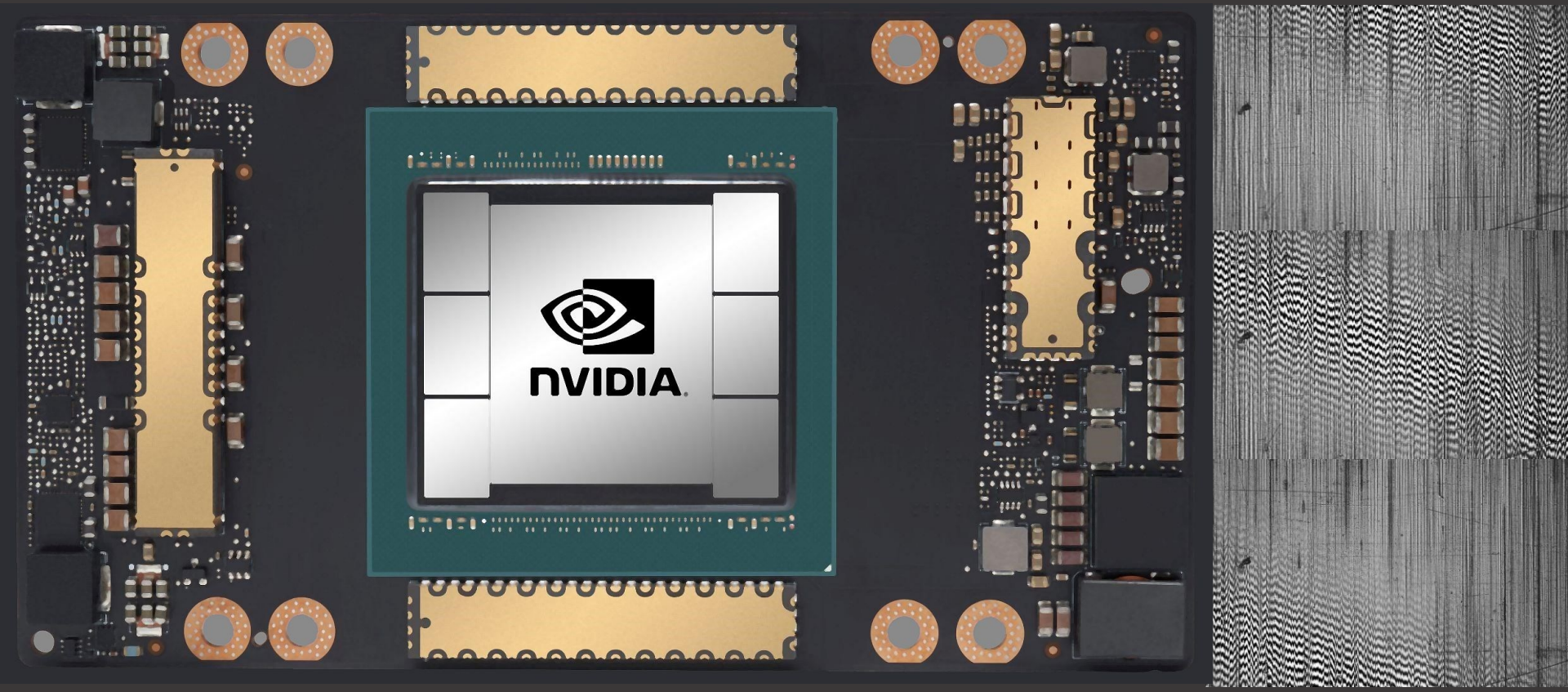
smartWLI — the impact of massive parallel data processing



gbs

ON COHERENCE-SCANNING (WHITE-LIGHT) INTERFEROMETRY

smart WLI GBS Ilmenau – company head quarter

roots in the institutional research
established since 1997

products
- ✓ optical 3d sensors
- ✓ optical profilers
- ✓ portal measuring systems

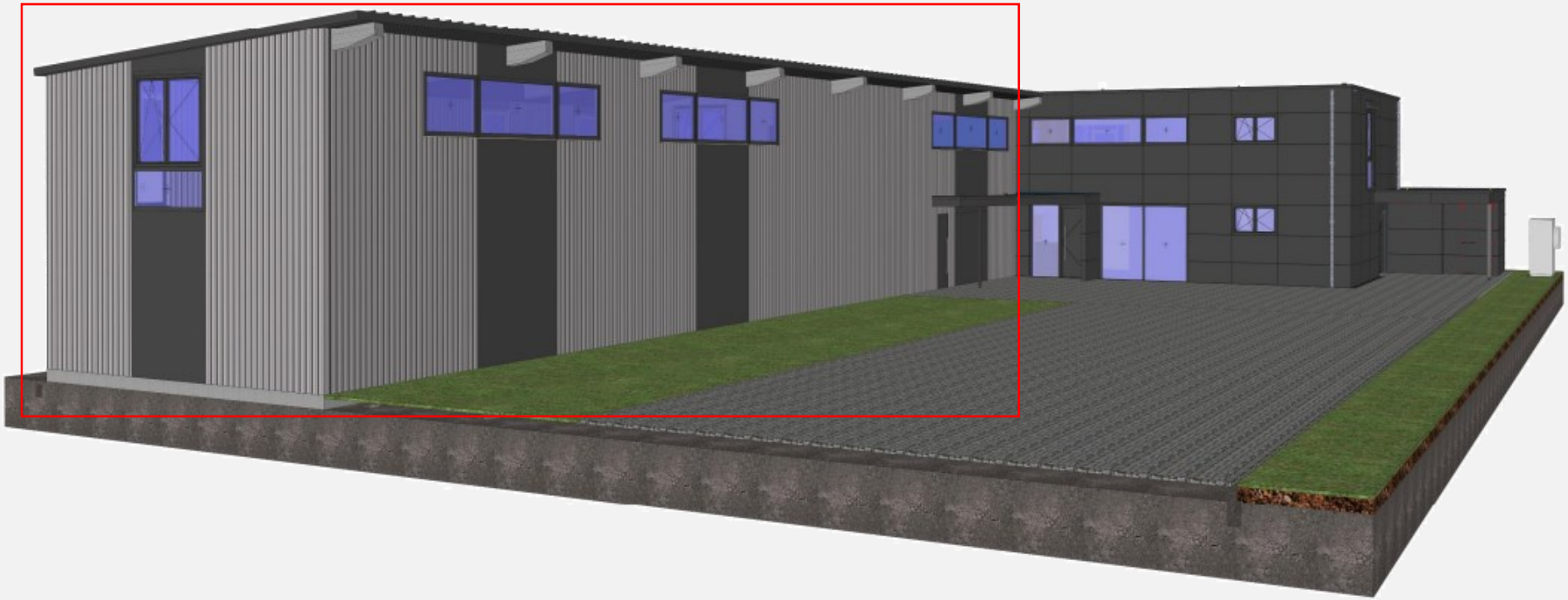
measuring technology
coherence scanning (white-light) interferometry

applications
measurement of surface structures,
measurement of micro- and nano geometries

branches
semiconductors, optics, precision machining

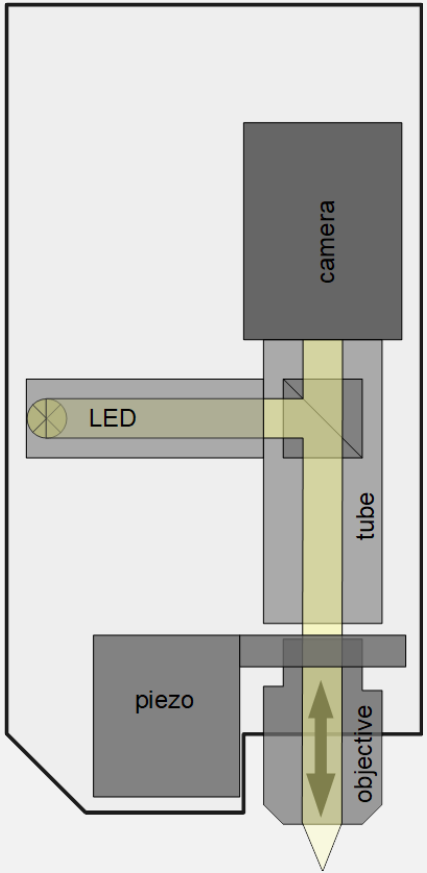
technical expertise
massive parallel image processing
acceleration of high-performance sensors

smart WLI expansion of the production



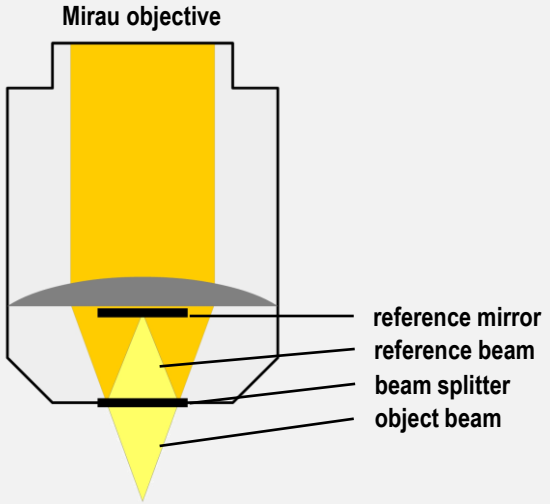
new building project starts in Q2/2023:
After moving into the new headquarter in February 2022 GBS is already confronted with limitations and will double the production capacities until the end of 2023.

smart WLI coherence-scanning (white-light) interferometer

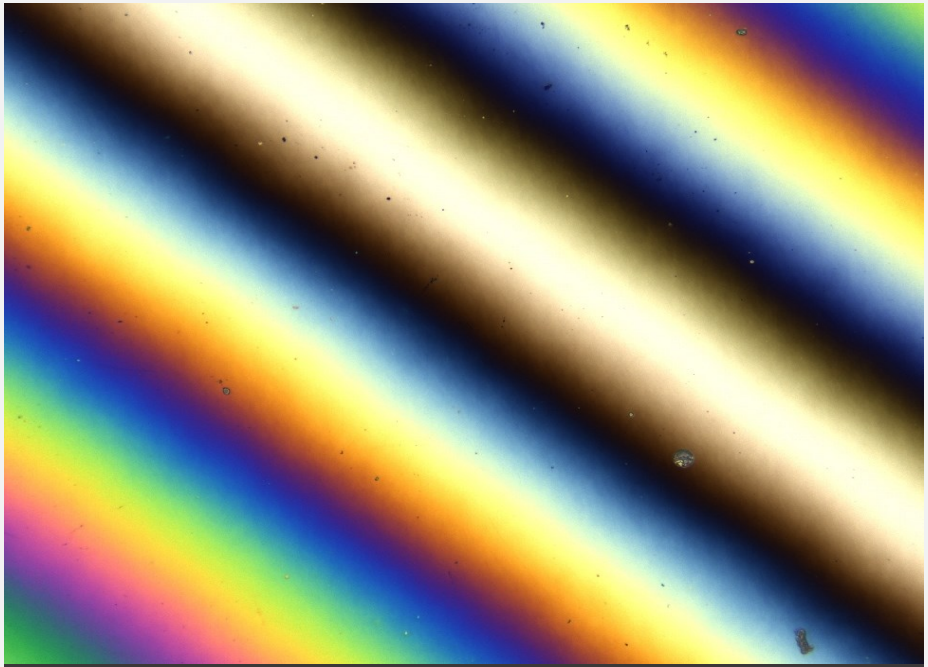


coherence-scanning (white-light) interferometer:

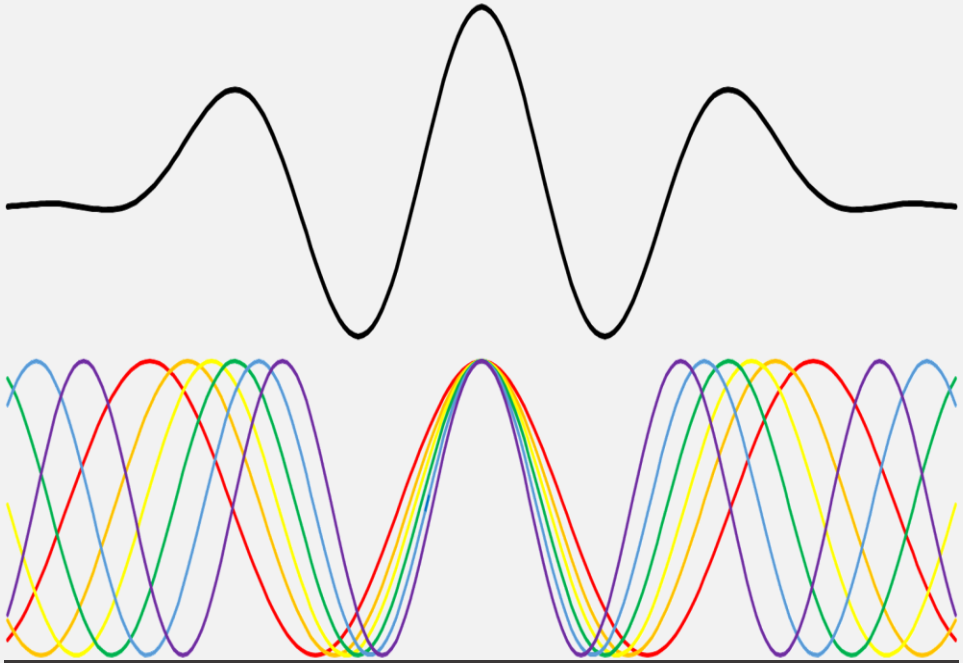
- are microscopic optical devices
- with an attached interference objective
- which can moved relative to the measuring object



smart WLI interferences of white light



camera image of a mirror / centre of the interference zone



resulting light intensity out of spectral shifted interferences

light from object and reference mirror interfere which each other
once object beam and reference beam are equidistant the complete all spectral colours interfere with max. intensity
the different wave length cause the decay of the resulting sinus like interference signal with growing distance from the centre point

strongholds	traditional limitation
touch free area measurements	sensitive to vibrations
extreme high resolution	not for rough surfaces
wide field measurements	low number of measuring points
quick measurements	limited angular characteristic

massive parallel data processing is used to overcome traditional limitation

smart WLI product development and acceleration

2009 / 14 fps

2012 / 30 fps

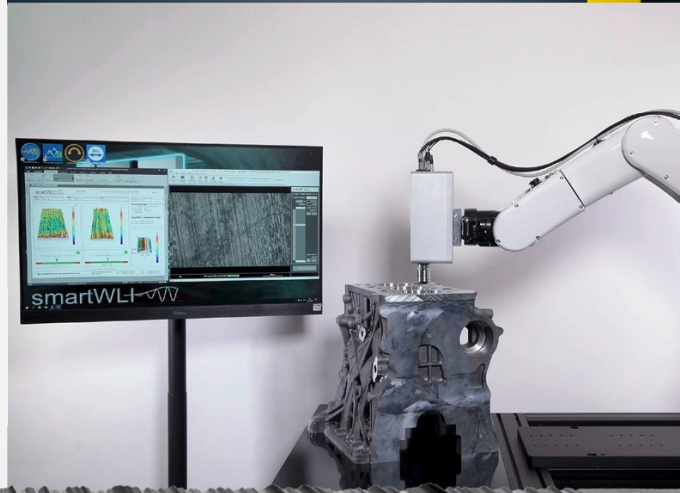
2014 / 60 fps

2017 / 169 fps

2021 / 935 fps

	present PC	increasing performance of modern GPGPUs			
	Core I9 13900K	GTX 1060	RTX 2060	RTX 3060	RTX 4090
release date	2022	2018	2019	2020	2022
FP32 (float) performance	0.74 TFLOPS	4,4 TFLOPS	6,4 TFLOPS	16,2 TFLOPS	82,6 TFLOPS

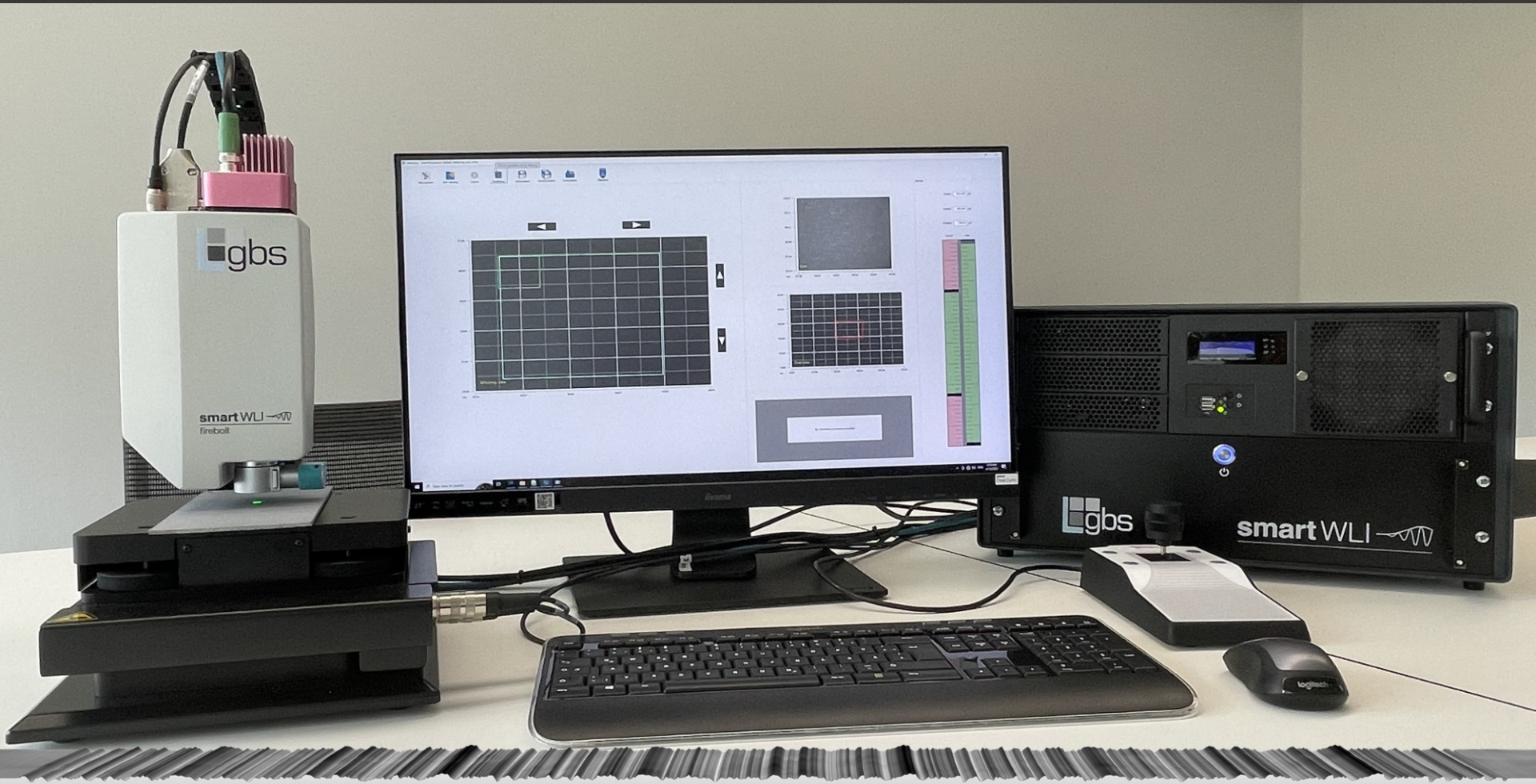
faster cameras / data acquisition and faster GPGPUs (general purpose graphic processing units) / data processing are the basis of new applications, higher resolution and accuracy and enables the operation in industrial environmental condition



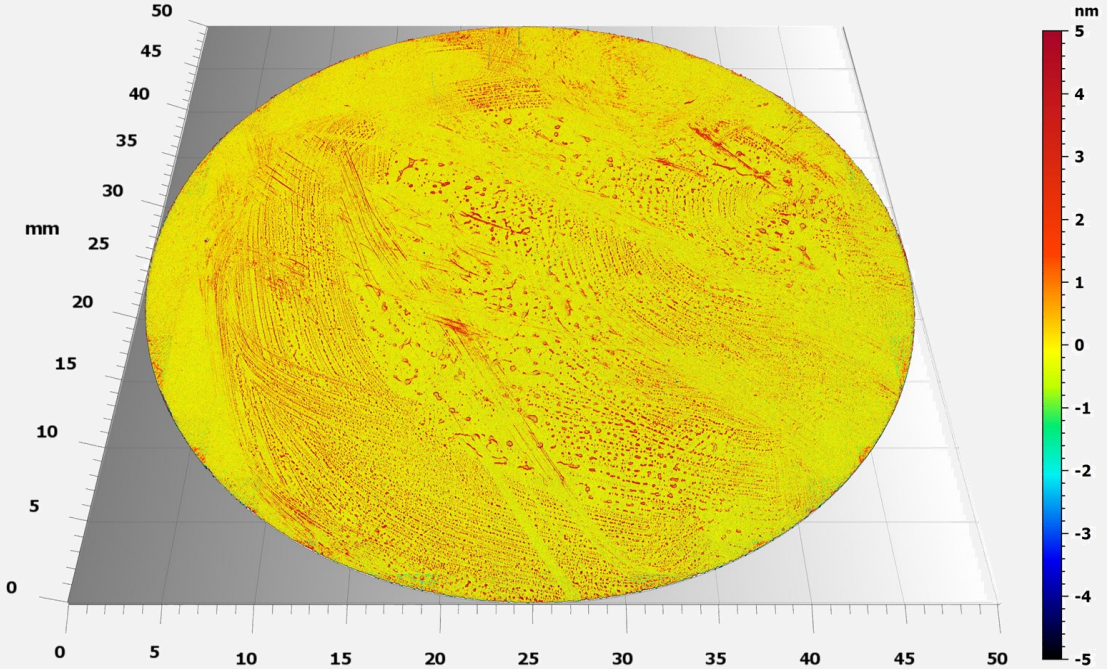
System acceleration:

- reduce the impact of environmental conditions, specifically vibrations
- reduce cycle times or enables the high resolution measurements of large areas

smart WLI system demonstration without anti-vibration system



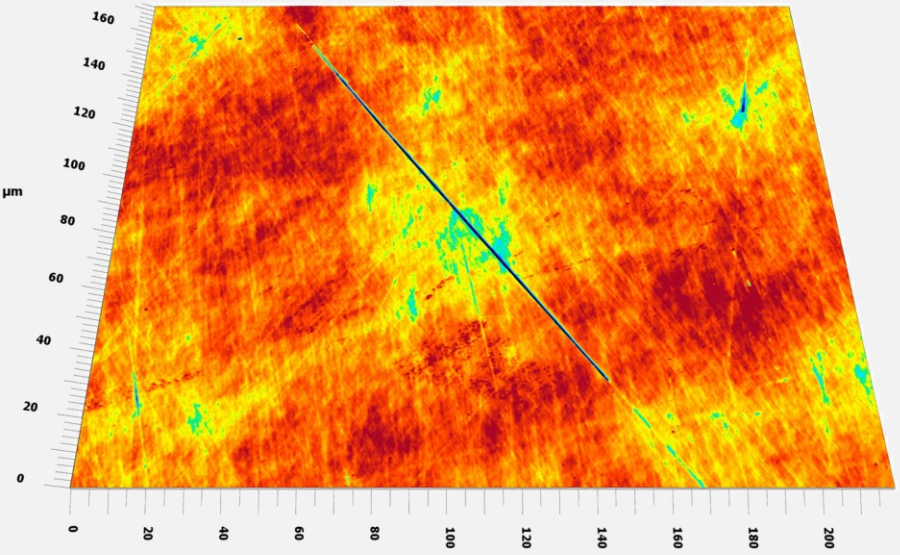
filter glass



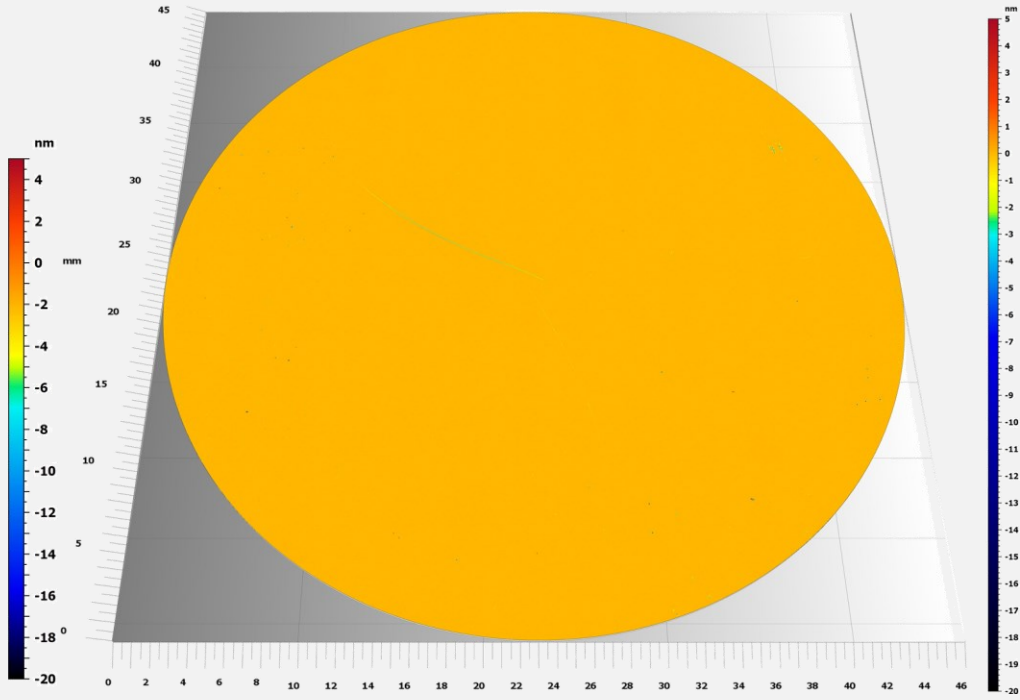
stitched image of a contaminated filter glass

sample cleaning is very important!

smartWLI high resolution measurements of large objects



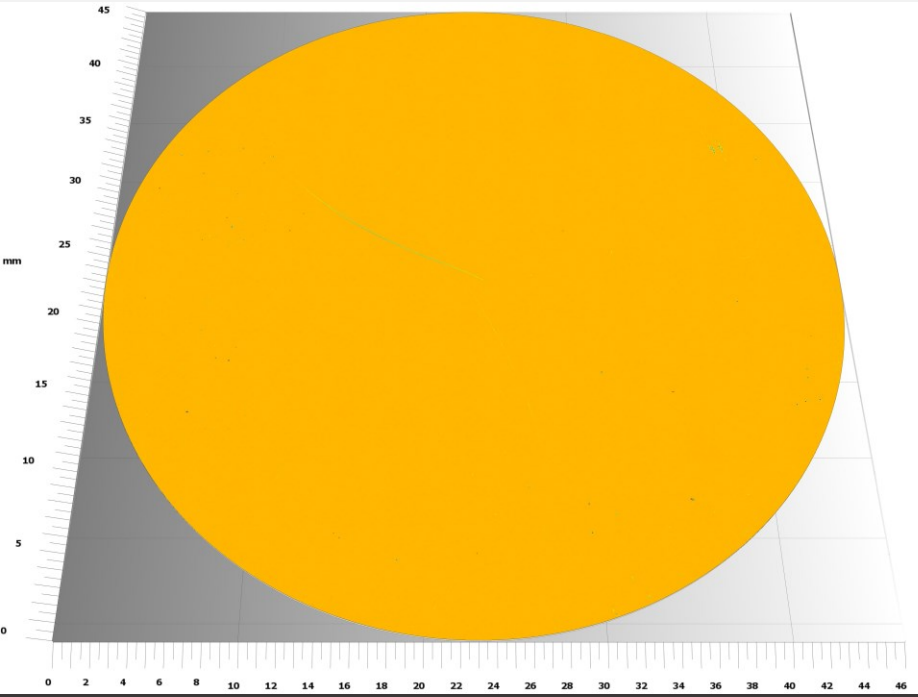
small defect



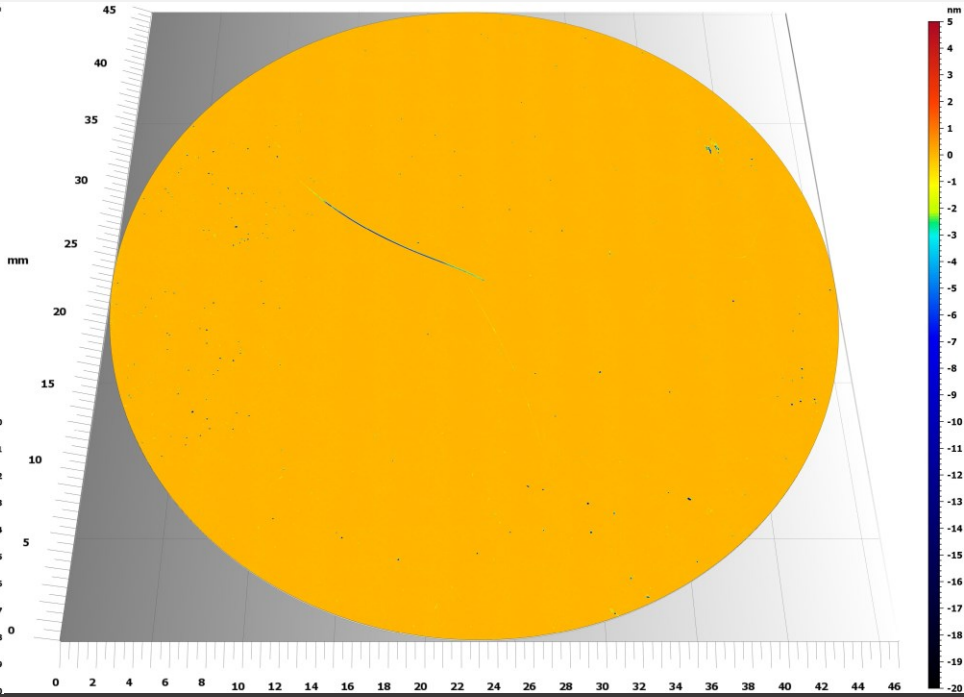
high resolution measurement of the complete sample

once the resolution of the scan is much higher than the screen resolution defect positions and shape information get lost

smart WLI visualization of small defects on large samples



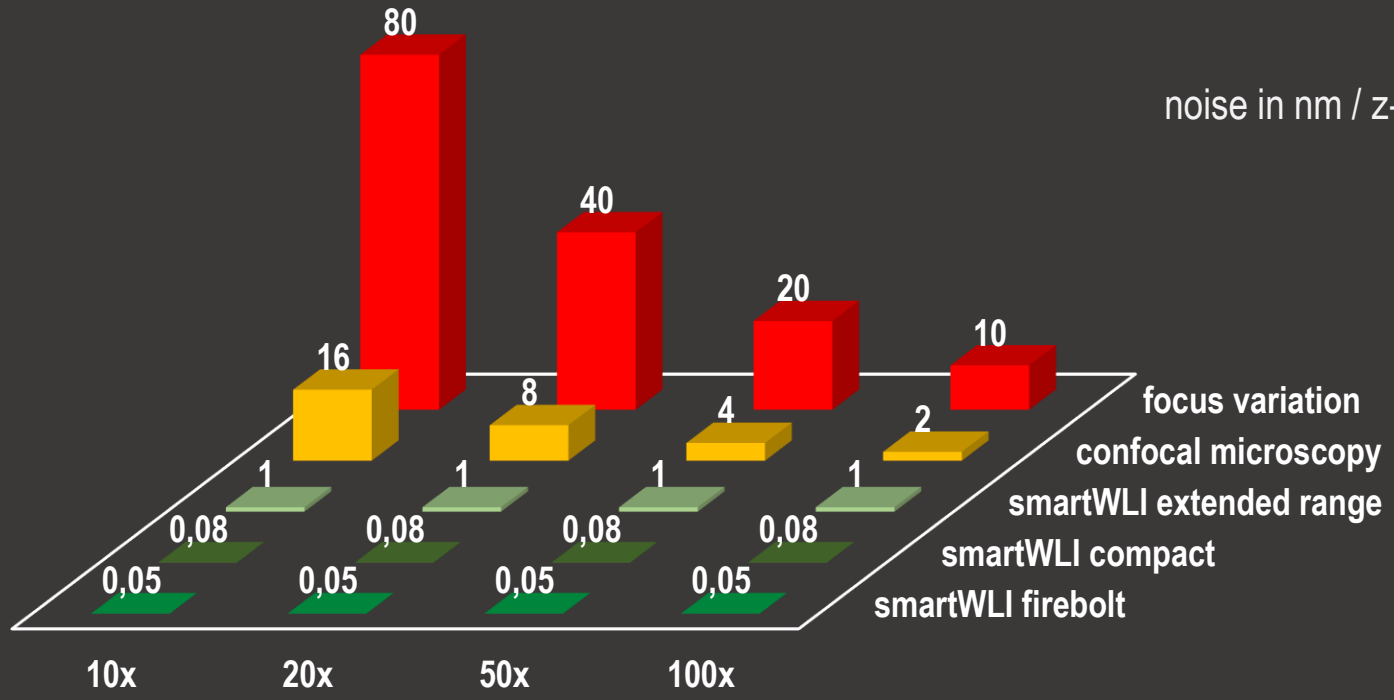
original data



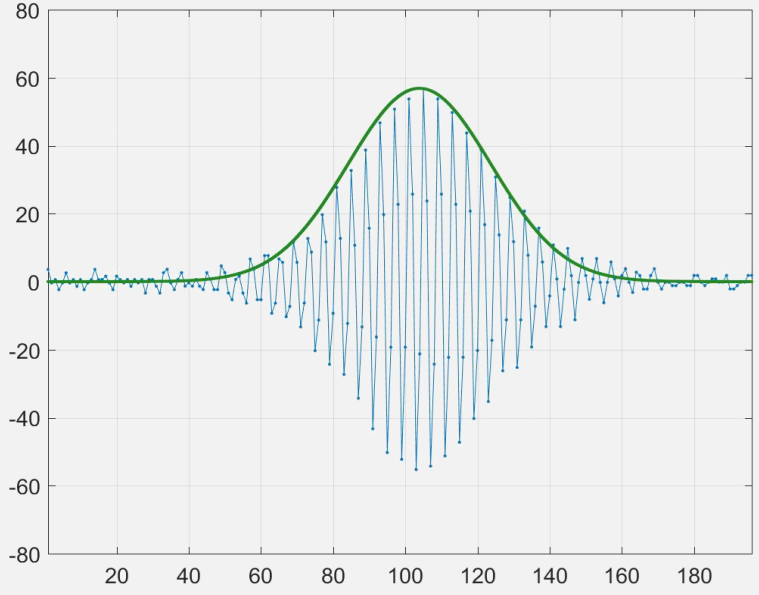
processed data – visualization of small defects

optimized data processing strategies simplify the visualization of small defects on large samples

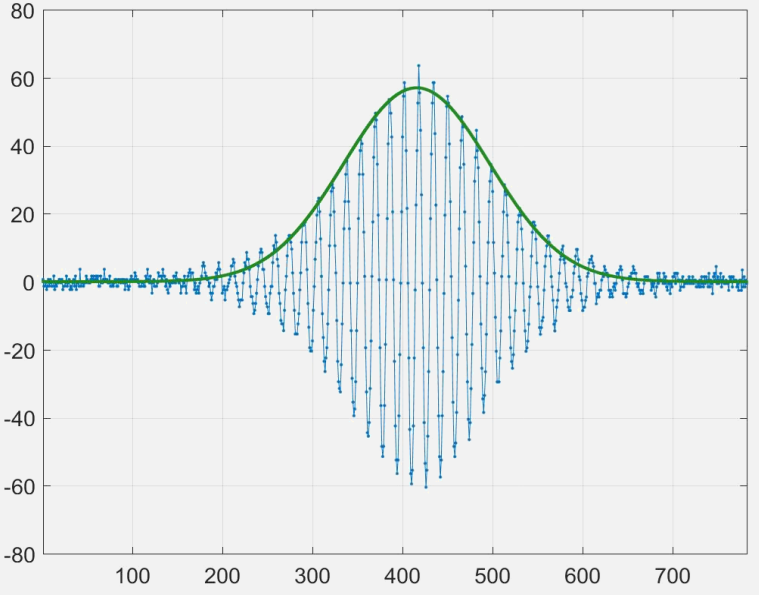
smartWLI traditional stronghold of the measuring principle



- *coherence-scanning (white-light)* interferometry *provide a extreme height resolution*
- *in contrary to alternative measuring principles is the resolution independent from the magnification*
- *smartWLI devices – noise rated using the topography reproducibility*



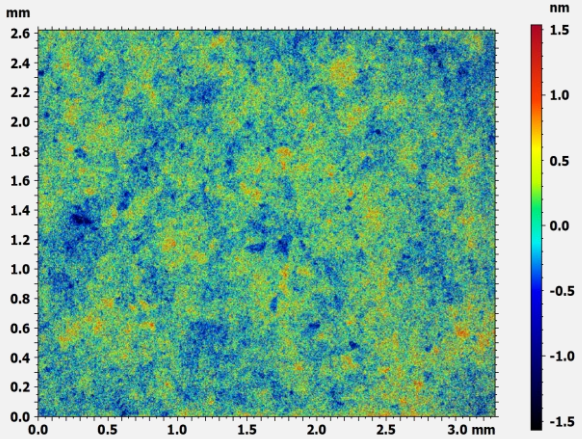
EPSI (extended phase shift interferometry)



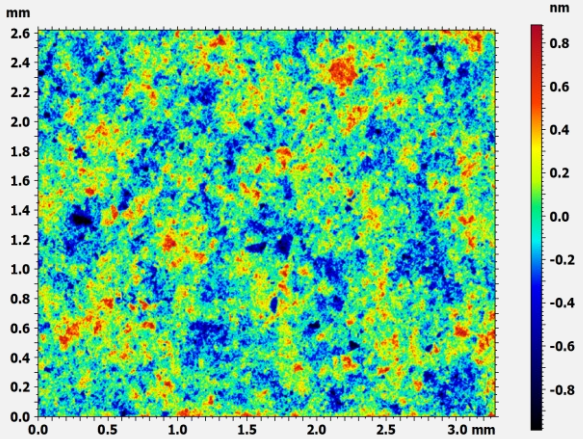
HD - EPSI (high density extended phase shift interferometry)

the data shows the correlograms - light intensity variation of a single camera pixel inside of the interference zone
camera speed and calculation power allow to acquire and process more data out of the interference zone in a shorter time period

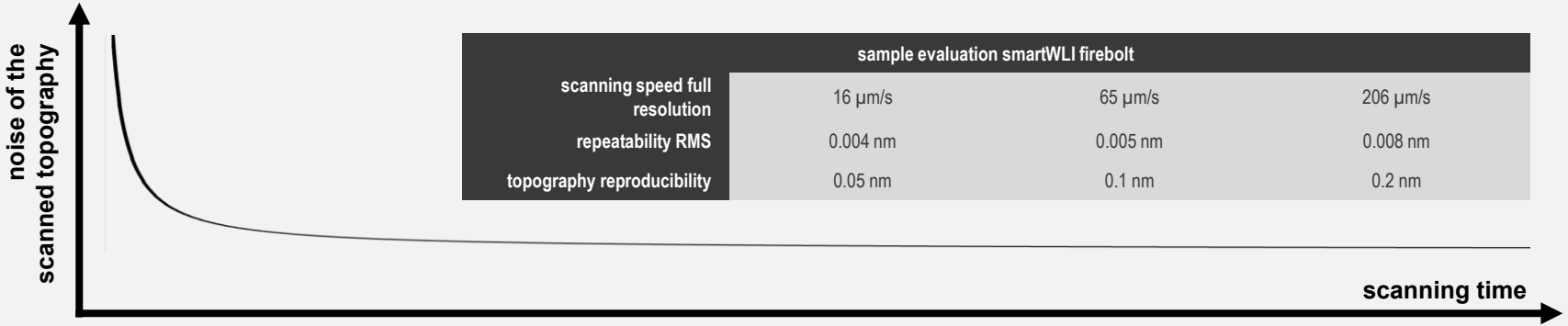
smartWLI HD-EPSI (high density-extended phase shift interferometry)



EPSI (extended phase shift interferometry)

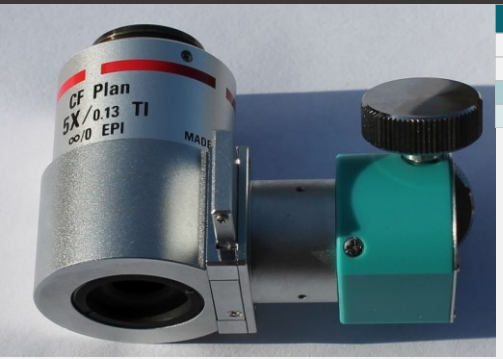


HD - EPSI (high density extended phase shift interferometry)

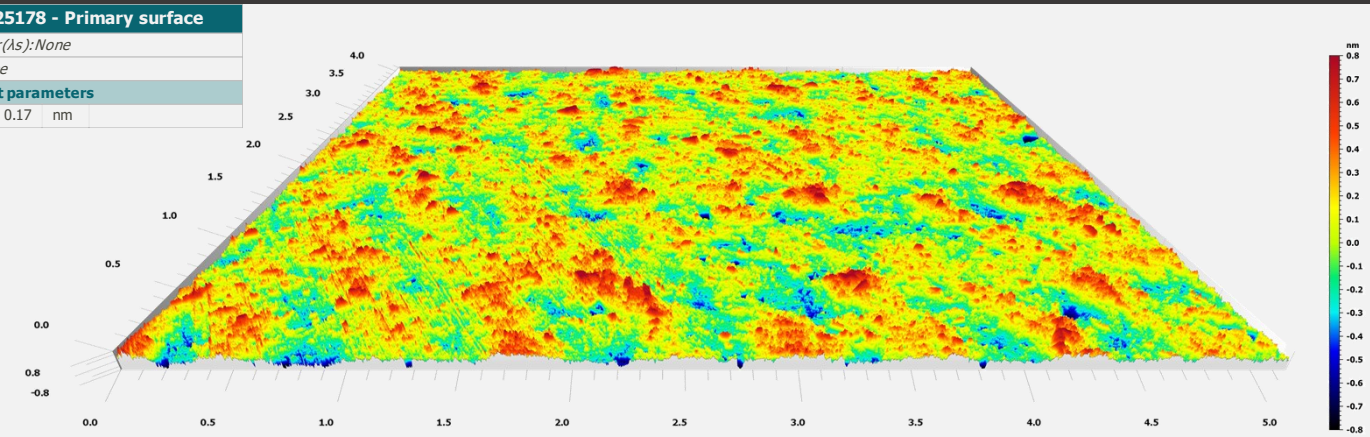


	sample evaluation smartWLI firebolt		
scanning speed full resolution	16 µm/s	65 µm/s	206 µm/s
repeatability RMS	0.004 nm	0.005 nm	0.008 nm
topography reproducibility	0.05 nm	0.1 nm	0.2 nm

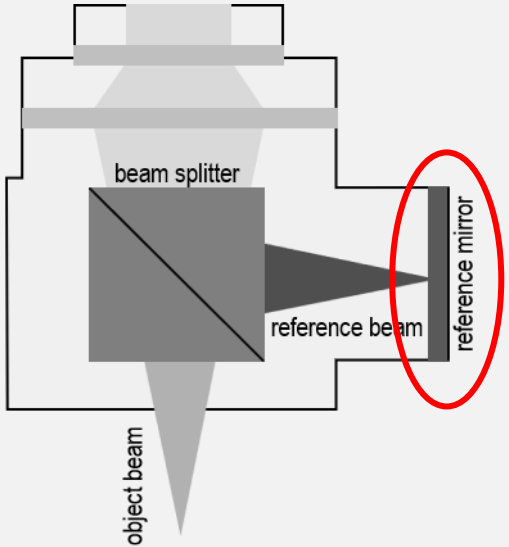
smartWLI improved calibration processes

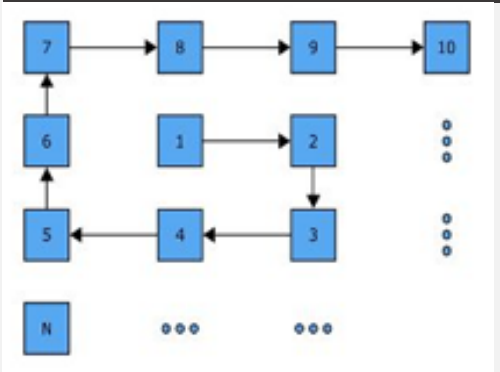


ISO 25178 - Primary surface		
S-filter(λs):None		
F: None		
Height parameters		
Sa	0.17	nm



SiC mirror - surface roughness of one of the best flatness standards



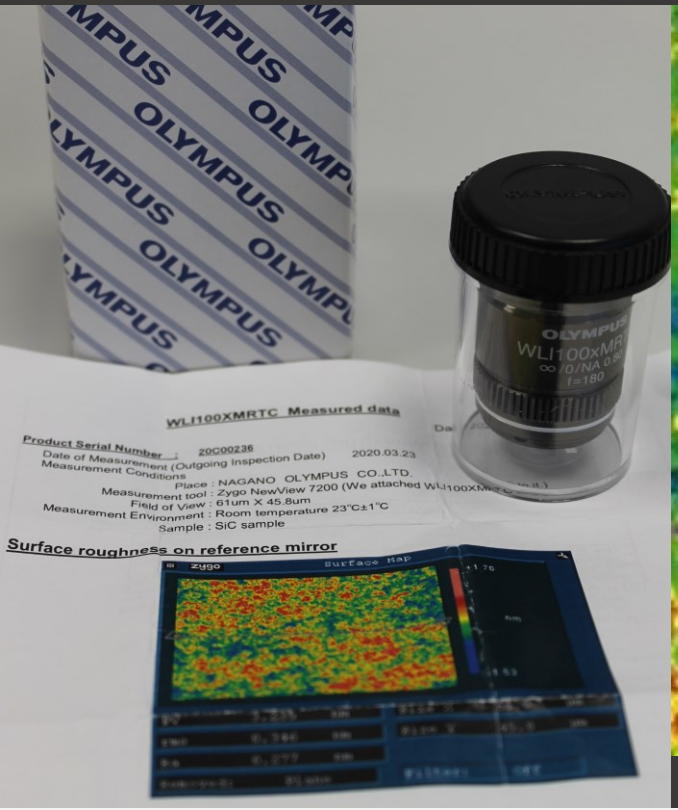


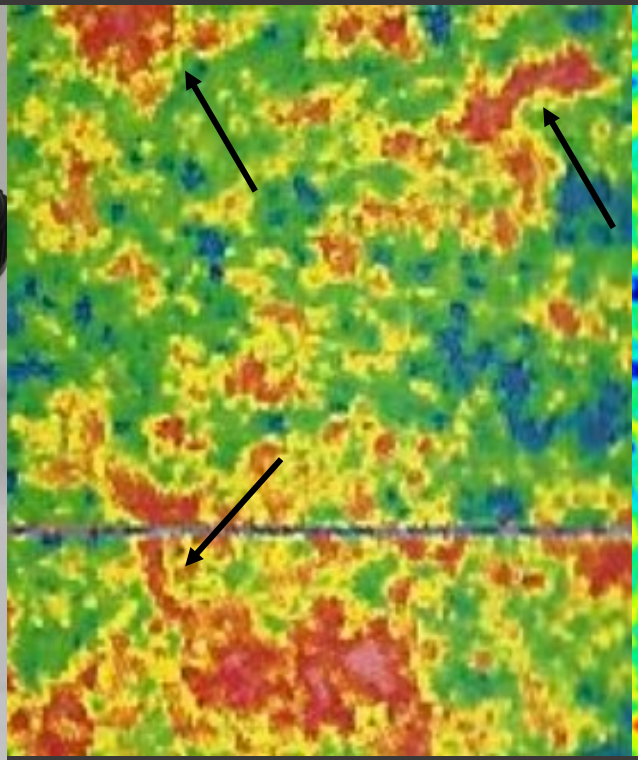
multiple positions

multiple positions – flatness calibrations

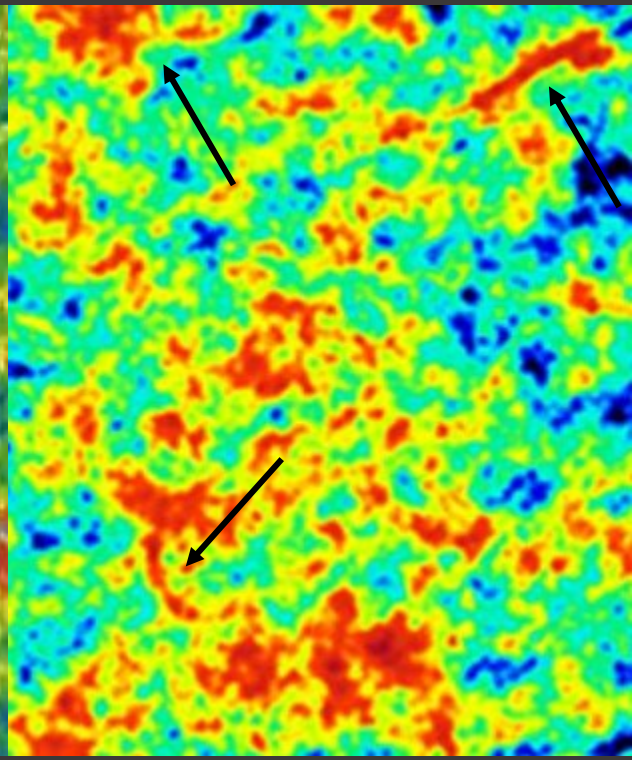
- even best flatness standards are not much better than the reference mirror of the interference objective
- multiple positions and state of art filtering and averaging processes are used for system calibration
- using 100 positions and automated positioning processes the systematically error can be reduced below Sa 0.02 nm

smartWLI elimination of reference mirror structures





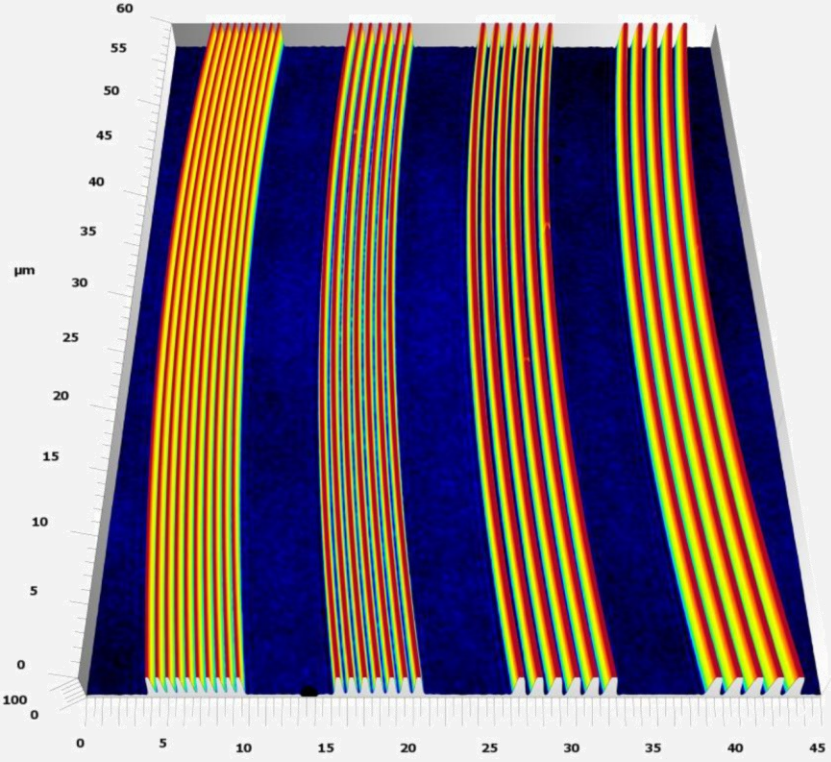
Zygo New View 7200 / partial area, Ra = 0.277 nm



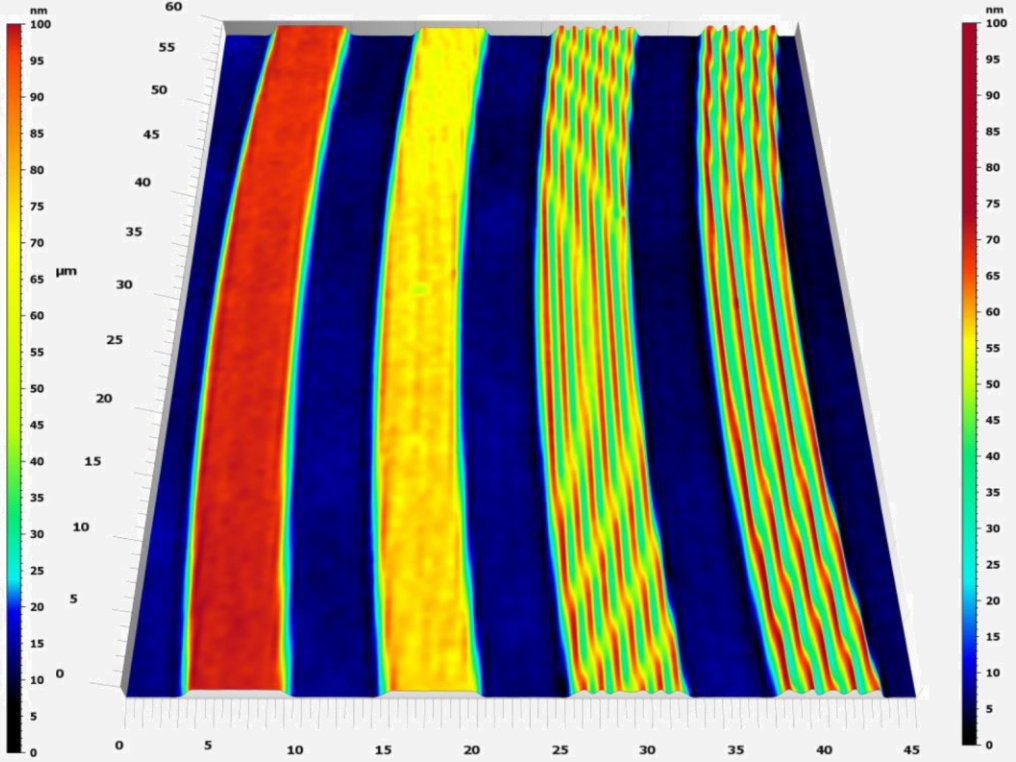
smartWLI nanoscan /partial area, Sa = 0.24 nm

- part of the delivery of the Olympus 100x WLI objective is a measuring protocol of the surface roughness from the reference mirror
- plausibility tests can reproduce the protocolled structures – using the objective on a complete different sensor – independent from the optical components and camera
- measurements can be reproduced and subtracted from scans as part as part of the system/objective calibration

smartWLI the lateral system resolution



smartWLI nanoscan, 100 x objective



smartWLI nanoscan, 20x objective - partial area

shorter cycle times for singles scans allows to use higher magnification objectives and getting more data from the same object in the same time

smartWLI high resolution cameras

50x objective, NA = 0.55

Sparrow's – criterion: $d=(0.47 * \lambda)/NA$

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

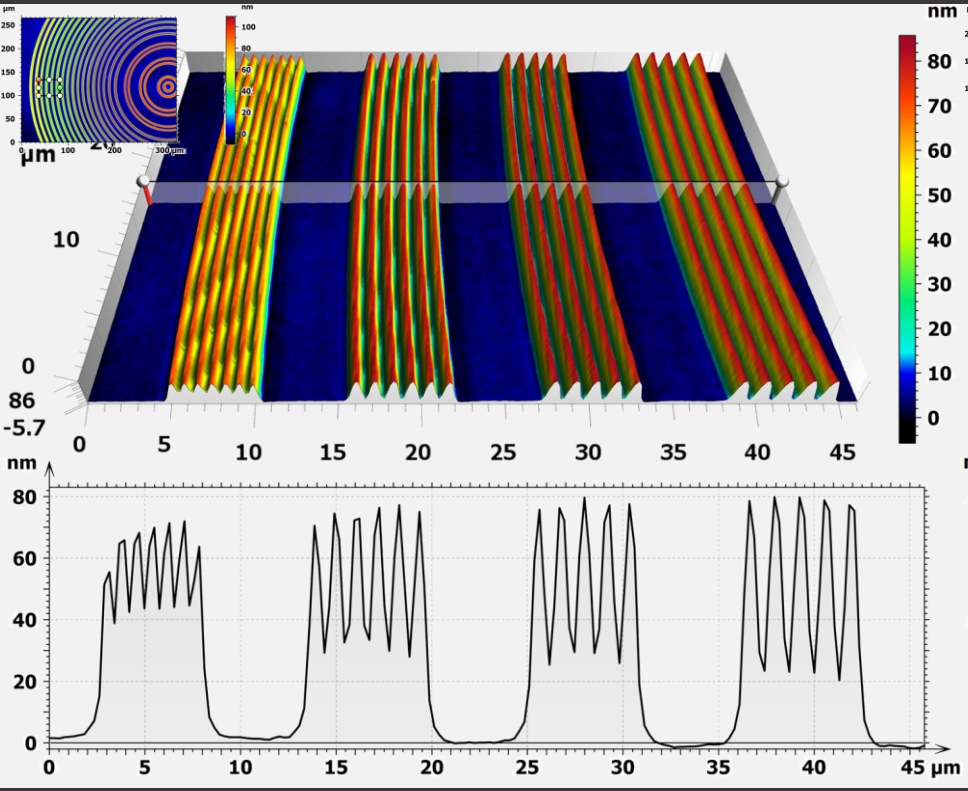
50x objective - separation limit of 2 light sources - 0.5 µm

sensor	firebolt	compact
camera	1280 x 1024	1920 x 1200
point density	0.29 µm / 50x objective	0.19 µm / 50x objective

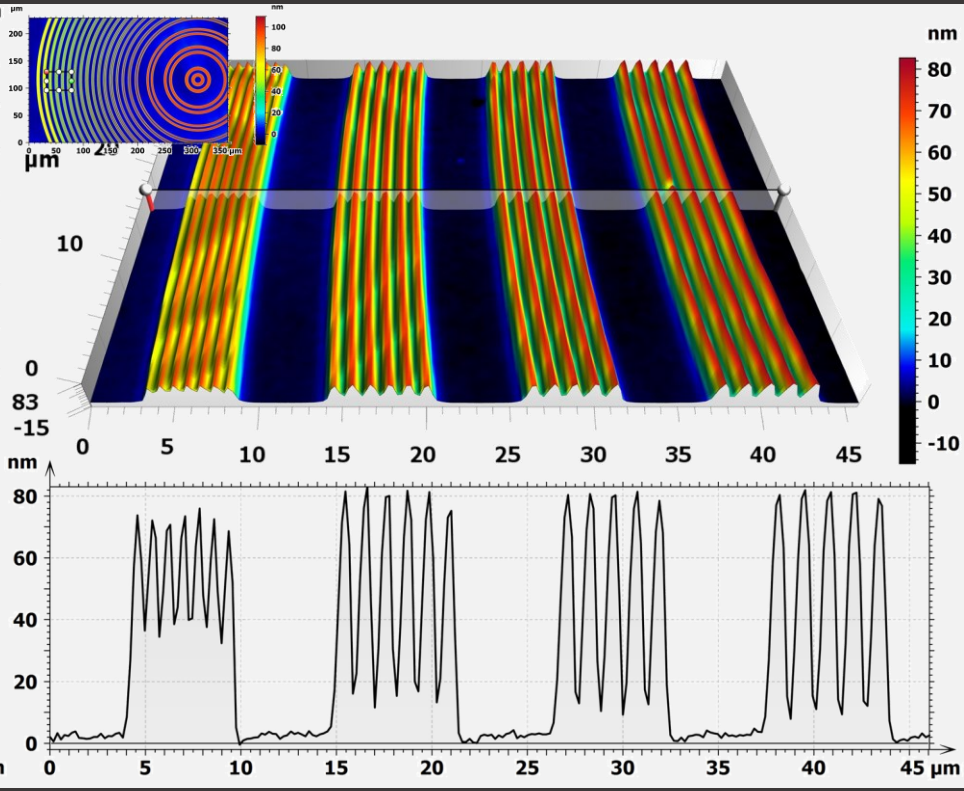
camera selection:

- the lateral resolution is limited from the aperture of the objective
- massive parallel data processing enable the use of high resolution cameras
- did the better point density of high resolution cameras make sense once the distance between measuring points is better than the optical resolution?
- can the sensor smartWLI compact provide better resolution than the smartWLI firebolt once both sensors are equipped with the same objective?

smartWLI comparison of smartWLI firebolt and smartWLI compact



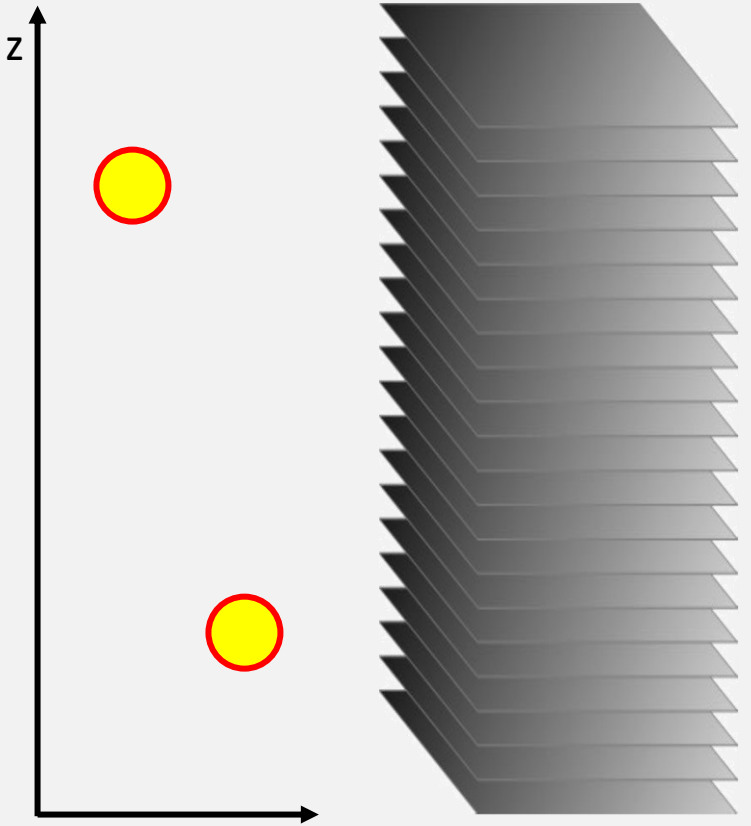
smartWLI firebolt

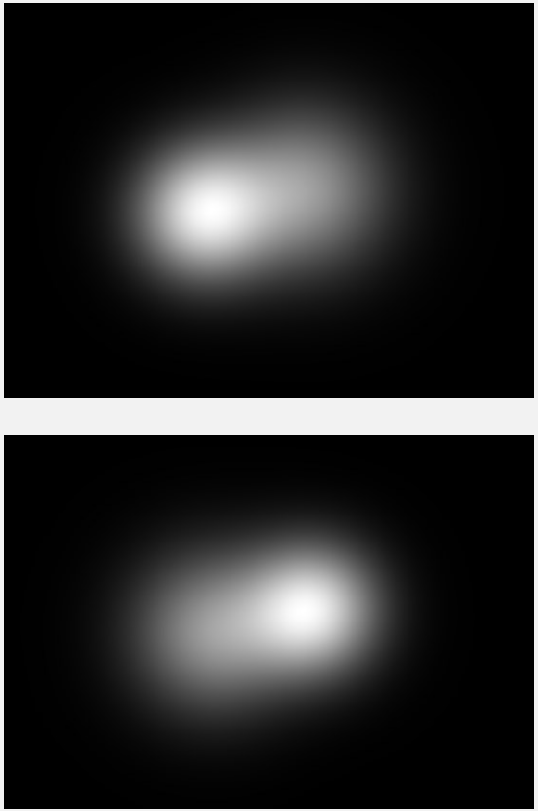


smartWLI compact

conclusion: cameras with higher resolution improve the lateral resolution – even with a point density below the Sparrow criterion

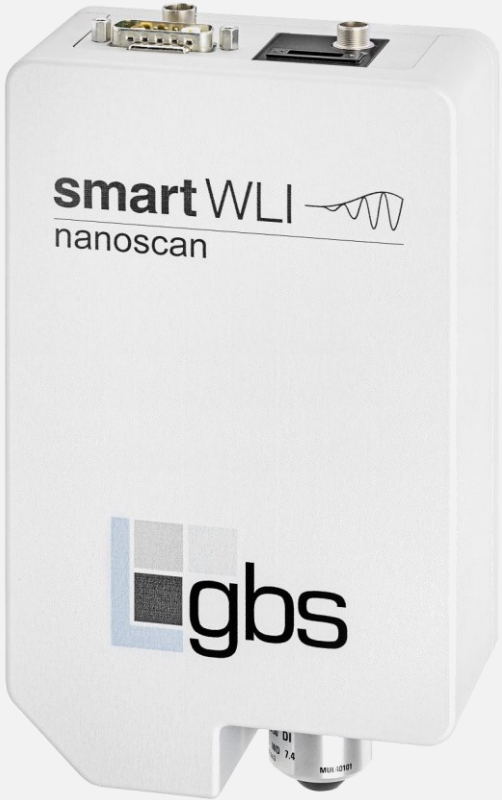
smart WLI improved resolution because of height differences

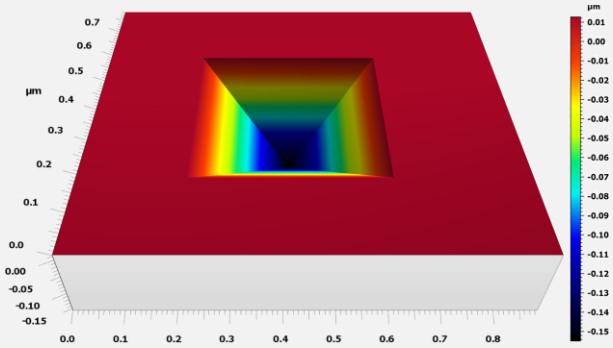




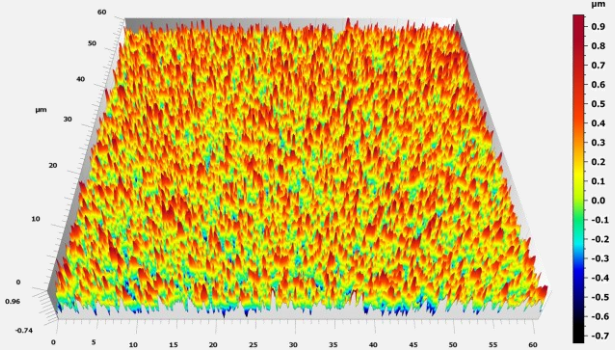
- height differences simplify the signal separation
- the light source in optimal sharpness can better separated from the other light source at a different height level
- aperture and optical resolution still have a big influence on the system resolution of optical area scanning systems but based on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

smart WLI improved resolution because of height differences

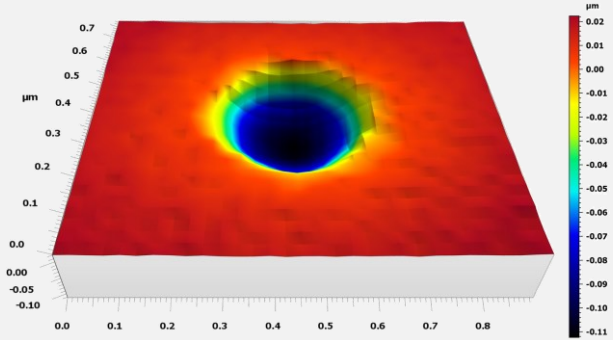




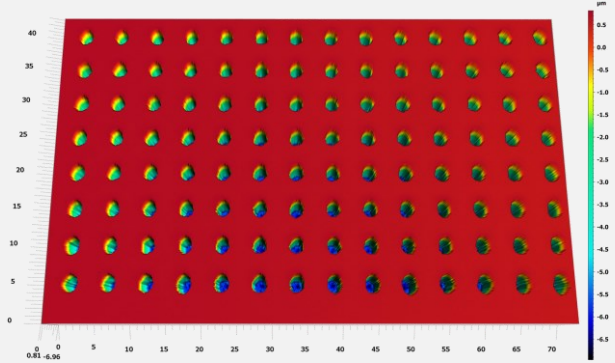
geometry on an AFM standard, 0.4 µm edge length



black silicon structure

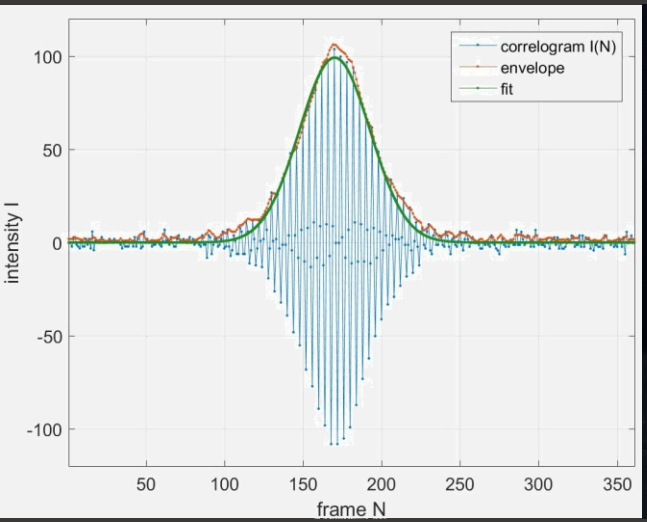


measured geometry / smartWLI nanoscan

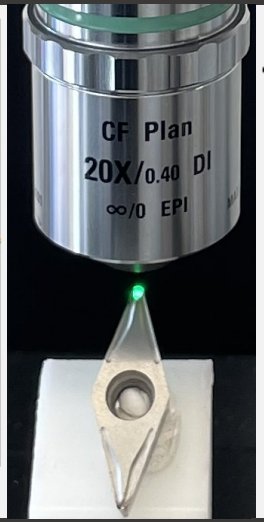


structured wafer

smart WLI — challenge to measure strongly inclined surface areas



ideal correlogram



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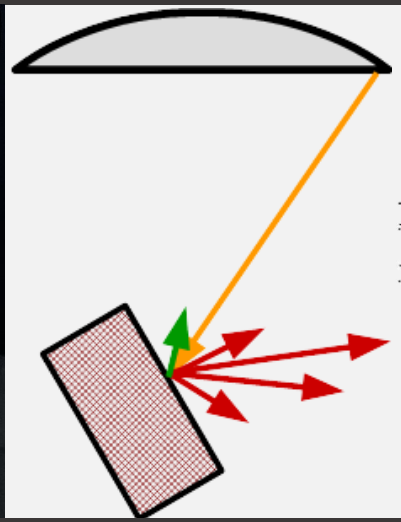
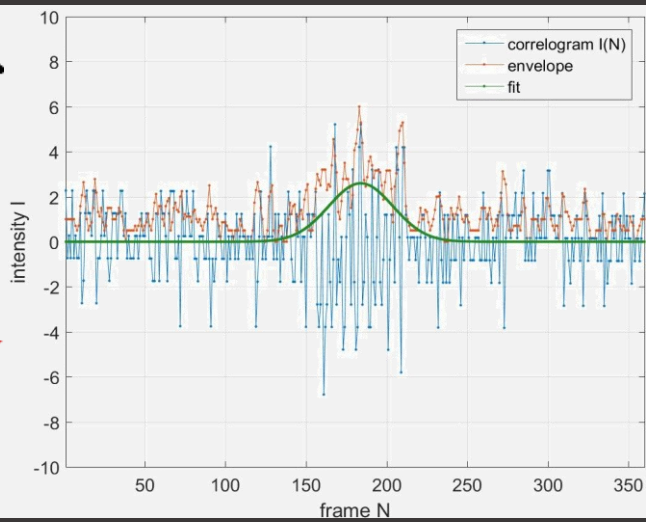
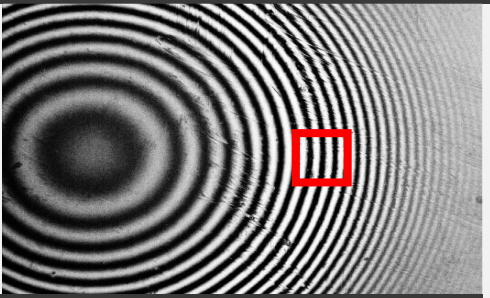


light reflection



correlogram on the flank



interferences on a ball

challenge to measure strong inclined rough samples

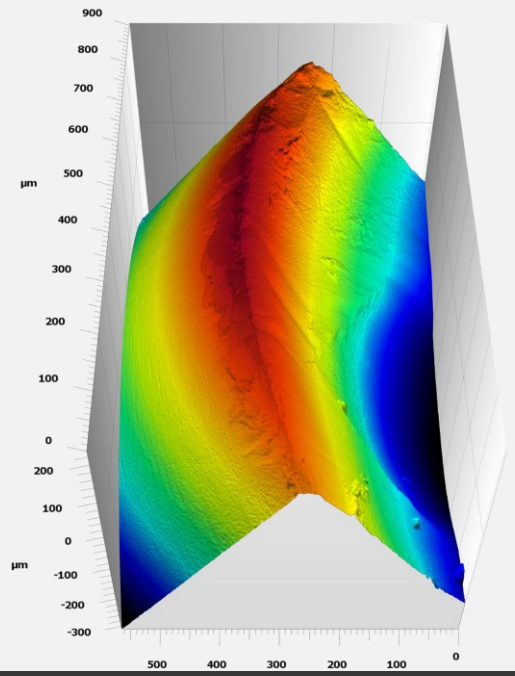
angle on the flank: app. 60°

measuring point density 20x objective: app. 0.5 µm

height difference fringe to fringe = λ/2: app. ¼ µm

A single pixel “looks” to an area which covers already 3 stripes. Out of this reason the signal / correlogram get noise. Advanced calculation are still able to analyse the signal and data quality for each single point.

smart WLI objects with strongly inclined features



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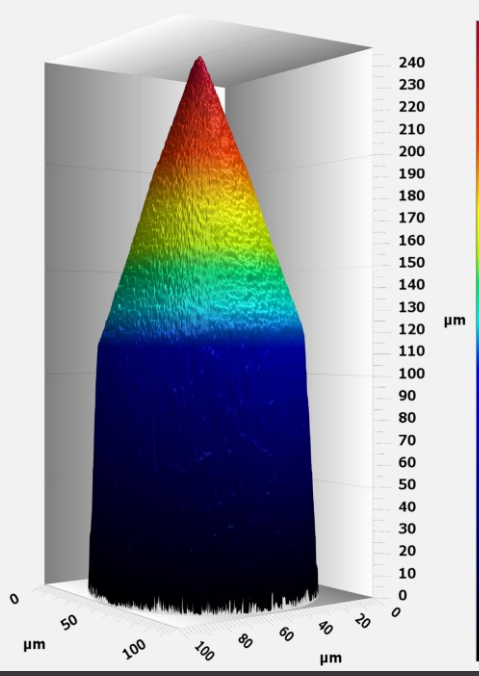
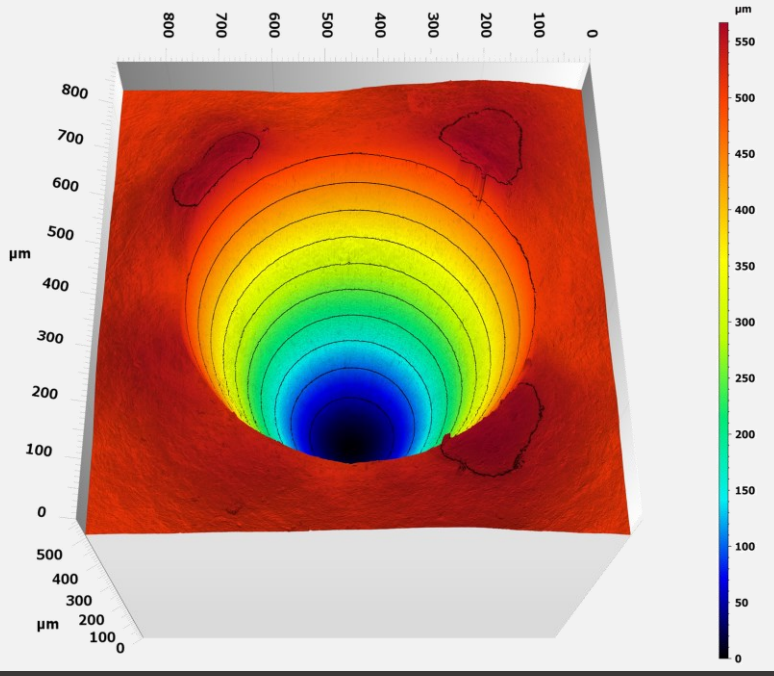


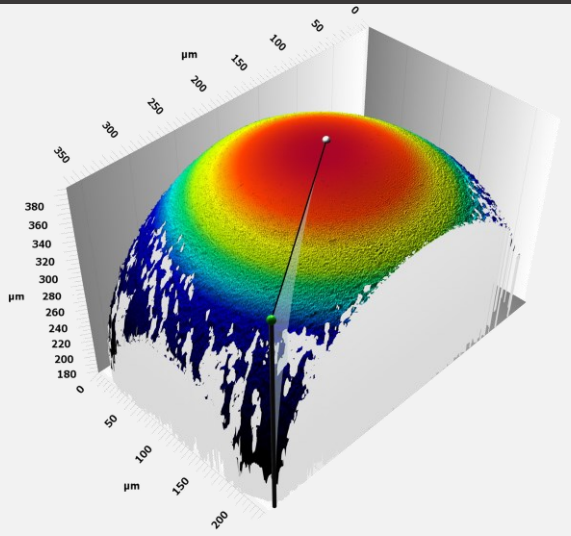
„needle" – tool for spinnerets



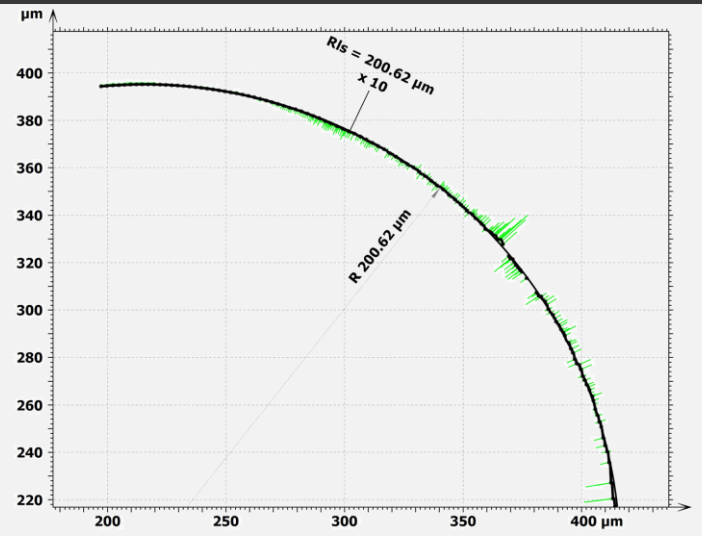
"concave lens" – structure for focusing x-rays

smartWLI performance tests on Rubin spheres

Rubin spheres



smartWLI compact, 50x objective



profile analysis

calculated maximum angle on high reflecting surfaces:

The maximum angle limited by the aperture that could be measured on high reflecting surfaces:

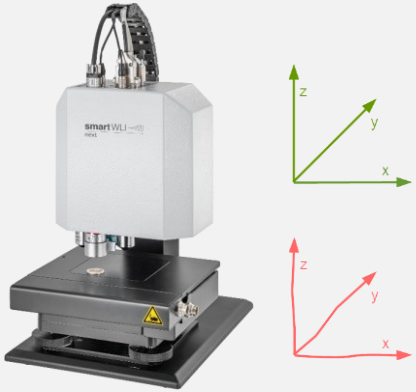
α = sin-1•NA

- α: calculated maximum angle
- NA: numerical aperture

calculation sample:

- NA 50x objective = 0.55
- calculated maximum angle on high reflective surfaces α = 33,4°
- minimal roughness on the Rubin ball generate enough scattered light which can be analysed with advanced algorithms and provide data to an much bigger acceptance angle on the Rubin ball

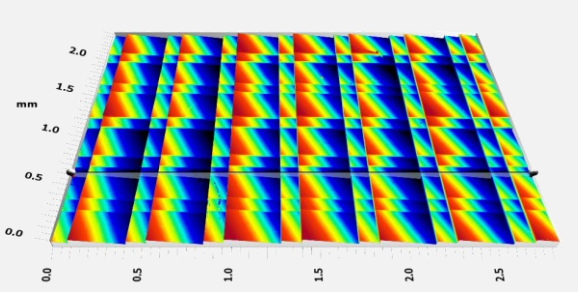
smartWLI smartSTITCH - perfect scans of larger areas



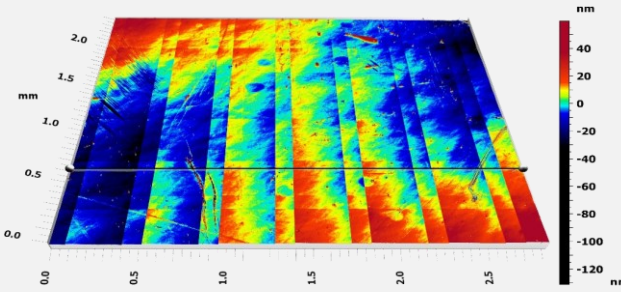
feature	flatness	straightness	pitch	yaw	technology
sensor	< 1 nm	< 1 nm	single µrad	single µrad	optics
positioning system	>> 1 µm	>> 1 µm	>> 10 µrad	>> 10 µrad	mechanics

smartSTITCH – optimized for a form correct stitching process

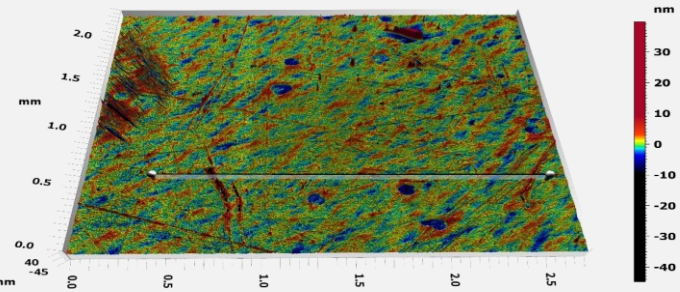
- mechanical positioning systems are very accurate for movements in axis direction and encoder provide a xy resolution which is better that the optical resolution of high resolution objectives
- smartSTITCH compensates not only height but also angular errors based on overlapping zones



stitching without error compensation

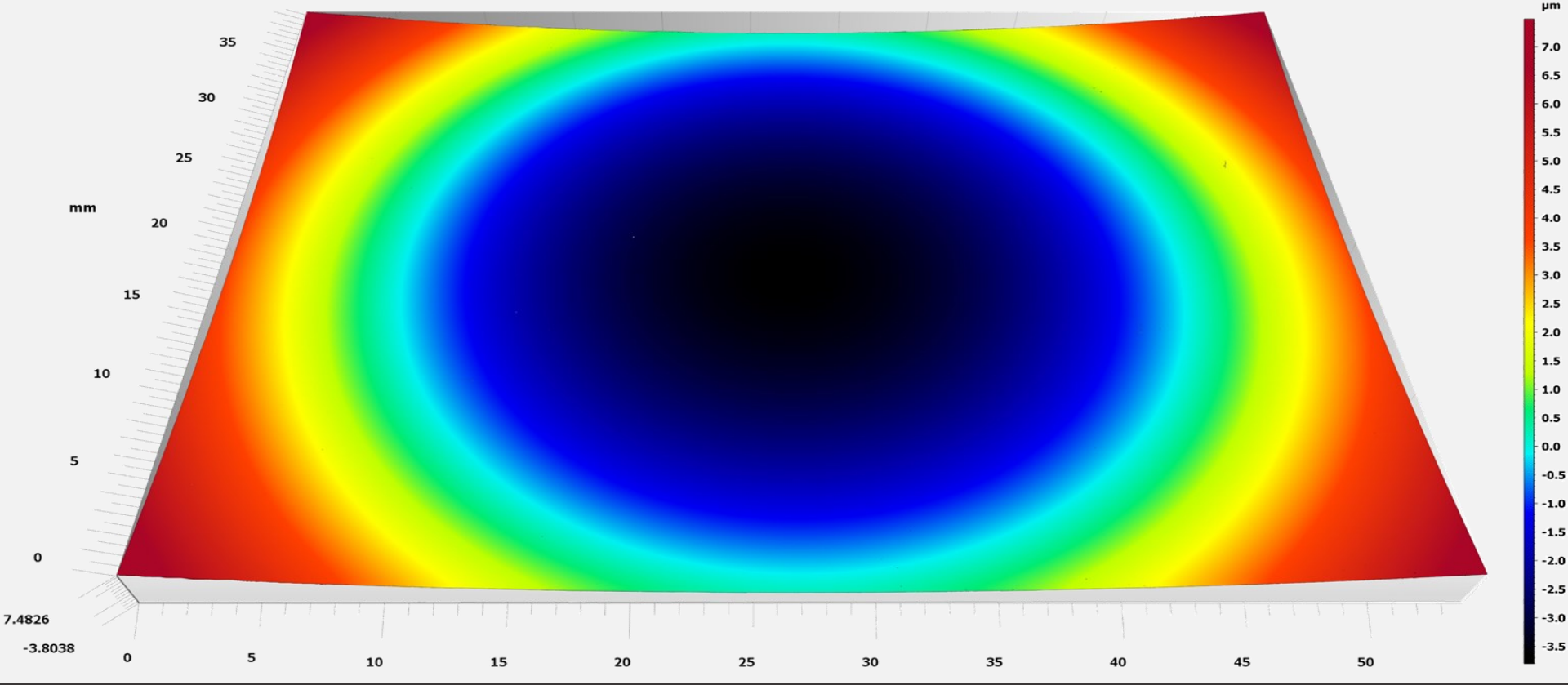


stitching with height compensation

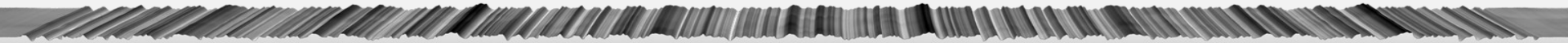


smartSTITCH with height and angular compensation

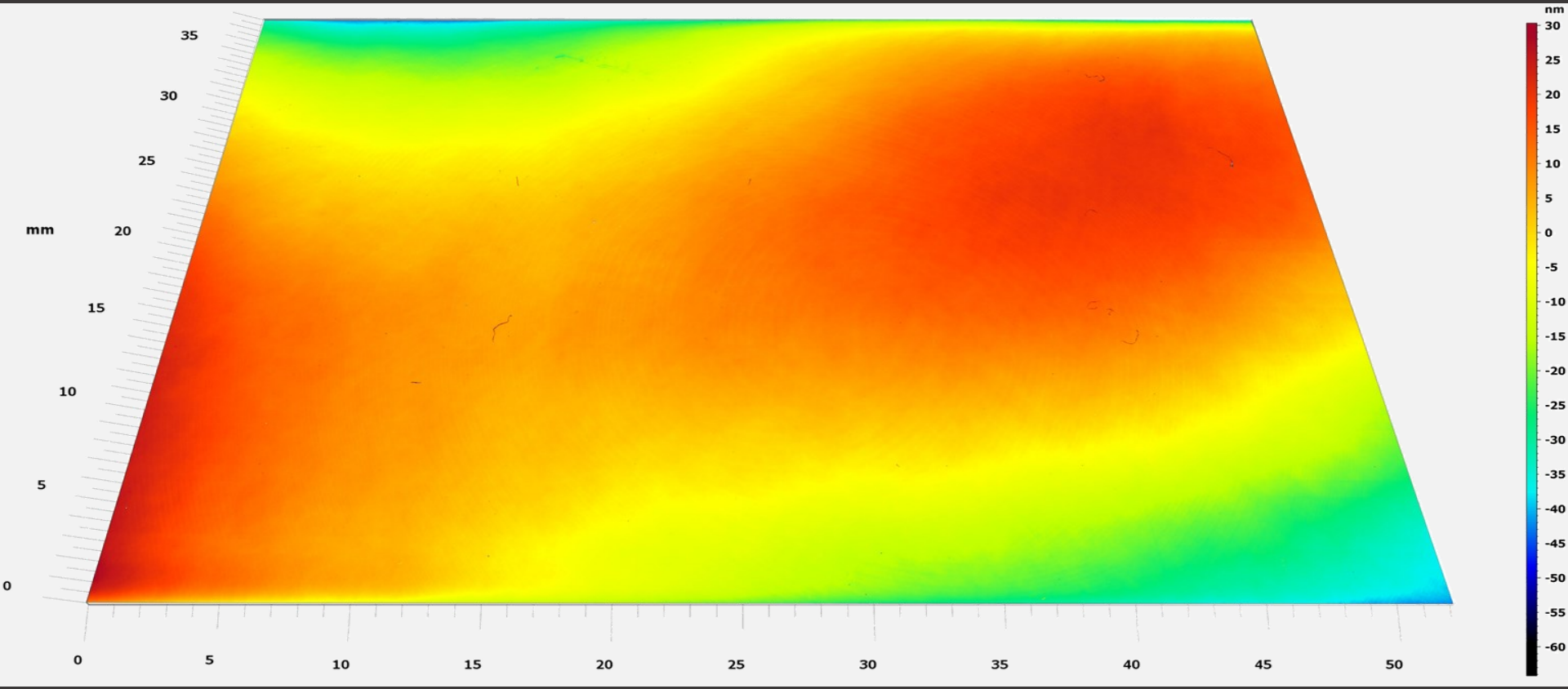
smart WLI silicon laser mirror for high power application



smart stitched high resolution point cloud from the laser mirror

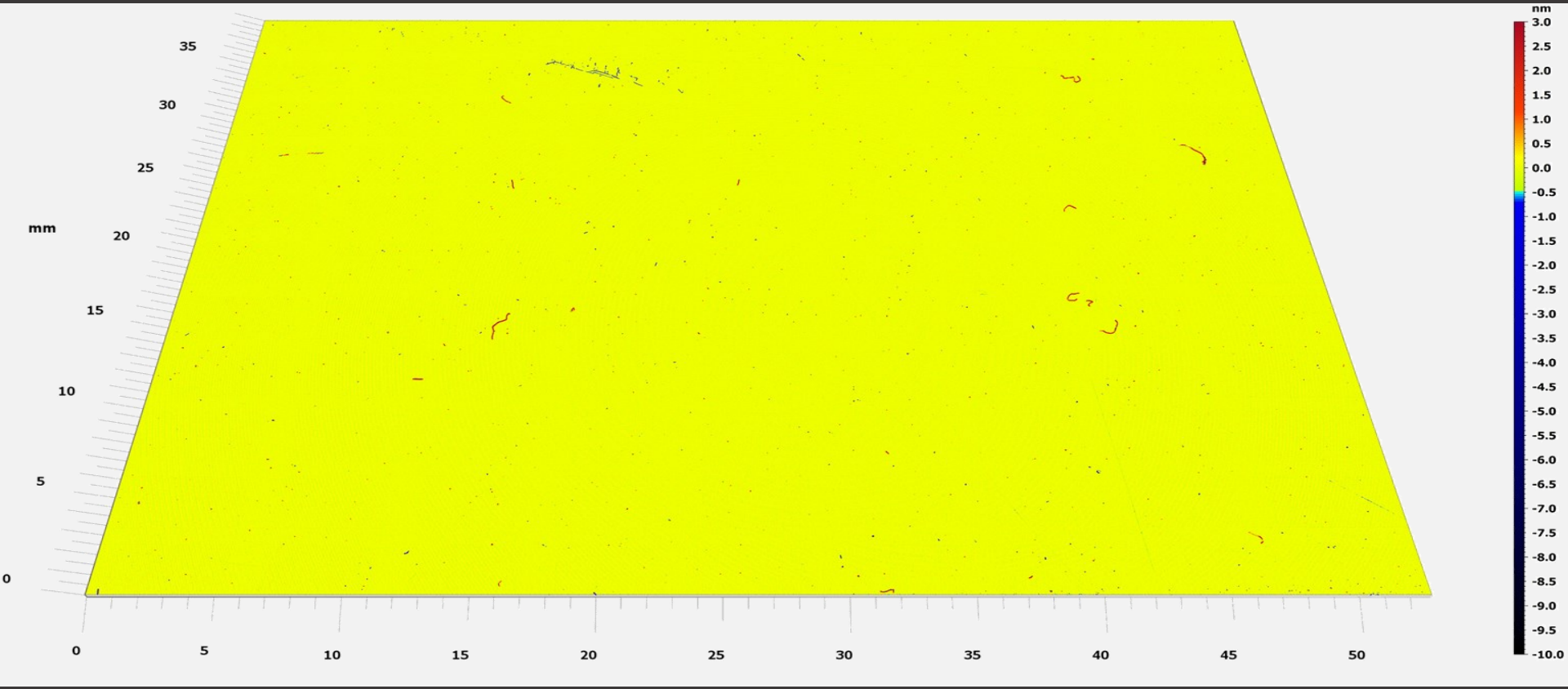


smart WLI form deviation



point cloud after subtraction of the ideal form with an 50 m diameter

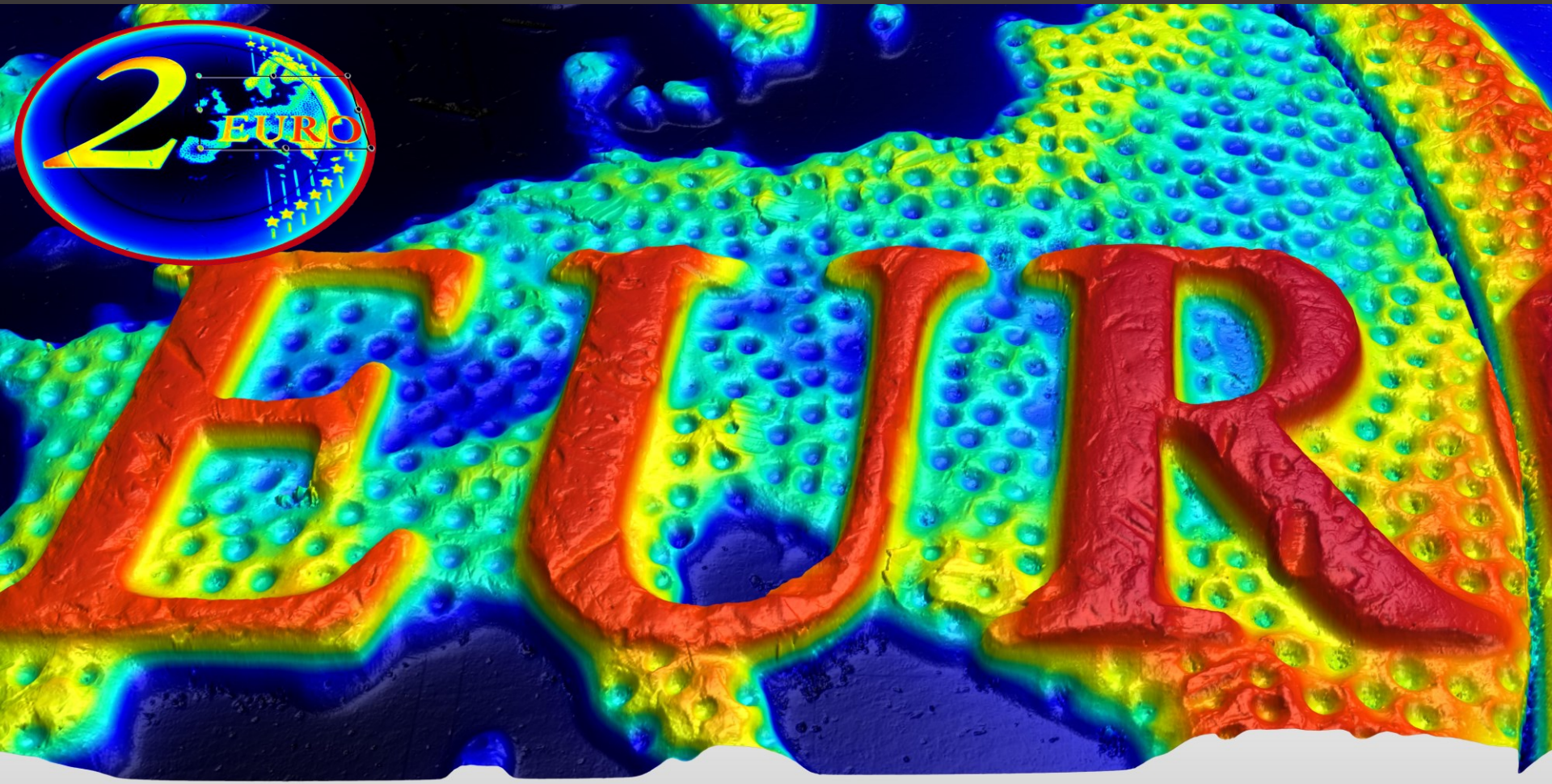
smart WLI surface defects and contamination



point cloud after high pass filtering

time is money

- faster measurements save time and money
- the additional benefit is the improved stability against vibrations
- coins are a very common measuring object and often used as marketing tool for instruments
- since larger coins are not suitable for most instruments and a challenge for measuring time and data processing the higher value of the coin is a good demonstration of the higher value from the instrument


2
EURO
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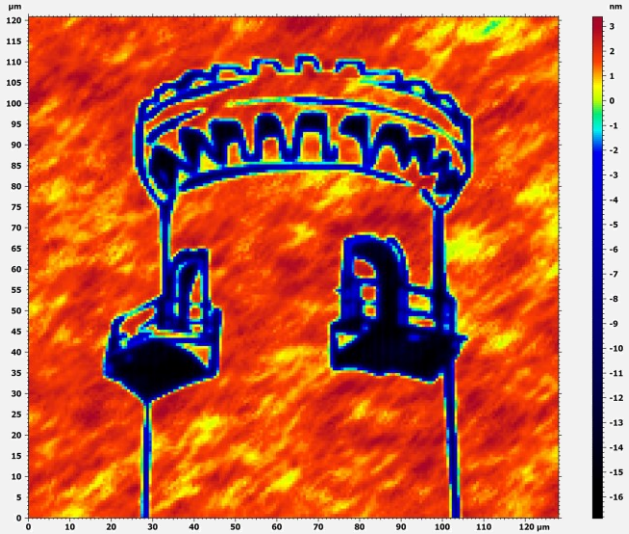
smart WLI — Thank you for celebrating the world interferometry day in Ilmenau!

new strongholds

faster measurement of larger areas with even higher resolution

measurement of extreme rough surfaces and inclined features possible

inline measurement, integration in productions centres and robotic measurements possible



coming up system demonstrations

WORLD interferometryday

April 19th, Ilmenau

Control 35. Control 2023 09.–12. MAI STUTTGART

May 09th – 12th, Stuttgart

LASER World of PHOTONICS

June 27th – 30th, Munich