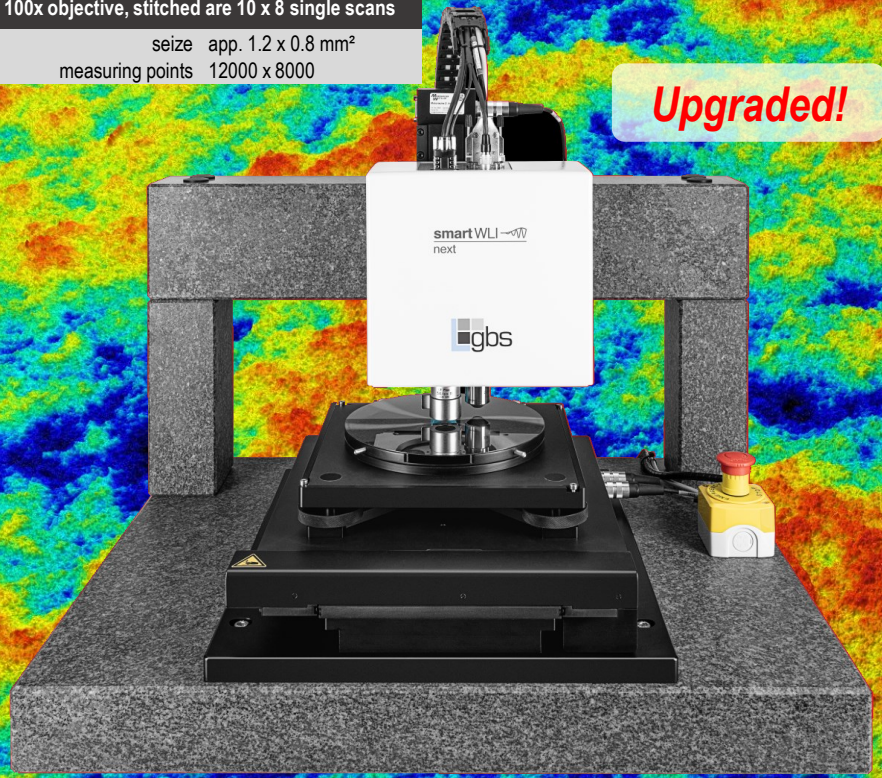
smart WLI optical high performance profilers for wafer metrology

100x objective, stitched are 10 x 8 single scans

seize	app. 1.2 x 0.8 mm²
measuring points	12000 x 8000



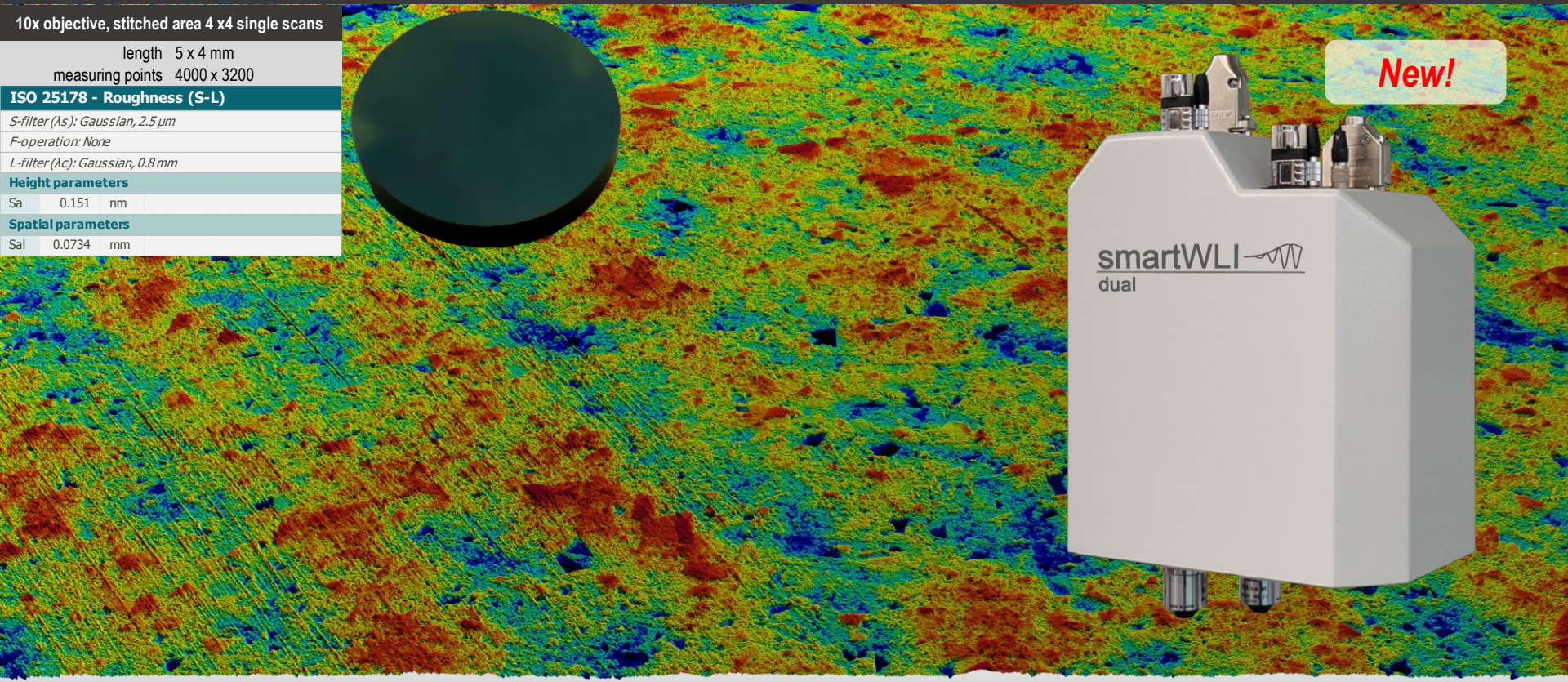
Upgraded!

ISO 25178 - Roughness (S-L)		
S-filter (λs): Gaussian, 2.5 µm		
F-operation: None		
L-filter (λc): Gaussian, 0.25 mm		
Height parameters		
Sa	1.10	nm

gbs

BASED ON COHERENCE SCANNING (WHITE-LIGHT) INTERFEROMETRY

smartWLI — combined advantages of the smartWLI series



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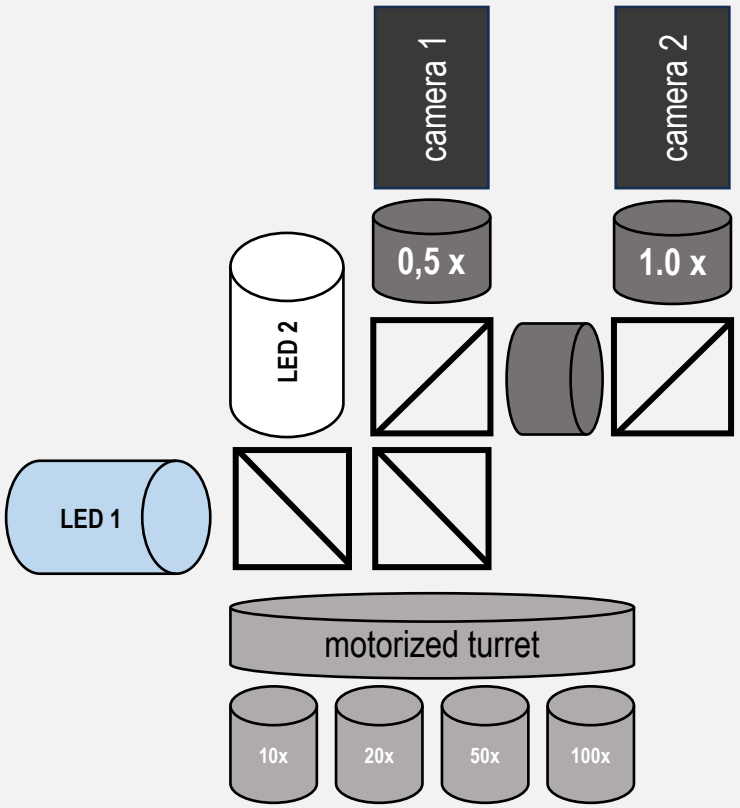
COMBINES EXTREME SPEED WITH SUPERIOR RESOLUTION

smart WLI — universal solution for wafer and other measuring stations



Intention:

Time is money:
Important for all serial productions – specifically in the production of semiconductors - a fast and reliable quality control is very important to improve the yield rate and save money. The dual tube technology allows to optimize the scanning process of multiple measuring task with different speed and resolution requirements without typically limitation of optical 3d sensors / profilers.

Advantages:

SDK (software development kit):
The SDK including libraries and the source code from test application simplifies the sensor integration in any third party system.

HD-EPSI:
High Density – Extended Phase Shift Interferometry, reduce the noise level without time consuming repeated scans of the same measuring positions down to an topography reproducibility of 0.03 nm (ISO conform rated noise level).

real time processing of image stacks using GPGPUs:
GPGPUs with up to app. 80x of the calculation power of Core I9 CPUs allows the instant data processing for shorter cycle times.

dual tube technology:
The dual tube technology allows – in contrary to zoom objectives – the instant switch between 2 tube magnifications and 2 cameras. This allow the decision between high speed measurements for geometrical feature and large area measurement of flatness and waviness or highest resolution for extreme small structures

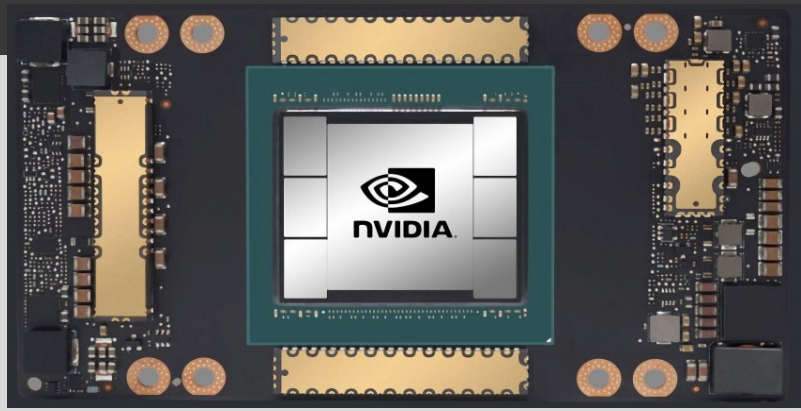
dual cameras:
The dual camera technology combines the advantages of high resolution and 5 MP and high speed 2.3 MP (extreme speed 1.3 MP cameras). Combined with dual tube technology it provides a spatial sampling factor 3x (4x) similar to zoom objectives without the disadvantages of the zoom (contrast reduction, calibration requirements).

dual LED:
The short wavelength of blue light provide a higher optical resolution, a higher rate of scattered light on reflective surfaces and a smaller penetration depth on silicon wafers. The white light reduce the width of the correlogram. This allows to improve specific measuring tasks as thickness measurements on transparent coatings.

motorized focus – interference zone adjustments:
Specifically higher magnification objectives shows chromatic and thermic drifts between focus and interference zone. The motorized focus – interference zone adjustment allows the adjustment without manual system access – critically for high resolution measurements.

smartWLI specification of the smartWLI dual

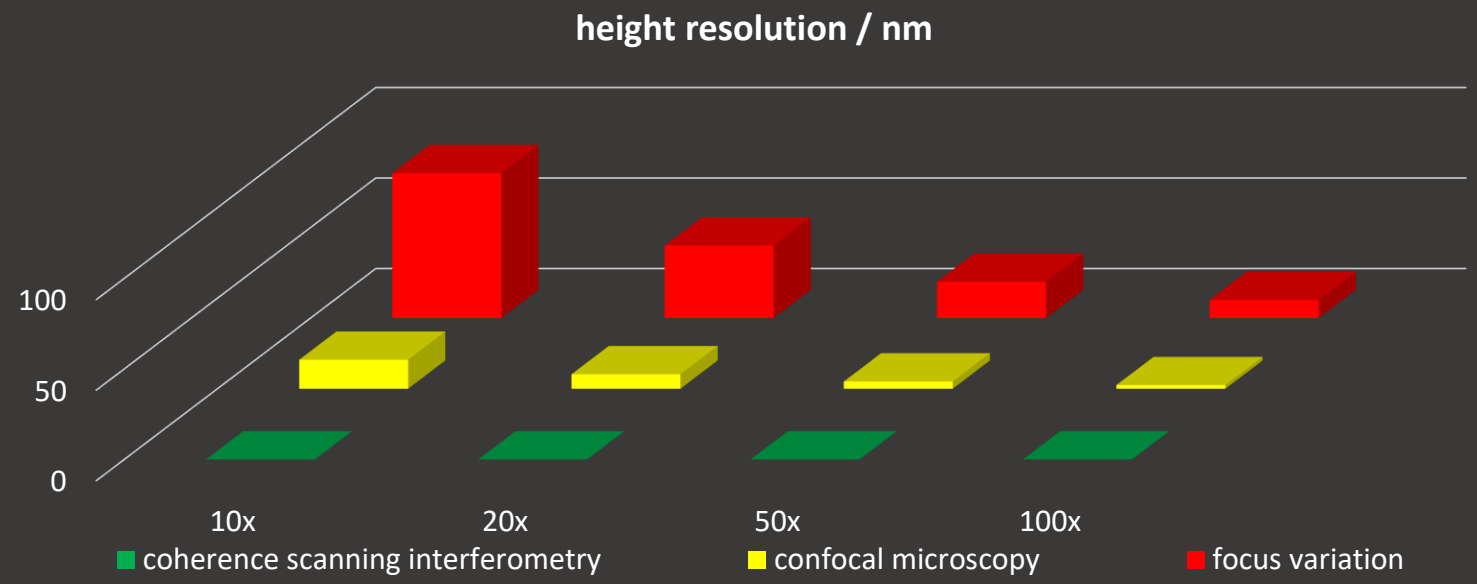
specification	
optical 3d sensor	high performance sensor for measuring stations and stand alone systems
objectives	motorized turret for up to 4 objectives
measuring principle	coherence scanning (white-light) interferometer
scanning device	piezo with close loop capacitance gauge control
topography reproducibility	0.03 nm (single scan without profile averaging)
repeatability RMS	0.003 nm (single scan without profile averaging)
optional system building kits	100 x 100 x 50 mm³ – 300 x 300 x 100 mm³ (xyz), tip-tilt (optional motorized)
dual camera	5 MP - 77 fps and acceleration / 2.3 MP – 169 fps (optional 1.3 MP – 935 fps)
point evaluation	massive parallel in real time on the GPGPUs
evaluation algorithms	VSI (vertical scanning interferometry)
	HD-EPSI (high density extended phase shift interferometry)
profile averaging	automated averaging over up to 40 single scans for noise reduction
scanning increments	variable optimization between speed and resolution



- using the GPGPU provides the calculation power
  - real time 3d calculation
  - noise reduction to measure extreme smooth surface
  - fast measurements with typically 1 … 3 s for single scans
  - stitching of several 100 single scans
  - data quality surveillance
  - optional export of quality and infinite focus camera images
  - model based signal processing and correction

	standard objectives 2d localization		interference objectives for 3d measurements					
available objectives	2.5x	5x	5x	10x	20x	50x	100x	115x **
aperture	0.075	0.13	0.13	0.3	0.4	0.55	0.7	0.8
working distance	8.8	22.5	9.3	7.4	4.7	3.4	2	0.7
tube0.5x 2.3 MP measuring area / mm²	7.3 x 4.6	3.7 x 2.3	3.7 x 2.3	1.8 x 1.2	0.9 x 0.6	0.37 x 0.23	0.18 x 0.12	0.16 x 0.1
tube0.5x 2.3 MP sampling interval / µm	3.8	1.9	1.9	0.96	0.48	0.19	0.1	0.08
tube 1x 5 MP measuring area / mm²	3.4 x 2.8	1.7 x 1.4	1.7 x 1.4	0.85 x 0.71	0.43 x 0.36	0.17 x 0.14	0.09 x 0.07	0.075 x 0.06
tube 1x 5 MP sampling interval / µm	1.4	0.7	0.7	0.35	0.175	0.07	0.035	0.03

smart WLI coherence scanning (white-light) interferometry

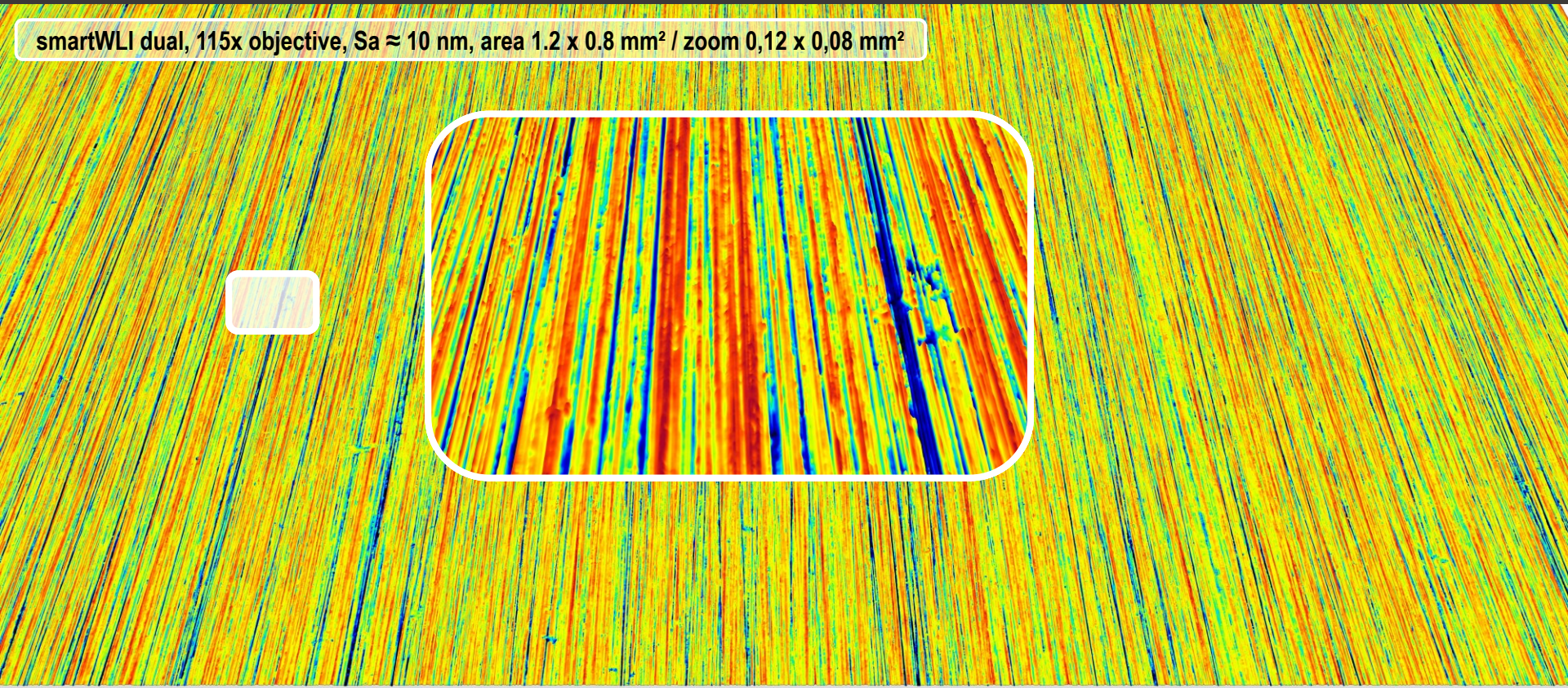


- coherence scanning (white-light) interferometry provide the required sub nanometer height resolution
- the extreme height resolution is – in contrary to the other mentioned principles – to a great extend independent from the magnification

THE HIGHEST RESOLUTION FOR ALL OBJECTIVES

smartWLI

measuring of small structures over large areas



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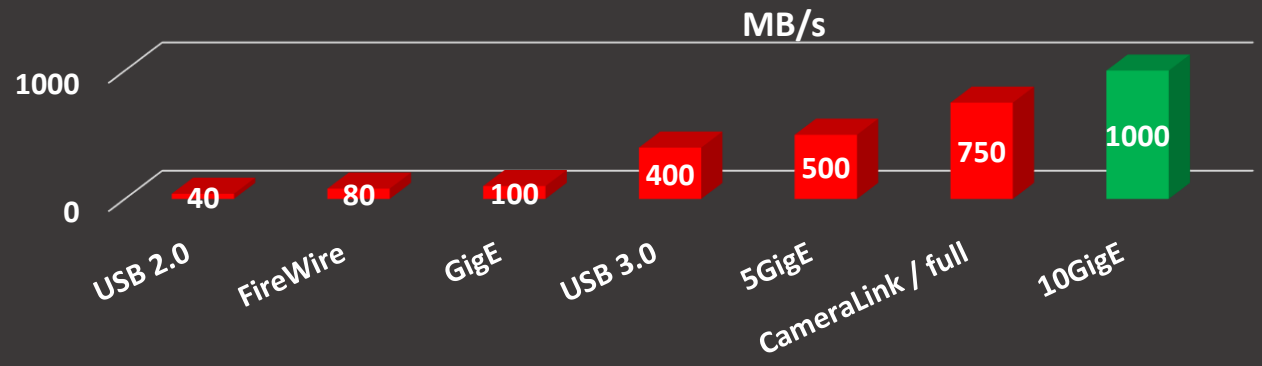
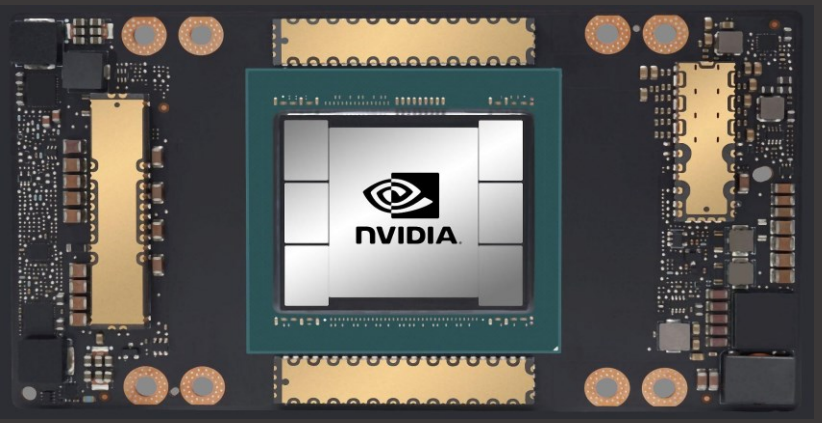
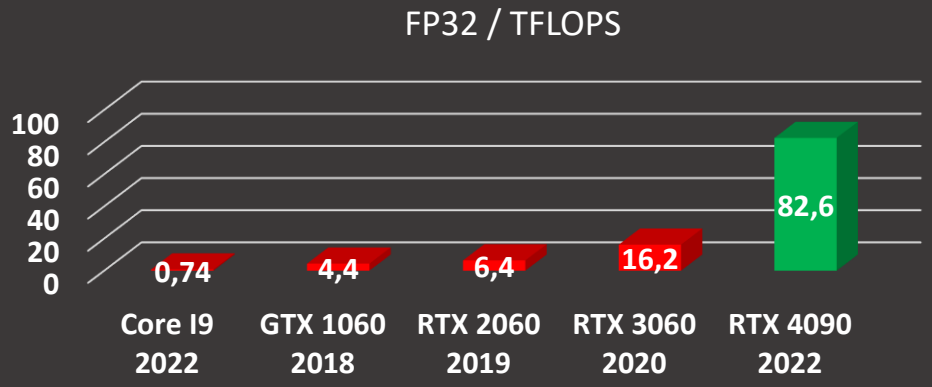
FINE STRUCTURED GRIND WAFER

smartWLI the highest speed for data acquisition and processing







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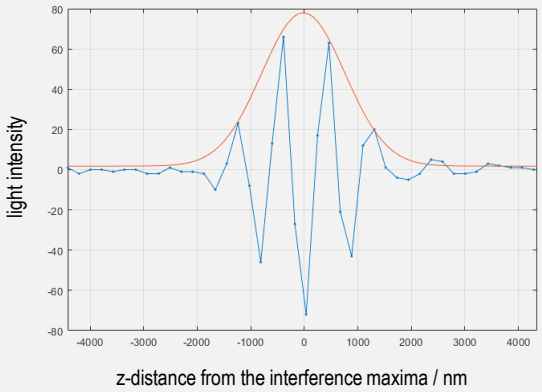
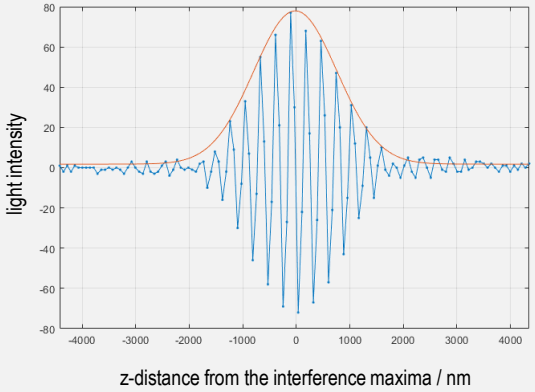
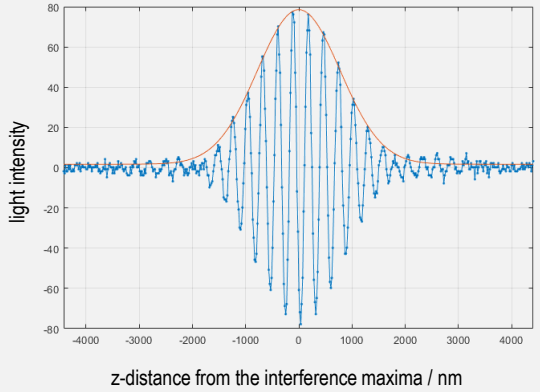
935 FPS (FULL RESOLUTION) – PROCESSED IN REAL TIME WITHOUT DELAY







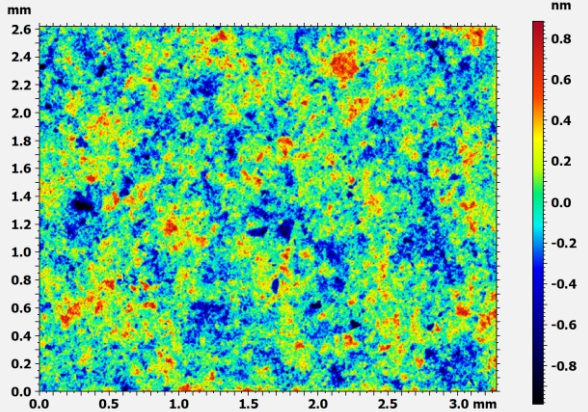
$$\text{resulting noise} \sim \sqrt{scanning\ intervall}$$

comparison of profile averaging and HDEPSI:

- profile averaging reduce the noise but the time grows proportional to the number of scans
- HDEPSI reduce the noise but reduce the scanning speed similar to the profile averaging

advantages of the HDEPSI – effective up to 2x faster than profile averaging:

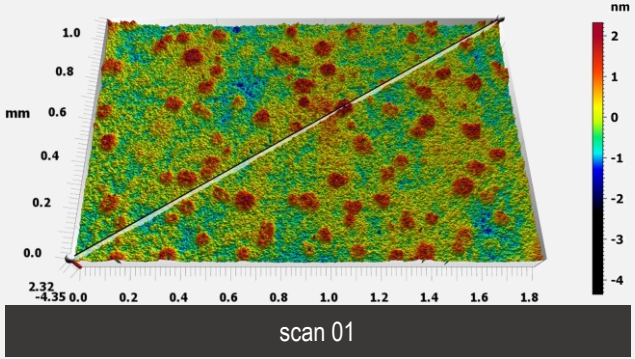
- single scan without multiple objective acceleration, synchronizations of piezo and camera, 3d calculations, data averaging
- less motion blur and drift effects



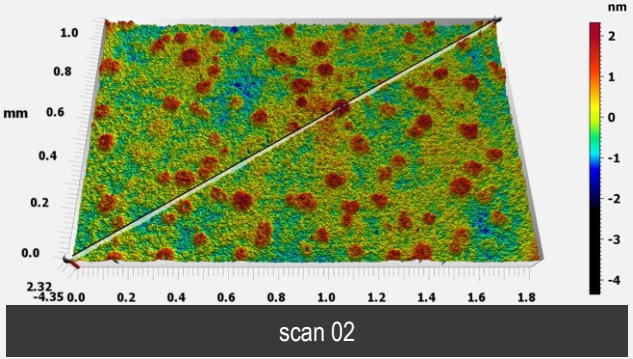
selection of a optical profiler providing the required height resolution

comments:

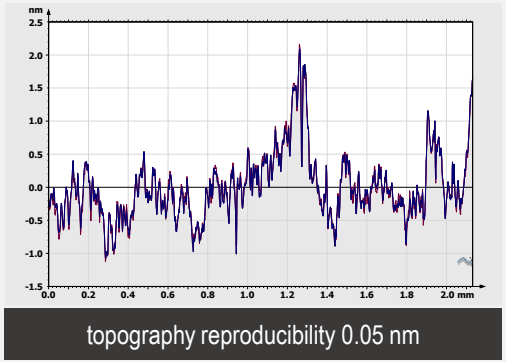
- “much smaller” would be the noise Nm (->see definition in ISO 25178) < 1/10 of Sq
- Nm is defined as the measurement noise from the unfiltered profile and the application of λs should reduce the noise level further
- the topography reproducibility is a common principle to test the noise level calculating Sq out of the difference from 2 scans of the same sample with the following advantages
  - common flat surfaces can be used without a specified flatness and nature of the test specimen
  - test and evaluations are simple but have a high significance
- the smartWLI series provide a extreme small noise level for single scans without – time consuming! - continuously data acquisition over a certain time period or profile averaging over several single scans
- optional profile averaging over up to 40 single scan can be used and will reduce the noise level further



scan 01

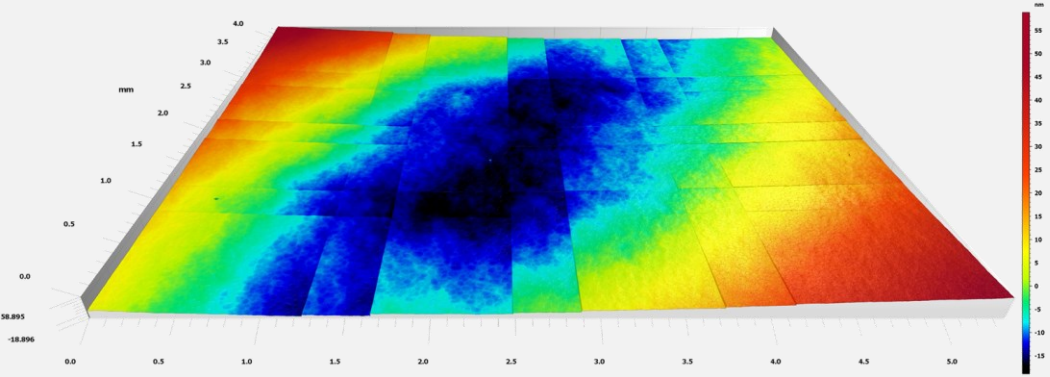


scan 02



topography reproducibility 0.05 nm

smartWLI smartSTITCH for perfect stitched high resolution measurements

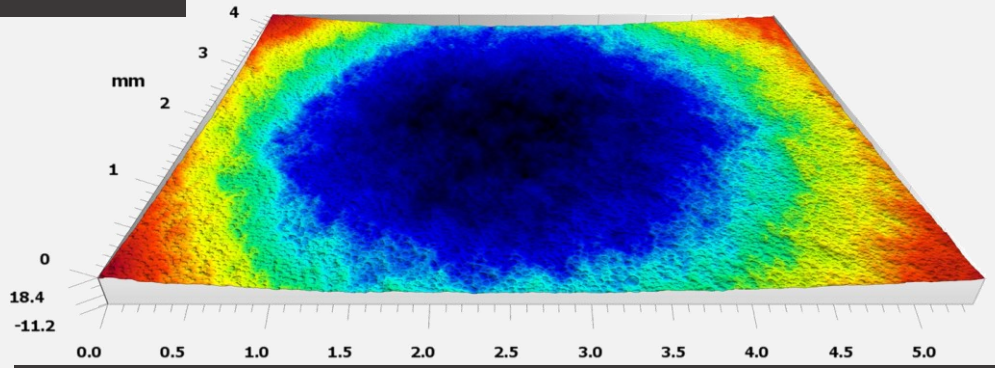


standard algorithms - stitching with height compensation only

data acquisition limited through the stage accuracy

result of the standard stitching algorithms

error elimination through smartSTITCH

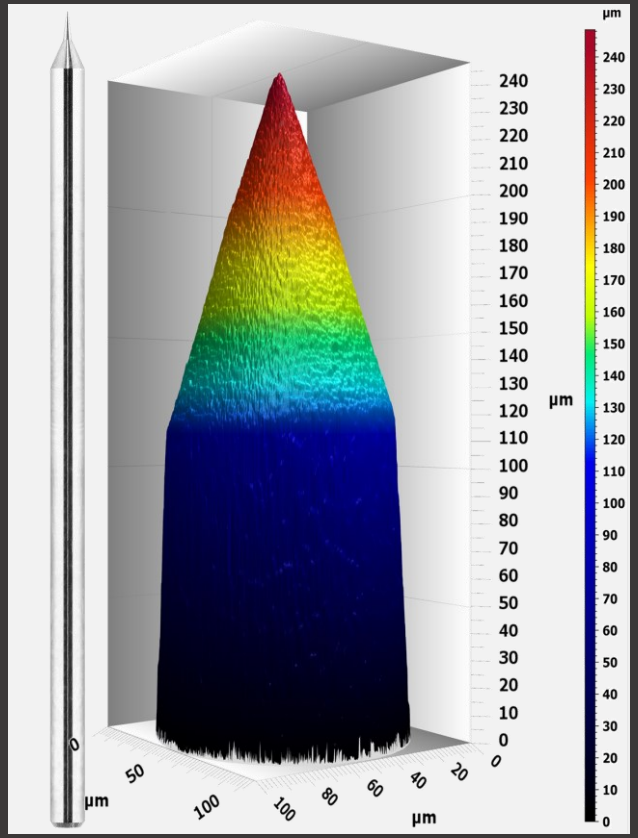


smartSTITCH with height and angle compensation in overlapping areas

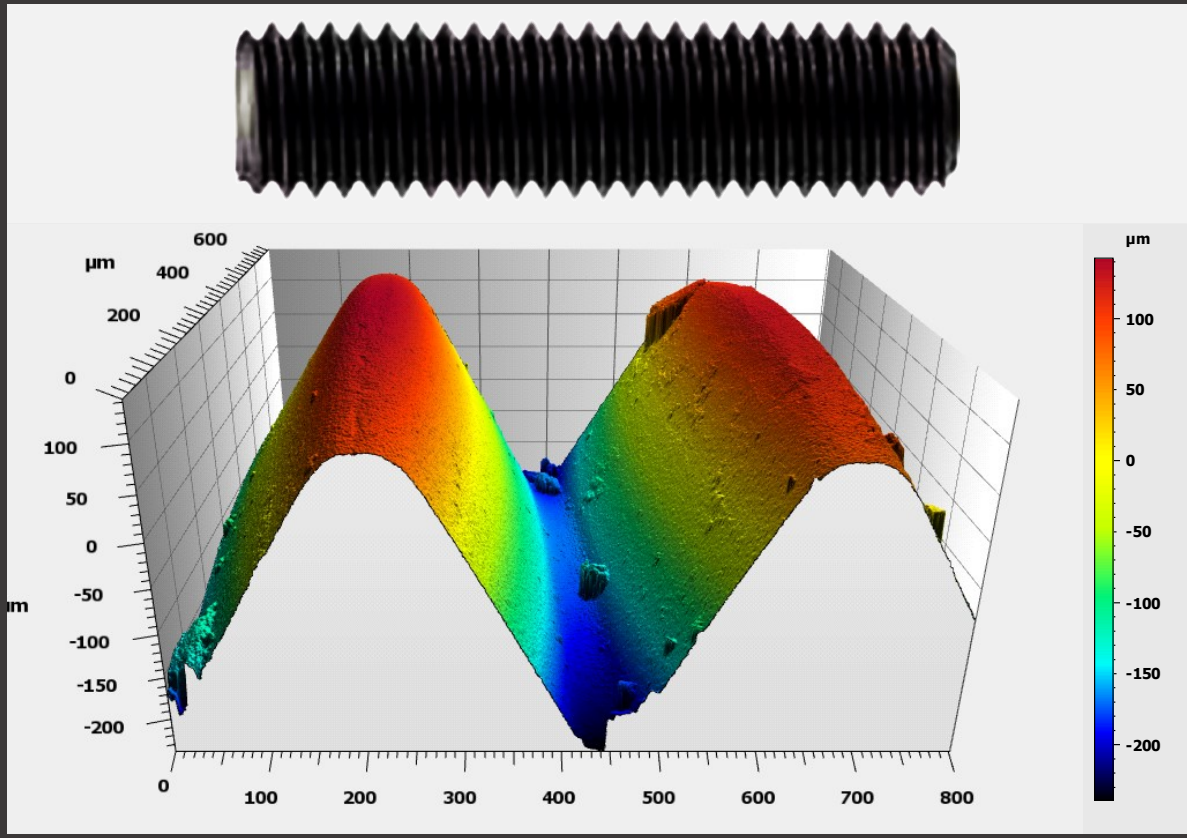
DEMONSTRATED ON THE SIMETRICS FLATNESS STANDARD

smart WLI increased acceptance angle for highly sloped surfaces

100x objective, needle for spinnerets

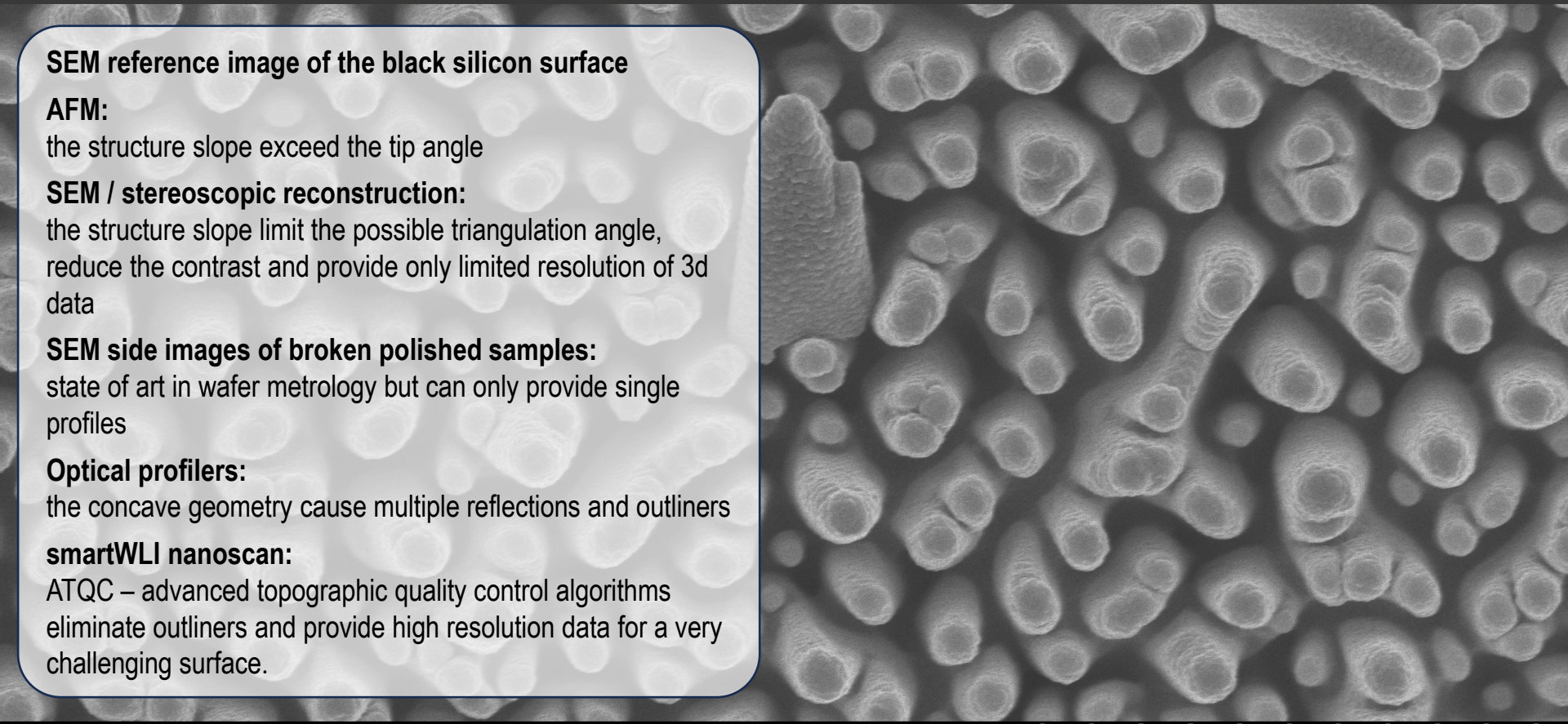


10x objective, thead of a screw



EVEN USING OBJECTIVES WITH A MODERATE MAGNIFICATION

3d measurements of fine structured surface with an high aspect ratio



SEM reference image of the black silicon surface

AFM:
the structure slope exceed the tip angle

SEM / stereoscopic reconstruction:
the structure slope limit the possible triangulation angle, reduce the contrast and provide only limited resolution of 3d data

SEM side images of broken polished samples:
state of art in wafer metrology but can only provide single profiles

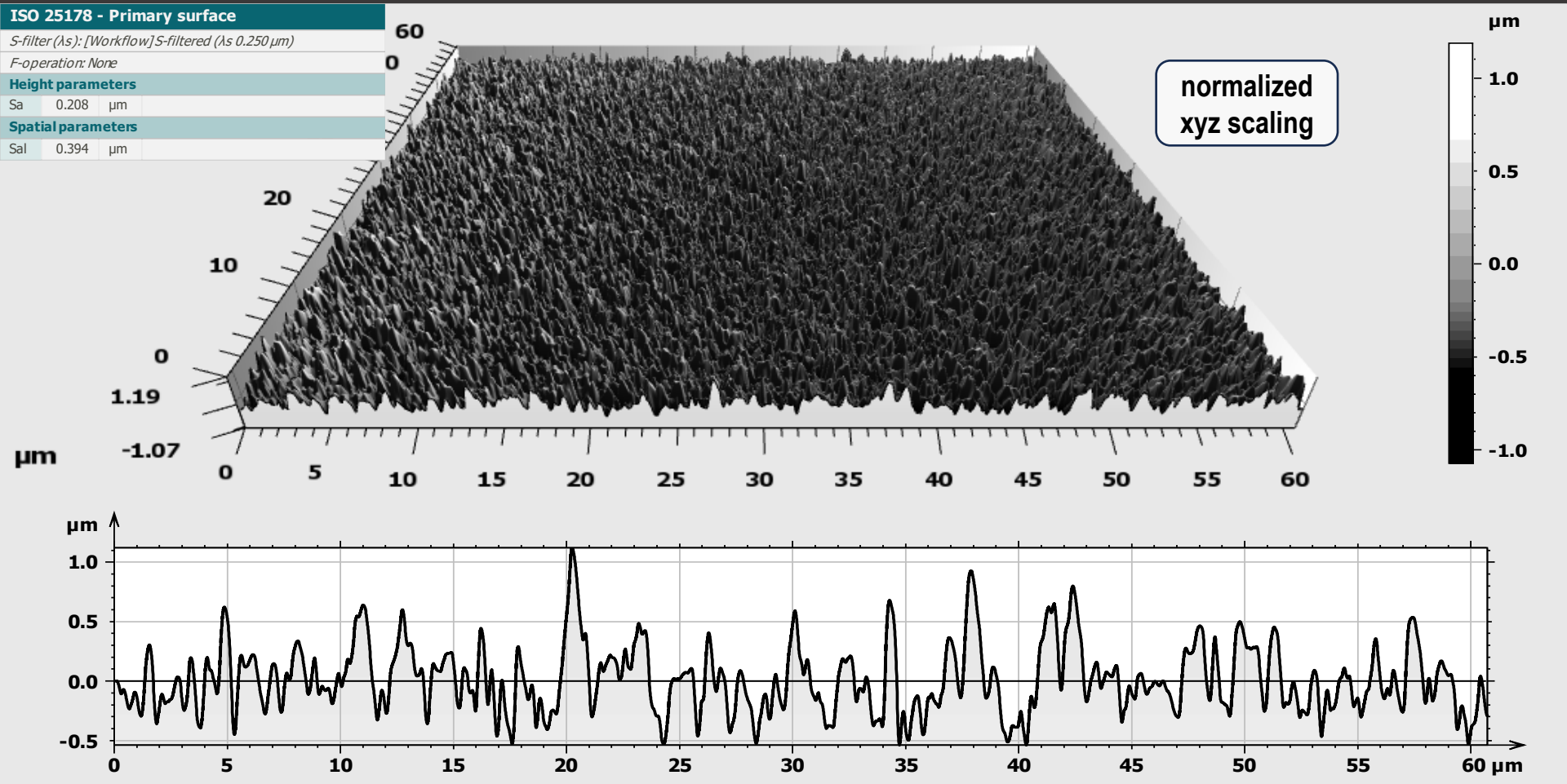
Optical profilers:
the concave geometry cause multiple reflections and outliners

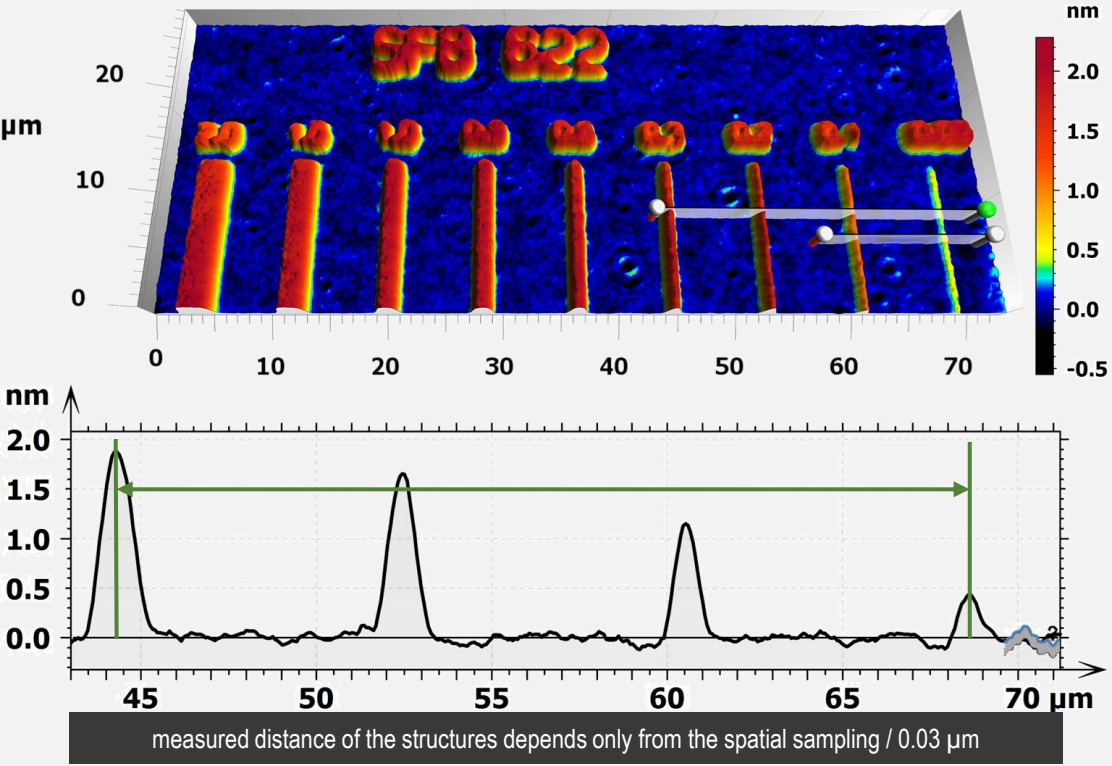
smartWLI nanoscan:
ATQC – advanced topographic quality control algorithms eliminate outliners and provide high resolution data for a very challenging surface.

smart WLI

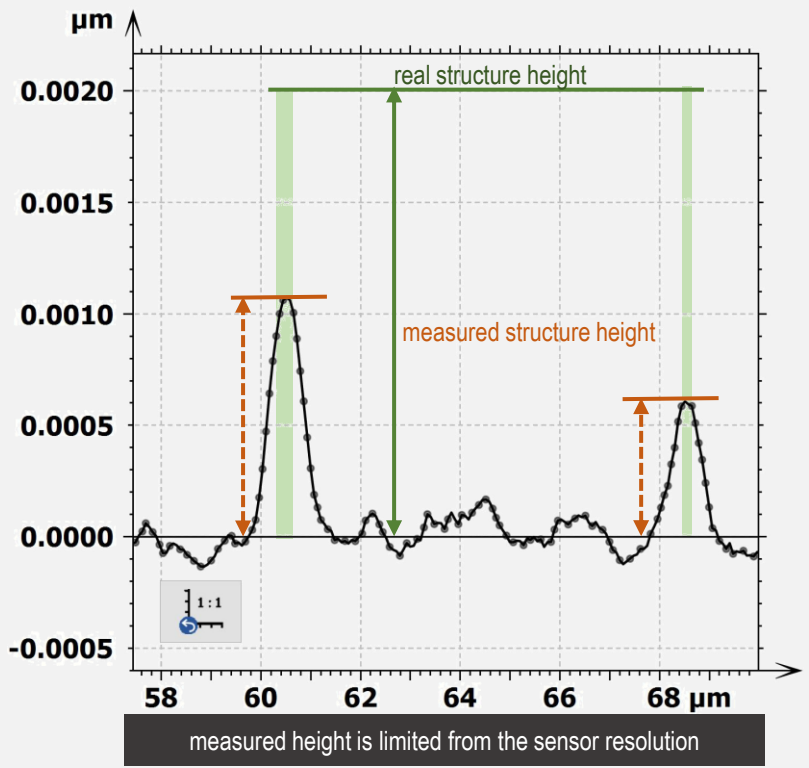
115x objective, black silicon, λs 0.25 µm

ISO 25178 - Primary surface		
S-filter (λs): [Workflow] S-filtered (λs 0.250 µm)		
F-operation: None		
Height parameters		
Sa	0.208	µm
Spatial parameters		
Sal	0.394	µm



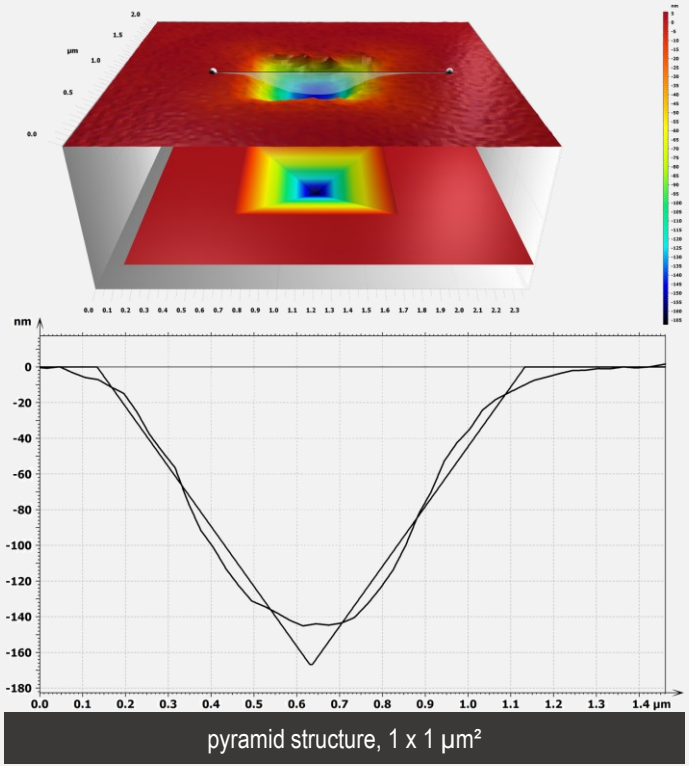


measured distance of the structures depends only from the spatial sampling / 0.03 µm

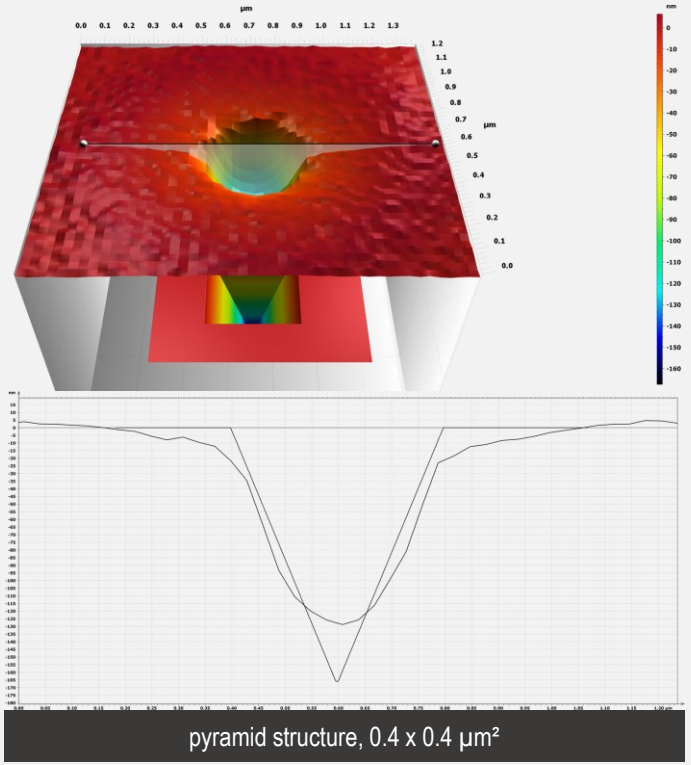


measured height is limited from the sensor resolution

smart WLI profile fidelity tested on pyramid structures of an AFM target



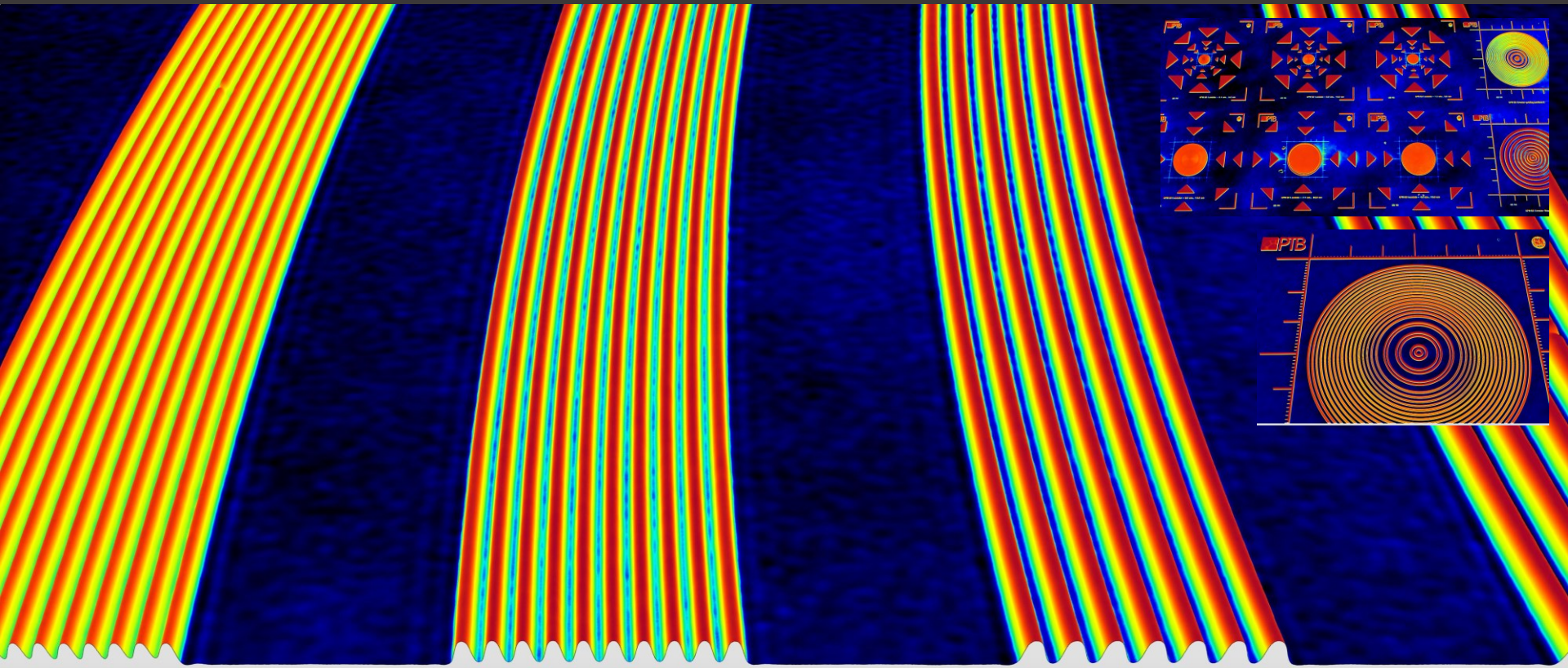
pyramid structure, 1 x 1 µm²



pyramid structure, 0.4 x 0.4 µm²

MEASUREMENTS OF SMALL STRUCTURES - POSSIBLE BUT NOT ACCURATE

smartWLI ISO conform lateral period limit D_{LIM} tested on a PTB target



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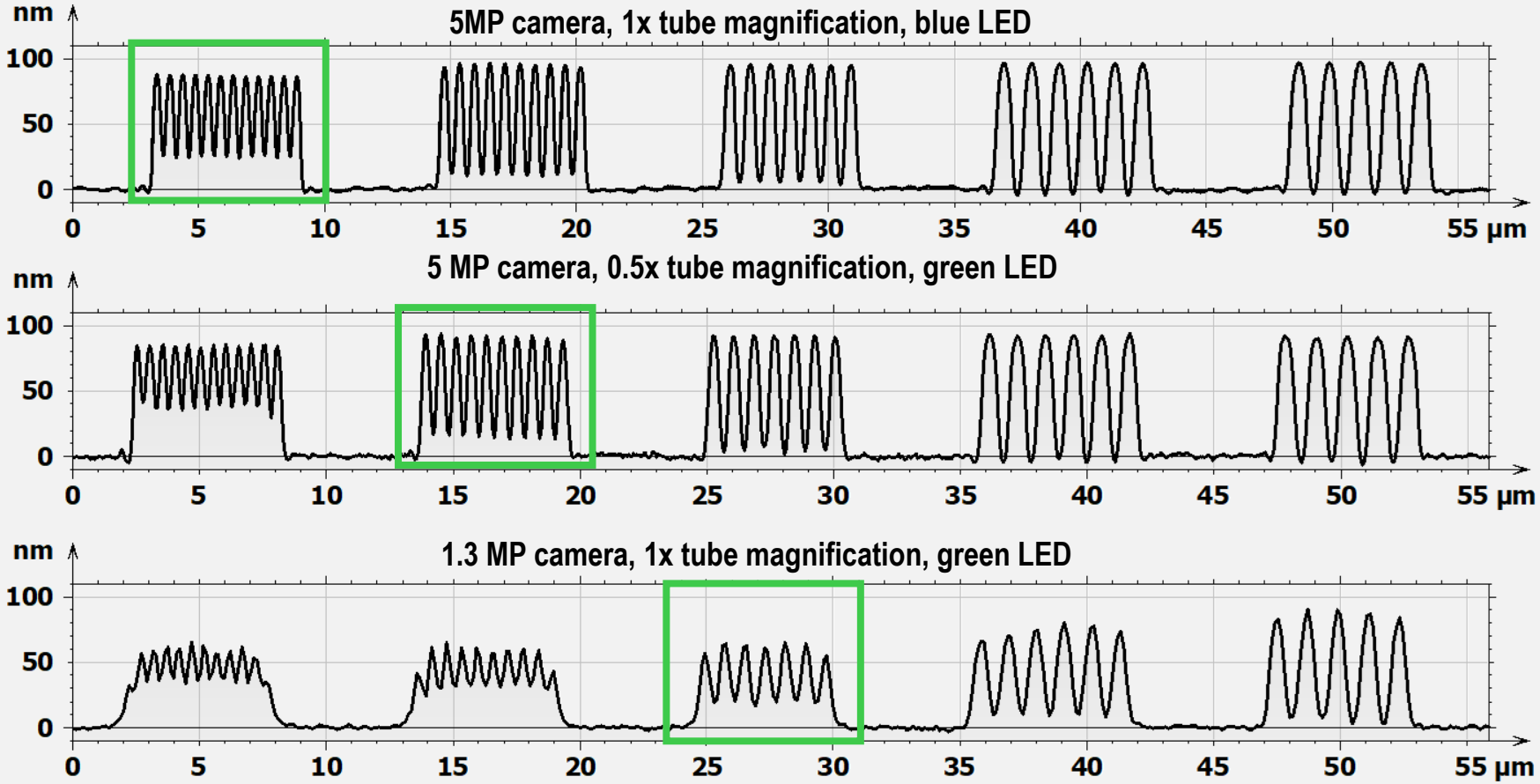
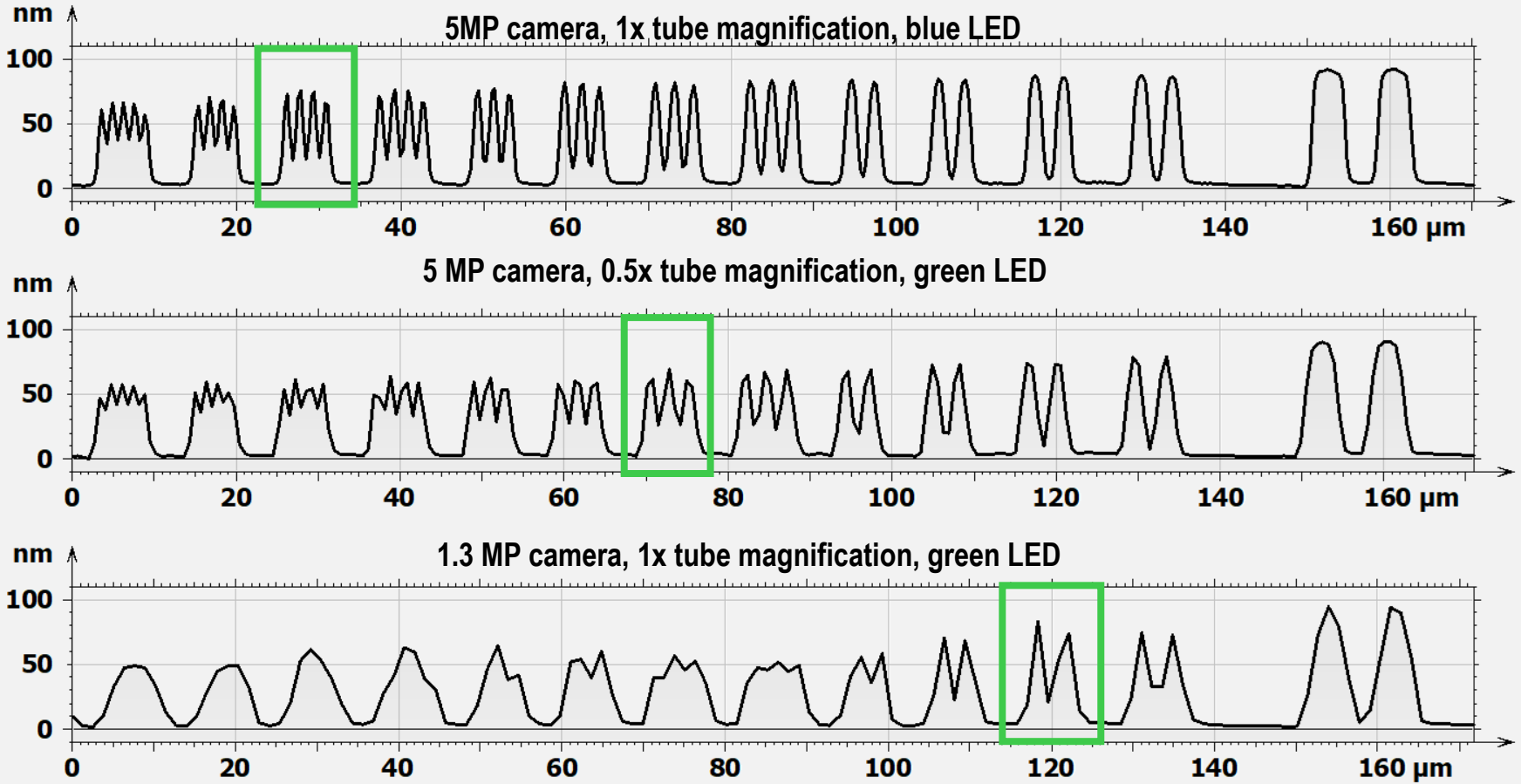
OBJECTIVE COMPARISON OF ALL SMARTWLI PROFILERS AND OBJECTIVES

smart WLI — sensor comparison 115x objective



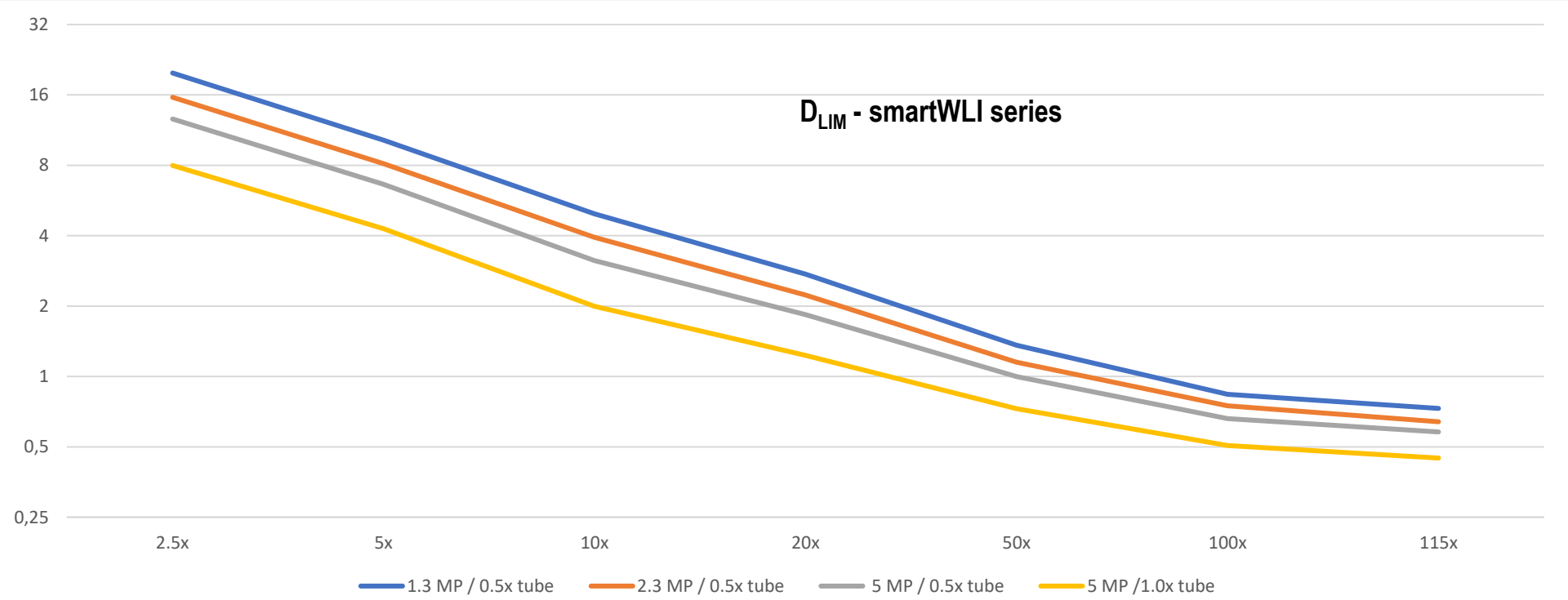
wavelength	0.5 µm	0.6 µm	0.8 µm	1.1 µm	1.23 µm

sensor comparison 10x objective



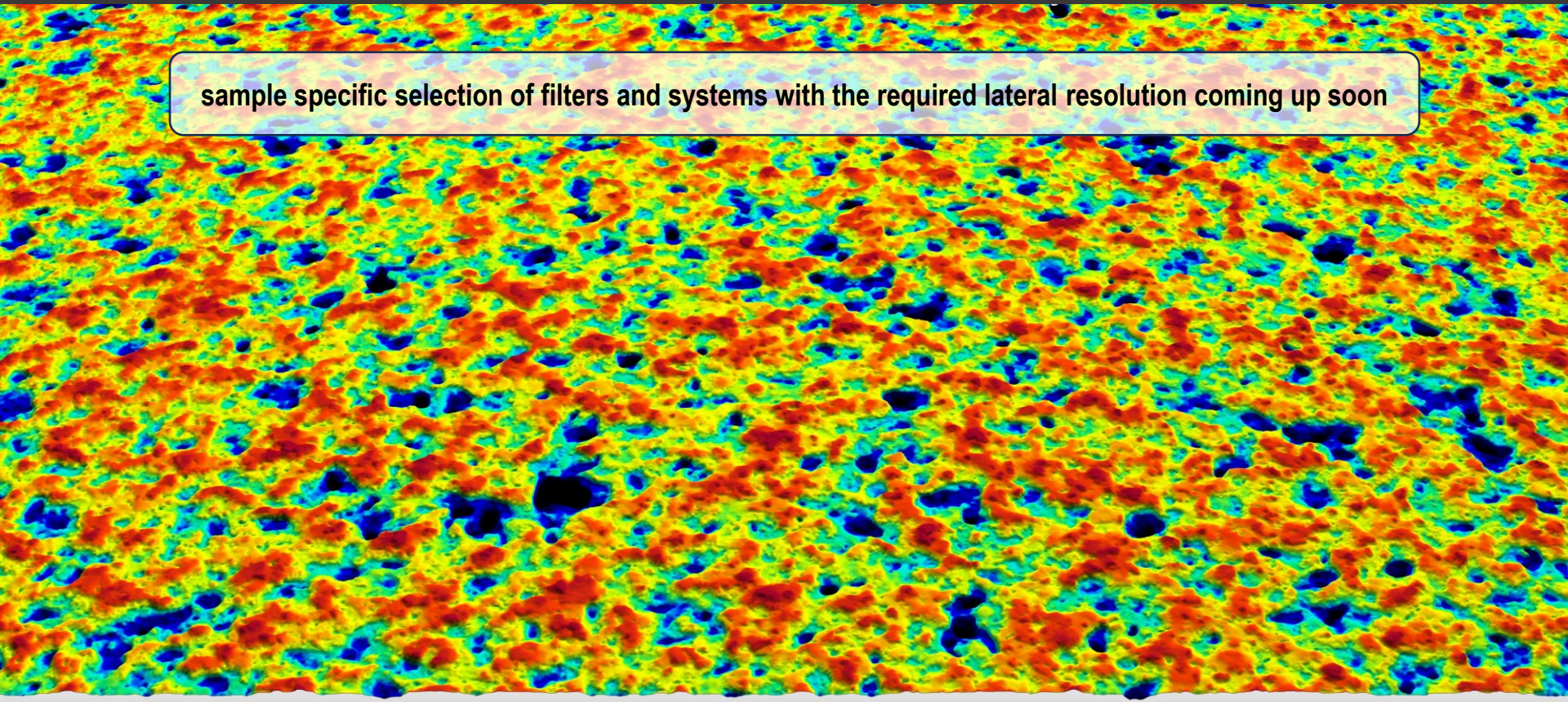
wavelength	1.3 µm	1.5 µm	1.6 µm	1.8 µm	2.0 µm	2.2 µm	2.4 µm	2.6 µm	2.8 µm	3.0 µm	3.5 µm	4.0 µm	8 µm

smartWLI — lateral period limit D_{LIM} for the smartWLI series



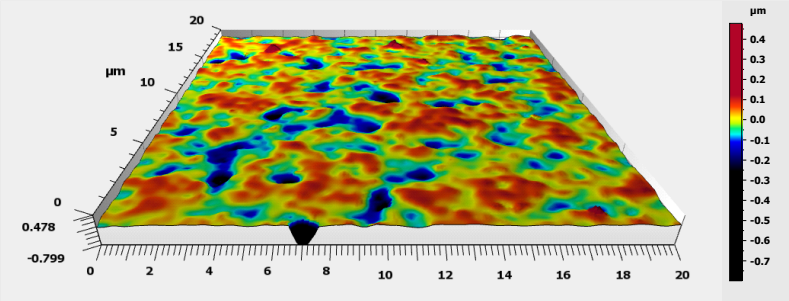
magnification / LED	2.5x	5x	10x	20x	50x	100x	115x
1.3 MP / 0.5x tube / green	19,83	10,24	4,96	2,74	1,36	0,84	0,73
2.3 MP / 0.5x tube / green	15,63	8,14	3,94	2,23	1,15	0,75	0,64
5 MP / 0.5x tube / green	12,63	6,64	3,13	1,84	1	0,66	0,58
5 MP /1.0x tube / blue	7,98	4,28	2,00	1,23	0,73	0,51	0,45

SiMETRICS roughness standard ARS C3 / Ra = 0.23 µm

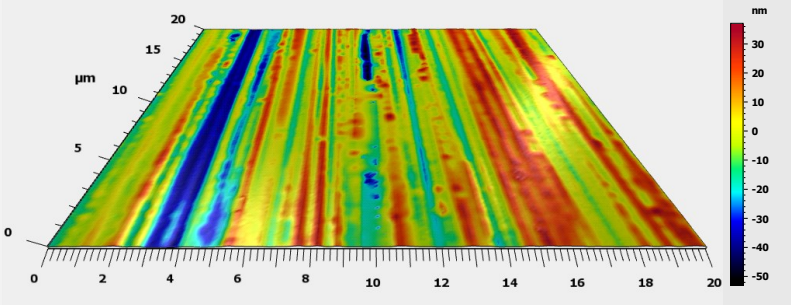


smart WLI

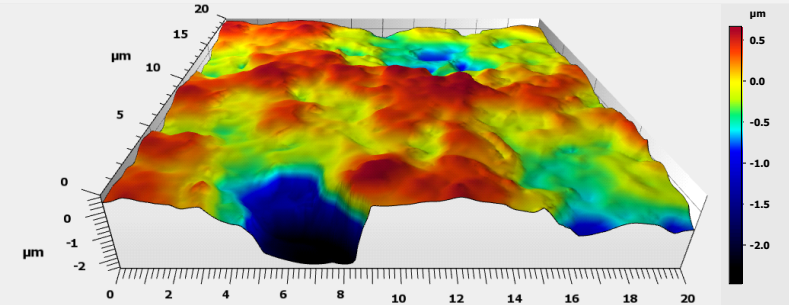
small partial areas of various surface / normalized 1 : 1 : 1 xyz scaling



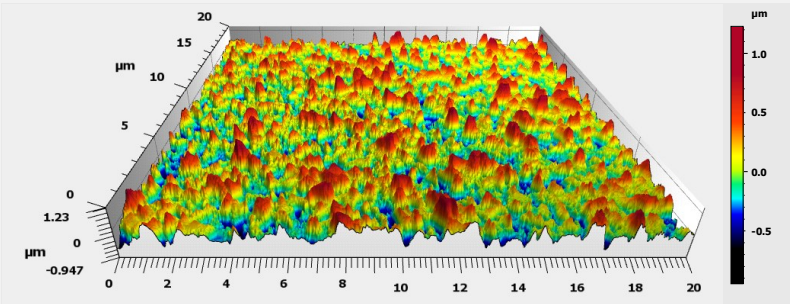
ARS F2, Sal ≈ 0.8 µm, Sq ≈ 67 nm



grind wafer, Sal ≈ 0,8 µm, Sq ≈ 14 nm



ARS C3, Sal ≈ 4 µm, Sq ≈ 350 nm



black silicon, Sal ≈ 0,35 µm, Sq ≈ 290 nm

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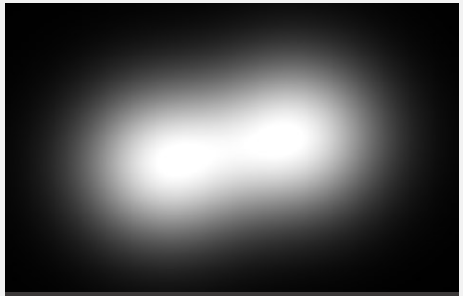
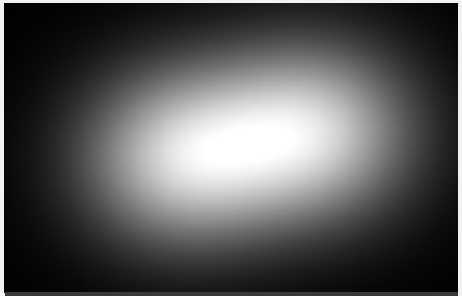
the profiler has to provide the required resolution to capture the details of the surface

differences from microscopy and coherence scanning interferometry

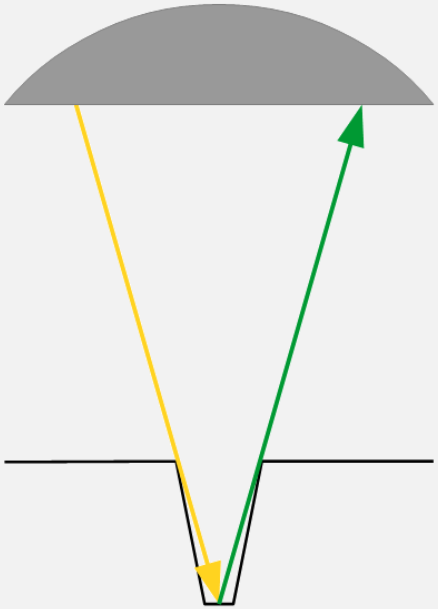
light sources at the same height level



separation limit



separation impossible



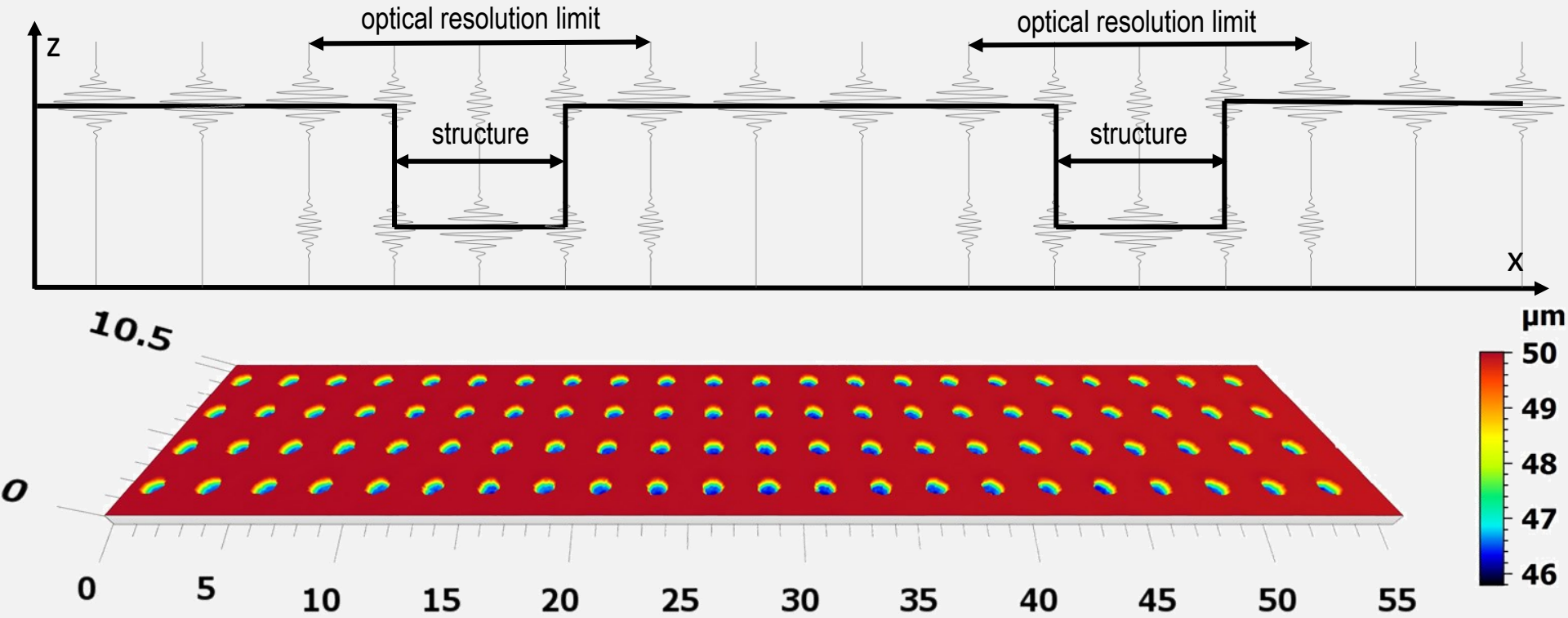
concave structure

height differences between light sources

upper image

lower image

- The separation of close light sources (small structures) is not physical limited if light sources (structures) are located on different height levels
- Concave structures may limit the aperture themselves – using objectives with lower aperture may reduce disturbing wall reflections


optical resolution limit
optical resolution limit
z
structure
structure
x
10.5
0
µm
50
49
48
47
46
0
5
10
15
20
25
30
35
40
45
50
55

business activities

direct sales
components for integration partners
support of world-wide distribution partners

products

optical 3d sensors
optical profilers
portal measuring systems

technology

coherence scanning (white-light) interferometry
acceleration using GPGPUs

applications

surface metrology
- roughness measurements
- measurement of micro geometries

quality control
inline process control