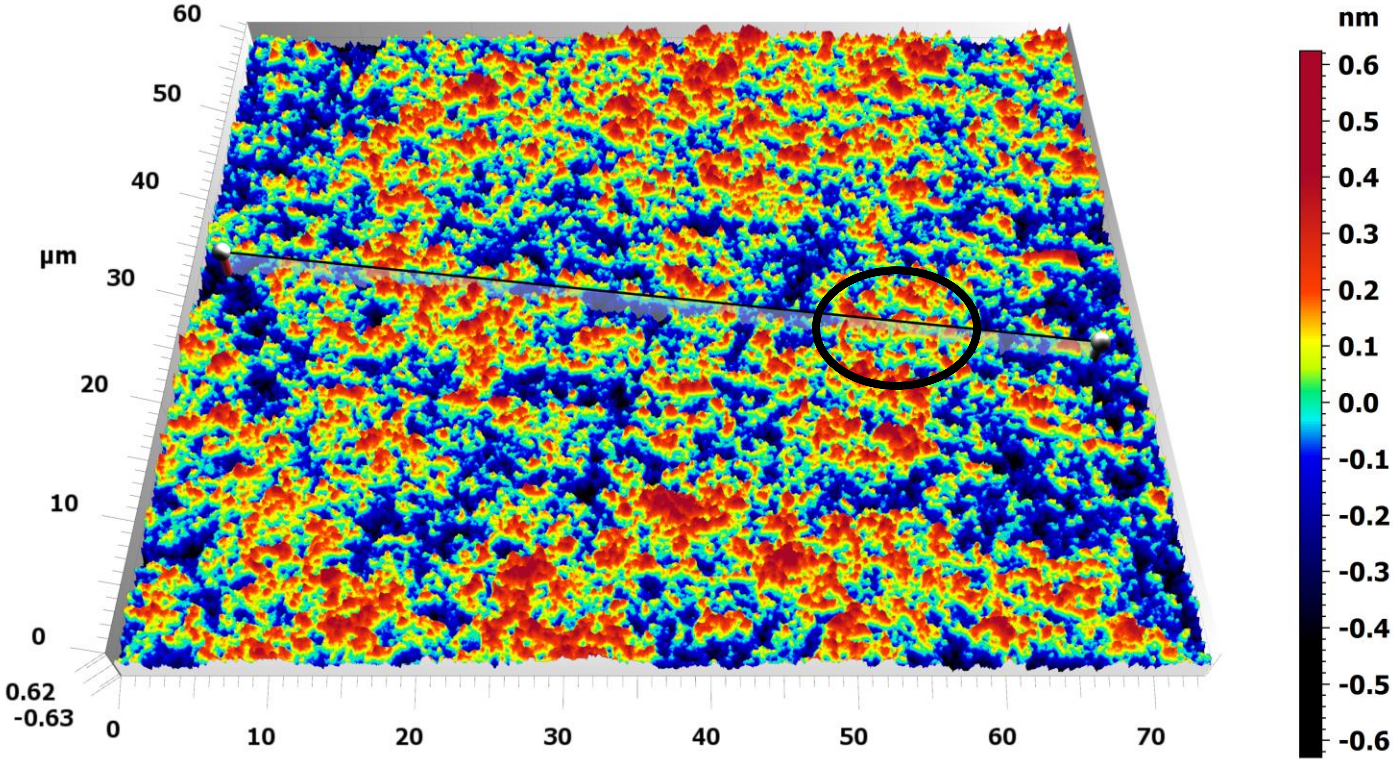
Part of the delivery from the Olympus 100x objective (here SN 20C00236) is a quality control of the reference mirror using a Zygo NV 7200.

Measurements with subatomic height resolution require a subtraction of the reference surface.

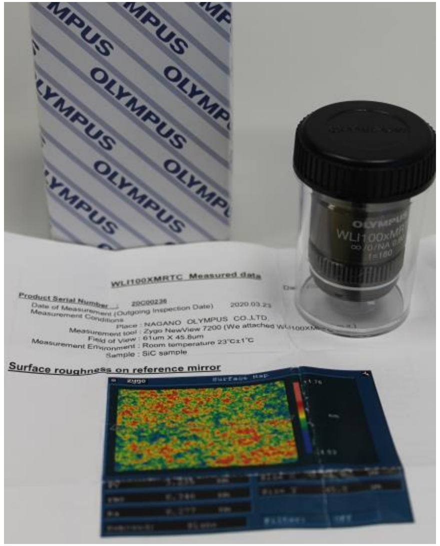
Since any measurement error of the reference mirror gets “added” to the height map of the real measuring object, a much higher resolution in xyz of the reference surface is required.

The circle shows a structure which proofs that the high resolution measurement on the next page shows a larger area the same reference mirror in a different rotation angle.

high resolution measurement of the mirror



ISO 25178 - Primary surface		
F: None		
S-filter (λs): None		
Height parameters		
Sq	0.17	nm
Sa	0.14	nm

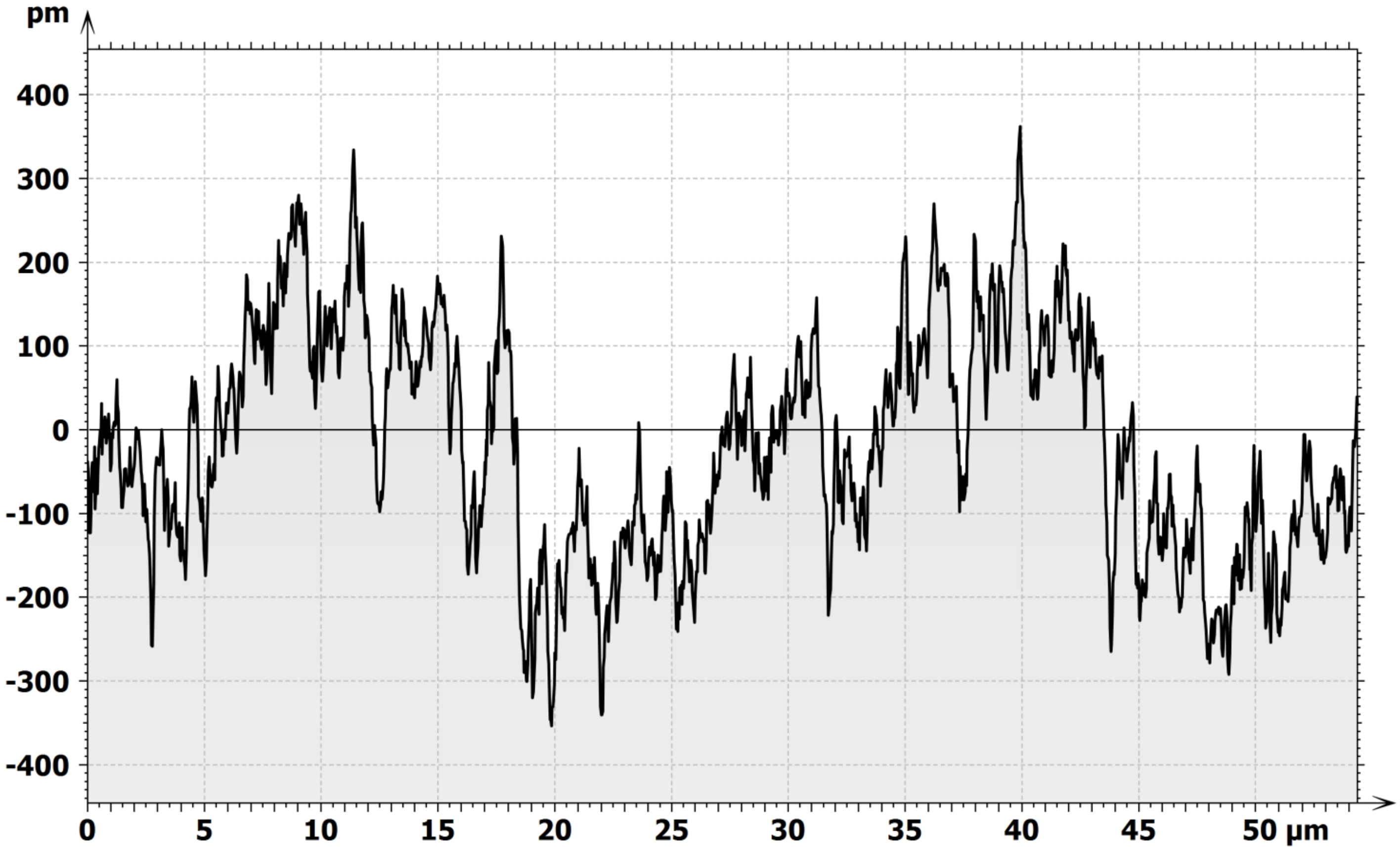


WLI100XMRTC Measured data

Product Serial Number : 20C00236
Date of Measurement (Outgoing Inspection Date) 2020.03.23
Measurement Conditions
Place : NAGANO OLYMPUS CO.,LTD
Measurement tool : Zygo NewView 7200 (We attached WLI100XM
Field of View : 61um X 45.8um
Measurement Environment : Room temperature 23°C±1°C
Sample : SiC sample

Surface roughness on reference mirror

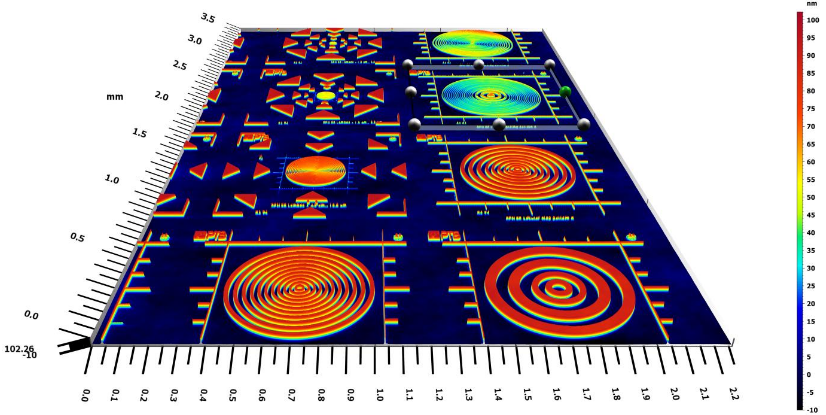
profile of the plane glass



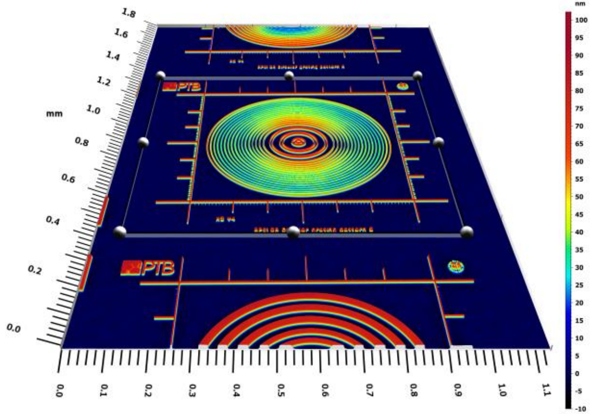
ISO 4287 - Primary profile		
F: None		
S-filter (λs): None		
Amplitude parameters		
Pt	715.00	pm
Pa	112.67	pm
Pq	134.33	pm

target with sinus structures for resolution tests

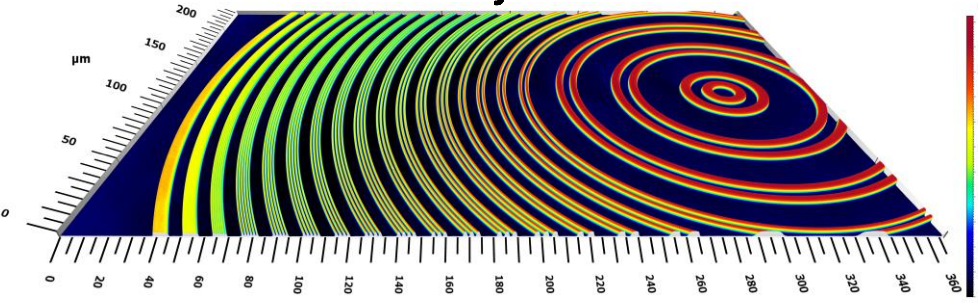
5x objective



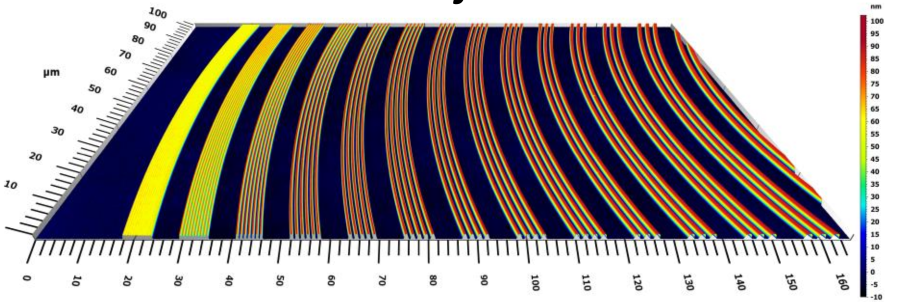
10x objective



50x objective

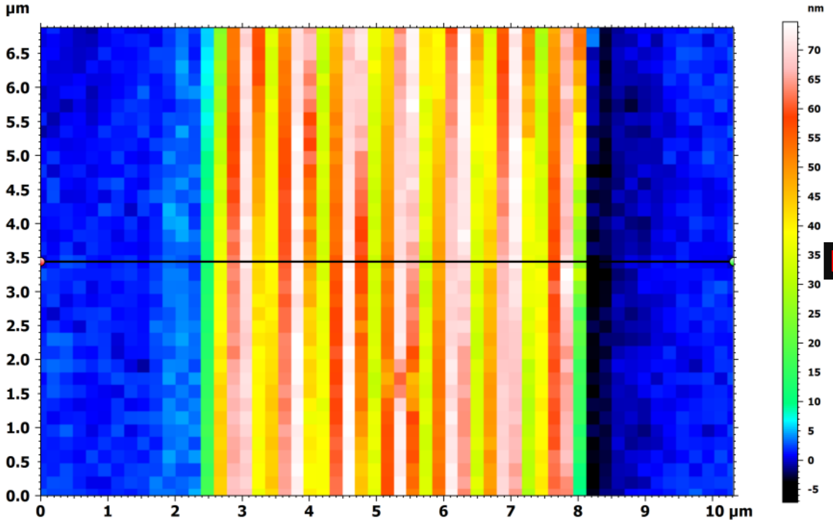


115x objective



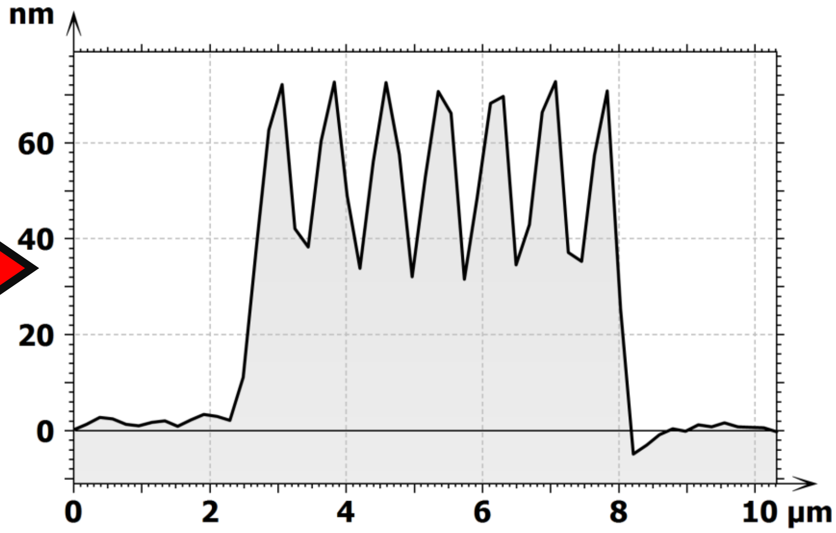
can the data processing be improved?

color coded 3d plot



unfiltered raw data

profile

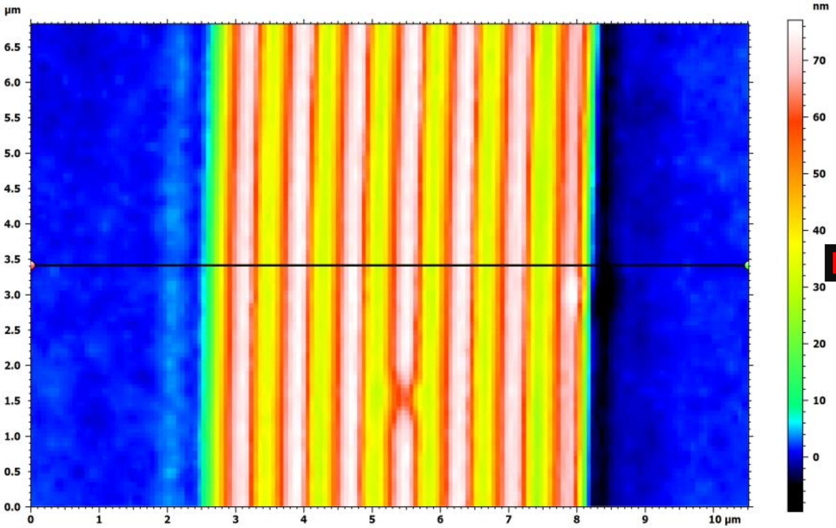


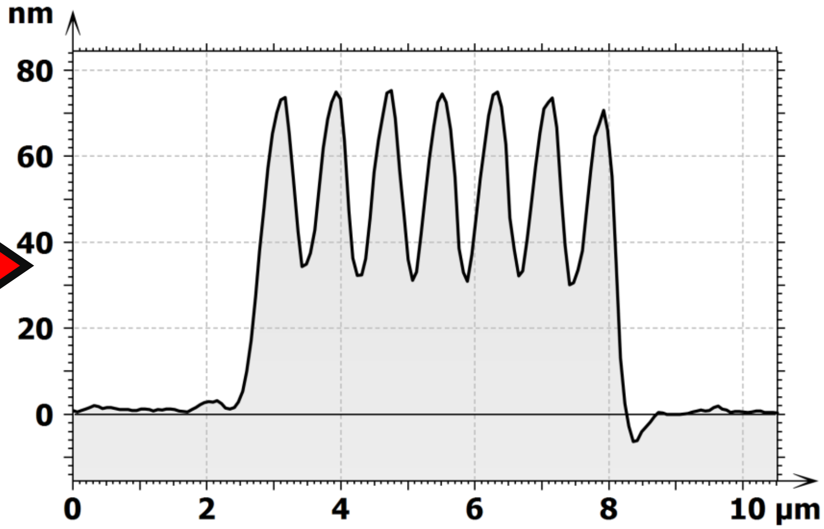
modulation below 50% of the real structure height

advanced data processing with super resolution

color coded 3d plot

profile



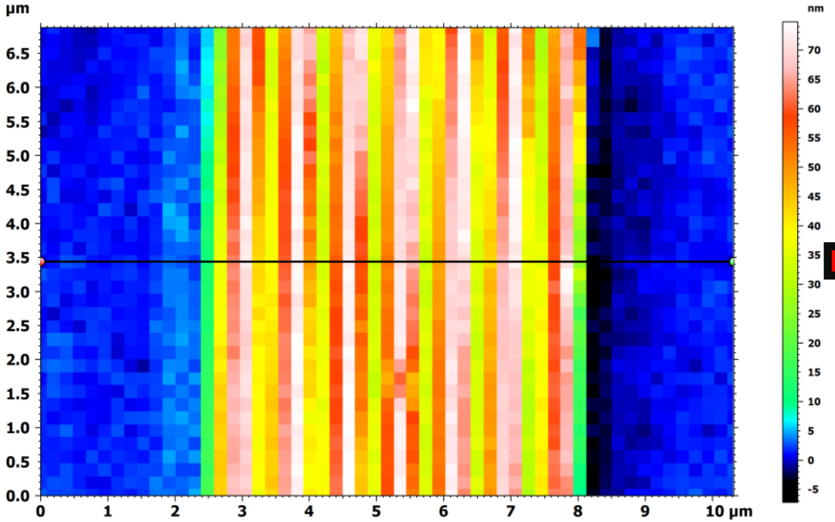


noise reduction, increased resolution

improved height signal

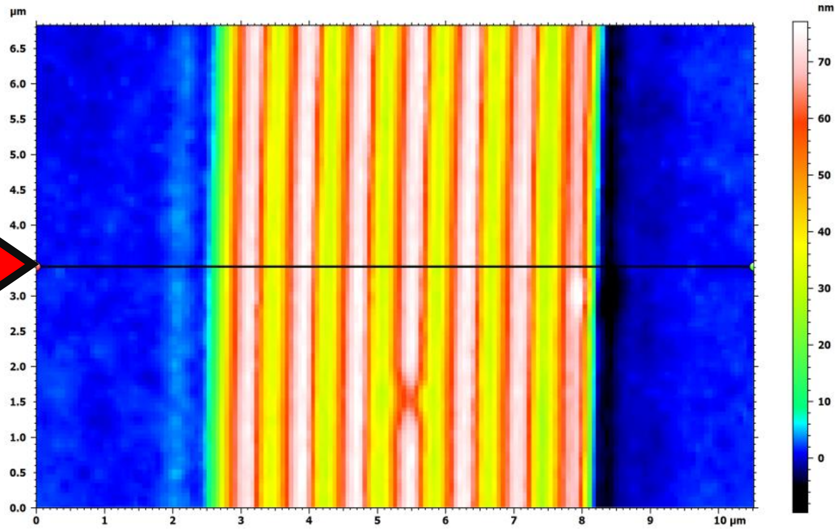
comparison of the 3d data

standard resolution



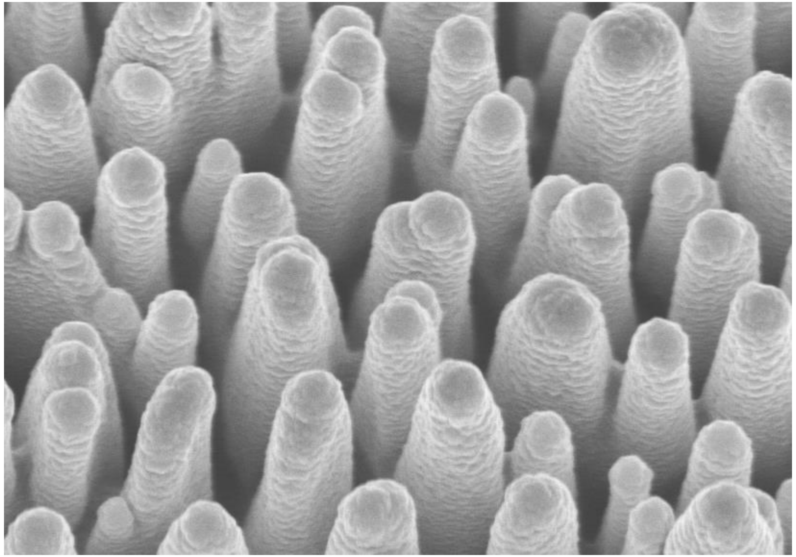
moiré effects, zones with reduced amplitude

super resolution



significant closer to the real 3d structures

the challenge to measure nano structures 3d



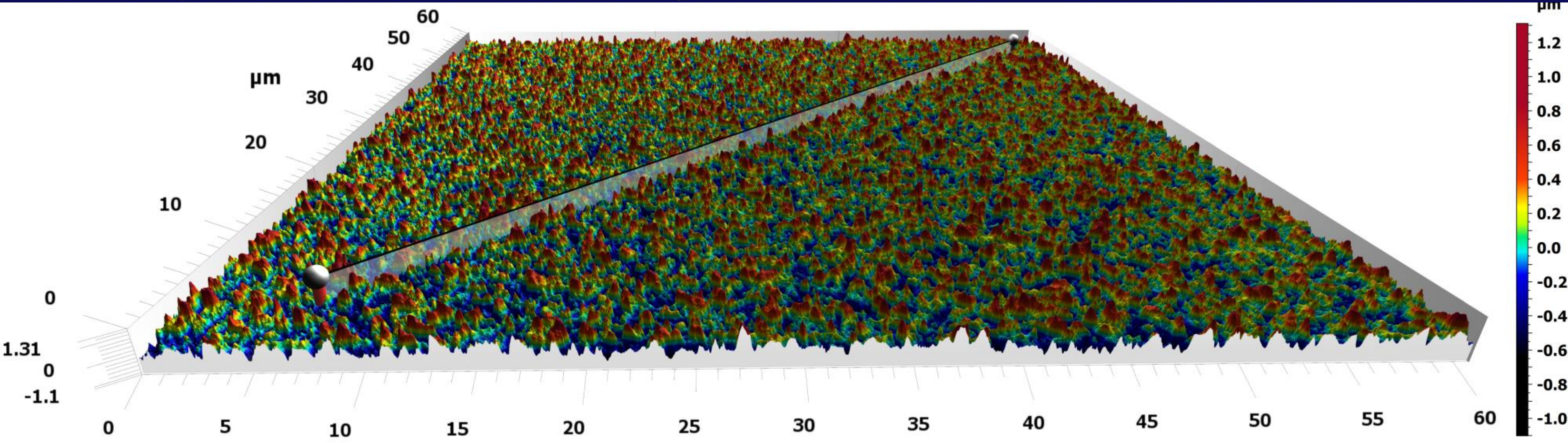
SEM image
functional “black silicon” structure

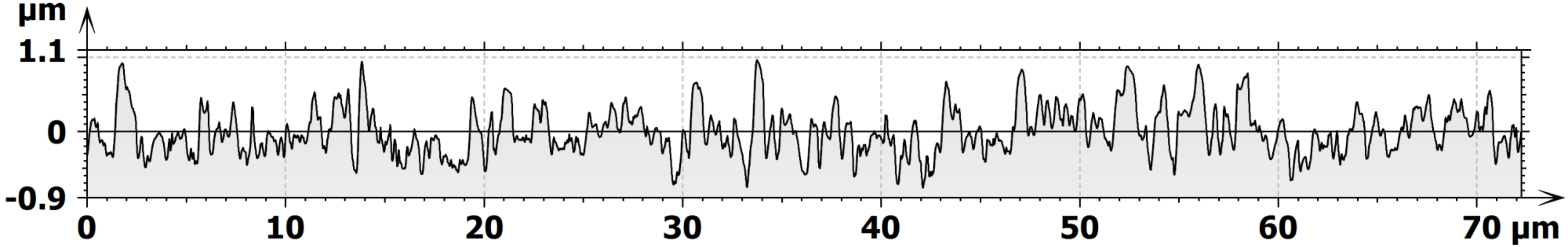
AFM:
- structures could not be reached
- and potentially break the tip

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

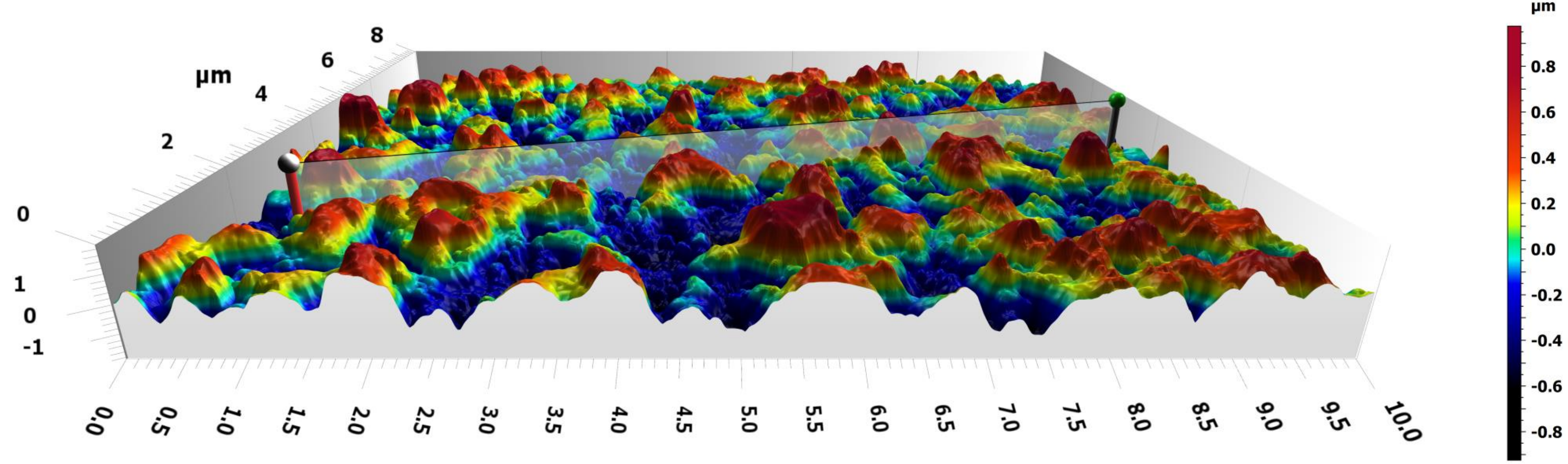
smartWLI:
- is it possible to measure such structures?
- what are the smallest structures which can be measured?

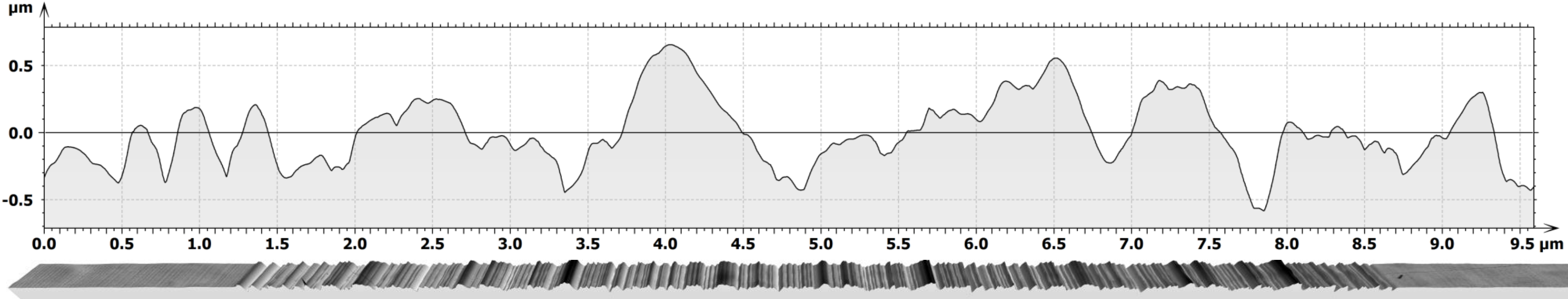
smartWLI nanoscan: “black silicon” structures





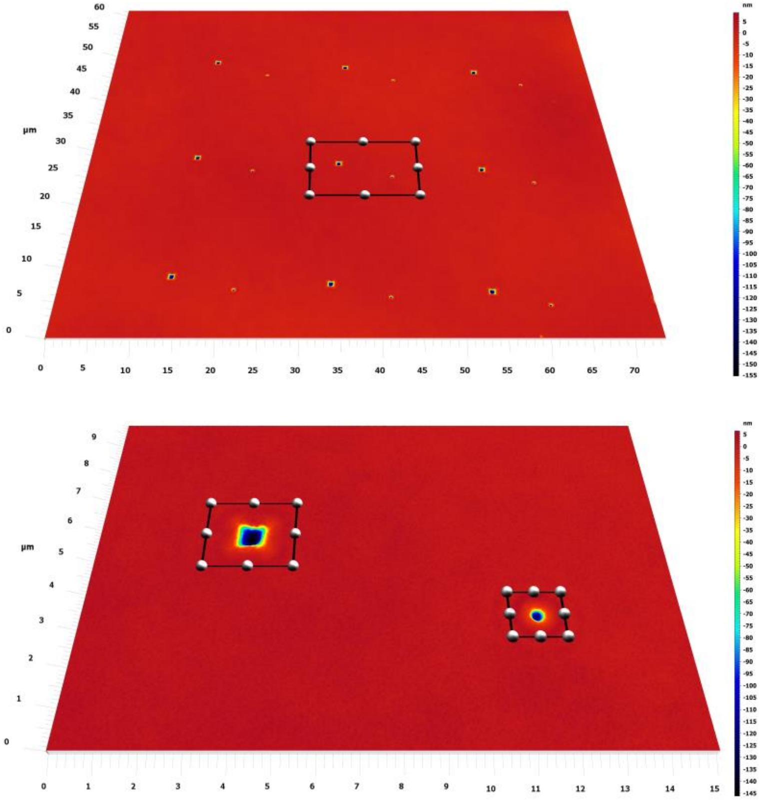
“black silicon” structures – partial area



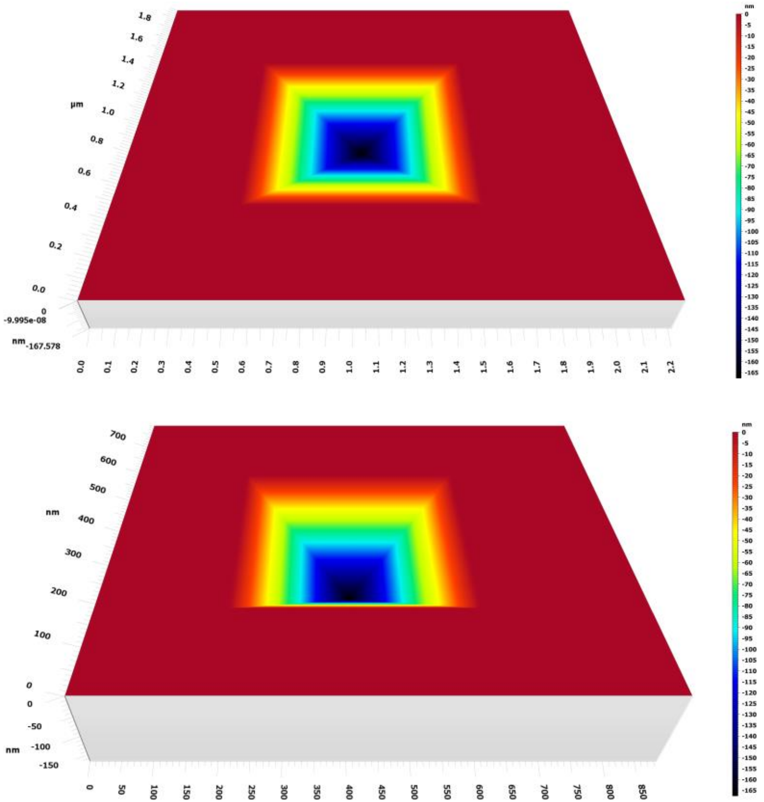


profile fidelity on sub micrometer structures

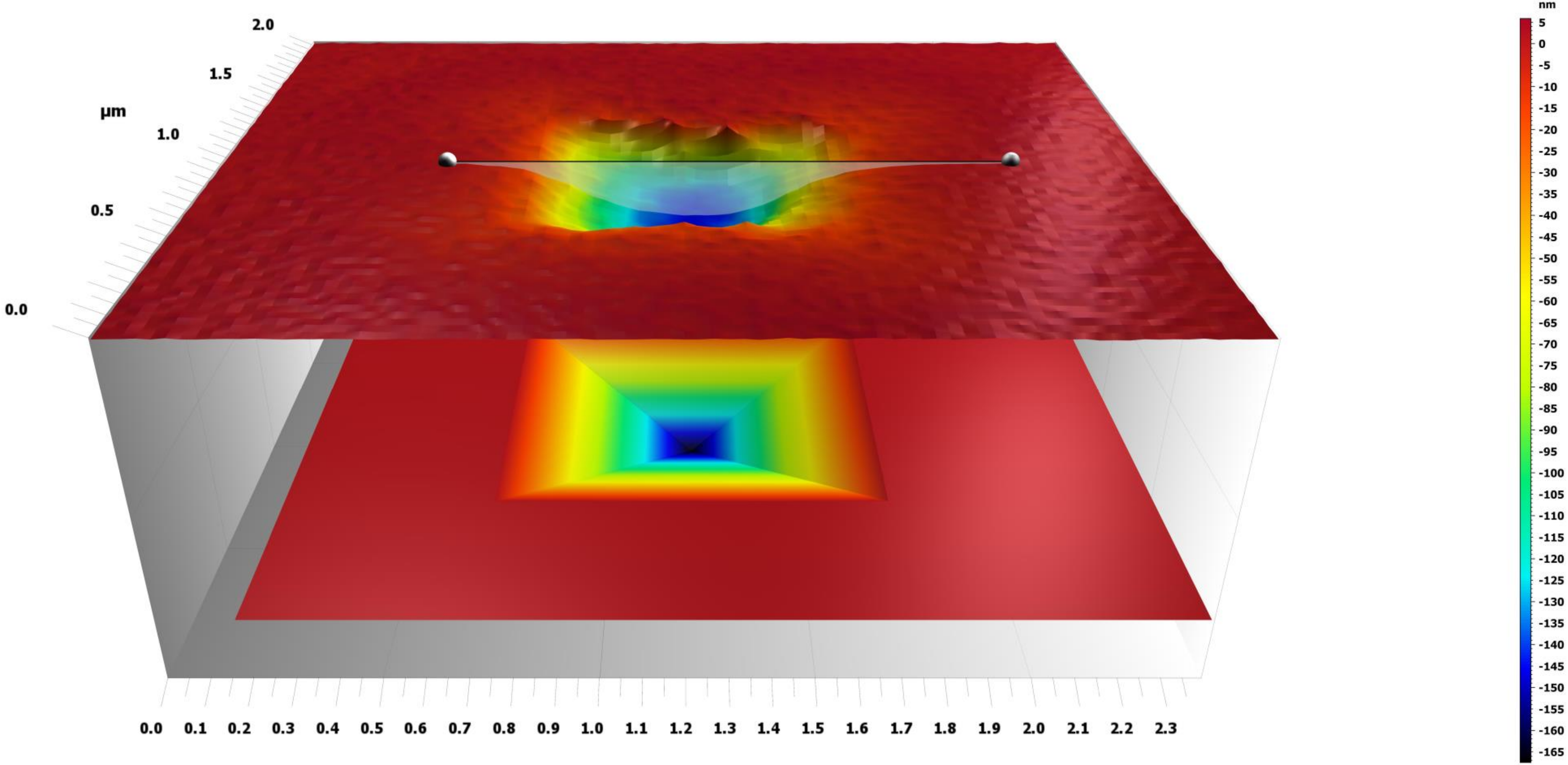
smartWLI nanoscan / superresolution



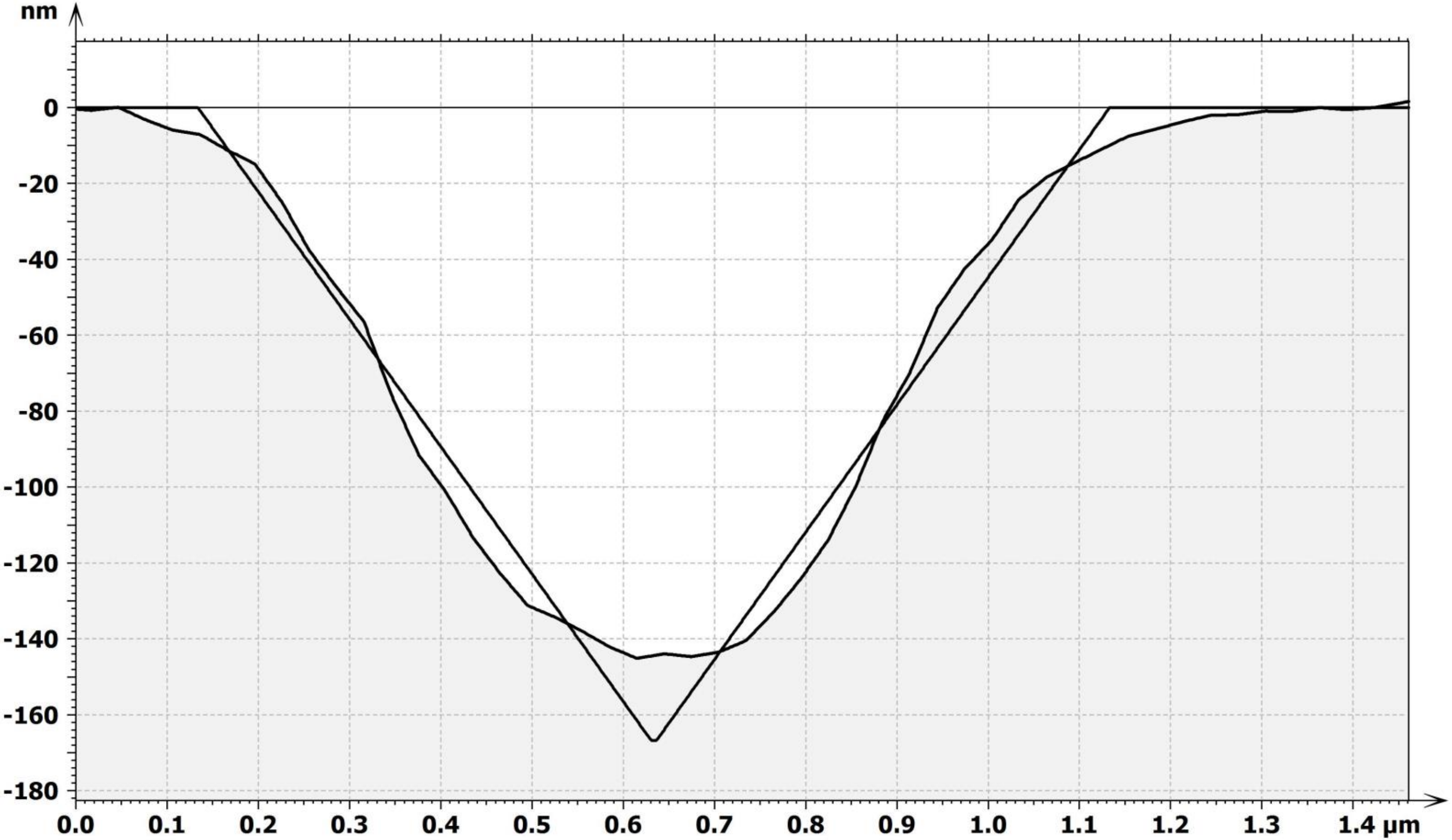
AFM pitch standard reference geometry



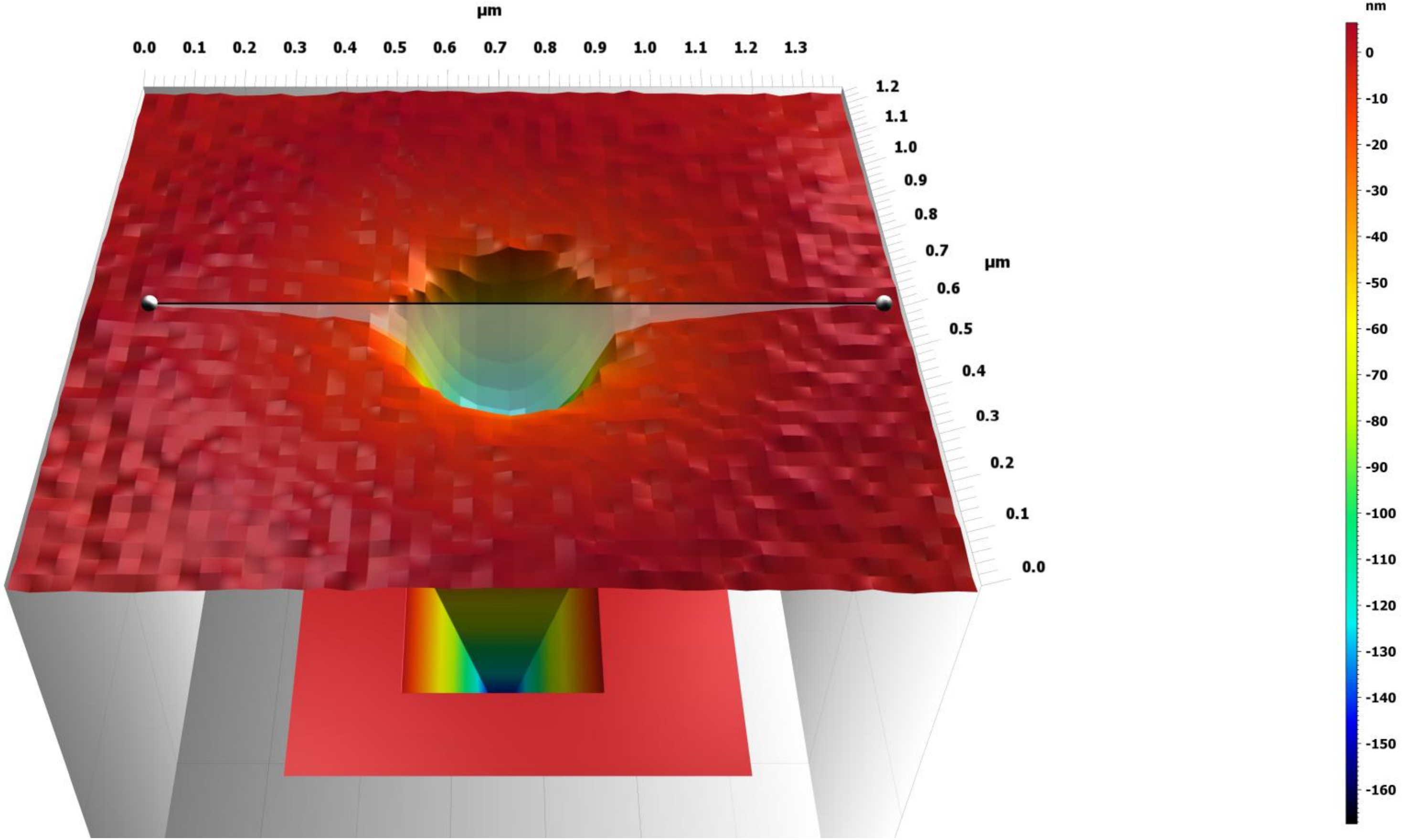
profile alignment / 1 µm pyramid structure



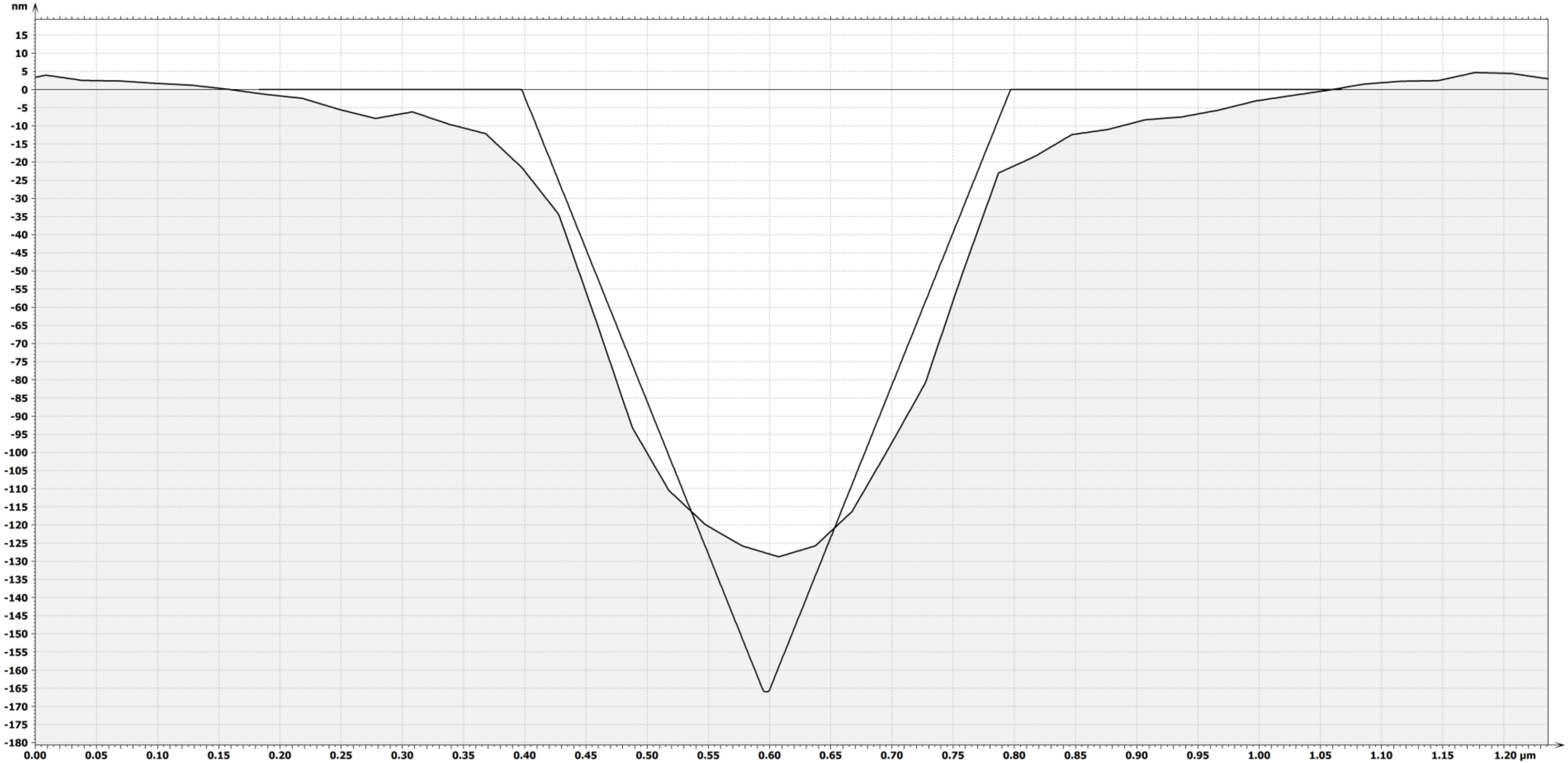
profile comparison 1 µm pyramid structure



profile alignment / 0.4 µm pyramid structure



profile comparison 0.4 µm pyramid structure



conclusion

- *super resolution improve the measuring results:*
  - *increase the point density*
  - *reduce the noise*
  - *improve the profile fidelity*

- *the systems can be used to measure structures with an height below 0.1 nm and achieve a profile fidelity down to app. 0.1 µm on structures below 1 µm*

- *the processing on the GPGPU (general purpose graphic processing unit) enables the calculation of 3d with super resolution in real time*