A Novel 2D/3D X-ray Microscopy Alignment and Inspection Solution for Thermocompression Bonding (TCB) in a Highly Integrated Flip Chip Fan-Out Wafer Level Package (FO-WLP)

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Agenda

- Packaging Strategies & Challenges
  - FC FO-WLP
- Experimental Setup
- Chip/Array Isolation & AI Training
- Boundary/Threshold Definition for Analysis
- Statistics & Scan Method Comparison
- Conclusion/Future Work
- Q&A

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Packaging Strategies & Challenges

- **Various strategies**
  - Increased data rates
  - Wide I/O counts
  - Highly integrated functionality SiP
  - Opportunities for HI (BoB)
  - Modularity (chiplet)
  - Overarching PPAC concerns

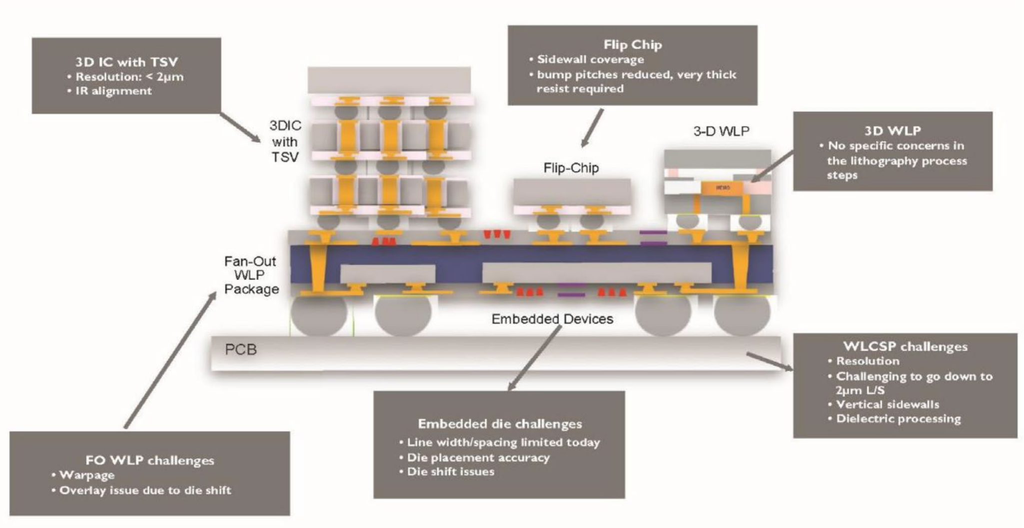


Image courtesy Yole (2015)

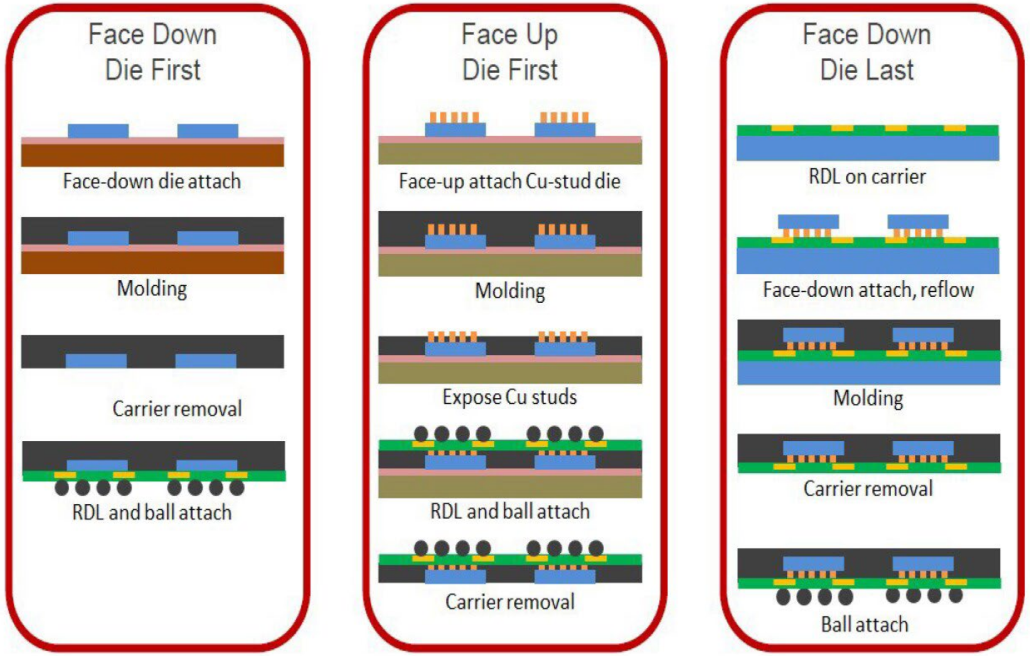
- **Each strategy has benefits and challenges**

- **FO-WLP**
  - Lower thermal resistance
  - Reduced package size and cost
  - Embedded passives (V reg, C) reduces system loss

Packaging Strategies & Challenges

- **Face-down/up die first (mold first)**
  - Die shift w/over-molding
  - Worsens with large die
  - RDL litho problematic at small CD
- **Face-down die last (RDL first)**
  - Line and space resolution limited

Typical FO-WLP approaches



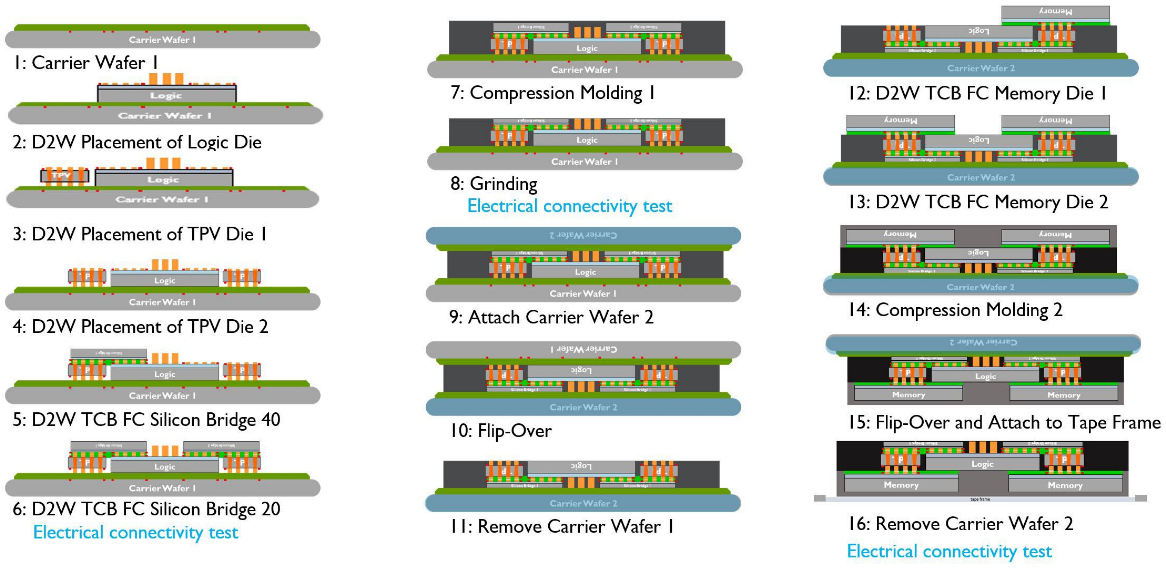
Packaging Strategies & Challenges

- **Flip Chip FO-WLP**
  - Lower die shift
  - Interconnect prior to molding
  - Enables bump small pitch
  - Thin final package

- **Challenges**
  - Die shift still possible (electrical test)
  - Alignment (logic/TPV) critical
  - Additional die stacking (HBM) requires localized reflow

- **Thermocompression Bonding (TCB)**
  - Die tilt, placement, ball dimensions, chip gap height critical to successful bond

Flip Chip FO-WLP



Podpod et al, IMEC (2019)

Packaging Strategies & Challenges

- **Thermocompression bonding (TCB)**
  - Ideal for large die area
  - Chip gap height closely controlled compared to mass reflow
  - Ability to control accuracy and repeatability in the x,y plane
  - Ability to control chip gap height in the z-plane
  - No-flux processes can create challenges to wettability

❖ Non-destructive analytical technique in 3-dimensions needed

Besi TC Advanced

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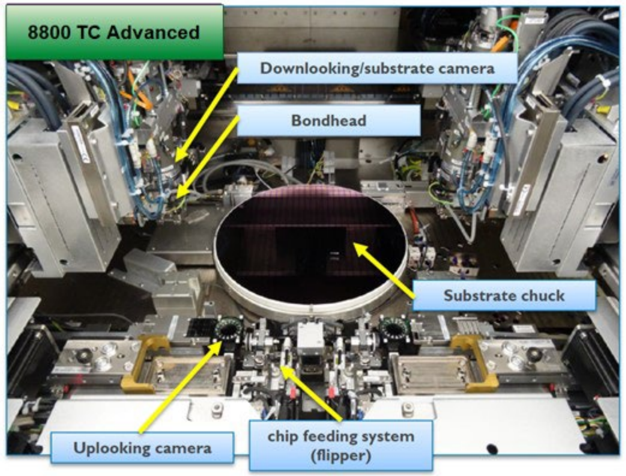
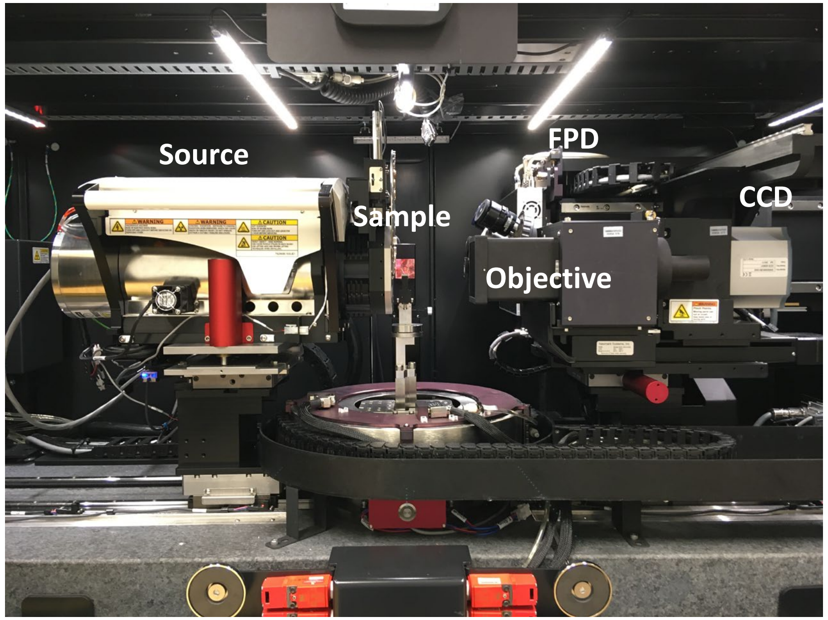
Experimental Setup

- **Besi TC Advanced FC System**
  - Die bonding
- **ZEISS Xradia Versa 620 3D X-ray Microscope**
  - Flat panel scan (CT) to identify ROI
  - CCD (XRM) for adequate detail of ROI
  - DeepRecon Pro (AI) for improved TP
- **Additional software for vision algorithm**



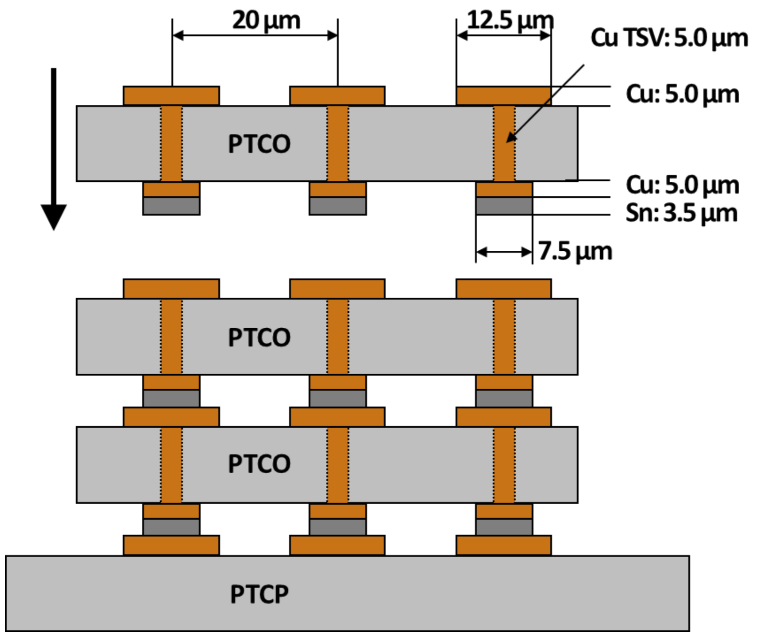


Experimental Setup

- **15-stacked 5mm^2 PTC-Type O die aligned and stacked on Type-P substrate**
  - 20μm solder bump pitch
  - 12.5μm x 5 μm top Cu
  - 5μm Cu TSV
  - 8.5μm Cu/Sn bottom

- Goal: quantitative/qualitative analysis of 3,828 periphery bump/via to validate alignment and bond

IMEC PTCO/P Die



Courtesy Besi

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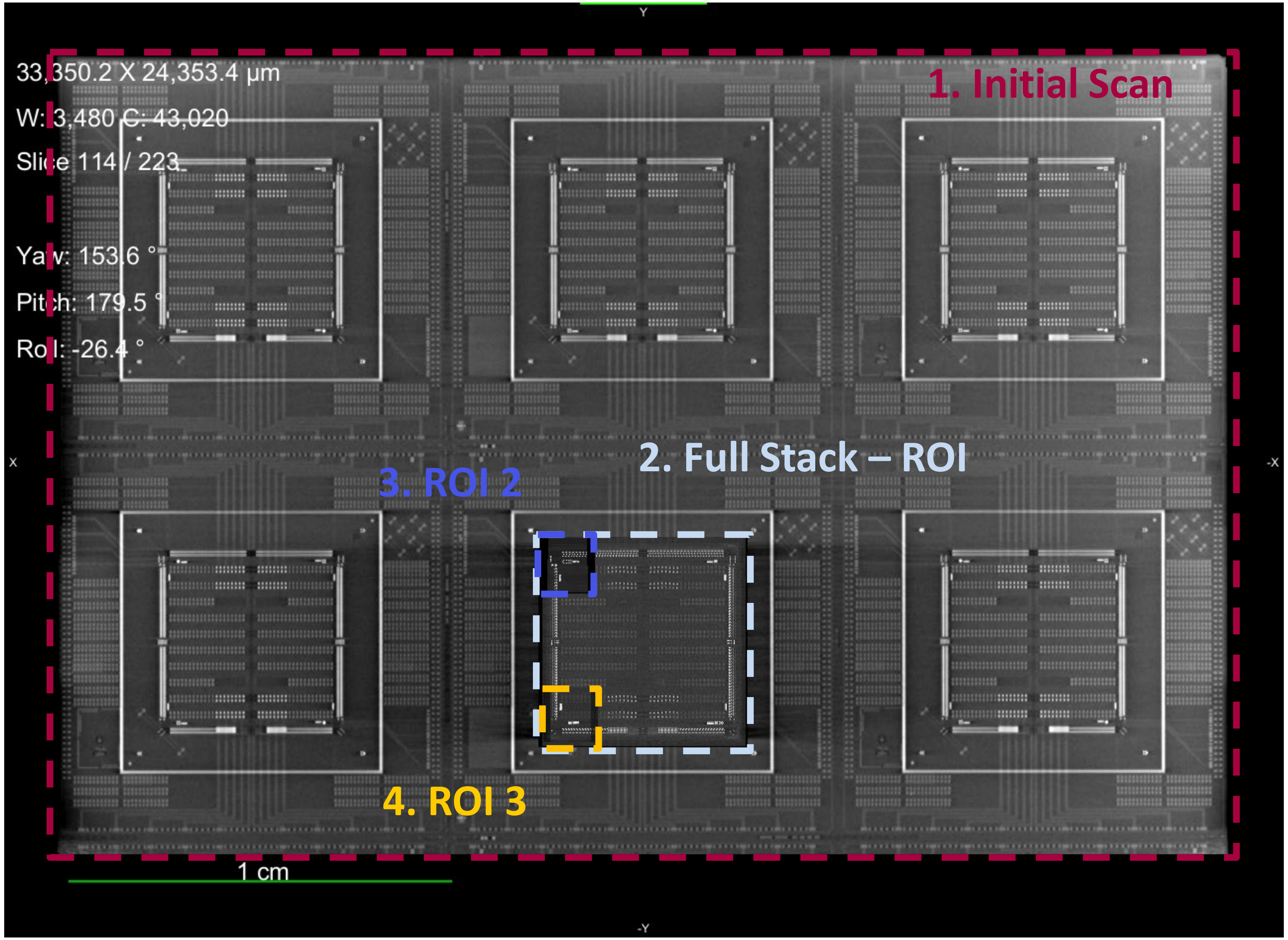
Chip/Array Isolation & AI Training

1. Initial Scan
   - Flat Panel (traditional CT)
   - 16 µm voxel
   - 42 min scan

2. Full Stack - ROI
   - 4x optical objective
   - 2.7 µm voxel
   - 10.9 hour scan

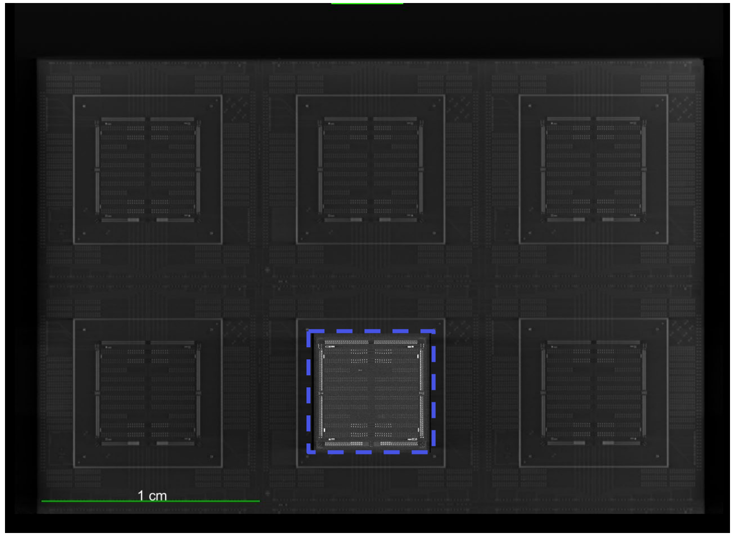
3. ROI 2
   - 4x optical objective
   - 0.7 µm voxel
   - 20.5 hour scan (full detail scan)
   - 1.4µm voxel, 2 hour scan (AI training)

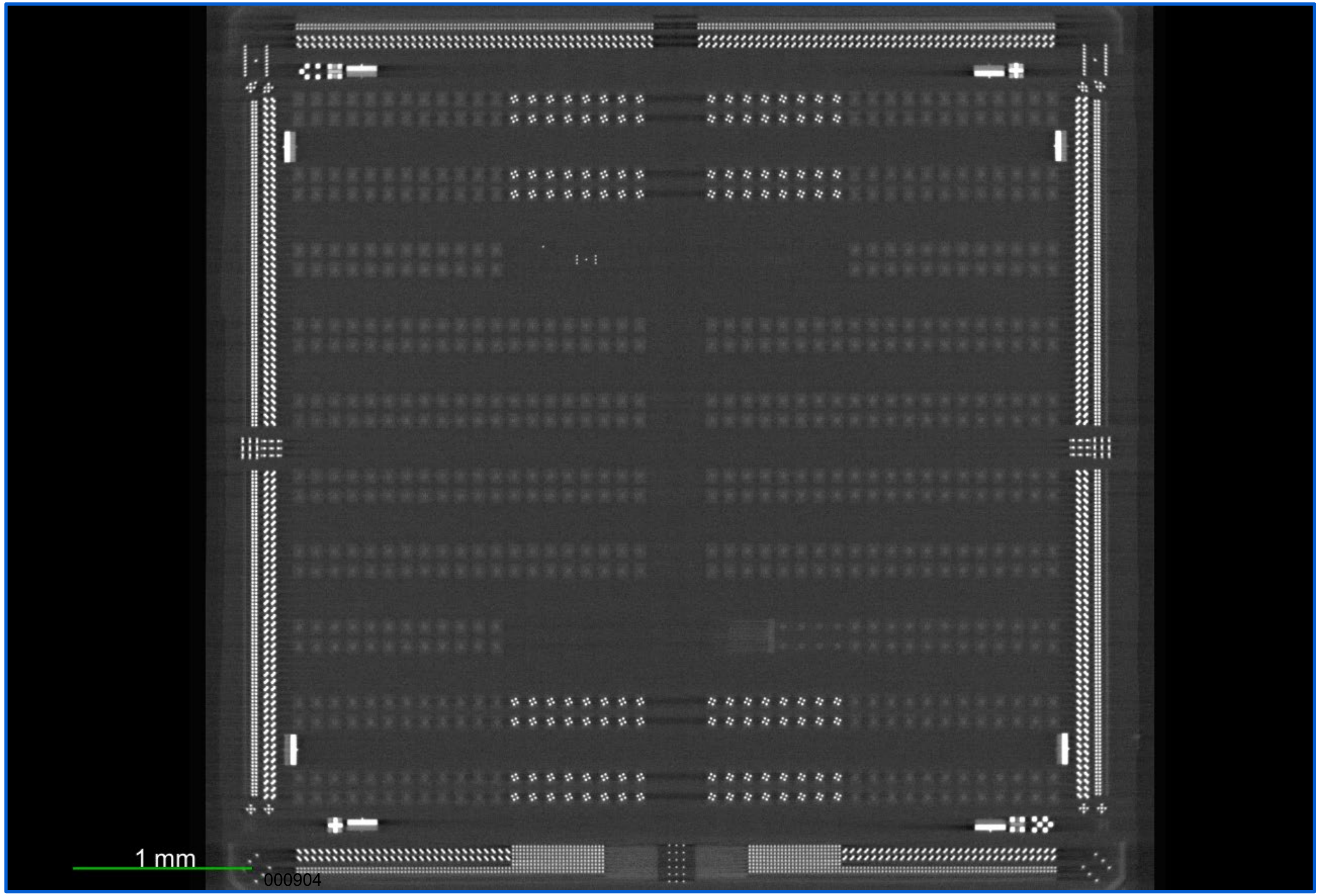
4. ROI 3
   - 4x optical objective
   - 0.7 µm voxel
   - 20.5 hour scan (ground truth)
   - 1.4µm voxel, 15 min scan (DeepRecon)



Chip/Array Isolation & AI Training

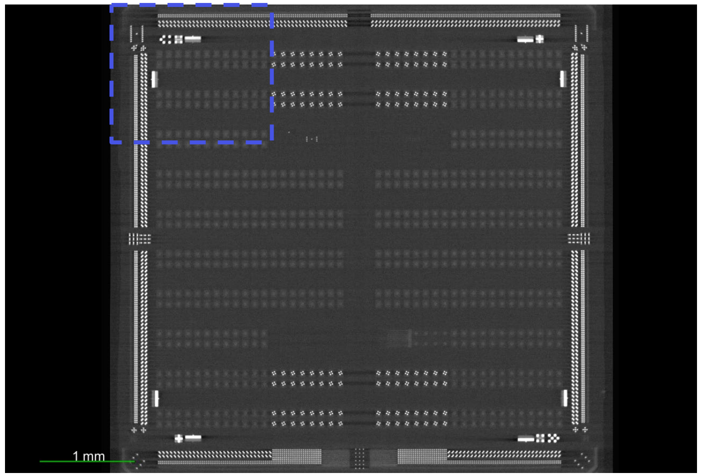
- Identifying ROI from full stack
- 4x objective
- 2.7μm voxel
- Sufficient resolution for line/space measurement of periphery array

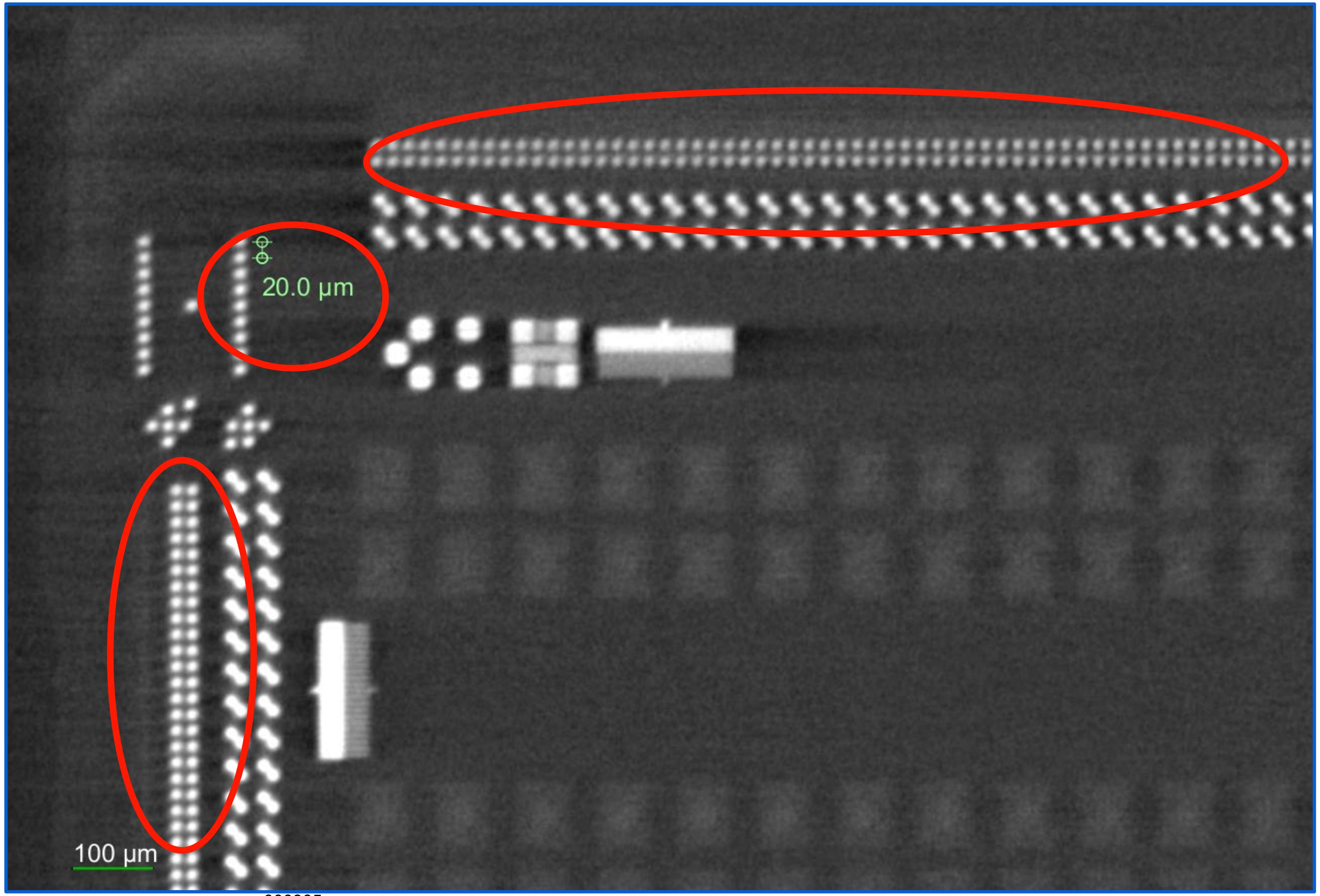




Chip/Array Isolation & AI Training

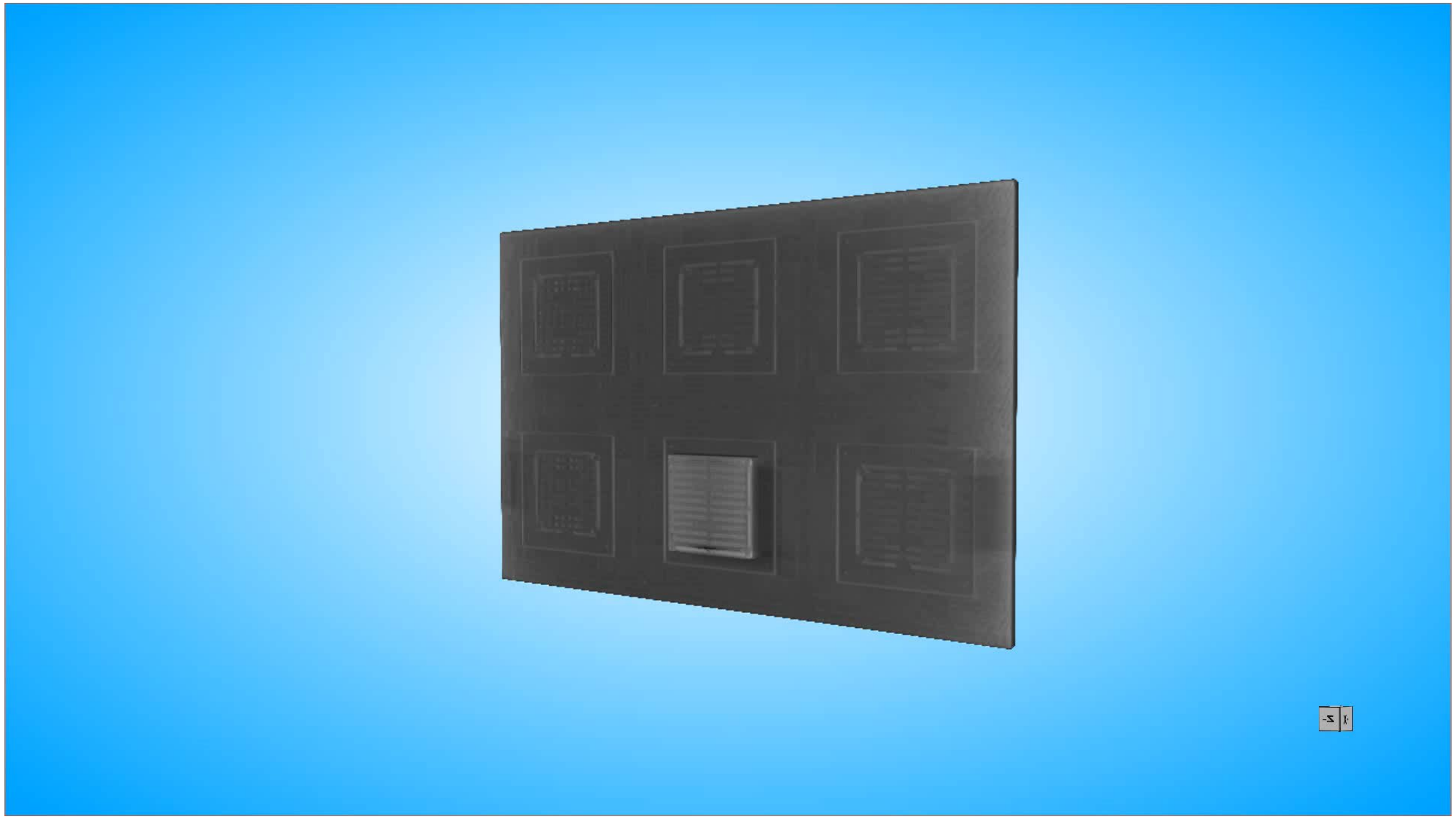
- 20µm bump pitch array verified
- ROI 2 selected (blue square)





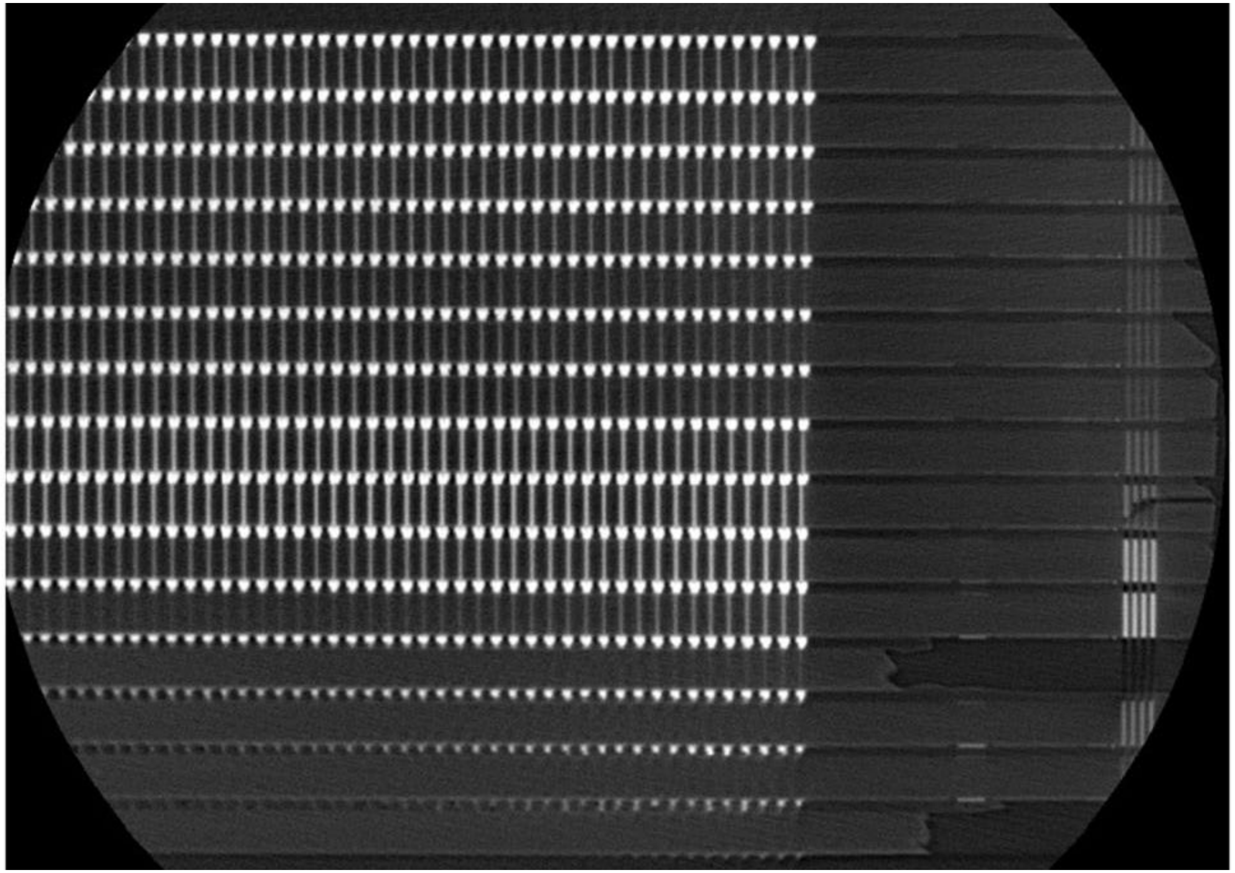
Chip/Array Isolation & AI Training

- **3D reconstruction animation of ROI 2**
  - 16μm voxel FPD scan
  - 0.7μm voxel XRM scan

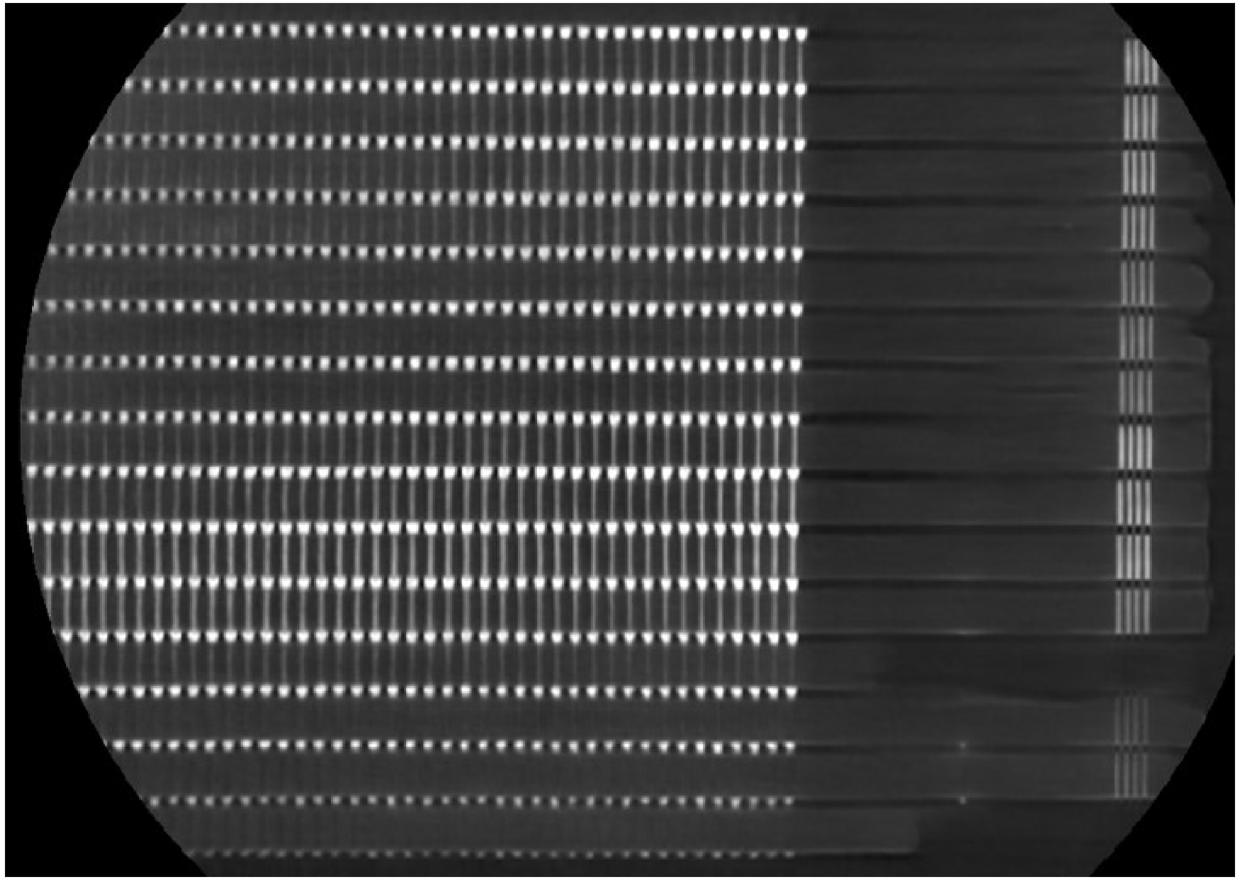


Chip/Array Isolation & AI Training

- **Virtual cross-sectional comparison of ROI 3**



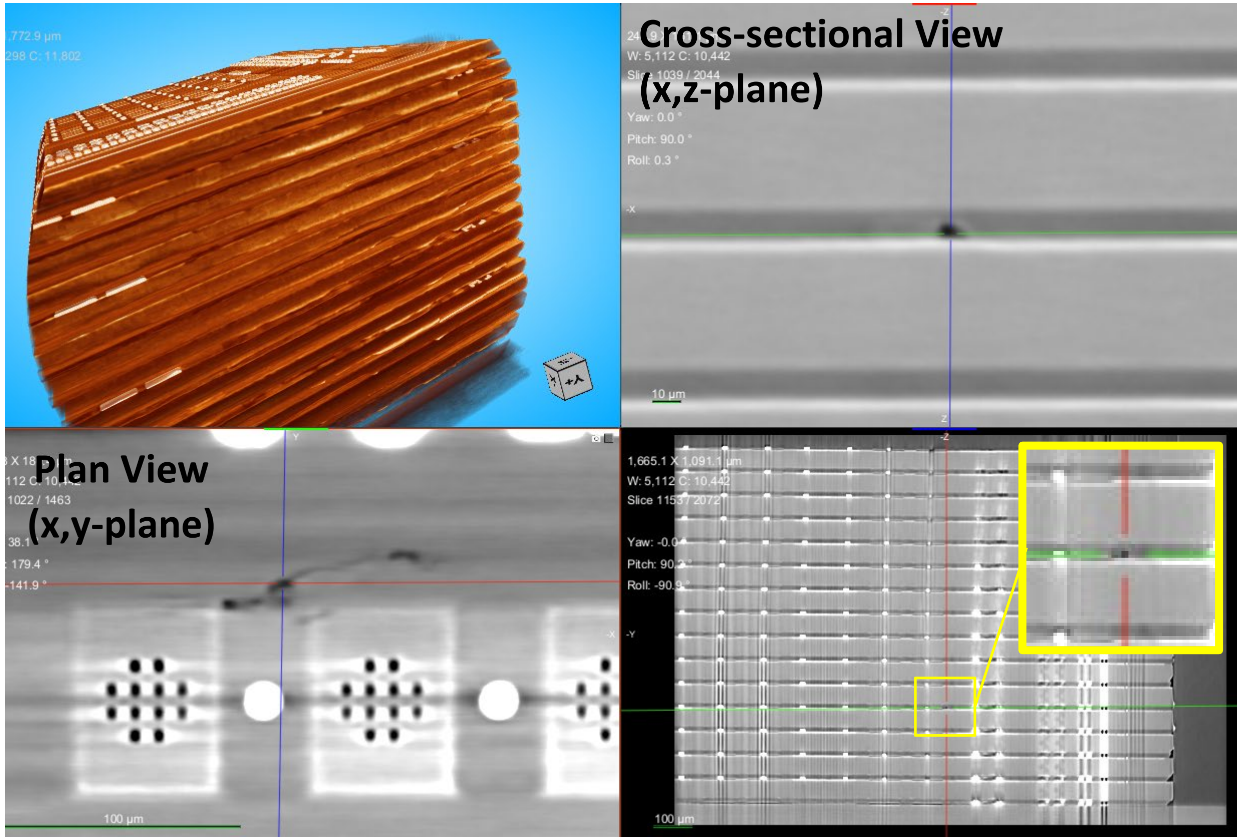
20.5h, 0.7μm voxel



15 min, 1.4μm voxel, DeepRecon

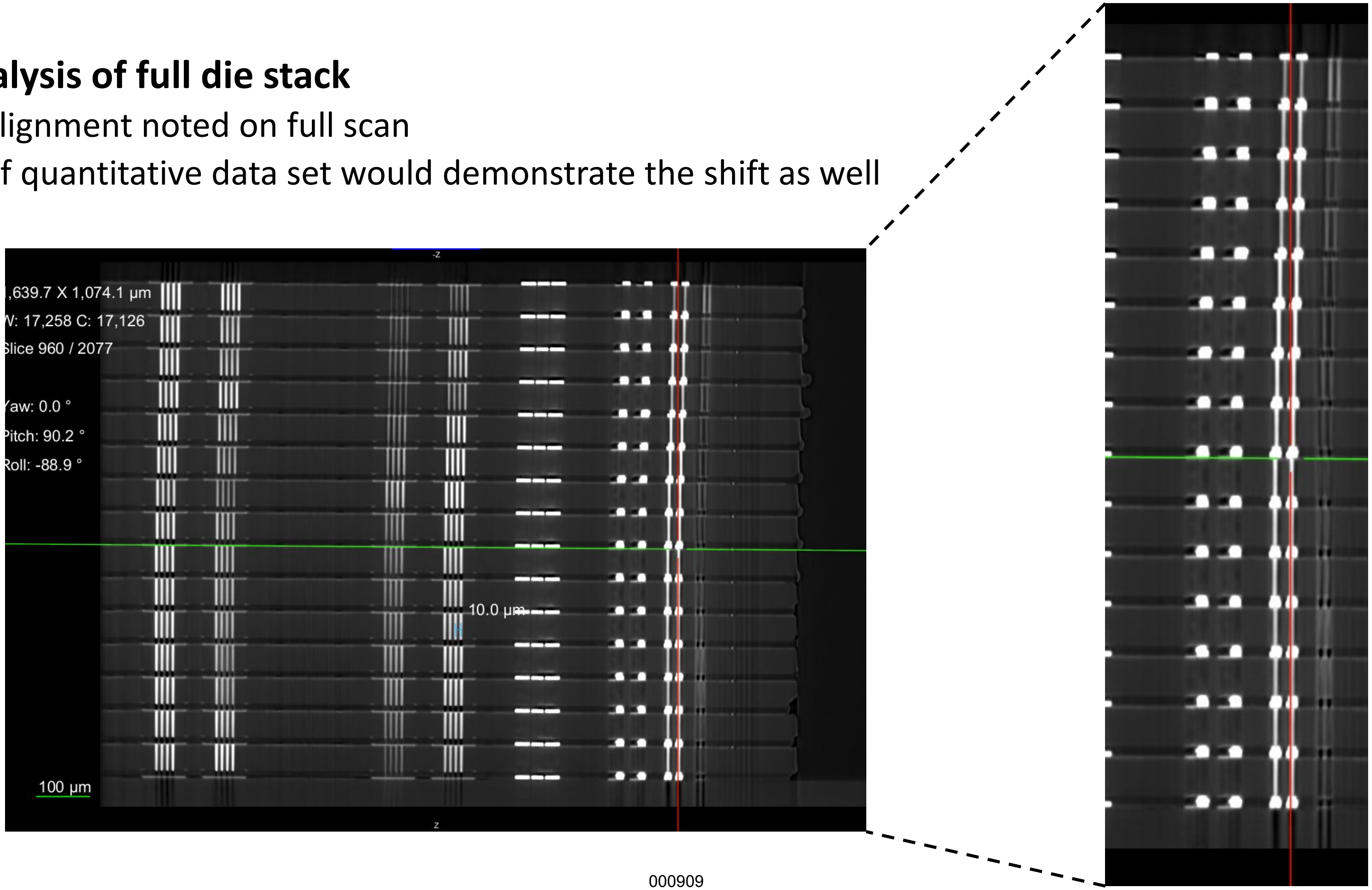
Chip/Array Isolation & AI Training

- **Defect detection in 3D**
  - 10μm buried underfill void looks isolated in single virtual cross-sectional view
  - Same void from virtual plan view shows void propagates significantly



Chip/Array Isolation & AI Training

- **Qualitative analysis of full die stack**
    - Global misalignment noted on full scan
    - Determine if quantitative data set would demonstrate the shift as well



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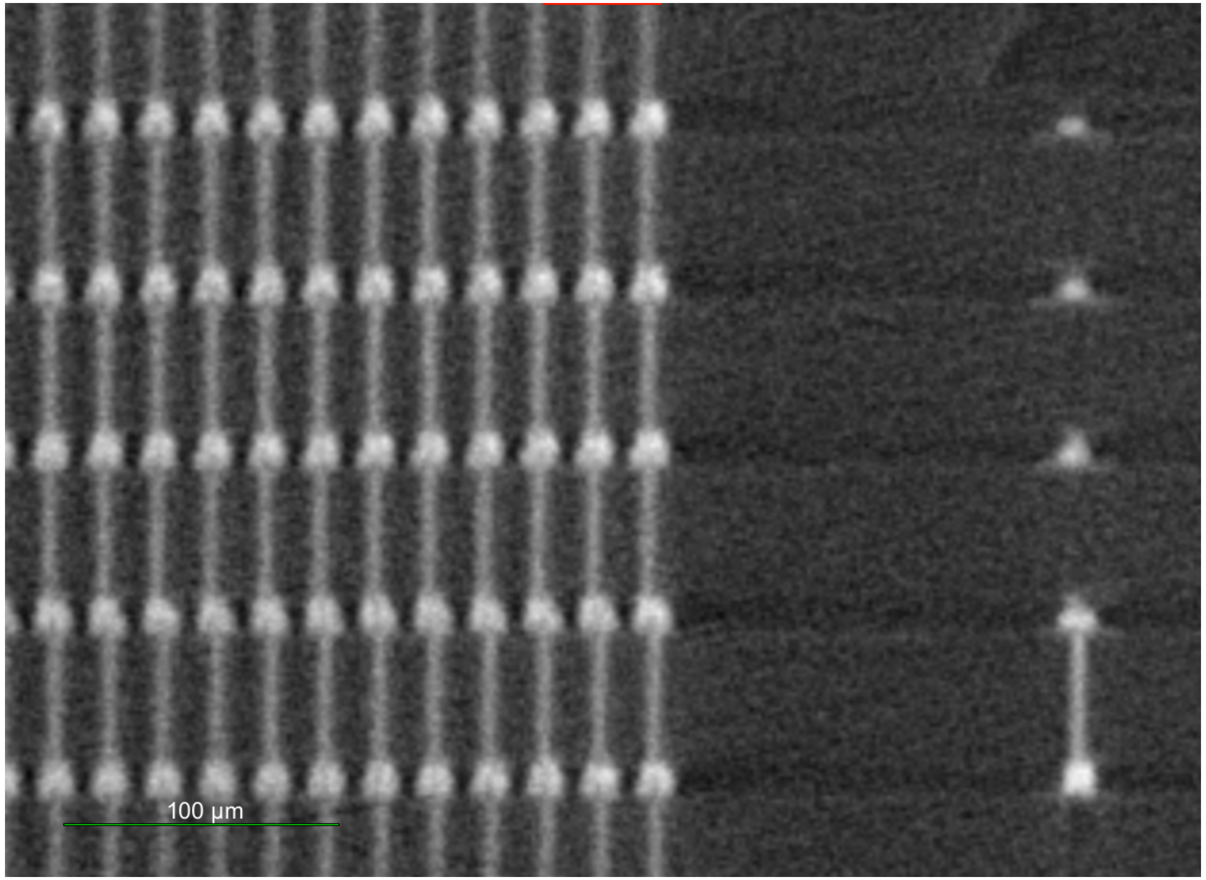
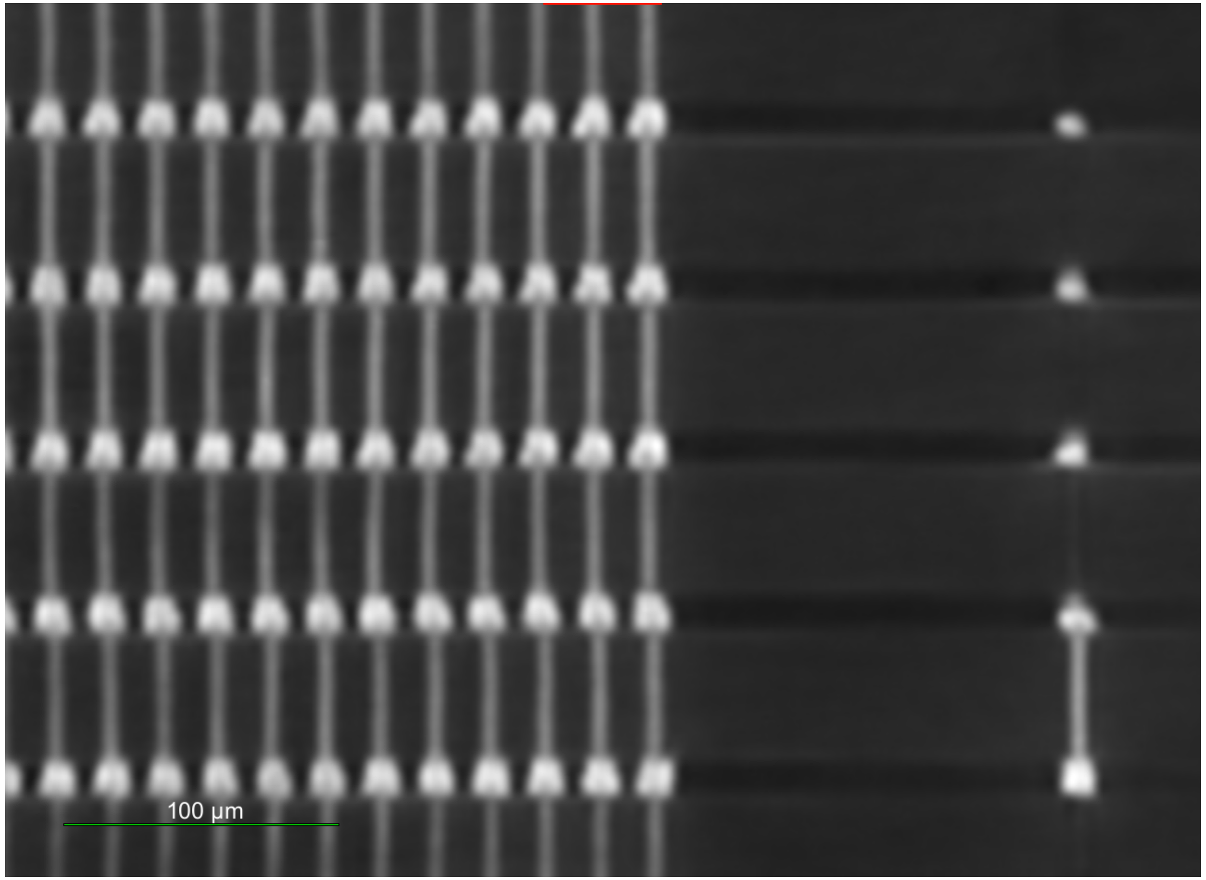
Boundary/Threshold Definition for Analysis

- **Virtual cross-sectional comparison of ROI 3: 4x objective, 1.4μm voxel size**
- **DR Pro provides sufficient noise reduction for accurate threshold determination**



2 hours, Standard FDK Reconstruction



15 min, 1.4μm voxel, DeepRecon Pro

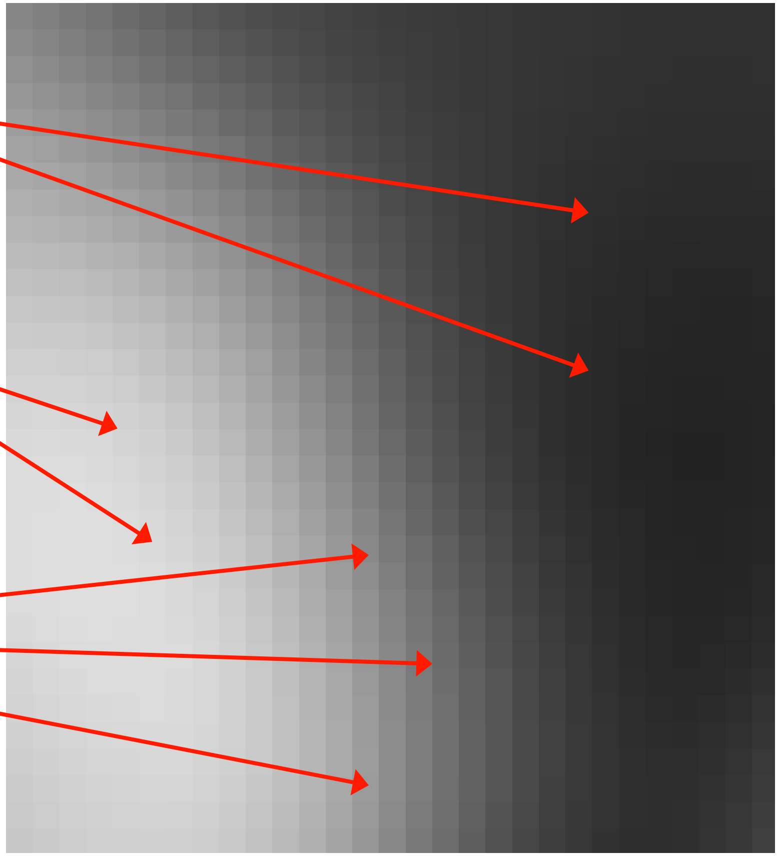
Boundary/Threshold Definition for Analysis

- **Threshold definition for bump and pillar analytics**

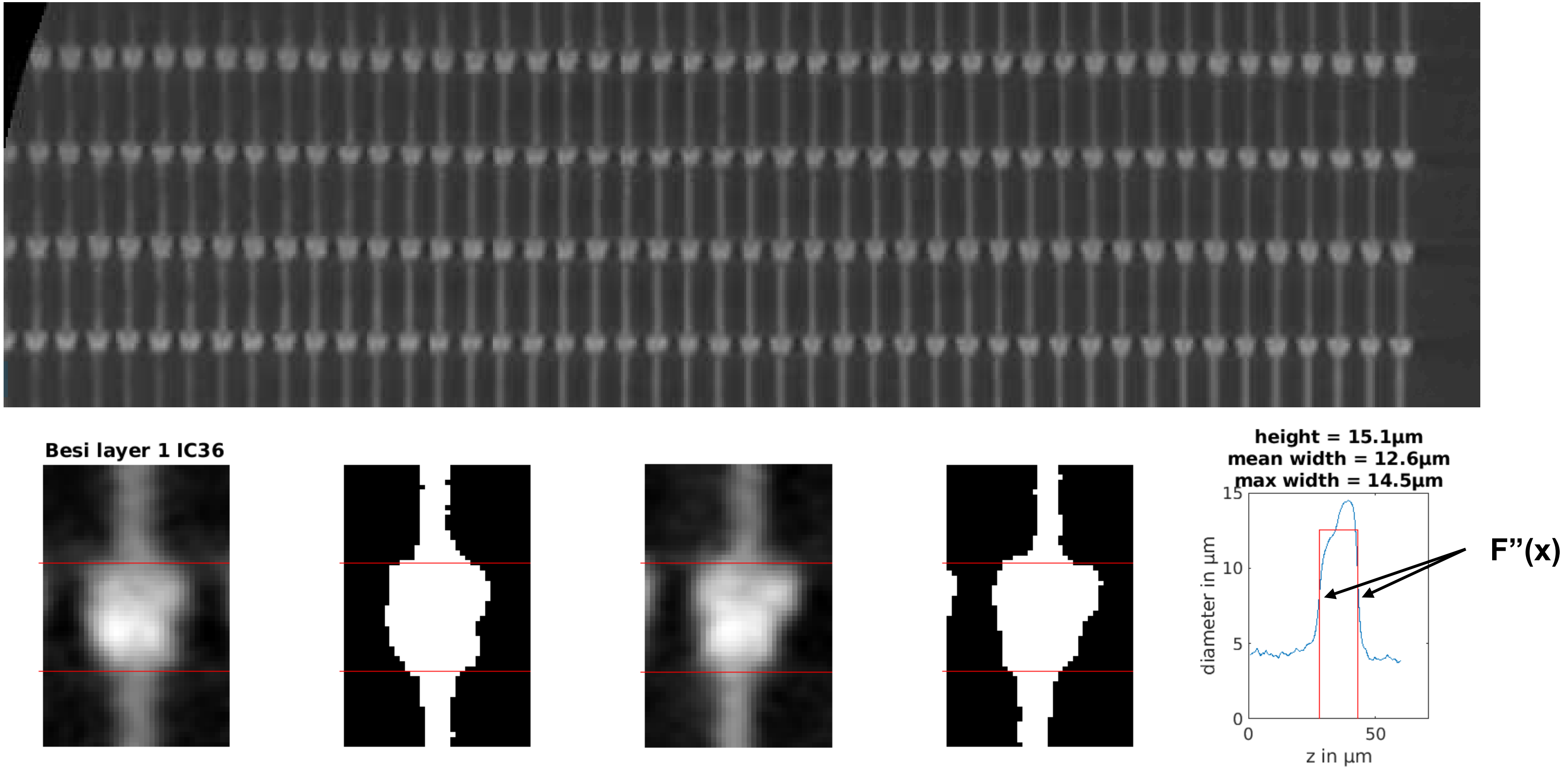
High-z is a solid black pixel (no metal)

Low-z is a solid white pixel (metal)

Greyscale pixels need to be binned to one or the other



Boundary/Threshold Definition for Analysis



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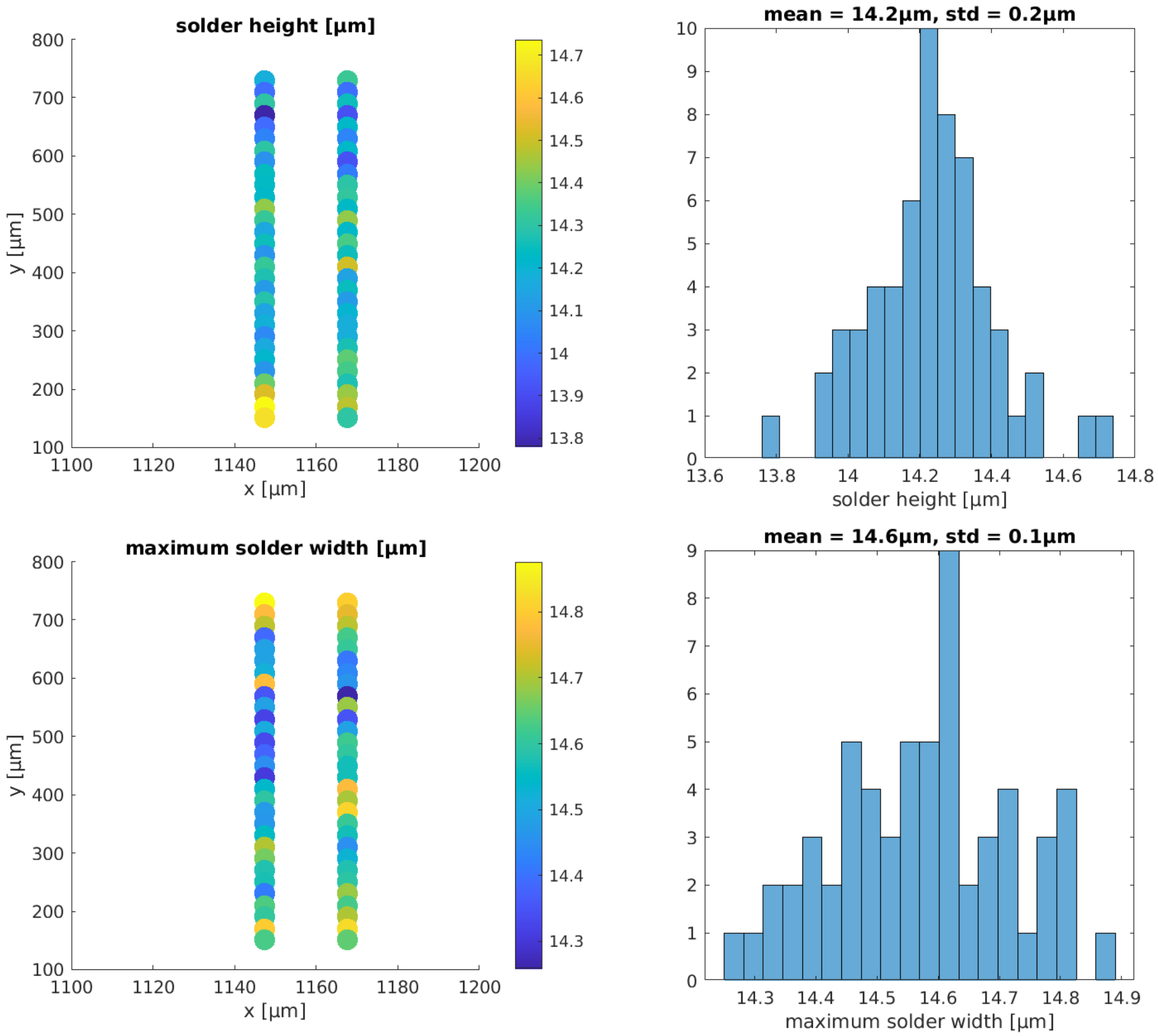
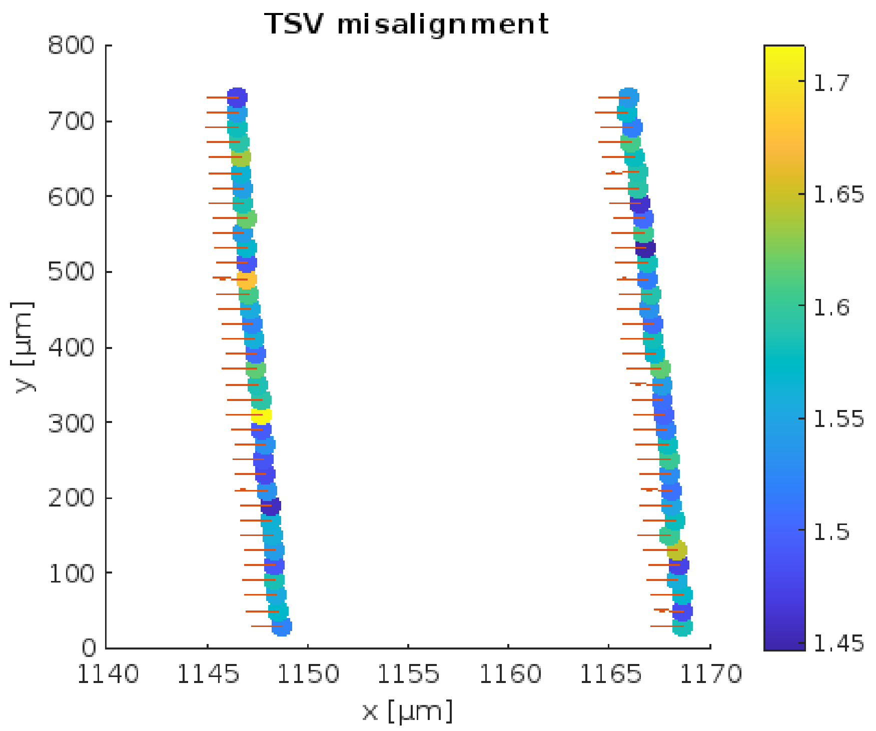
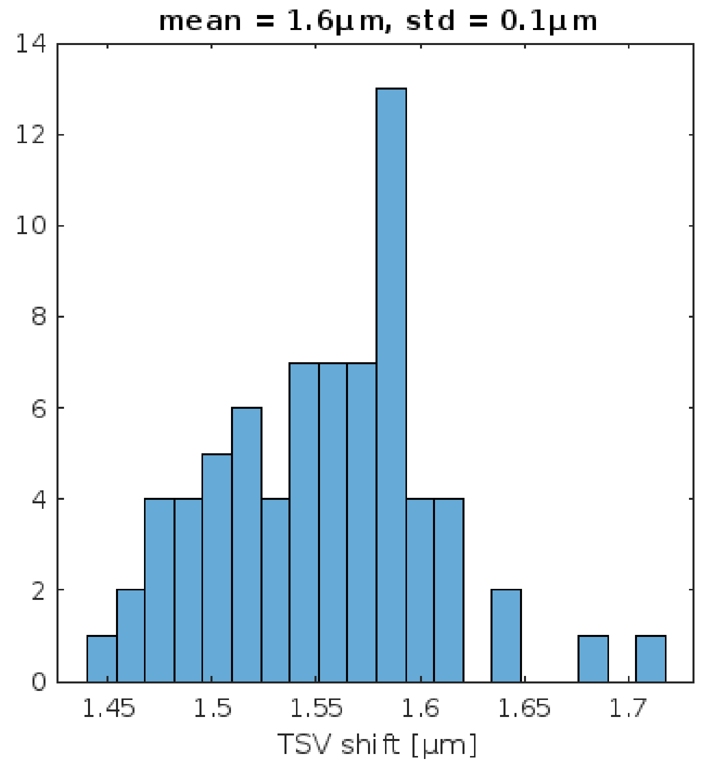
Statistics & Scan Method Comparison

- **X,y-coordinates based on predefined point of origin for individual array**
- **Each individual 15-layer stack within FOV represented as mean and max width**
- **Solder height (chip gap) and width (spread) shows reasonably tight distribution**
- **Excellent localized reflow confirmed statistically**



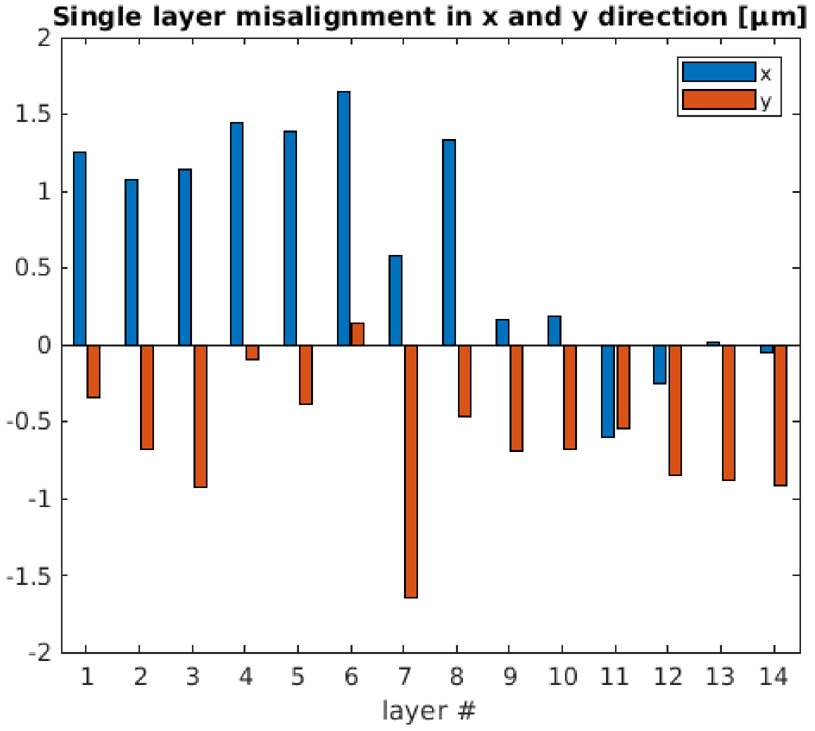
Statistics & Scan Method Comparison

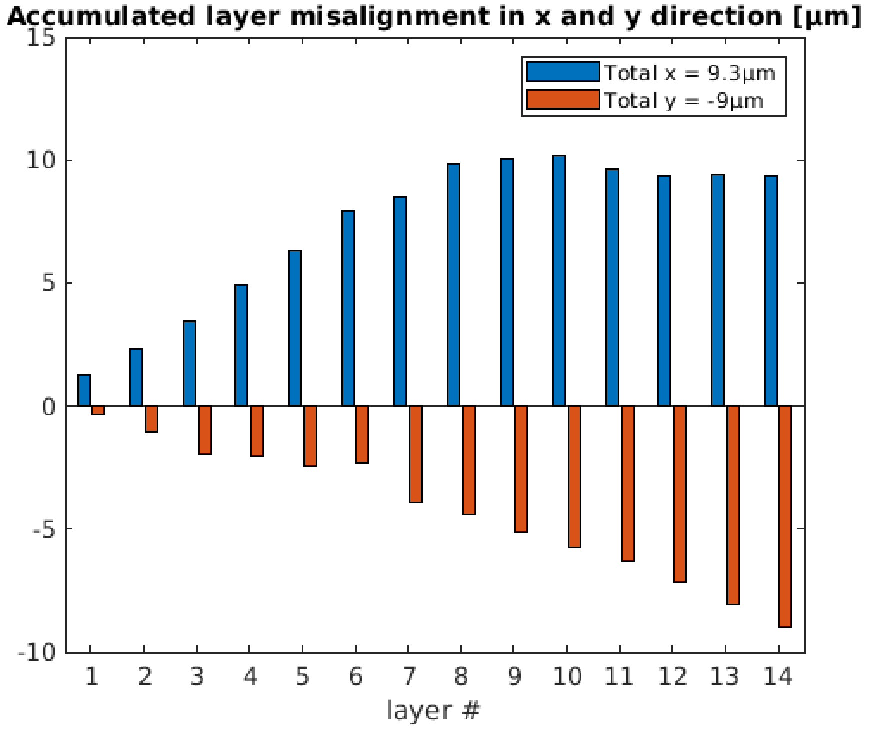




- **Vectors for each bump/via represent shift from expected position in array (not to scale)**
- **Local alignment excellent**
- **Global drift of stack confirmed**
  - **As expected, not substrate aligned (wasn't needed)**
  - **Easily handled with fiducials on substrate to align die-to-die and die-to-substrate**

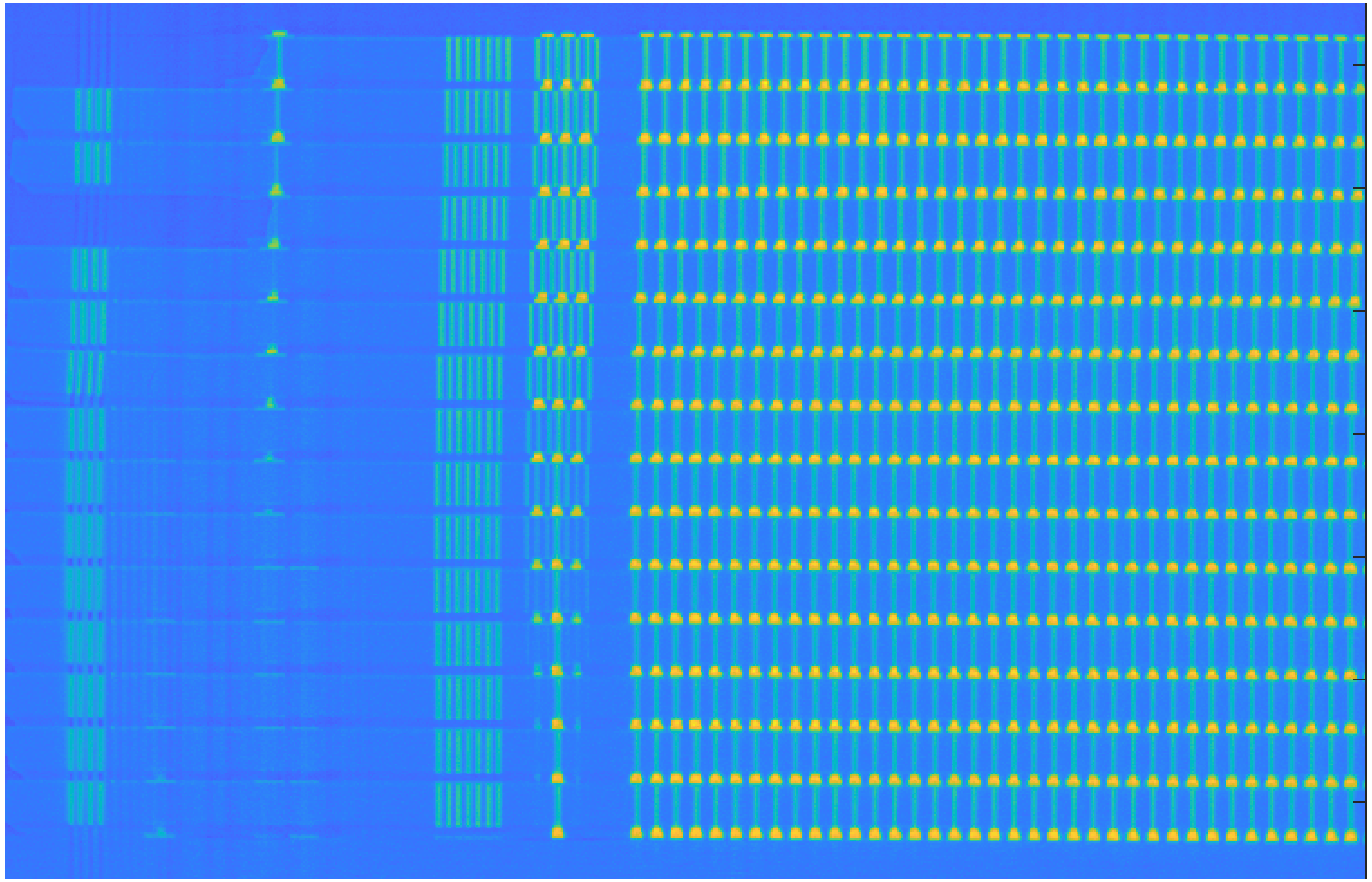
Statistics & Scan Method Comparison

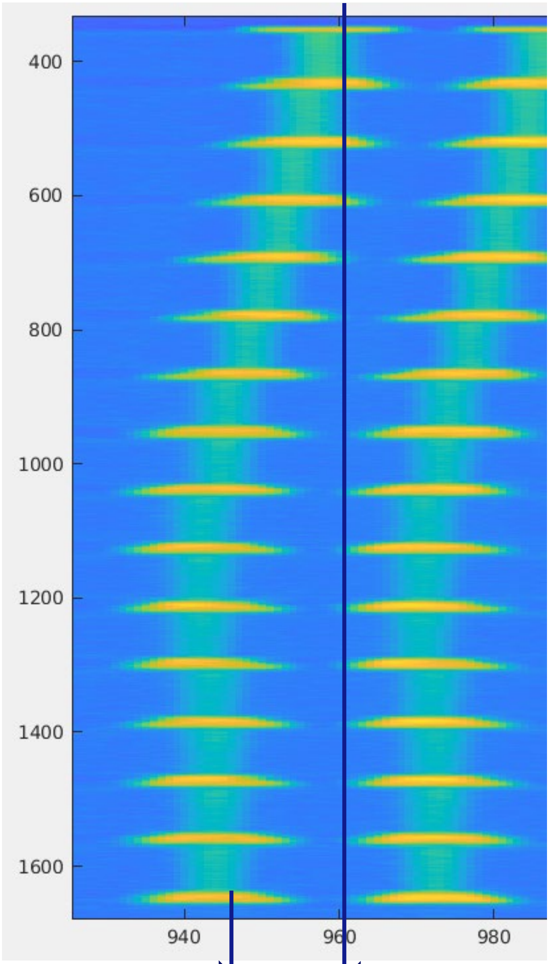




- **Analysis of a single 15-die bump/via chain (vertical) shows localized position misalignment is minimal**
- **Accumulated shift as structure progresses can be seen in global data**

Statistics & Scan Method Comparison



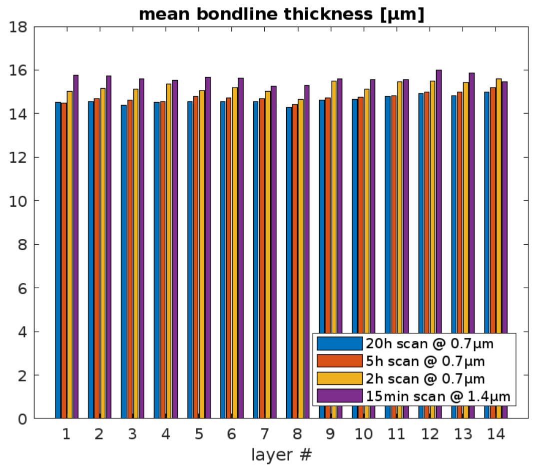


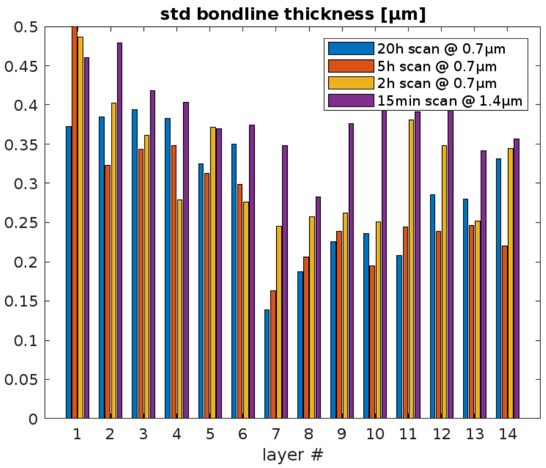
Δ=14px = 9.8μm

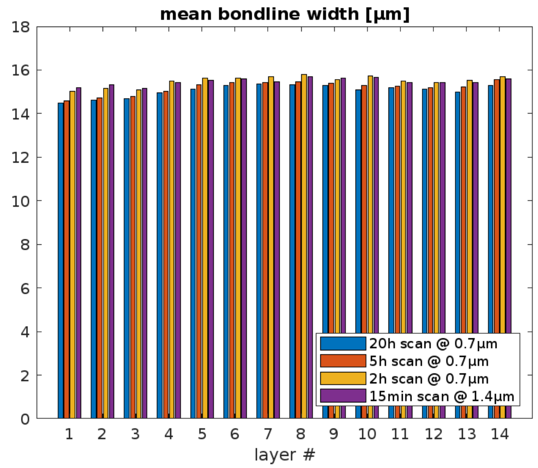
pixel number 944 958

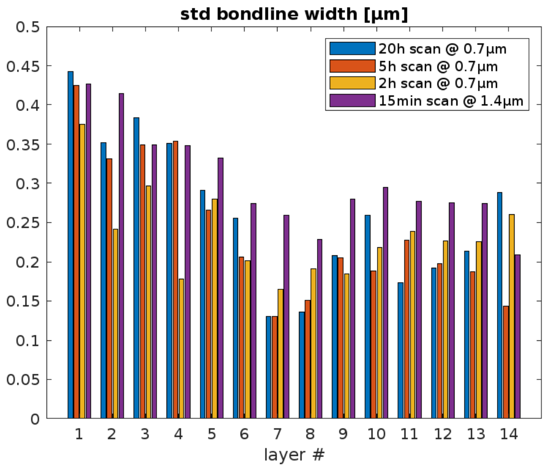
- **Pixel count, virtual cross-section confirms quantitative data set**

Statistics & Scan Method Comparison

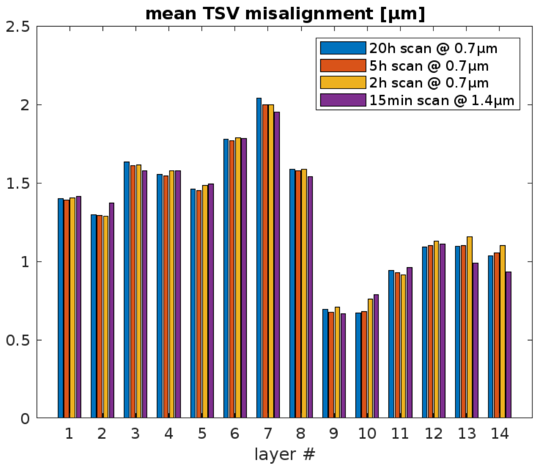


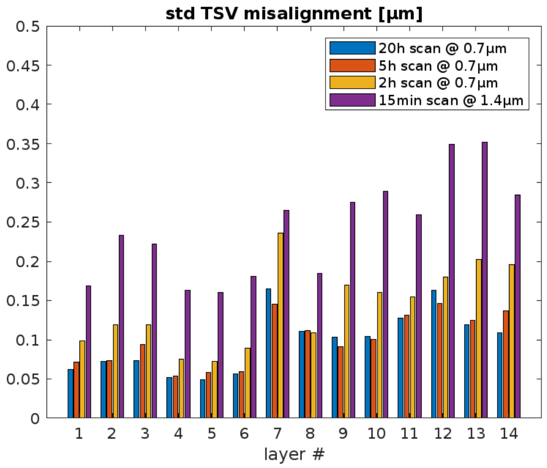






- Data comparison across FOV for each data capture/processing method
- Low variance among methods





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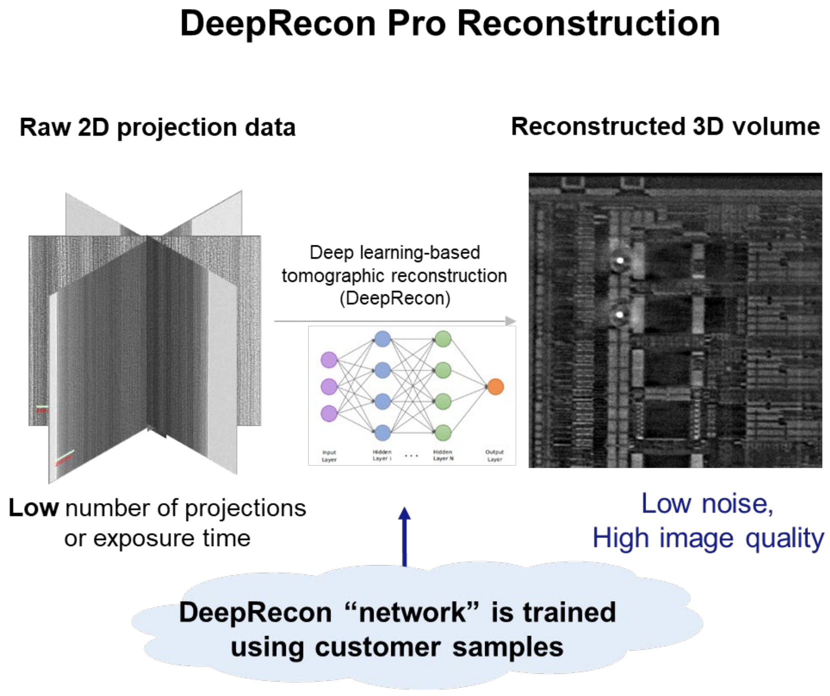
Conclusion/Future Work

- **Developed a novel 2D/3D non-destructive alignment and inspection solution for TCB via 3D x-ray microscopy, AI and machine vision algorithm**
- **Qualitative and quantitative evaluation of TSV and bump in all three spatial planes (x, y, z)**
- **Near-line capability for highly integrated packages with reasonable TP for process validation/development and error correction guidance**

Conclusion/Future Work

- **Additional implementation of new deep learning SW to improve data reconstruction and throughput**
  - Enable full array scan in minutes
- **Automation of data extraction through machine learning**
- **Improvement/development of threshold AI**
- **Automated detection of buried defects**
- **Segmentation based on pre-defined type across multiple toolsets (cloud)**



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Seeing beyond