

OPTICAL PROFILOMETRY

Surface Roughness Characterization for Smooth Operators

COVALENT ACADEMY

INTRO TO SURFACE CHARACTERIZATION PART 2 / 3

RSVP at:
https://bit.ly.covalent03

Covalent Metrology



- **Founded 2016**
- **Testing, measurement & characterization** Platform
- **30 team members (13 PhDs)**
- **9,500 ft² lab in Sunnyvale**
- **1-Stop-Shop Source for Answers**
  - 30 instruments in-house
  - 6 partnerships with instrument makers
  - 11 partner labs
  - 6 corporate “tool shares”
- **>275 customers** (80% repeat)

Covalent Technical Groups and Organization

hello@covalentmetrology.com

Electron & Scanning Probe Microscopy

(SEM/TEM, AFM, EDS, EELS, Nanoindent, acoustic microscopy)

Surface Analysis

(XPS, Auger, ToF-SIMS, dSIMS)

Optical Microscopy & Spectroscopy

(Laser Confocal, White Light, Chromatic Dispersion, Spectral Ellipsometry, UV-Vis-NIR Spectroscopy)

Materials/ PC Board FA

(Cross Sections, Inspections, Dye & Pry)

X-Ray Characterization

(XRD/XRR, XRF, µCT)

Chemical Analysis

(ICPMS, GCMS, FTIR, Raman, Solid & Solution NMR, 2D NMR)

Nanoparticle Analysis

(DLS, PSA, Particle Zeta Potential)

Bulk Properties Characterization

(DSC, TGA, DMA, Rheometry, Tensile Test, Pencil Test, Surface Zeta Potential)

Matthew Wong, Director of Optical Spectroscopy and Metrology



Matt joined the team in August 2019 and leads the Optical Metrology group at Covalent. Along with surface characterization, the group also provides analysis through other optical techniques such as UV-vis, FTIR and Spectral Ellipsometry.

Prior to joining Covalent, Matt managed technical teams and programs involved in the development of solar-selective and anti-reflective thin film coatings for concentrating solar power technologies. There he built up metrology and reliability testing capabilities to support the productization of materials used in the solar thermal industry.

Episode 3 Overview

- Overview of instrumentation and capabilities

- Measurement principles and applications for the following techniques:
  - Laser Confocal Scanning Microscopy
  - White Light Interferometry
  - Wide Area Patterned/Structured Light
  - Chromatic Dispersion

- All can measure surface roughness, what are other uses?

Why Use Optical Over Stylus Techniques?

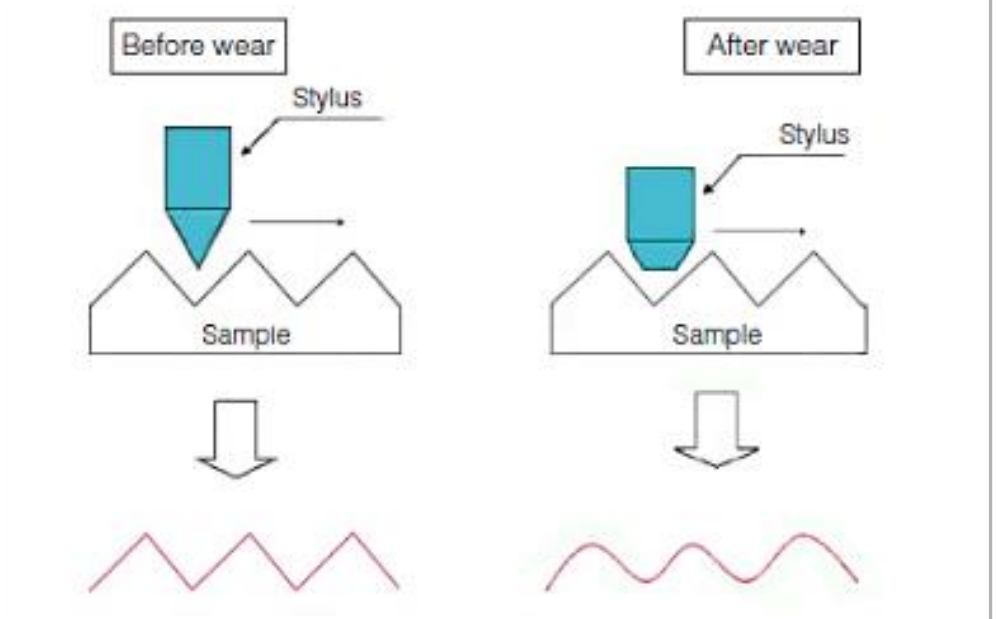
Optical Technique Advantages

Non-destructive and non-contact method of characterizing the surface and dimensional features of samples with light.

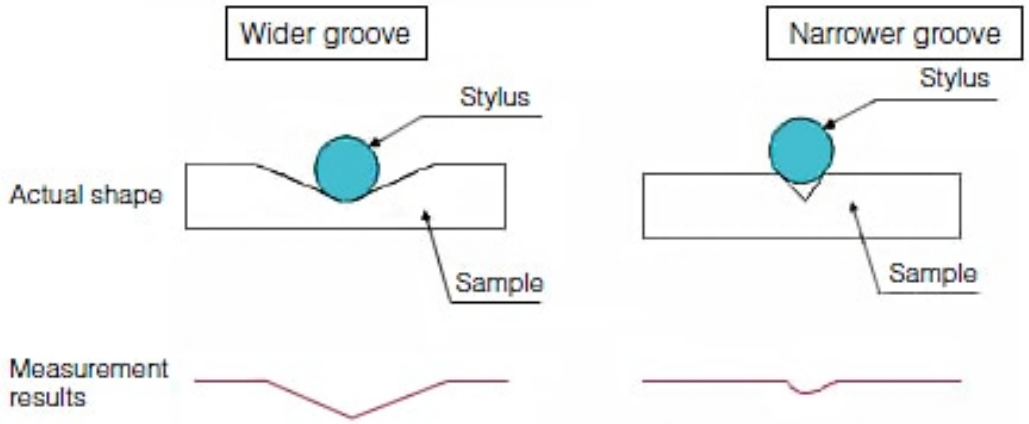
- No sample preparation and high throughput for image capturing
  - Measure multiple points for statistical confidence within a reasonable time frame
  - Quick feedback on analysis area
- Compatible with many materials, hard, soft, specular, diffuse
  - Contact profilometry can scratch surfaces of interest, leading to unwanted damage or errors in data
- High versatility
  - Measure complex shapes that are hard to reach by mechanical means
  - More than just surface roughness, step heights, and wear volumes

Concerns For Stylus Techniques

Differences in measurement results due to wear of stylus



Radius of stylus tip and groove width of sample



- Is the tip still the same shape?
  - Wear and tear can cause the tip to give inaccurate results
- Did I pick the correct tip for the application?
  - Multiple stylus choices, and tip-to-tip variations
- All of these can lead to less efficiency

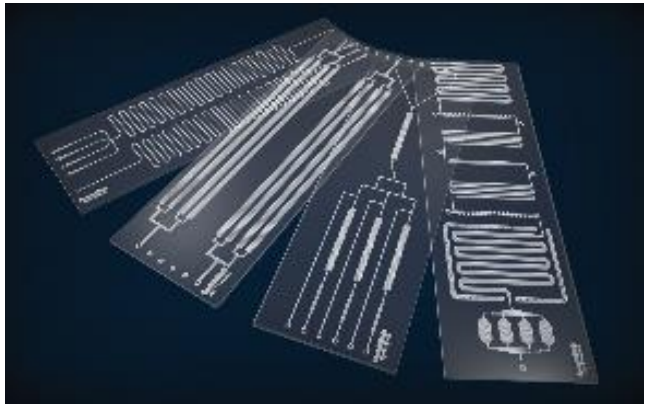
Why Use Optical vs Stylus Techniques?

COVALENT METROLOGY

Optical Technique Disadvantages:

- Line of sight required
  - Dimensional features that are related to other faces or facets cannot be assessed
  - Steep features, high aspect ratios
  - CMM probes are better suited, but often require large gantries and takes more time
- Substrate or optical properties of material can cause low signal to noise
  - Transparent samples
  - Attenuation from thin films or coatings
  - Highly absorbing materials
  - Spray coatings or depositions can solve this but with a tradeoff
- Sub nanometer height resolution is challenging
  - Atomic Force Microscopy – Stay tuned for Episode 4!

Broad Array of Applications



Microfluidics



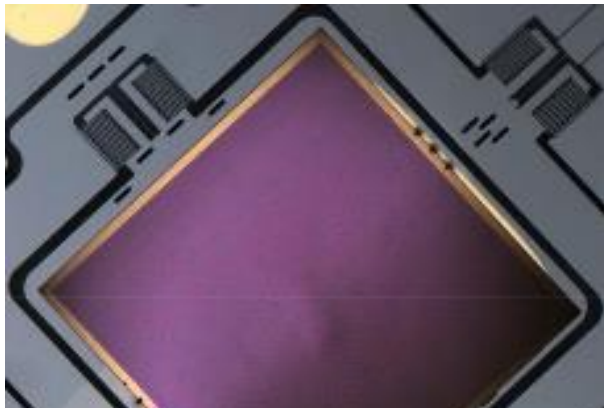
Injection Molding



Automotive

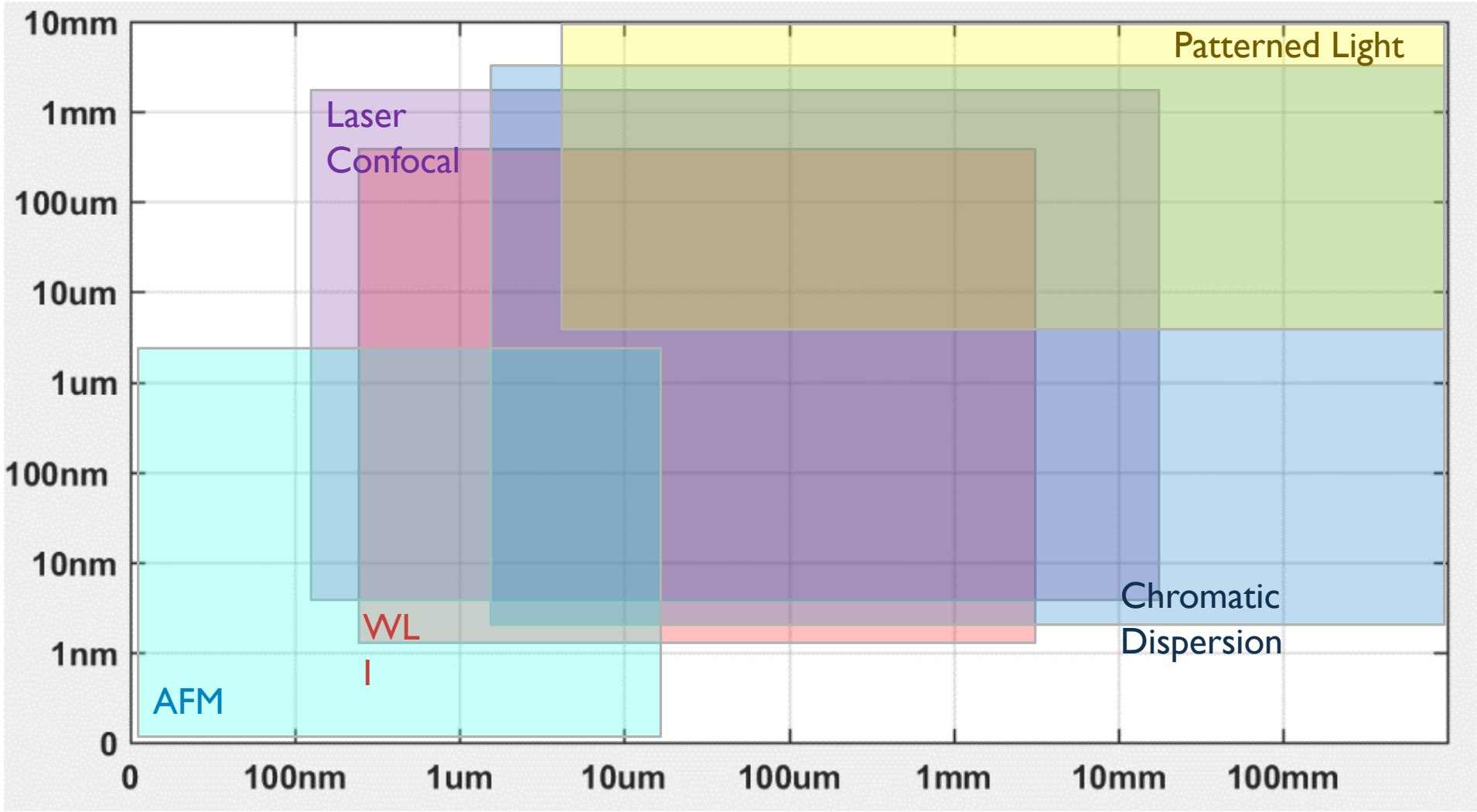


Small Mechanical Parts



MEMS, Semiconductor

General Operation Range at Covalent



Instruments at Covalent





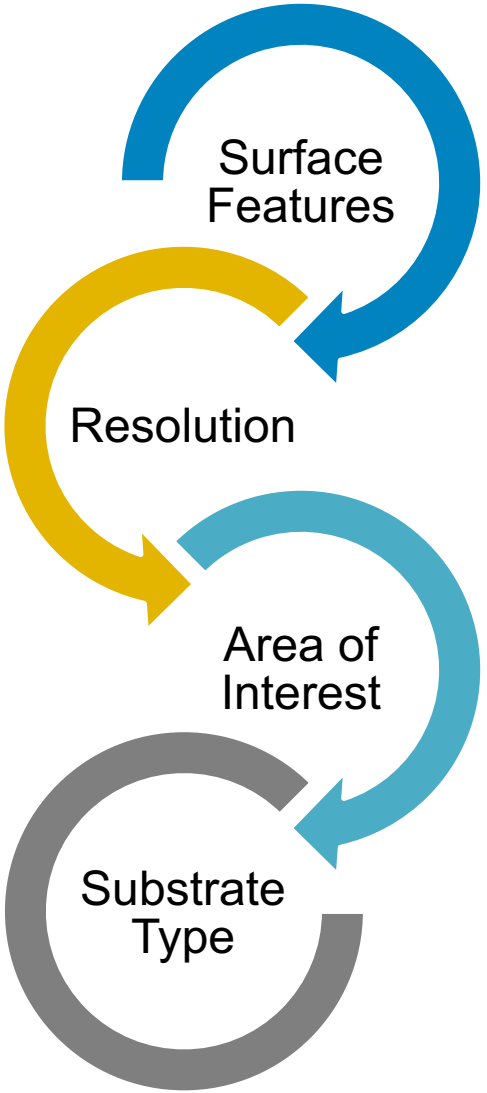




Technique	Laser Scanning Confocal Microscopy	Patterned/Structured Light	White Light Interferometry	Chromatic Dispersion
Covalent Instrument	Keyence VK-X1100	Keyence VR-5200	Zygo ZeGage Plus	FRT MicroProf 200
Sampling Area	µm to mm	mm to cm	µm to mm	µm to cm
Best Resolution (z)	5nm	5um	1nm	5nm
Best Resolution (x,y)	120nm	5um	160nm	2um
Unique Feature/Application	High Lateral and Height Resolution, Focus Variation	3D-CAD Comparison, Dimension Analysis (FAI, CD), Contour/Shape	Best Height Resolution, Wafers, Lenses	Bow, Warp, Large Area Scanning, Thickness

Which Technique to Choose?

- Questions to keep in mind when deciding:
  - What surface metrics or features am I interested in?
    - Roughness, step heights, dimensions etc.
  - What resolution, height and lateral?
    - Nanometers, 10s of nanometers, microns
  - What is the area of interest?
    - Surface area, aspect ratio, specific topographies
  - What type of substrate or material am I imaging?
    - Metal, glass, plastic
    - Opaque or transparent



Laser Scanning Confocal Microscopy

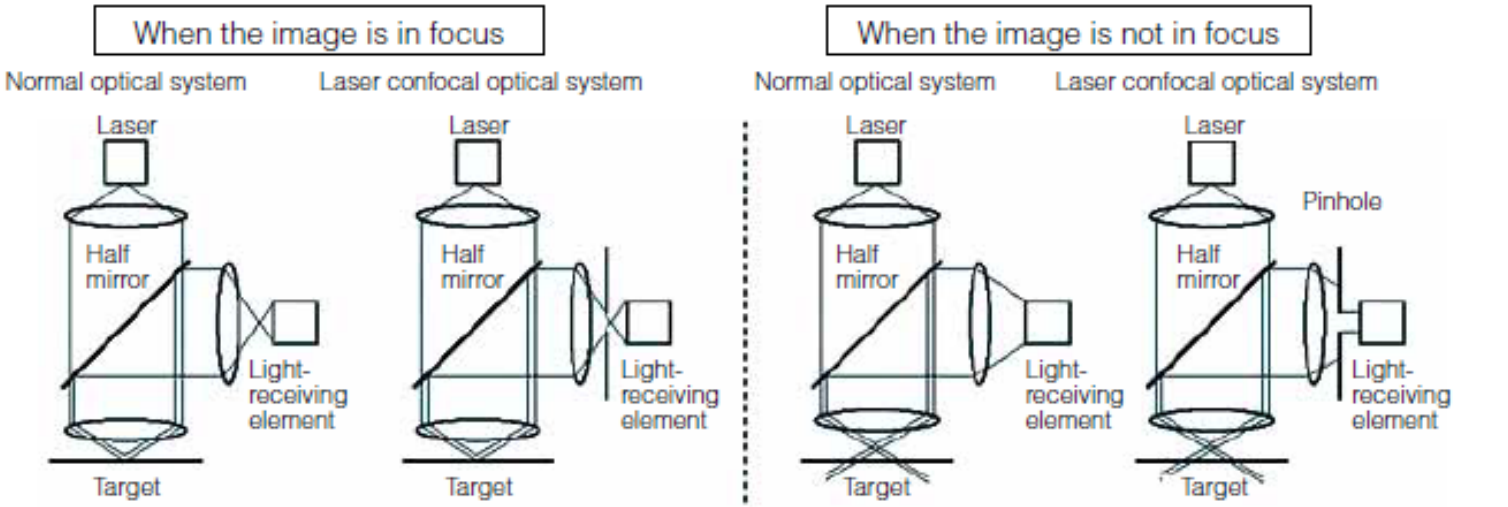


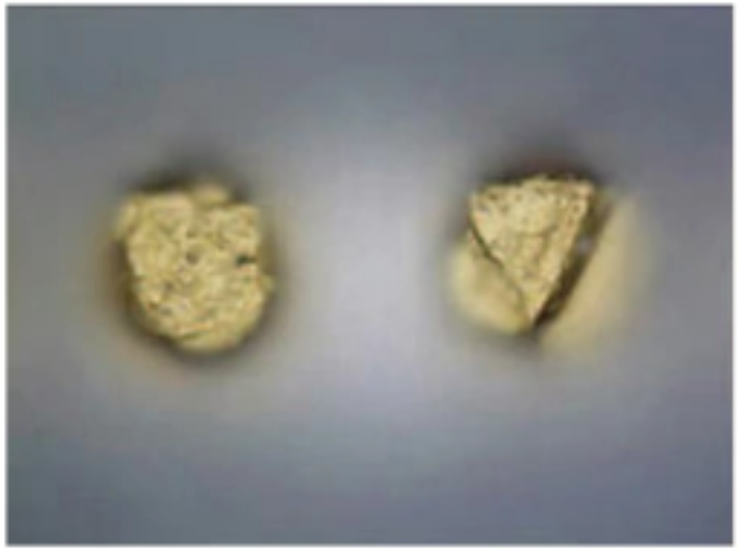
Figure Source: KEYENCE

- Short wavelength light (404nm)
- Out-of-plane light is blocked by the pinhole aperture.
- Reflected light within the focal plane is returned to the detector. The objective lens moves in the z-direction changing the focal plane to build the 3D topography.

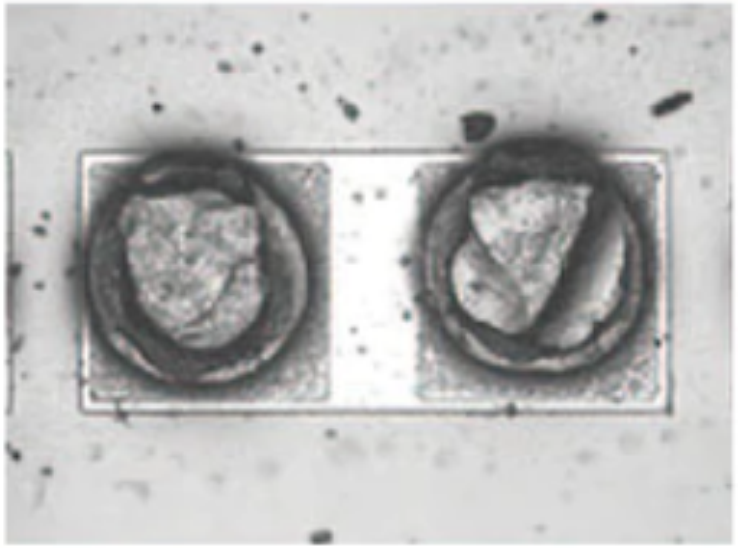
	10x	20x + SLWD	50x	100x ELWD	150x
Field of View	1455 x 1090um	720 x 540um	290 x 220um	145 x 110um	100 x 75um
Pixel Resolution	1.420um	0.700um	0.285um	0.140um	0.095um

Keyence VK-X1100

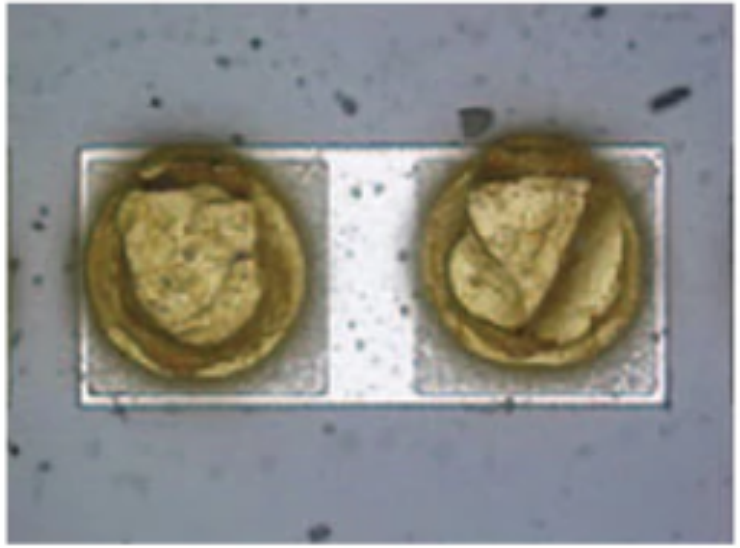
KEYENCE



Standard Optical Scope



Laser Confocal Scope

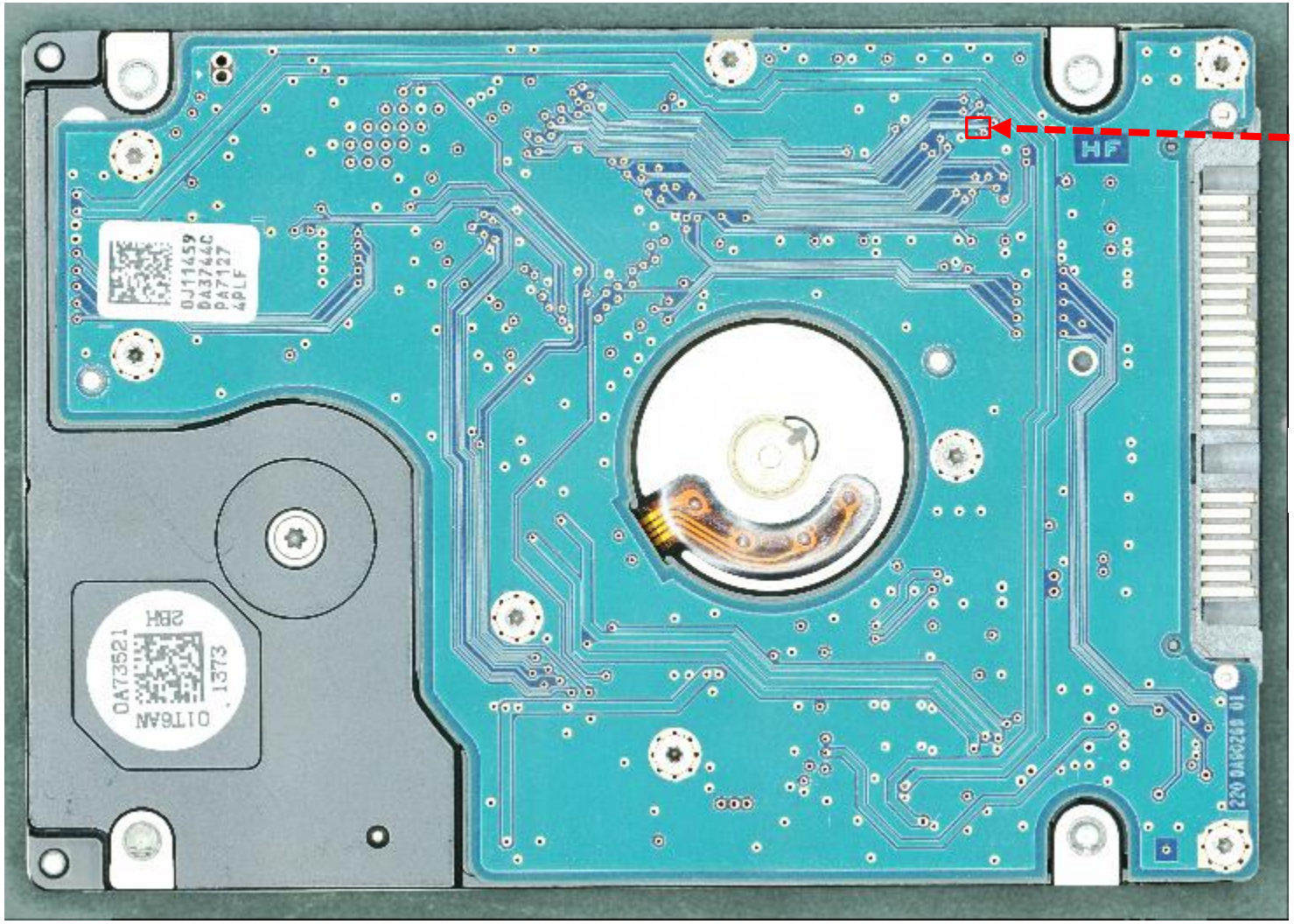


Standard + Laser Confocal Scope

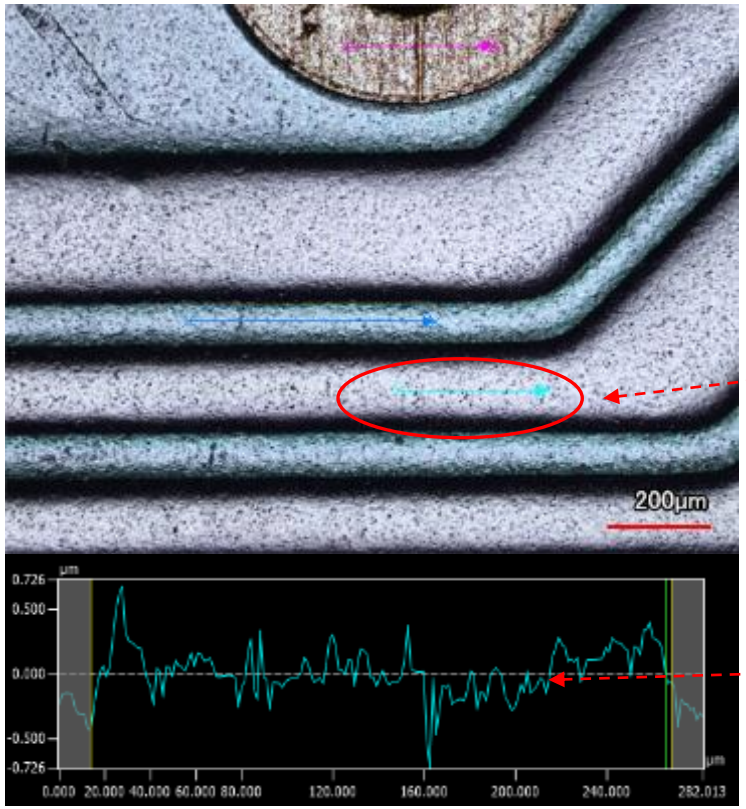
- Large depth of field for standard scopes can be prone to height errors for samples with rough features
- Laser confocal scopes overcome this with a small depth of field and precise z scanning
- Combination of the two can provide true color and accurate surface characterization

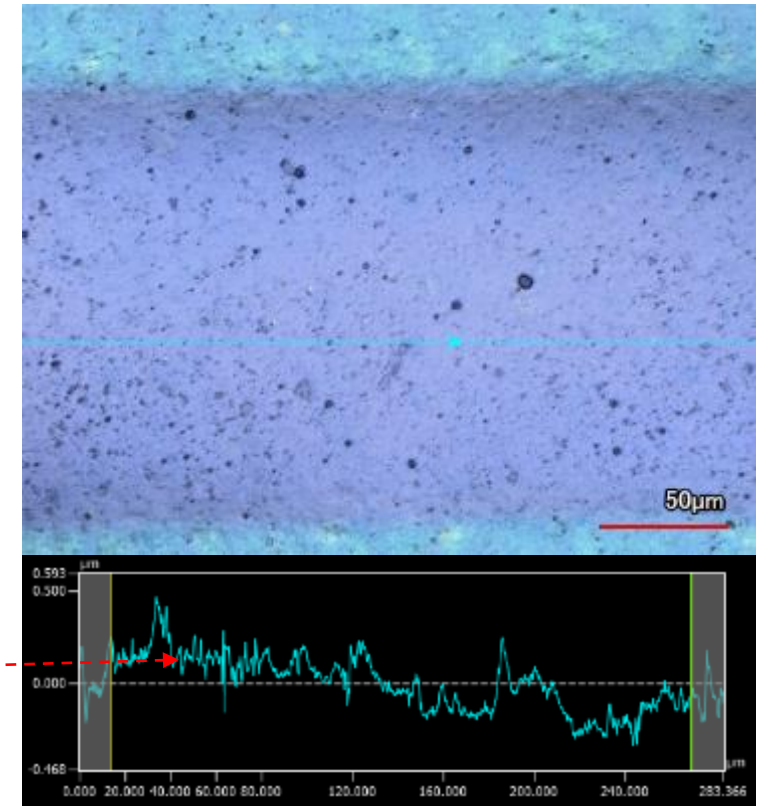
Hard Disk Drive PCB

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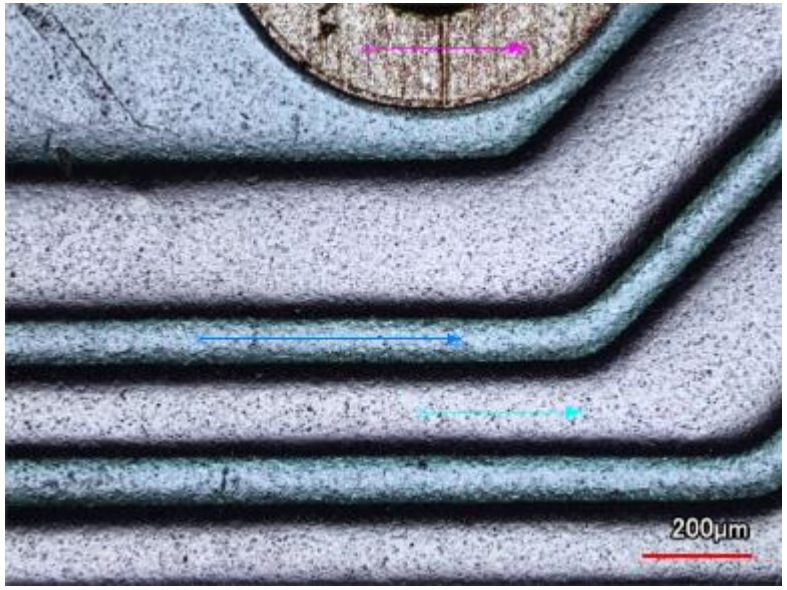
Magnification 10x and 50x

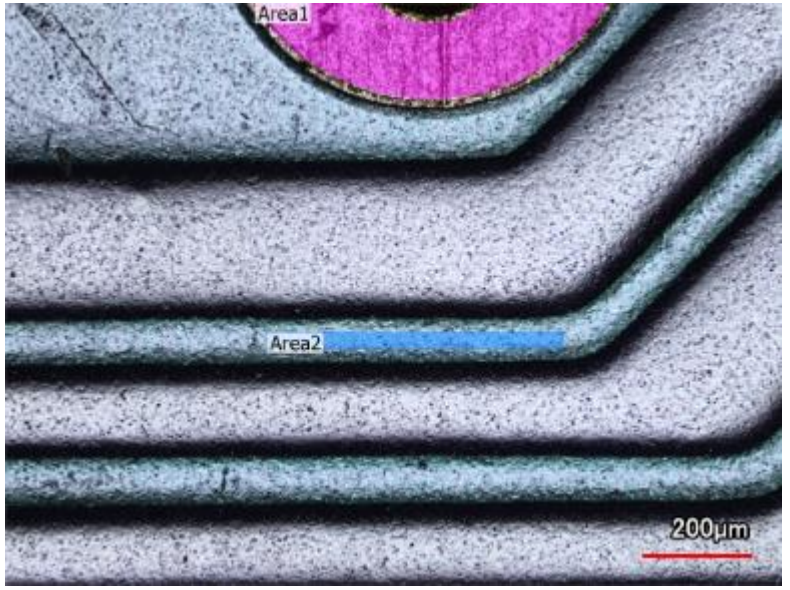




Magnification	Ra (um)	Rz (um)	Rp (um)	Rv (um)	Rsk	Rku
10x	0.137	1.404	0.679	0.726	0.435	4.986
50x	0.127	0.803	0.468	0.335	0.112	2.488

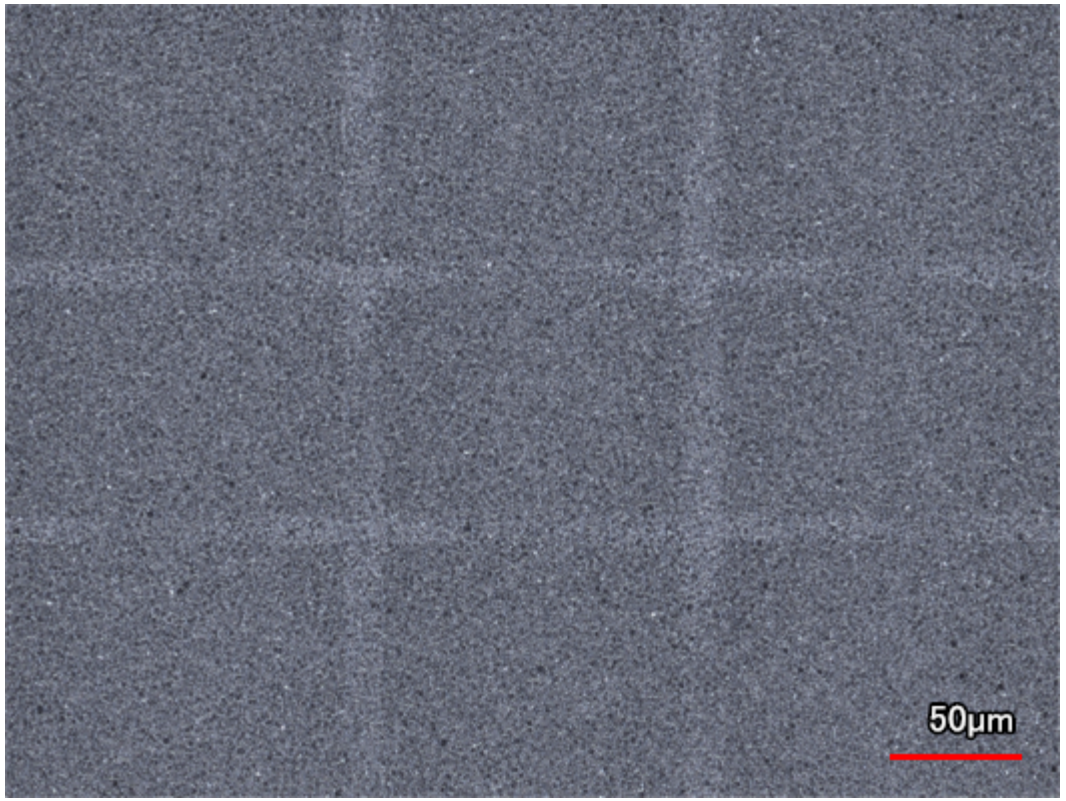
Line vs Surface Area Roughness

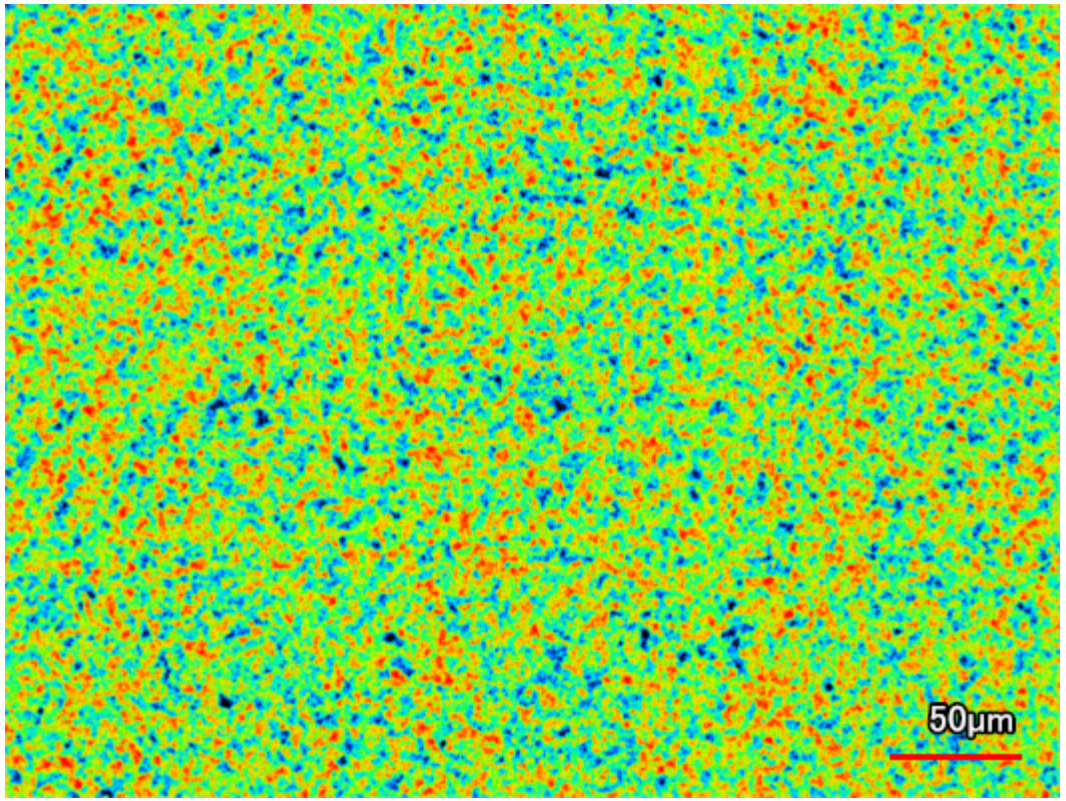




Line	Ra (um)	Rz (um)	Rp (um)	Rv (um)	Rsk	Rku
Magenta	2.750	17.172	5.582	11.589	-1.329	4.177
Blue	0.810	5.939	3.288	2.650	0.205	3.480
Area	Sa (um)	Sz (um)	Sp (um)	Sv (um)	Ssk	Sku
Magenta	2.998	32.563	14.678	17.884	-0.544	3.890
Blue	1.081	12.356	6.462	5.894	0.141	2.902

Image Stitching





- In general, image stitching can be useful to capture larger areas, but it is also sample dependent and requires extra care when analyzing the data so that you do not include artifacts.

Patterned/Structured Light

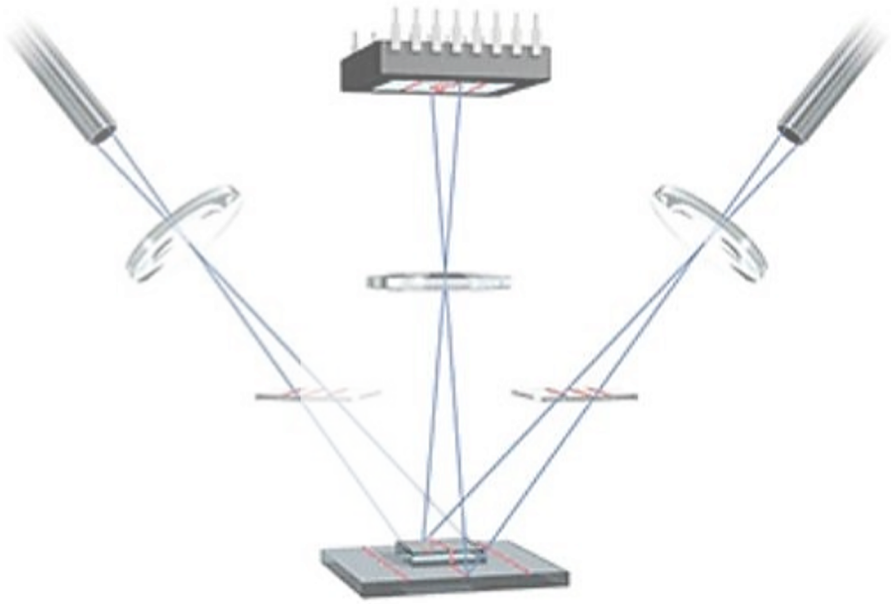


Figure Source: KEYENCE

- Striped patterns of light are projected onto the sample at a 35 deg angle of incidence.
- The interaction or distortion of the light upon hitting the sample is captured by an overhead camera.
- Triangulation software can then generate the 3D topography.
- Height range is suitable for surface roughness >5um

	12x	25x	40x	80x
Field of View	24 x 18mm	12 x 9mm	7.5 x 5.7mm	3.8 x 2.8mm
Pixel Resolution	23.5um	11.7um	7.3um	3.7um

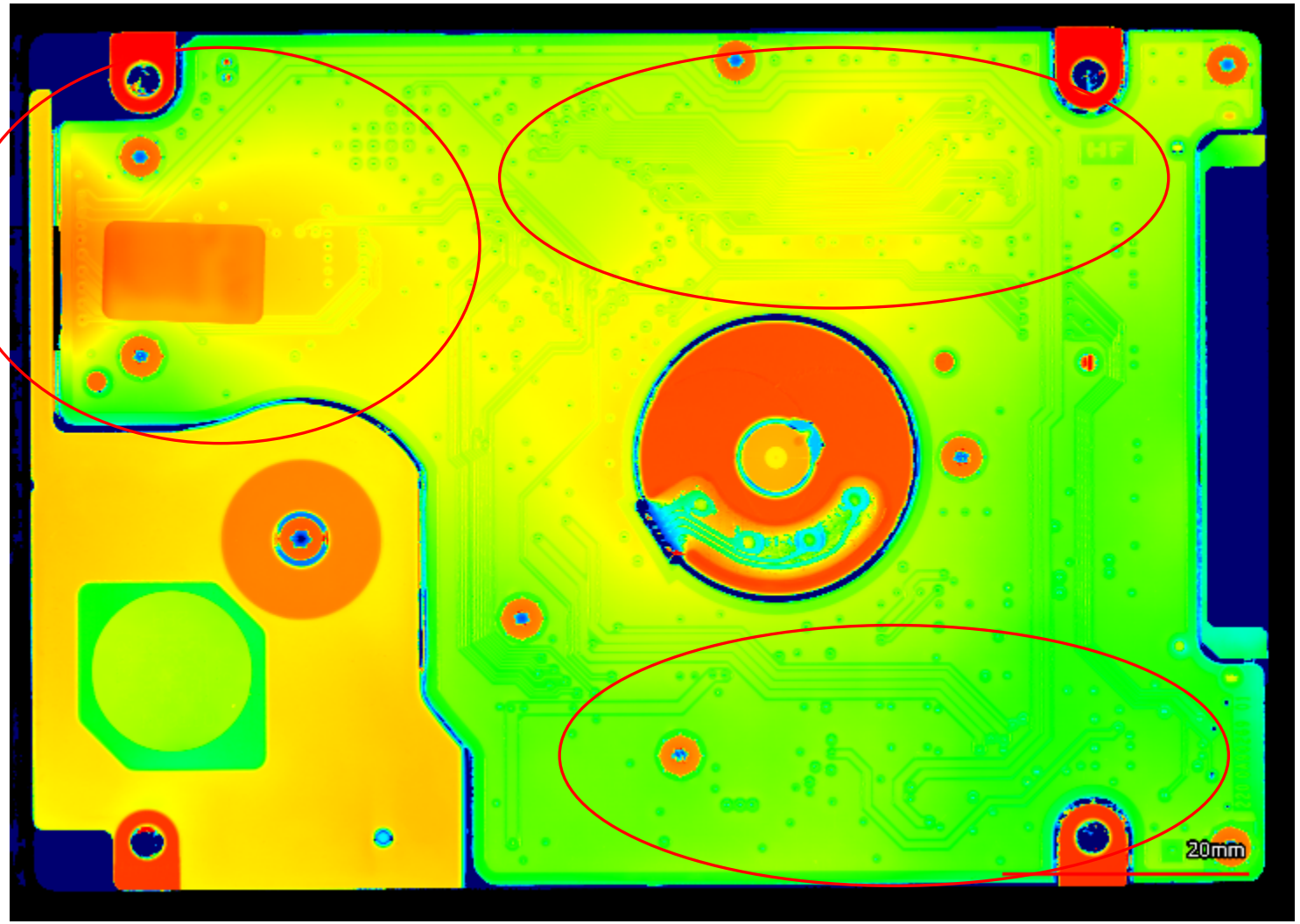
Surface Area Roughness





Area	Sa (um)	Sz (um)	Sp (um)	Sv (um)	Ssk	Sku
Area 1 (left)	32.773	336.950	254.451	82.499	0.792	3.846
Area 1 (right)	10.430	56.100	22.154	33.946	-0.579	2.413
Area 2 (right)	9.782	72.790	14.336	58.454	-1.906	6.251

Surface Area Roughness



- Take extra care when analyzing large areas, as contour and warp will affect your surface roughness analysis
- Either choose smaller subset areas or correct for the surface shape

White Light Interferometry

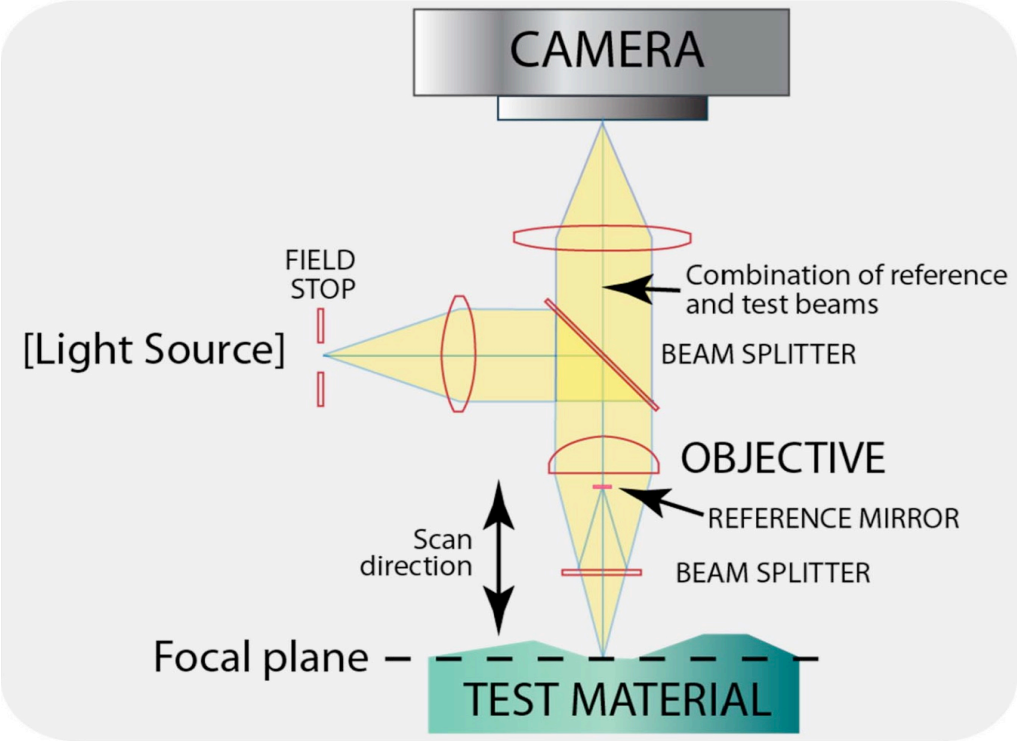


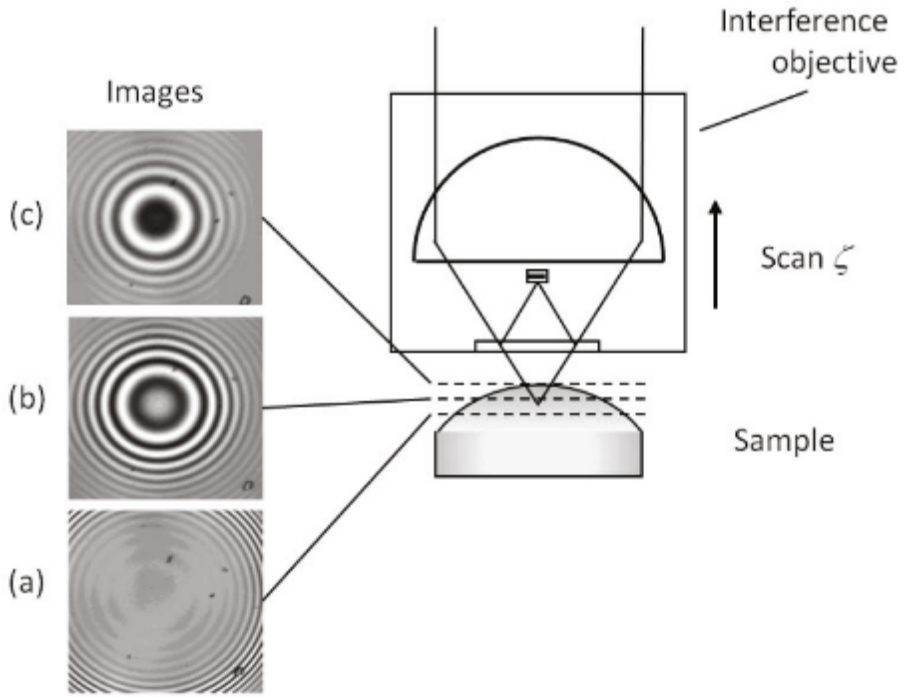
Figure Source: Zygo

- A comparison of the optical path length between a reference mirror and the surface.
- Constructive and destructive interference occurs when light is recombined, which creates the black and white fringes.
- The reference mirror is a high quality optical flat, therefore any difference in the optical path is a variance in height.

	10x Mirau	20x Mirau	50x Mirau
Field of View	800 x 800um	400 x 400um	160 x 160um
Pixel Resolution	0.780um	0.390um	0.160um

Fringe Patterns

Representation of fringe patterns and how it corresponds to height and surface topology



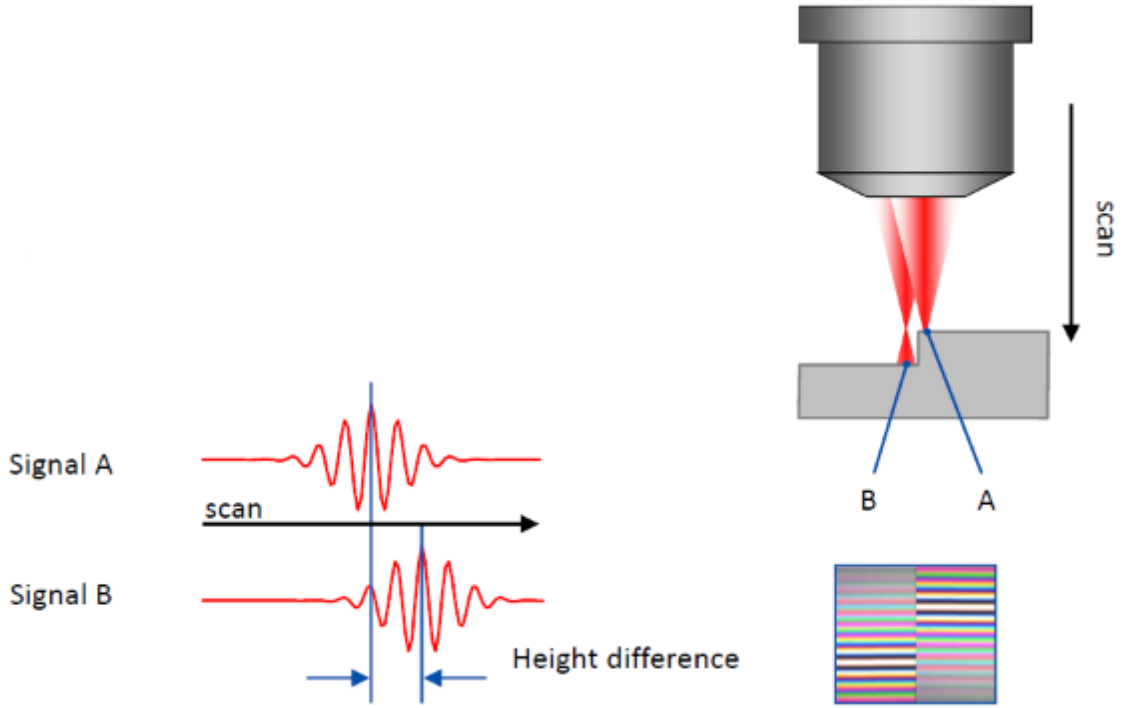
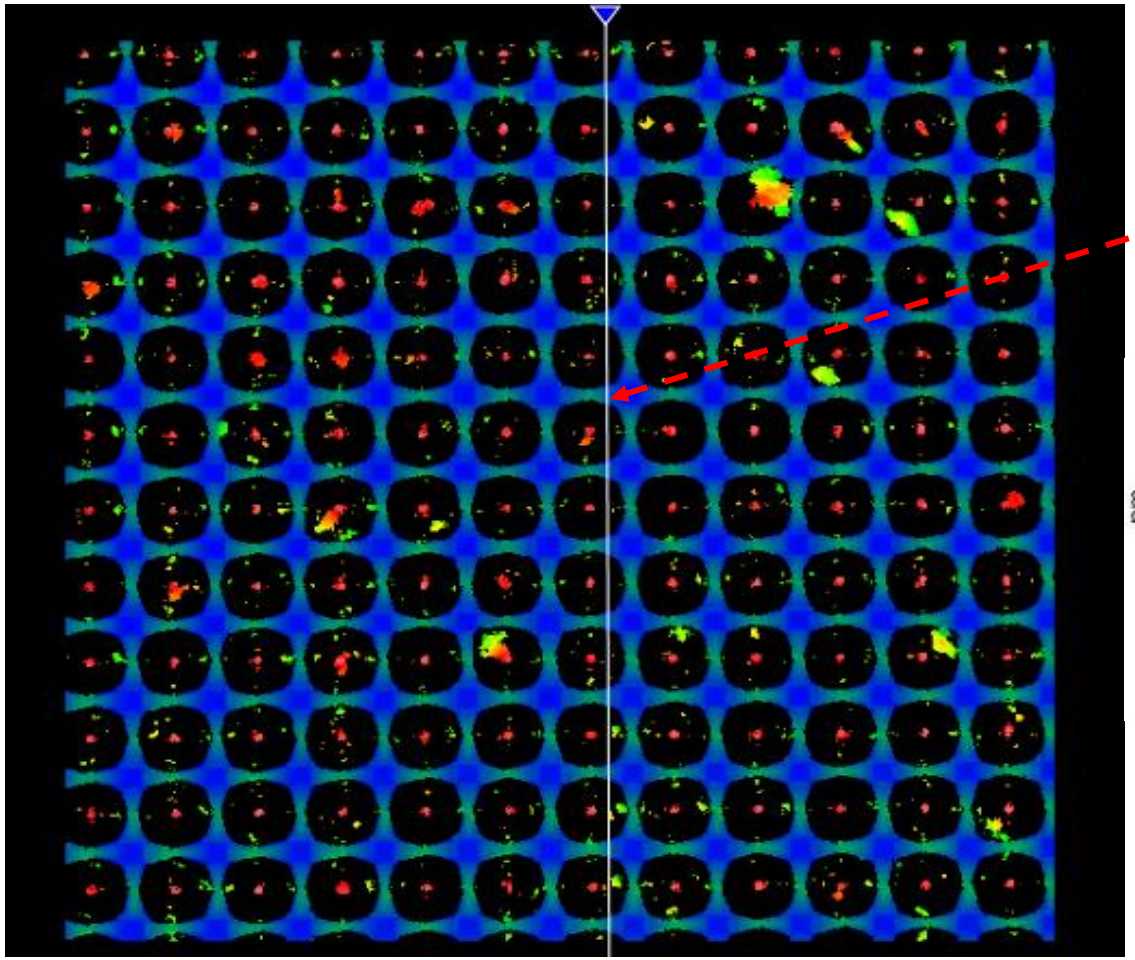
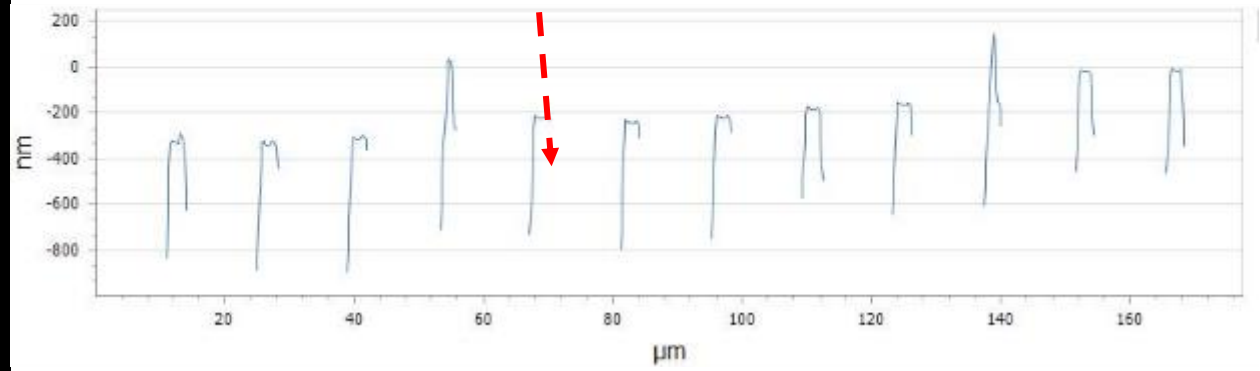


Figure Source: Zygo

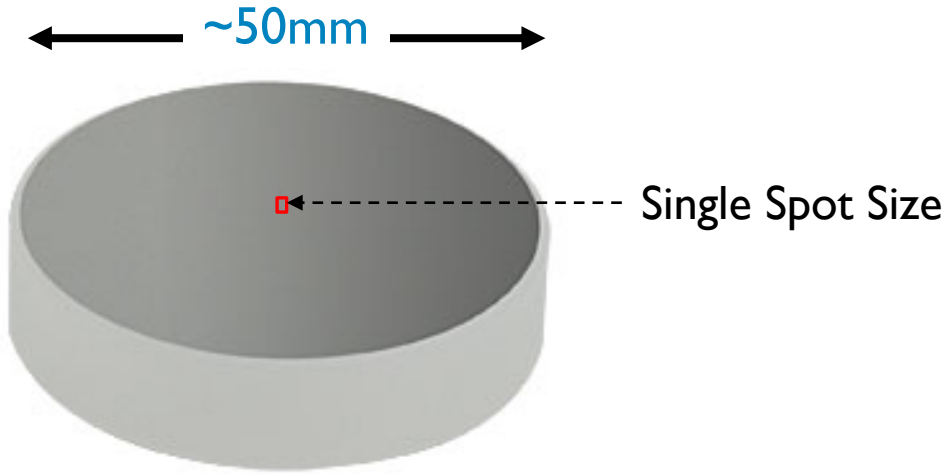
WLI Weakness

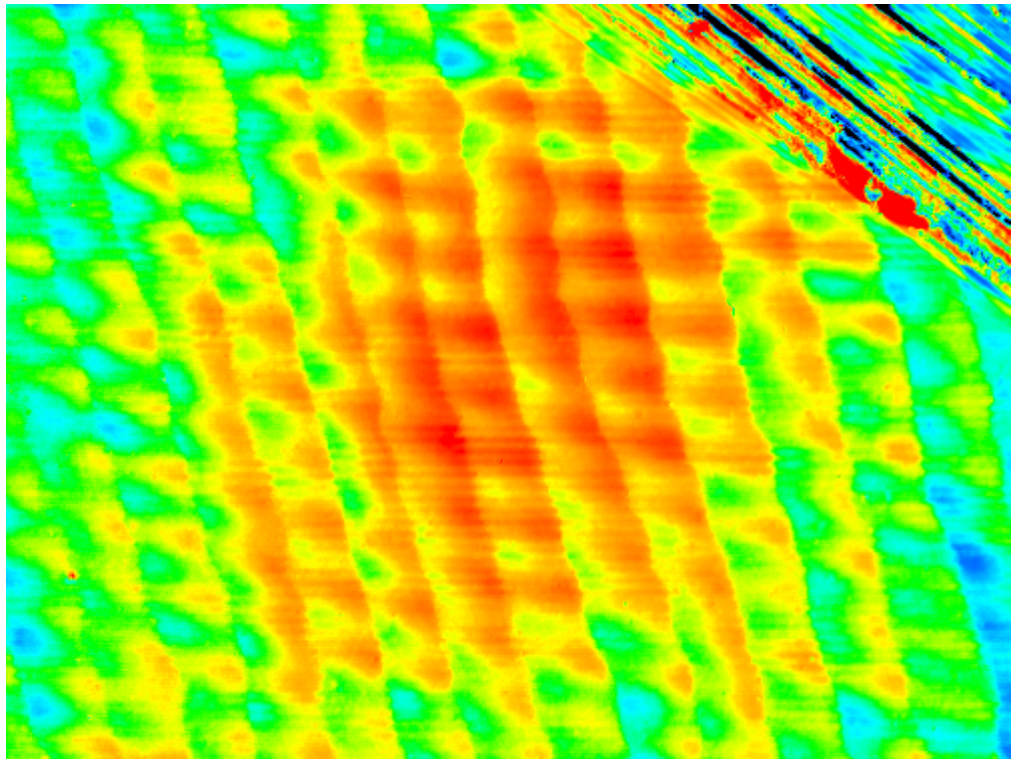


Cannot be captured due to reflectance at steep angles and spatial resolution



Front Surface Mirror

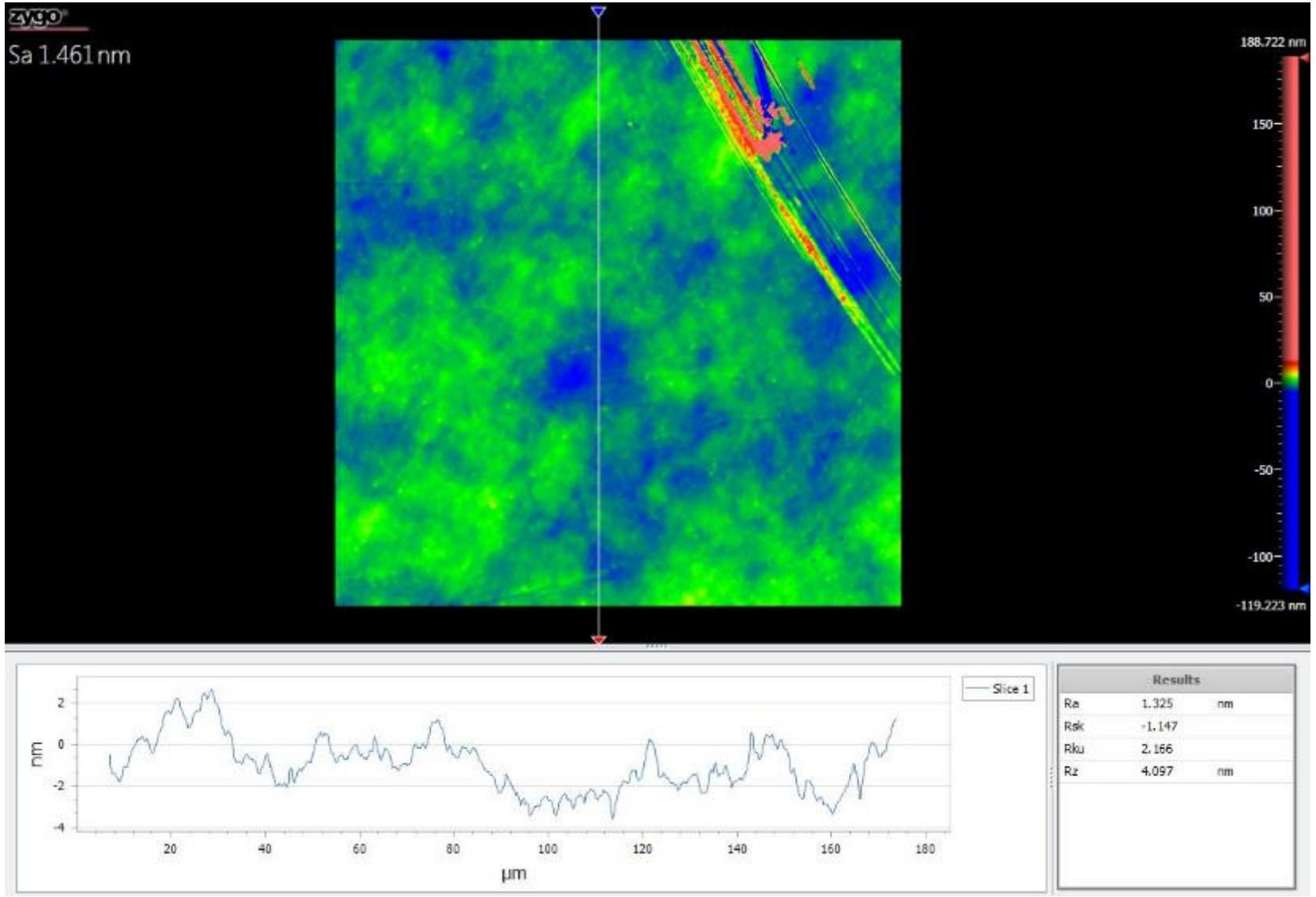




Laser Confocal Image

- Surface roughness of a very flat, smooth substrate
- Ideal candidate for WLI, not laser confocal

Surface Roughness Output at 50x



Chromatic Dispersion

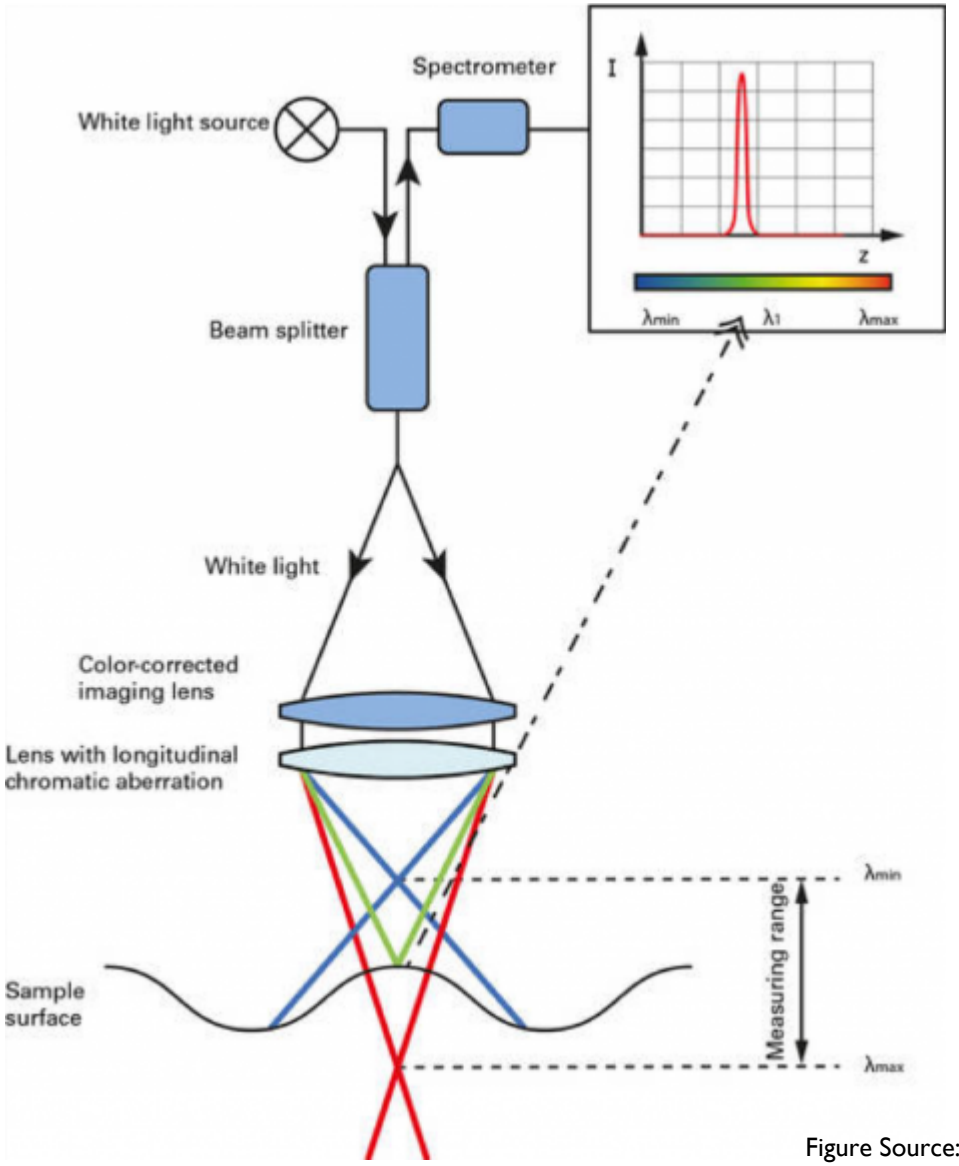
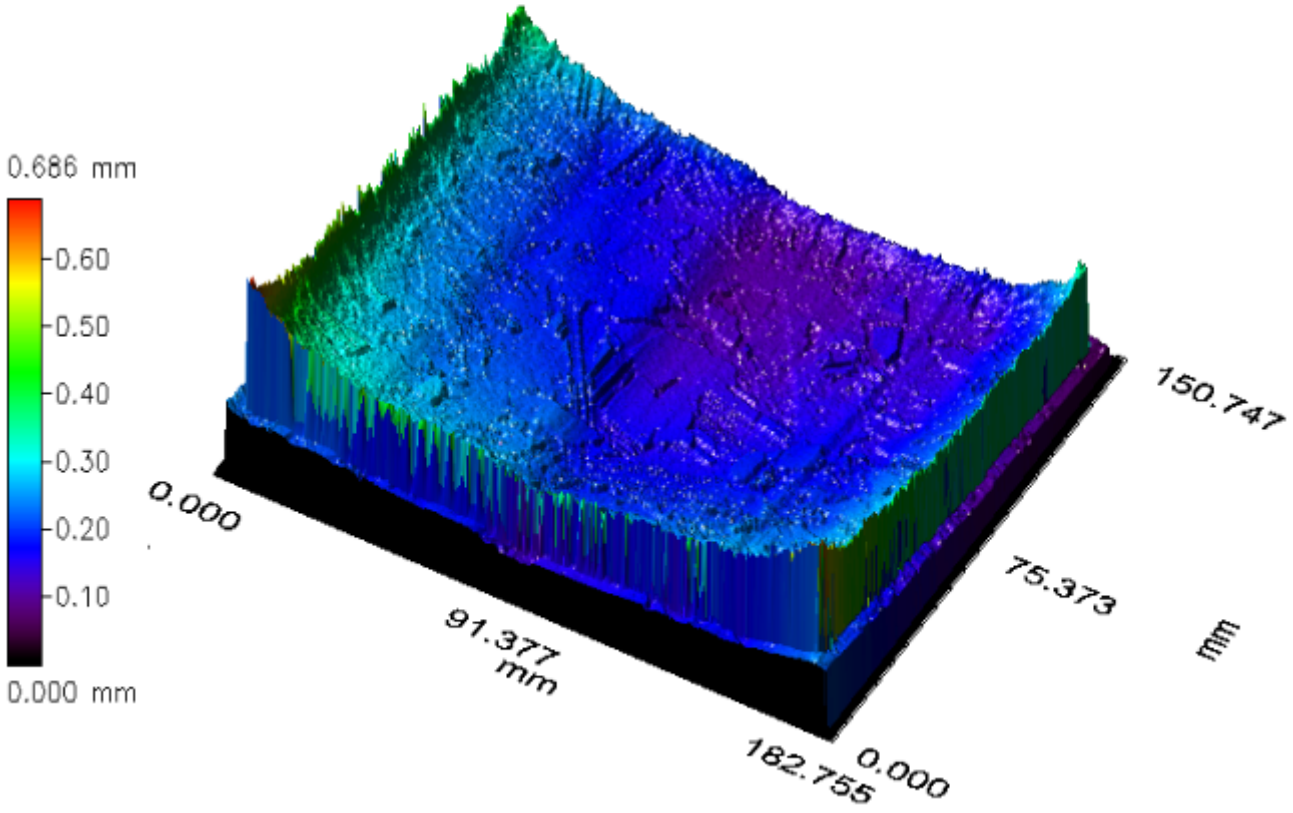


Figure Source: Nanofocus

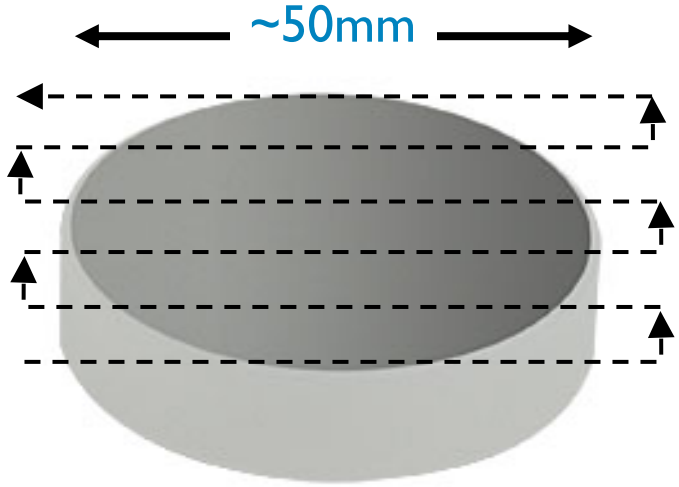
- The measurement range is created by chromatic dispersion, wavelengths of light at different focal lengths.
- Light delivered from fiber optics to the sample surface and back to a spectrometer.
- A single wavelength of white light will be in focus, highest intensity, which corresponds to the height position.
- Specified height ranges or heads based on sample surface.
  - 100um, 300um, 1mm, 3mm

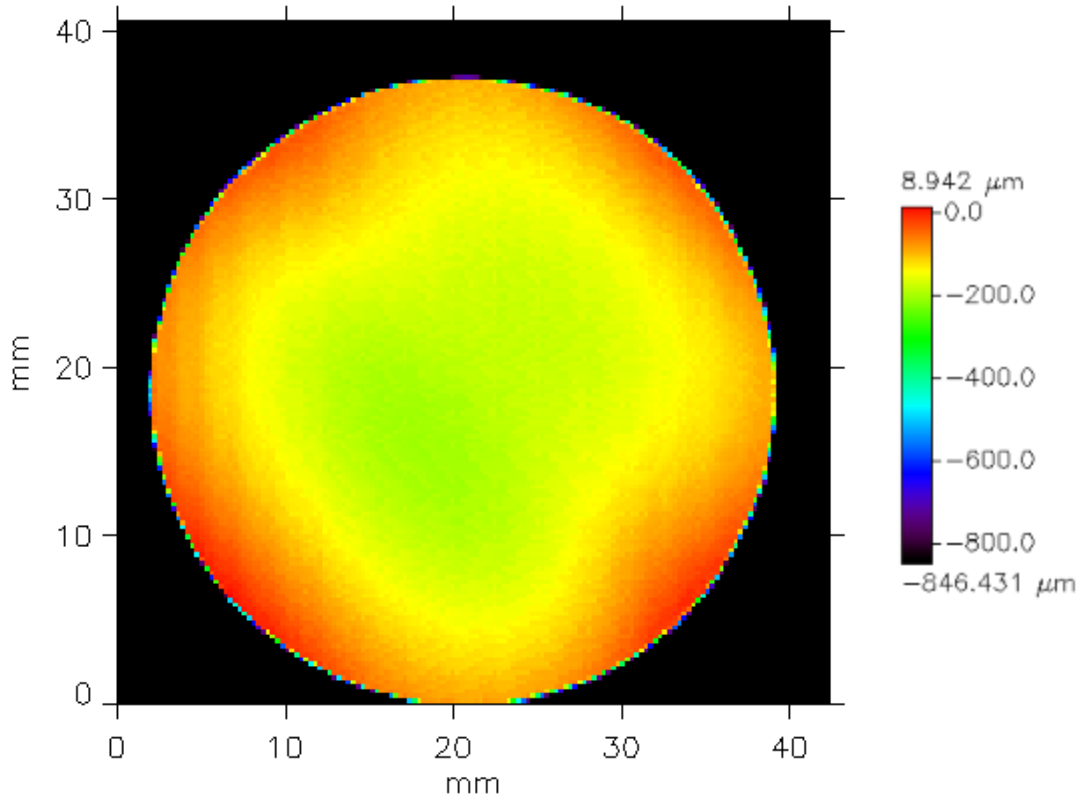
Chromatic Dispersion



- Fast for a line scan, but slow for a full map
- 2D surface area roughness or line roughness over a large area
- Contour and shape can be determined

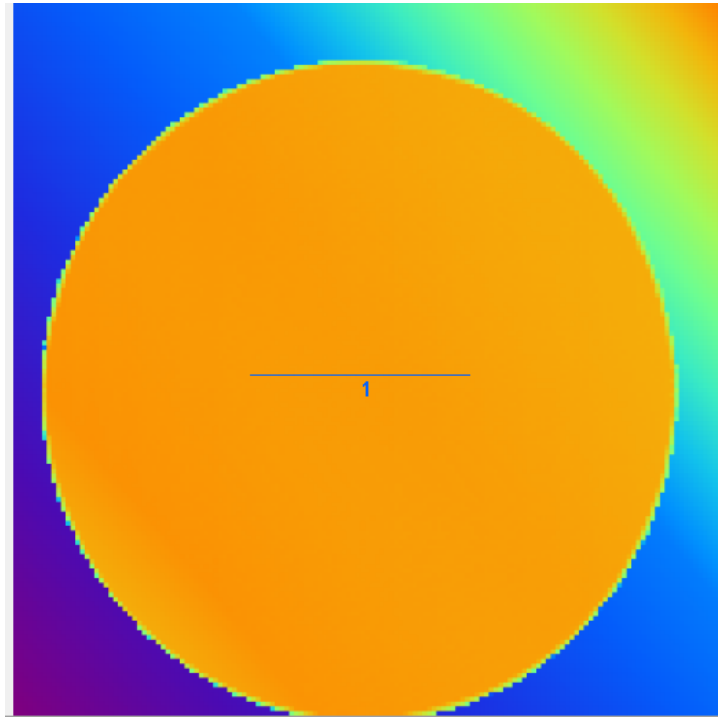
Front Surface Mirror

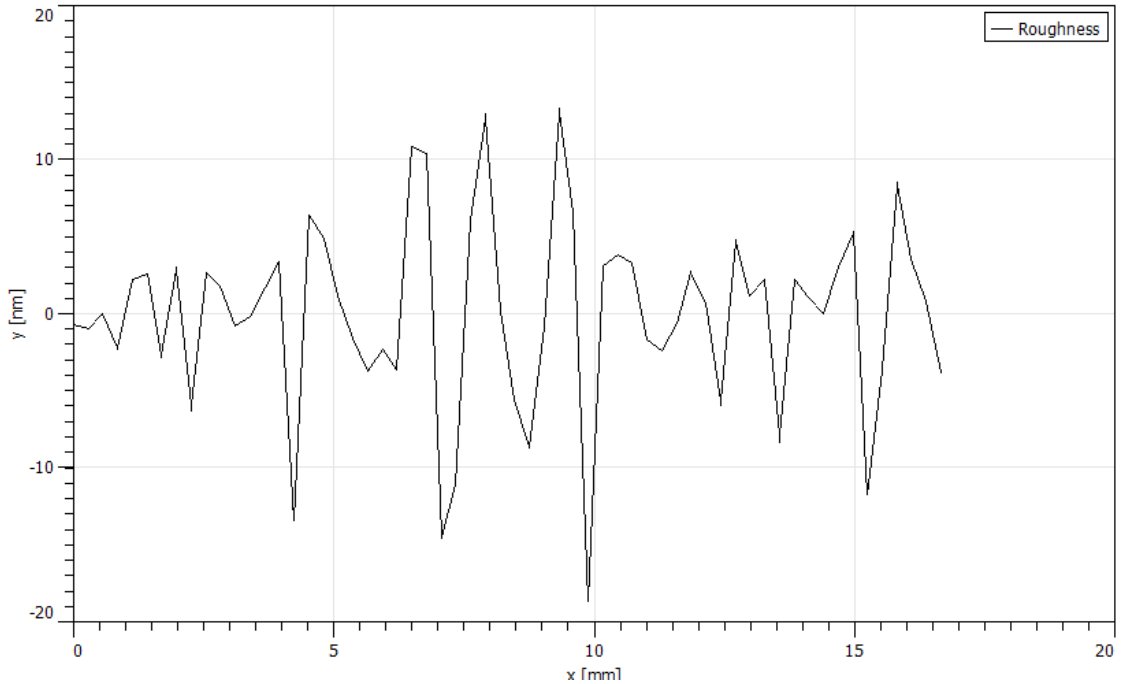




- Line scans spaced 10um apart to create a full map of the sample (~20min to scan), a 2um spacing is the best achievable resolution, but would take > 1hour

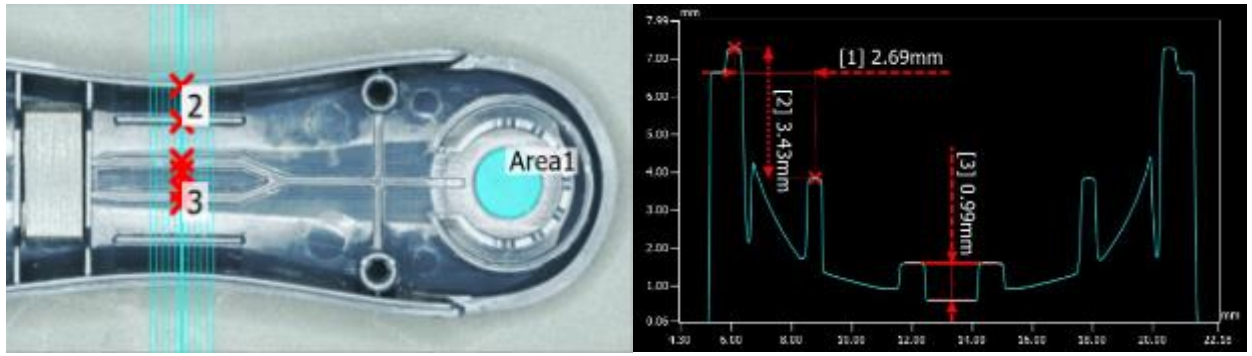
Curvature Correction



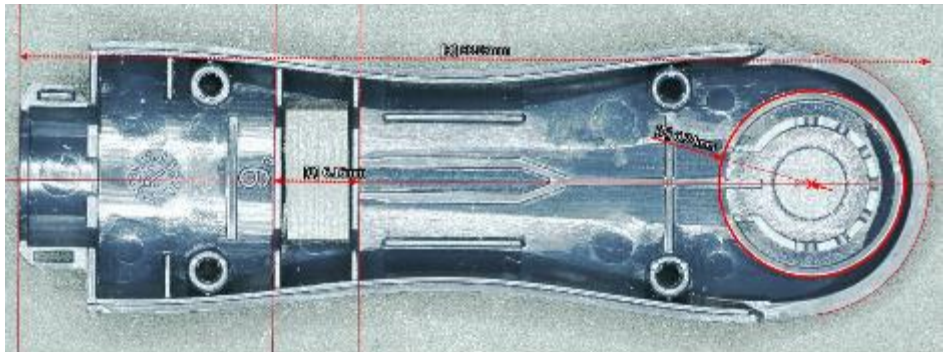


	Ra (um)	Rz (um)	Rp (um)	Rv (um)
Line 1	0.007	0.031	0.013	-0.018

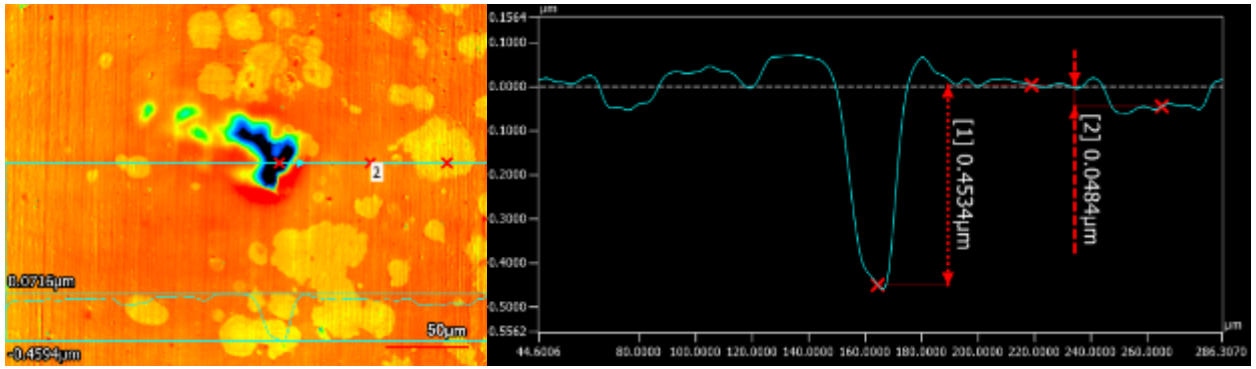
Other Types of Analyses



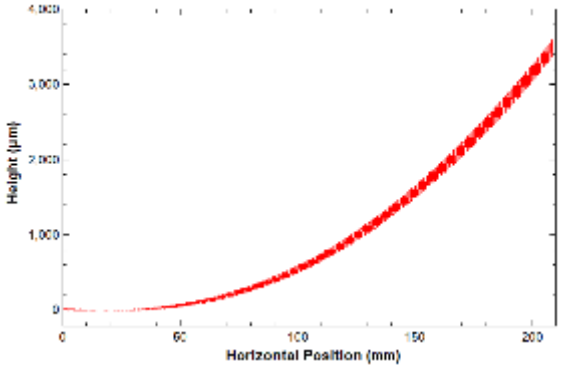
Cross-section Profiles



Planar Dimensions for FAI



Defect Analysis to Support SEM/TEM EDX



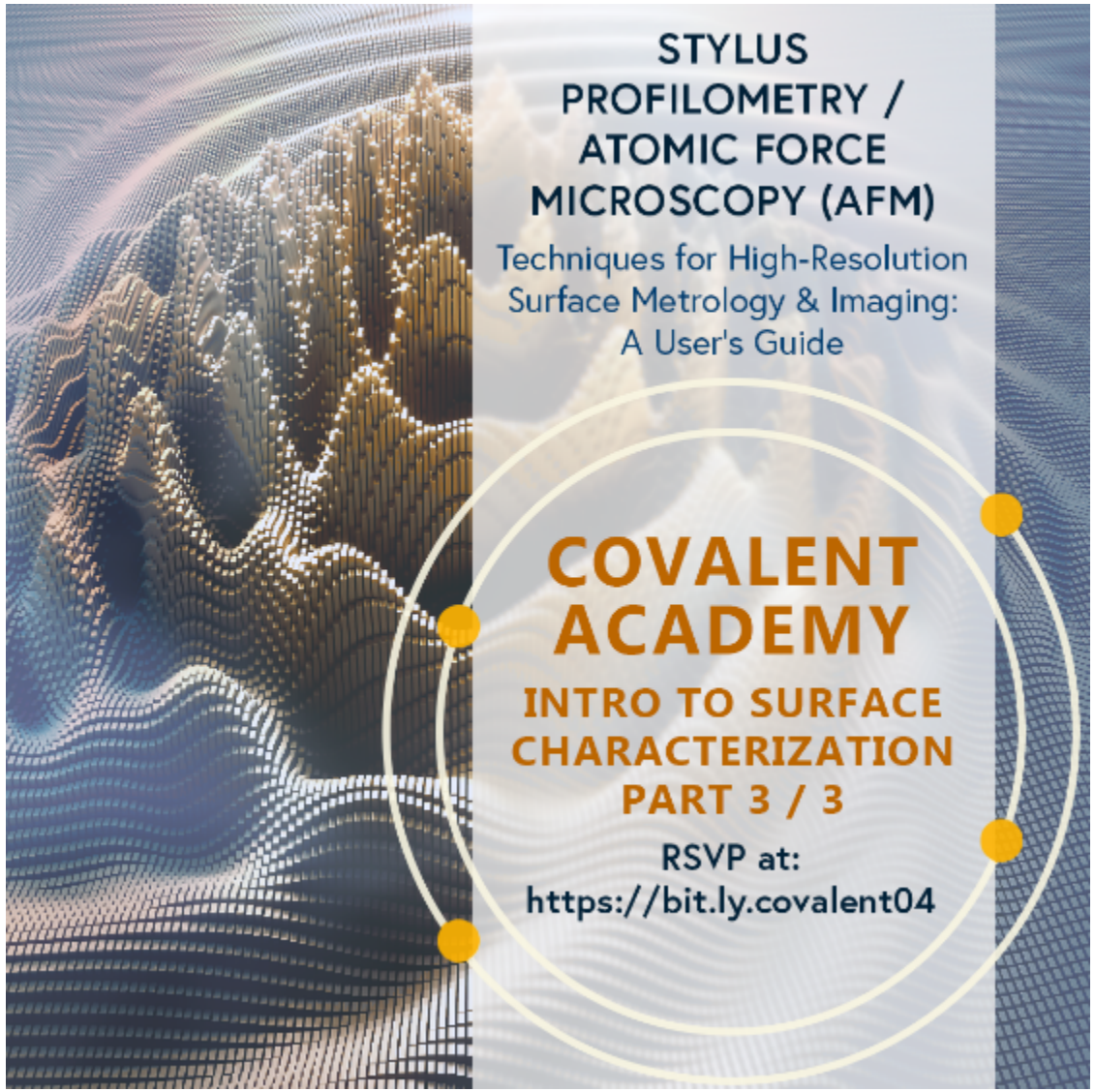
Curvature or Warp

Summary

COVALENT METROLOGY

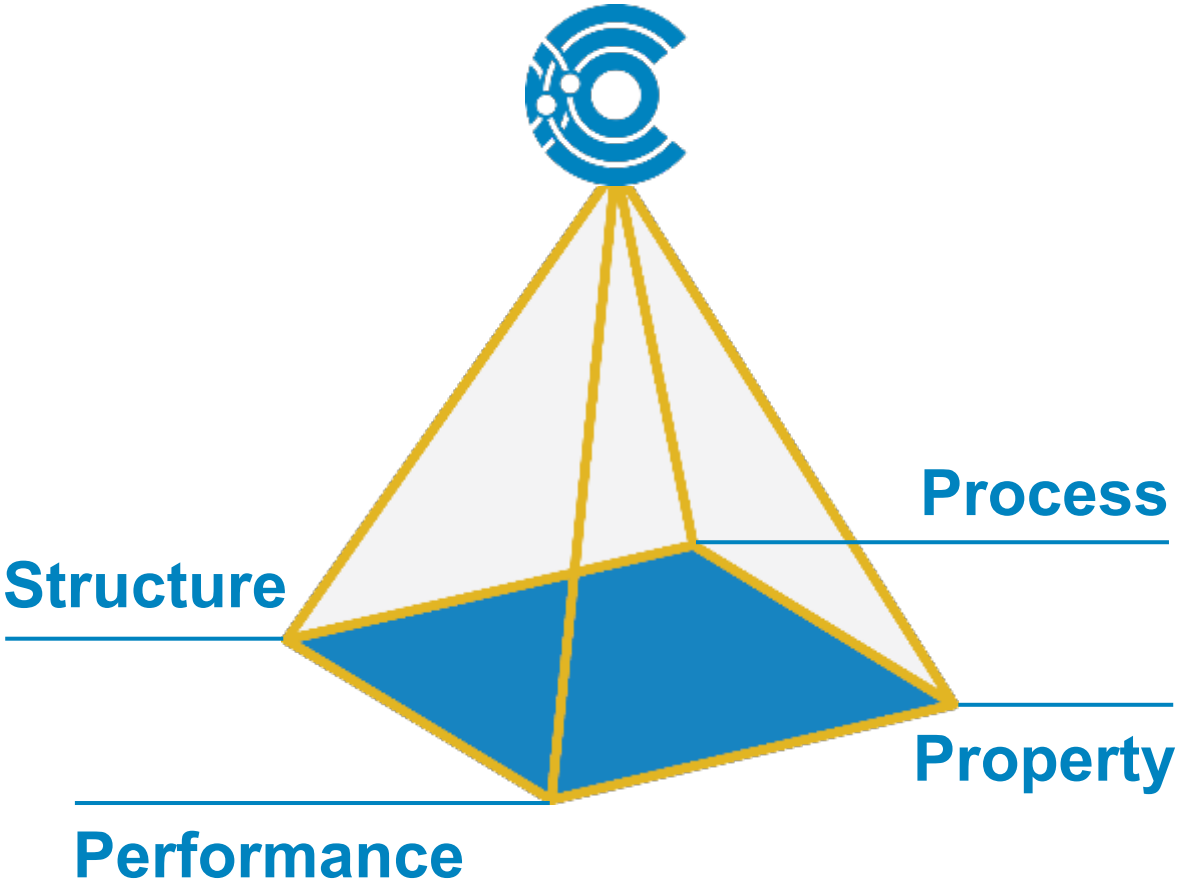
Technique	Laser Scanning Confocal Microscopy	Patterned/Structured Light	White Light Interferometry	Chromatic Dispersion
Speed	Moderate	Fast	Moderate/Fast	Moderate
Best Resolution (z)	5nm	5um	1nm	5nm
Best Resolution (x,y)	120nm	5um	160nm	2um
Defining Attributes	Widest range of applications	Dimensional characterization	Z-resolution	Large area scanning, bow and warp
Weakness	Very flat surfaces, multi-layer thin films	Transparent substrates, shadowing due to angled light source	Steep features, reflectance	Steep features, sample tilt, thin films
Price	$300/hour	$275/hour	$225/hour	$360/hour

Coming Episodes



Expertise You Can Trust

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