3DMC 3D METROLOGY CONFERENCE

Aachen, 2022

White light interferometry for surface roughness inspection

- an industrial aspect -

Dr. Istvan Biro

17.11.2022.

AGENDA

- Introduction of Heliotis AG & WLI
- Roughness and how to measure it
- Validation of roughness measurements
- Roughness and functional consequences
- Q & A

Heliotis - A Strong Partner

Specialized in 3D metrology for precision applications

- designing & building high precision sensors & instruments based on White Light Interferometry
- in-house R&D, assembly and quality assurance

… what can Heliotis White Light Interferometry do for you?

White Light Interferometry & Other Techniques

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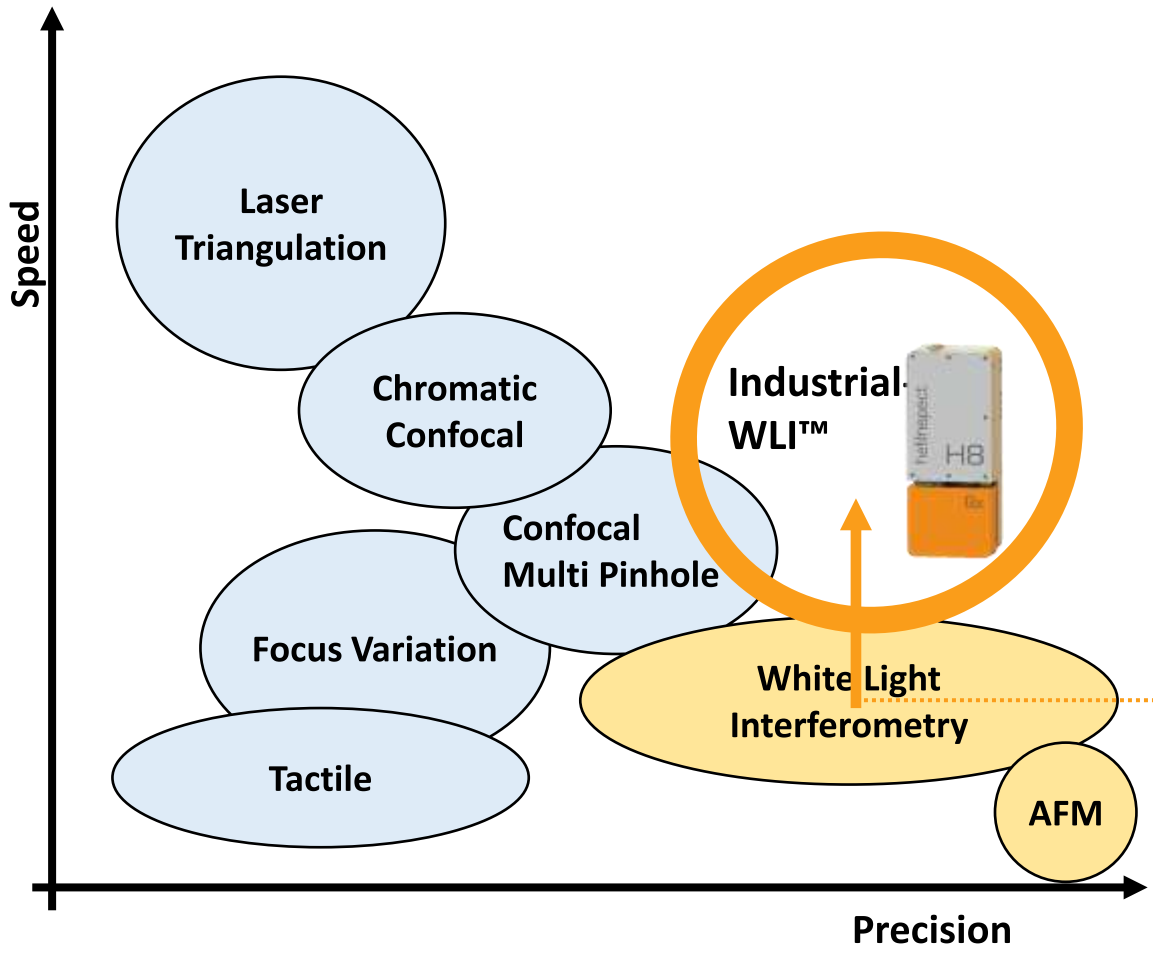
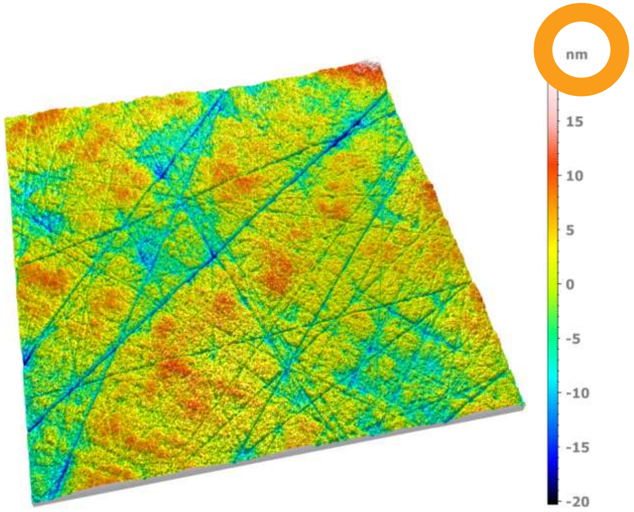
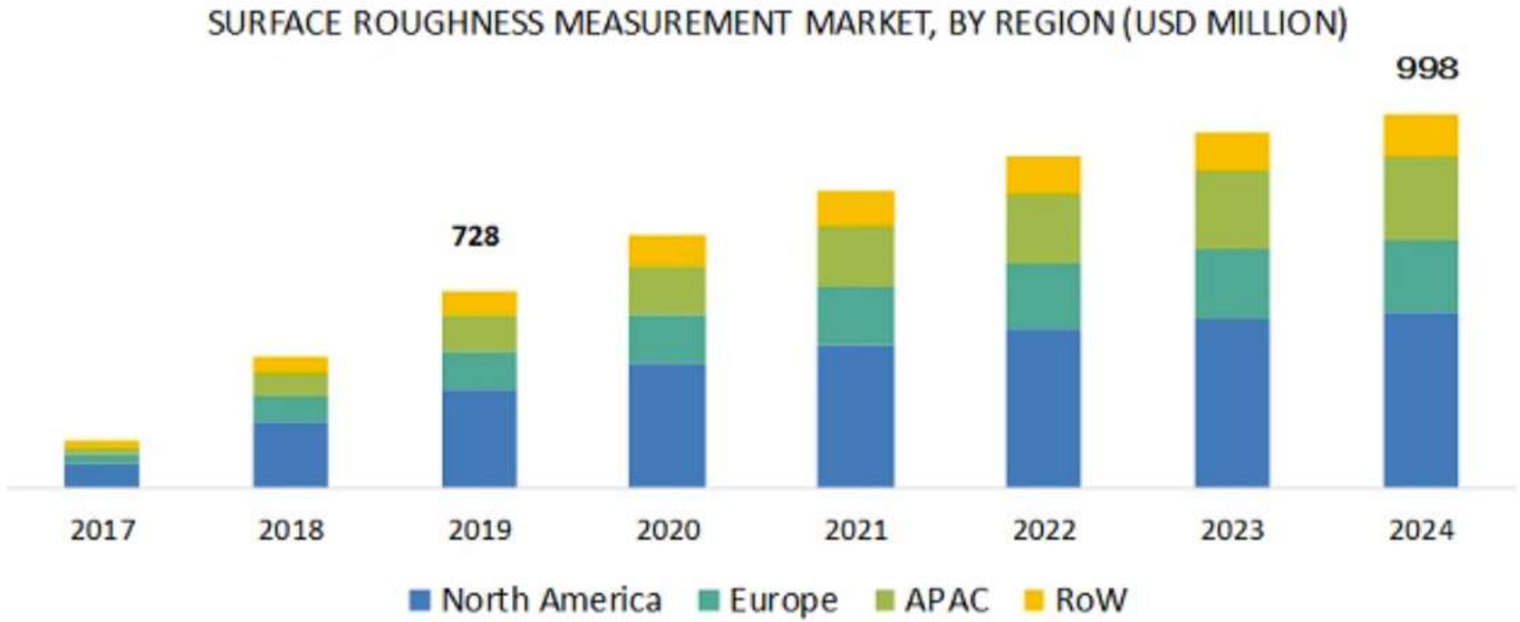
- **non-contact, optical 3D** measurement method
- **nanometer** resolution
- **Up to 100X faster** due to in-pixel processing (Heliotis)





… what about roughness ?

... why roughness ?



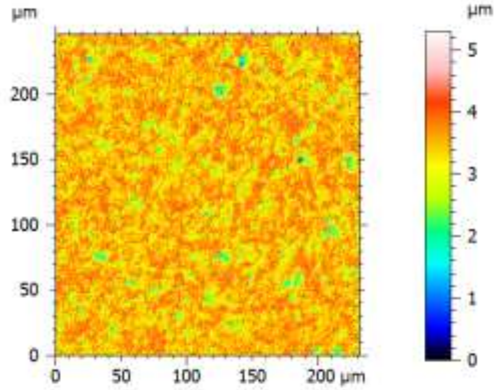
https://www.marketsandmarkets.com

- Increasing demand for at-line and in-line quality control involving roughness
- @Heliotis: increased frequency of roughness related requests

Roughness

- is a component of surface finish / characteristics (next to shape, waviness, ….) --- this talk: roughness only
- described as Geometrical Product Specification (GPS), in:

  - ISO 25178(-2) → surface/areal roughness

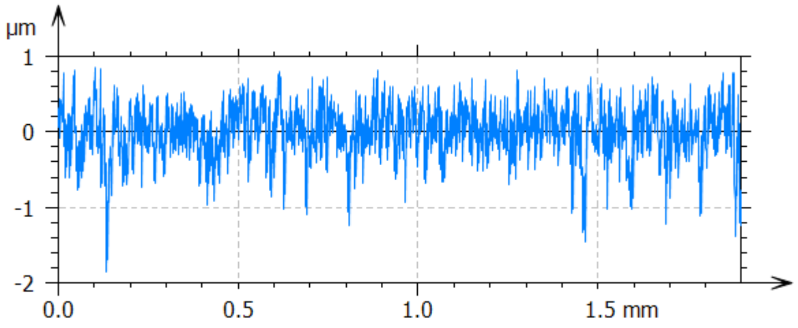


→ Many parameters, like Sa, Sz, Sq, …

ISO 25178 - Roughness (S-L)			
F: [Workflow] Form removed (LS-poly 2)			
F: Leveled (LS), Angle -2.648e-11°, -2.419e-11°			
S-filter (λs): Robust Gaussian (order 0), 1 µm			
L-filter (λc): Robust Gaussian (order 0), 0.2 mm			
Height parameters			
Sq	0.3698	µm	*Root-mean-square height*
Sz	4.734	µm	*Maximum height*
Sa	0.2834	µm	*Arithmetic mean height*
Spatial parameters			
Sal	4.239	µm	*Autocorrelation length*
Functional parameters (volume)			
Vv	0.4508	µm³/µm²	*Void volume*

…

  - ISO 21920(-2) → profile roughness



→ Many parameters, like Ra, Rz, Rq, …

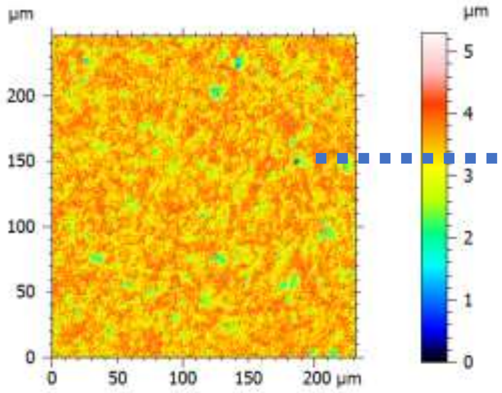
ISO 21920 - Roughness (S-L)			
F: Leveled (LS), Angle 0.000743°			
S-filter (λs): Robust Gaussian (order 0), 1 µm			
L-filter (λc): Robust Gaussian (order 0), 0.25 mm			
Evaluation length: All λc (7)			
Height parameters			
Rq	0.3098	µm	*Root mean square height*
Rz	1.801	µm	*Mean height*
Ra	0.2330	µm	*Arithmetic mean absolute height*
Spatial parameters			
Ral	0.006642	mm	*Autocorrelation length*
Functional (volume) parameters			
Rvv	368807	µm³/mm²	*Void volume*

…

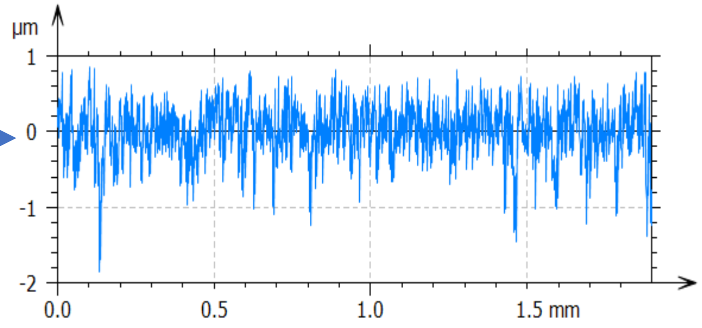
Roughness: WLI vs. Tactile

→ Mostly non-contact optical measurement

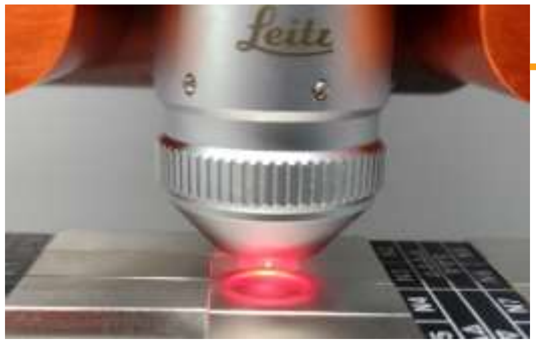
surface/areal roughness



profile roughness



→ Mostly tactile, but can be optical (including extraction from areal data!)



Does both!

Comparable?

Mahr

Roughness: WLI vs. Tactile

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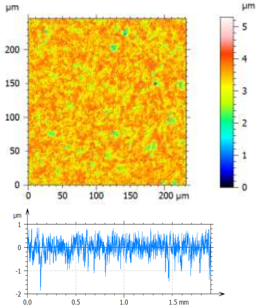
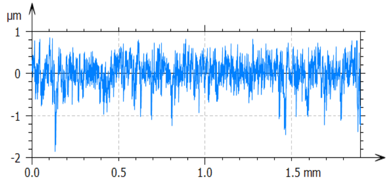
WLI : areal + profile roughness

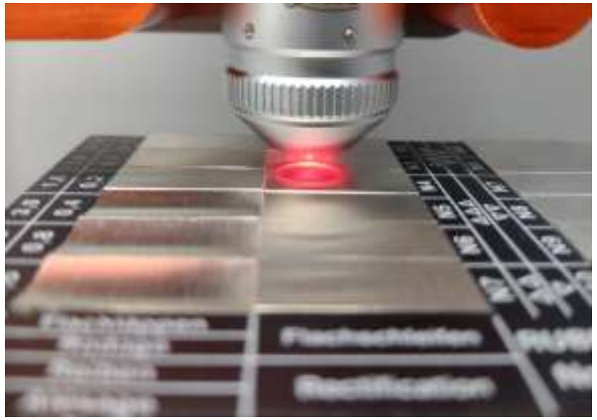


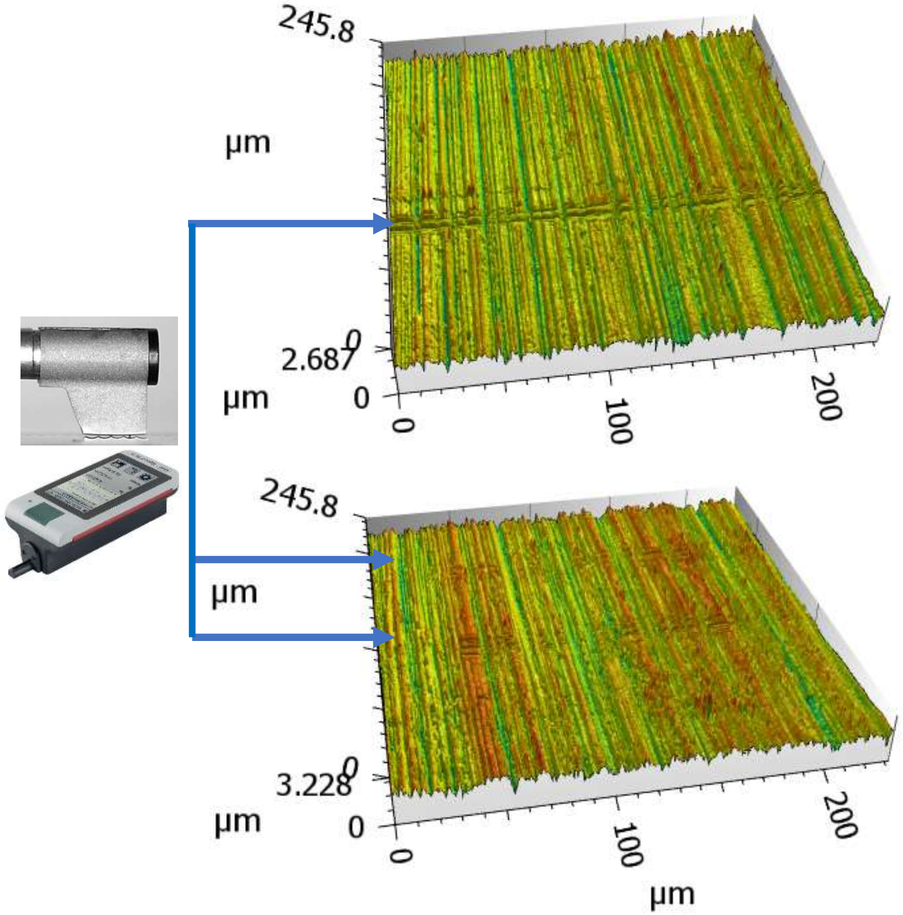
→ No surface alteration

Tactile : profile roughness



→ limited to harder /
less sensitive surfaces

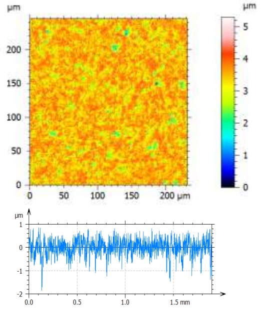




https://www.pexels.com/

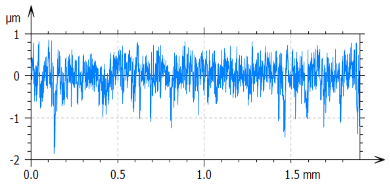
Roughness: WLI vs. Tactile

WLI : areal + profile roughness



→ More expensive

Tactile : profile roughness



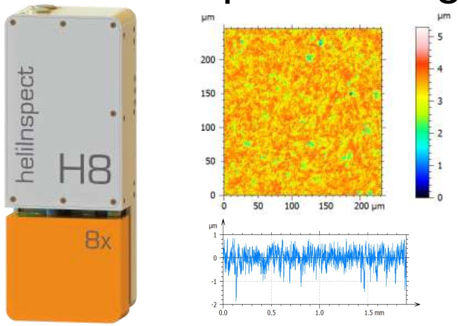
→ Cheaper

Few 10k Eur

Few 1000Eur

Roughness: WLI vs. Tactile

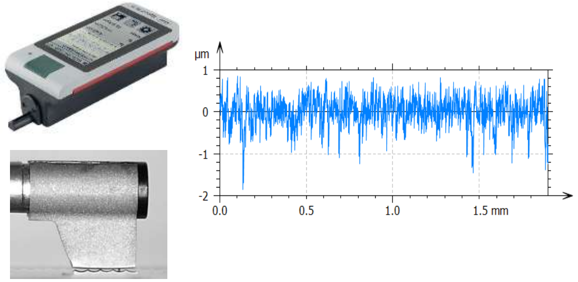
WLI : areal + profile roughness



→ Faster (with Heliotis)

~1s / less = full surface

Tactile : profile roughness

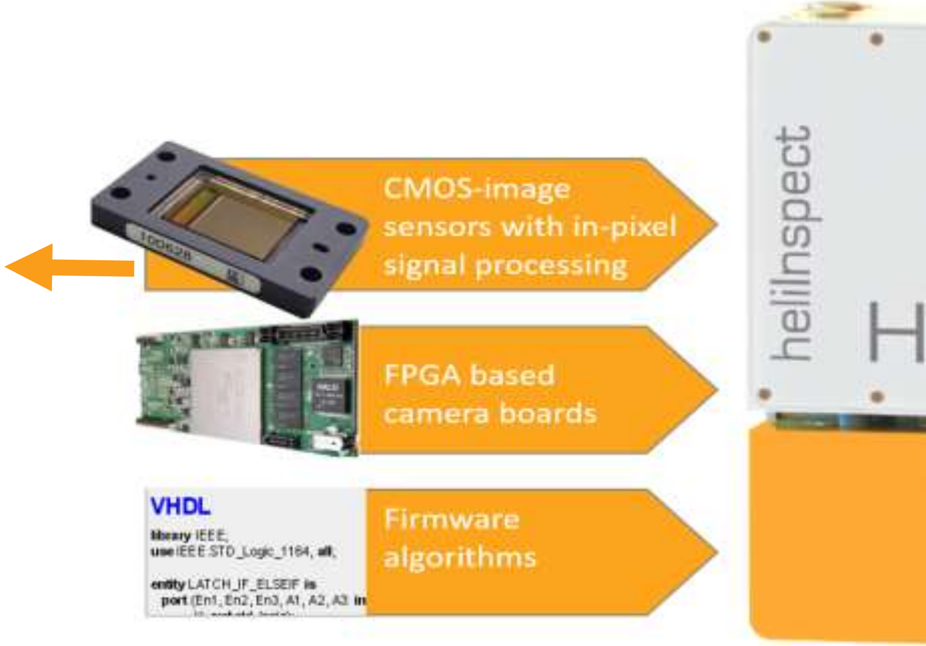


→ Slower (and less data)

Several seconds = 1 line

Production line :
Must keep up with cycle times!

Lab : Slow = no problem



→ with Heliotis: internal accelerated processing

→ automated Roughness evaluation with professional vision software

Roughness: WLI vs. Tactile

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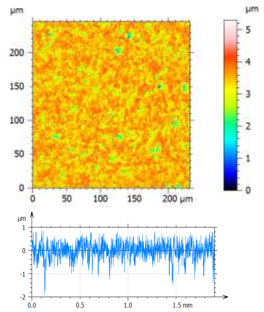
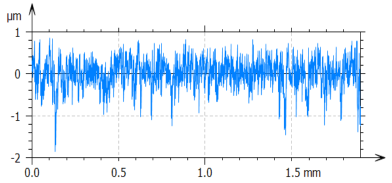
WLI : areal + profile roughness

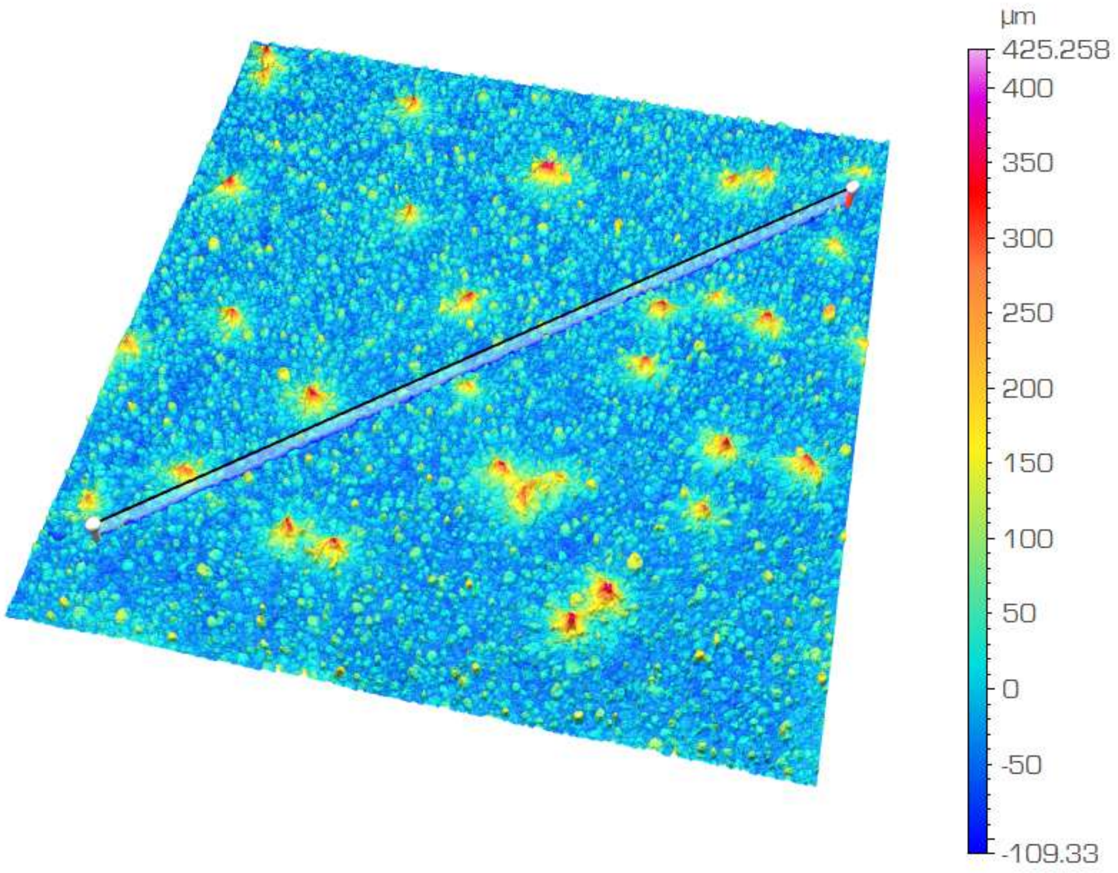


→ Extra dimension: more surface feature definition

Tactile : profile roughness

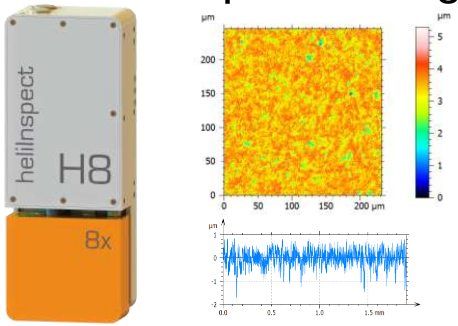


→ Not all surfaces can be measured



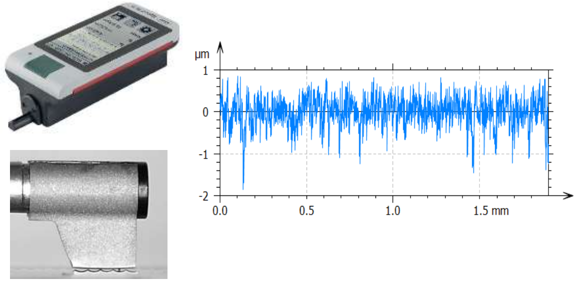
Roughness: WLI vs. Tactile

WLI : areal + profile roughness

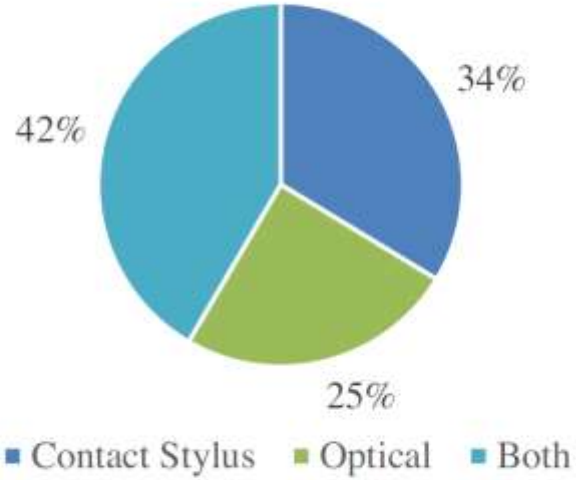


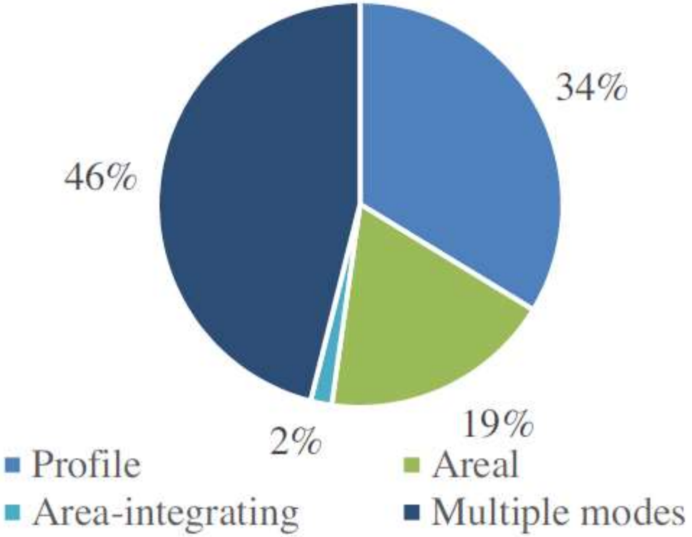
→ Newer, on the rise

Tactile : profile roughness



→ Well established in the industry





Contact instruments dominate
- Profile roughness ISO older than areal roughness

Mostly Profile/Mixed modes are used

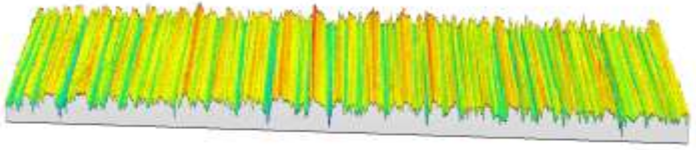
Todhunter et. Al., CIRP Journal of Manufacturing Science and Technology, 2017

Transitioning (customer-critical question):
→How to ensure compatibility?
→Do the results match?

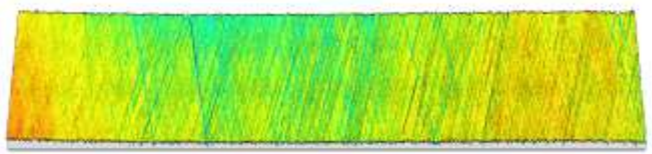
Roughness: WLI results validation

→ Directly comparing measurement results (WLI, tactile stylus, …) on a sample

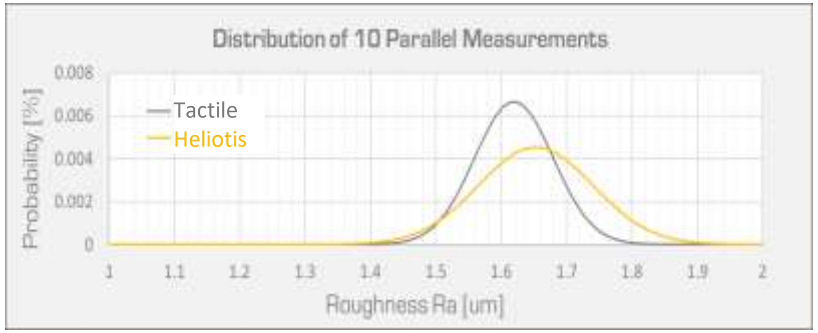
Grinding

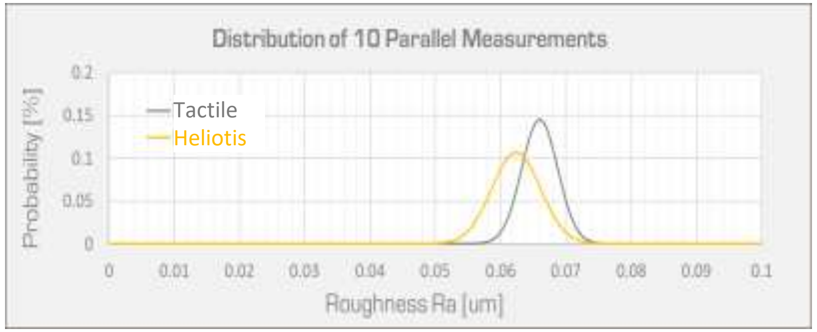


Lapping



Comparison Tactile & Heliotis





	Tactile	Heliotis	Deviation [um]	Deviation [%]
Average [um]	1.620	1.653	0.034	2.03
Sigma1 [um]	0.060	0.088	/	/

VALIDATED

	Tactile	Heliotis	Deviation [um]	Deviation [%]
Average [um]	0.066	0.062	0.004	5.77
Sigma1 [um]	0.003	0.004	/	/

VALIDATED

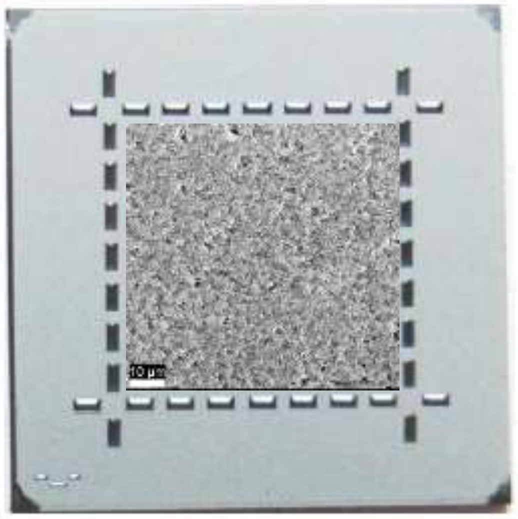
- Good overall agreement
- Note: different instrument transfer functions
  - Corrections needed.
  - Match quality differs by material, manufacturing method, …

Roughness: WLI results validation

→ Using calibration targets: R and S

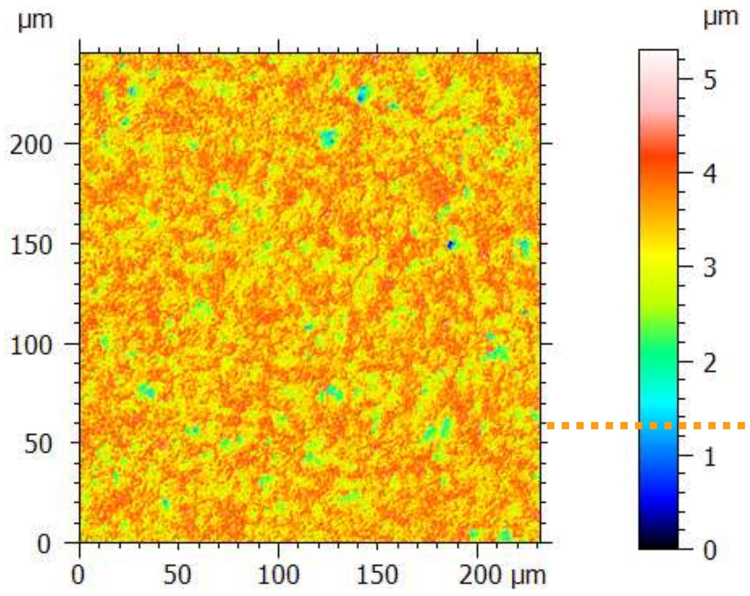
For:

- Validation reference (lacking other instrument)
- Periodic capability check (! must in industry !)
- Especially: link S AND R parameters

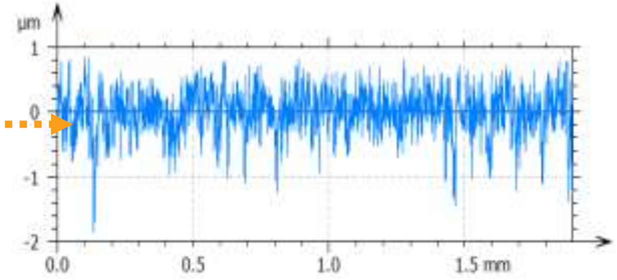


SiMetrics ARS c3 :

- highly isotropical
- Sa = 290nm → from confocal microscopy, 50X
- Ra = 230nm → from tactile, R=2µm



Heliotis, 50X



ISO 25178 - Roughness (S-L)			
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F: Leveled (LS), Angle -2.648e-11°, -2.419e-11°			
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ISO 21920 - Roughness (S-L)			
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Height parameters			
Rq	0.3098	µm	*Root mean square height*
Rz	1.801	µm	*Mean height*
Ra	0.2330	µm	*Arithmetic mean absolute height*
Spatial parameters			
Ral	0.006642	mm	*Autocorrelation length*

? ? ? ?

Roughness: WLI results validation

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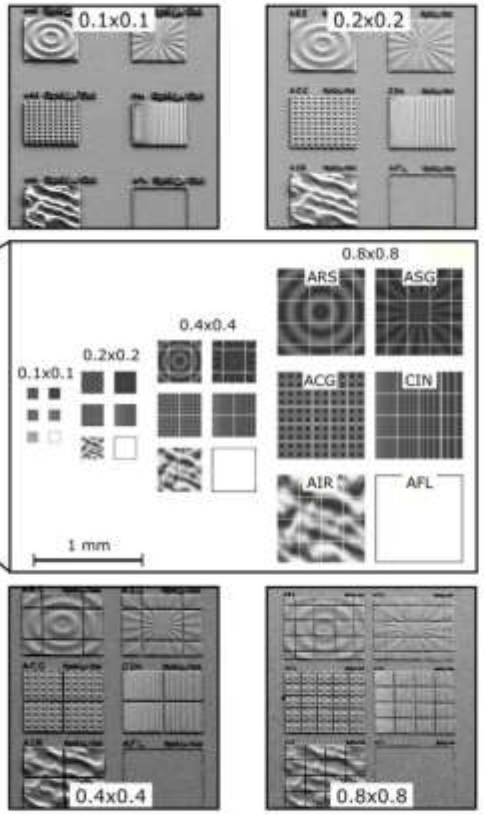
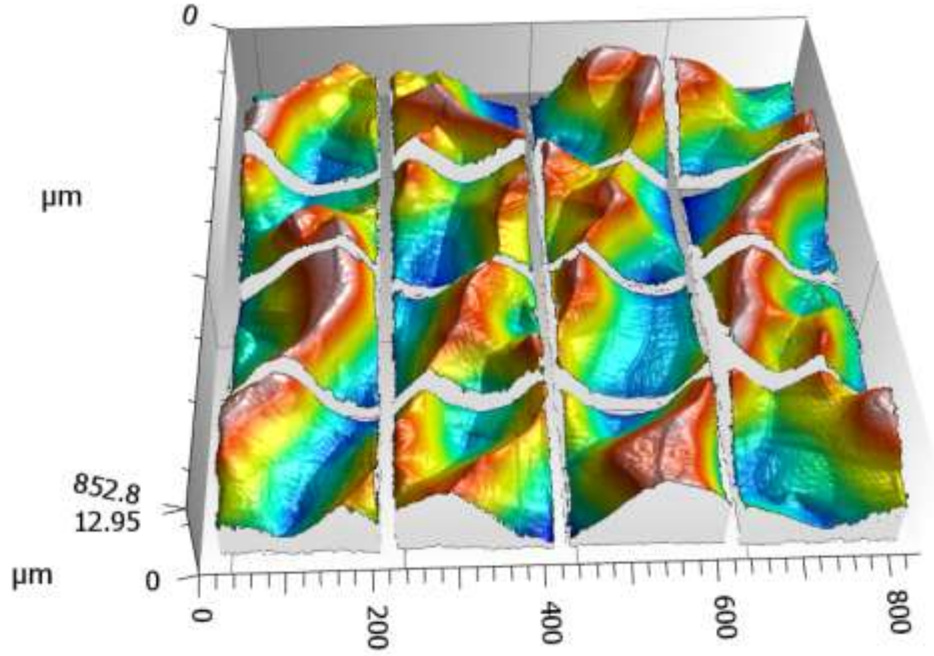
→ Using calibration targets : Complex features for ISO-conform-verification

Opti Cal
Universalnormal



AIR:
Sq = 2,655 µm
Sa = 2,297 µm

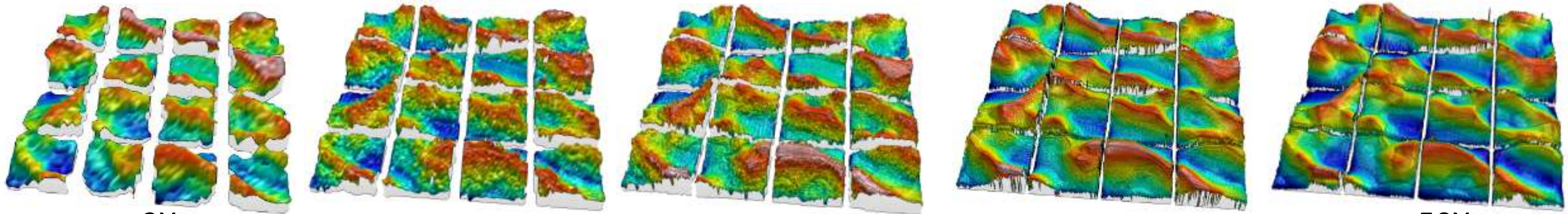
Heliotis, 20X, stitched



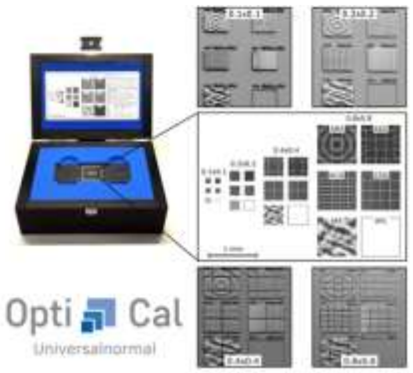
ISO 25178 - Roughness (S-L)			
F: [Workflow] Form removed (LS-poly 2)			
F: Leveled (LS), Angle -0.004265°, 0.002809°			
S-filter (λs): Robust Gaussian (order 0), 2.5 µm			
L-filter (λc): Robust Gaussian (order 0), 0.8 mm			
Height parameters			
Sq	2.683	µm	*Root-mean-square height*
Sa	2.307	µm	*Arithmetic mean height*

Roughness: WLI results validation

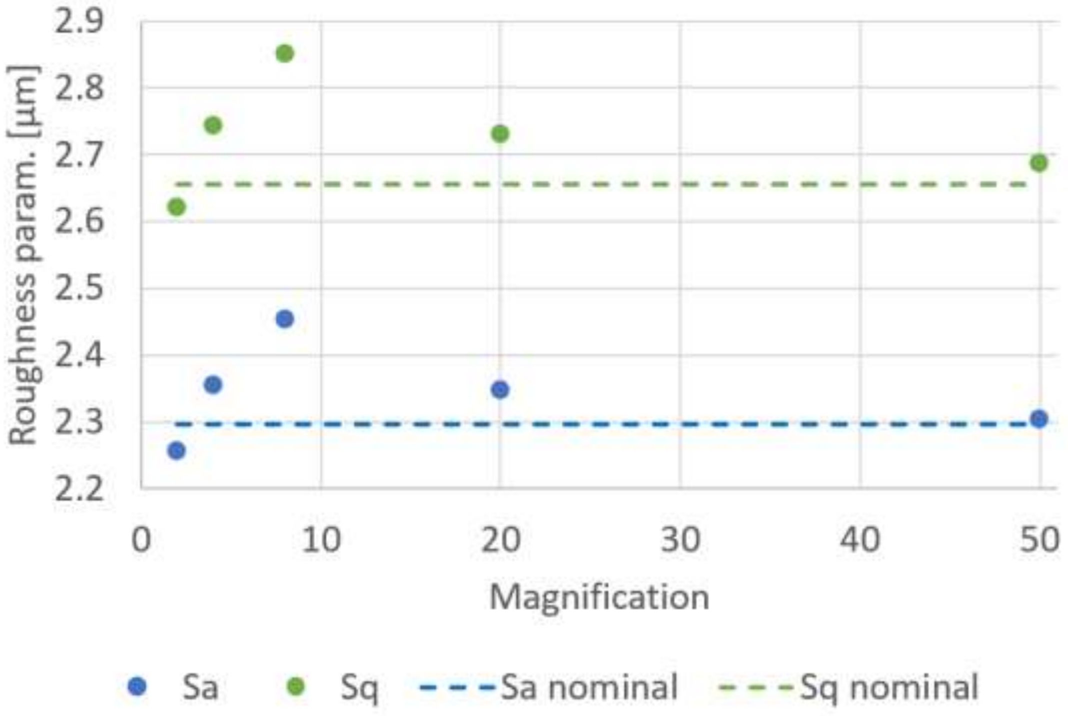
→ How about different optics (lateral resolution)?



2X | 4X | 8X | 20X | 50X



AIR:
Sa = 2,297 µm
Sq = 2,655 µm



→good agreement with all optics due to

- course lateral structure of sample
- high Z accuracy of Heliotis H8 for all optics

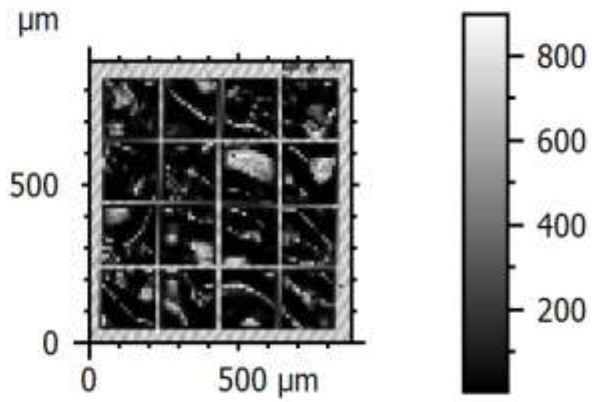
heliOptics™ WLI8	2 x	4 x	8 x	10 x	20 x	50 x	100 x
Field of view [mm²]	6.5 x 6.1	3.3 x 3.1	1.6 x 1.5	1.3 x 1.2	0.65 x 0.61	0.26 x 0.25	0.13 x 0.12
Optical resolution [µm]	12	6	3	2.4	1.2	0.48	0.24[*]
Working distance [mm]	43.0	42.9	12.8				
Nikon Mirau				7.4	4.7	3.4	2.0
Leica Mirau				3.6	3.6	2.5	n. a.
Numerical aperture	0.1	0.15	0.25	0.3	0.4	0.5	0.7

[*] pixel resolution

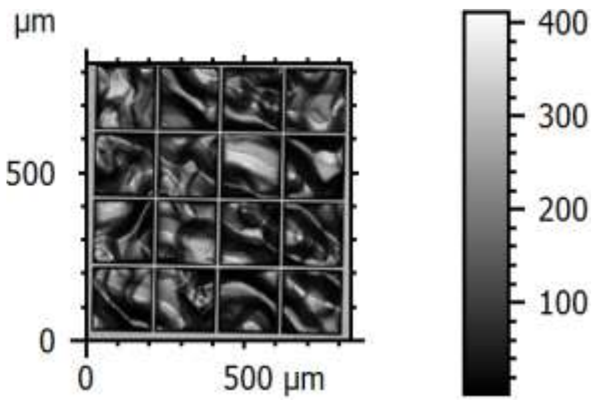
Roughness: WLI results validation

→ Measurability of difficult surfaces

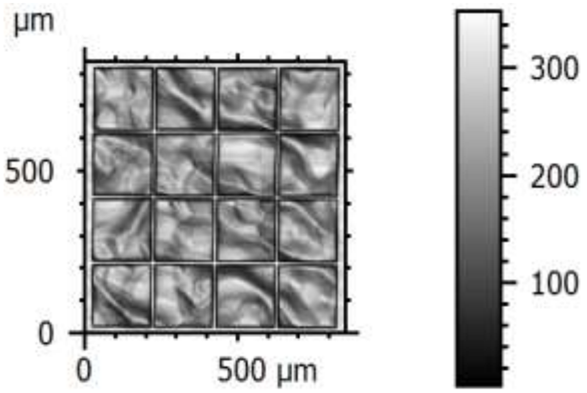
Signal intensity variation



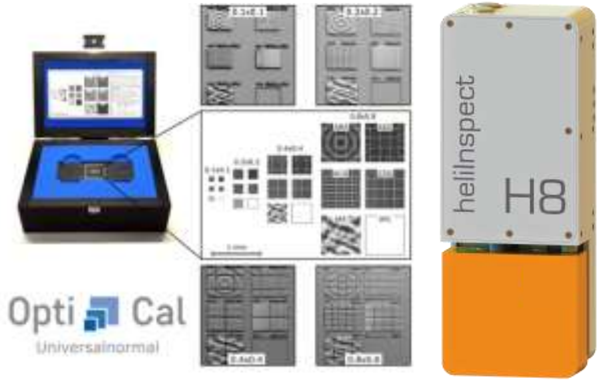
2X



8X



50X



→ steep and shiny surface results in highly non-uniform reflected light distribution on the image sensor (especially for low magnification, low NA optics)

→ only measurable due to very high dynamic range of Heliotis H8

Roughness: WLI results validation

heliotis advancing 3D metrology

→ Limitations

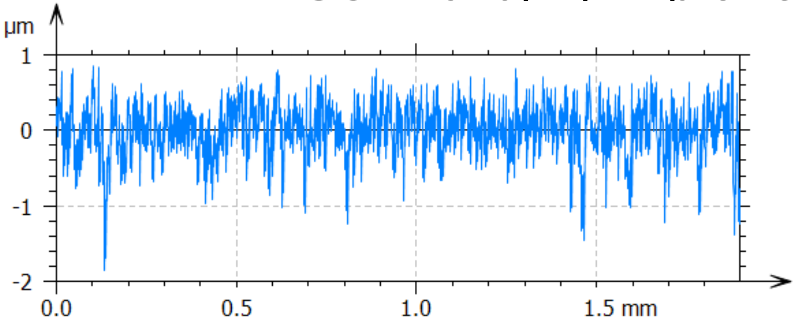
- **Instrument-to-instrument comparison works**. But: roughness observed through instrument transfer function…
- **Calibration targets work** for validation. But: high variability required to match individual industrial use cases : manufacturing methods, roughness scales, roughness parameters, material, ….
- Traceable / calibrated artefacts are very expensive

What else can we do additionally?

→use the complexity to our advantage
→focus on parameter-functionality link

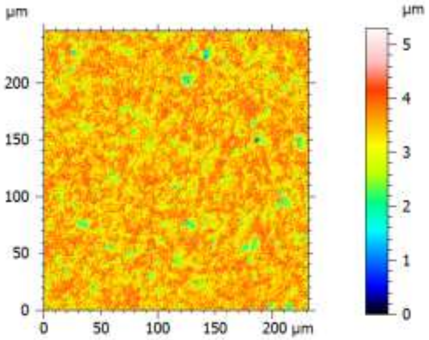
Roughness – which parameter?

- ISO 21920(-2) → profile roughness

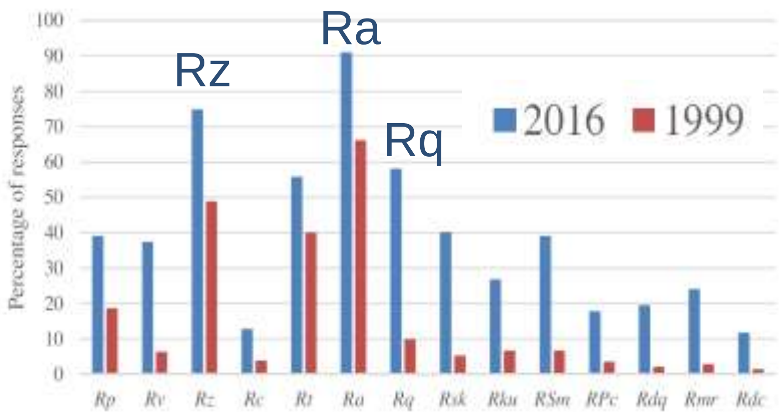


~67 roughness parameters
+ primary surface par.
+ waviness surface par.

- ISO 25178(-2) → surface/areal roughness

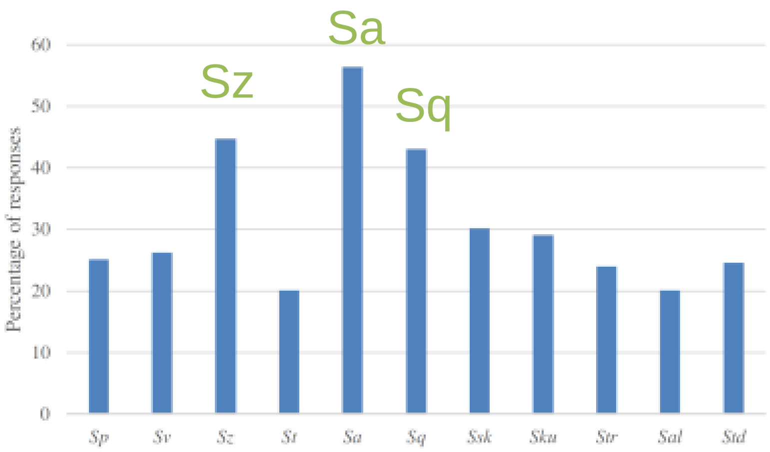


~85 roughness parameters
+ primary surface par.
+ waviness surface par.



… Ra, Rz, Rq dominate

- Use more of them!
- Correlate parameters to functional testing

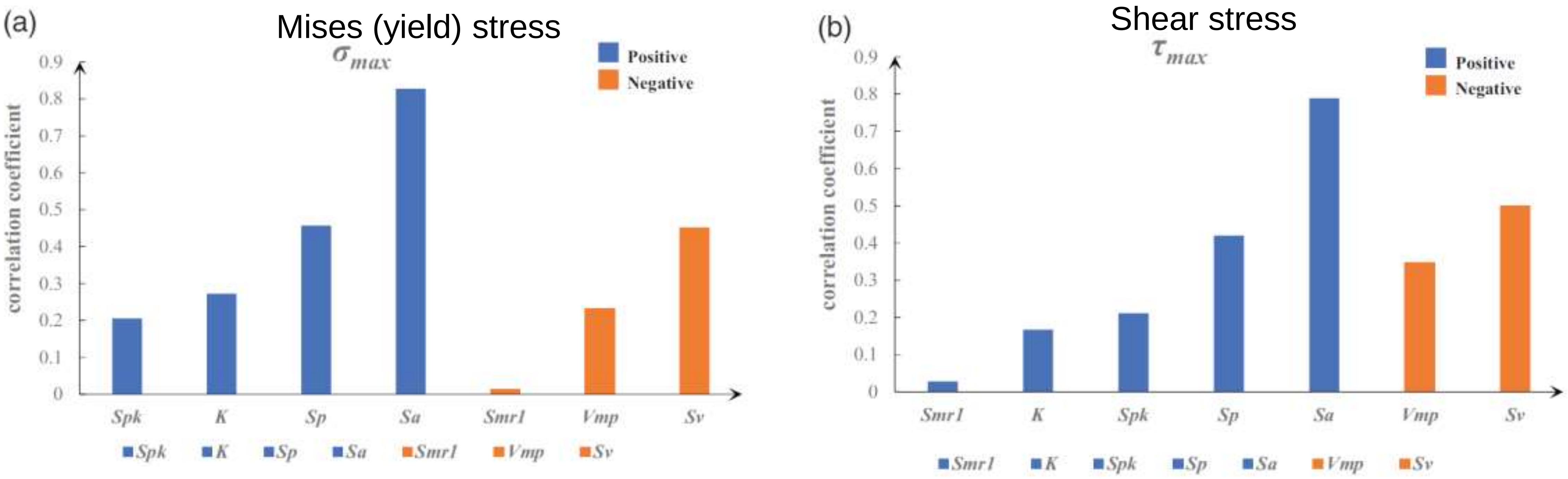


… Sa, Sz, Sq dominate
… good usage variability!

Todhunter et. Al., CIRP Journal of Manufacturing Science and Technology, 2017

Roughness: functional link

→ Example: gear contact stress and surface roughness parameters



→ Forms of mechanical stress correlate with specific roughness parameters

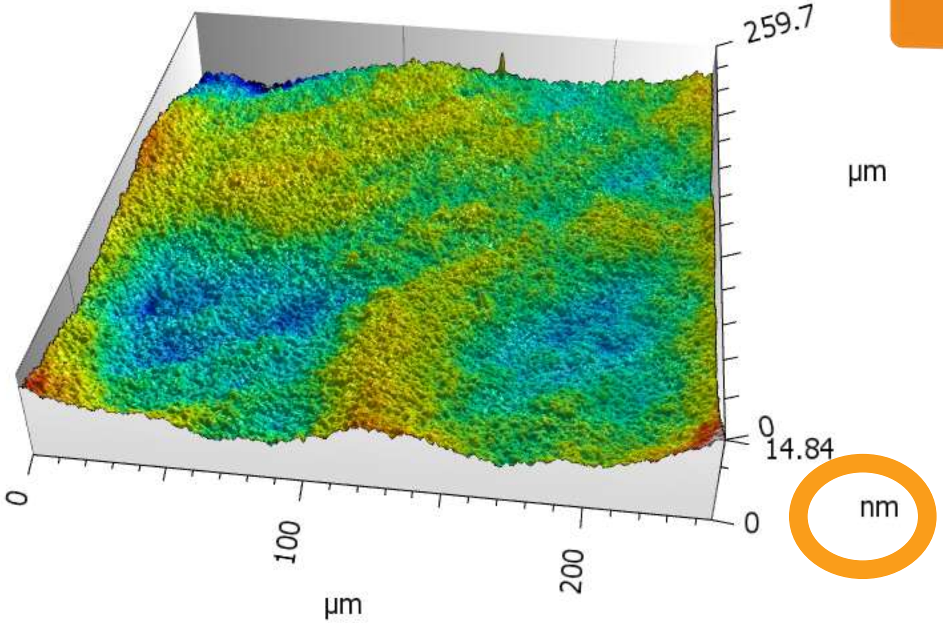
Duo et. Al., J Engineering Tribology, 2020

Roughness: functional link

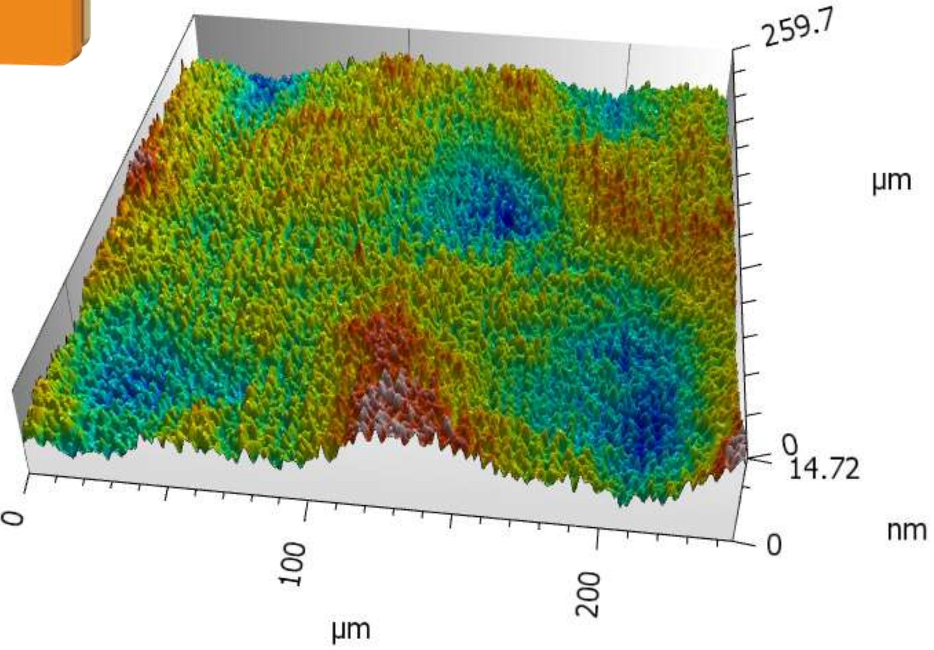
→ Comparing original and laser treated watch glass surfaces

https://www.pexels.com/

original



lasered

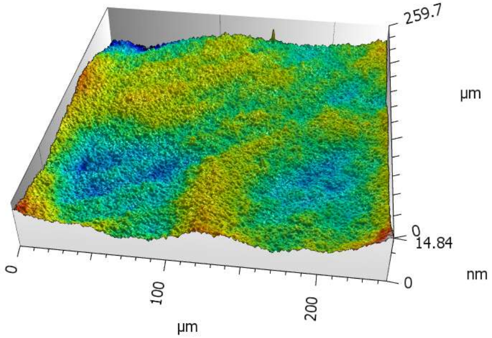


Nanometer surface height change!

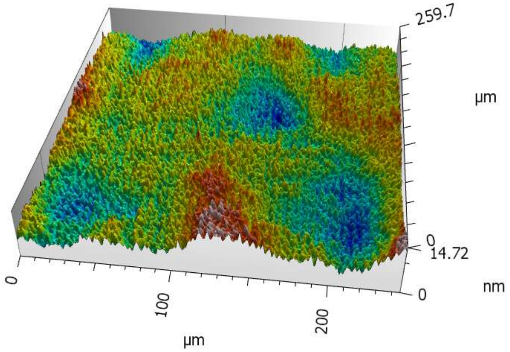
Roughness: functional link

→ Comparing original and laser treated watch glass surfaces

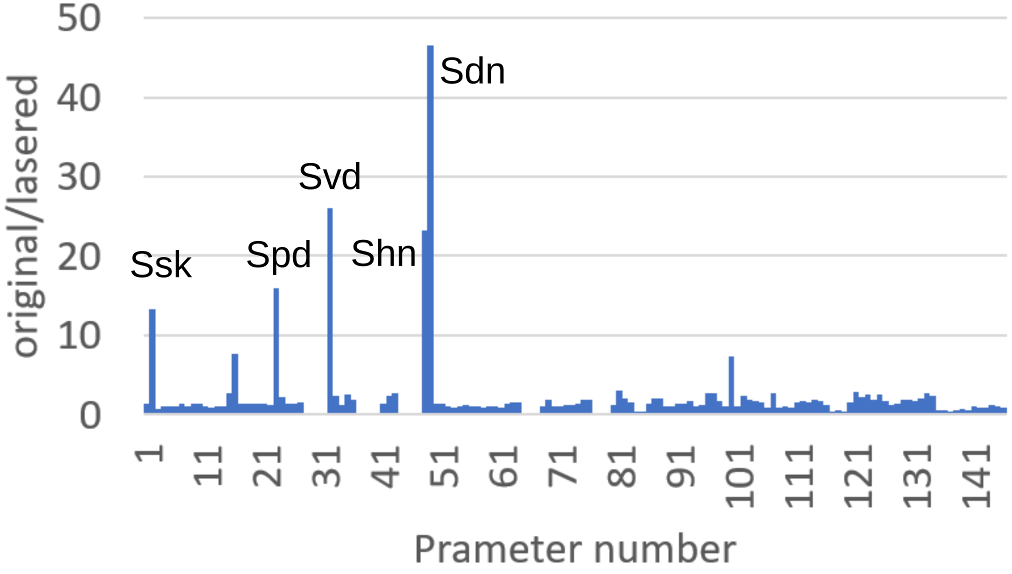
original



lasered



ParamRatio



ISO 25178 - Roughness (S-L)

F: [Workflow] Form removed (LS-poly 2)

F: Leveled (LS), Angle -5.976e-12°, 6.394e-12°

S-filter (λs): Robust Gaussian (order 0), 1 µm

L-filter (λc): Robust Gaussian (order 0), 0.2 mm

	Height parameters		**Height parameters**			
different	Ssk	0.02104	Ssk	0.2781		*Skewness*
similar	Sa	1.027	Sa	1.401	nm	*Arithmetic mean height*
	Feature parameters		**Feature parameters**			
different	Spd	0.0009891	Spd	0.01568	1/µm²	*Density of peaks*
	Svd	0.0006908	Svd	0.01796	1/µm²	*Density of pits*
	Shn	38.00	Shn	879.0		*Hill count*
	Sdn	22.00	Sdn	1023		*Dale count*

original lasered

→ Clear differentiation between surfaces
– function related

Summary

- Increased demand for roughness measurements drives the market
- New measurement methods have huge improvement potential but must be validated
    - Measurement comparison
    - Artefacts
    - Practical approach: functionality correlations

Thank you!

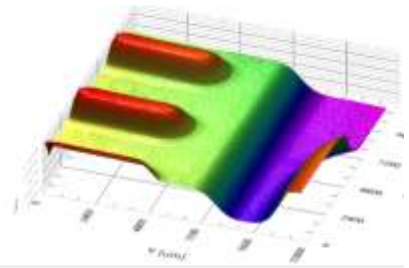
Q & A

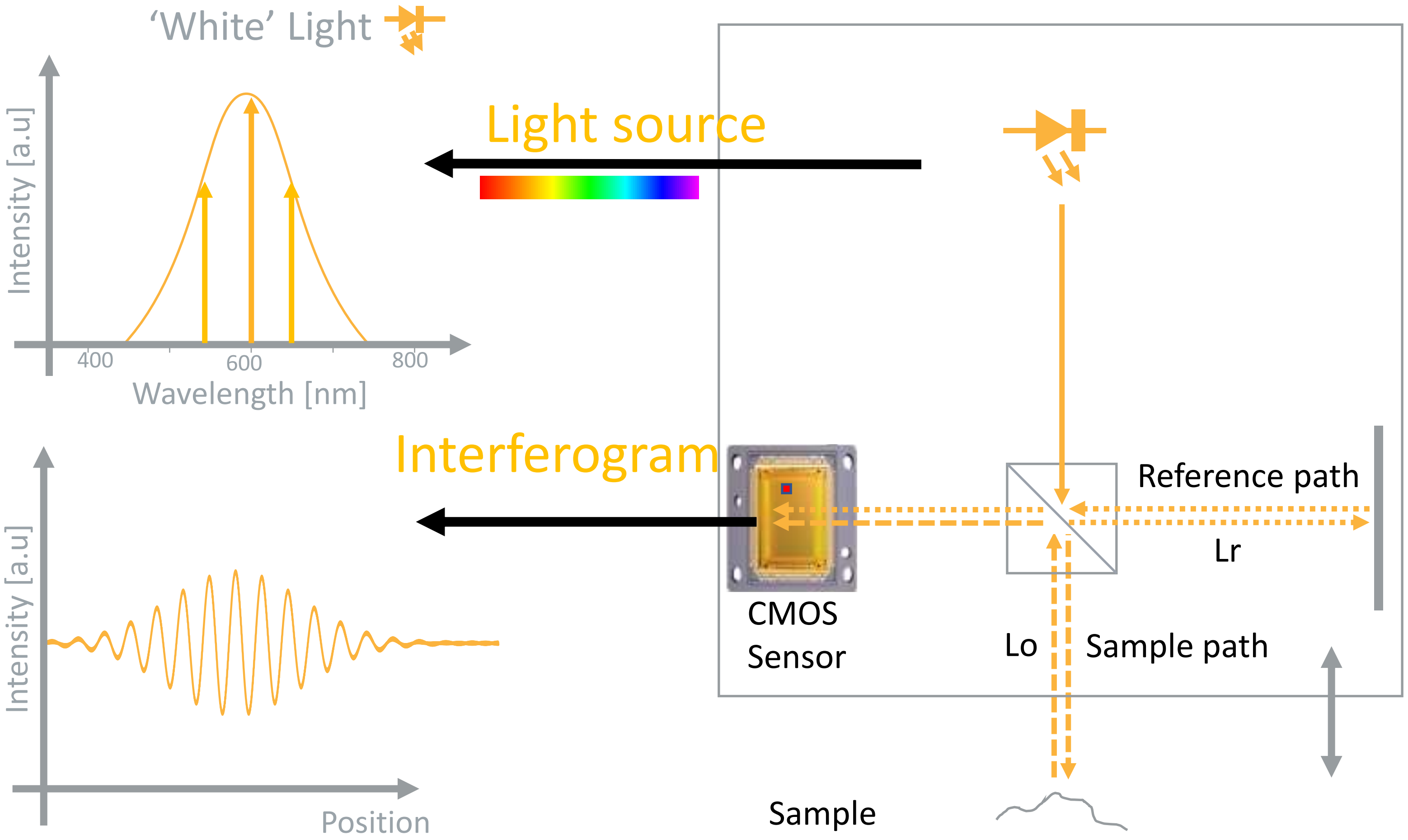
PLEASE VISIT OUR DEMO

Extra slides

White Light Interferometry - Principle

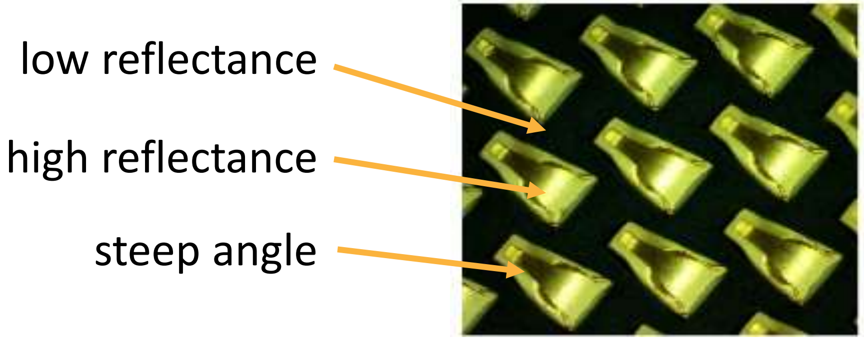
- principle: interferometry
- use “white” light
- record changing interferogram
- reconstruct 3D shape from changing interferogram – all pixels





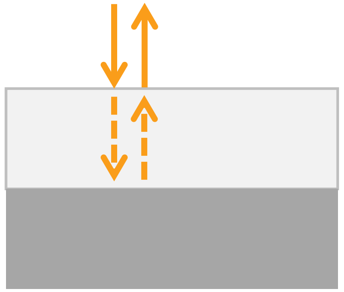
3D with absolute height & nanometer precision

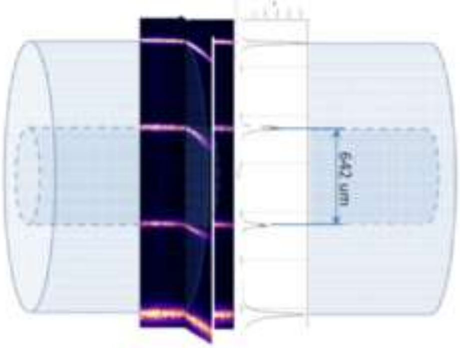
Heliotis White Light Interferometer Measurement Capability



Large intra-scene dynamic

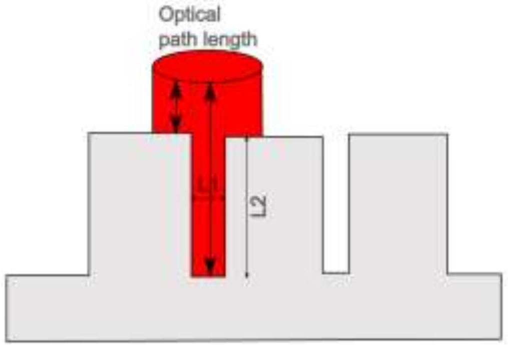
- dark & shiny surfaces
- steep & flat regions





Measures multiple Surfaces

- WLI is inherently tomographic
- multiple interfaces are detected separately

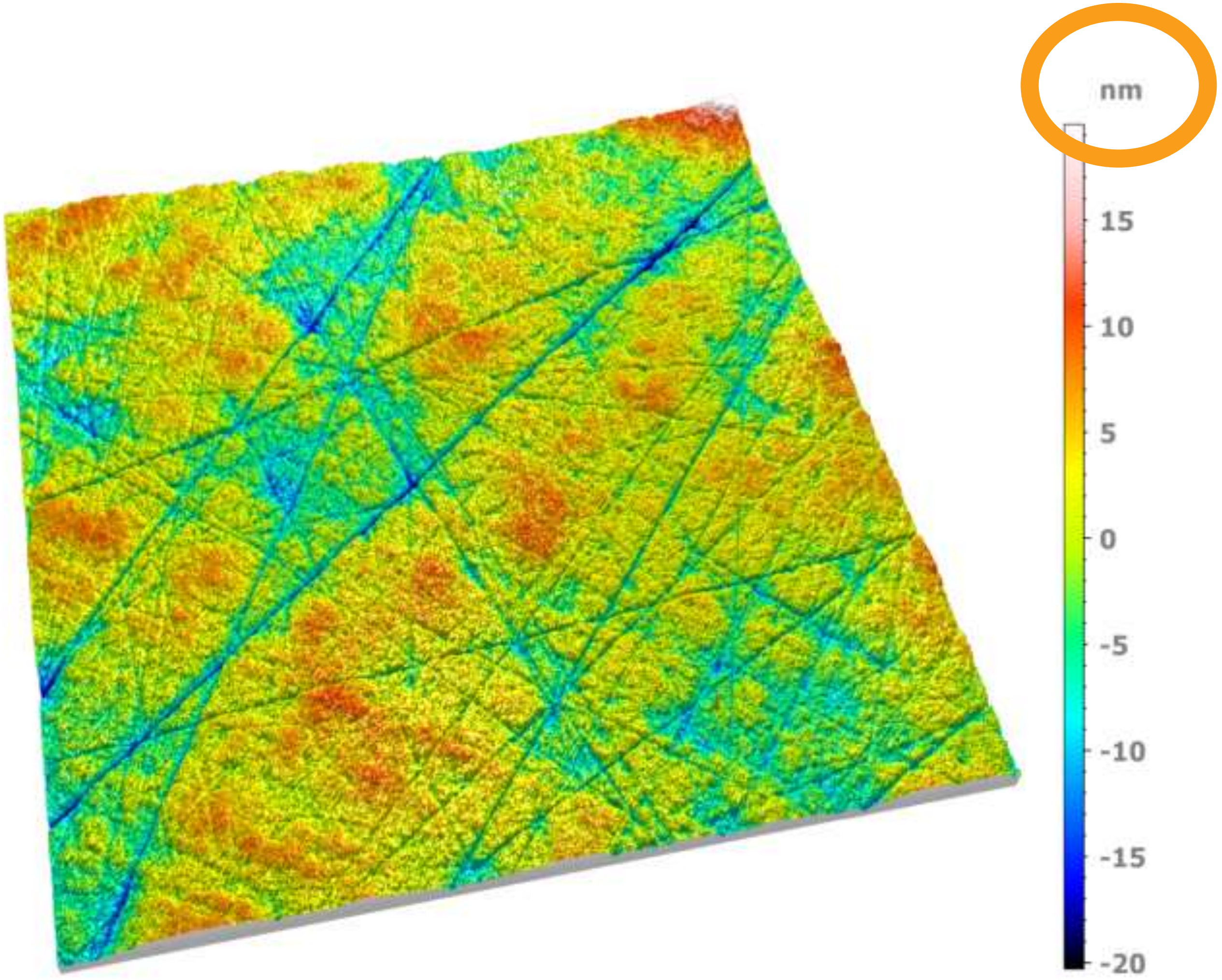


Measures deep cavities

- no shadowing

Heliotis White Light Interferometer Measurement Capability

heliotis
advancing 3D metrology



Very high z resolution

- nm Z measurements
- lateral resolution defined by variable optics

heliOptics™ WLI8		2 x	4 x	8 x	10 x	20 x	50 x	100 x
Field of view [mm²]		6.5 x 6.1	3.3 x 3.1	1.6 x 1.5	1.3 x 1.2	0.65 x 0.61	0.26 x 0.25	0.13 x 0.12
Optical resolution [µm]	H8	12	6	3	2.4	1.2	0.48	0.24(*)
	H8M	6	3	1.5	1.2	0.6	0.24(*)	0.12(*)

Configuration		3 x	2 x	1.5 x	1 x	0.8 x	0.5 x
Field of view [mm²]		4.10 x 4.35	6.14 x 6.53	8.19 x 8.70	12.29 x 13.06	15.36 x 16.32	24.58 x 26.11
Optical resolution [µm]	H9	8	12	16	24	30	48
	H9M	4	6	8	12	15	24