New High-Speed 3D Surface Imaging Technology in Electronics Manufacturing Applications

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Abstract

This paper introduces line confocal technology that was recently developed to characterize 3D features of various surface and material types at sub-micron resolution. It enables automatic microtopographic 3D imaging of challenging objects that are difficult or impossible to scan with traditional methods, such as machine vision or laser triangulation. Examples of well-suited applications for line confocal technology include glossy, mirror-like, transparent and multi-layered surfaces made of metals (connector pins, conductor traces, solder bumps etc.), polymers (adhesives, enclosures, coatings, etc.), ceramics (components, substrates, etc.) and glass (display panels, etc.). Line confocal sensors operate at high speed and can be used to scan fast-moving surfaces in real-time as well as stationary product samples in the laboratory. The operational principle of the line confocal method and its strengths and limitations are discussed. Three metrology applications for the technology in electronics product manufacturing are examined: 1. 3D imaging of etched PCBs for micro-etched copper surface roughness and cross-sectional profile and width of etched traces/pads. 2. Thickness, width and surface roughness measurement of conductive ink features and substrates in printed electronics applications. 3. 3D imaging of adhesive dots and lines for shape, dimensions and volume in PCB and product assembly applications.

Introduction

Line confocal sensors—and scanners based on them—are used in the imaging of surfaces, transparent materials, and multi-layered structures in various metrology and inspection applications on discrete parts, assemblies, webs, and other continuous products. Imaging results can be used to characterize a product's form, surface topography, roughness, flatness, thickness and 3D volume. The line confocal method also has a tomographic functionality, which enables the capture of 3D structures under transparent layers, as well as the simultaneous acquisition of 2D gray-scale (intensity) images from single or multiple surfaces with a large depth of focus covering the sensor's entire z range, up to 5.50 mm.

Line Confocal Method

Figure 1 shows the line confocal sensor models that are currently in production. Each sensor has two front lenses—one for its transmitter and another for the receiver.

Figure 1 - Line confocal sensors

Figure 2 depicts the sensor's operating principle. The transmitter has a light source that emits white light containing all visible wavelengths. An optical assembly separates the light into wavelengths and focuses a horizontal line of each color at a different distance from the sensor, forming a focal plane (Figure 3).
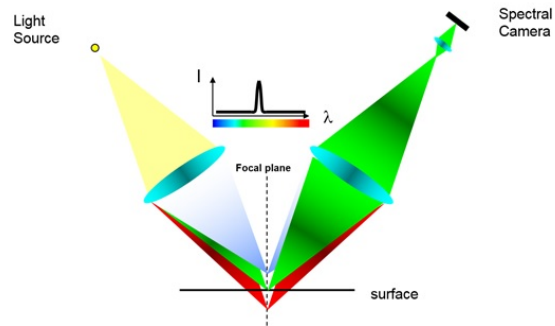
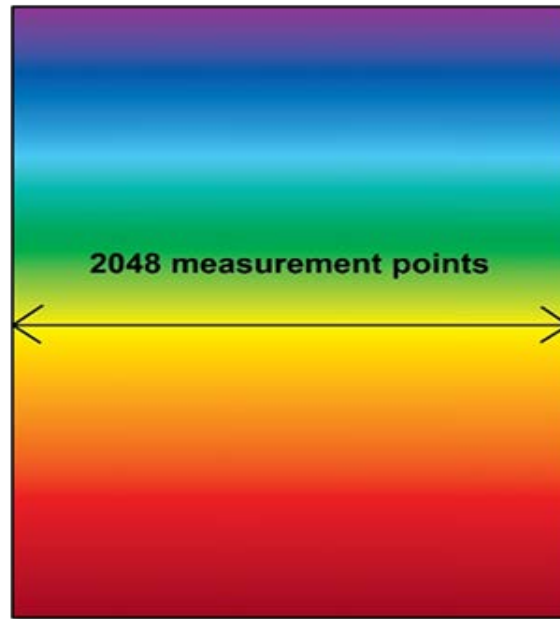**Figure 2 - Line confocal method principle**

Figure 3 - Focal plane

Depending on the vertical position of the imaged surface within the plane, corresponding wavelengths from 2048 lateral points are reflected back to the sensor's receiver. The receiver's spectral camera captures wavelength and intensity information from each point to form related height profile and gray-scale lines. When the surface is moved in front of the sensor (Figure 4), a 3D point cloud and 2D gray-scale image are generated from the scanned area line by line. The resulting data can be processed, analyzed and reported with various 3D surface analysis and image processing software packages.
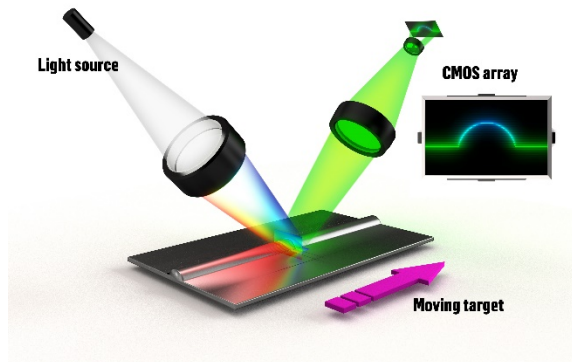
Figure 4 - Line confocal method principle

Line Confocal Method Imaging Capabilities

The line confocal sensors and systems work well in applications that require high-speed imaging of challenging materials at sub-micron resolution. Scanning an area that would require tens of minutes or hours for traditional 3D imaging methods, such as point confocal or interferometric technologies, can be completed within a few seconds.

Transparent materials and products with highly reflective or mirror-like surfaces are ideal for the line confocal method. The sensors' large numerical aperture and high tolerance for surface angle allow for imaging of steep slopes and glossy curved surfaces. This method does not suffer from speckle noise; this enables surface imaging at much higher resolution than laser triangulation sensors.

The quality of the raw image data produced by the line confocal sensors is good and rarely needs filtering or other manipulation of any kind. Since the sensors capture 2,048 measurement points simultaneously, vibration of the imaged surface or the sensor itself seldom causes issues; relative point height positions within the measurement profile line remain unaffected.

Example 1: 3D imaging of Printed Circuit Boards

In this imaging example a section of rigid PCB with fine lines at the top (Figure 5) was scanned to characterize the width, height, cross-sectional area and surface roughness of conductor traces. The scan below was performed with a table-top scanner. A line confocal sensor mounted on the production line can capture similar 3D profiles from a moving surface for automated real-time analysis.
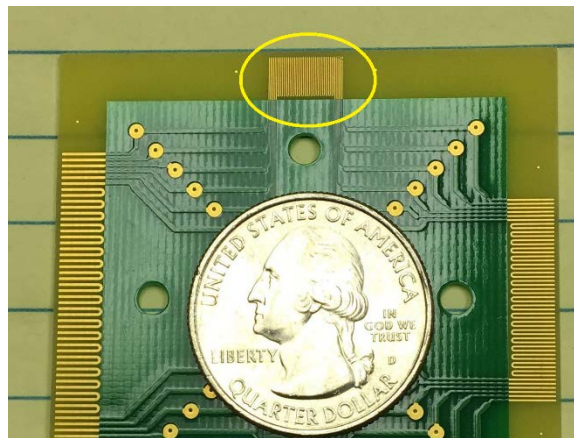

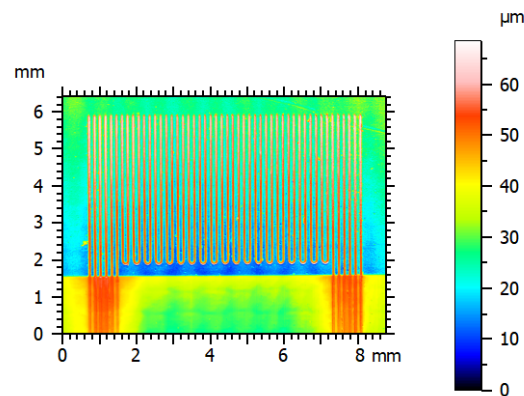**Figure 5 - Scanned area with fine lines**
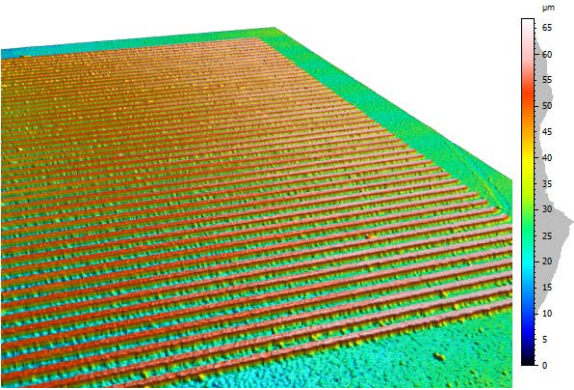

Figure 6 - 2D pseudo-color view of the scanned area

Figure 7 - 3D view of the surface

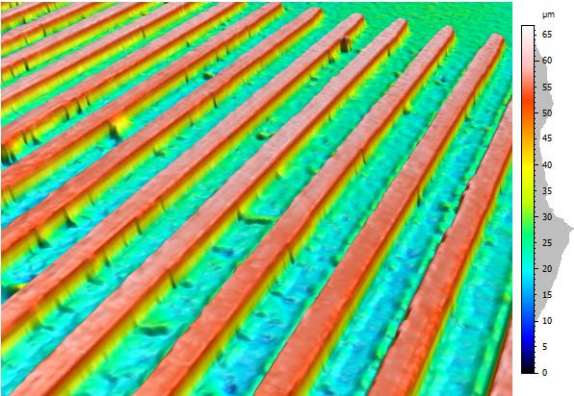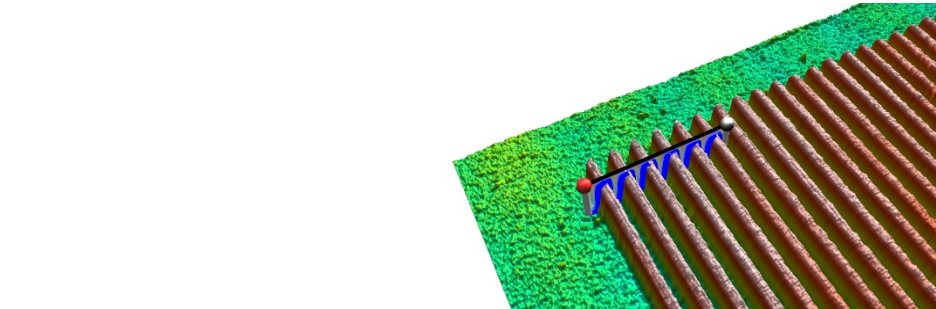**Figure 8 - Zoomed-in 3D view of the surface**
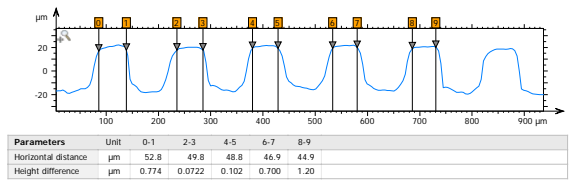

Figure 9 - Extracting a cross-sectional profile

Parameters	Unit	0-1	2-3	4-5	6-7	8-9
Horizontal distance	µm	52.8	49.8	48.8	46.9	44.9
Height difference	µm	0.774	0.0722	0.102	0.700	1.20

Figure 10 - Trace width measurement at the top from extracted profile

Distance measurement - Extracted profile

Parameters	Unit	0-1	2-3	4-5	6-7	8-9
Horizontal distance	µm	98.7	94.8	104	102	85.0
Height difference	µm	-1.46	3.33	0.435	0.418	-0.991
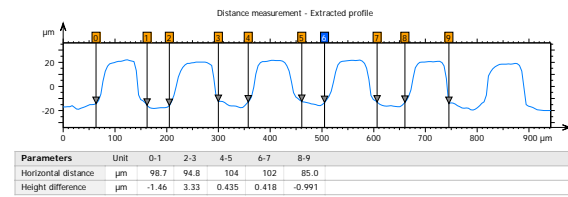
Figure 11 - Trace width measurement at the foot

Parameters	Unit	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Width	µm	42.8	47.1	47.1	47.1	42.8	42.8
Maximum height	µm	38.6	36.7	38.1	38.4	37.2	35.5
Mean height	µm	37.1	36.1	37.5	37.7	36.9	34.7
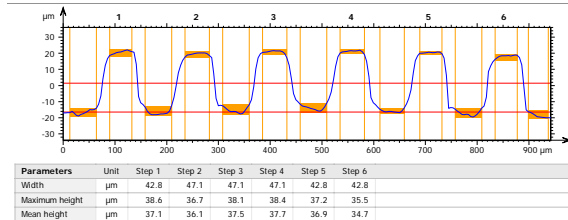
Figure 12 - Trace height measurement

Parameters	Value	Unit
Maximum height	36.8	µm
Area of the peak	2572	µm²
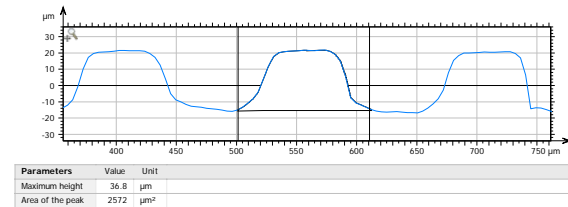
Figure 13 - Measurement of a trace's cross-sectional area
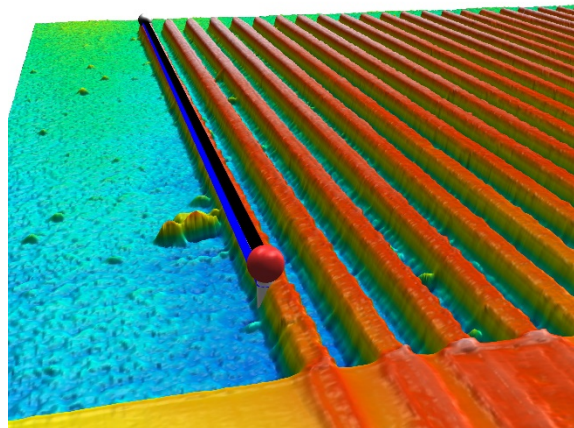
Figure 14 - Extracting copper surface profile from a single trace

Parameters	Value	Unit
Length	3.84	mm
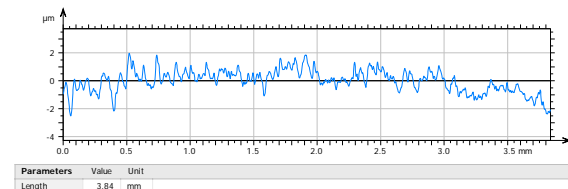
Figure 15 - Extracted surface profile

ISO 4287			
Amplitude parameters - Roughness profile			
Rp	1.34	µm	*Gaussian filter, 0.8 mm*
Rv	1.54	µm	*Gaussian filter, 0.8 mm*
Rz	2.88	µm	*Gaussian filter, 0.8 mm*
Rc	1.23	µm	*Gaussian filter, 0.8 mm, ISO 4287 w/o ame…*
Rt	3.89	µm	*Gaussian filter, 0.8 mm*
Ra	0.402	µm	*Gaussian filter, 0.8 mm*
Rq	0.514	µm	*Gaussian filter, 0.8 mm*
Rsk	0.000311		*Gaussian filter, 0.8 mm*
Rku	3.40		*Gaussian filter, 0.8 mm*
Material Ratio parameters - Roughness profile			
Rmr	4.93	%	*c = 1 µm under the highest peak, Gaussian…*
Rdc	0.831	µm	*p = 20%, q = 80%, Gaussian filter, 0.8 mm*

Figure 16 - Roughness measurements from the extracted profile

<u>**Example 2:**</u> **3D imaging of Printed Features and Substrates in Printed and Flexible Electronics Applications**
The line confocal method works well in characterizing multi-material high-contrast surfaces that are typical in printed electronics products. The system's capability to image clear highly reflective substrates with non-transparent and often matte conductive inks with the same parameter settings in a single pass speeds up scanning and analysis of the entire product.

Below is shown a sequence to measure ink height (thickness) and width, gap width between traces, substrate radius and thickness/height of the dielectric coating in a flexible hybrid electronics circuit with a die. Silver traces are shown on a clear, glossy substrate. A 2D gray-scale image from the scanned surface and additional 3D scans show 0.004" silver lines and printed pads for a 0402-size component are included as well.
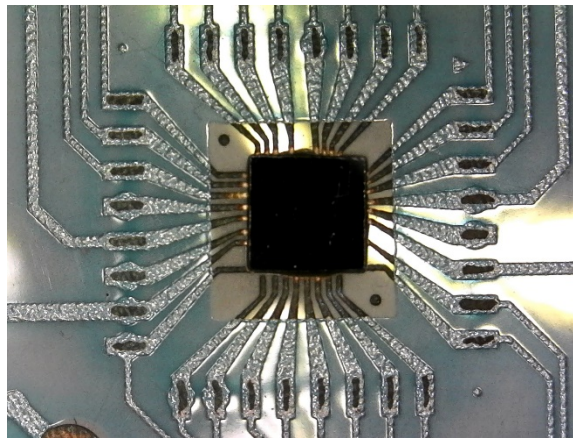
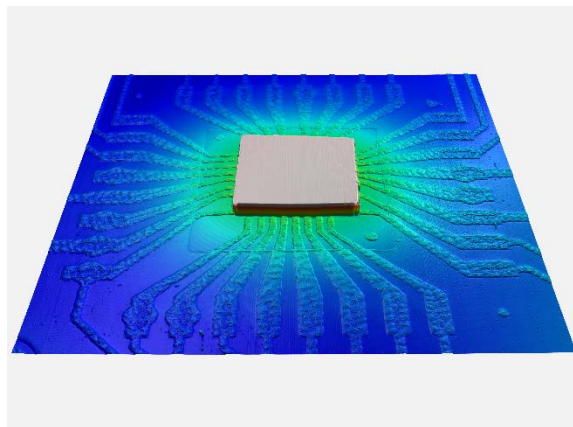**Figure 17 - Digital microscope photo of the scanned area. Notice the tinted dielectric coating**

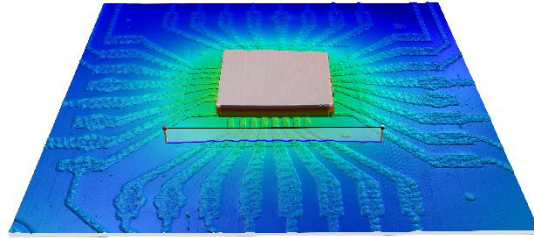**Figure 18 - 3D view of the scanned area**

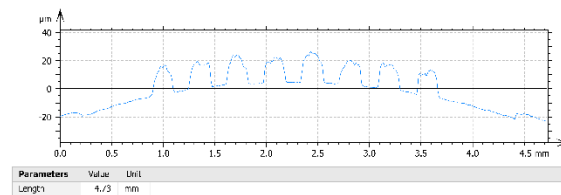**Figure 19 - Extracting a cross-sectional surface profile**

Figure 20 – Profile that can be used to determine trace height, width and shape; gap width; radius of substrate; and height of dielectric coating at the edges
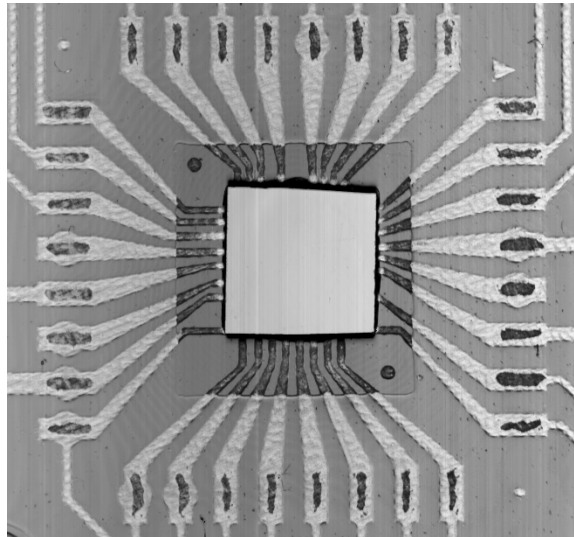

Figure 21 – Line confocal method sensors simultaneously capture 2D gray-scale image from the scanned area

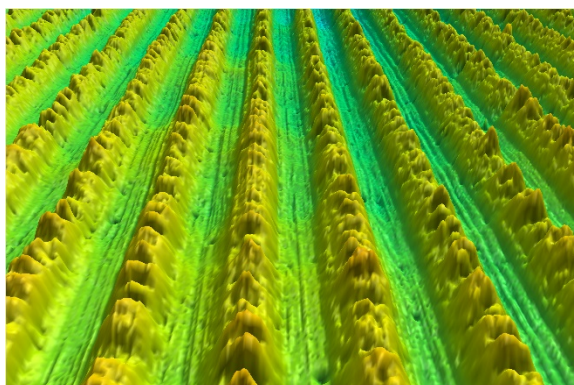**Figure 22 - Microscope photo of 0.004" printed silver lines with 0.006" gap in-between**
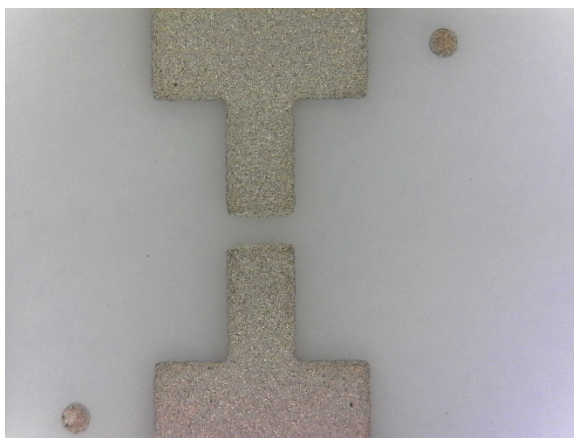

Figure 23 - Zoomed-in 3D view of the lines

Figure 24 - Microscope photo of land pads for a 0402-size component
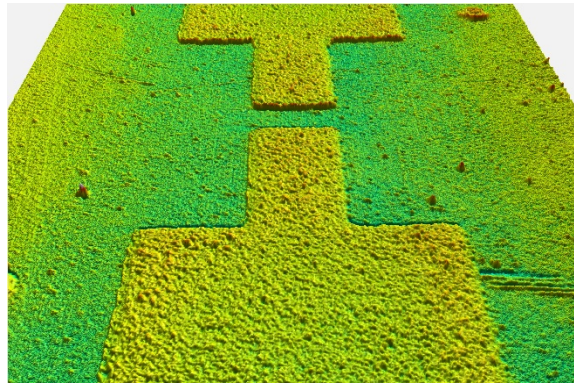
Figure 25 - 3D view of the pads

Example 3: 3D Imaging of Adhesives and Other Dispensed Materials

The line confocal method can be used to image transparent, translucent and opaque structural and pressure-sensitive adhesives, sealants, and other materials in liquid, paste, and solid forms. Shape, size, cross-sectional area, height, width, volume, surface roughness and position of glue dots and lines can be measured with the system's sensors. The technology works equally well on sealants and other dispensed materials. Materials can be characterized with the system's sensors both in laboratory and production conditions in real time.

The technology works well in challenging applications, such as imaging transparent glue dots on transparent or mirror-like surfaces. Figure 26 shows a 3D view of an approximately 85 µm high bead of transparent cyanoacrylate glue on a glossy transparent glass substrate. The bead was scanned with a line confocal sensor. Figure 27 depicts a 2D top view of the same bead with its automatically calculated volume and height values.
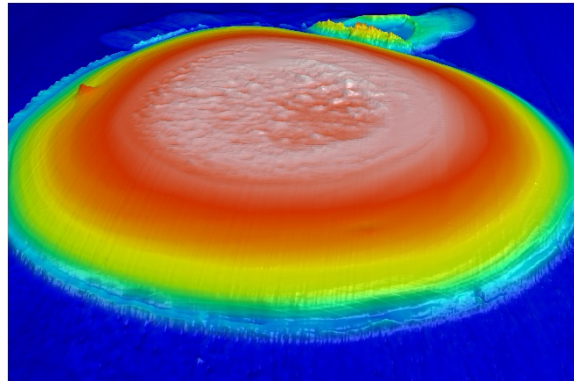
Figure 26 - A bead of cyanoacrylate glue on a glass surface

Parameters	Stat.	Value	Unit
Volume	Max	451483066	µm³
Max height	Max	85.8	µm
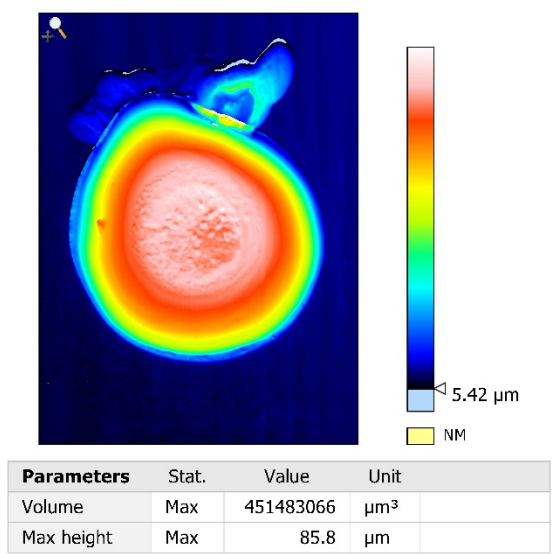
Figure 27 - Volume and height of a glue bead

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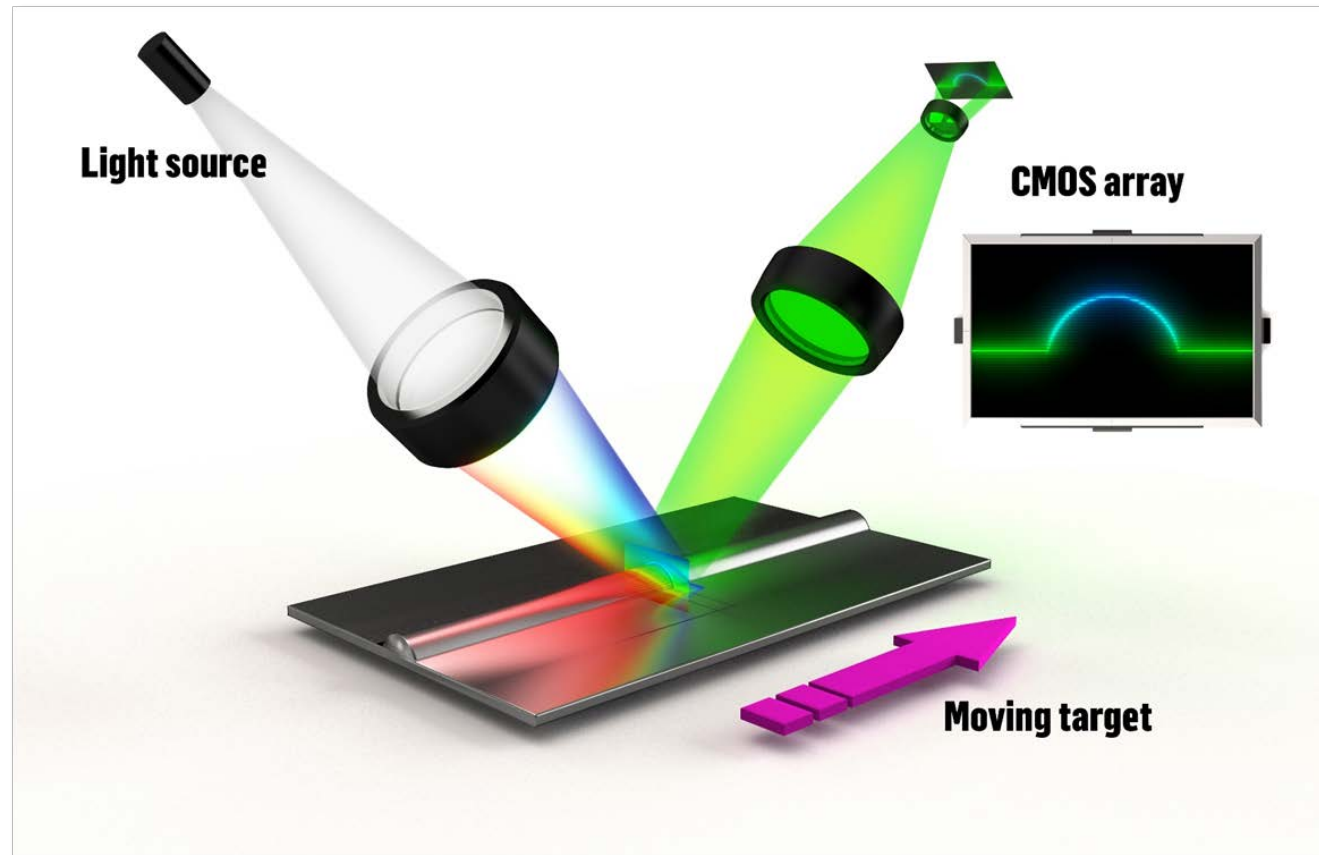**Juha Saily, FocalSpec, Inc., Santa Clara, CA, USA**

juha.saily@focalspec.com

Line Confocal Method

- Non-contact optical imaging method
- Simultaneous 3D and 2D imaging for
  - *Dimensions (height, width, length, gap, offset...)*
  - *Shape, profile*
  - *Flatness*
  - *Surface roughness, texture*
  - *Thickness*
  - *Volume*
  - *Tomography, etc.*

Line Confocal Method Principle

Line Confocal Method Principle

Line Confocal Method Principle

Line Confocal Method Principle

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MEETINGS AND COURSES: JANUARY 26–31, 2019
CONFERENCE AND EXHIBITION: JANUARY 29–31, 2019
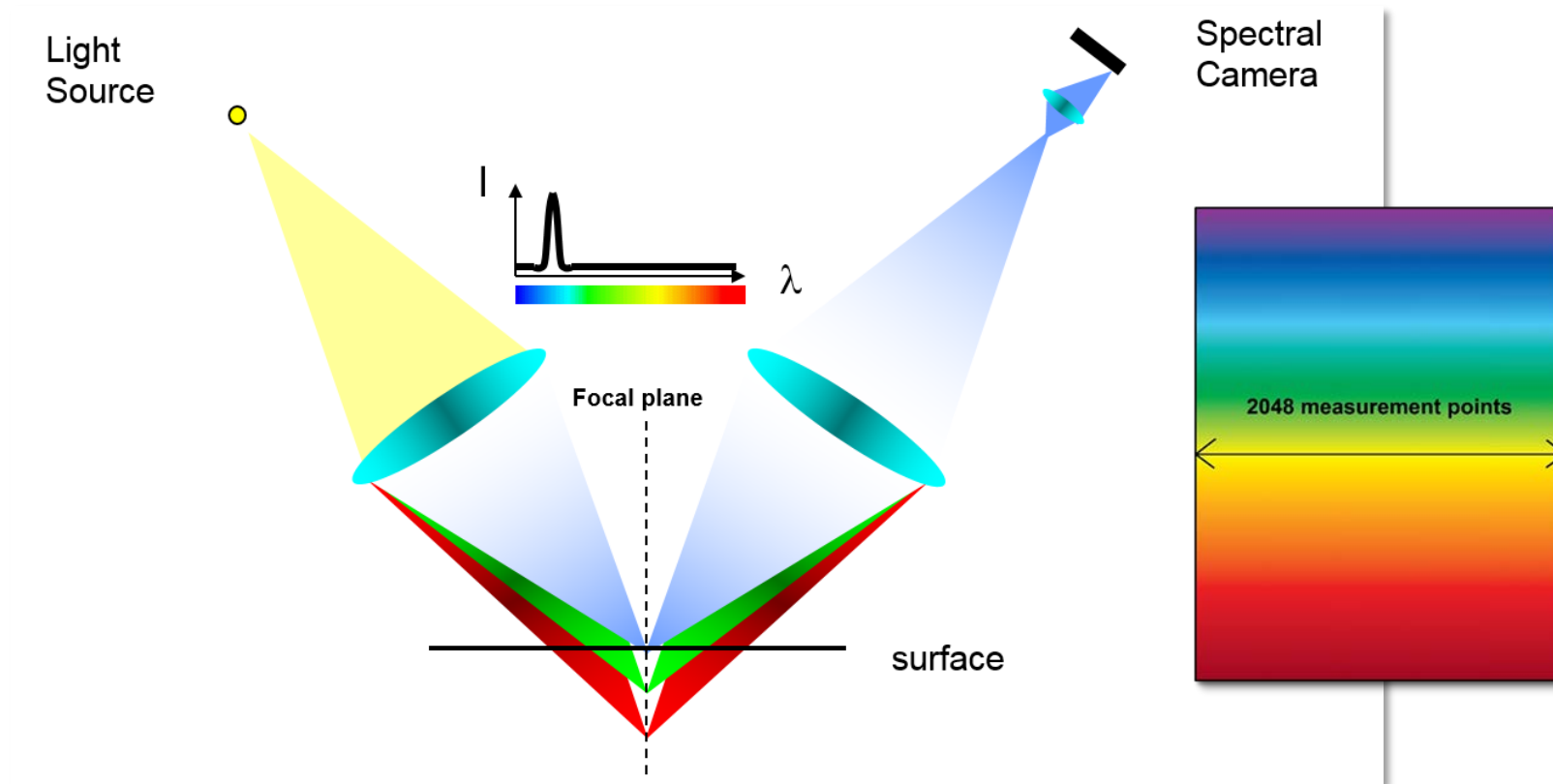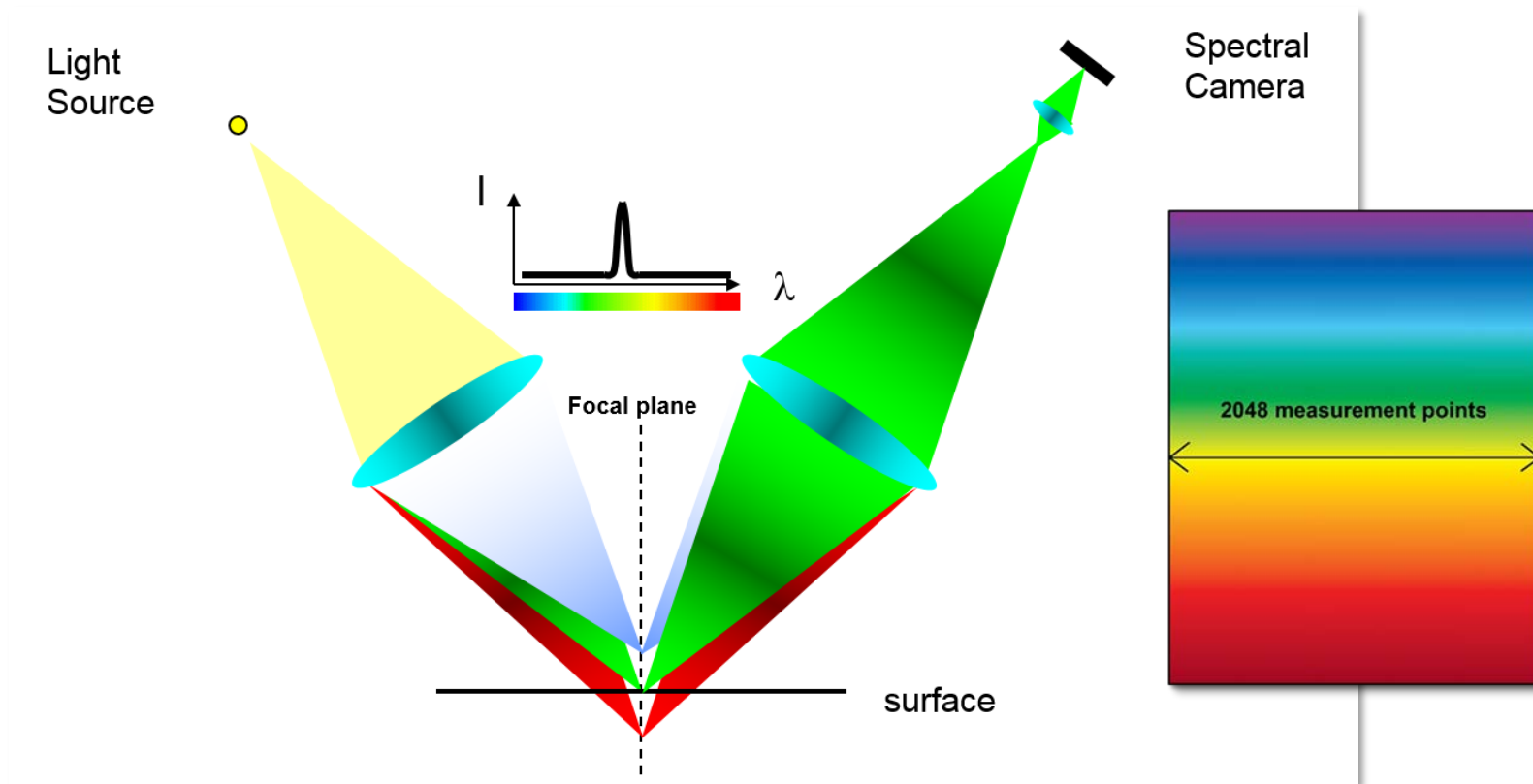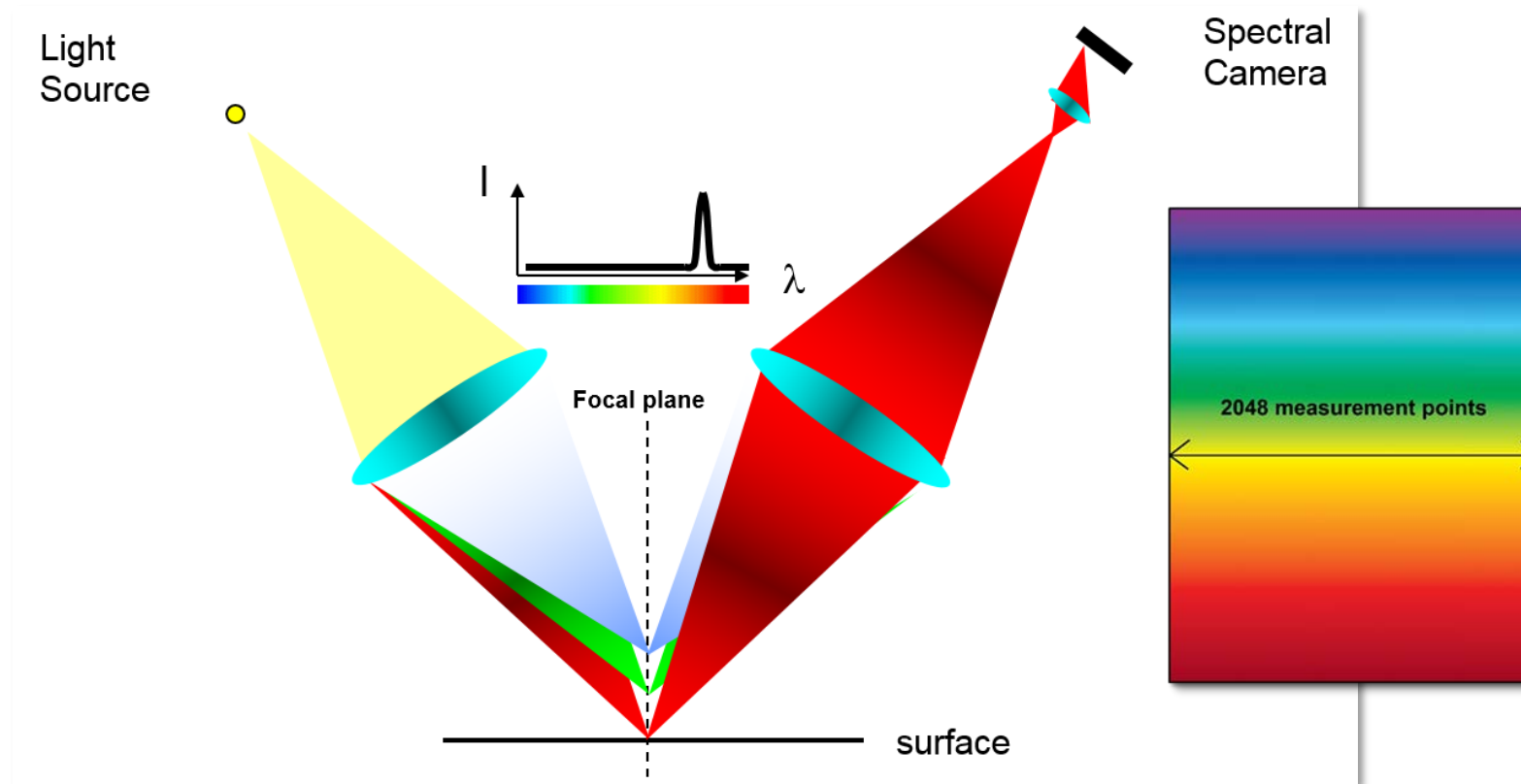
Application: In Situ Characterization

Application: Off-line Characterization

General Application Requirements

- Z (height) resolution   Up to 100 nm (0.0039 mil)
- Lateral resolution   Up to 2.2 μm (0.0866 mil)
- Z range (in situ)   Up to 5.5 mm (0.22")
- Scan width (without stitching)   Up to 16.40 mm (0.65")
- Scan rate   Up to 5,000 lines/sec.
- Data acquisition rate   Up to 10 million 3D points/sec.

Line Confocal Method Advantages

- High speed → in-situ and off-line applications
- Sub-micron resolution
- Simultaneous 3D and 2D imaging with large focal depth
- Performs well on
  - *Highly reflective and mirror-like surfaces*
  - *Clear and translucent surfaces*
  - *Curved and sloping surfaces*
  - *High-contrast multi-material surfaces*
  - *Soft, fragile, porous surfaces*
  - *All surface colors*

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Line Confocal Method Advantages

- Enables measurement of
  - *Thickness of clear layers and air gaps*
  - *Topography under clear layers (tomography)*
- Acquires 2048 surface points simultaneously → high tolerance for vibration
- High-quality raw data
- Safe

Imaging Application: Printed Circuit Board
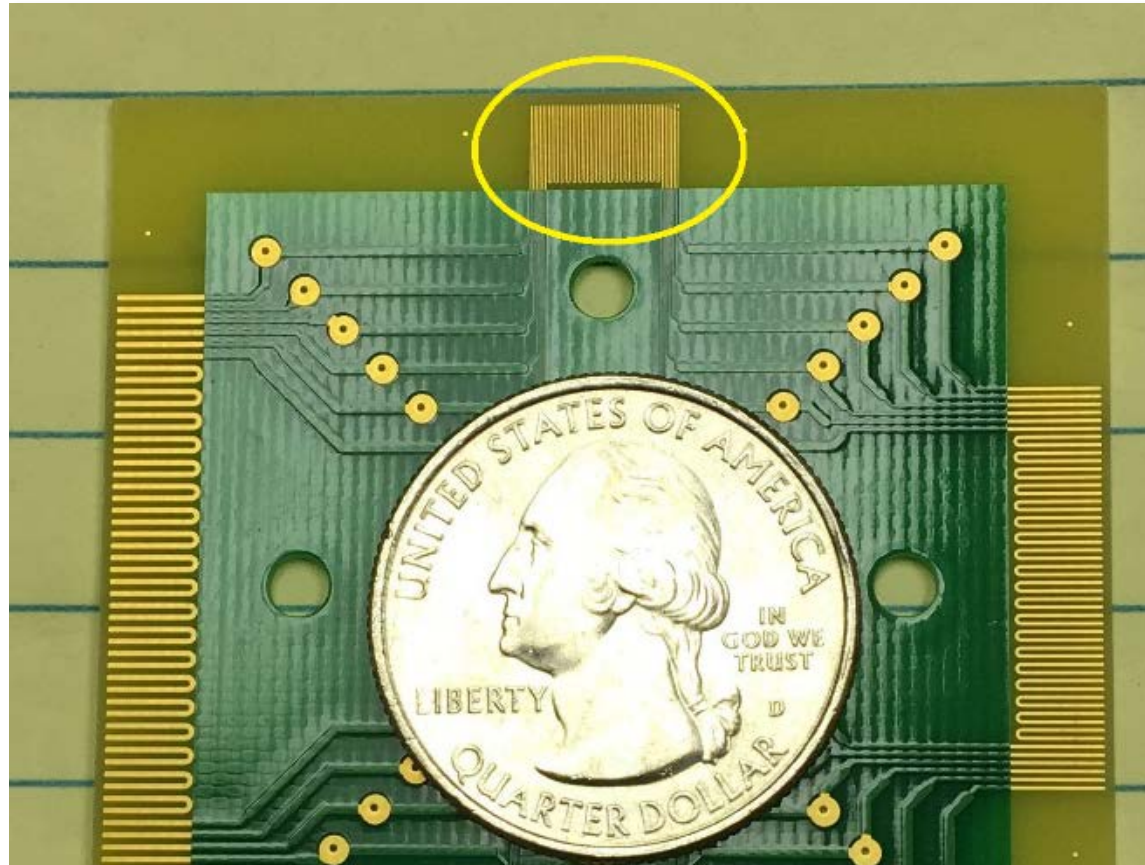
2D Pseudo-color View
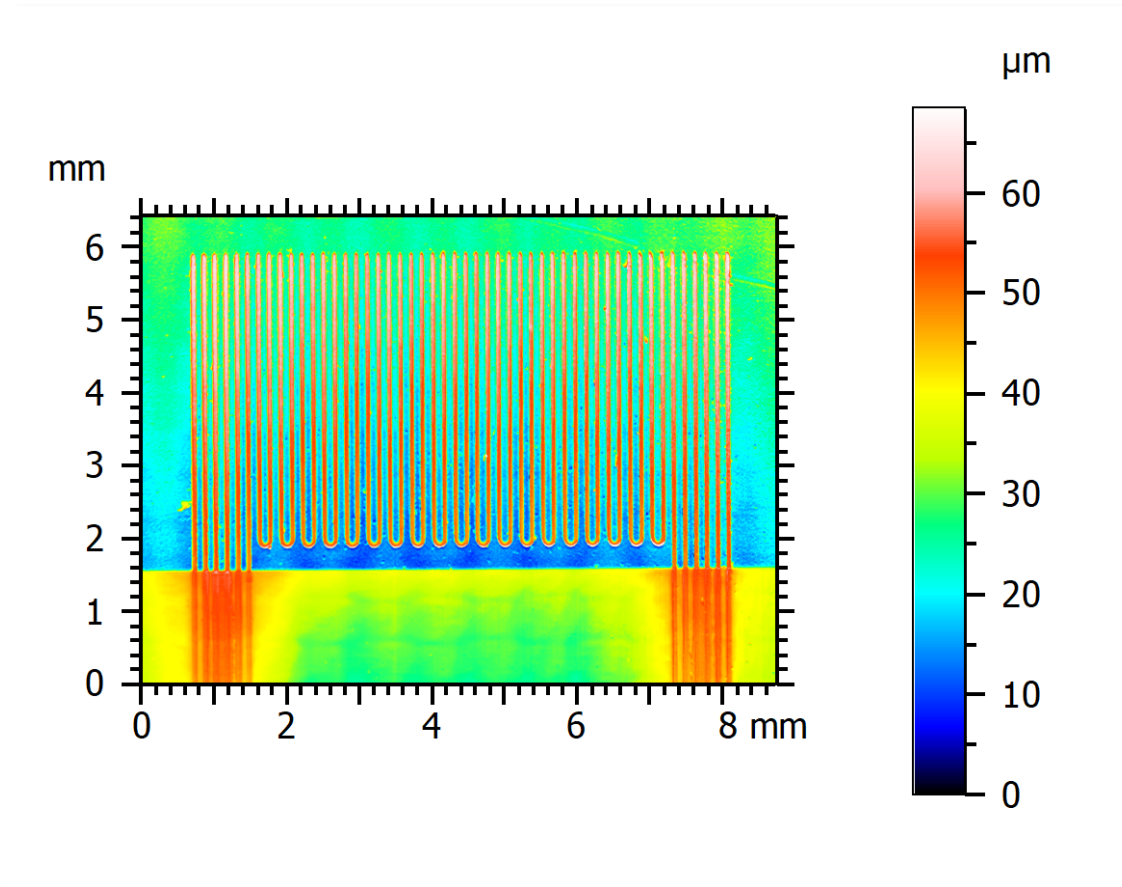
3D View
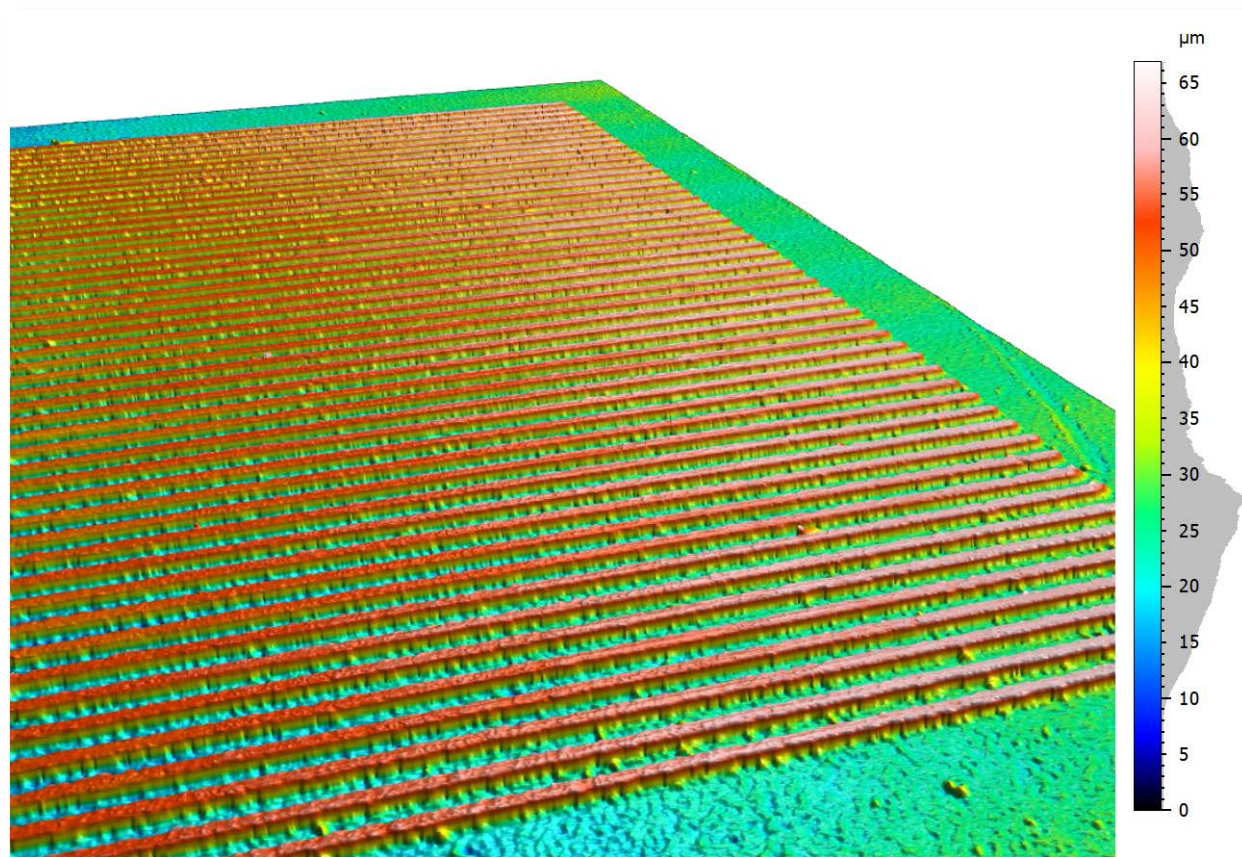
Zoomed-in 3D View
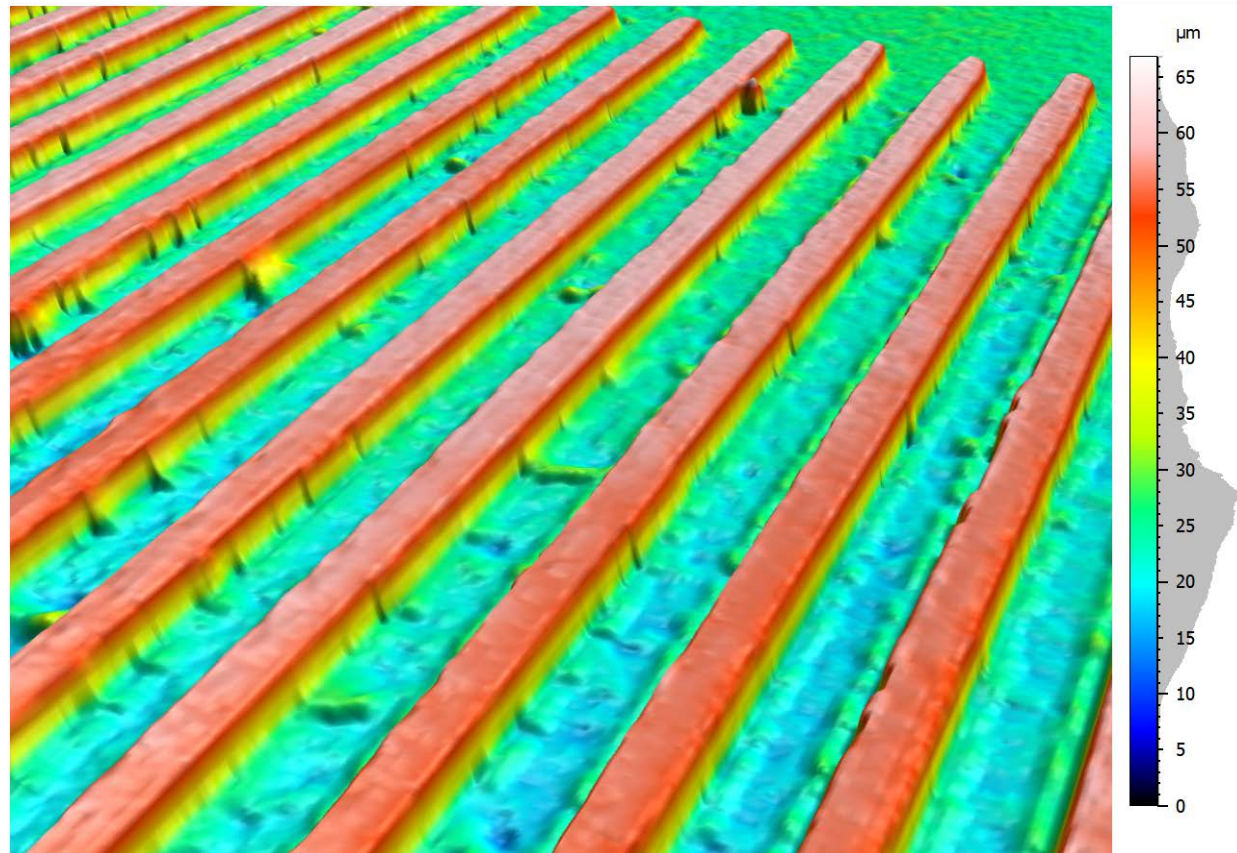
Profile Extraction
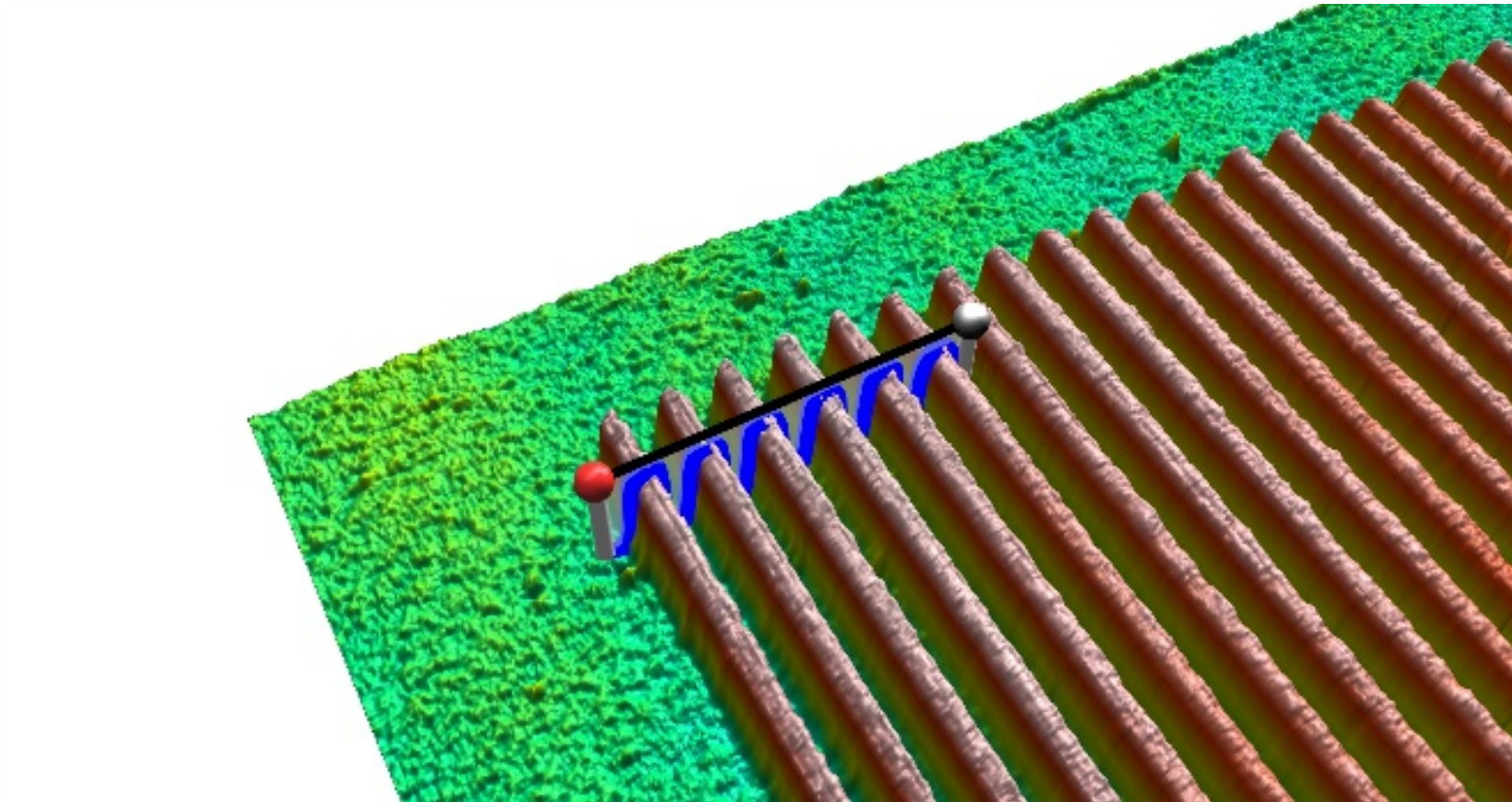
Trace Width Measurement at Top
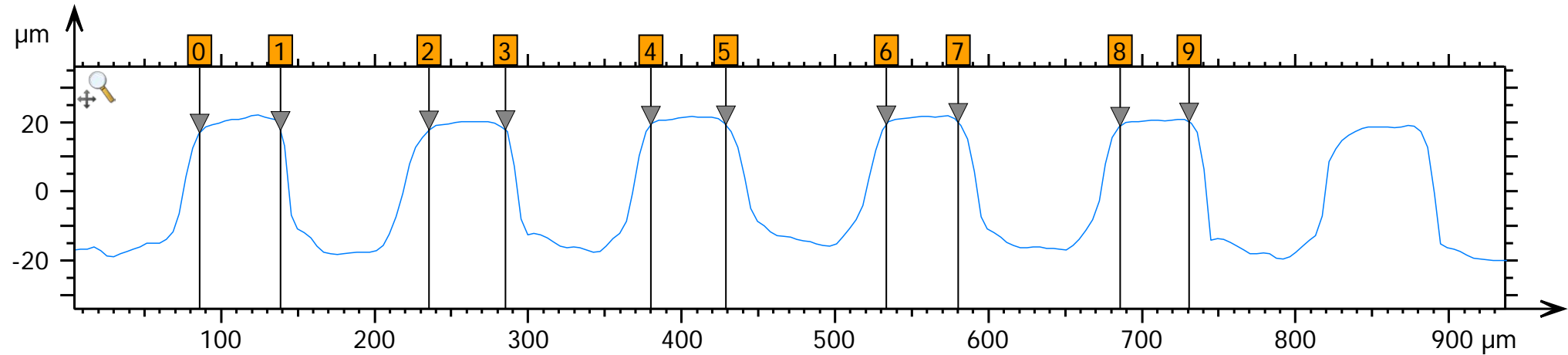
Parameters	Unit	0-1	2-3	4-5	6-7	8-9
Horizontal distance	μm	52.8	49.8	48.8	46.9	44.9
Height difference	μm	0.774	0.0722	0.102	0.700	1.20

Trace Width Measurement at Foot
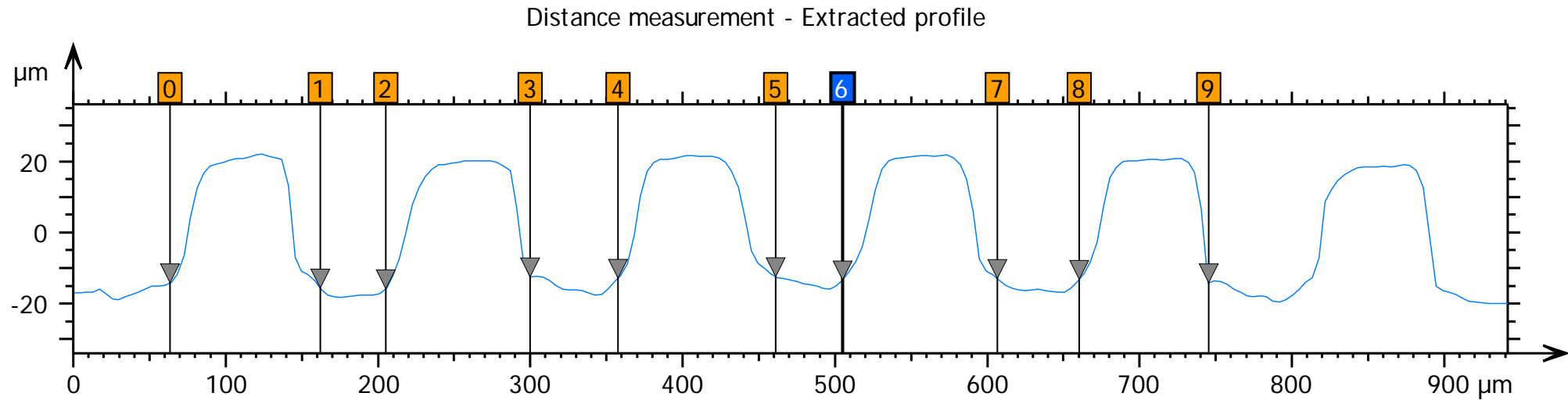
Distance measurement - Extracted profile

Parameters	Unit	0-1	2-3	4-5	6-7	8-9
Horizontal distance	µm	98.7	94.8	104	102	85.0
Height difference	µm	-1.46	3.33	0.435	0.418	-0.991

Trace Height Measurement
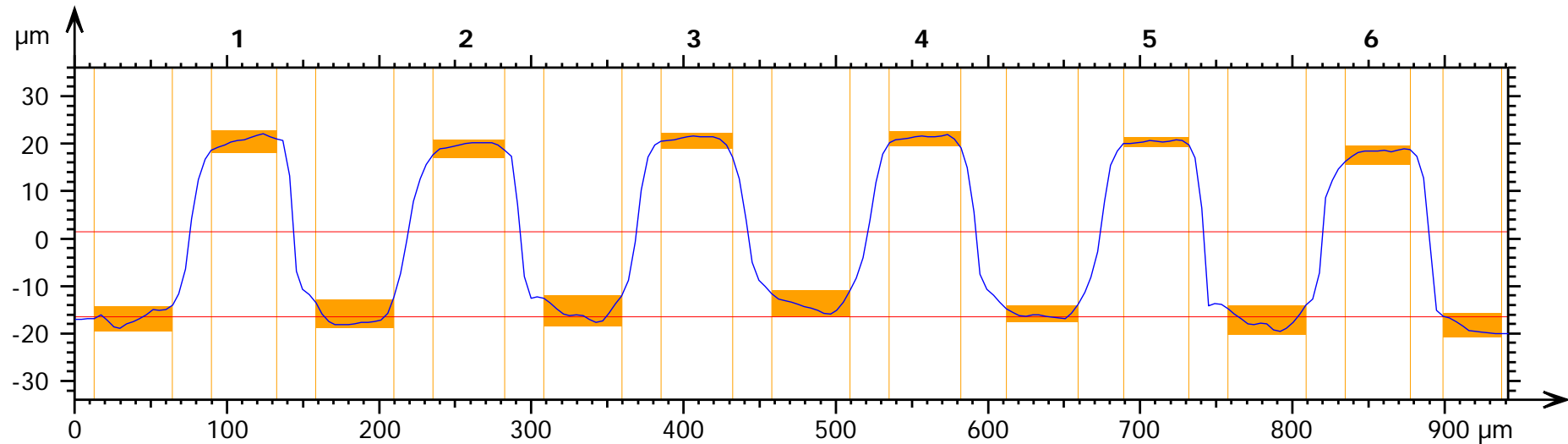
Parameters	Unit	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Width	µm	42.8	47.1	47.1	47.1	42.8	42.8
Maximum height	µm	38.6	36.7	38.1	38.4	37.2	35.5
Mean height	µm	37.1	36.1	37.5	37.7	36.9	34.7

Trace Cross-Sectional Area Measurement
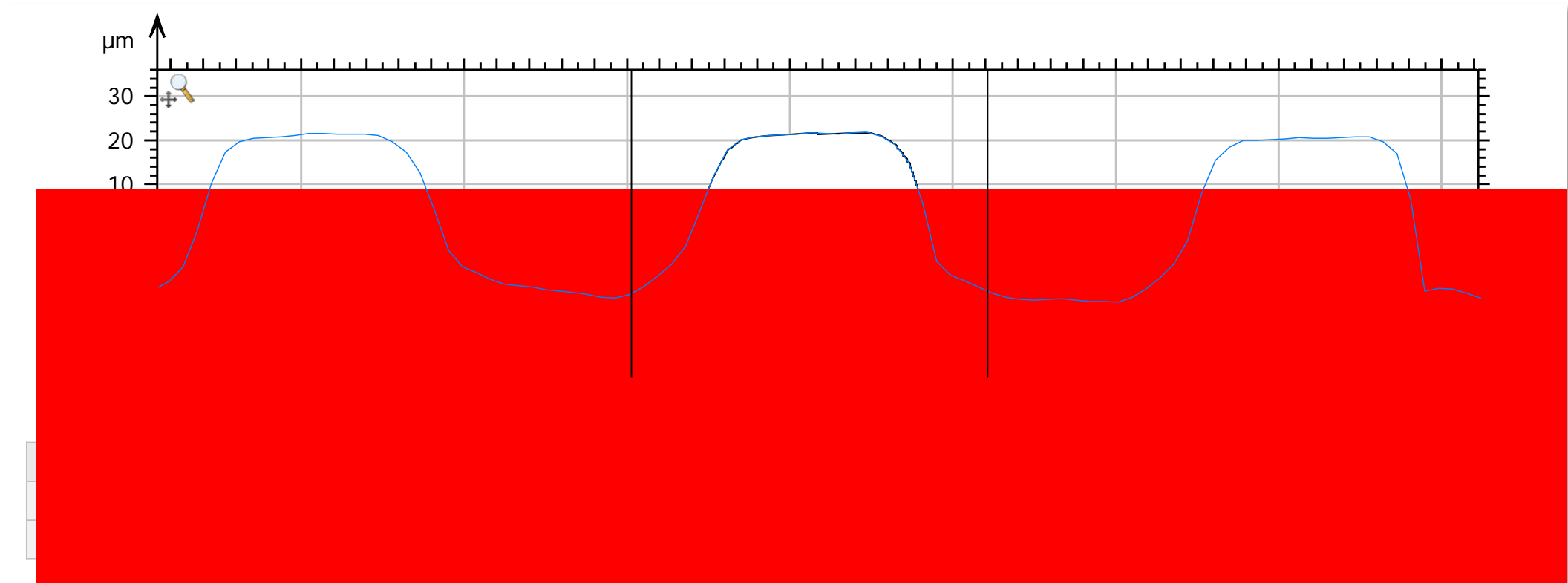
Copper Surface Profile Extraction
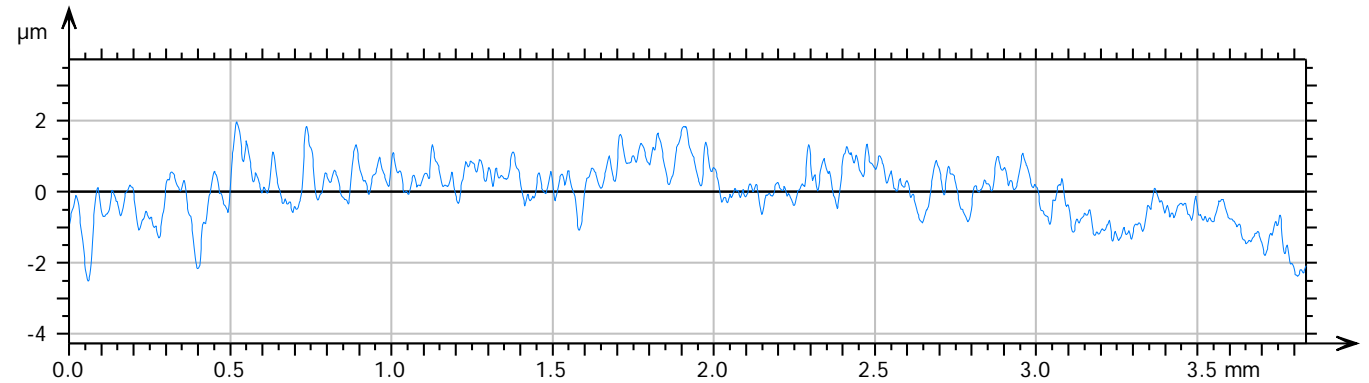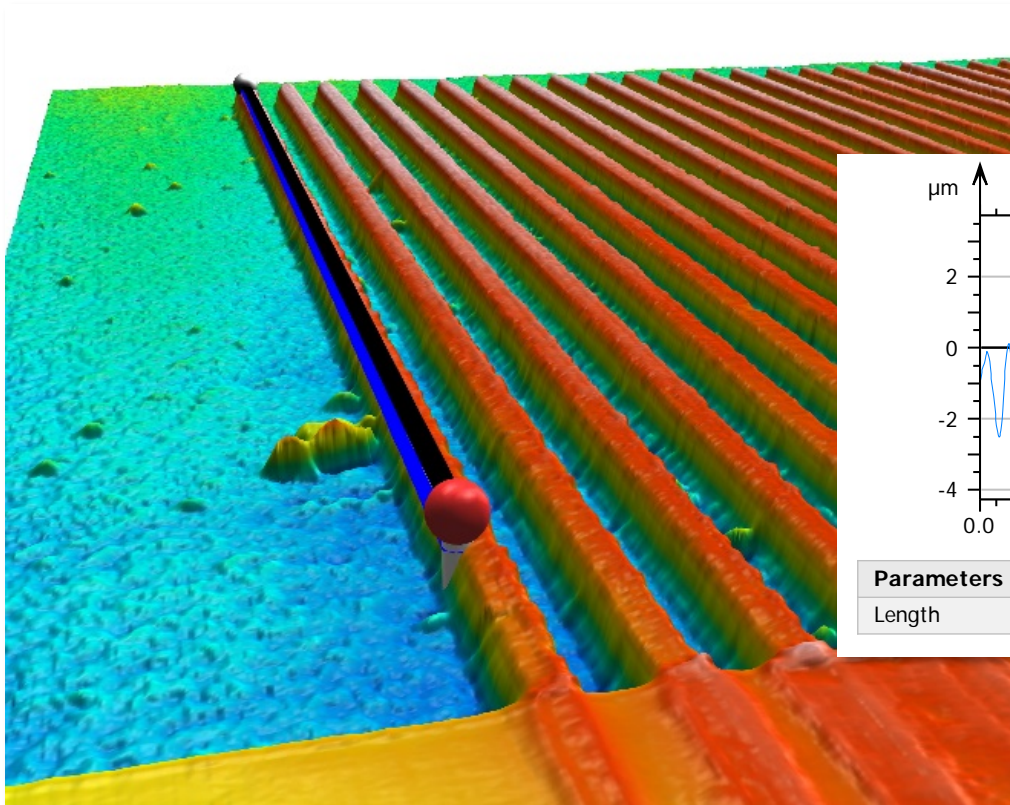
Surface Roughness Measurement from Extracted Profile

ISO 4287			
Amplitude parameters - Roughness profile			
Rp	1.34	µm	*Gaussian filter, 0.8 mm*
Rv	1.54	µm	*Gaussian filter, 0.8 mm*
Rz	2.88	µm	*Gaussian filter, 0.8 mm*
Rc	1.23	µm	*Gaussian filter, 0.8 mm, ISO 4287 w/o ame…*
Rt	3.89	µm	*Gaussian filter, 0.8 mm*
Ra	0.402	µm	*Gaussian filter, 0.8 mm*
Rq	0.514	µm	*Gaussian filter, 0.8 mm*
Rsk	0.000311		*Gaussian filter, 0.8 mm*
Rku	3.40		*Gaussian filter, 0.8 mm*
Material Ratio parameters - Roughness profile			
Rmr	4.93	%	*c = 1 µm under the highest peak, Gaussian…*
Rdc	0.831	µm	*p = 20%, q = 80%, Gaussian filter, 0.8 mm*

Imaging Application: Printed Flexible Hybrid Electronics
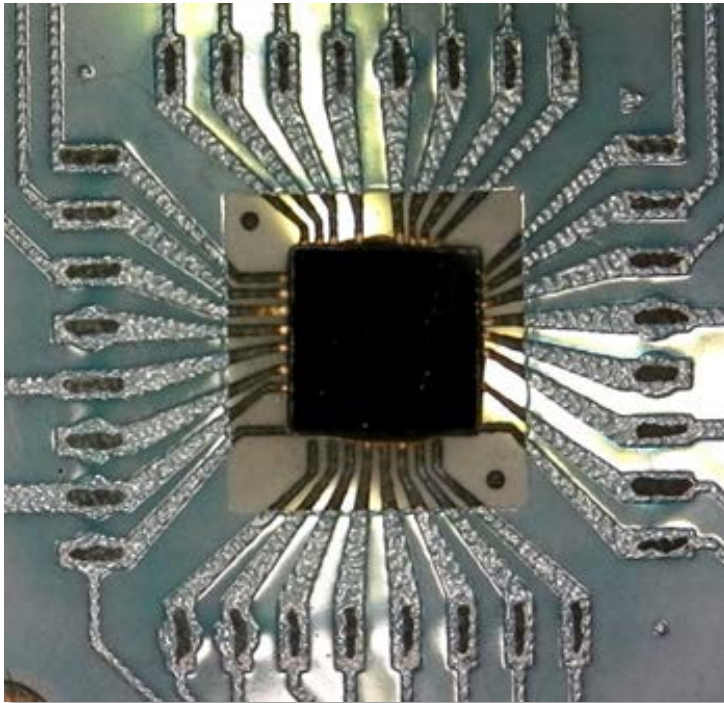
Microscope photo
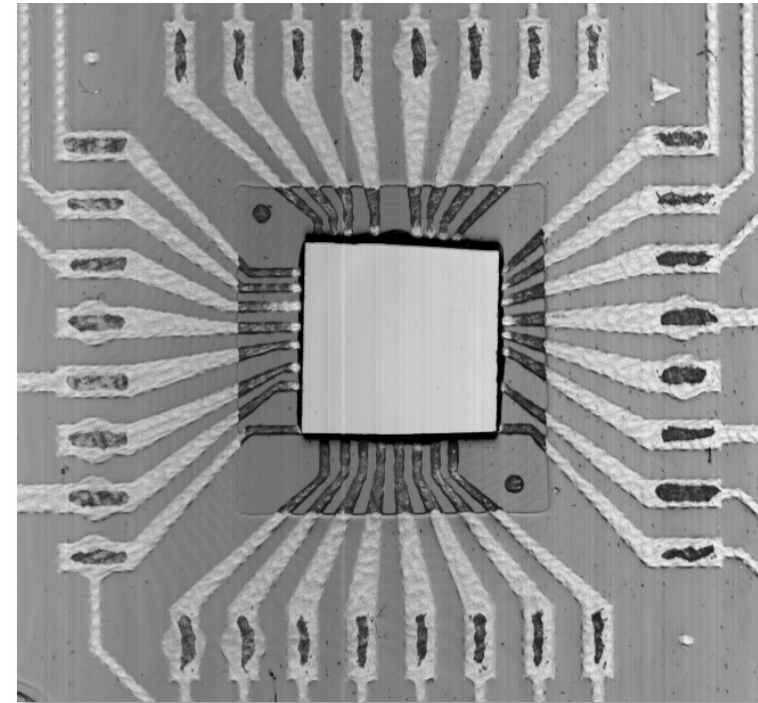
Line Confocal Method
2D gray-scale image

3D View

X = 10 mm
Y = 10 mm
Z = 355 µm
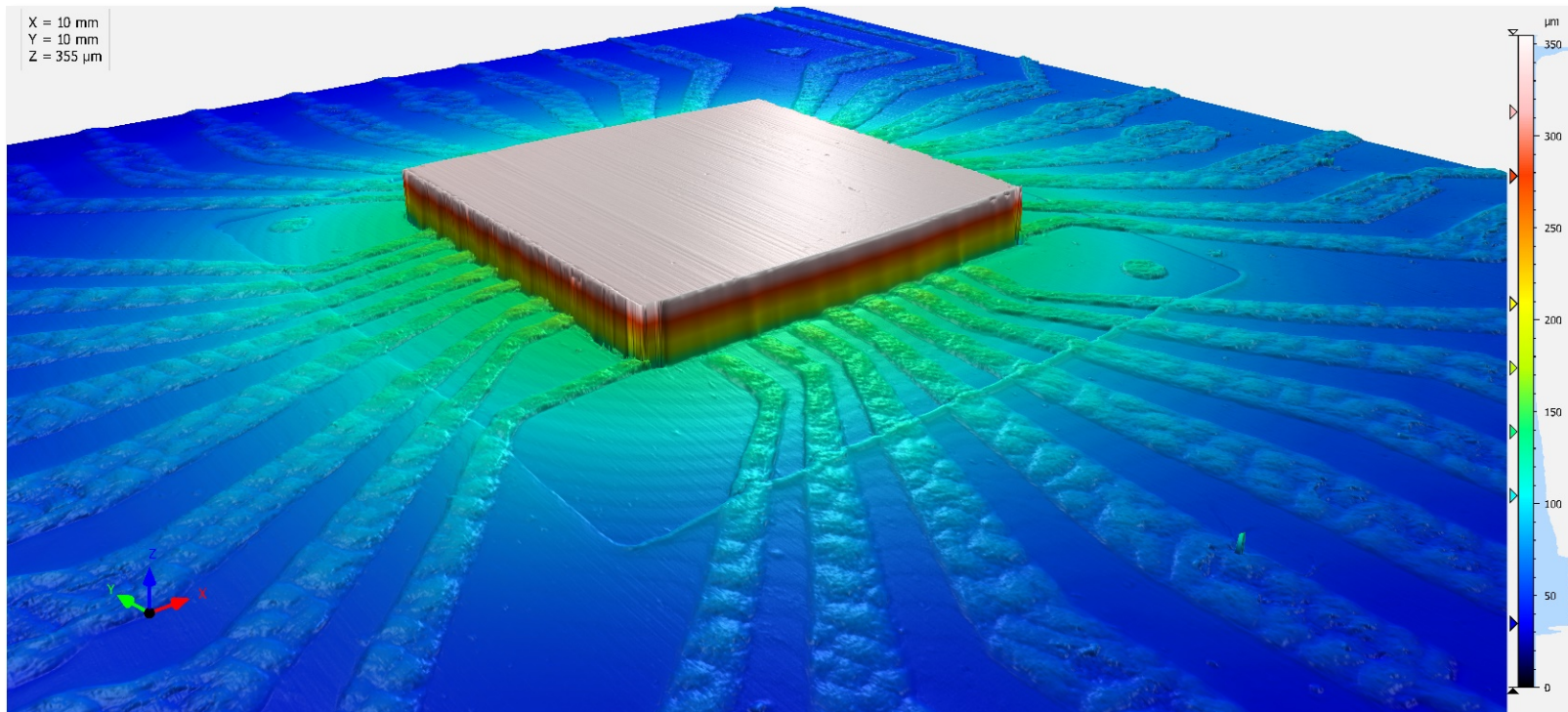
Characterization for:

- *Line/feature height, width, 3D profile, cross-sectional area*
- *Ink volume*
- *Gap width*
- *Surface roughness*
- *Substrate flatness*
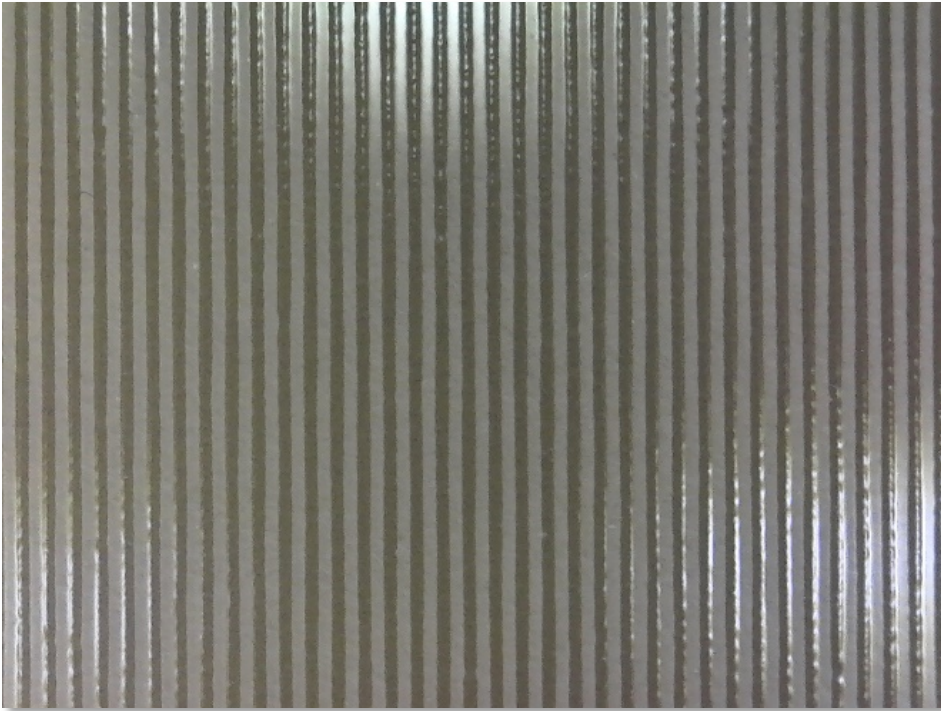- *Epoxy height and volume*
- *Die tilt*
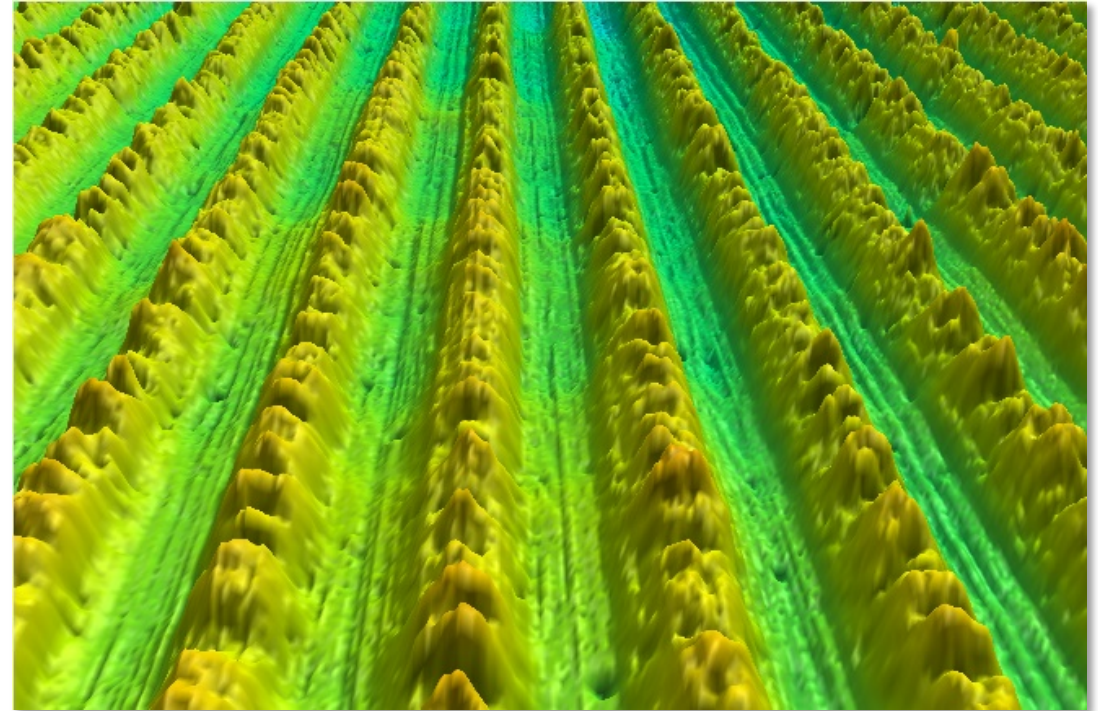- *Dielectric thickness*

Profile Extraction
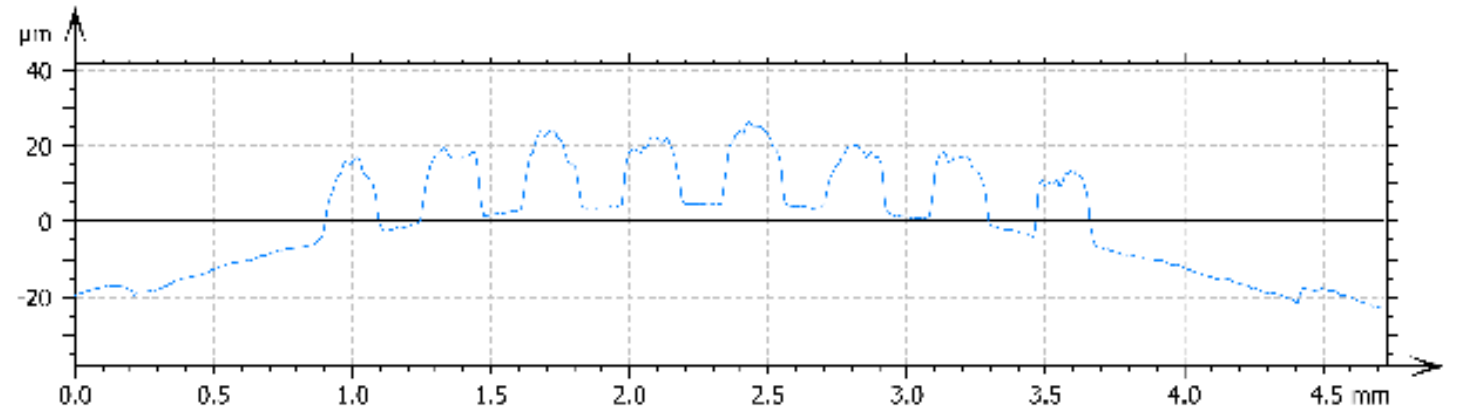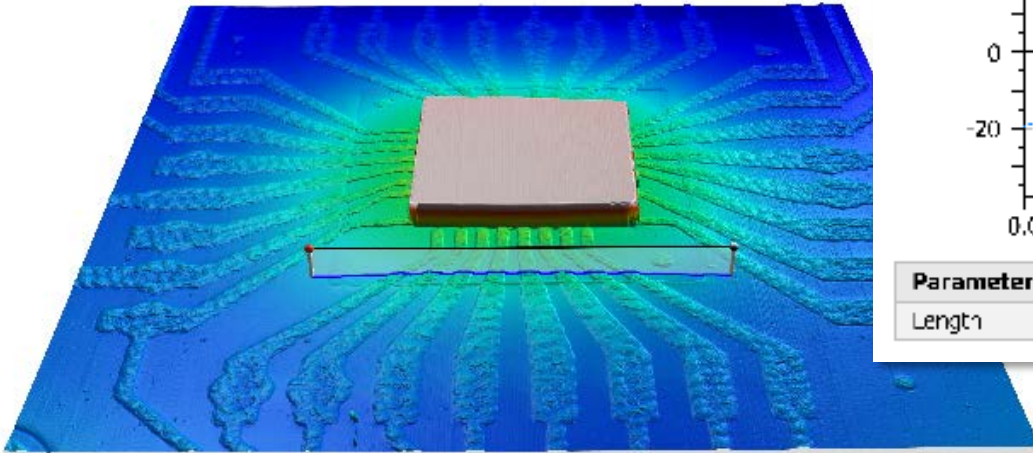
Parameters	Value	Unit
Length	4.73	mm

Imaging Application: Printed 0.004" Silver Lines

Microscope photo

Zoomed-in 3D view

Application: Printed Landing Pads for 0402 Size Component
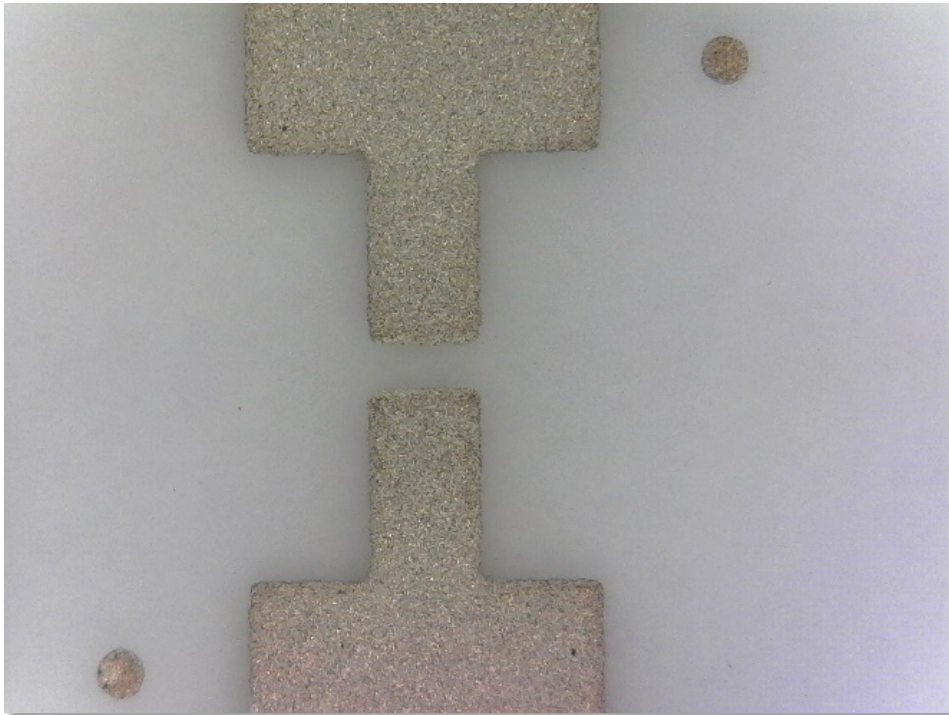
Microscope photo

3D view

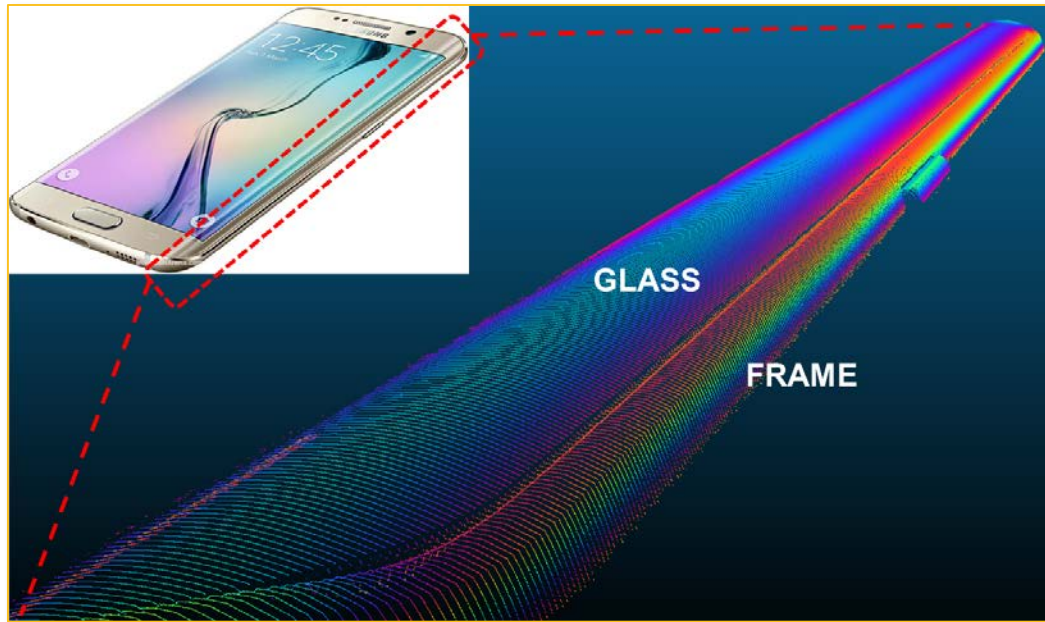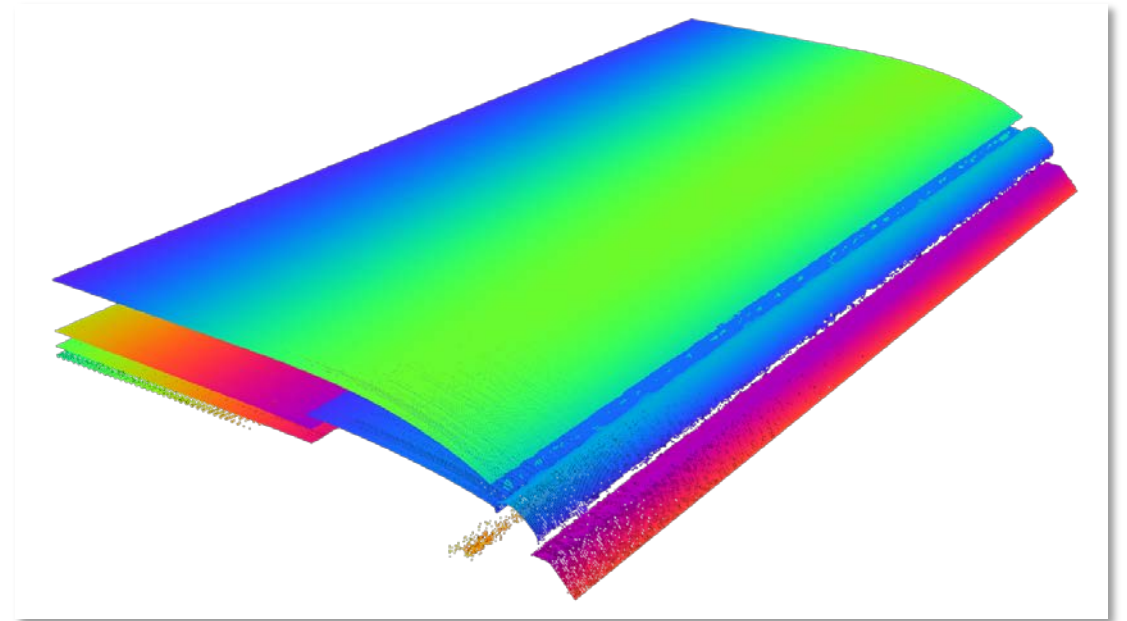# Application: Dispensed Materials - Clear Adhesive on Glass

Parameters	Stat.	Value	Unit
Volume	Max	451483066	µm³
Max height	Max	85.8	µm

5.42 µm

NM
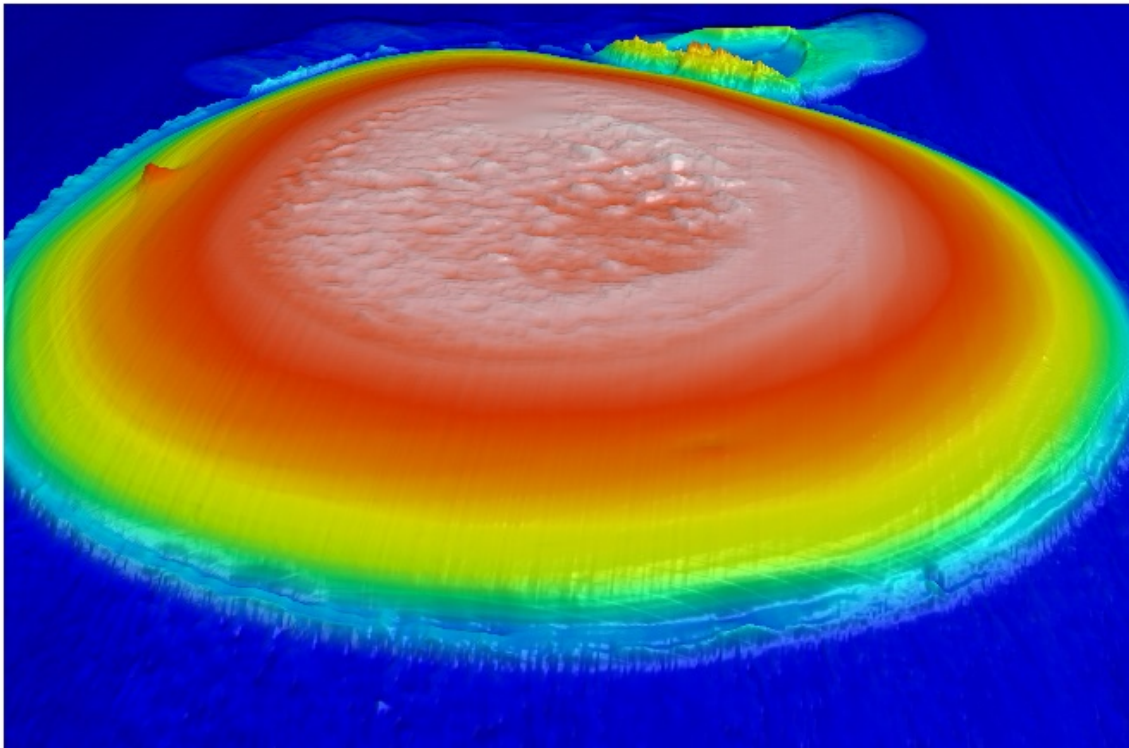
3D view
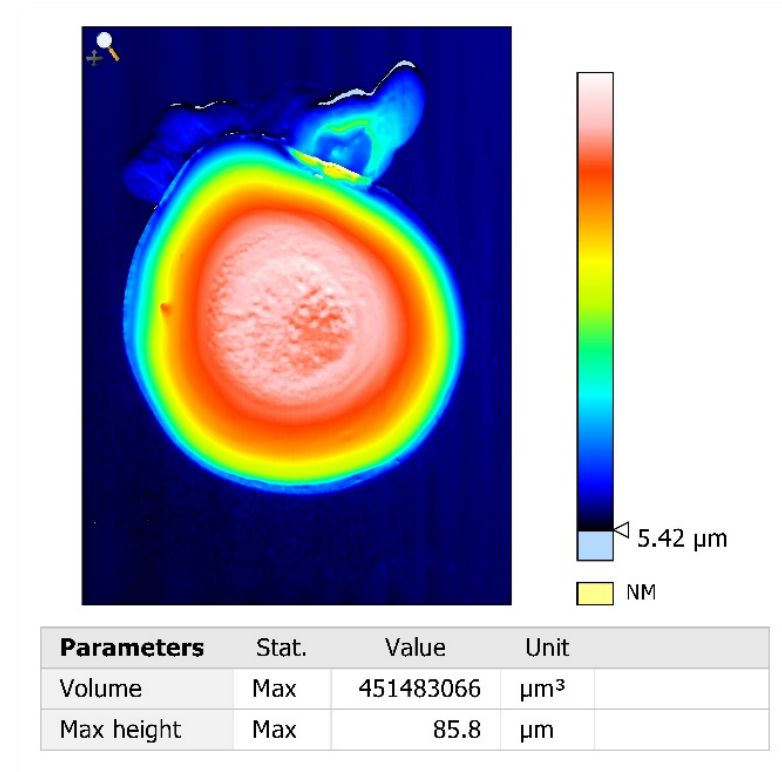
Volume and height

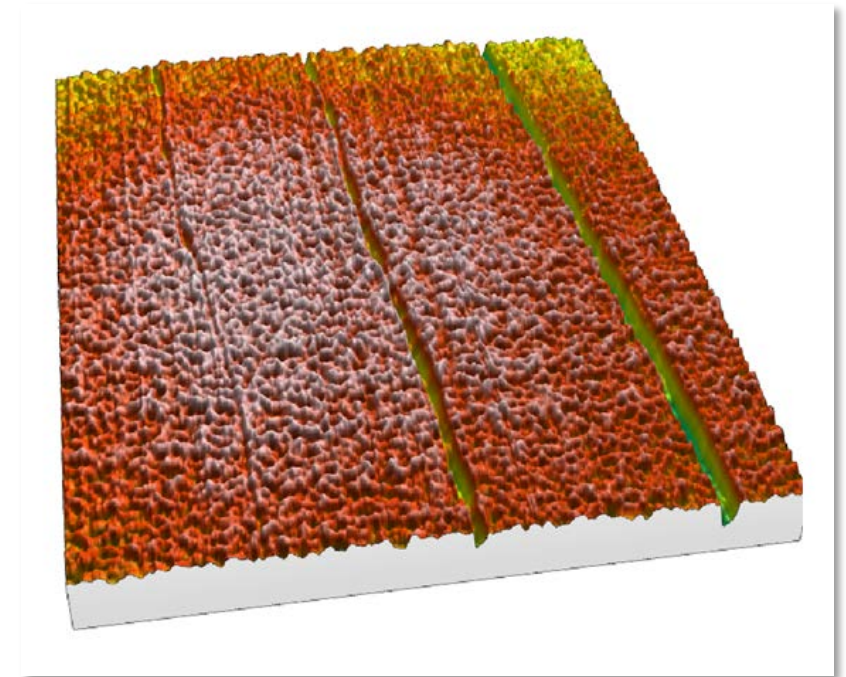# Imaging Application: Cellphone Cover Glass Assembly

Curved glass surface

Screen tomography

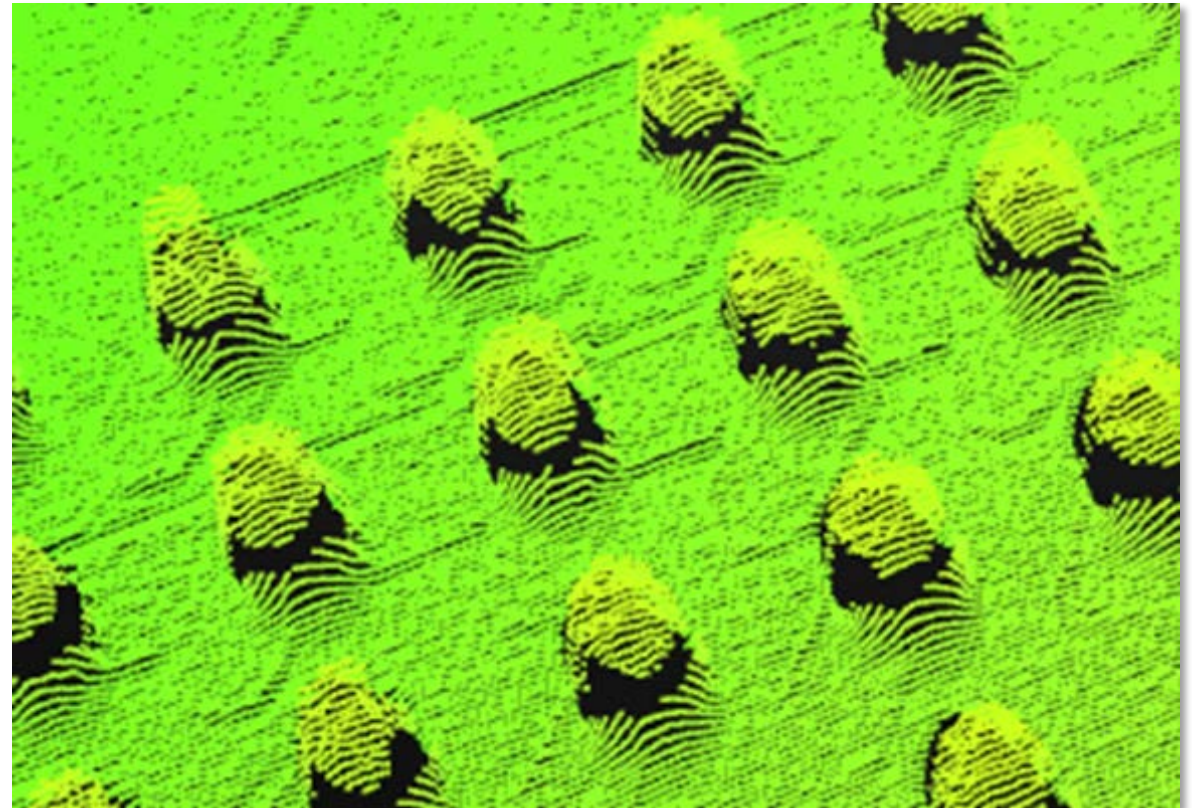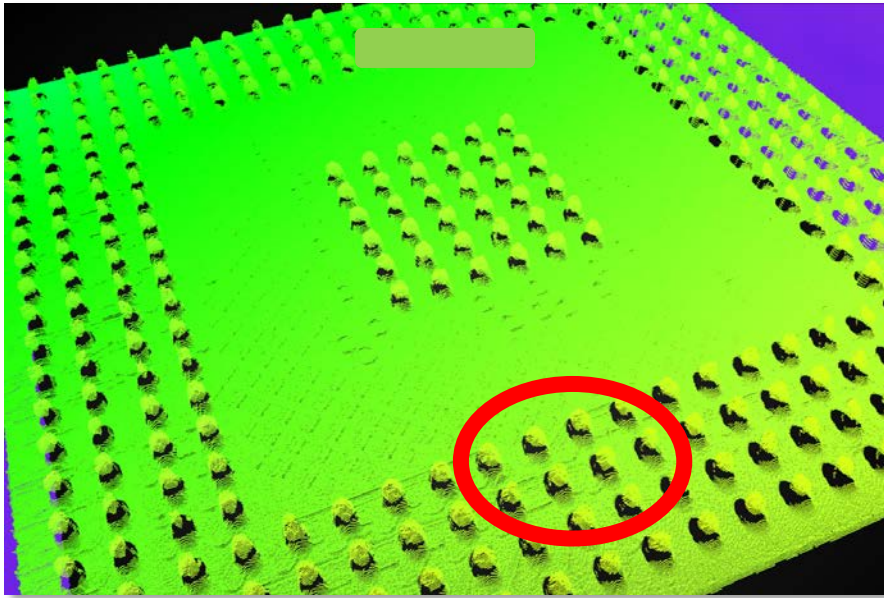# Imaging Application: Cosmetic Defects
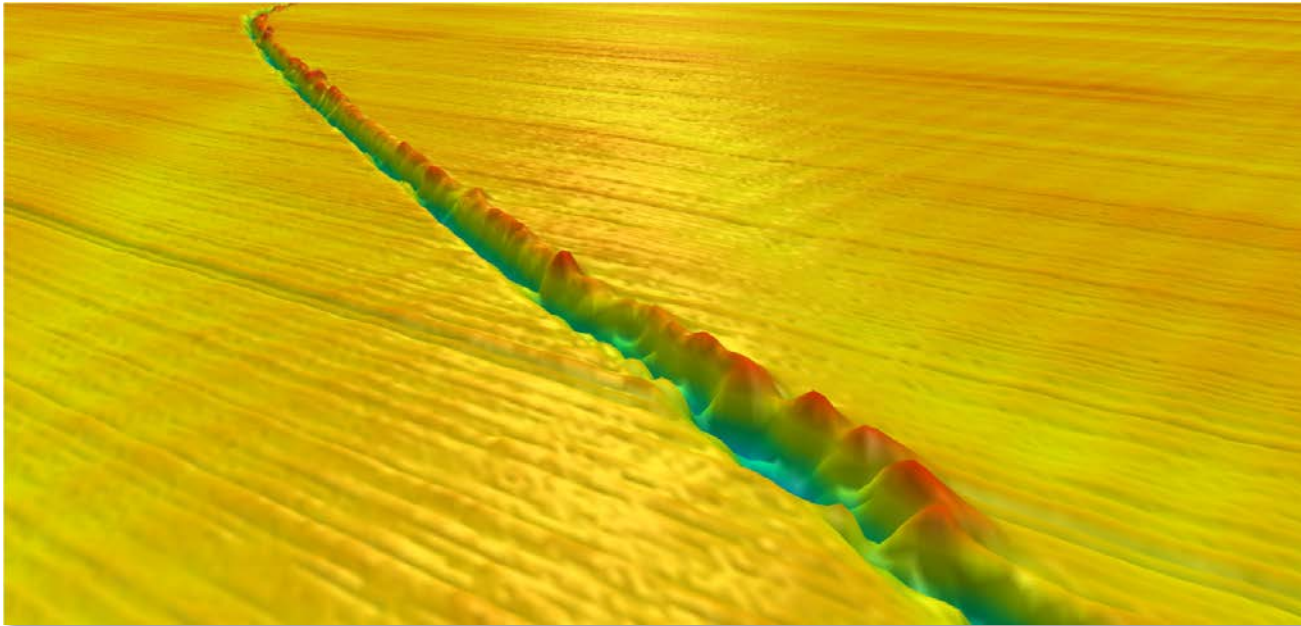
~3 µm deep scratch on glass

6.2 µm, 14.1 µm, 15.4 µm grooves on phone housing

Imaging Application: Solder Bumps

Application: Tomography of Smartphone Camera Lens Stack

Thank You!