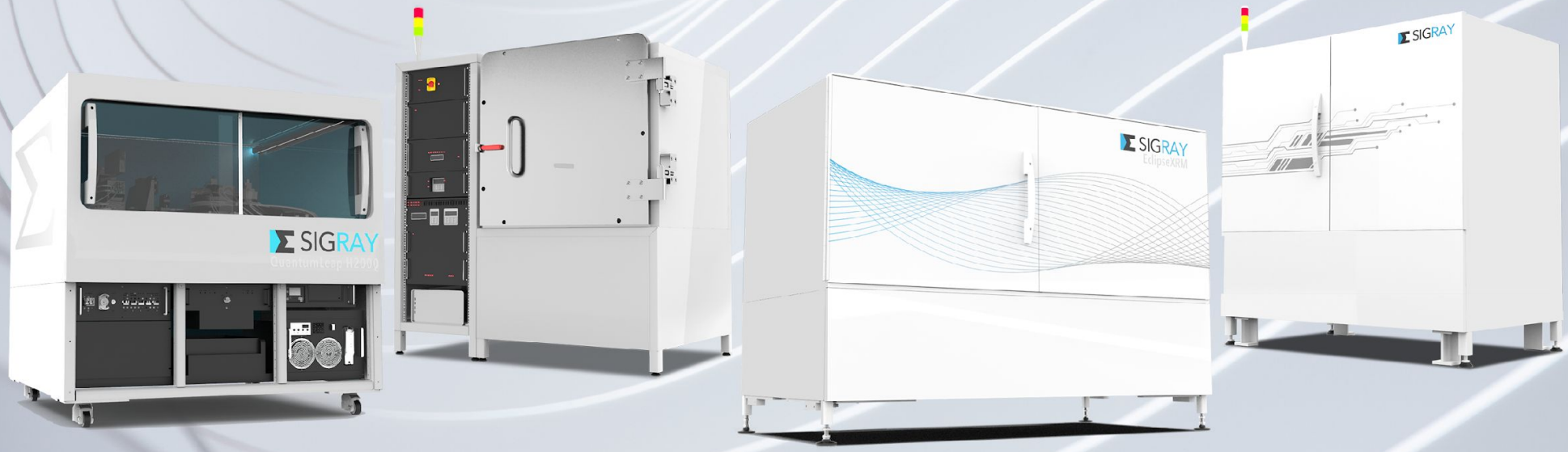
Advanced X-Ray Imaging Technologies

For Heterogeneous 3D IC Package Metrology and Inspection

SIGRAY



Jeff Gelb
Director, X-Ray Microscopy
August 21, 2024

Founded in 2013

- Dr. Wenbing Yun (OSA Fellow and serial entrepreneur that founded Xradia, now Carl Zeiss X-ray Microscopy) and Sylvia Lewis

Our Technology:

- Strong IP: 64 patents, 30+ pending, many trade secrets
- Disruptive x-ray components (source & optics)
- 5 world leading product families

Rapidly Growing:

- 34k sq. ft. facility in Concord, CA (San Francisco Bay Area) and 82 employees
- Global installation base of leading universities and companies (semiconductor & pharma)

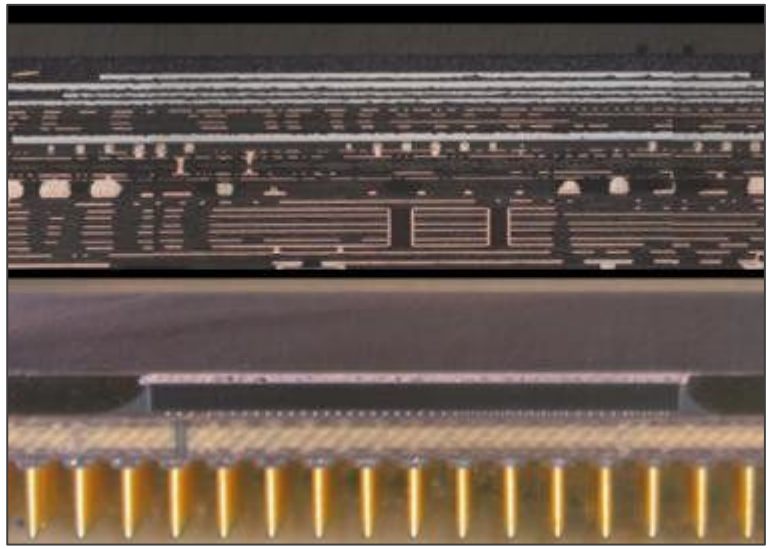
Intro to Sigray

Mission: Bring next-generation X-ray technologies to semi FA labs

Modern Challenges in Defect Detection

For Failure Analysis Labs & In-Line Inspection

- Inspect Multiple Layers of **Buried Structures** (Opaque/3D)
- Device Features rapidly Shrinking… Microbumps < 10 um, TSV ~ few microns with **defect sizes in submicron**
- **Inspection time** has to be compatible with in-line metrology
- **Non destructive**



Current Solutions

Optical Metrology

Buried/Opaque

Scanning Acoustic (SAM)

Multilayers/3D

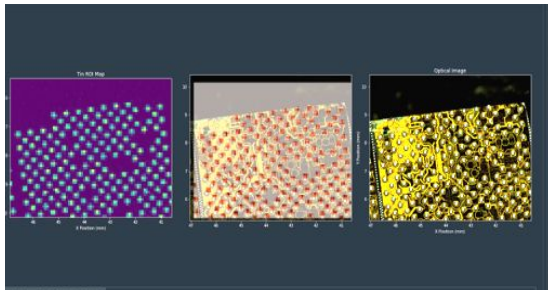
X-ray imaging

Resolution Limited, 3D too slow

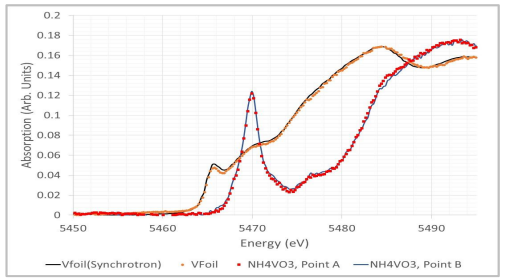
2D ⟵ 3D

Next-Generation X-Ray Systems from Sigray

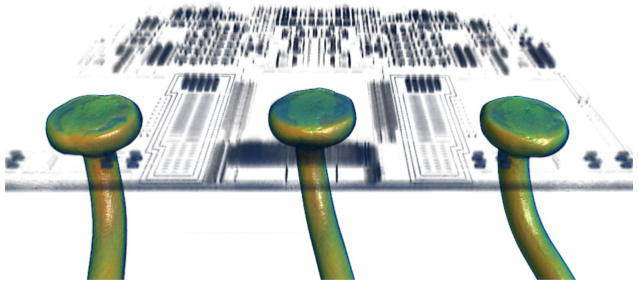
AttoMap microXRF
Highest sensitivity to low Z
Highest resolution microXRF

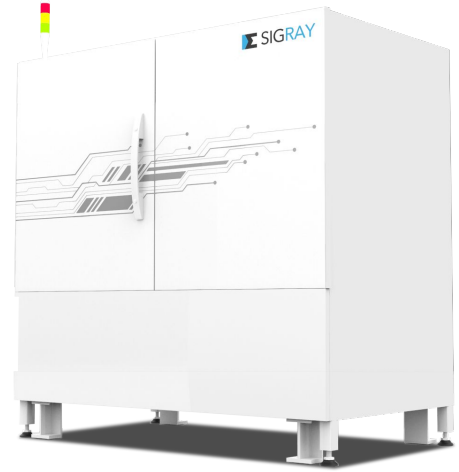


QuantumLeap XAS
Only commercial f-XAS
Highest quality EXAFS

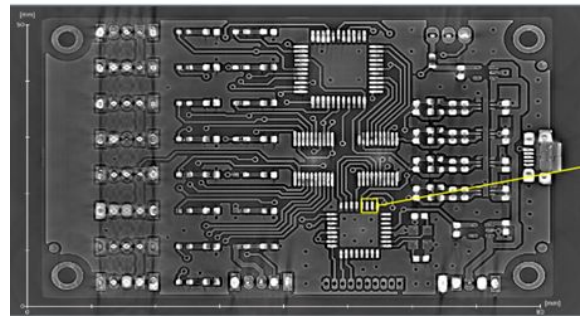


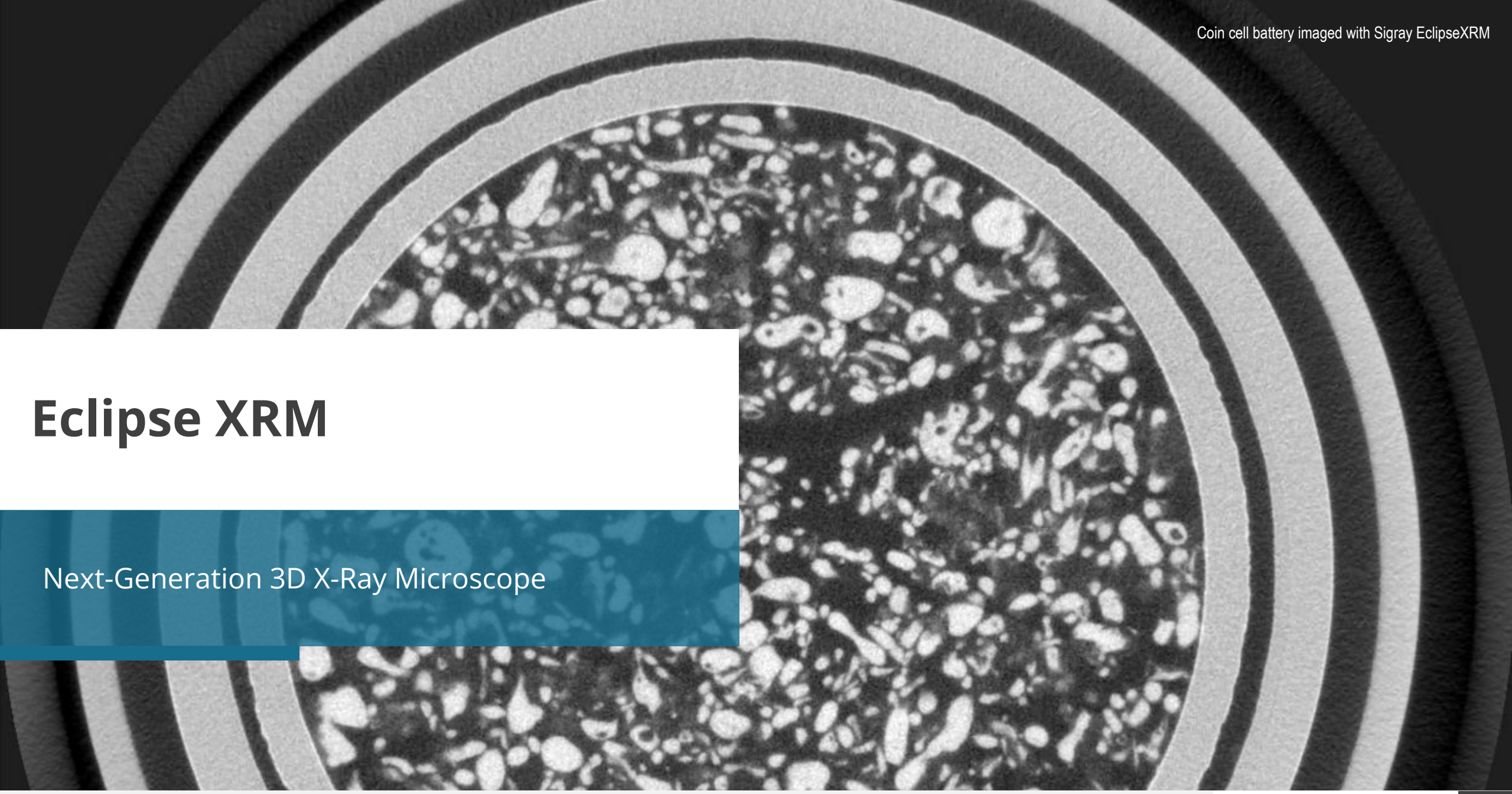
EclipseXRM
Highest resolution (0.3µm spatial) 3D x-ray microscope on the market





Apex XCT
Highest throughput 3D x-ray tool (>1000X) for semi





Coin cell battery imaged with Sigray EclipseXRM

Eclipse XRM

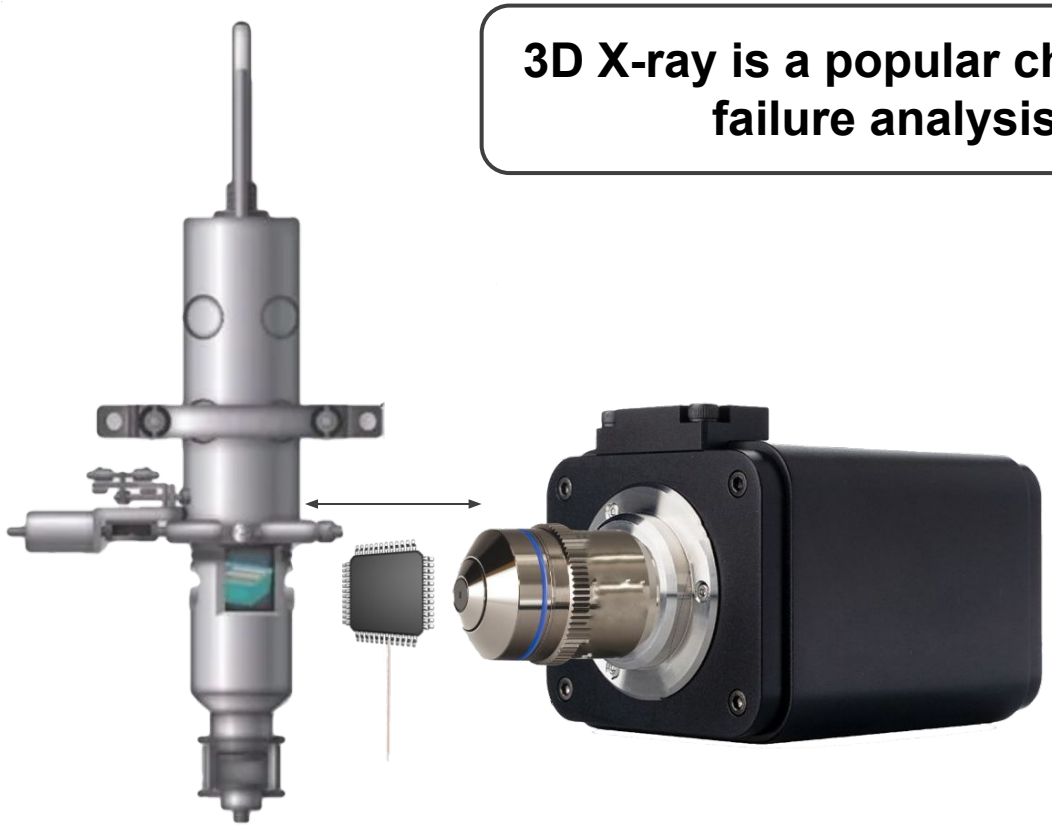
Next-Generation 3D X-Ray Microscope

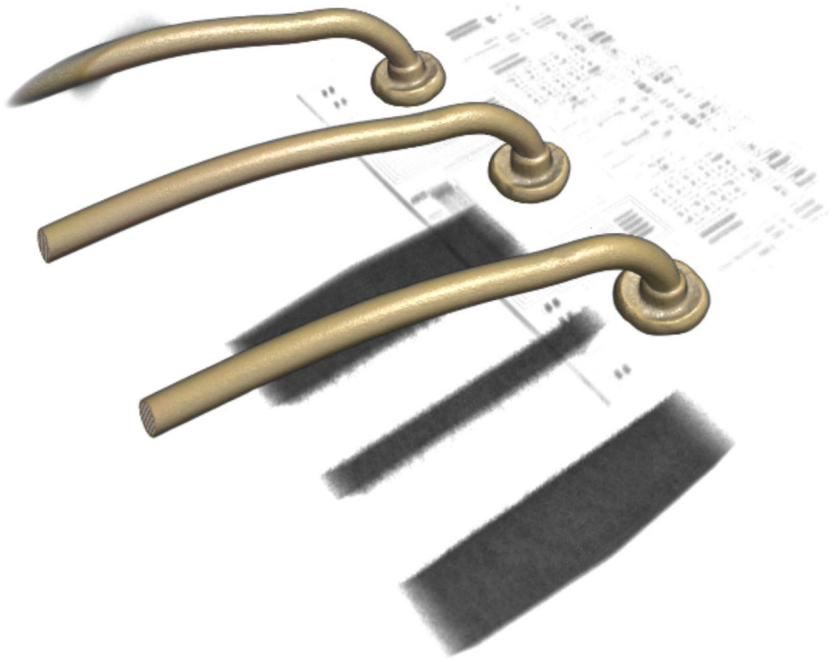
SIGRAY

XCT: An Essential Tool for Semi FA

Flexible, Non-Destructive Part Inspection

3D X-ray is a popular choice for non-destructive failure analysis of chips & dies.



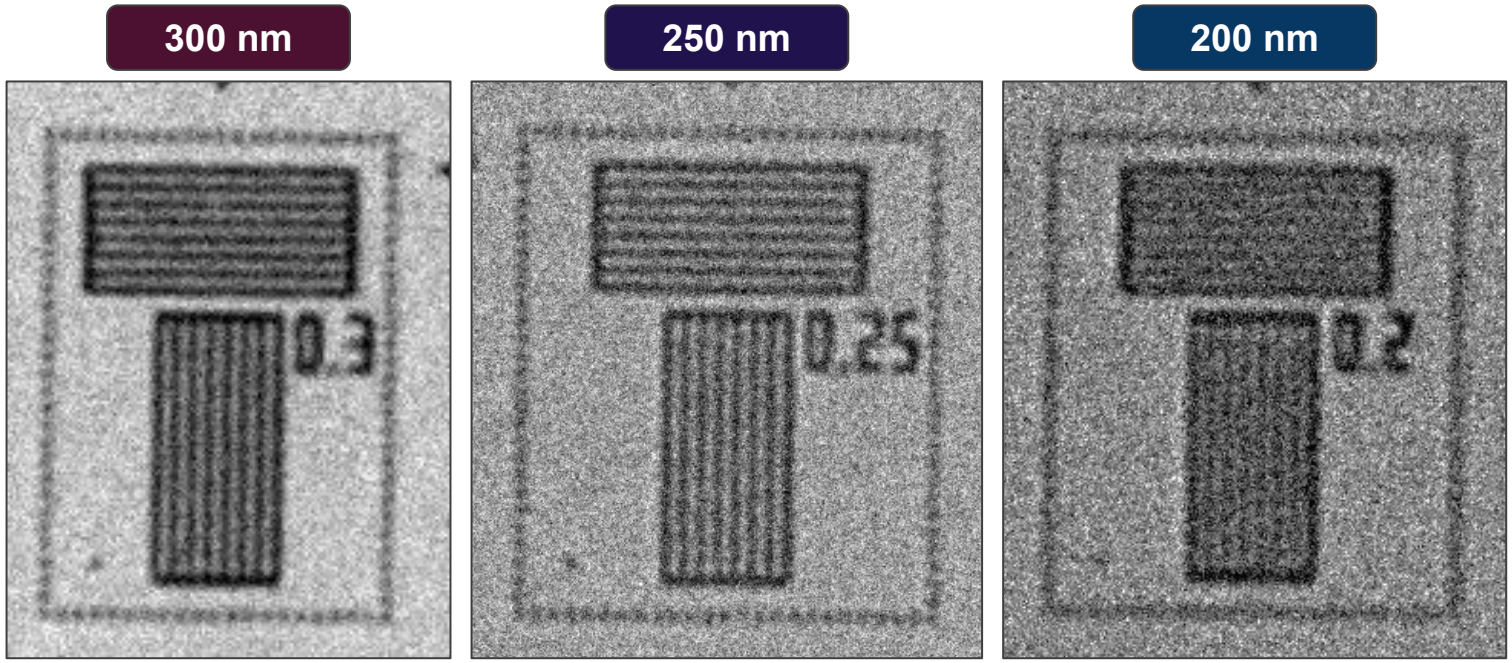


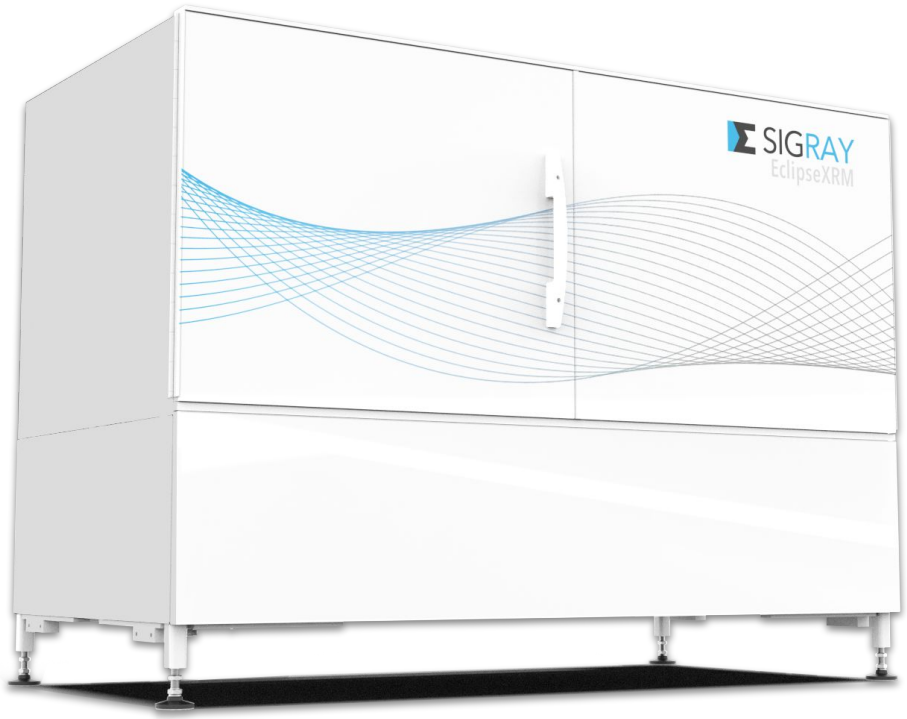
Eclipse XRM: A Revolution in Resolution

Major Architecture and System Changes for 300 nm Resolution

Highest Resolution Performance

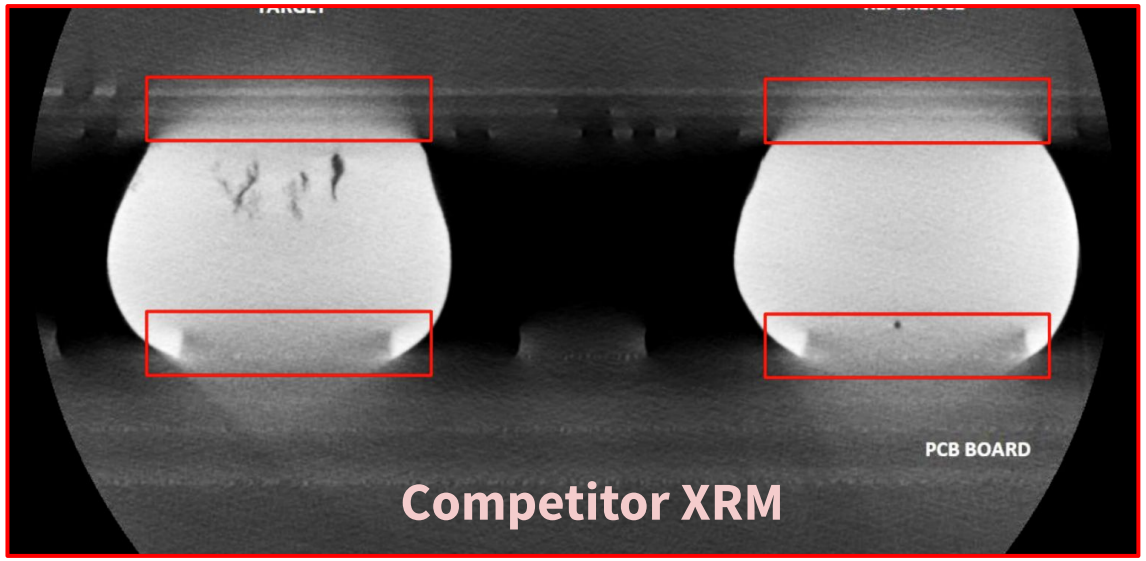
- 0.3 µm (300 nm) Resolution
- 0.7 µm at large working distances

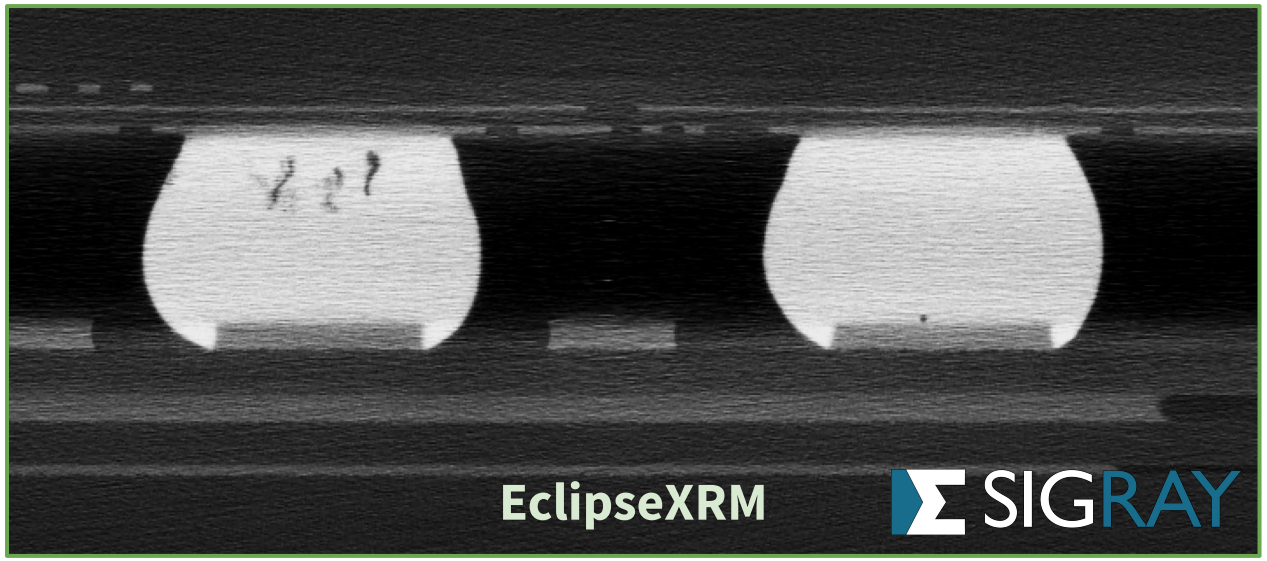


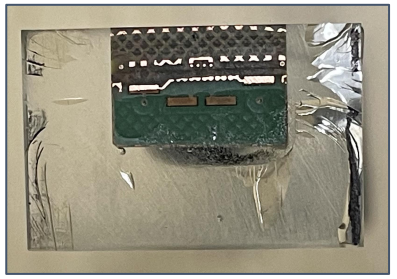


BGA Delamination Study: Semi FA

Clear Images, Superior to Competition | **EclipseXRM** with **Nanofocus Source**

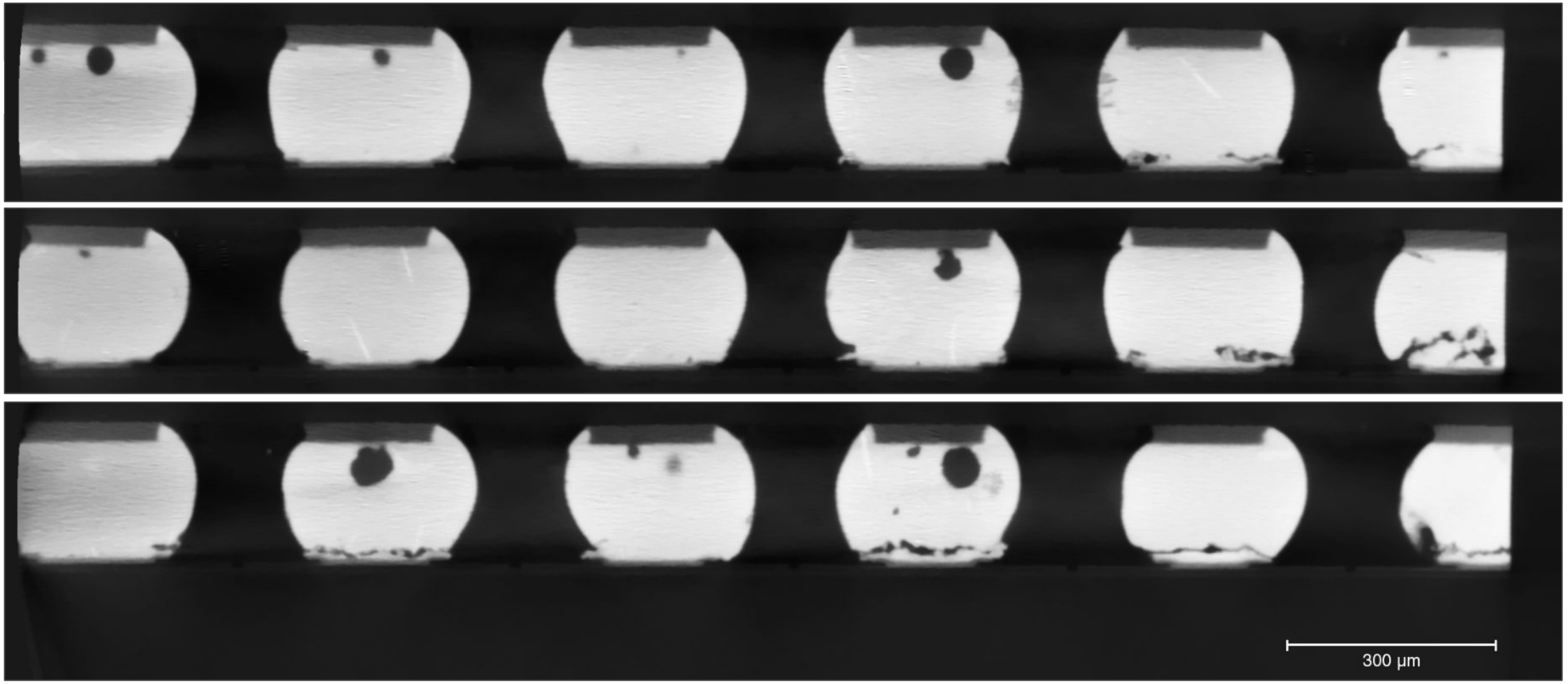






BGA Inspection in 3D

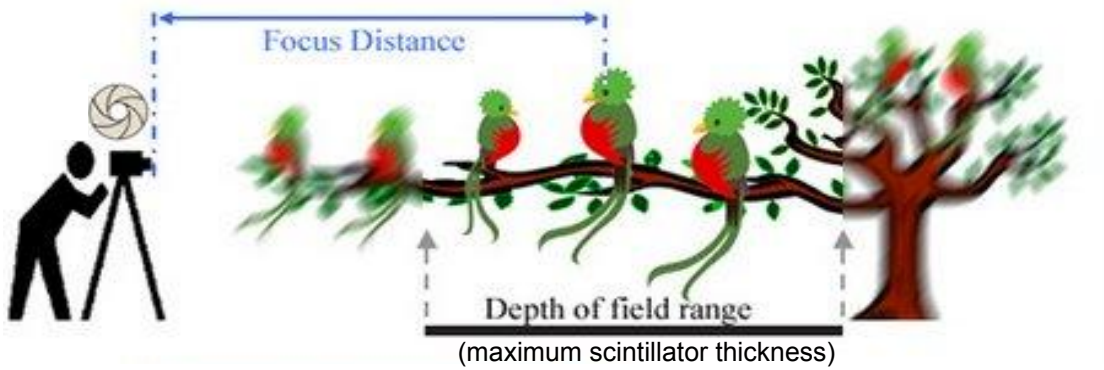
Cross-Sectional Views (Sagittal Plane) | **EclipseXRM** with **Nanofocus Source**

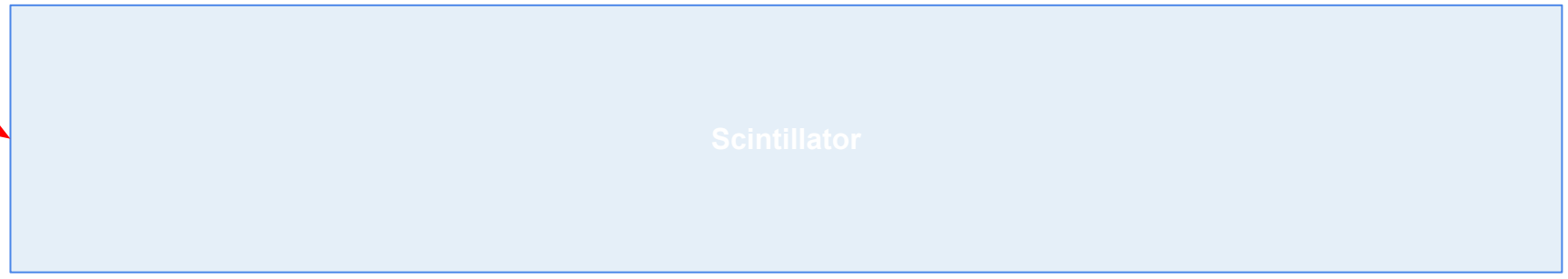


Limitations of Objective Magnification in XRM

Intrinsic Inefficiency due to Depth-Of-Field

- **Microscope objective lenses have a fixed depth of field (DOF)**
- **Images captured must be in focus → limited scintillator thickness**

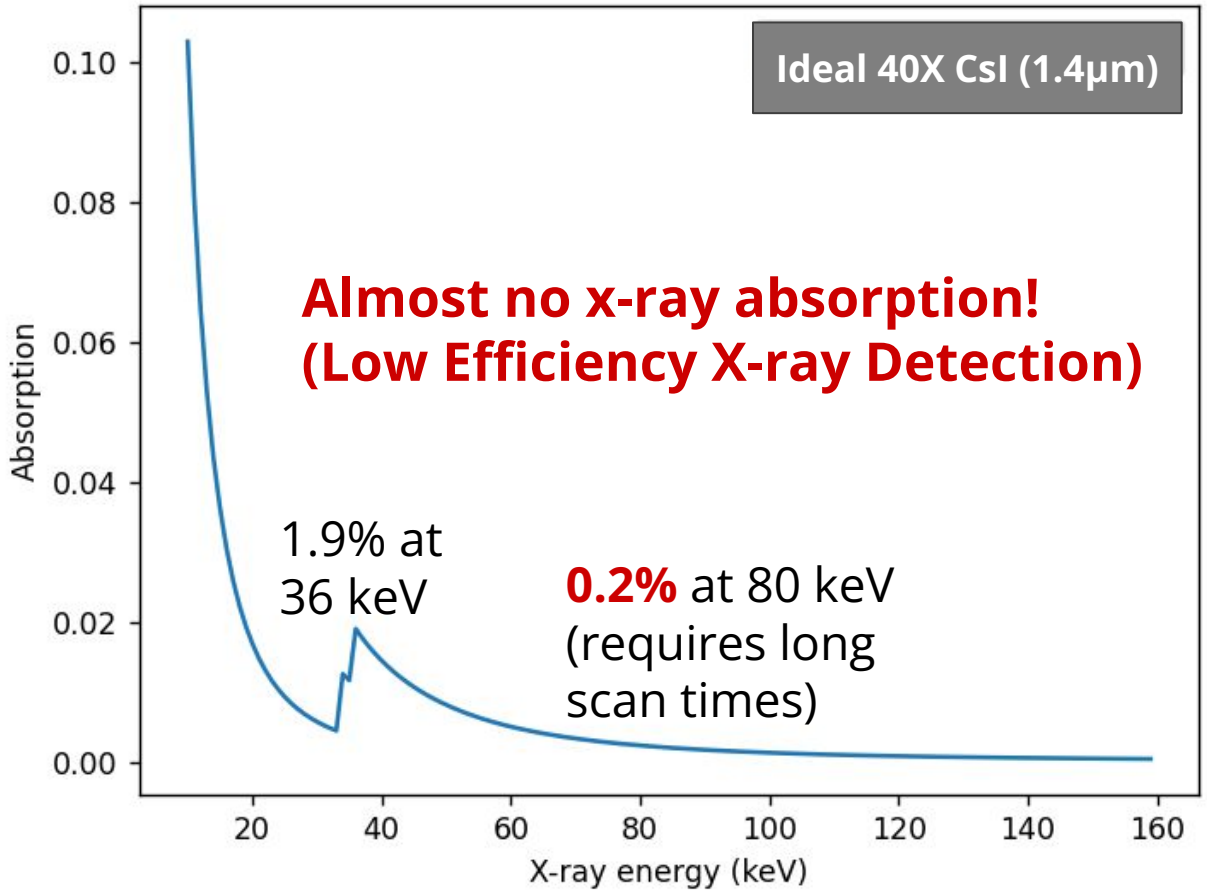




High Magnifications = Thin Scintillators

Objective	Depth of Focus
20X	3.6 µm
40X	1.4 µm

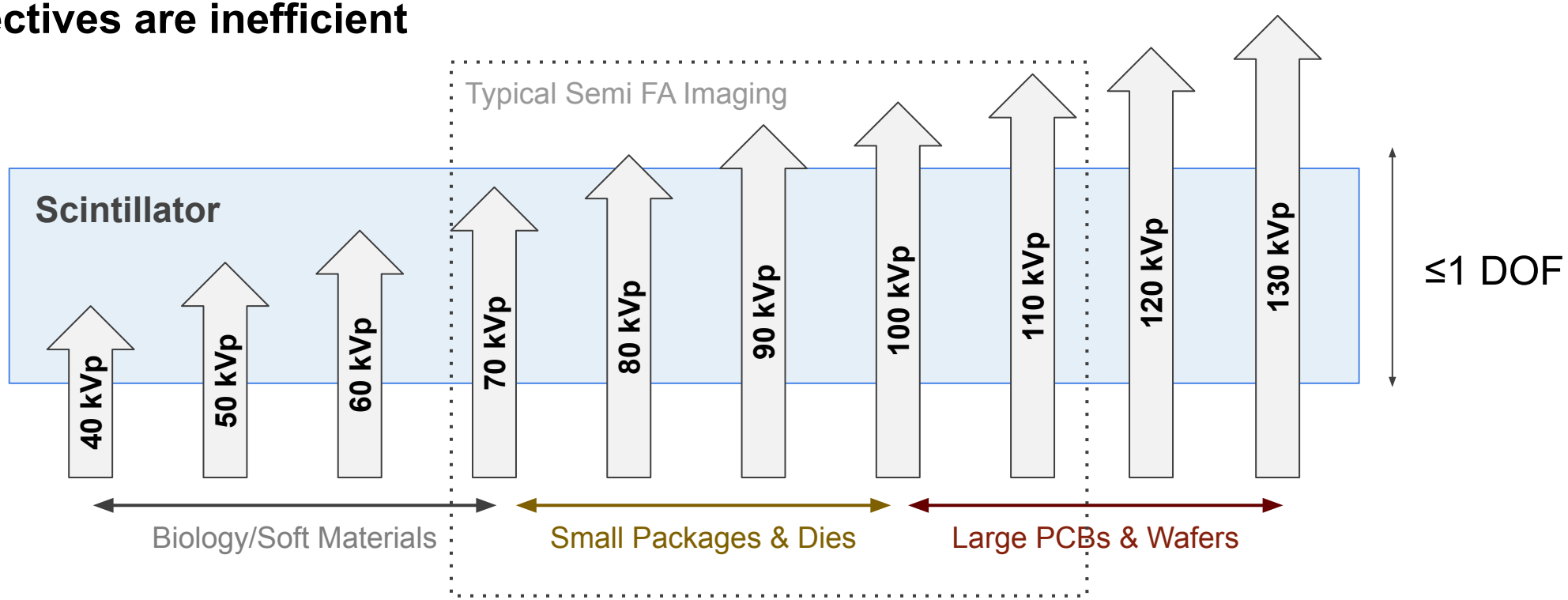
This is why we can't simply move to 60X or 100X magnifications for higher resolution



Limitations of Objective Magnification in XRM

Thin Scintillator = Small fraction of x-rays absorbed = low detector efficiency

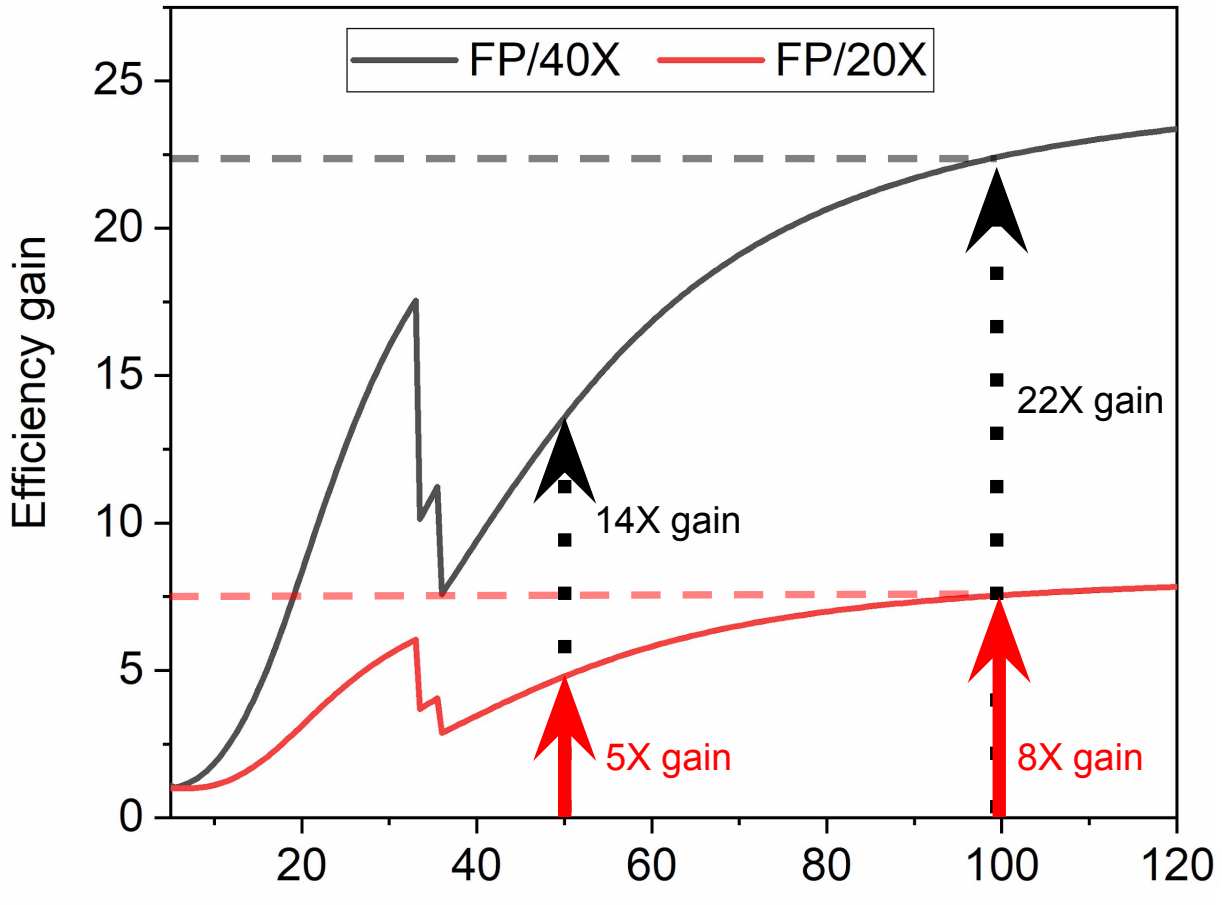
- ➔ **X-ray penetration depth varies with accelerating voltage**
- ➔ **Matching scintillator thickness to accelerating voltage → maximized SNR**
- ➔ **Semiconductor samples require high accelerating voltages → scintillator-coupled objectives are inefficient**



Industry-Leading Flat Panel Detector

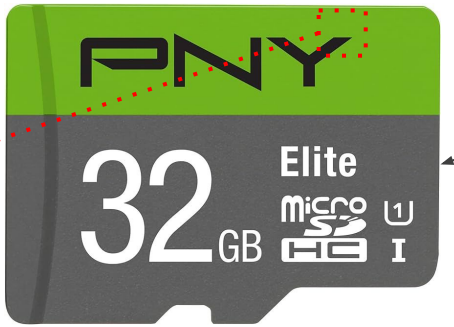
Featuring Sigray *HyperCapture* Technology for Optimized Sensitivity

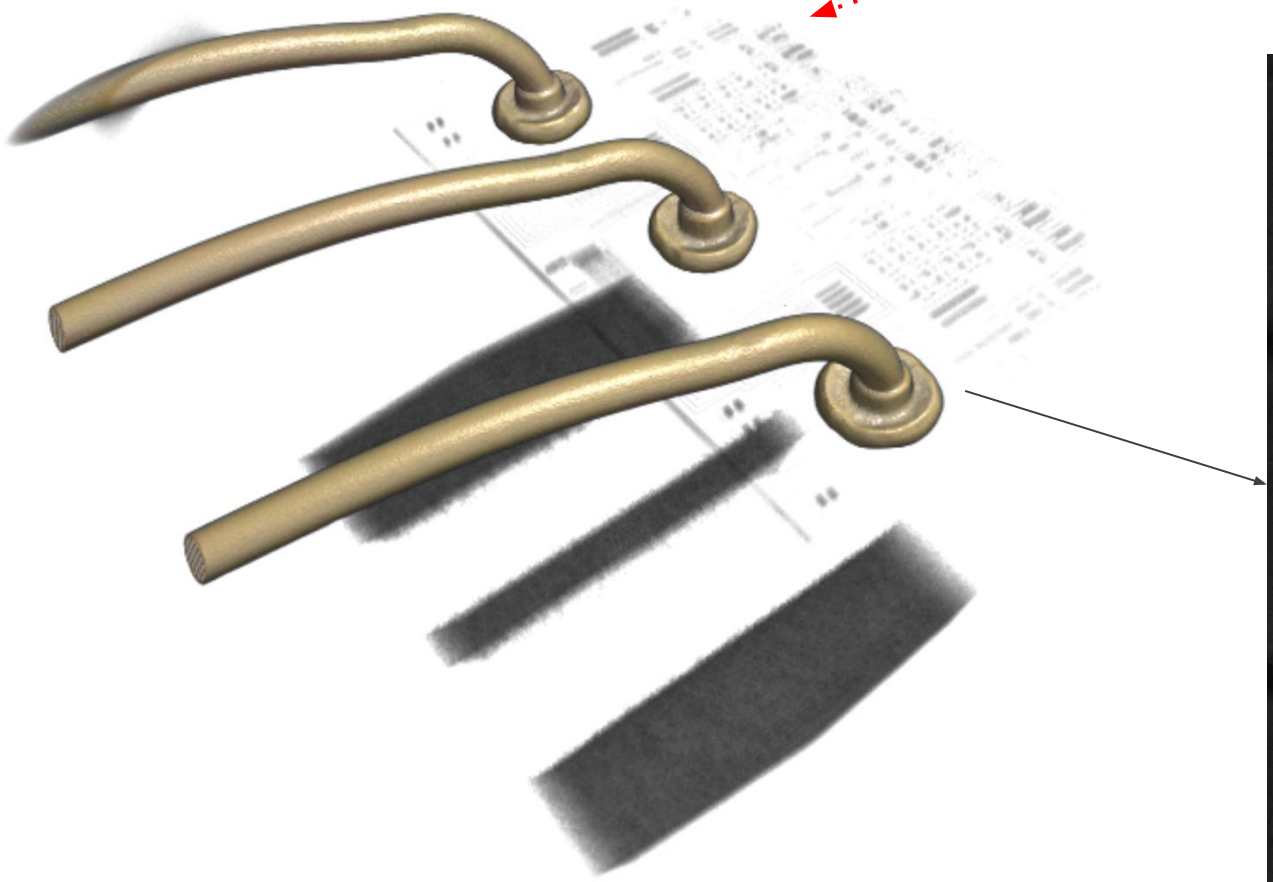
- Sigray design using flat panel detector provides up to **22x efficiency gain over objective lenses**
- Physics-based design produces **optimal results** over a range of sample types and magnification settings, with **>6 MP** of capture area
- **Optional large-format detectors** provide custom-engineered fields of view for inspecting large parts

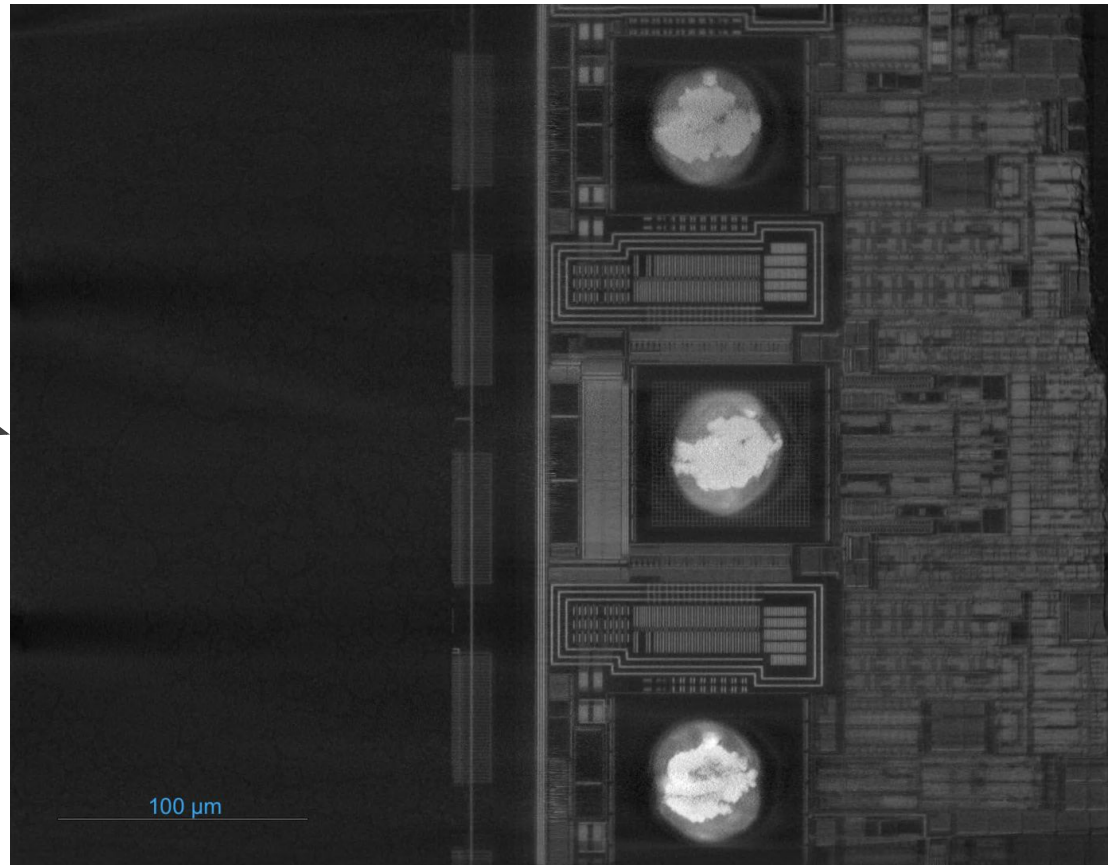


Wire Bond Inspection

Characterizing IMC @ 0.15 µm



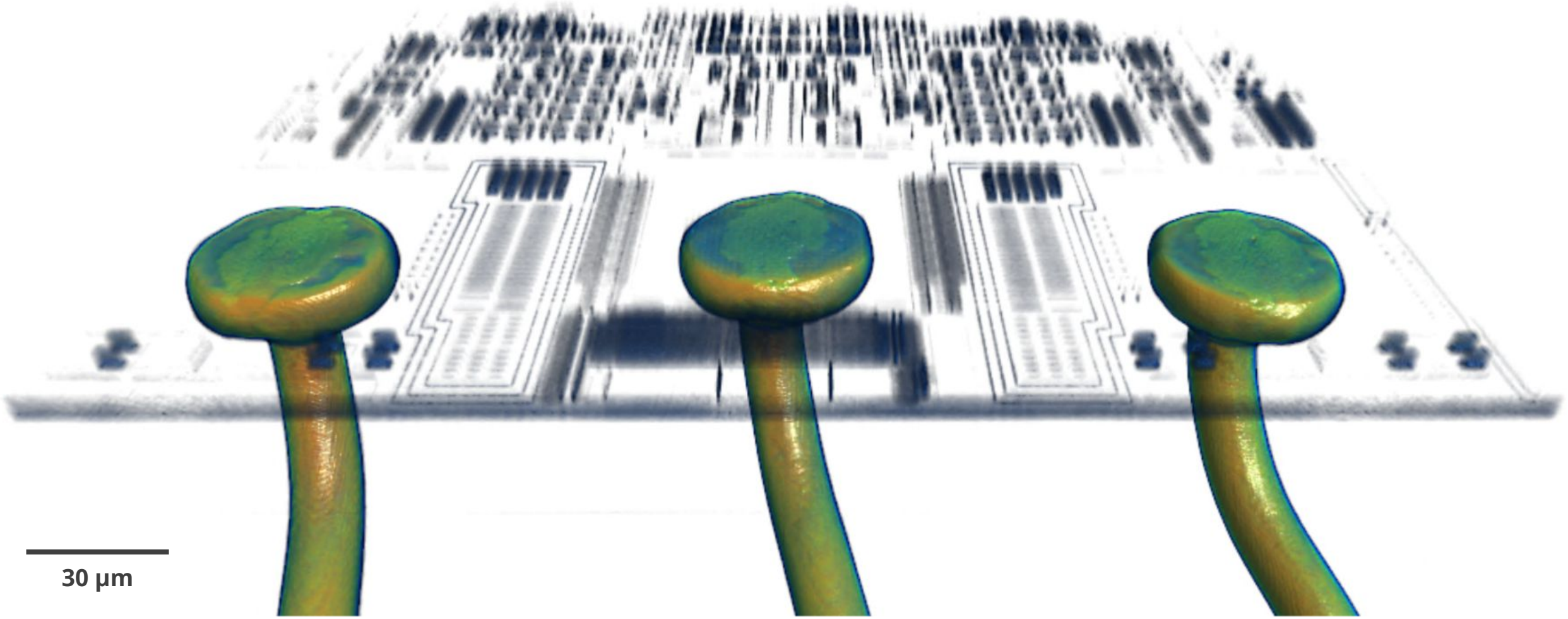




SIGRAY

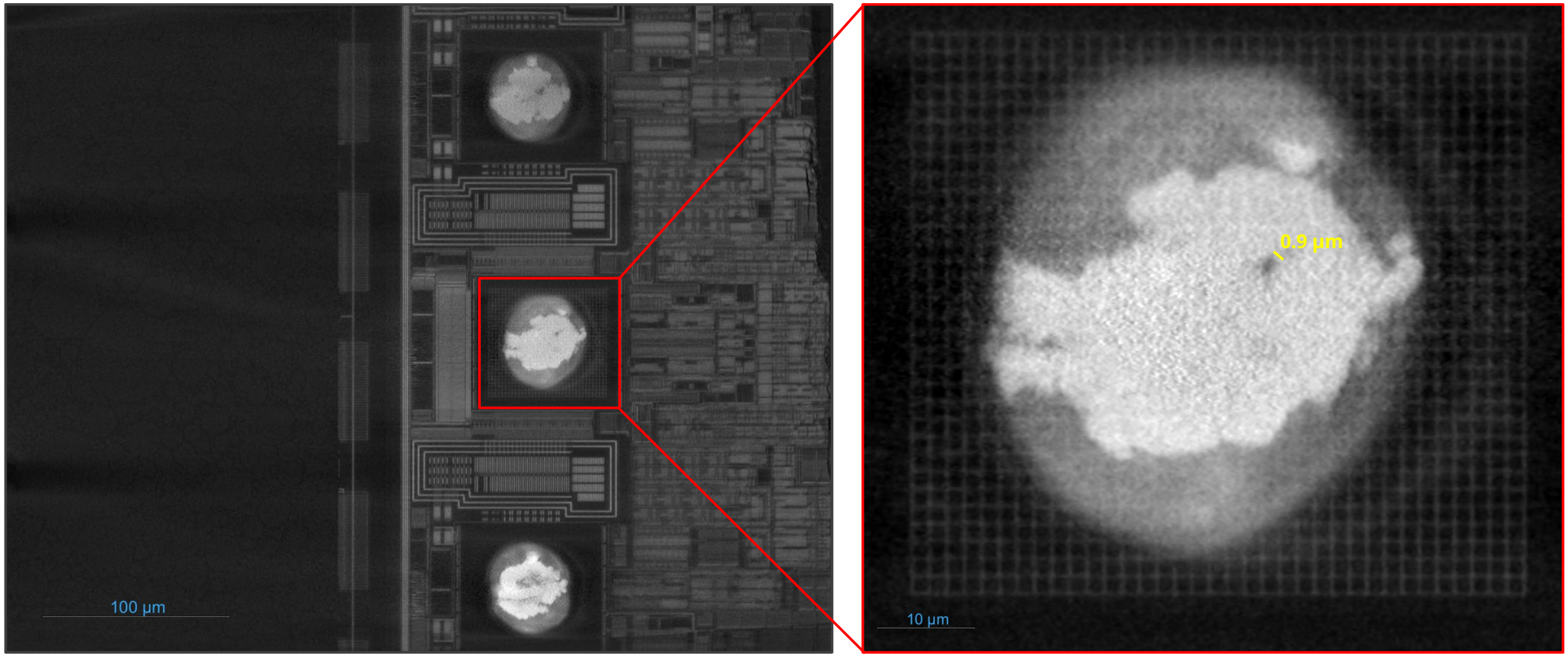
Wire Bond Inspection: 3D Rendering at Bond Interface

Visualizing IMC at Bonding Interface @ 0.15 µm



Wire Bond Inspection: Virtual Slice Analysis

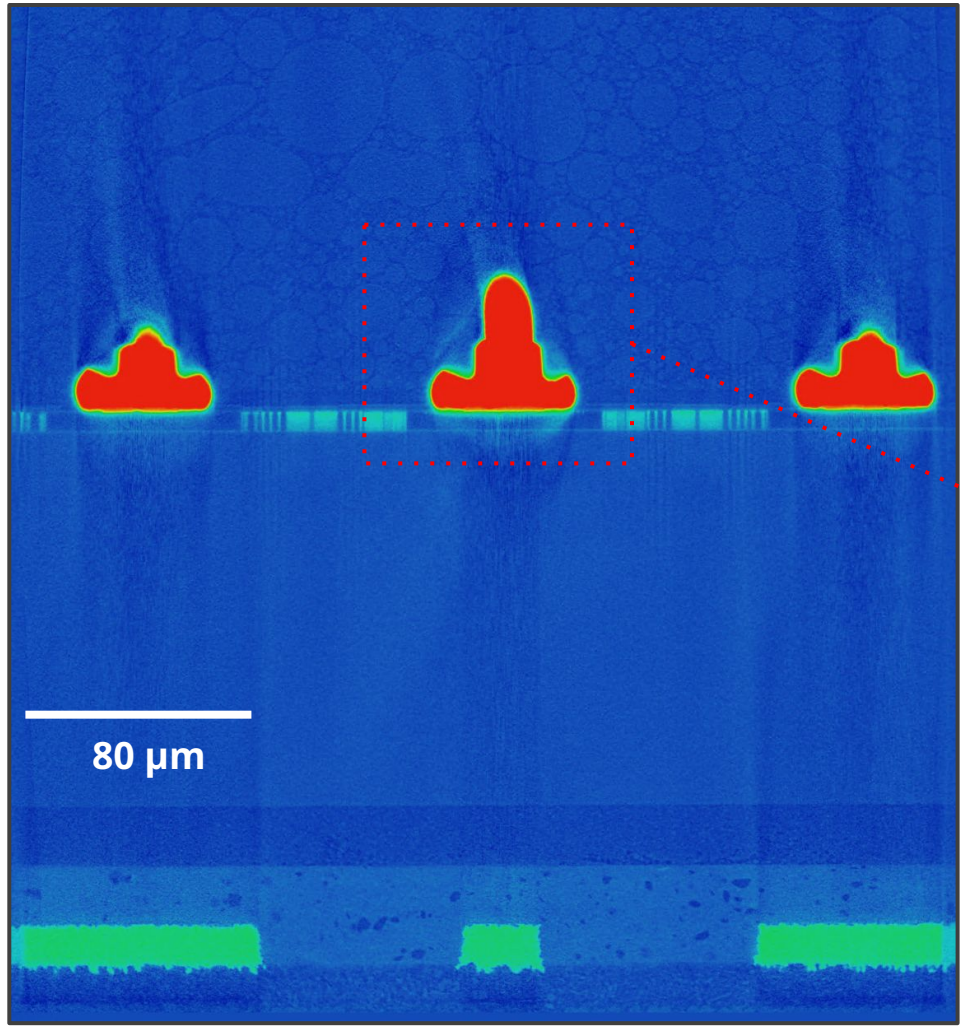
Visualizing IMC at Bonding Interface @ 0.15 µm

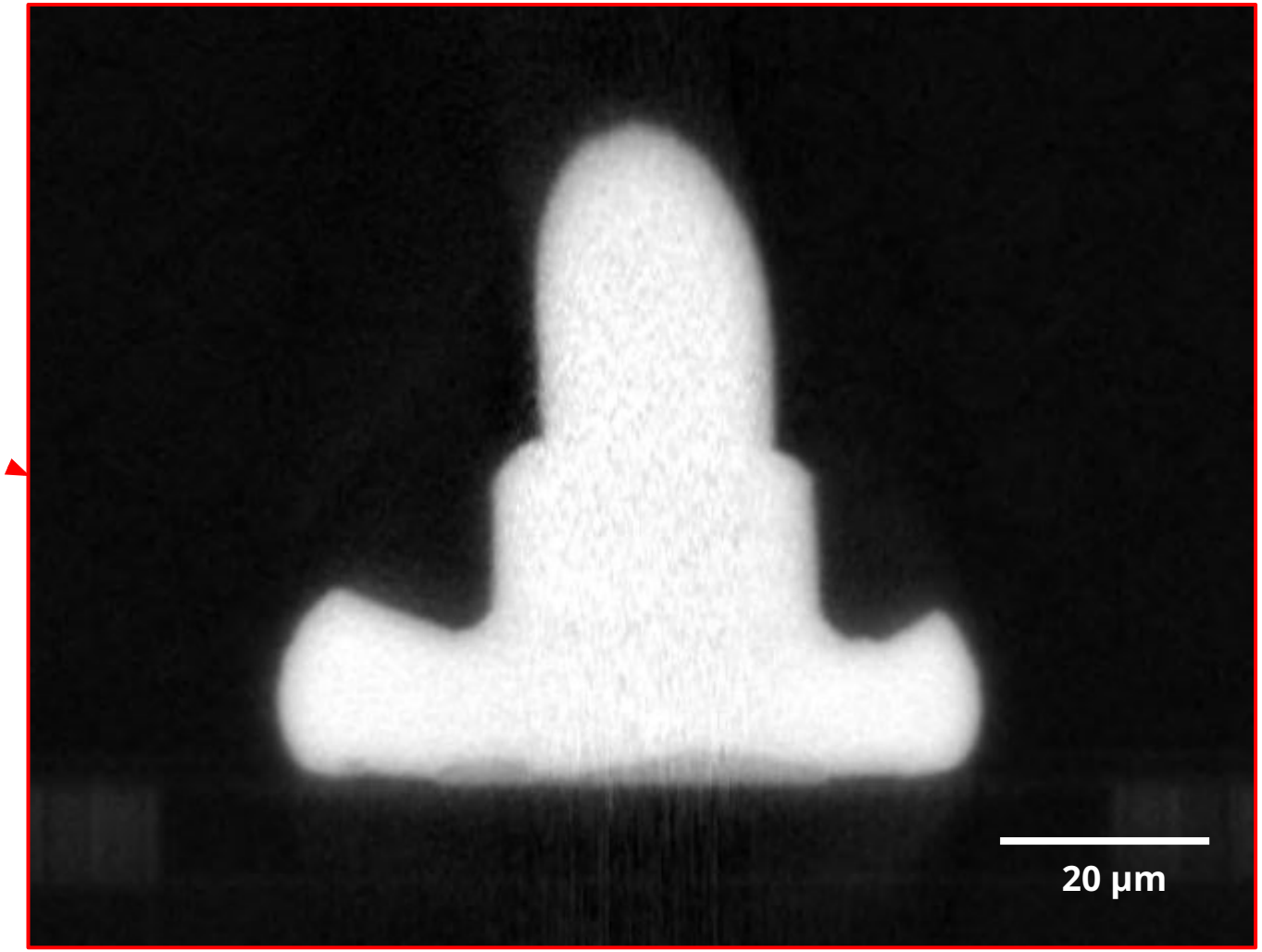


SIGRAY

Wire Bond Inspection: Virtual Slice Analysis

Visualizing IMC at Bonding Interface @ 0.15 µm

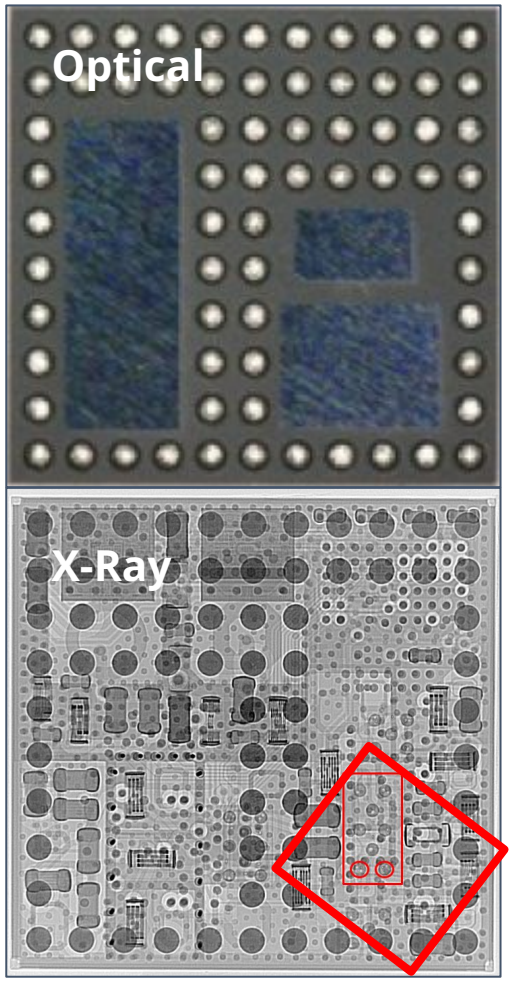




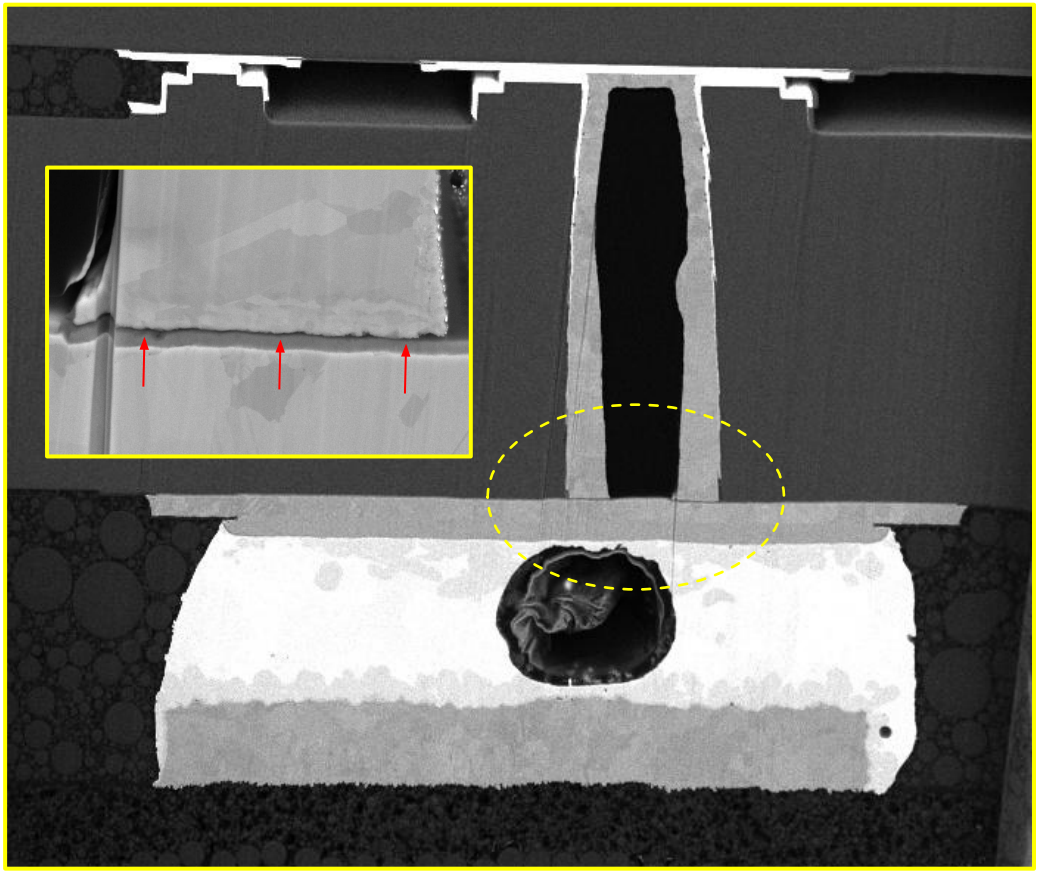
SIGRAY

Package Inspection at Via Connection

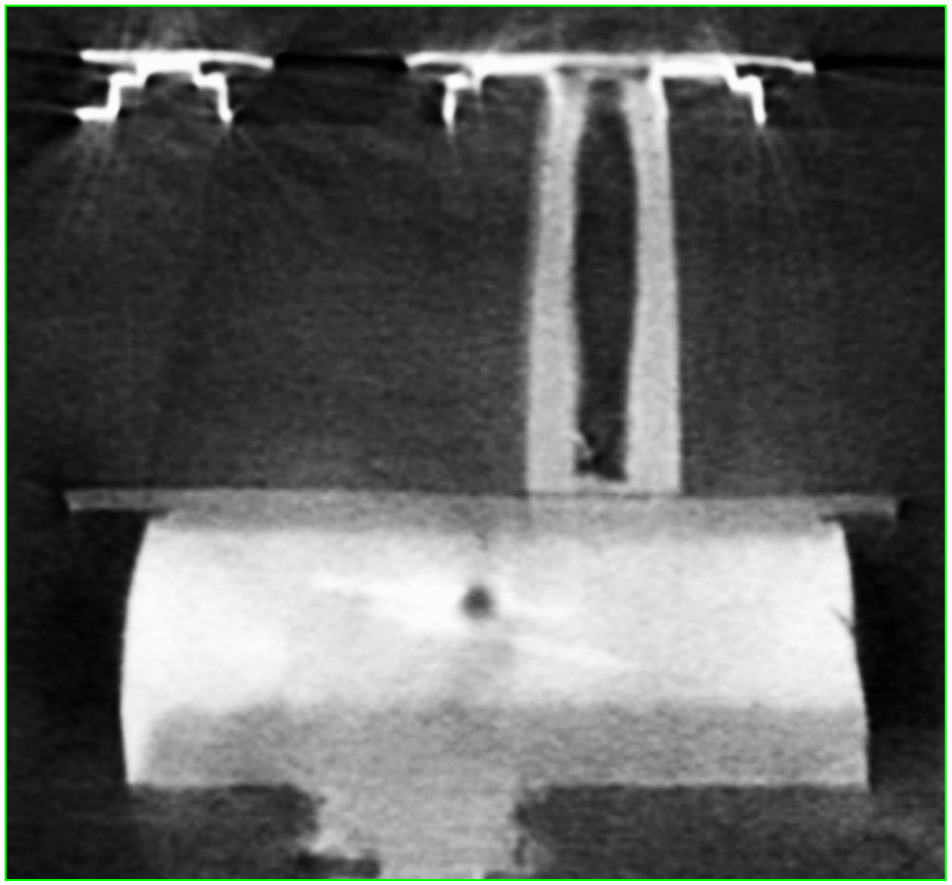
Via Interface Separation: 12 hrs @ 0.25 µm



SEM X-Sectional Image (Ex. ROI)

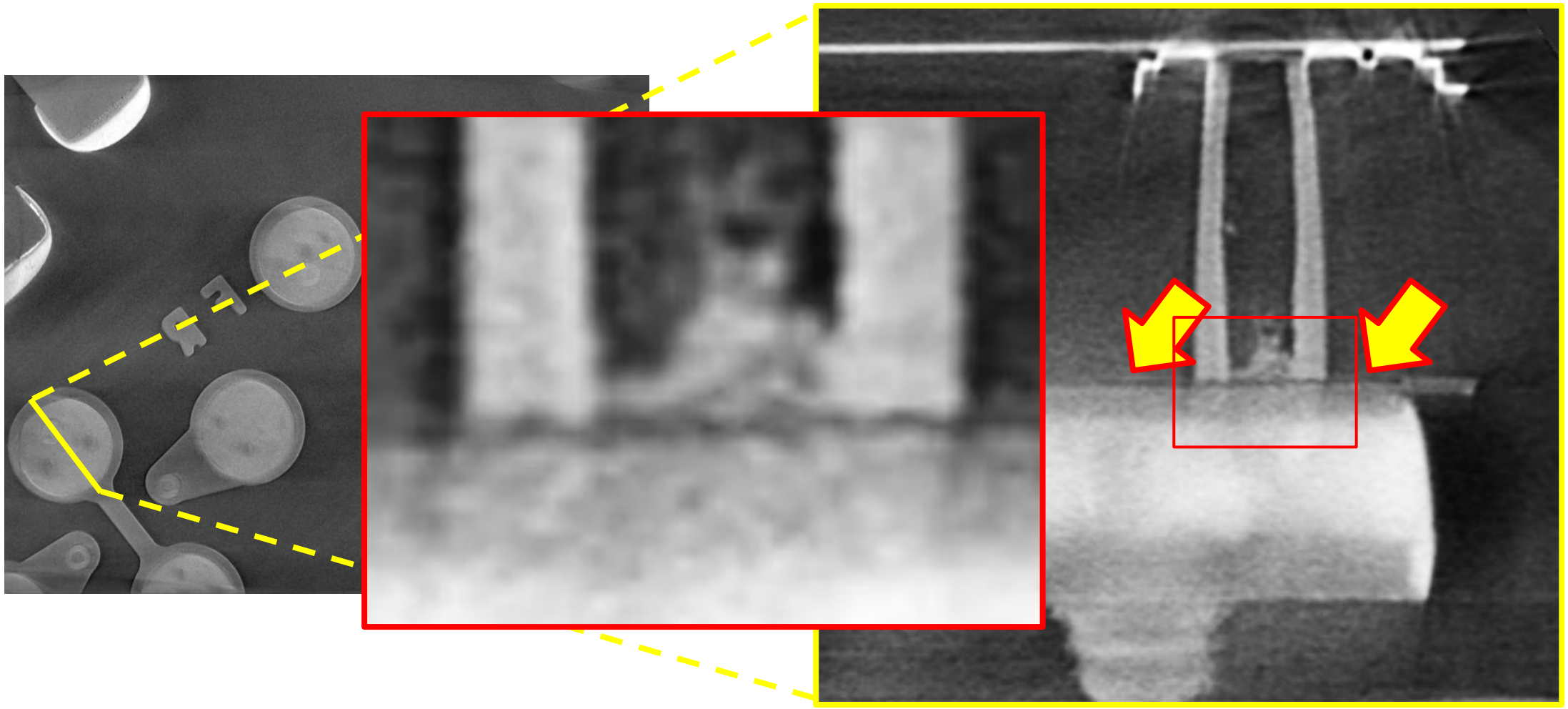


EclipseXRM @ 0.25 µm



Crack/Delamination at Via Interconnect

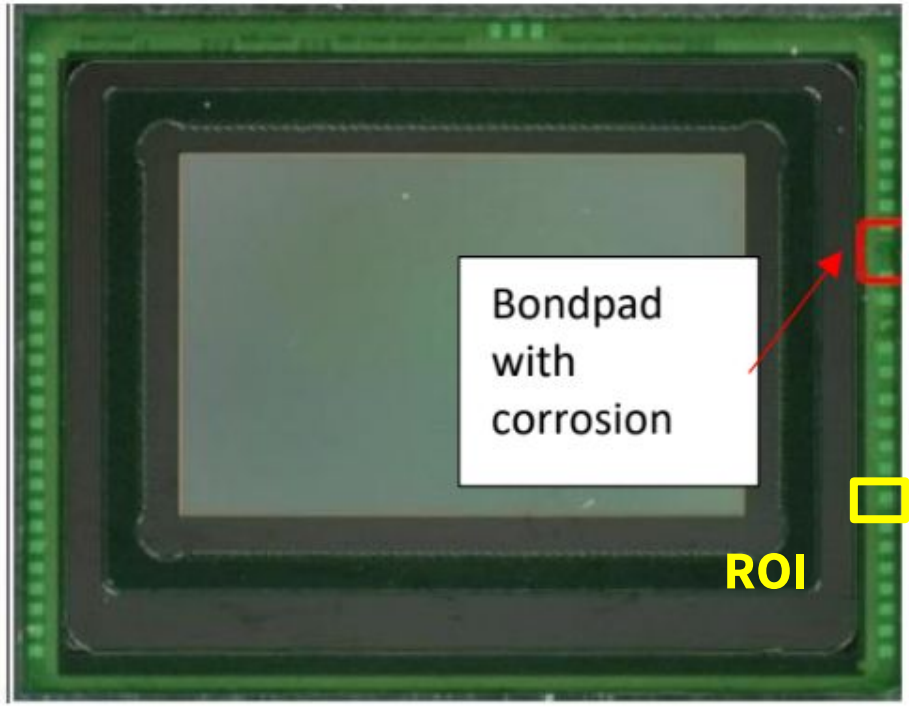
Virtual Slice Inspection: 12 hrs @ 0.25 µm

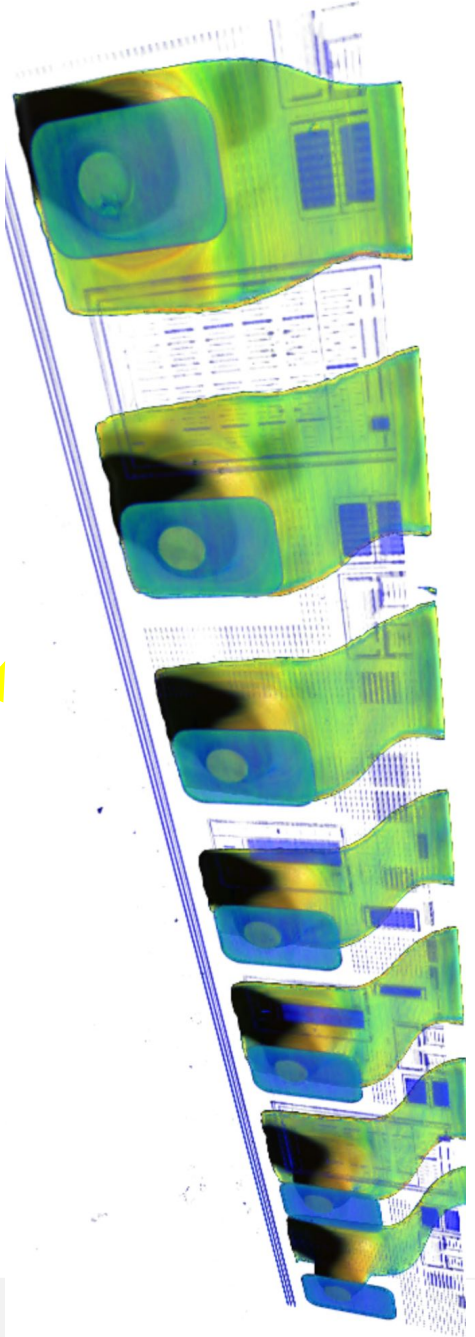


Corroded Bond Pads

EclipseXRM: 8 hhrs @ 0.37 µm

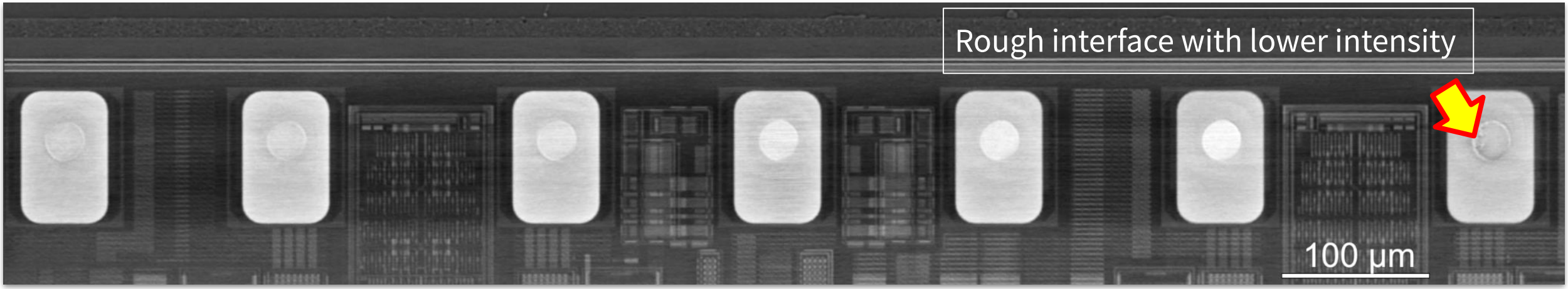
Sample	Sample 2
Total integration time	**8.0 hrs**
Voxel Size	**0.37 µm**
Field of View	**1.08 × 0.85 mm**

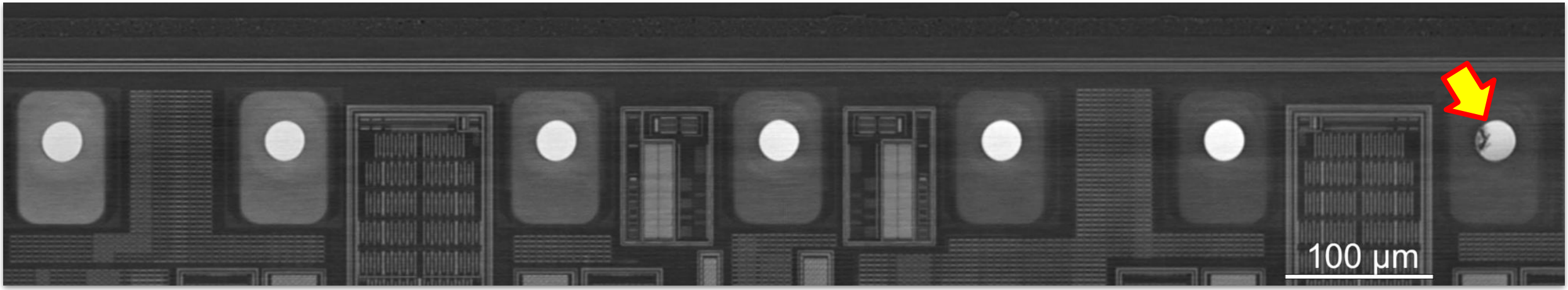




Corroded Bond Pads: Delayering View

Virtually Slicing Through the Volume

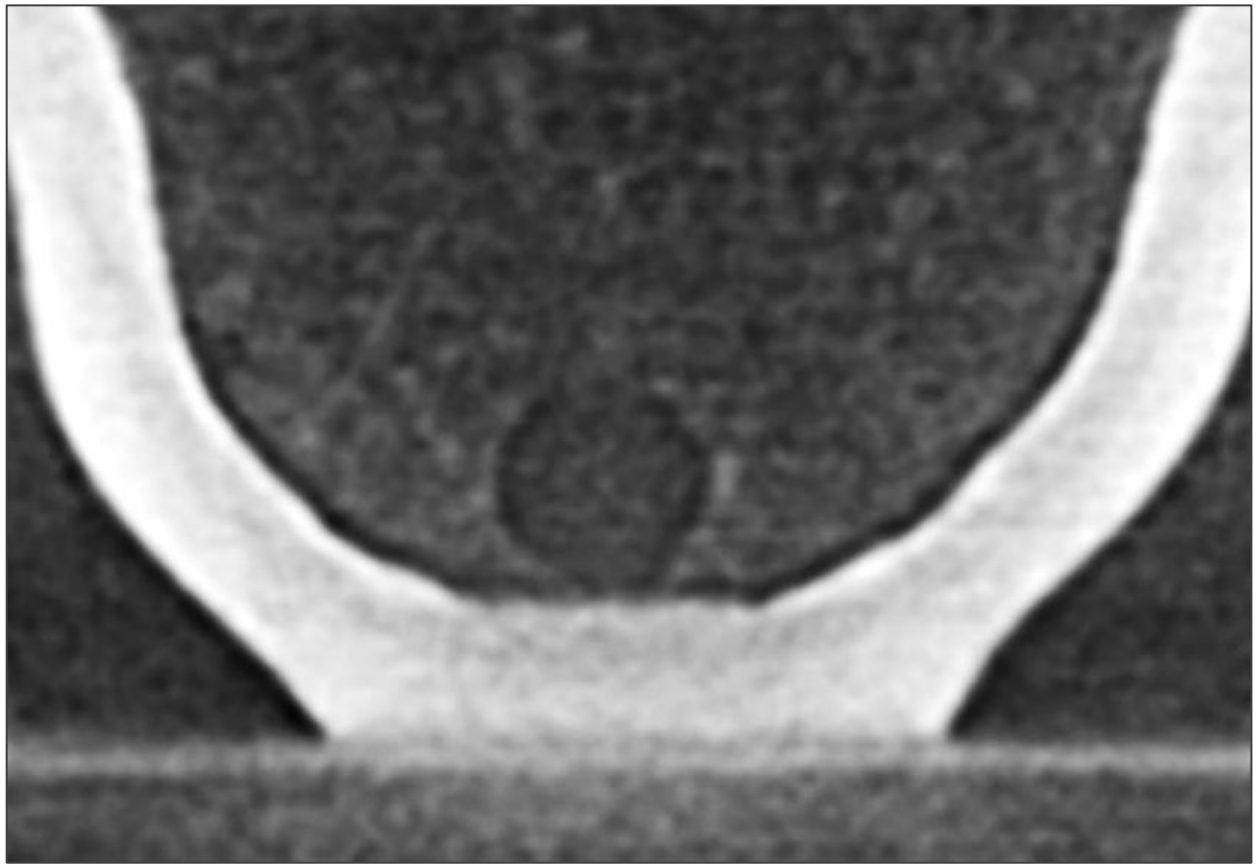




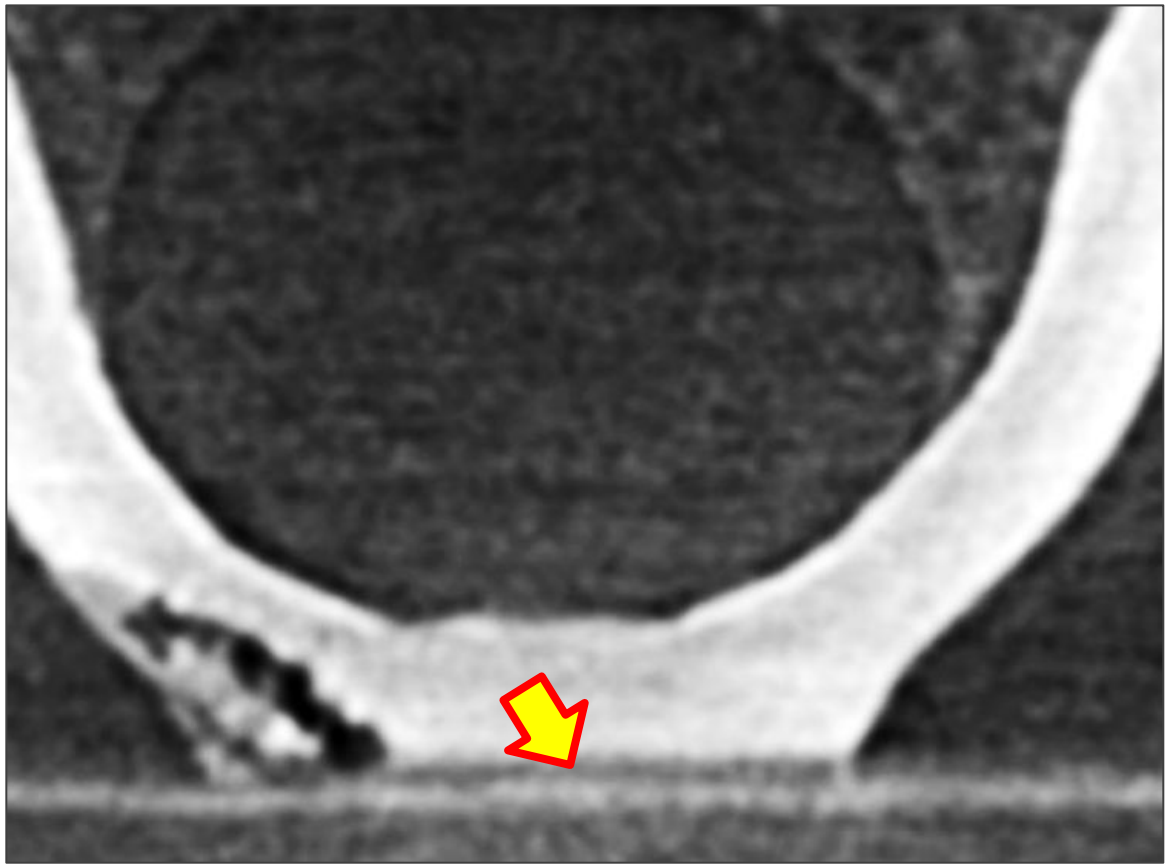
X-Sectional View: Delamination

Corroded Bond Pads: 8 hrs @ 0.37 µm

Neighbor (“Good”)



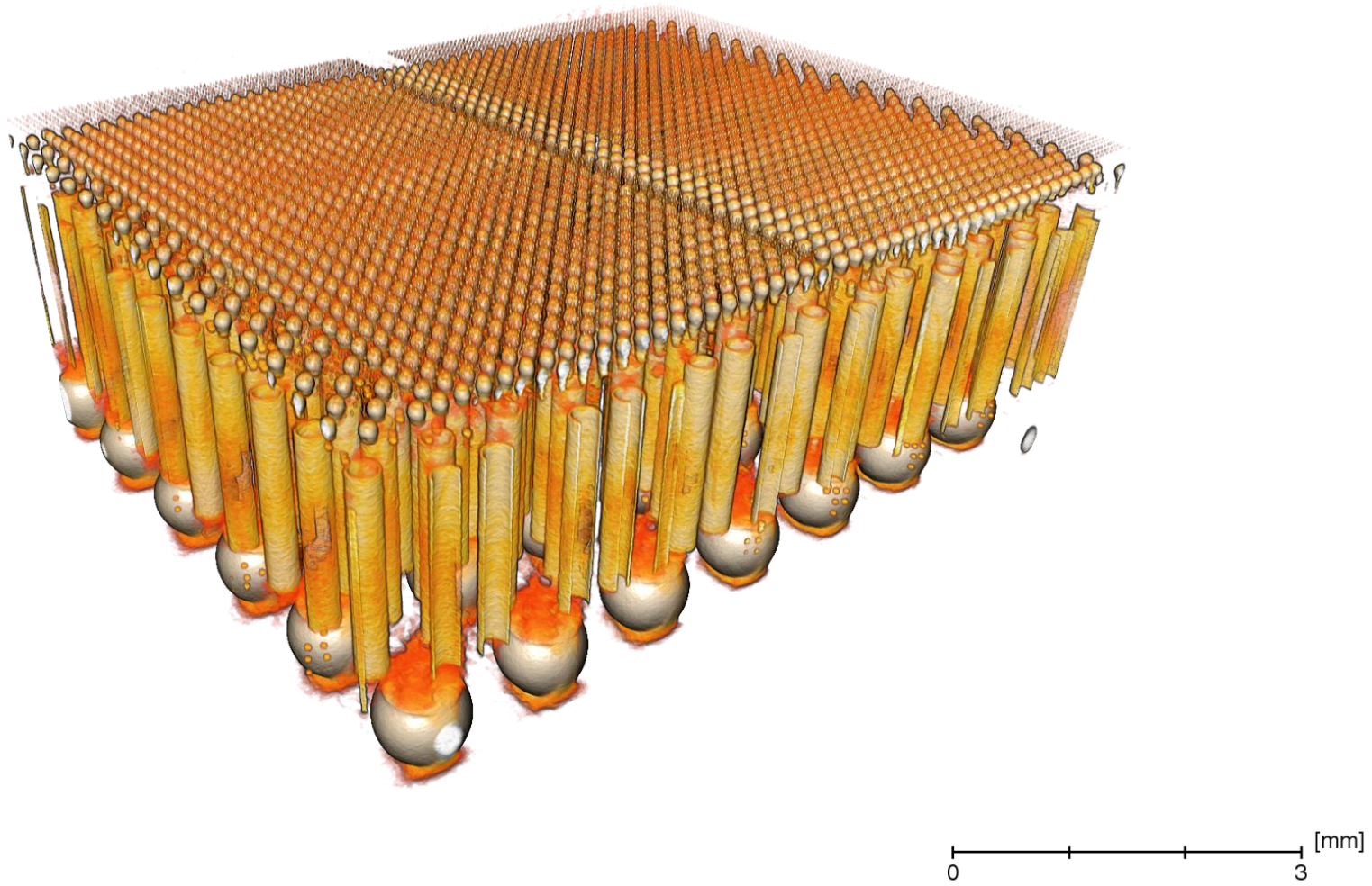
Delamination (“Bad”)



SIGRAY

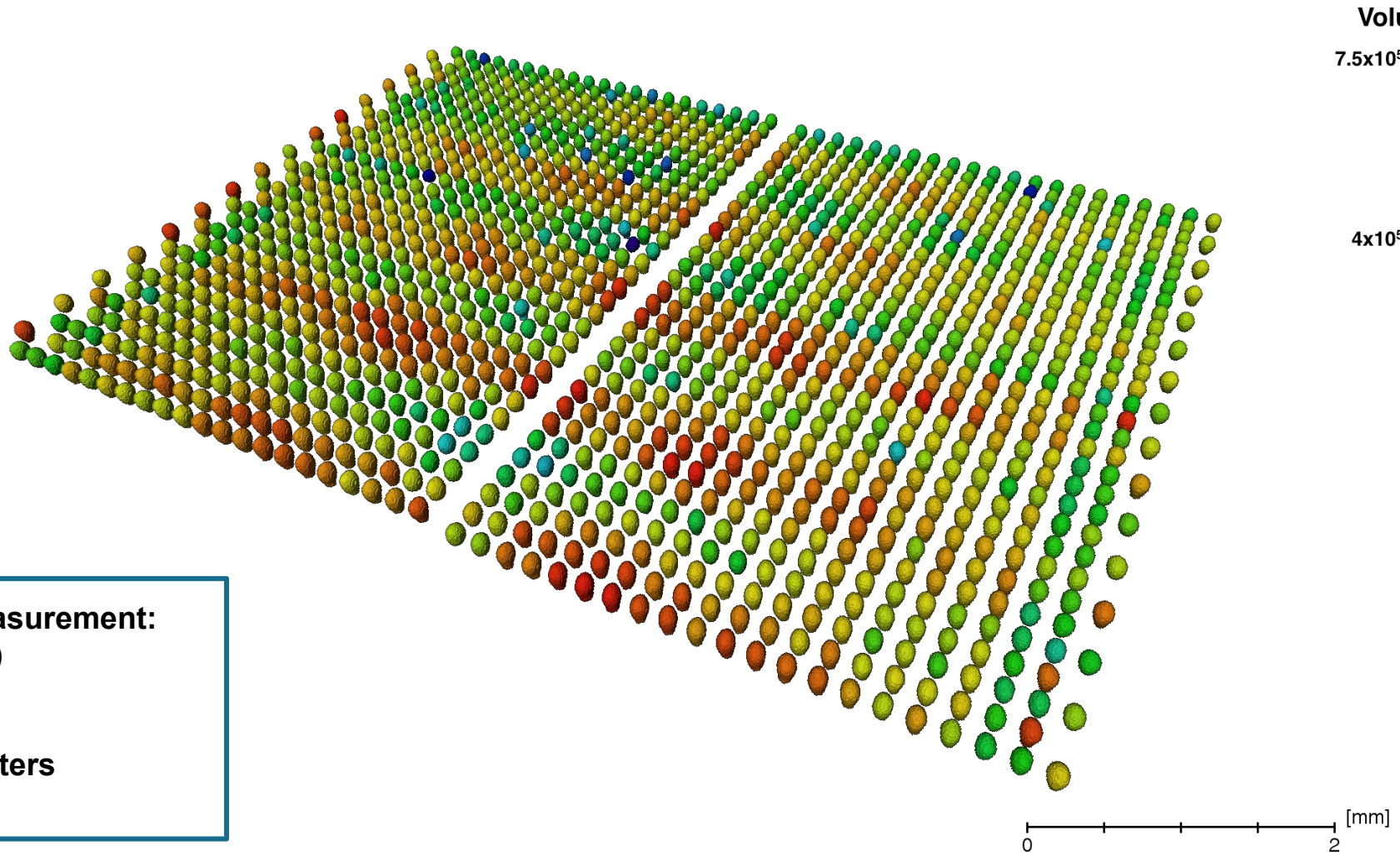
2.5D Integrated Circuit - Volume Rendering

Metal Layers Rendered in 3D (6 µm Resolution)



2.5D Integrated Circuit - Isolating Micro-Bumps

3D Rendering Color-Coded by Volume



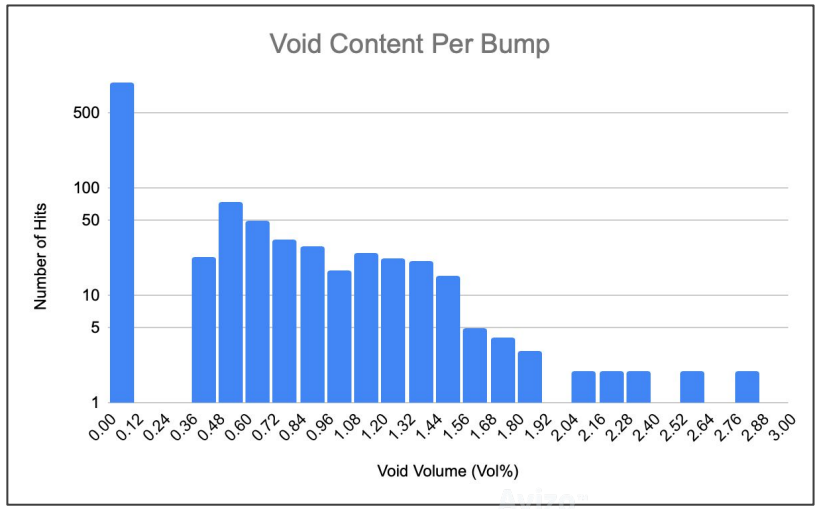
Features can be labeled by measurement:

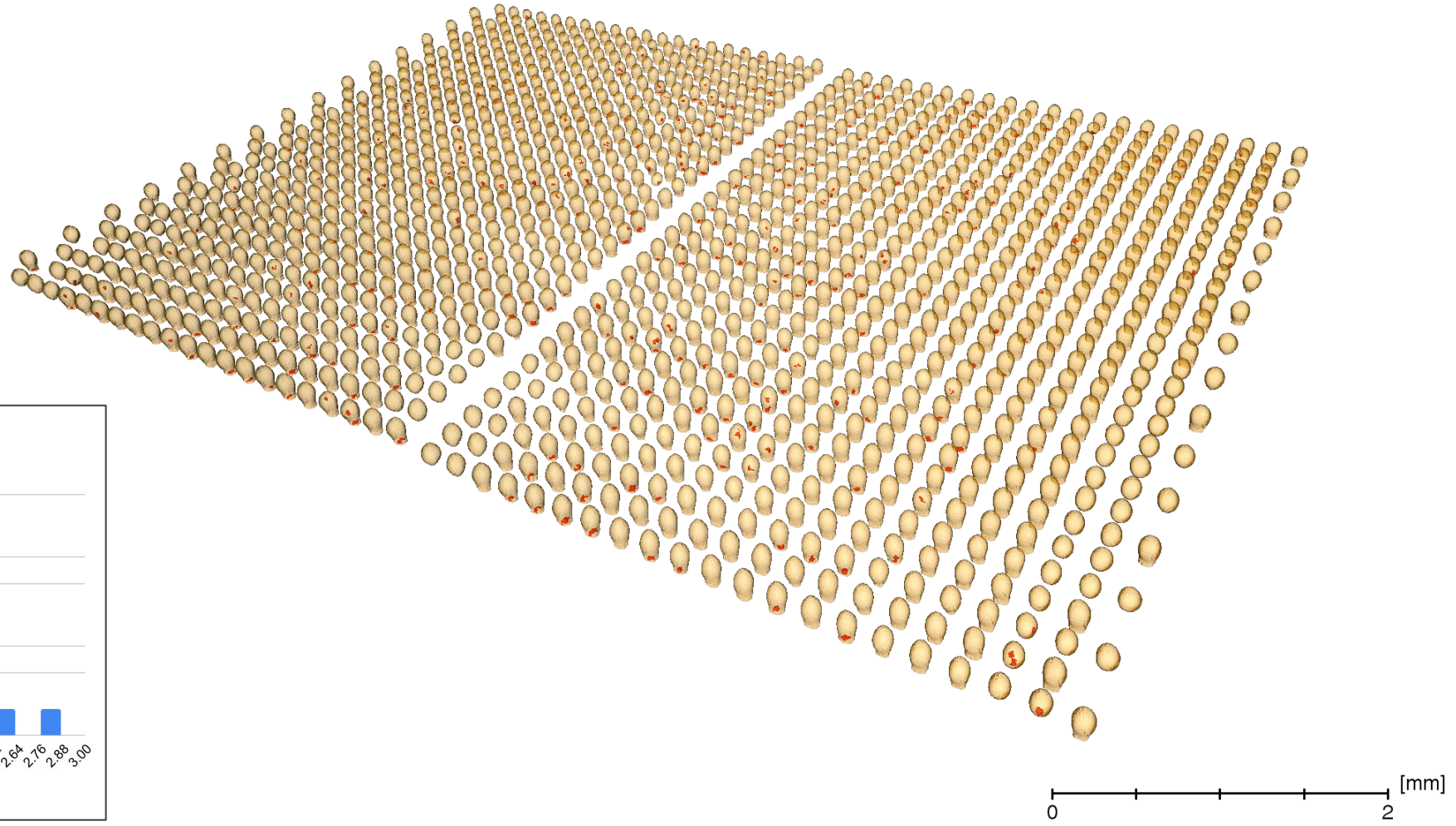
- **3D Volume (pictured here)**
- **Surface area**
- **Sphericity**
- **Aspect ratio / Feret diameters**
- **Etc.**

2.5D Integrated Circuit - Micro-Bump Voids in 3D

3D Surface Rendering of Voids Within Micro-Bumps

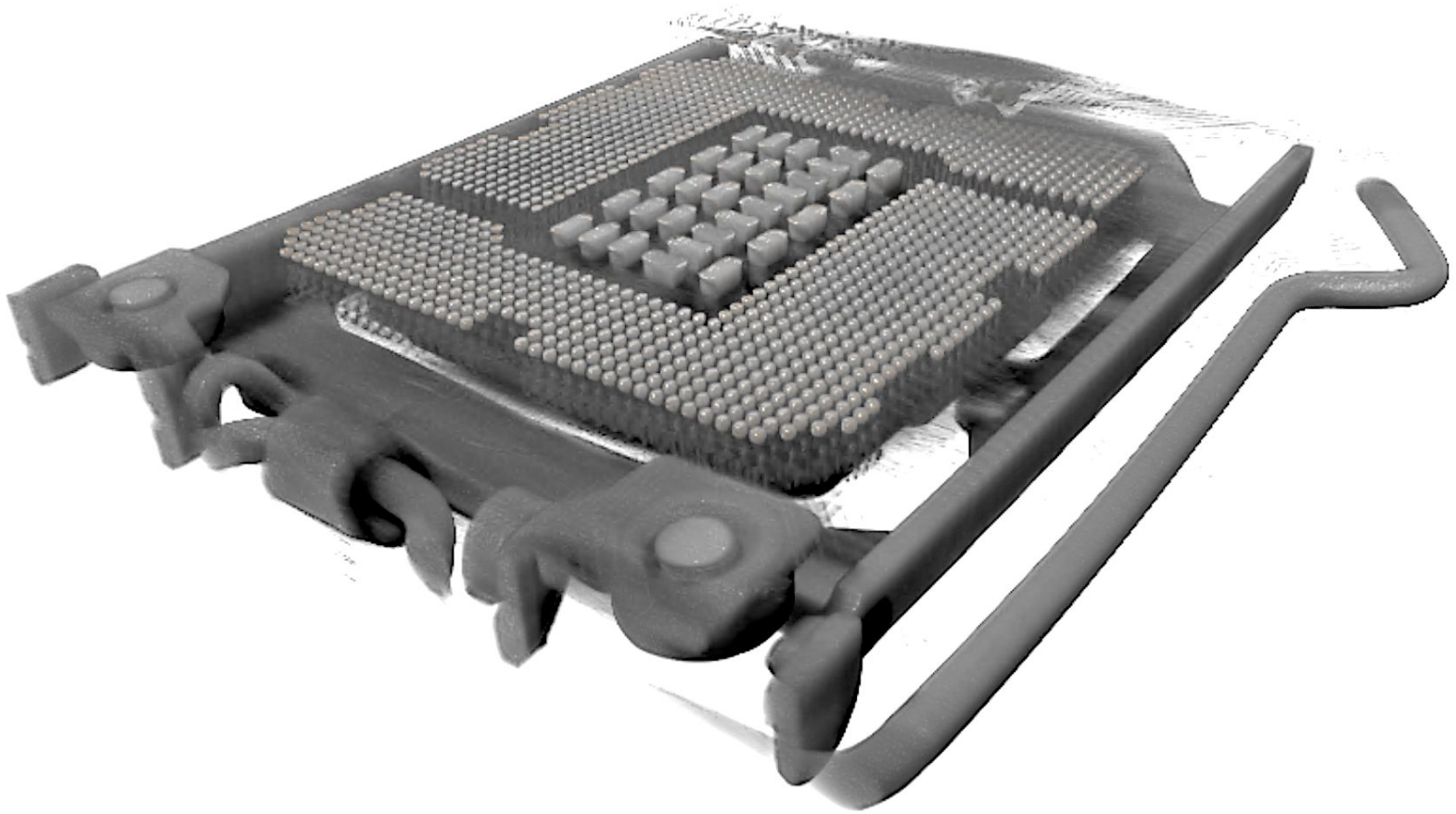
Automated image processing routines provide a statistical model of voids per bump

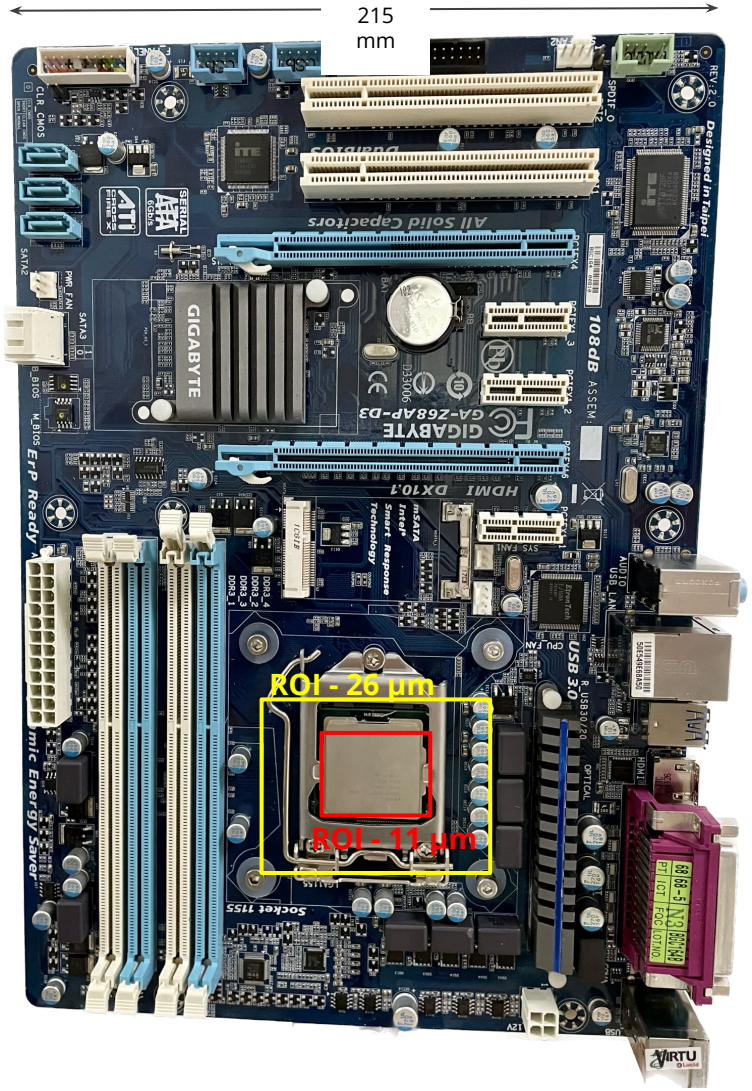




Motherboard @ 11 µm, 26 µm Resolution

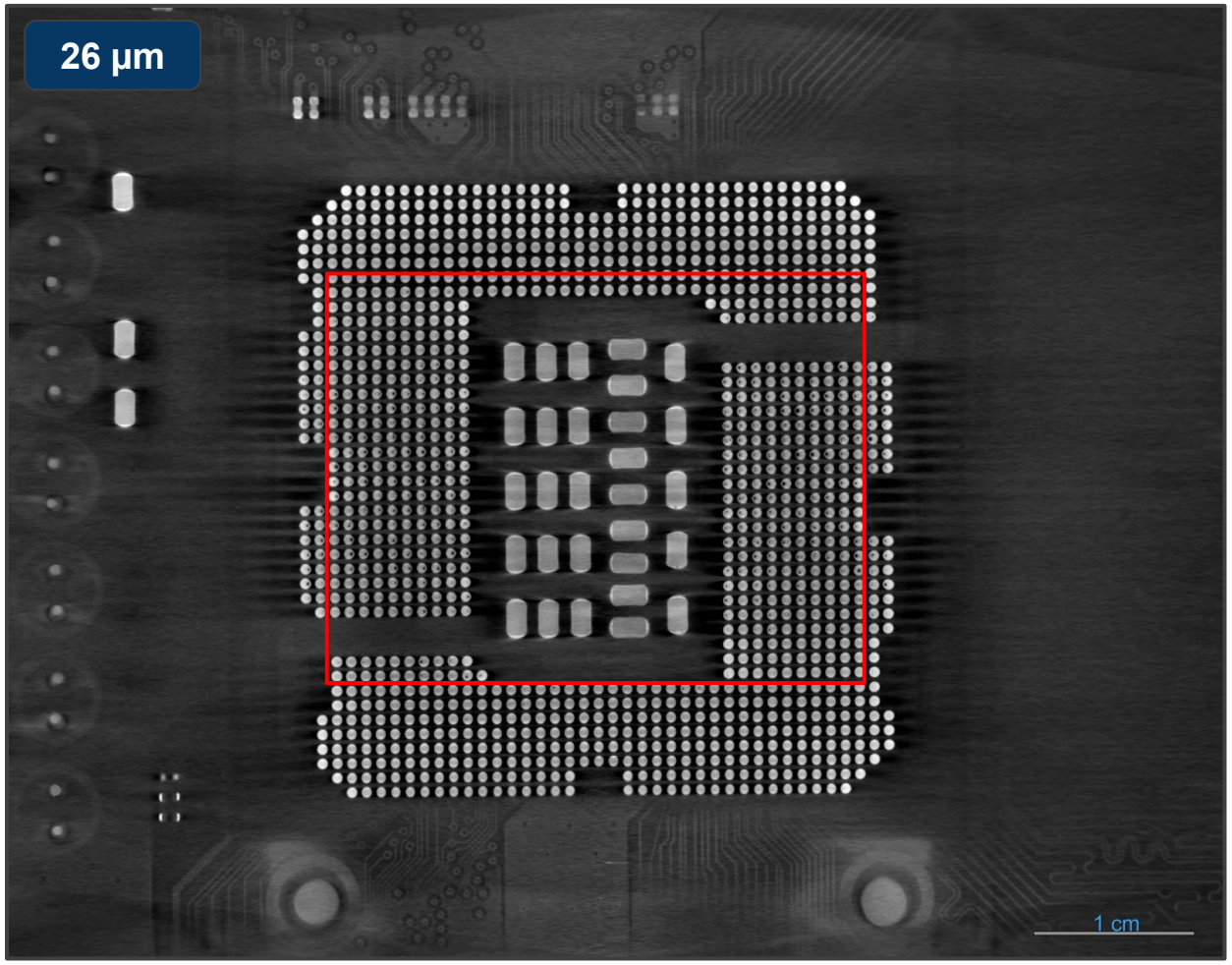
3D Non-Destructive Inspection of CPU

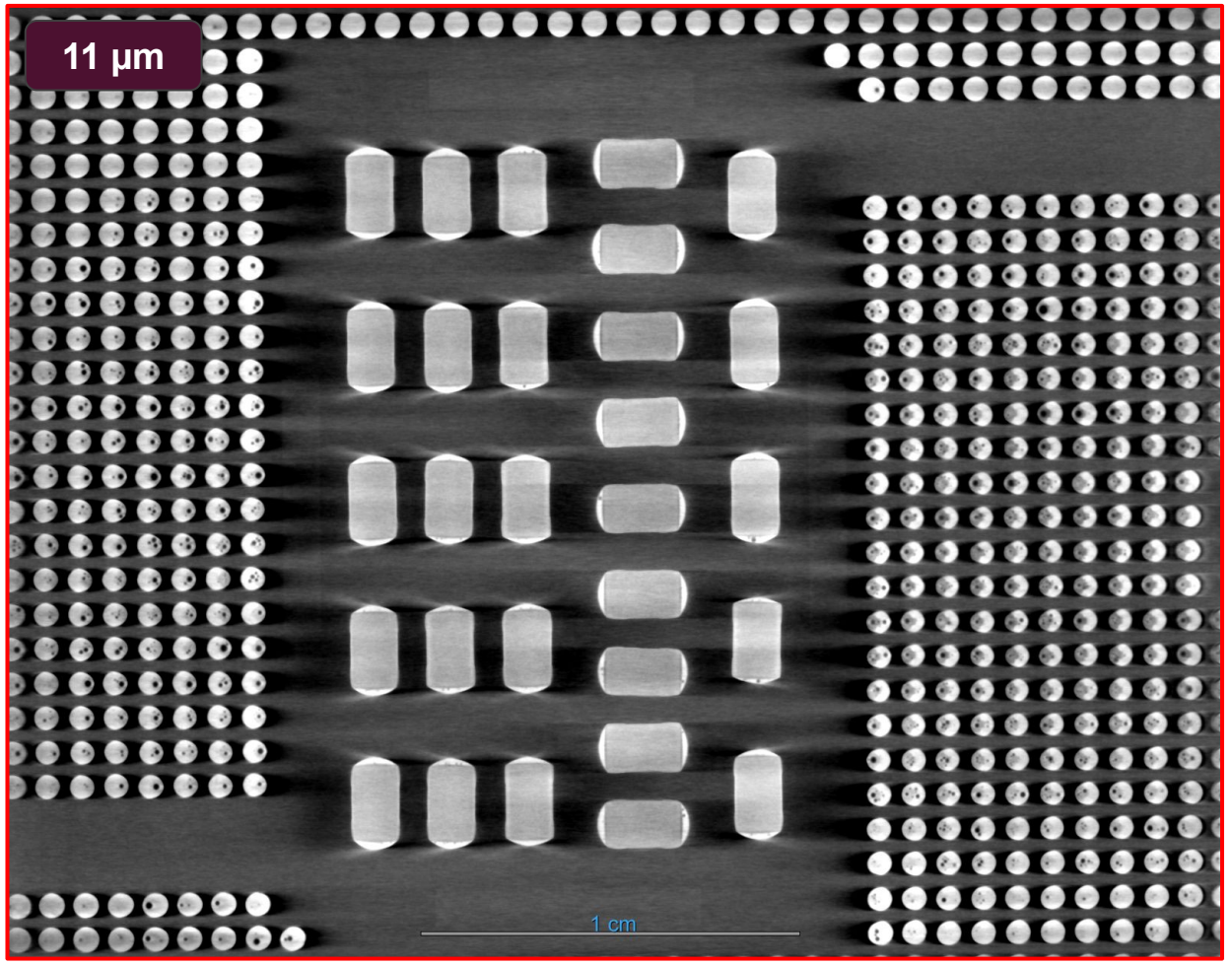




Motherboard Virtual Slice Details - BGA

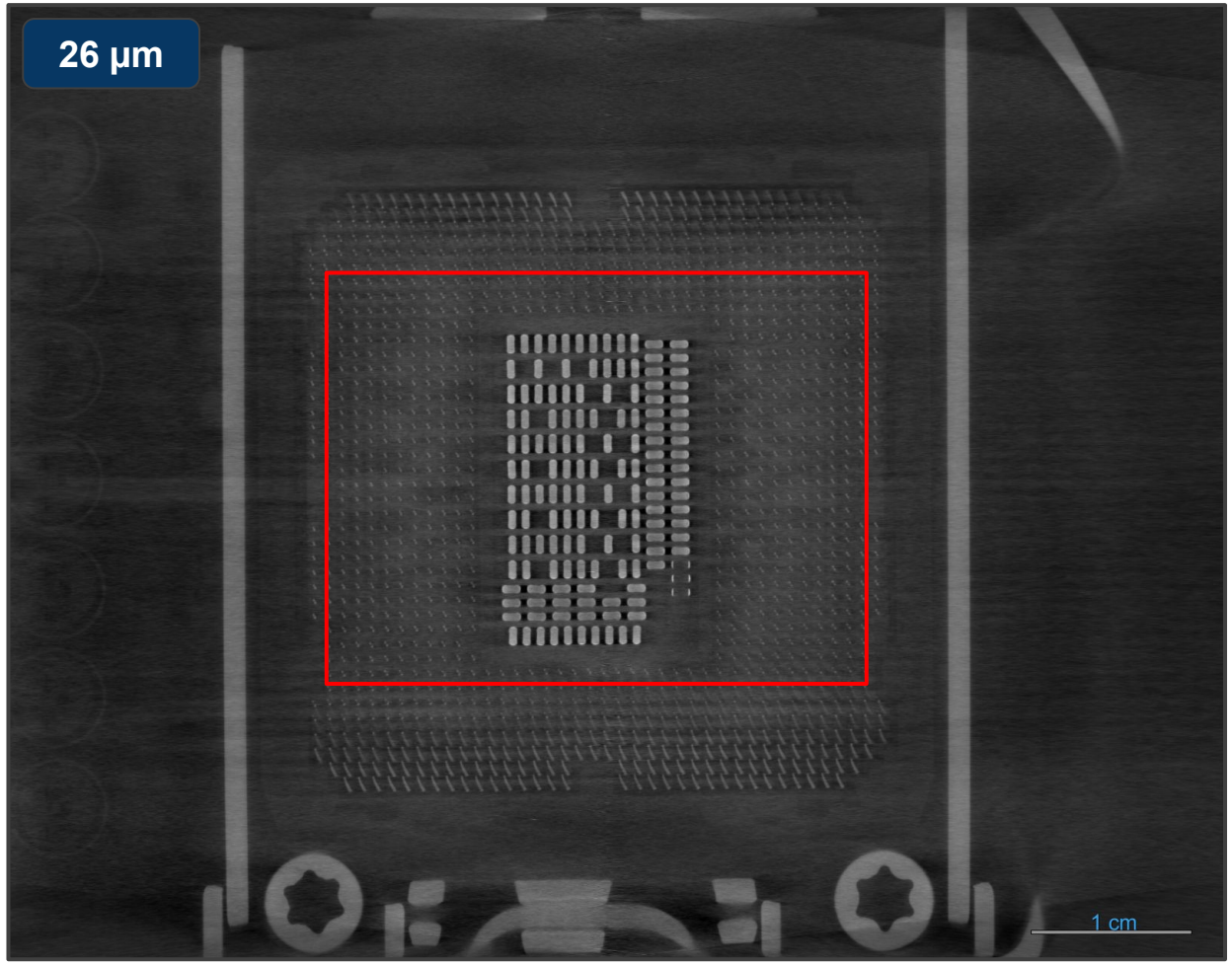
Multi-Scale Virtual Delayering

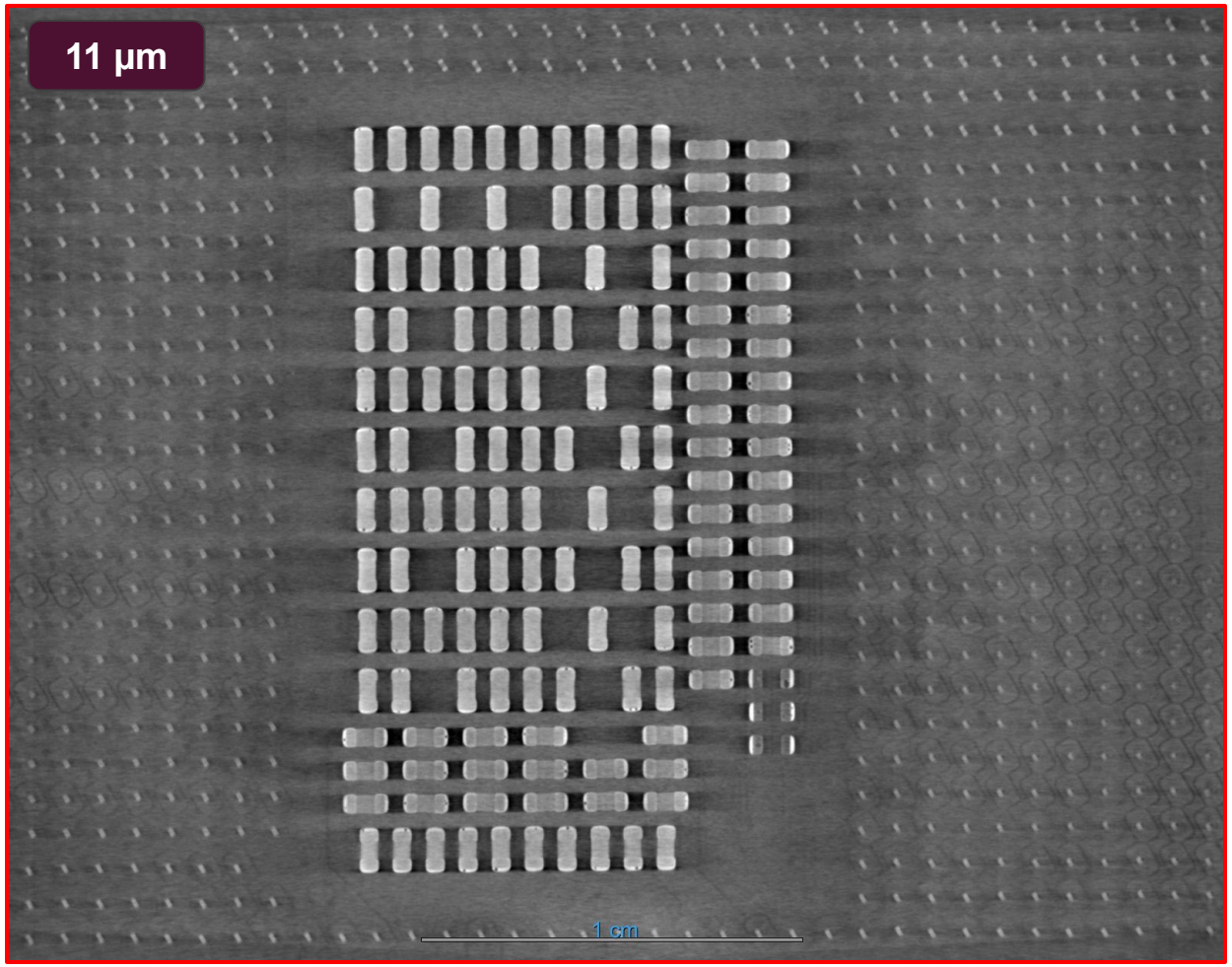




Virtual Slice Details - CPU Components

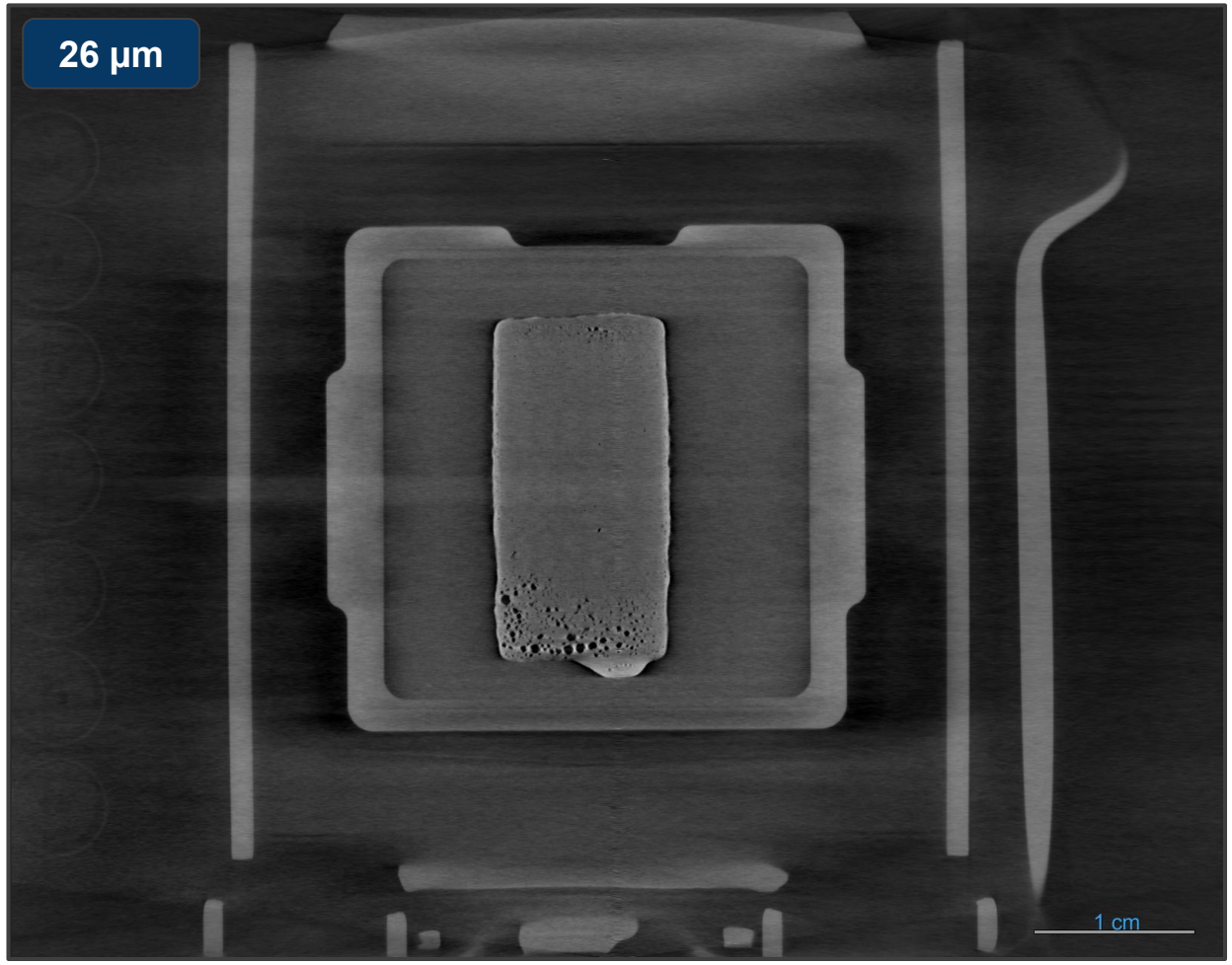
Multi-Scale Virtual Delayering

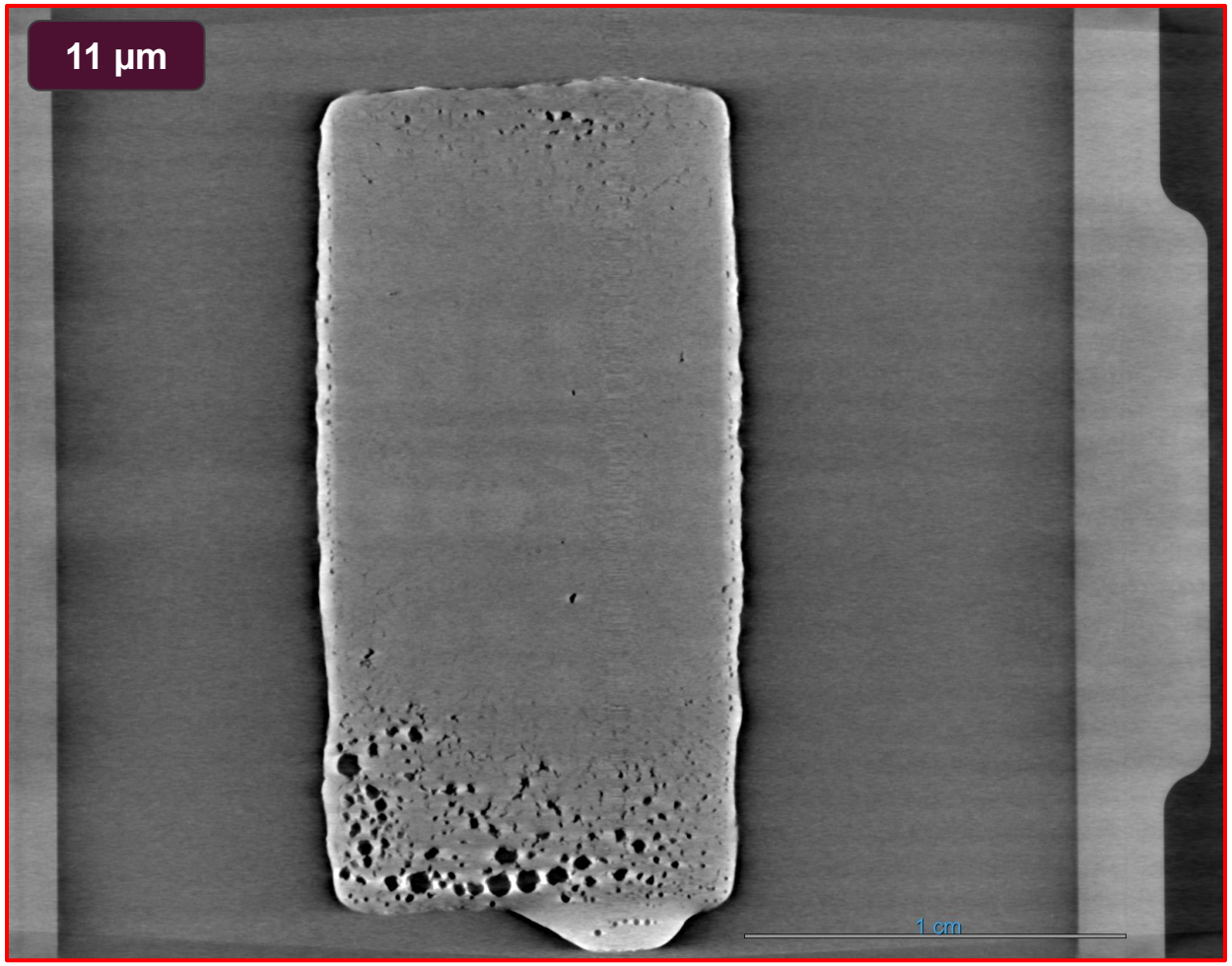




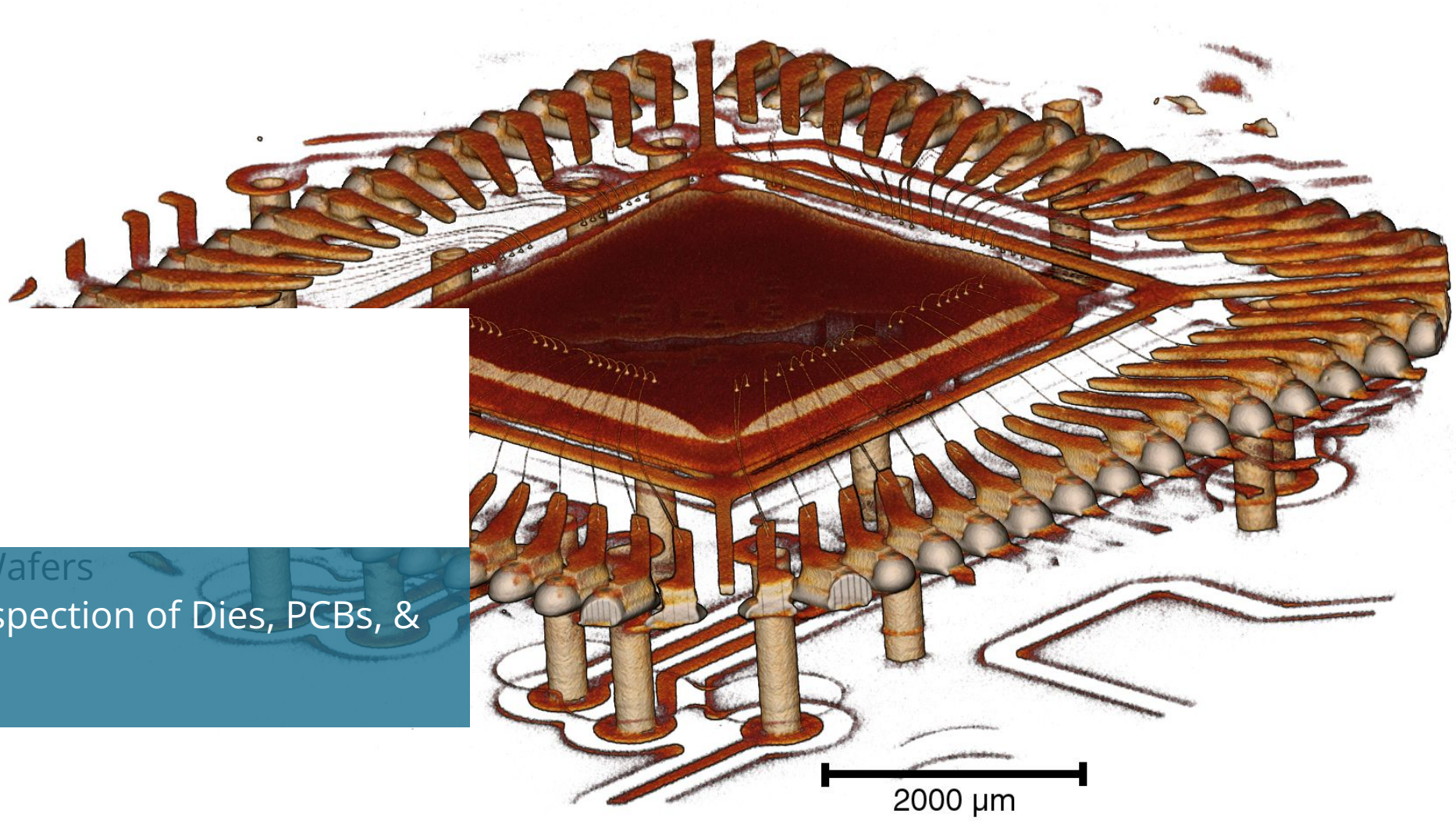
Virtual Slice Details - TIM

Multi-Scale Virtual Delayering





Component on Intact PCB imaged with Sigray Apex XCT at 1.5 micron



Apex XCT

Bs & Wafers

Rapid, High-Resolution Inspection of Dies, PCBs, & 300 mm Wafers

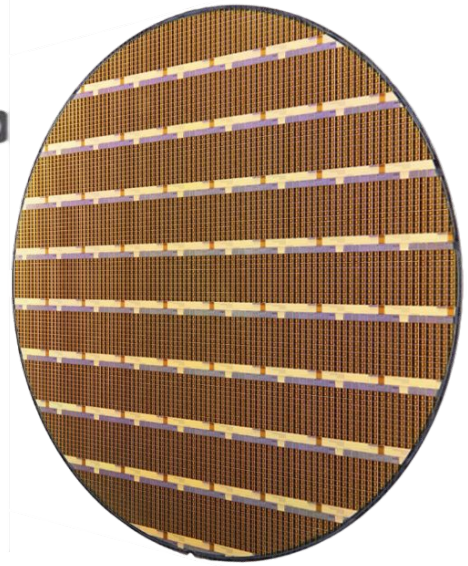
SIGRAY

Challenges of XCT

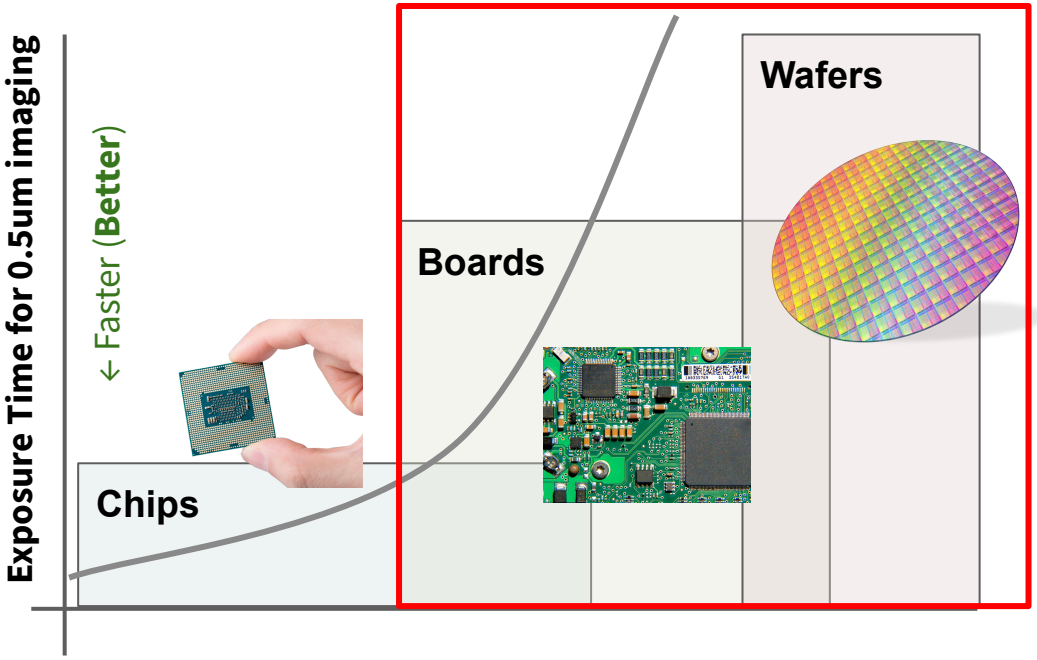
Larger Specimens Require Long Exposure Times

Increased Air Gap

Decreased X-Ray Flux



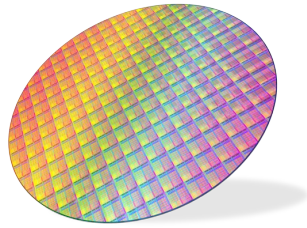
Larger samples require increased source-detector distances, which reduce X-ray flux by $1/r^2$ and increase exposure times.

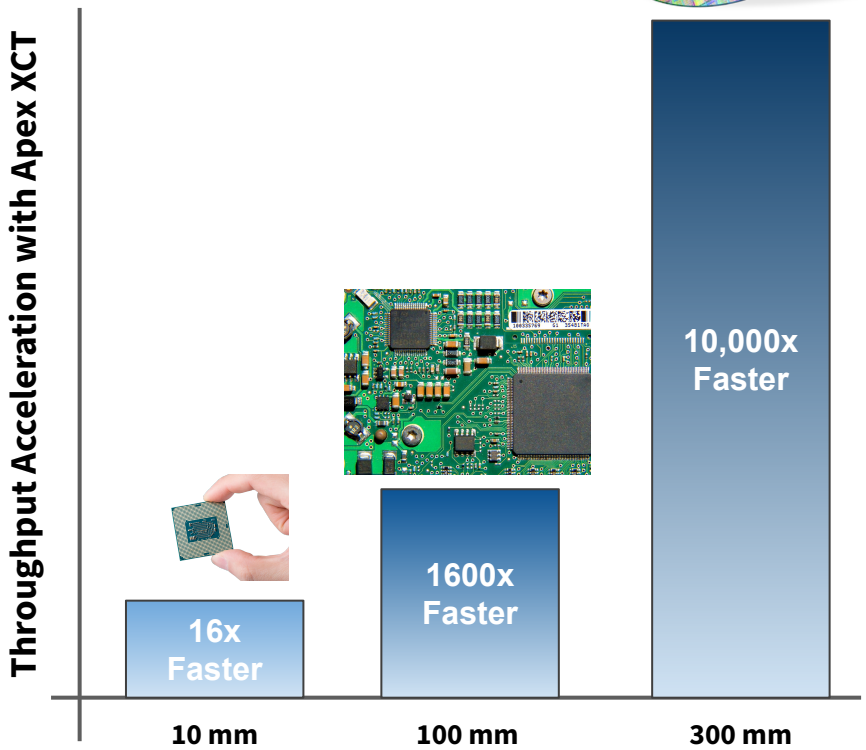


Apex XCT-150: Highest Throughput 3D X-ray

Comparing Apex XCT vs. Other 3D X-Ray

- Apex XCT preserves speed & resolution **even for large samples**.
- Enables **3D wafer spot analysis** in as little as **2-3 minutes.**





Apex XCT: Advanced Failure Analysis

What it is

3D X-ray Microscope designed for Inspection and FA on PCBs & wafers

Advantages at a Glance

- Highest spatial resolution (0.5 µm) laminography for next-gen microbumps & hybrid bonding
- 10-1000X TPT vs. XRM (<3 min)

How it Works

Throughput

Contrast-Noise Ratio

$$TPT \sim \frac{CNR^2}{FOD^2}$$

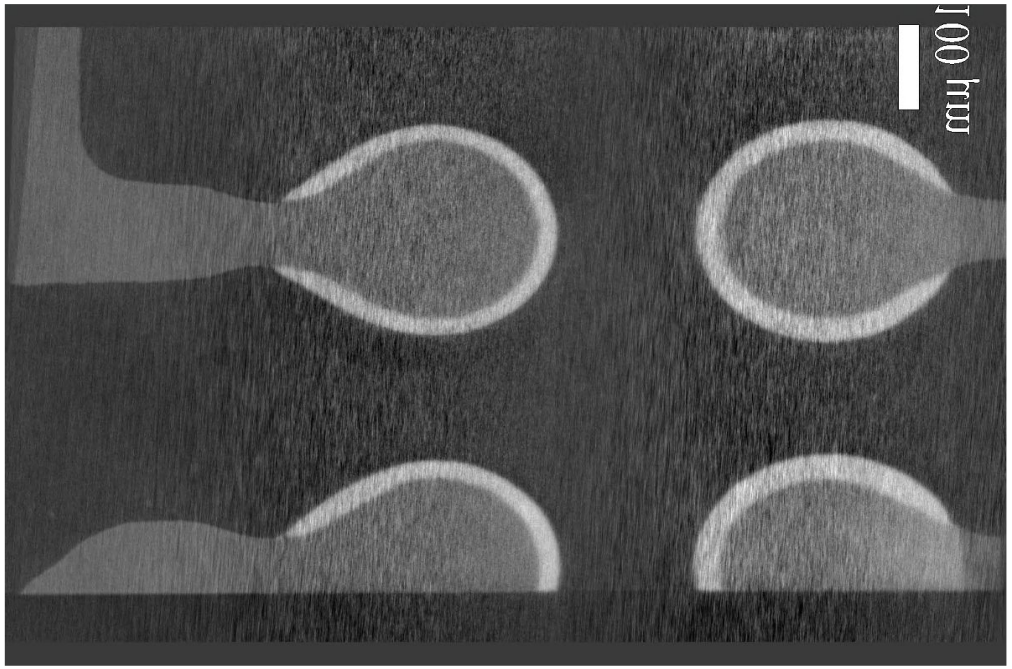
Focus-Object Distance

Sigray Innovations (World's First)

High **CNR**	Innovate Architecture | Finely-Tuned Processes ***Patent Pending***
Small **FOD**	1-3 mm vs. 30-100 mm → **>100X TPT gain** **US Patent 11/686,692**

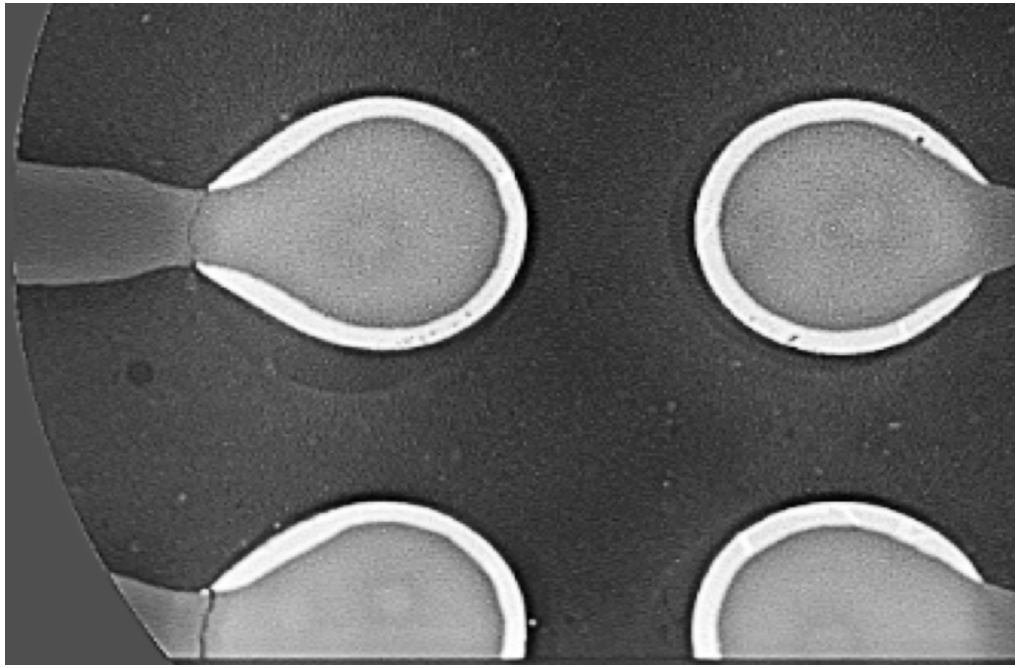
Exceptional Delaying Image with Unbiased Contrast

Conventional XRM



Same sample and region
Note poor signal to noise due to scintillator inefficiency
2.5x measurement time
Difficult to see cracks

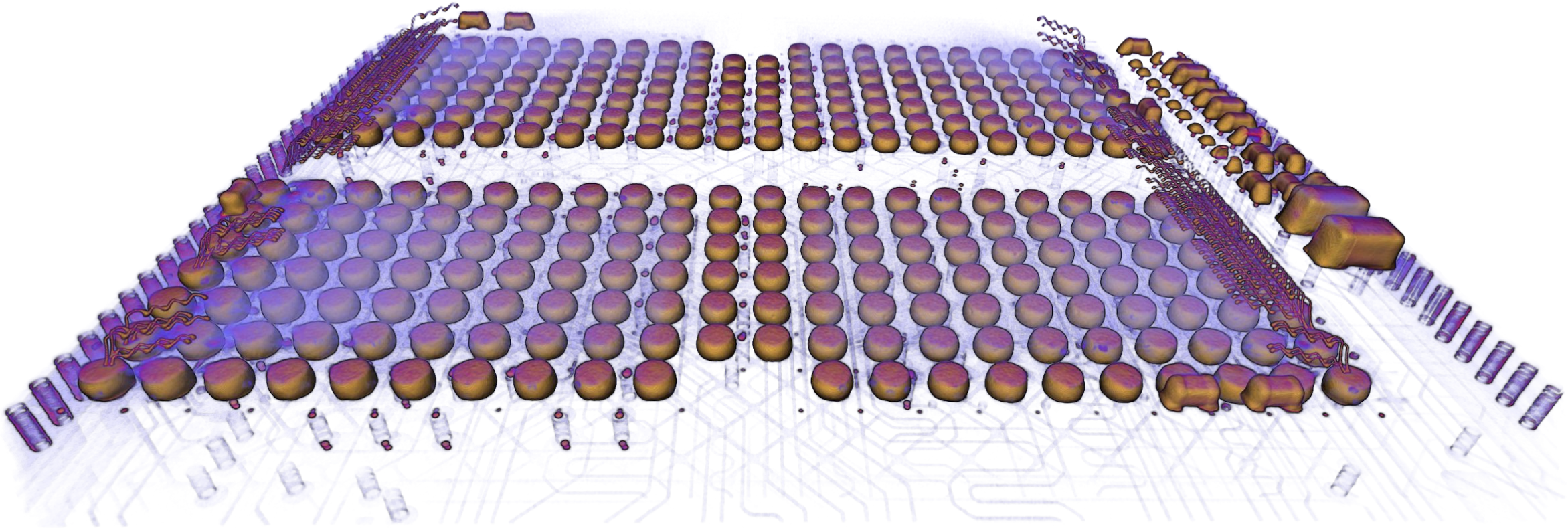
Apex XCT



Note excellent signal to noise **easily resolves cracks**
4x the field of view (image cropped to same FOV for comparison)

Commercial SSD: 3D Visualization (LFOV)

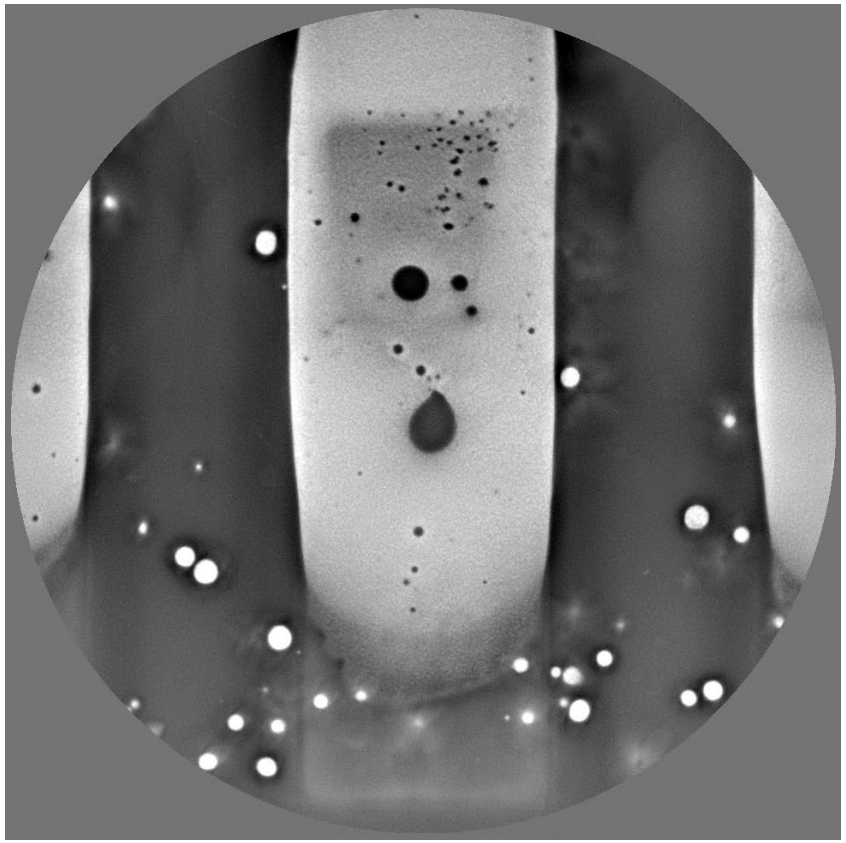
Rendering the Complex 3D Architecture of 3D NAND with Low Magnification



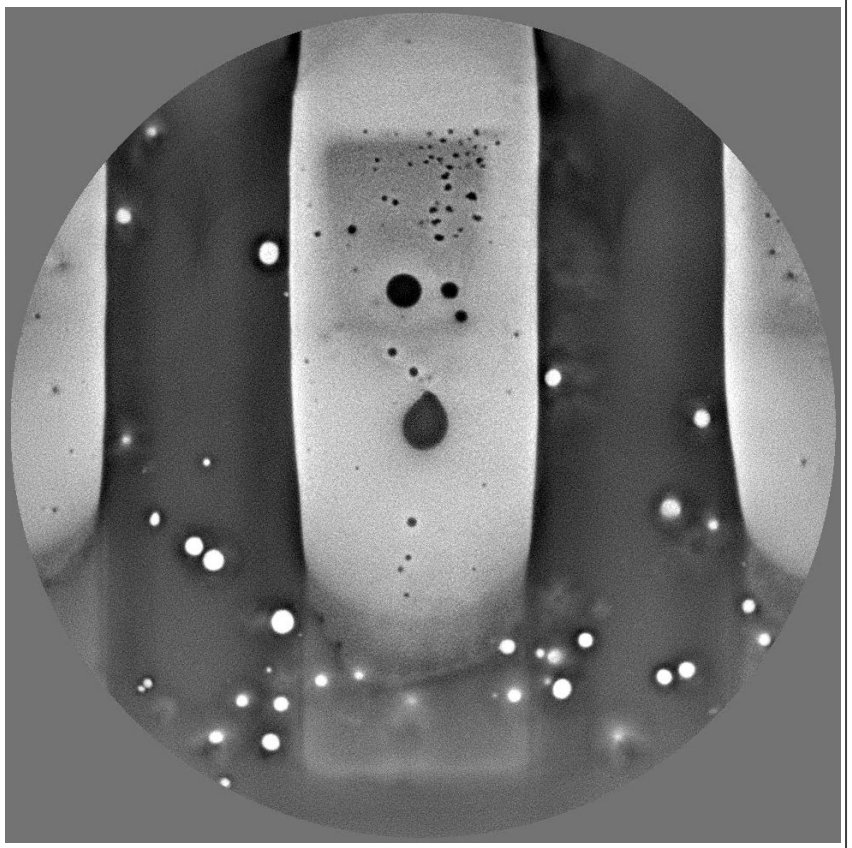
0.5 µm Resolution in 3 Minutes

Example Virtual Slice - Intact PCB (50 mm x 100 mm), Targeted Interior Volume @ 0.5 µm

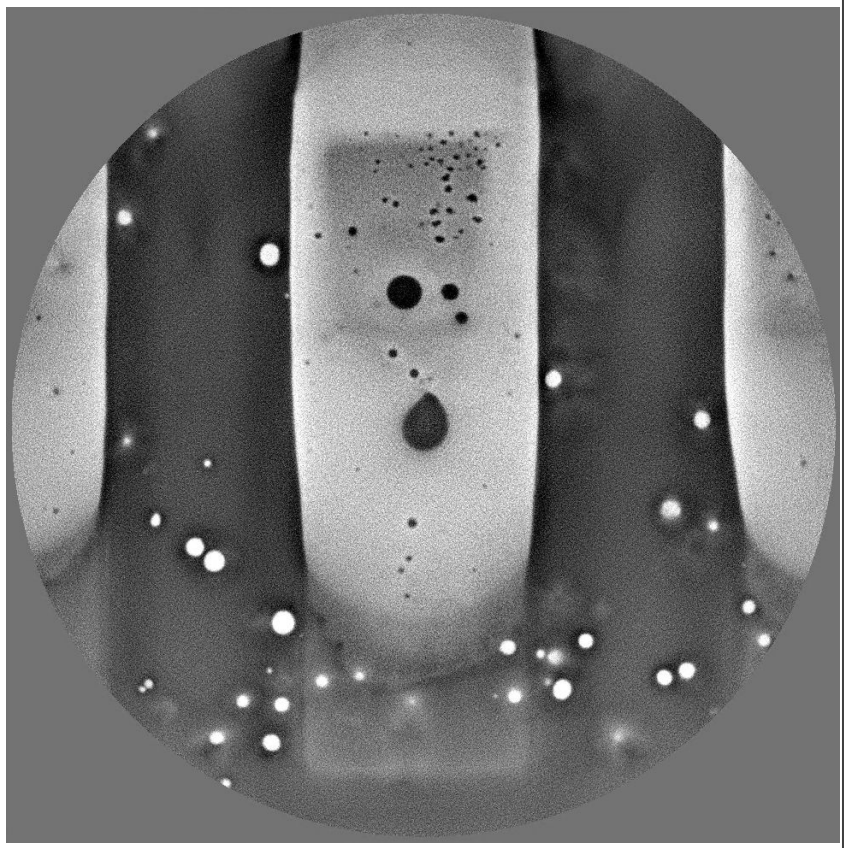
2.5 Hours



17 Minutes



3 Minutes



Scalable Technology with Apex XCT

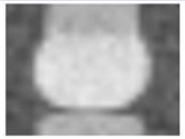
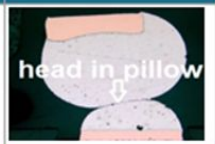
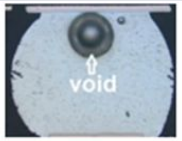
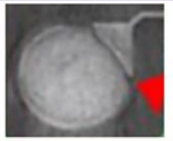
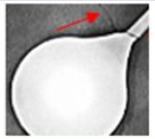
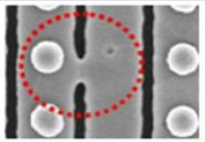
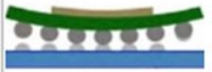
Non-Destructive Inspection Capabilities: From PCBs to Full Wafers

Sample Types

Components & PCBs

Wafers up to 300 mm+

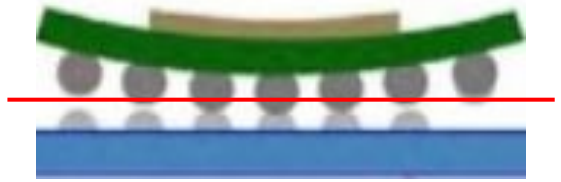
Inspection Workflows

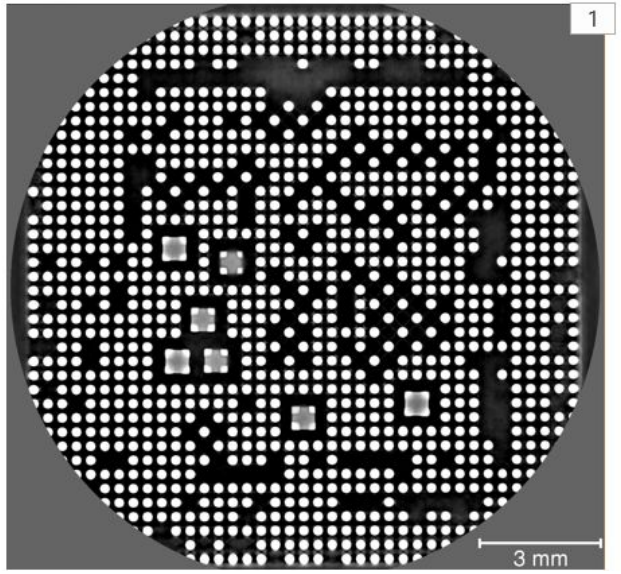
Defect	Good Solder Joint	Non Wet	Non Contact	Head in Pillow	Voids	Solder/RDL Crack	Die/Molding Compound Crack	Bridging	Warpage
									
Apex XCT	Y	Y	Y	Y	Y	Y	Y	Y	Y

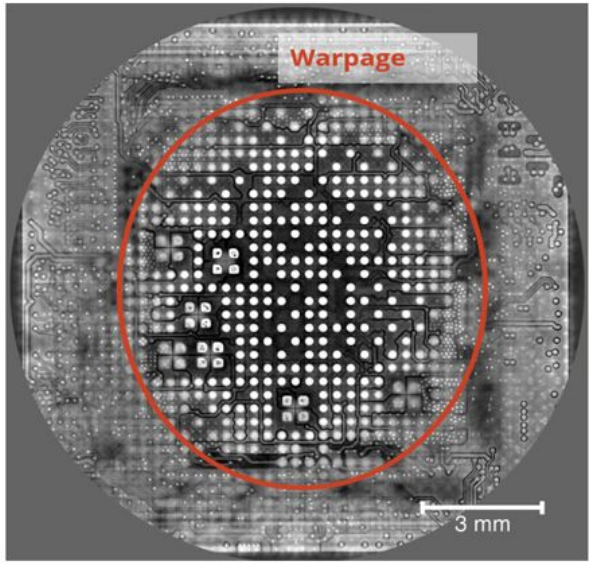
SIGRAY

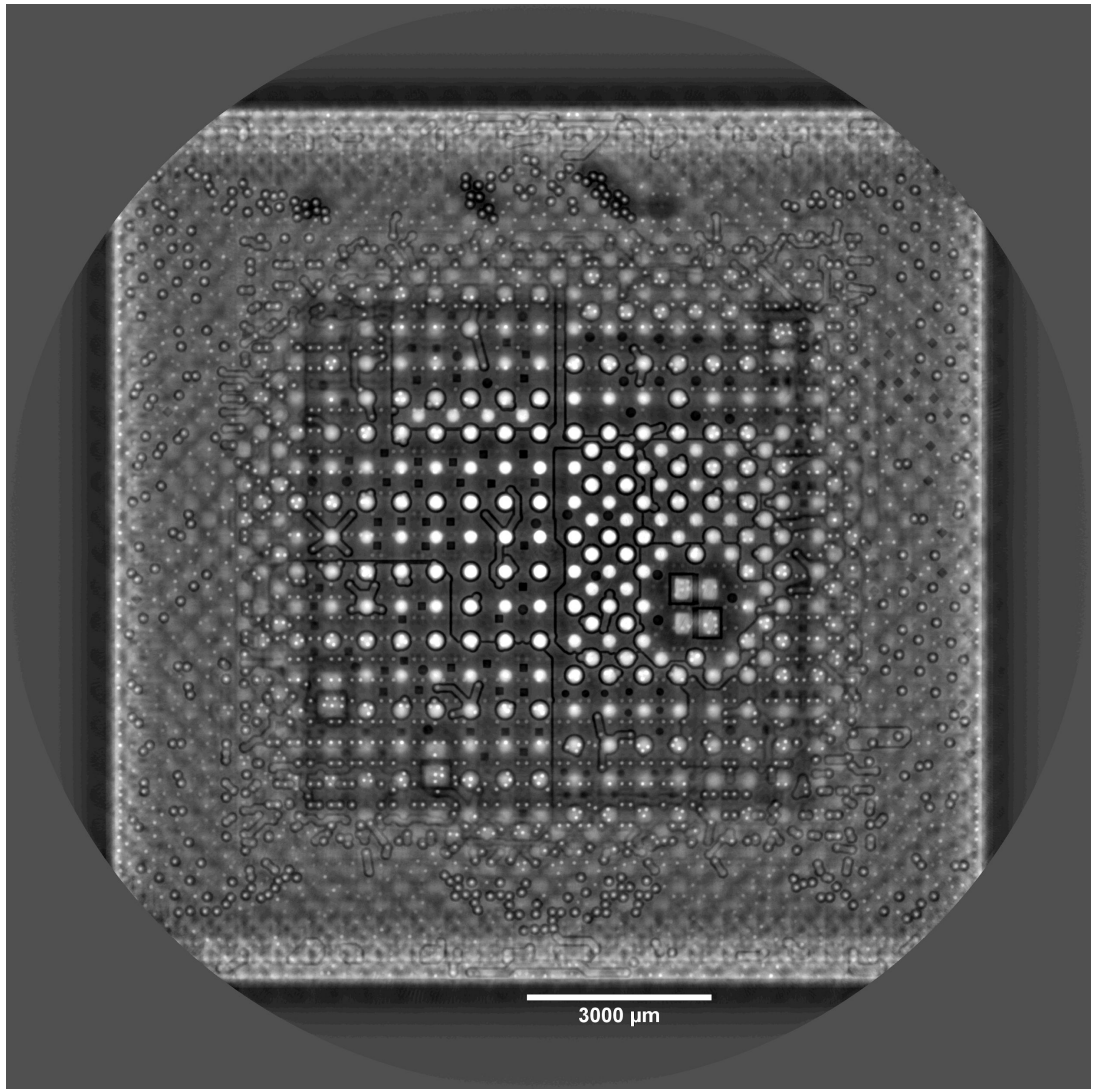
Warpage & Non-Wets / Cold Joints

Different layers can be seen in a single slice due to warpage (center vs edges)



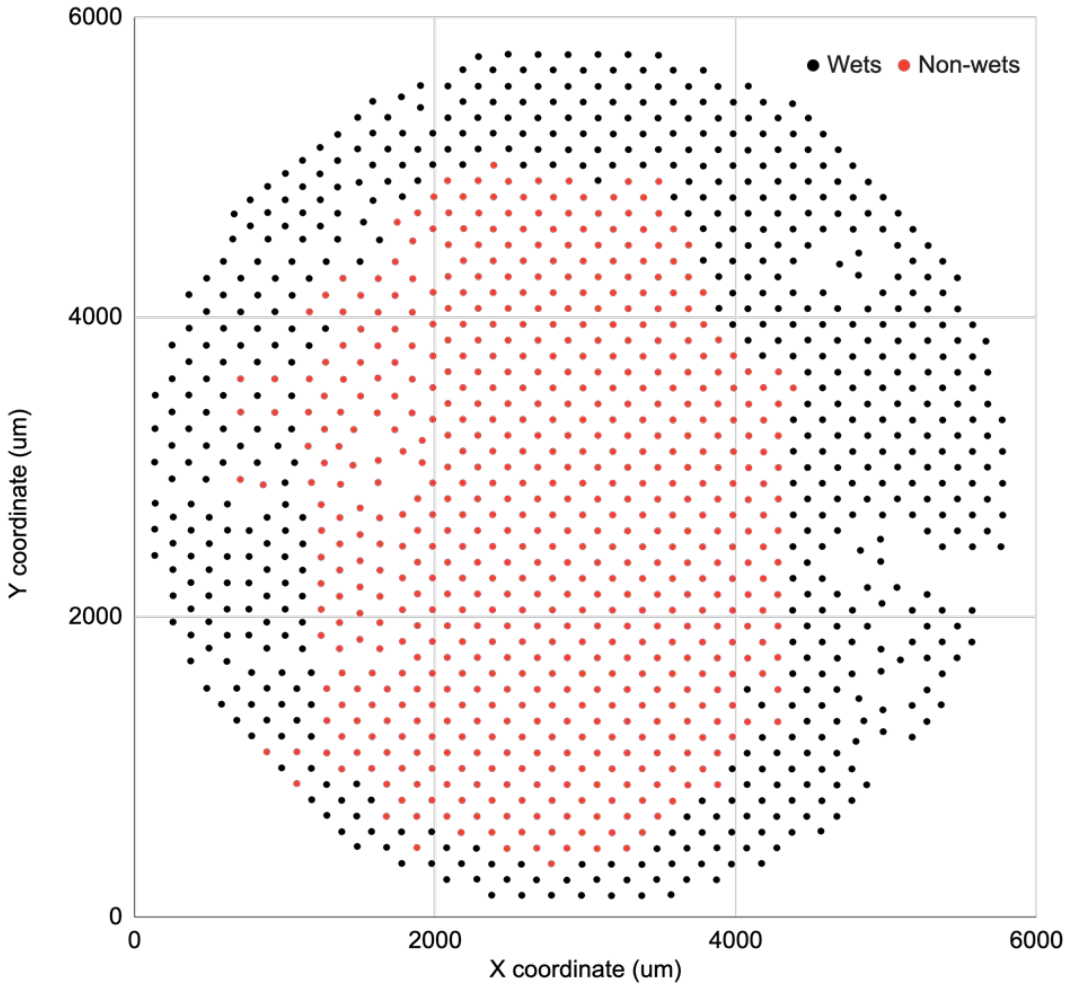


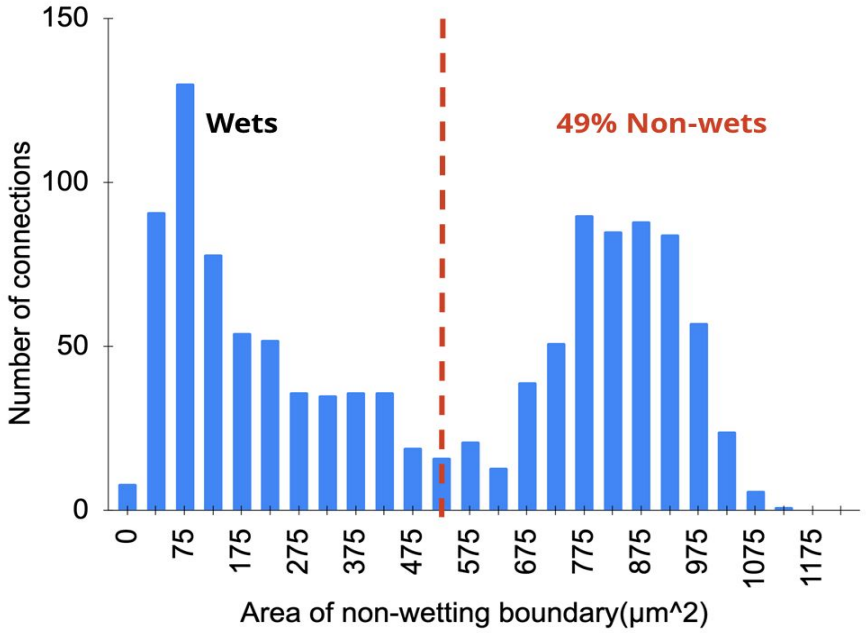




SIGRAY

Statistics: Wet vs. Non-Wet Joints



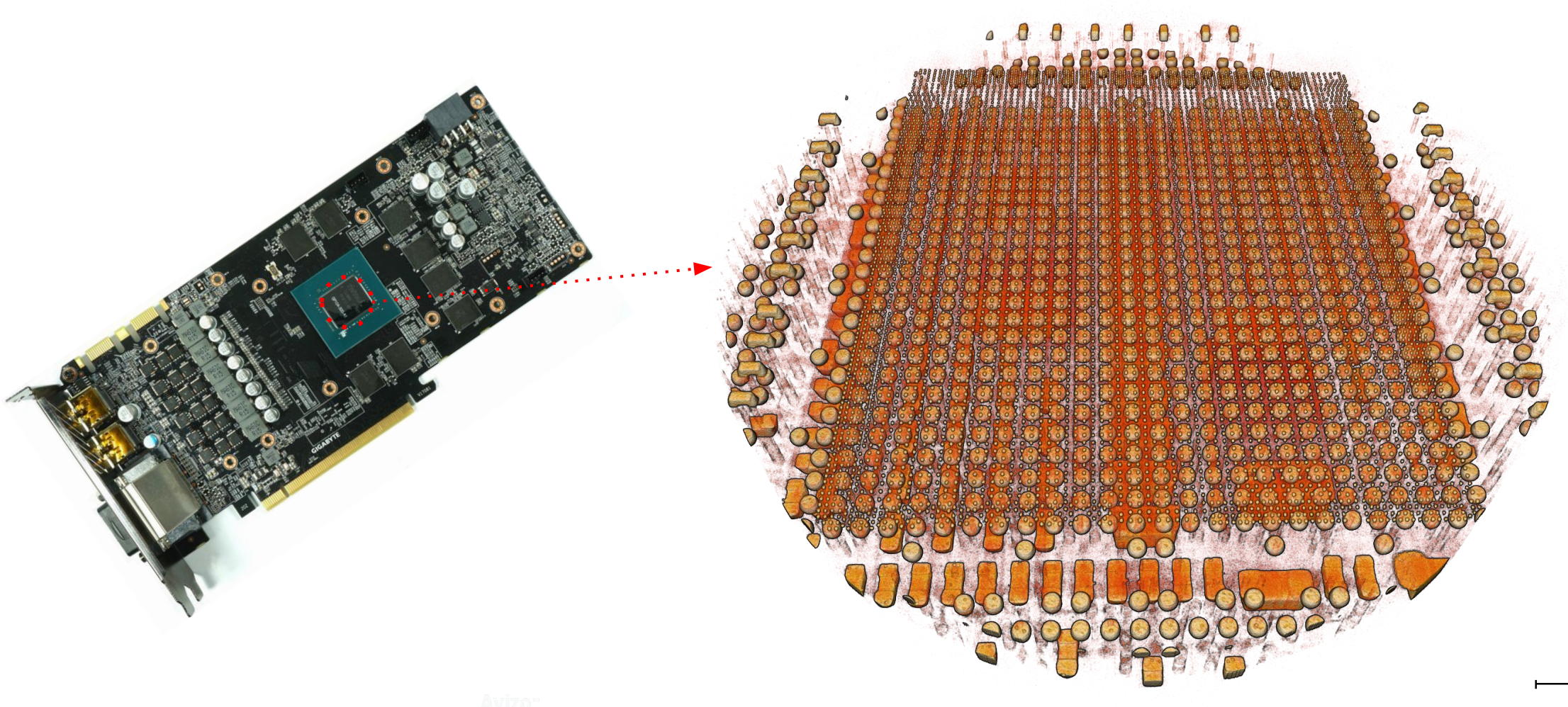


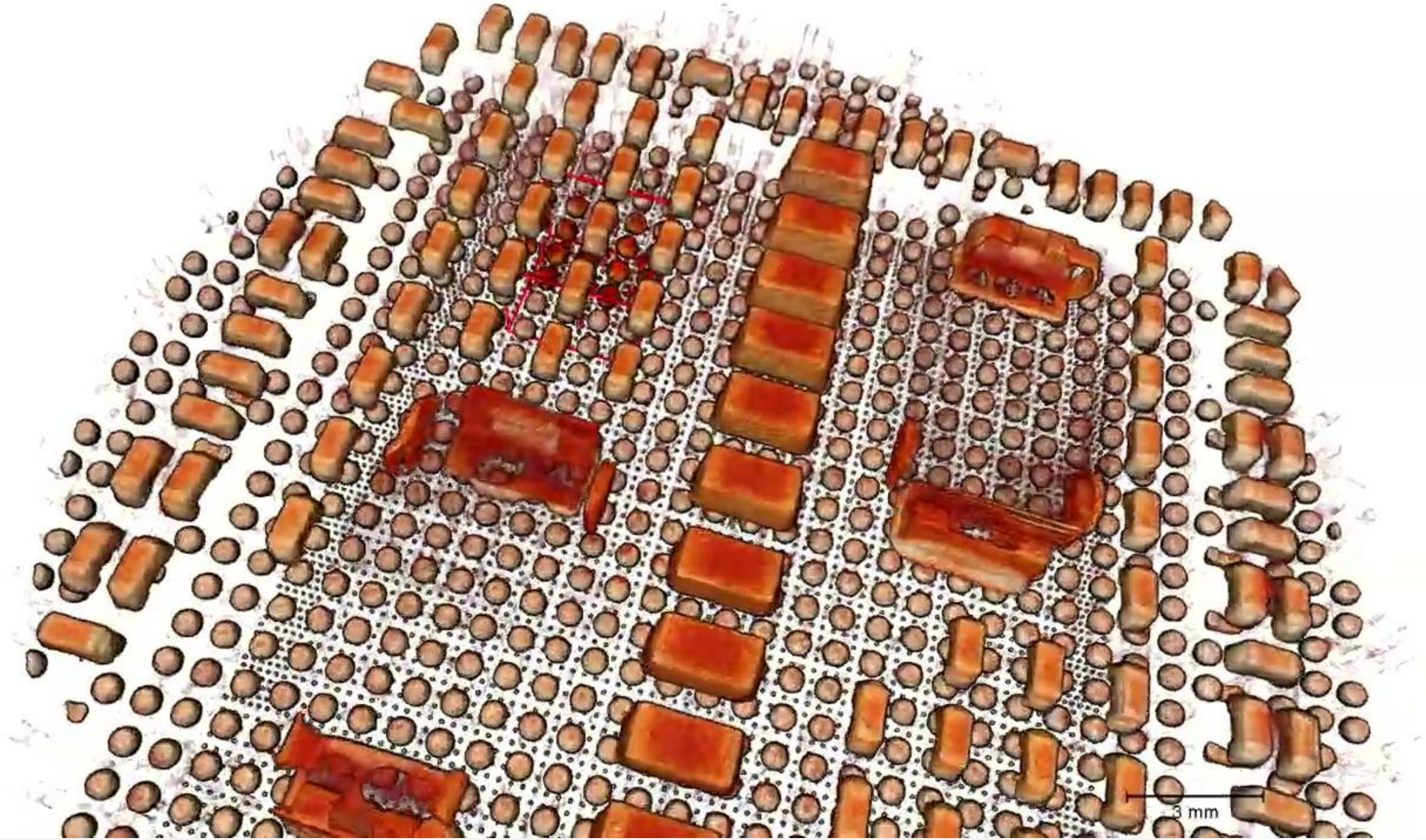
- The wetting status and locations of **1187** joints were analyzed **< 6 min**.
- 575 non-wets were detected
- The **distribution pattern** of non-wets is consistent with the **warpage** of the layer

SIGRAY

Apex XCT Example: PCIe Graphics Card (NVIDIA 1070 Ti)

True 3D Volumetric Data for Non-Destructive Analysis




3 mm

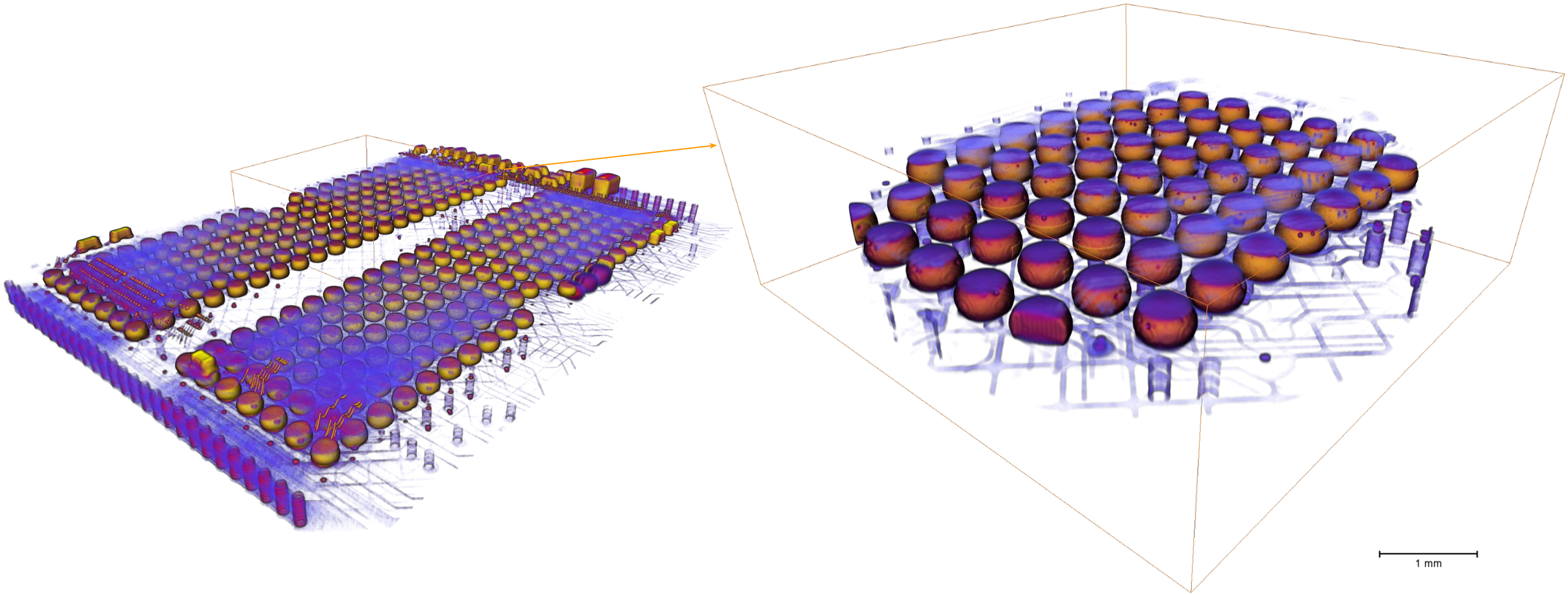
Apex XCT Example: Commercial SSD

3D NAND Structure

Parameter	Scan #1: LFOV	Scan #2: High-Res
Exposure time	2 sec	1.8 sec
Total scan time	27 min	18 min
Voxel Size	8.6 µm	2.5 µm
Field of View	25.4 mm x 20.1 mm	7.26 mm x 5.69 mm

Commercial SSD: High-Res Zoom-In

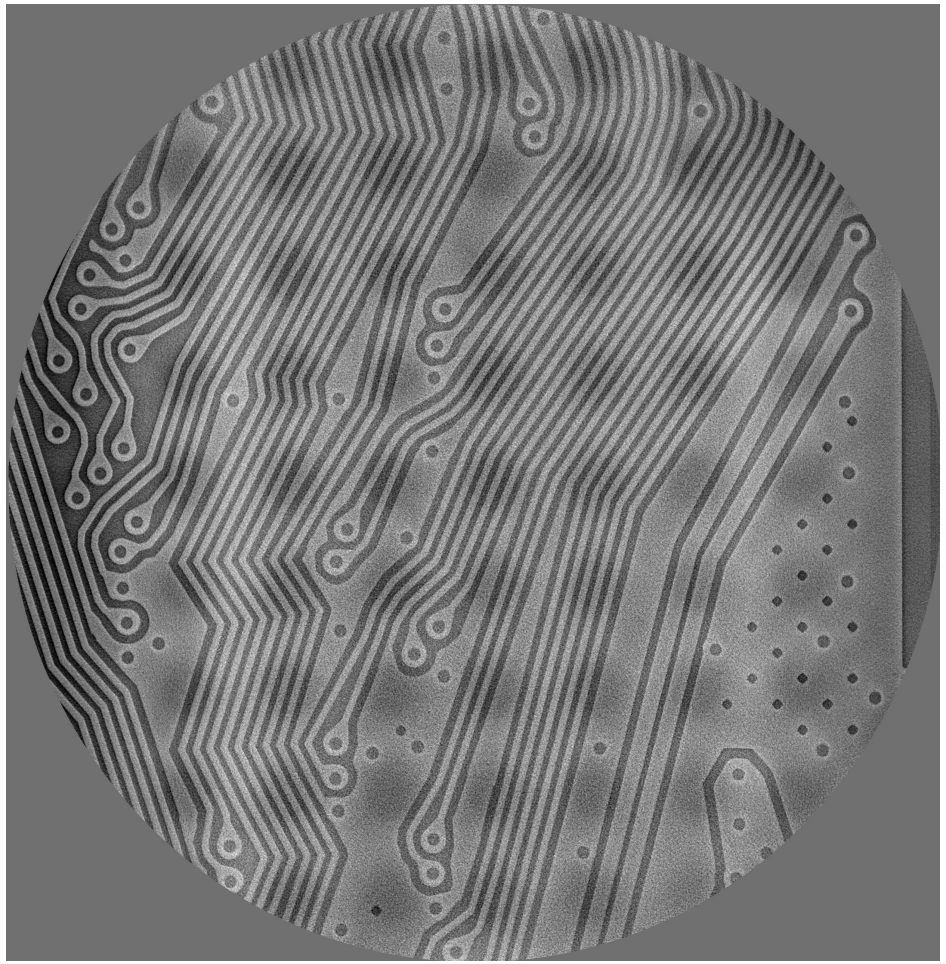
Targeted, Non-Destructive Analysis of Buried Regions with High Magnification



Commercial SSD: Virtual Slices

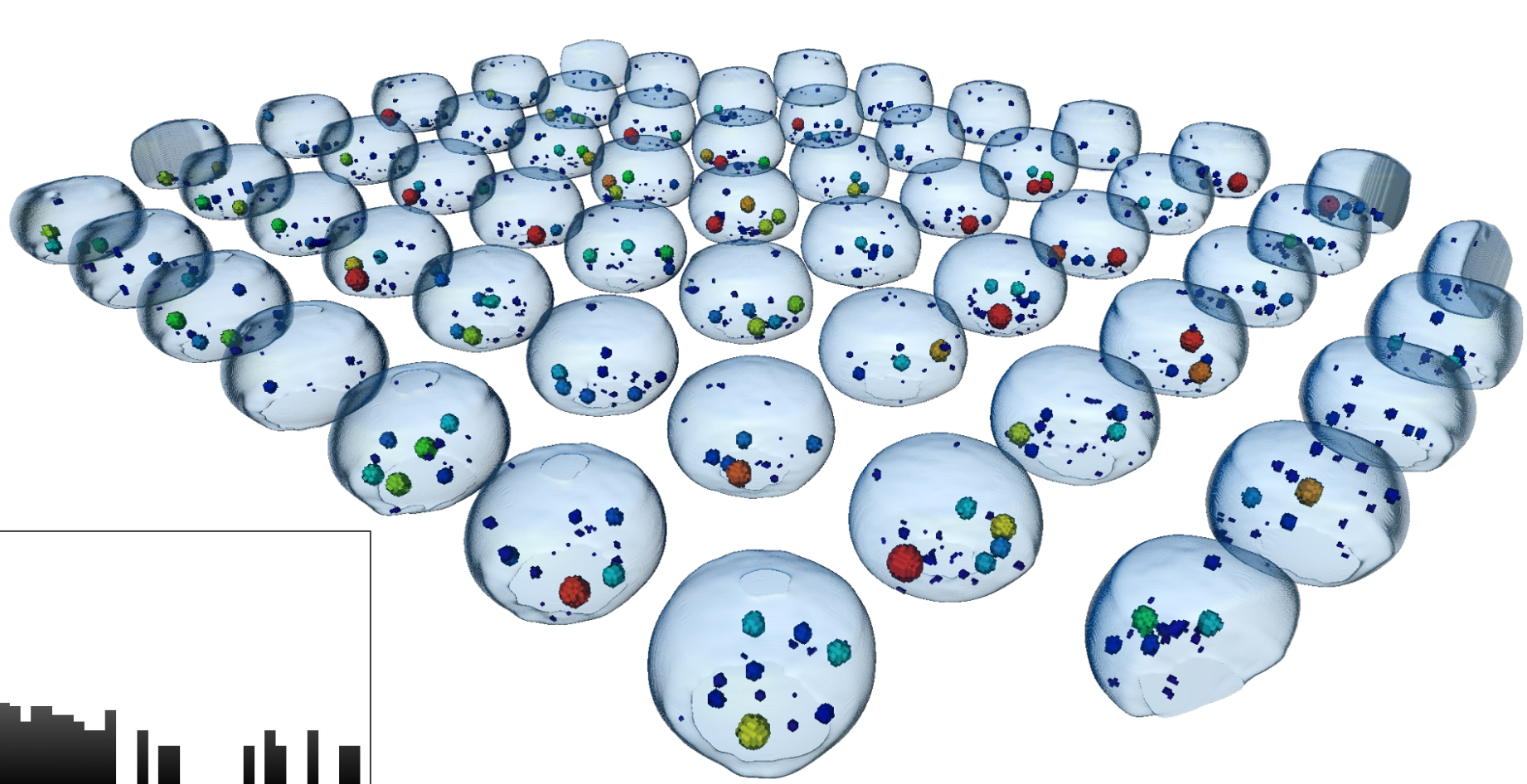
Virtual De-Layering

- Entire PCB sample imaged without sectioning
- Virtual de-layering provides insight for:
  - 3D chip architecture
  - Voids in BGA
  - Crack detection in RDL & UBM
  - TSV inspection & CD measurement



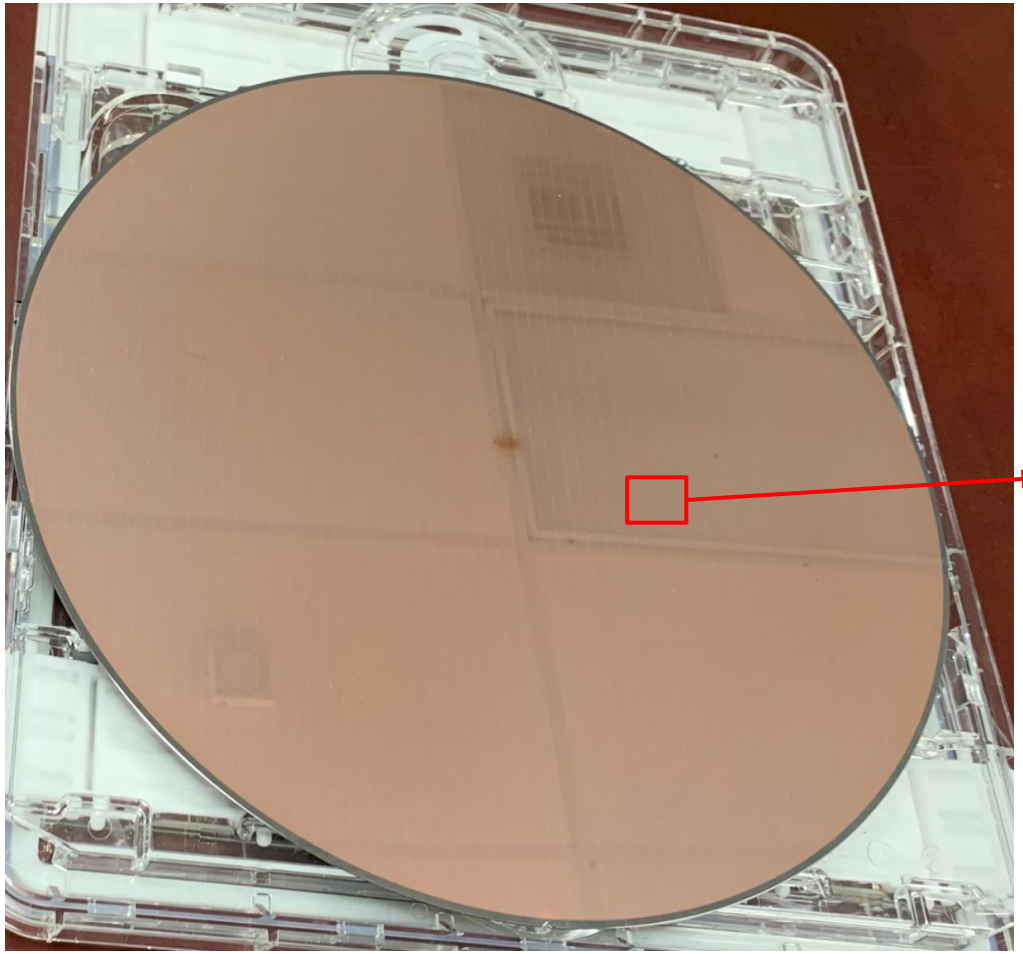
Void Size Distribution in BGA

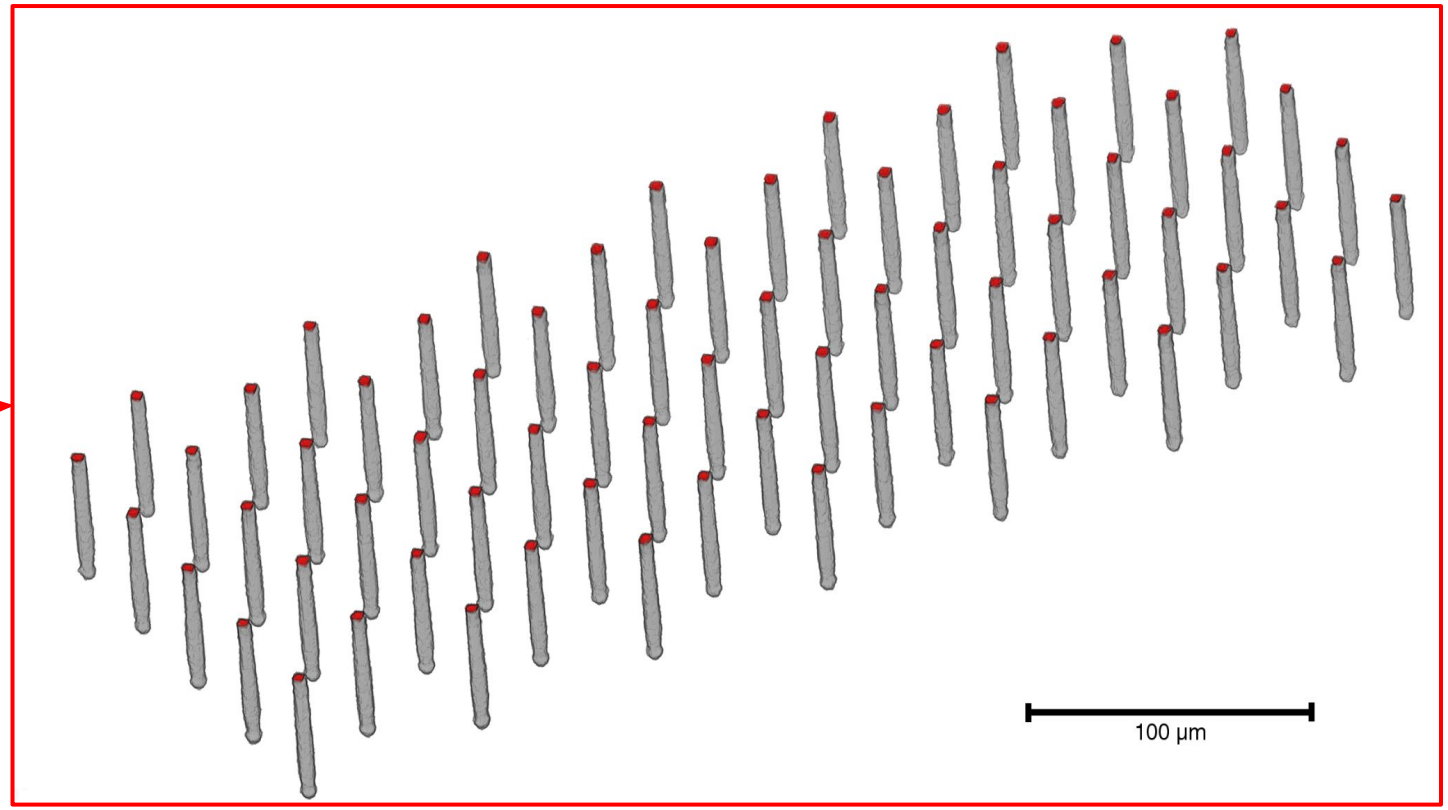
True 3D Capabilities for Quantitative Reporting



Apex XCT Example: 300 mm Wafer with TSVs

12 Minute Scan, 0.2 µm Pixel Size



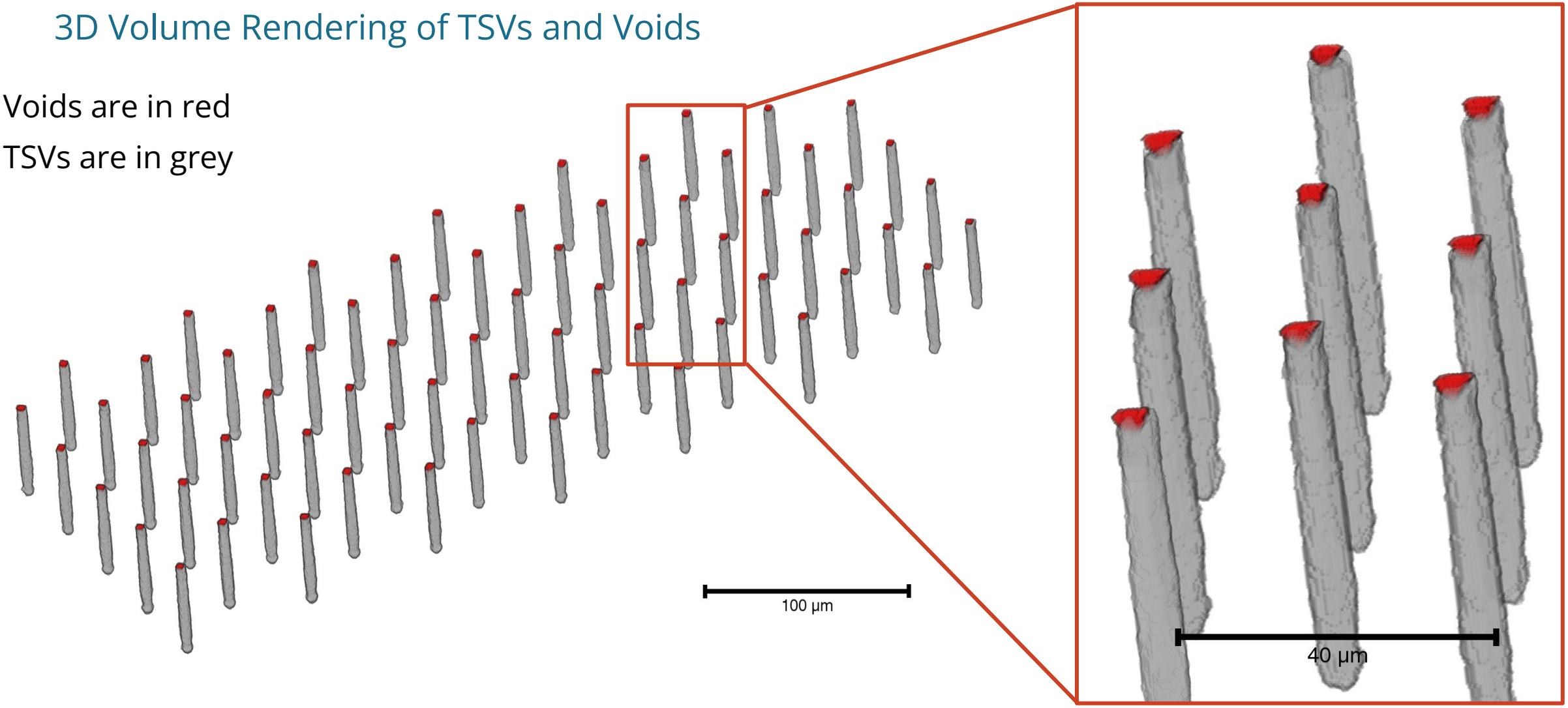


Void Identification in TSVs

3D Volume Rendering of TSVs and Voids

Voids are in red

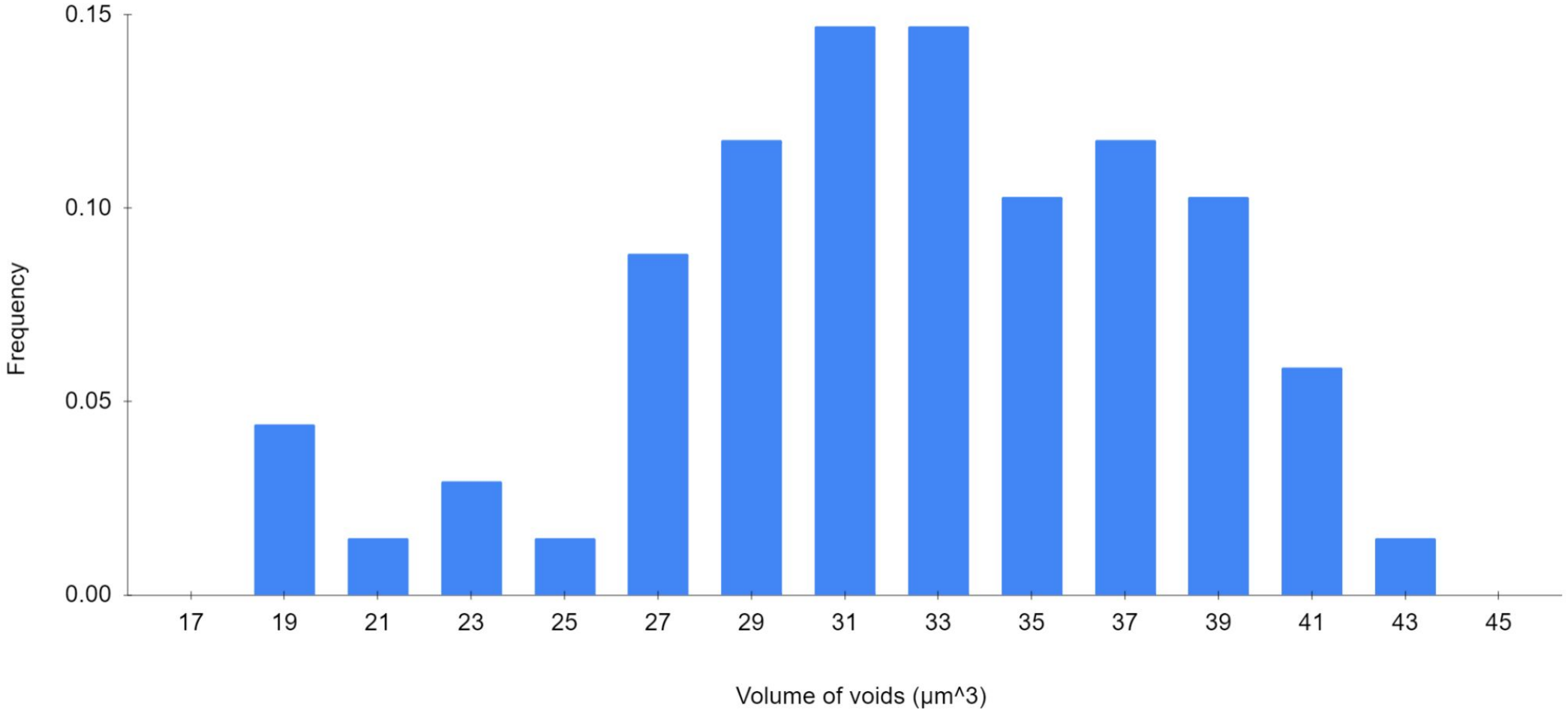
TSVs are in grey



SIGRAY

Quantitative Analysis

Void size distribution

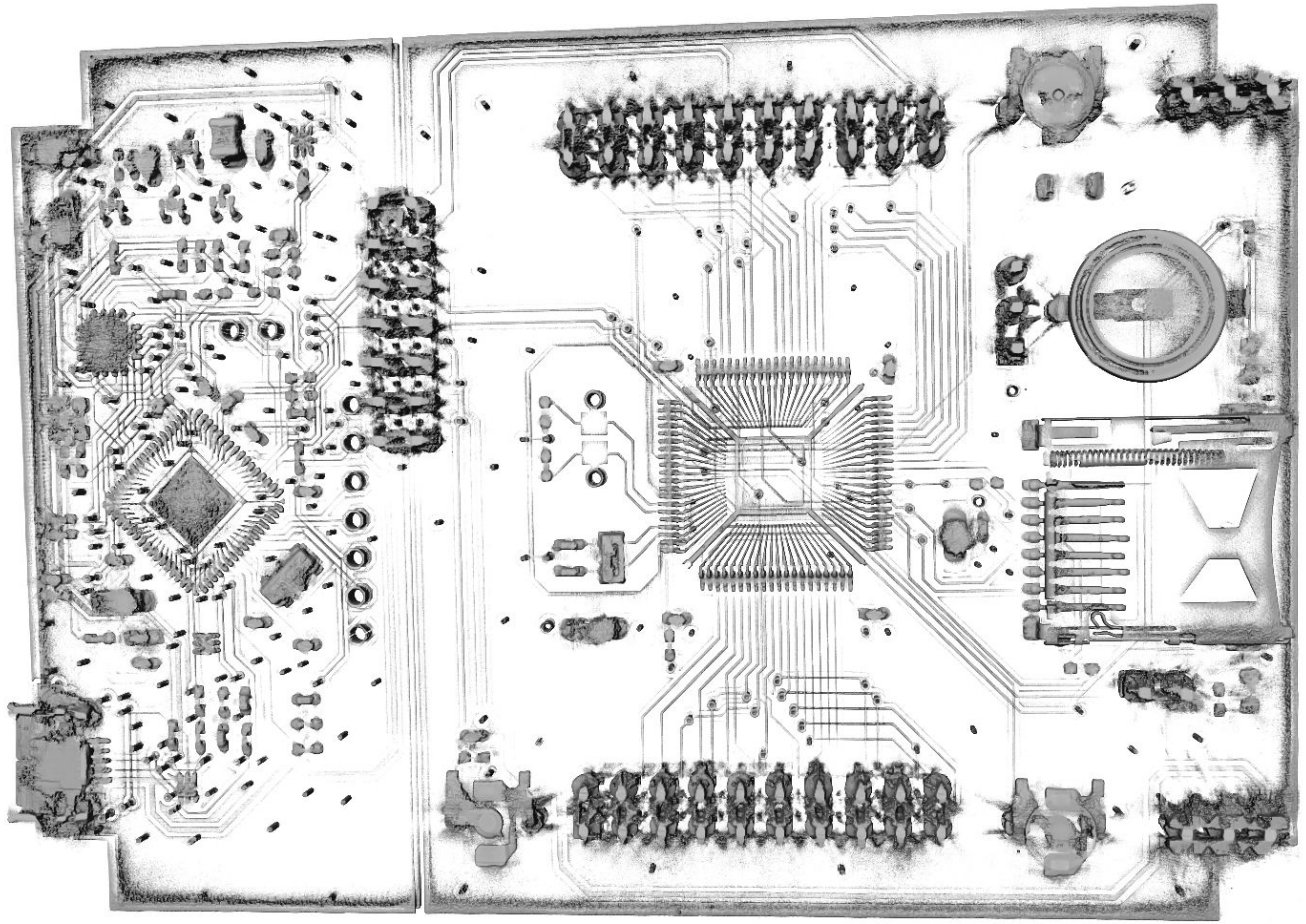


SIGRAY

Apex XCT Example: Ti LaunchPad Board

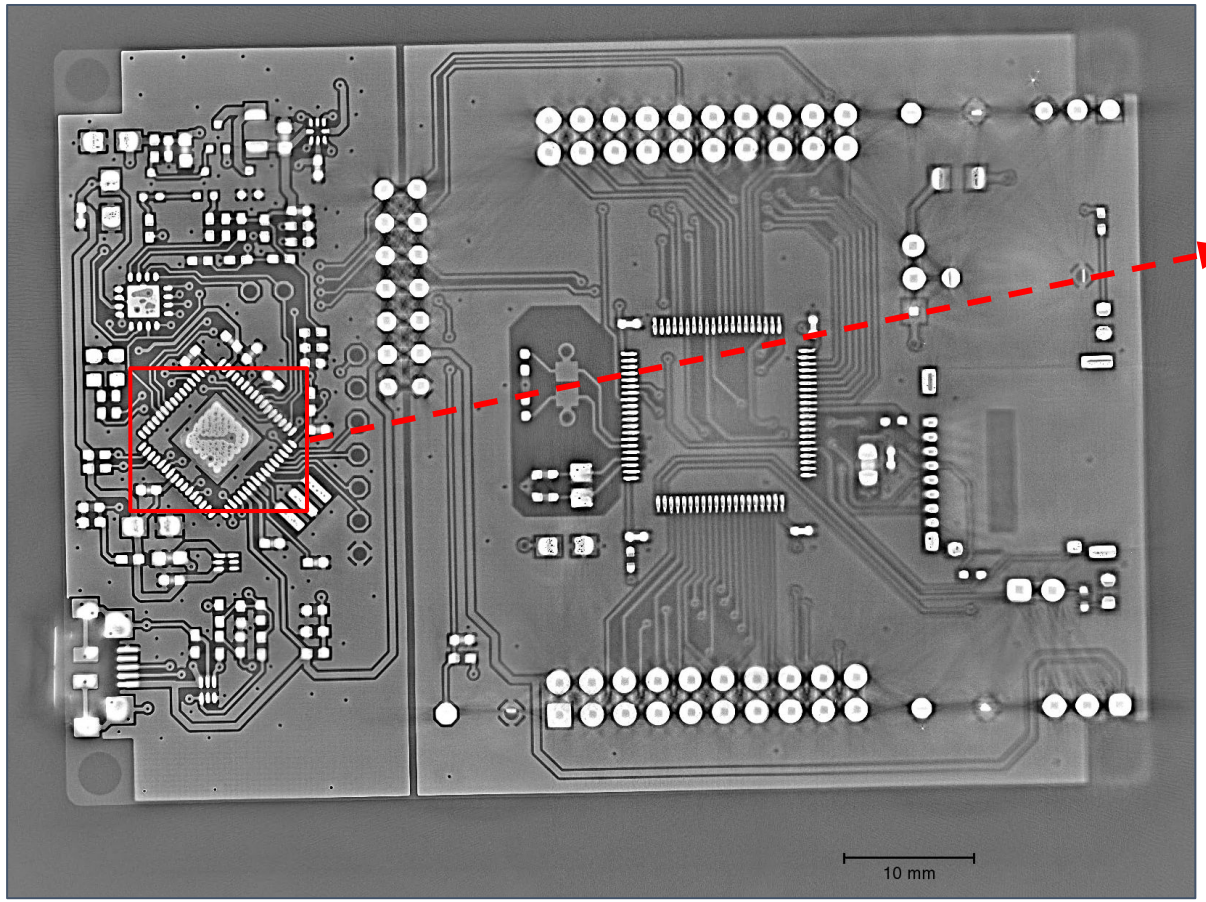
Full Device Mapping at 8 µm

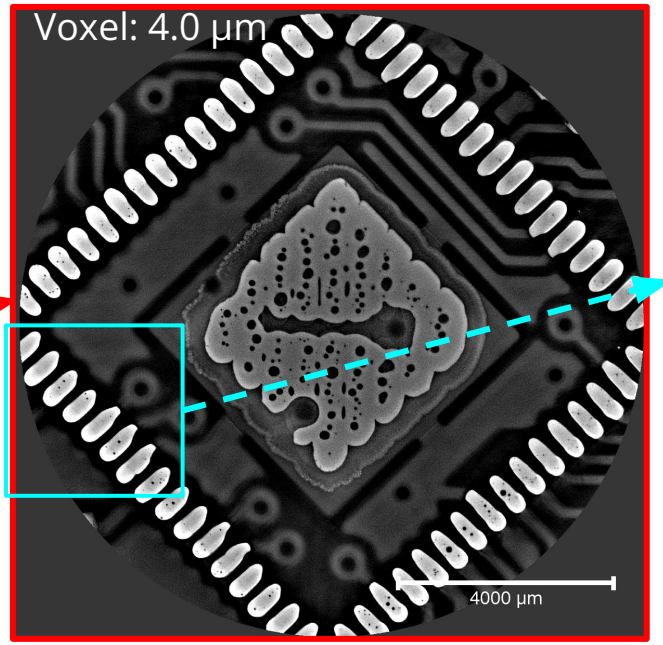
- 20 volumes collected and stitched together
  - 4 rows x 5 columns
- 12 hours total acquisition time
  - 36 mins/scan x 20 scans
- 8.0 µm voxel size
  - Full 8 µm voxels preserved in final stitched volume

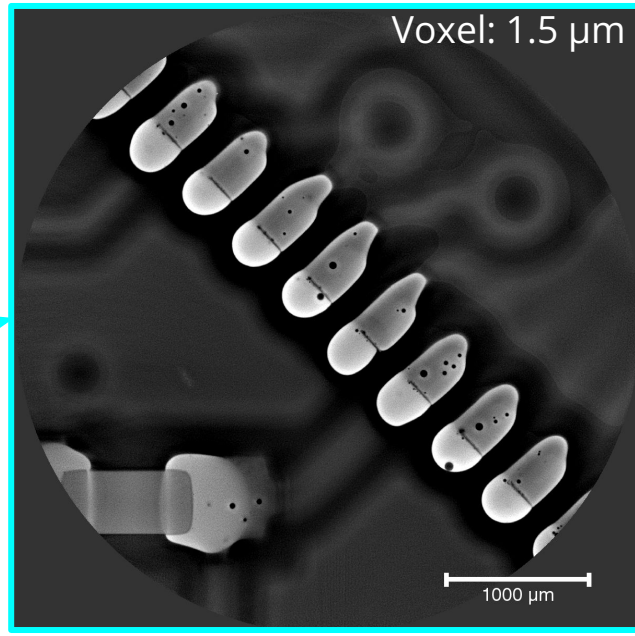


High Resolution, Large Volume

Targeting Selected ROIs with High Resolution (1.5 µm Voxels)







- Multi-scale imaging links the macro-, meso-, and micro-scales
- Targeted, data-driven inspections reveal fine-scale features in solder connections

SIGRAY

Apex XCT-300 Series

Full Automation | Optional Integrated EFEM | Wafer Support up to 300 mm

Coming: Q4 2024

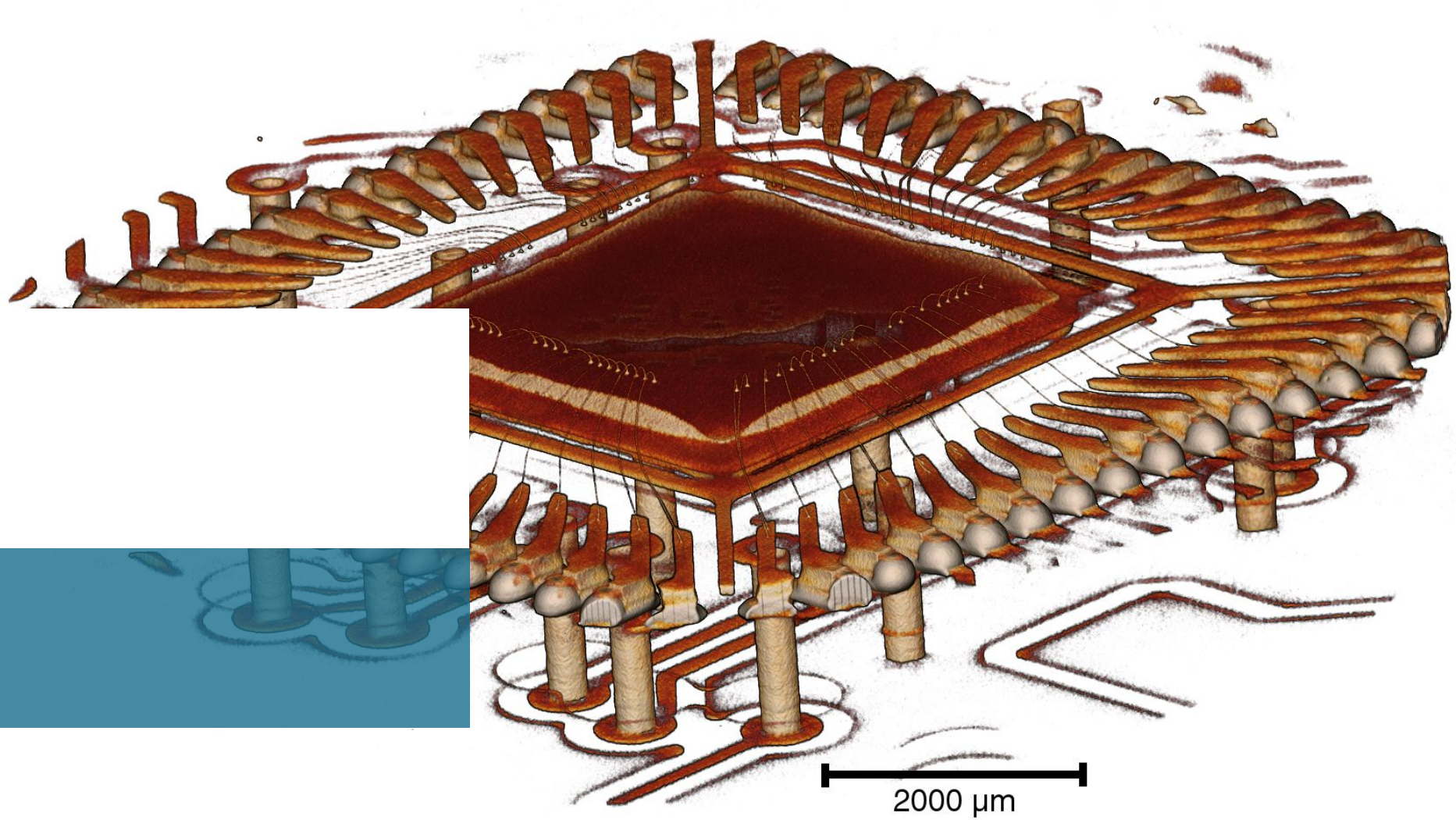
Coming Soon!
Apex XCT-300E / Apex XCT-300W

- **Industry-Leading Resolution: 500 nm**
- **Fast Site Inspection: Up to 10 WPH**
- **EFEM-Compatible (Optional Factory Integration)**
- **Support Wafer FOUPs to 300 mm**
- **Automated Recipes: Scan + Analysis Report**
- **Full Host Communication API w/ SECS/GEM**

SIGRAY

Summary

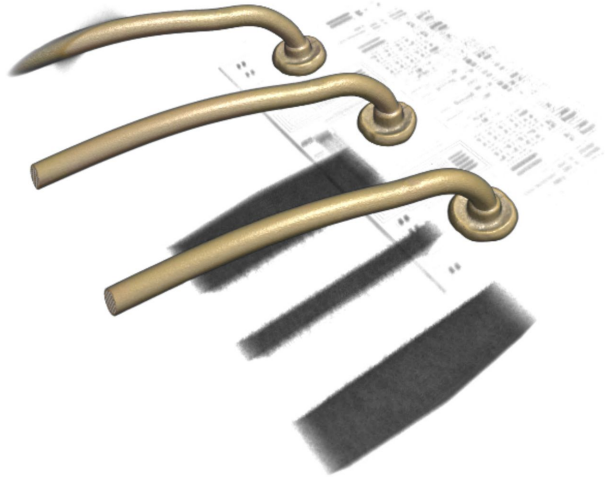
Component on Intact PCB imaged with Sigray Apex XCT at 1.5 micron



Summary

Advanced X-Ray Imaging Technologies for Heterogeneous 3D IC Package Metrology and Inspection

- ❏ 3D X-ray can provide **resolution down to 0.3 µm**, to satisfy next-generation demands.
- ❏ Automated, high-throughput 3D part inspection is now available, capable of handling of dies, PCBs, & wafers **up to 300 mm**.

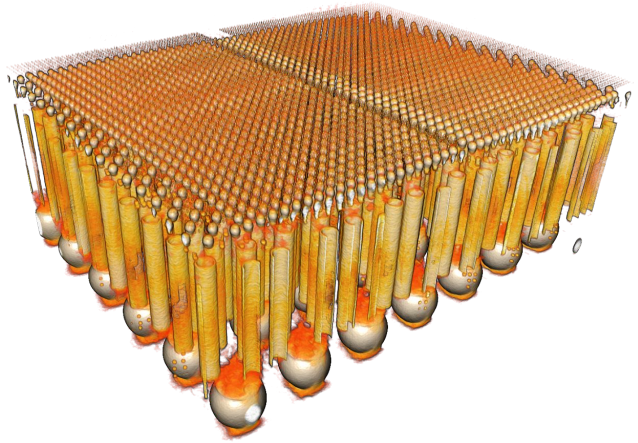


Resolution to 300 nm

Optimized Throughput

Highest Clarity

Automated Data Handling



Thank you for your attention!

jgelb@sigray.com

SIGRAY