

# High-Resolution 3D X-Ray Imaging of Hybrid Bonding

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ICEP-HBS | Hiroshima, Japan | 2026

Slides



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# Outline



## Introduction

- 3D X-ray imaging in advanced packaging
- X-ray Imaging basics
- Nano-CT & Laminography



## Methodology

- Imaging setups
- Sample – AMD Ryzen 7 5800X3D



## Results

- Nano-CT of hybrid bonding
- Laminography of hybrid bonding
- Improving data quality with iterative reconstructions
- Metrology



## Conclusions

Slides



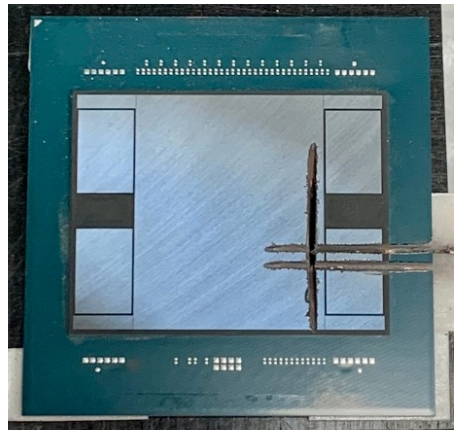
[excillum.com/icep-hbs-2026/](https://excillum.com/icep-hbs-2026/)



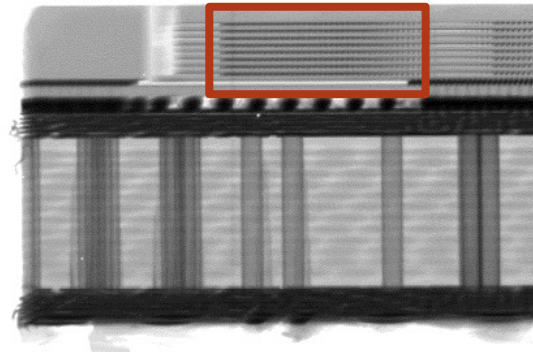
# Introduction

# X-ray Imaging in Advanced Packaging

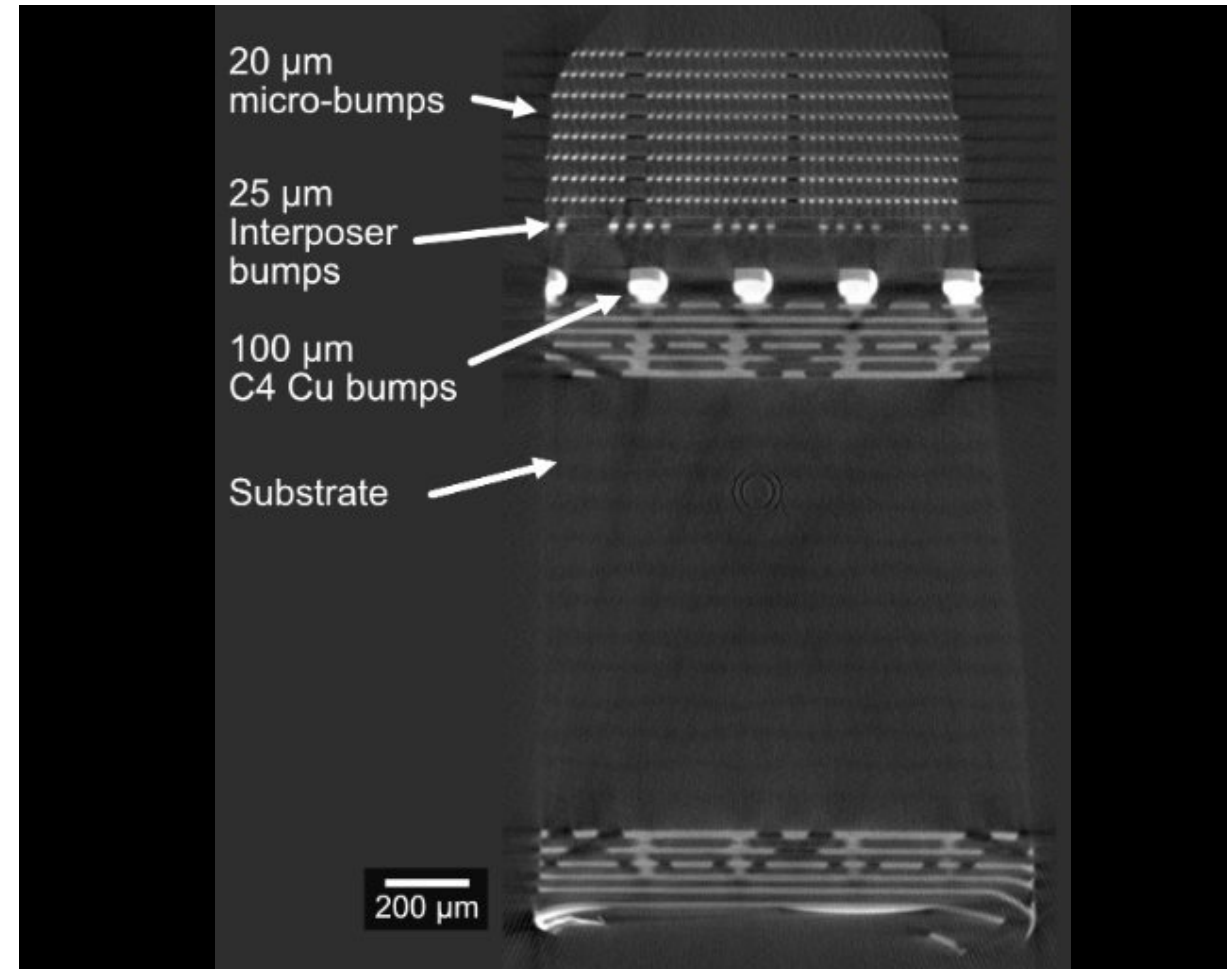
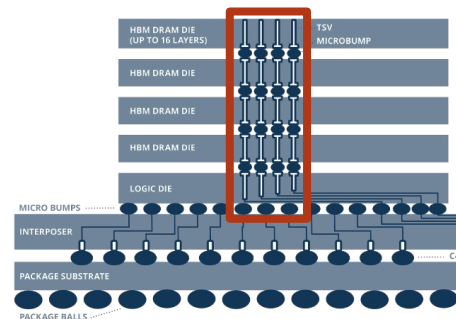
Commercially available GPU with HBM



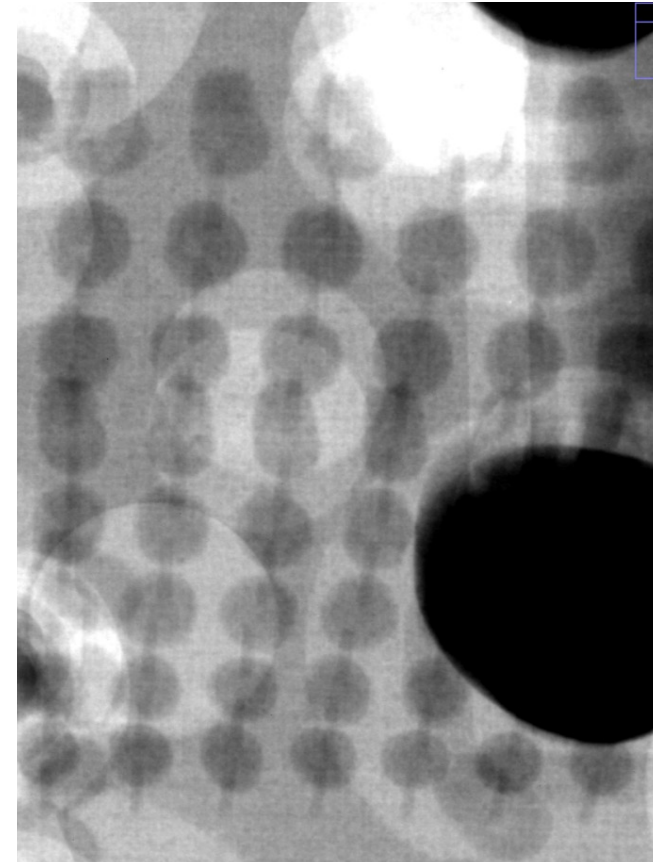
2D X-ray overview



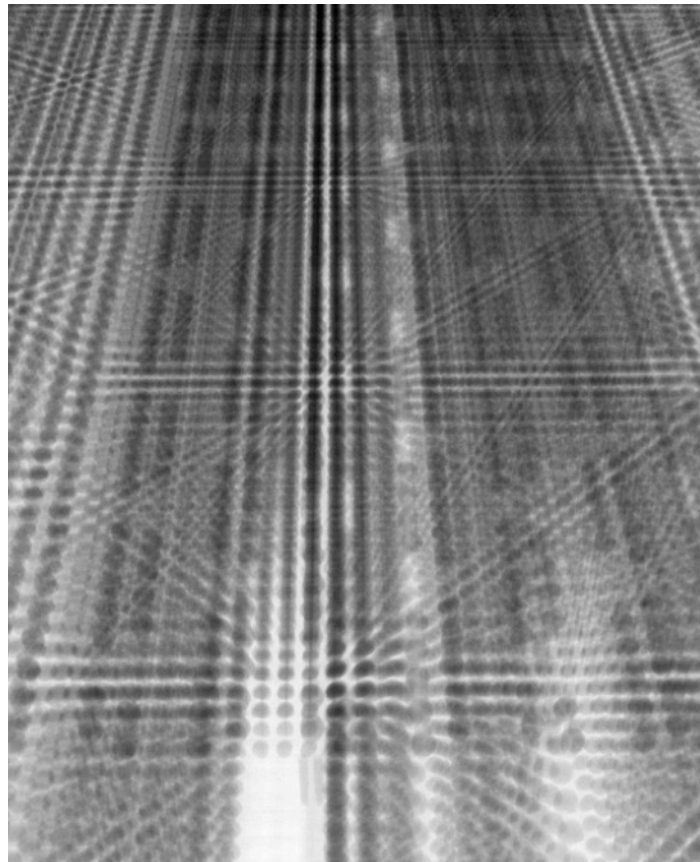
Sketch



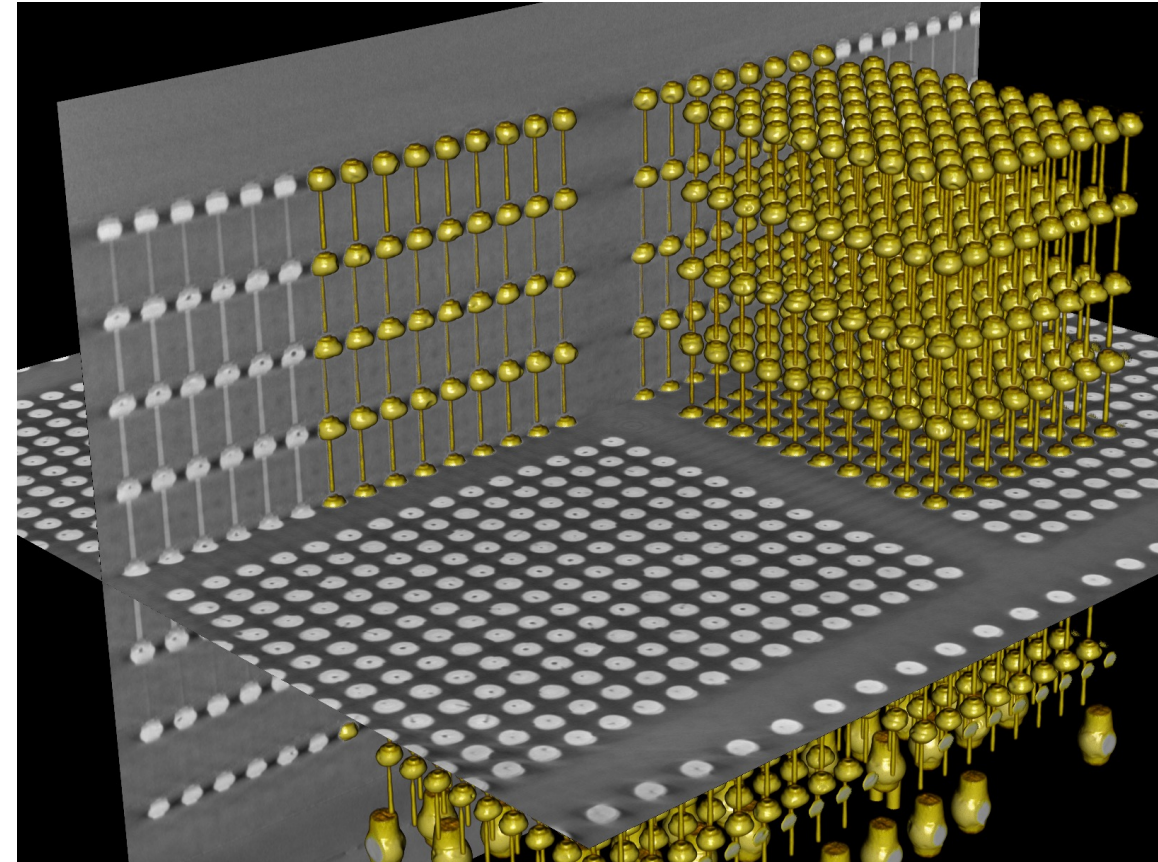
# The Need for 3D Imaging



Simple component



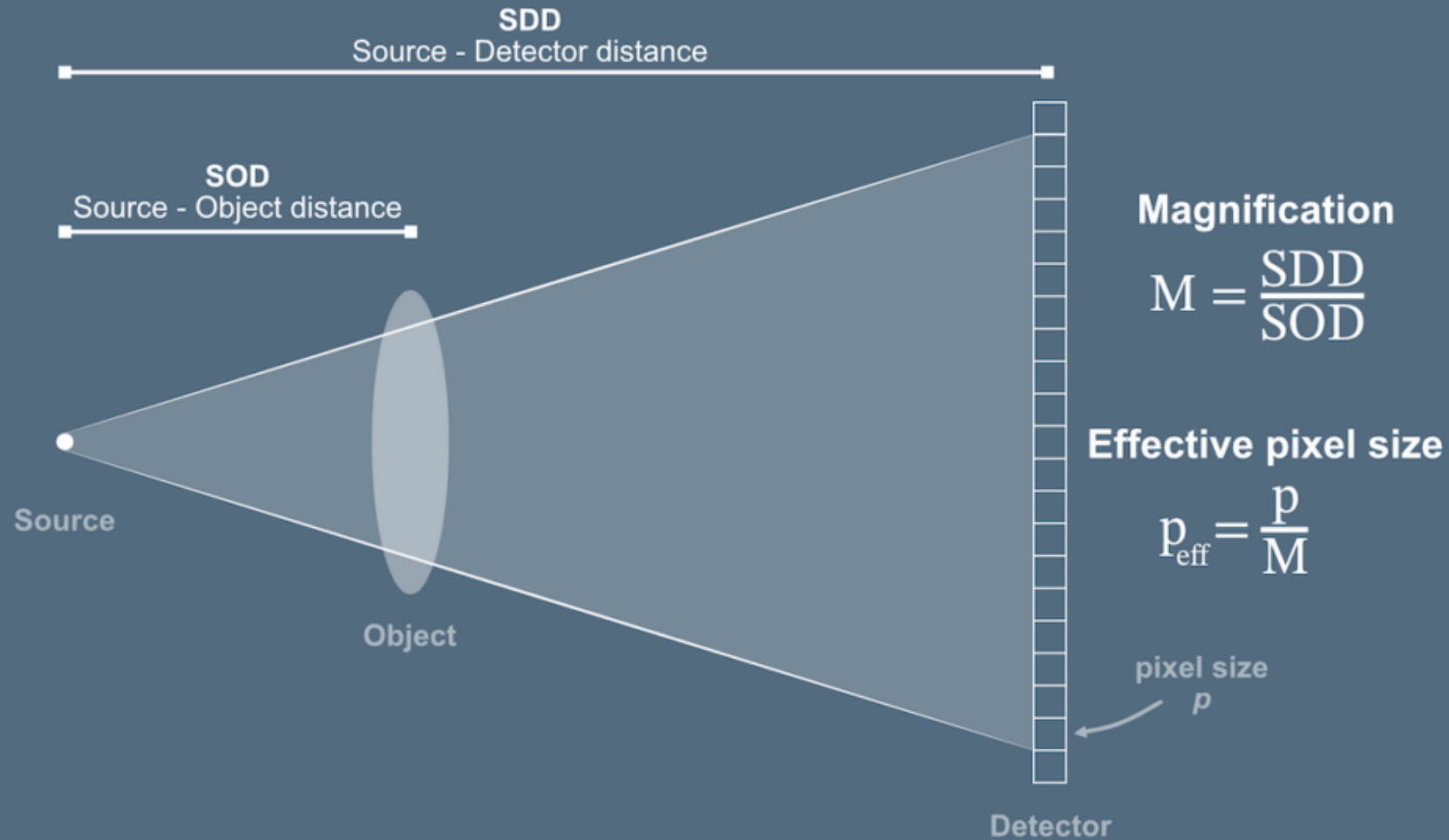
8-layer HBM stack



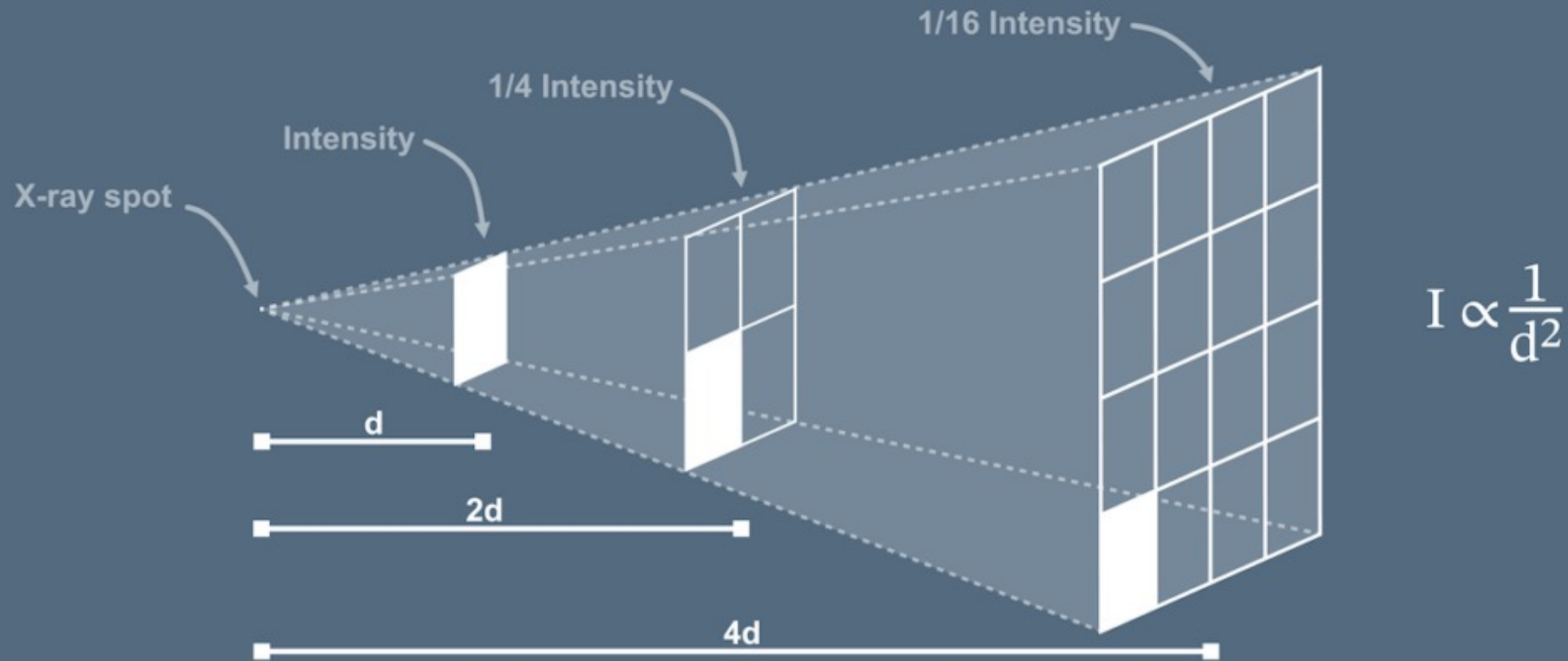
3D Reconstruction of 8-layer HBM stack

T. Dreier, J. Hållstedt: "Laminography: a Non-destructive 3D X-ray Breakthrough for Advanced Packaging" in 3D inCites, 7th October 2025

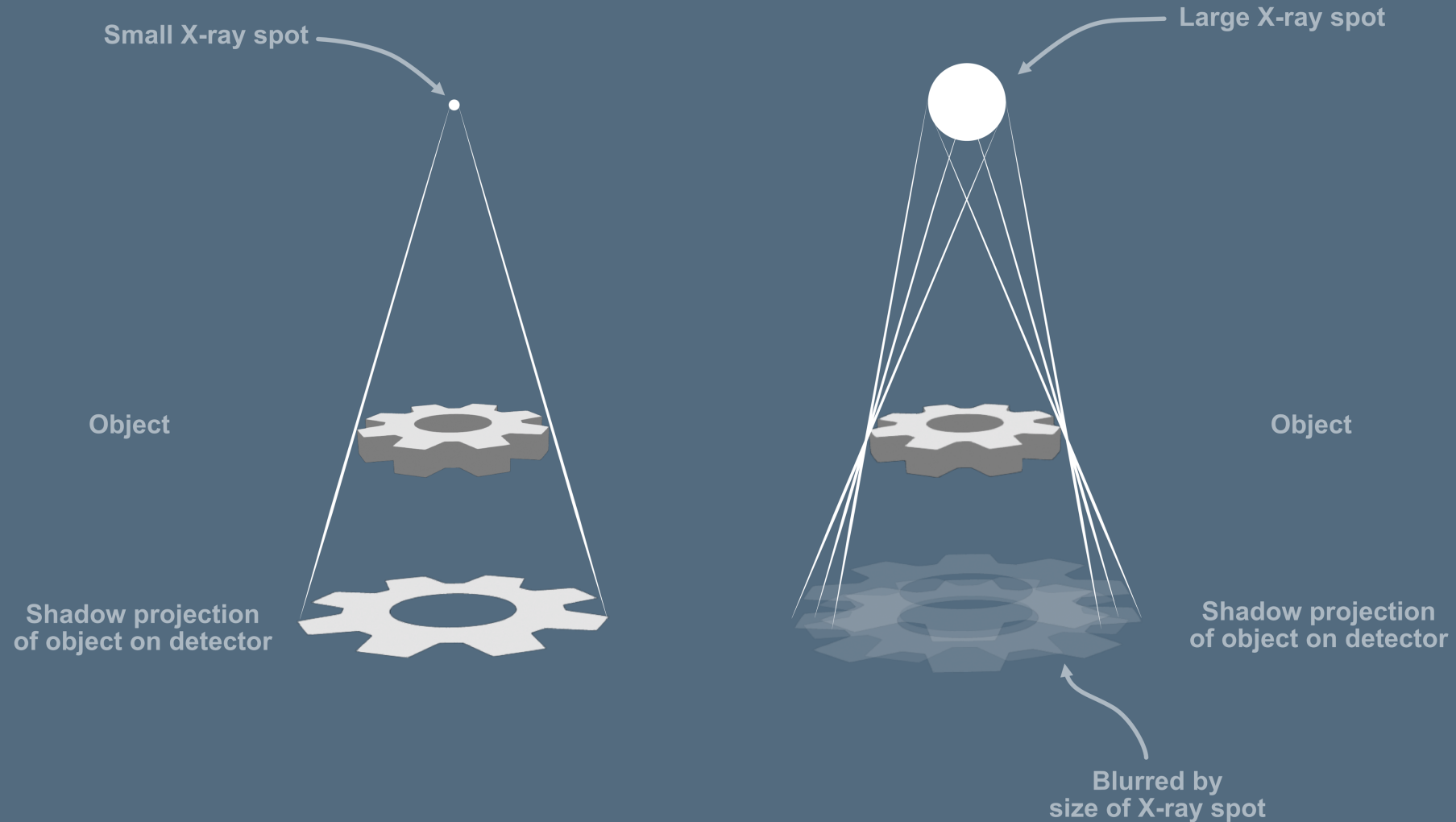
# High Resolution through Geometric Magnification



# Minimizing Scan Time using the Inverse Square Law

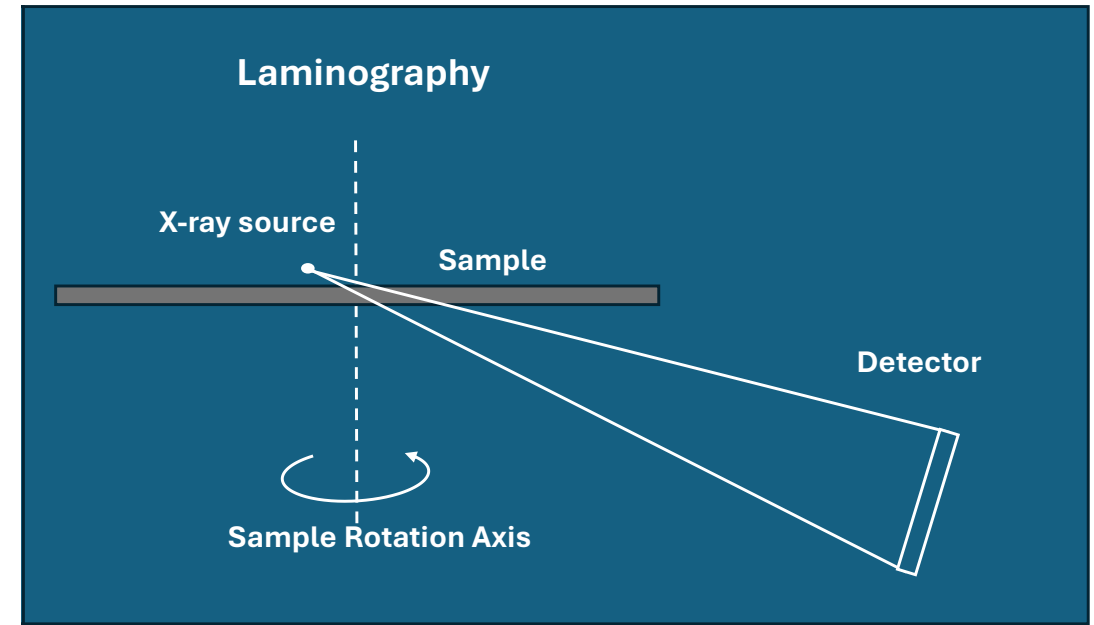
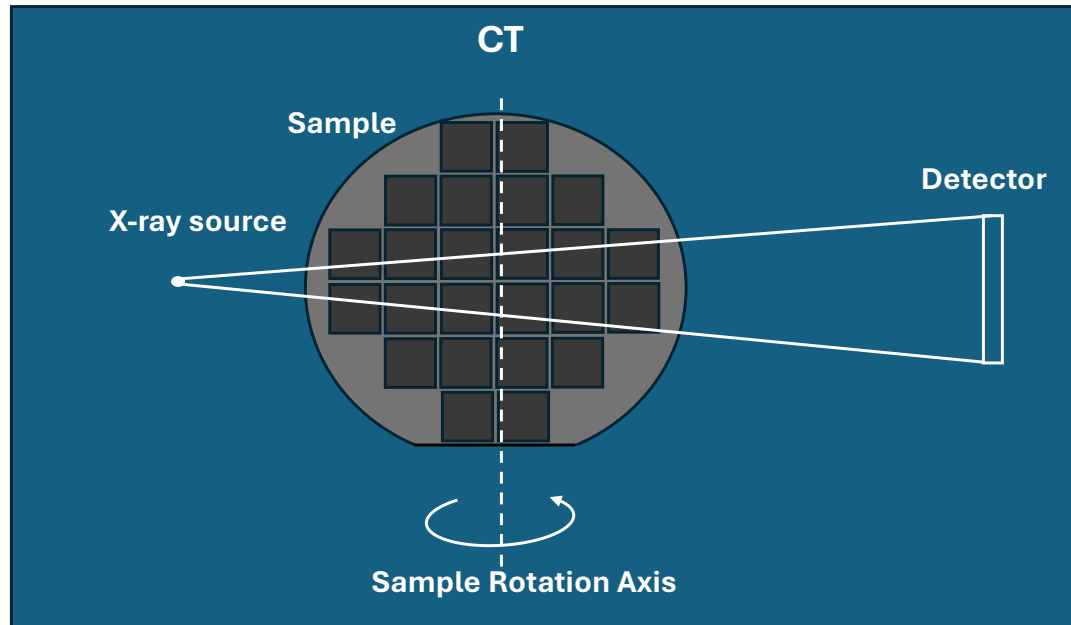


# Resolution Limit: Spot Size and Penumbra Blurring



T. Dreier, J. Hållstedt: Unlocking the Mystery of X-Ray Imaging for Electronics and Semiconductor Inspection”, 3D inCites, 23rd April 2025

# CT vs Laminography – Two Paths to 3D X-ray



## Computed Tomography (CT)

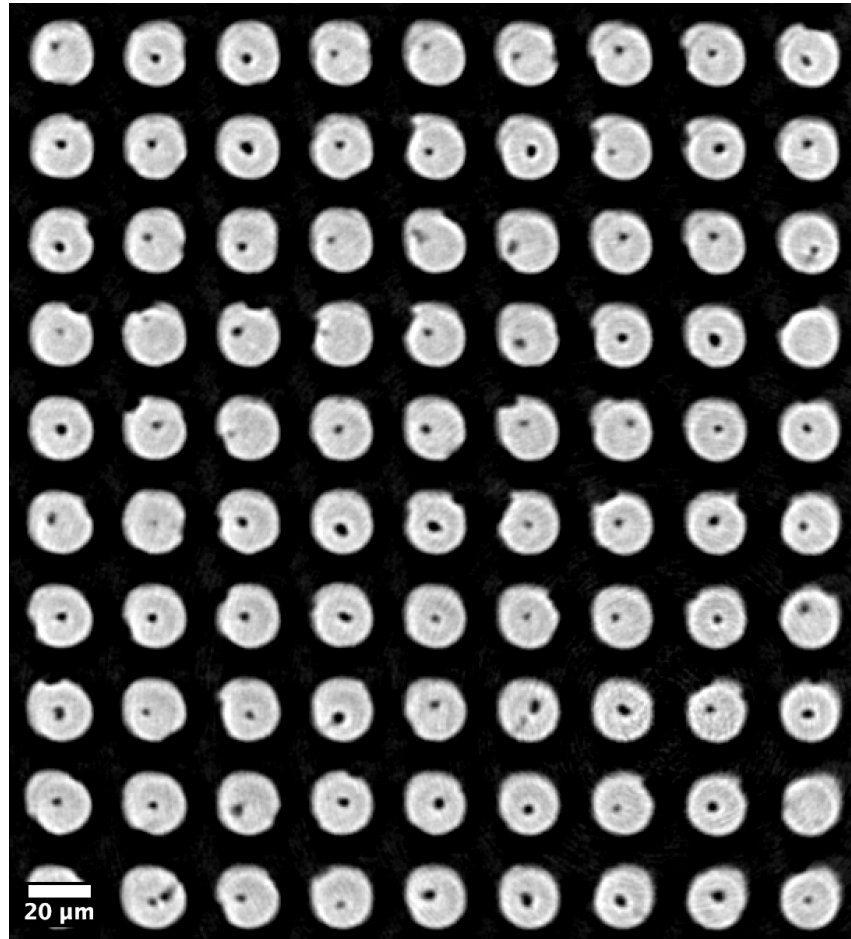
- Pro: Highest quality
- Con: Requires sample preparation since sample needs to have small diameter for high resolution imaging

## Laminography

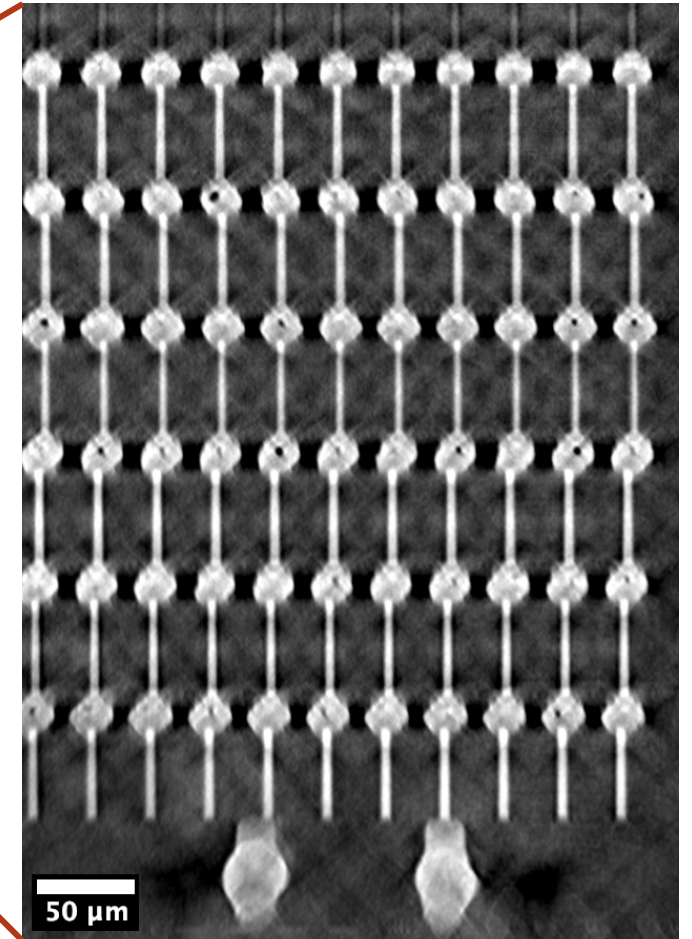
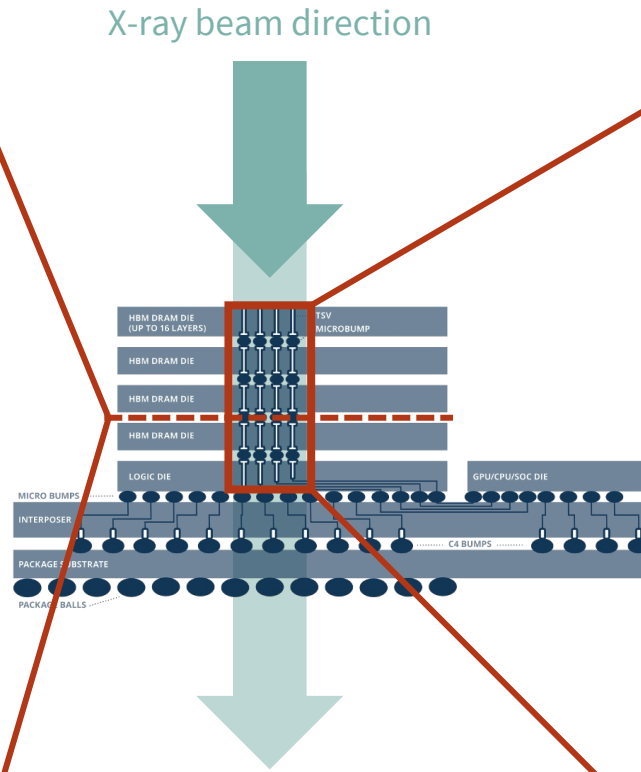
- Pro: Only require one small dimension (thickness). Ideal for large flat samples.
- Con: Somewhat reduced image quality, especially in one plane

T. Dreier, J. Hållstedt: "Laminography: a Non-destructive 3D X-ray Breakthrough for Advanced Packaging" in 3D inCites, 7th October 2025

# Laminography Trade-Off



Horizontal slice



Vertical slice

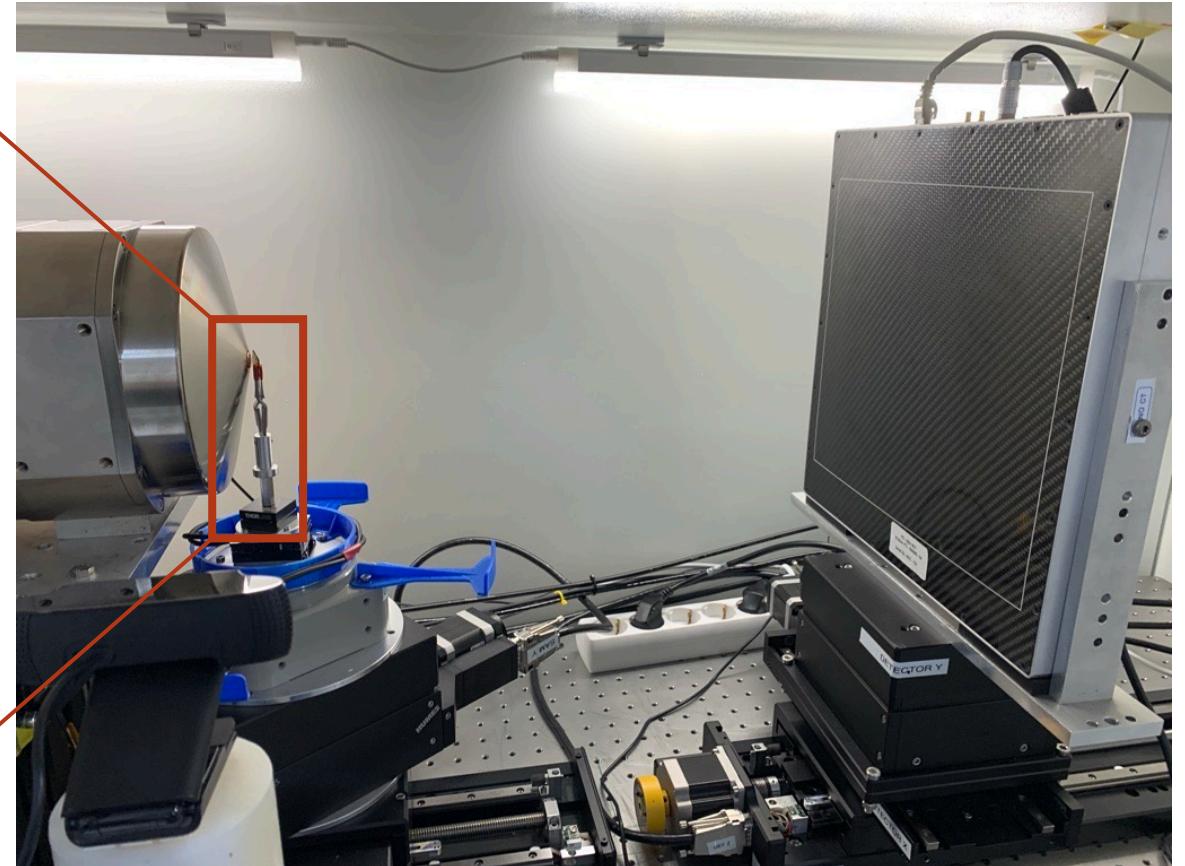
T. Dreier et al., SPIE Advanced Lithography + Patterning, San Jose, CA, USA (2026)



# Methodology

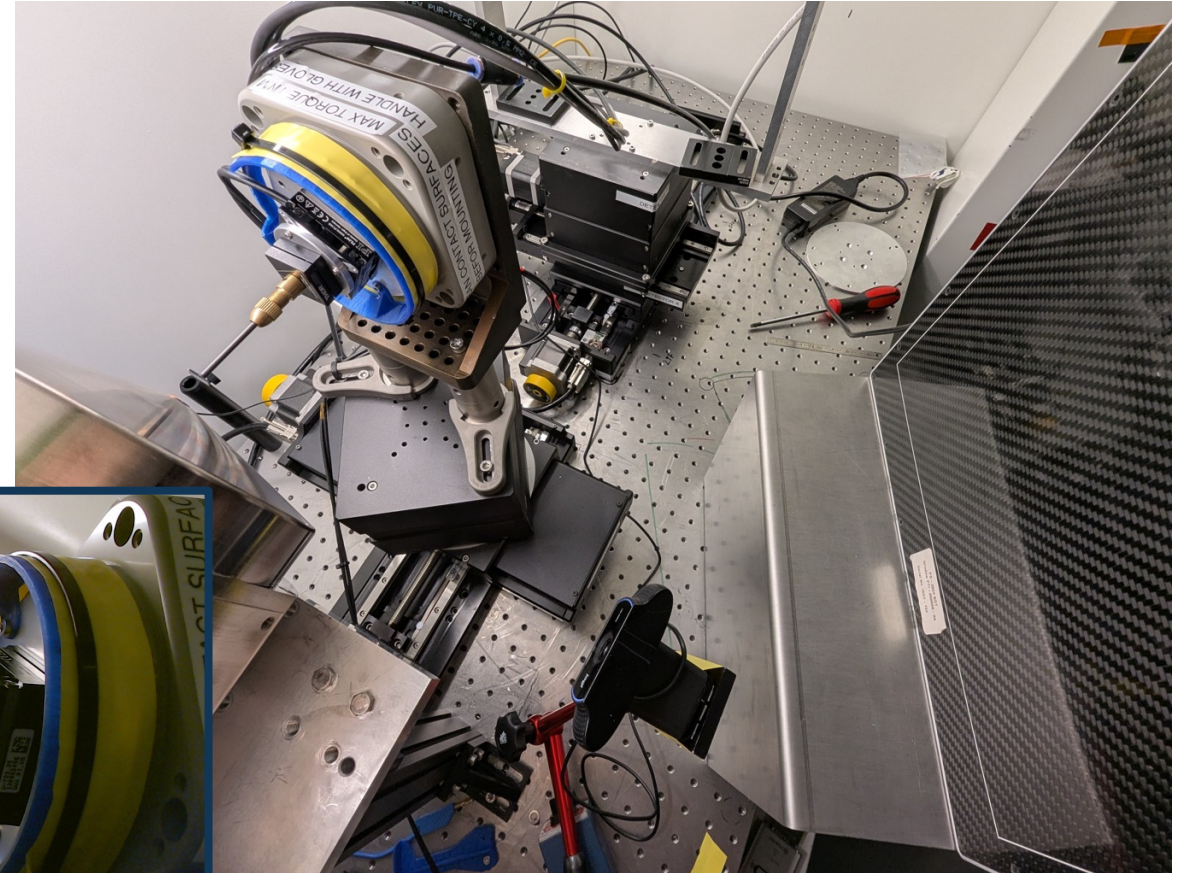
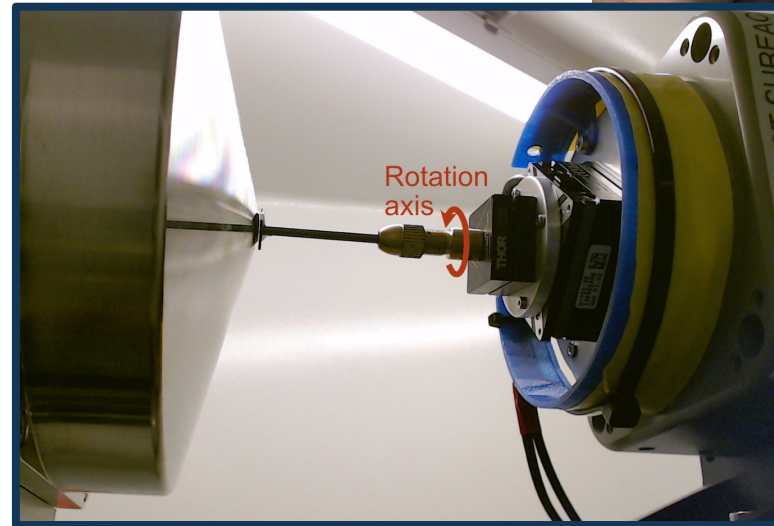
# Experimental Setup – Nano-CT

- Geometry
  - SOD = 1.0 mm
  - SDD = 440 mm
  - $M = 440 \rightarrow p_{eff} = 227 \text{ nm}$
  - Voxel size = 200 nm
- Source
  - 80 kVp
  - 0.7  $\mu\text{m}$  X-ray spot
- Acquisition
  - 3000 projections
  - 3.5 s exposure



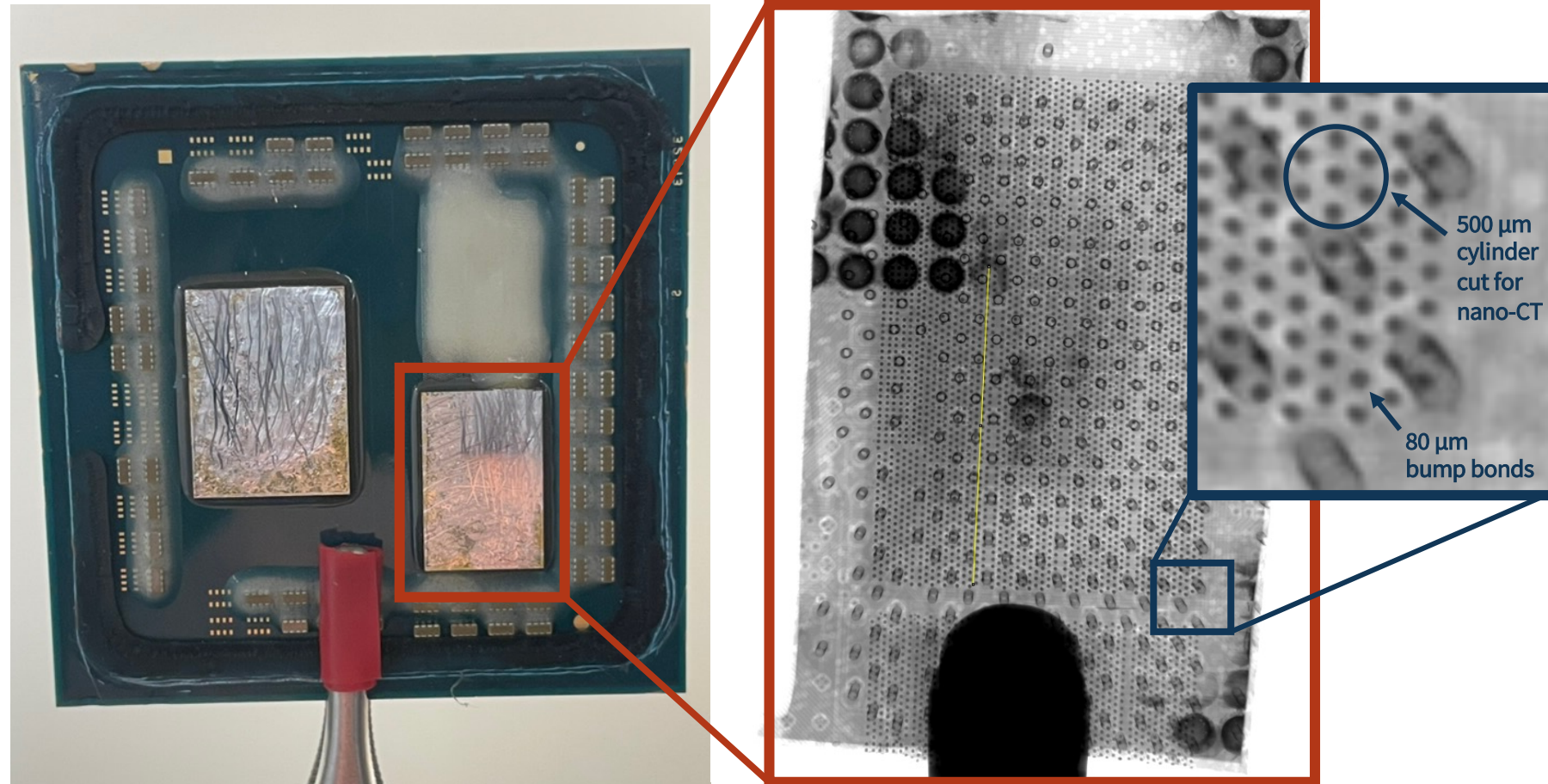
# Experimental Setup – Laminography | Oblique-CT

- Geometry
  - SOD = 0.75 mm
  - SDD = 405 mm
  - Detector angle =  $70^\circ$
  - $M = 540 \rightarrow p_{eff} = 185 \text{ nm}$
  - Voxel size = 150 nm
- Source
  - 60 kVp
  - $0.5 \mu\text{m}$  X-ray spot
- Acquisition
  - 2881 projections
  - 10 s exposure



# Sample

- AMD Ryzen 7 5800X3D
  - Bonding of CPU core and Vcache
  - Commercial hybrid bonding process
    - 9  $\mu\text{m}$  pitch/3  $\mu\text{m}$  pads
- Sample preparation
  - Cut out CPU
  - Remove PCB from back
    - OK for laminography
  - Laser cut ~500  $\mu\text{m}$  cylinder
    - OK for Nano-CT



# Hybrid bonding in AMD Ryzen 7 5800X3D

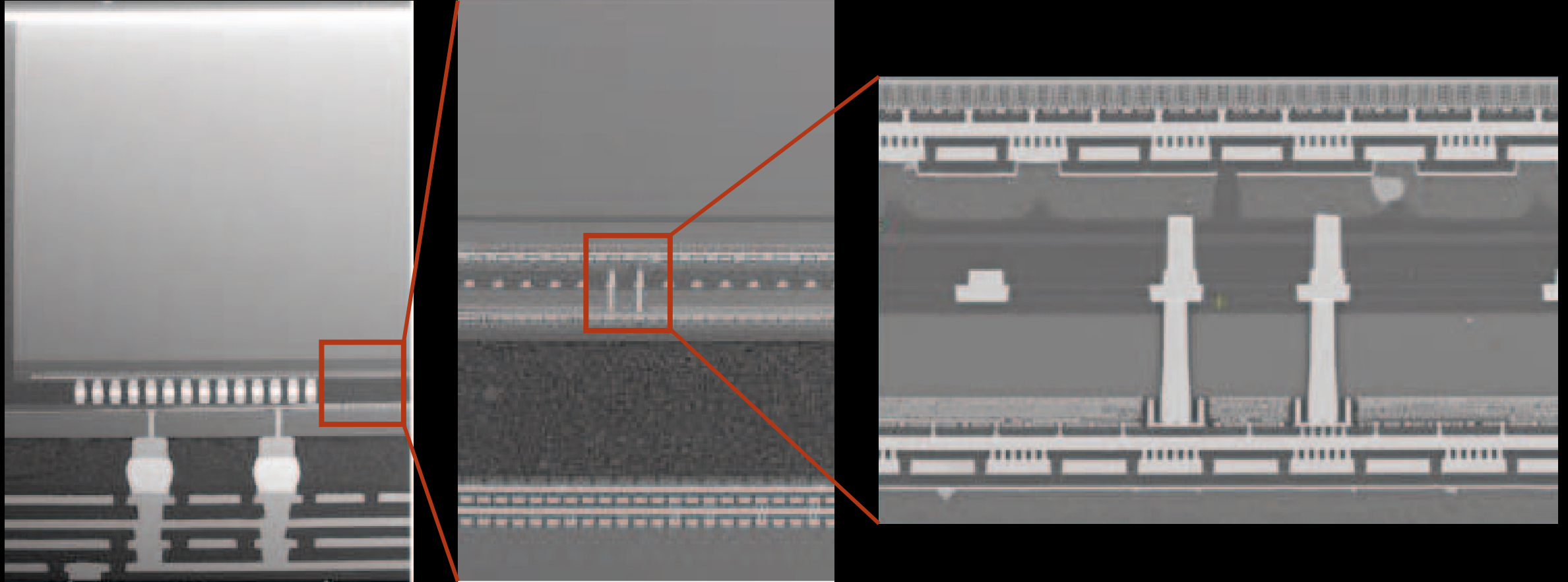


Figure adapted from:

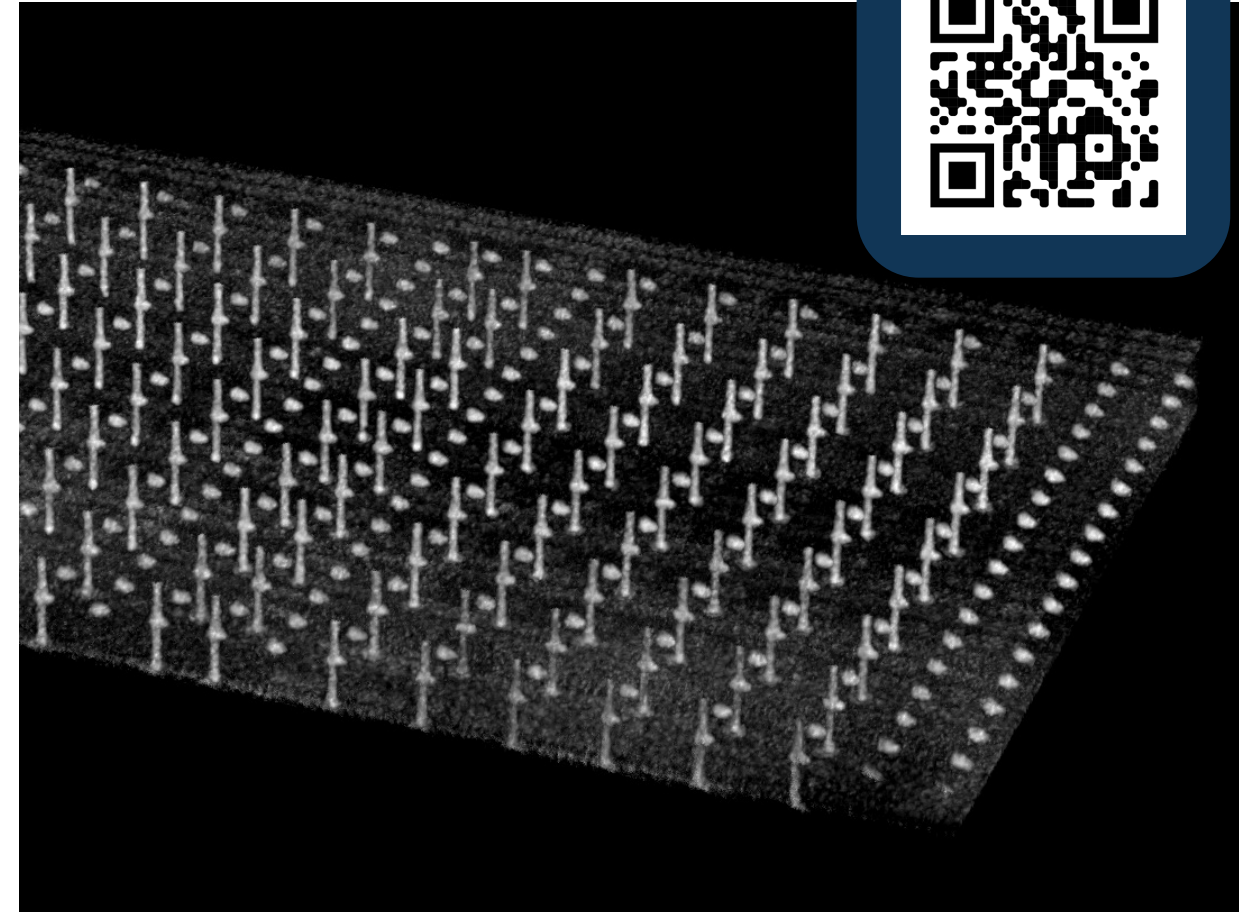
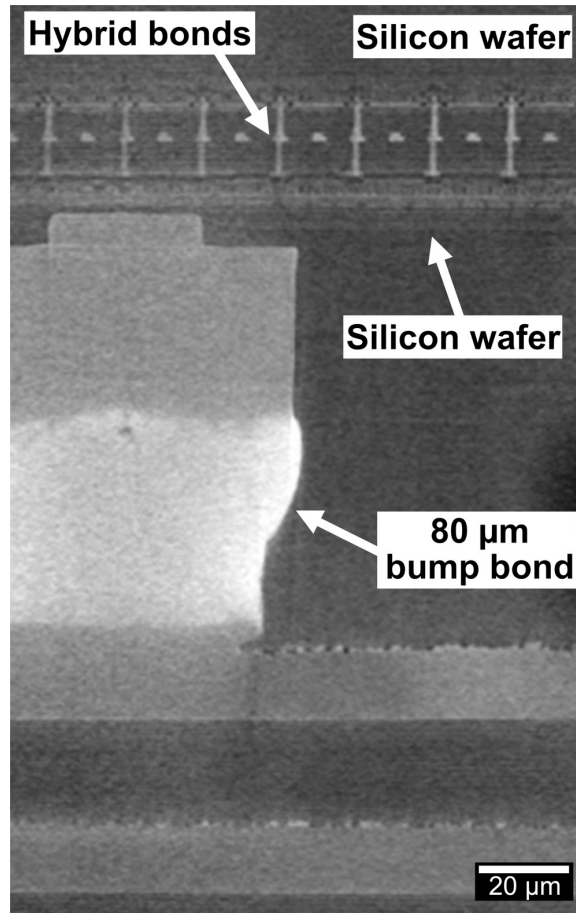
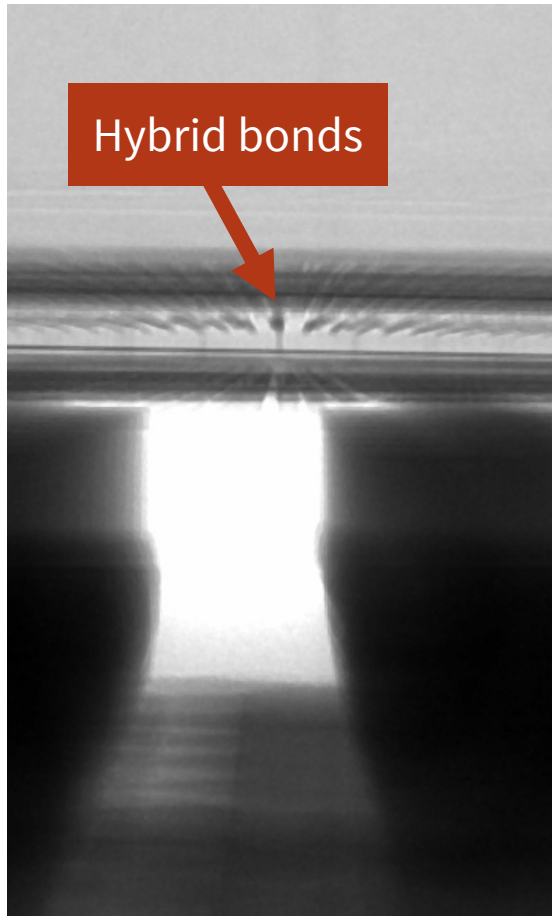
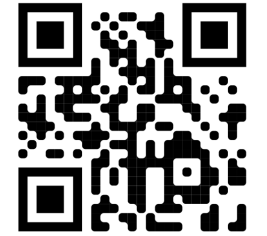
C. S. Mandalapu et al., "3.5D Advanced Packaging Enabling Heterogenous Integration of HPC and AI Accelerators," in IEEE 74th Electronic Components and Technology Conference (ECTC), Denver, CO, USA, 2024, pp. 798-802 (2024); doi: 10.1109/ECTC51529.2024.00391



# Results

# 3D Imaging of Hybrid Bonding

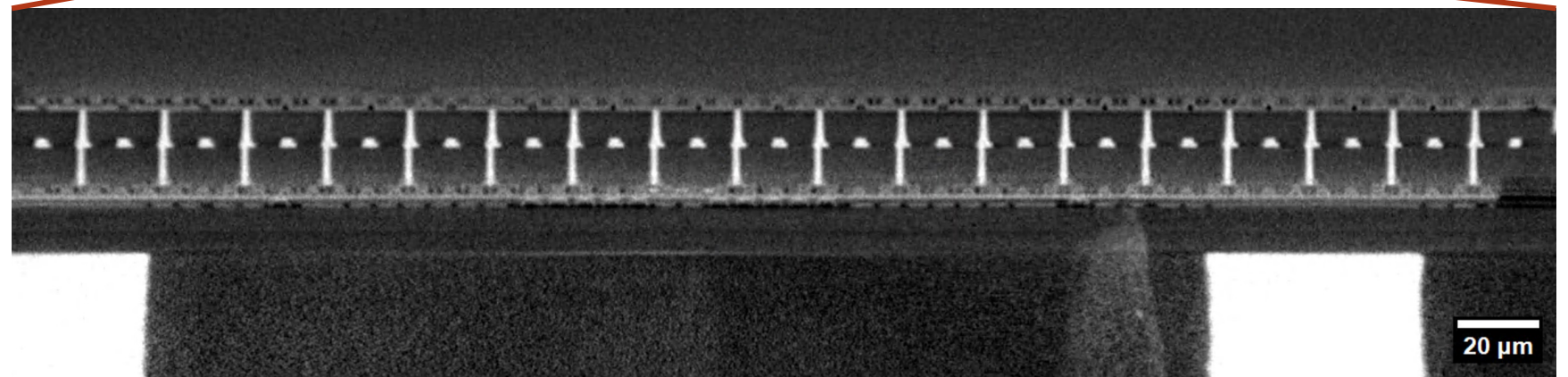
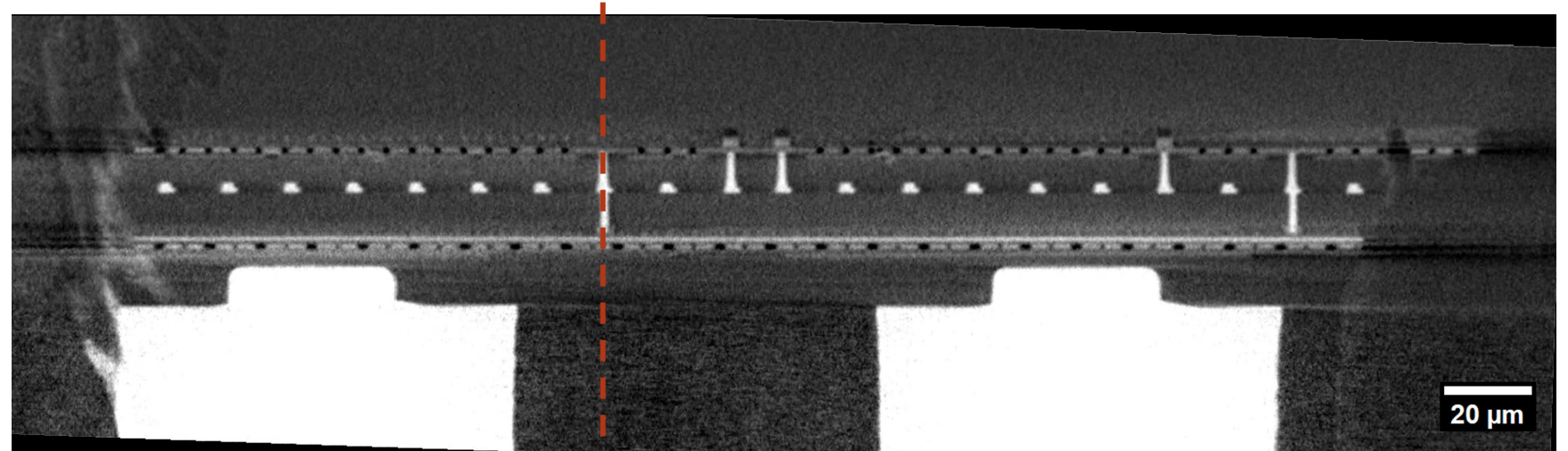
Video  
[youtu.be/1RYfxVdE8PU](https://youtu.be/1RYfxVdE8PU)



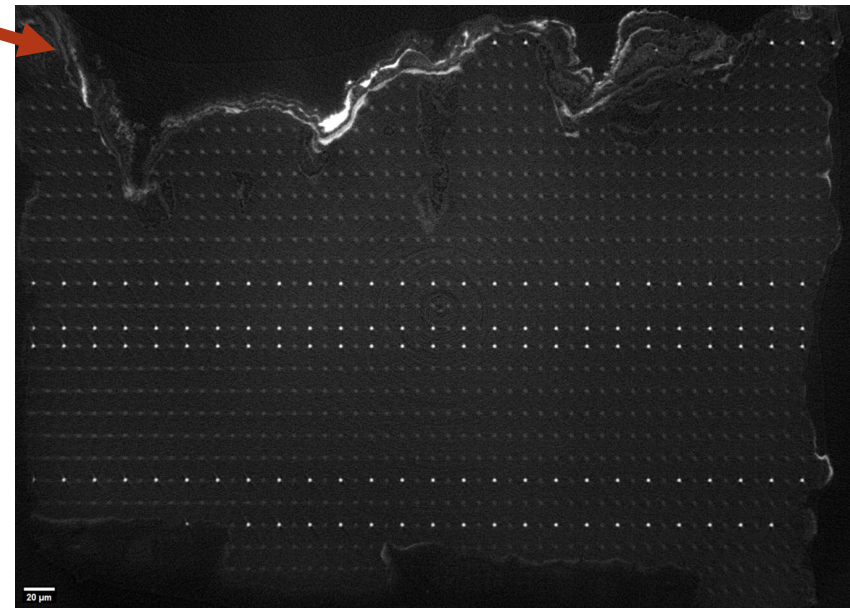
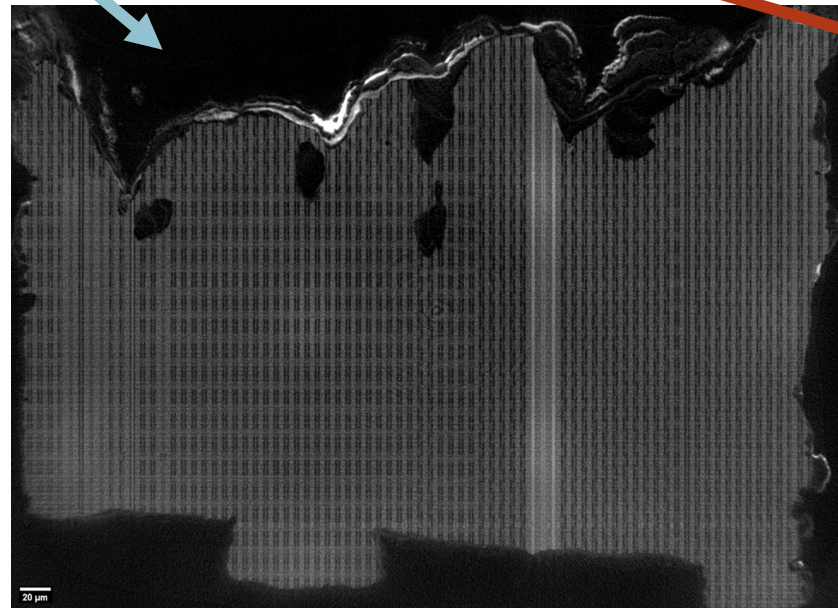
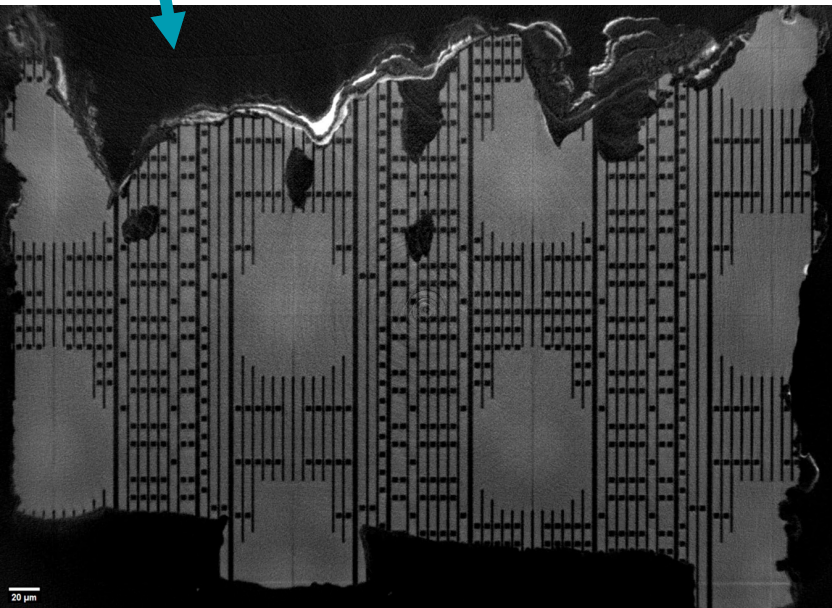
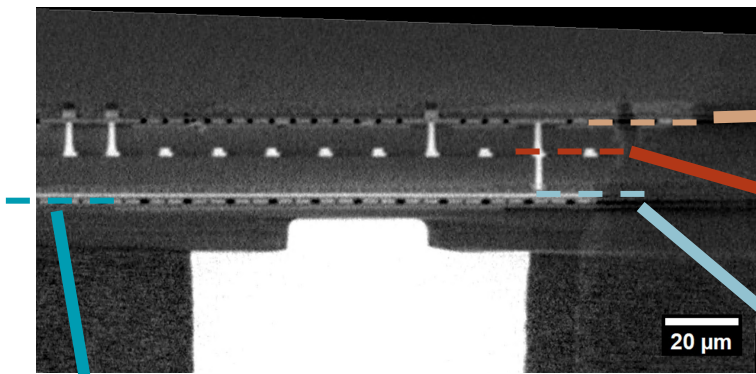
T. Dreier et al., NANOTS, Osaka, Japan (2024)

# Nano-CT

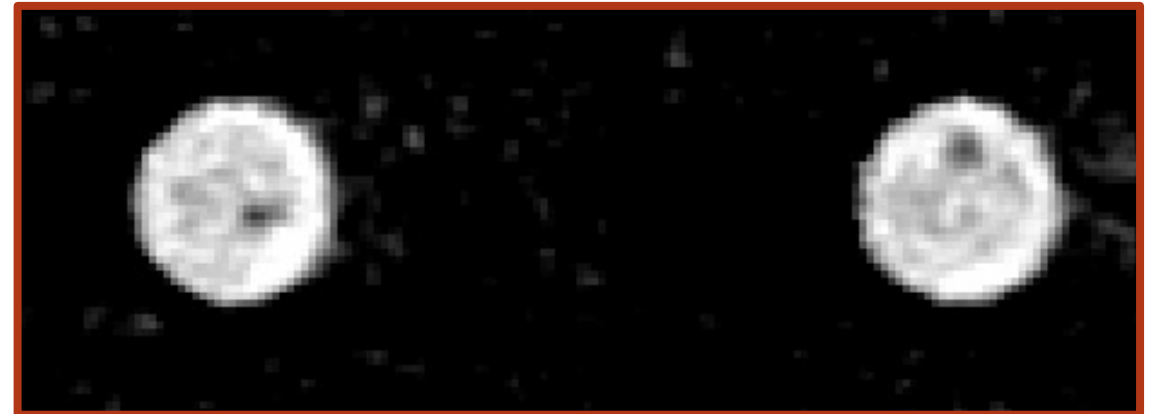
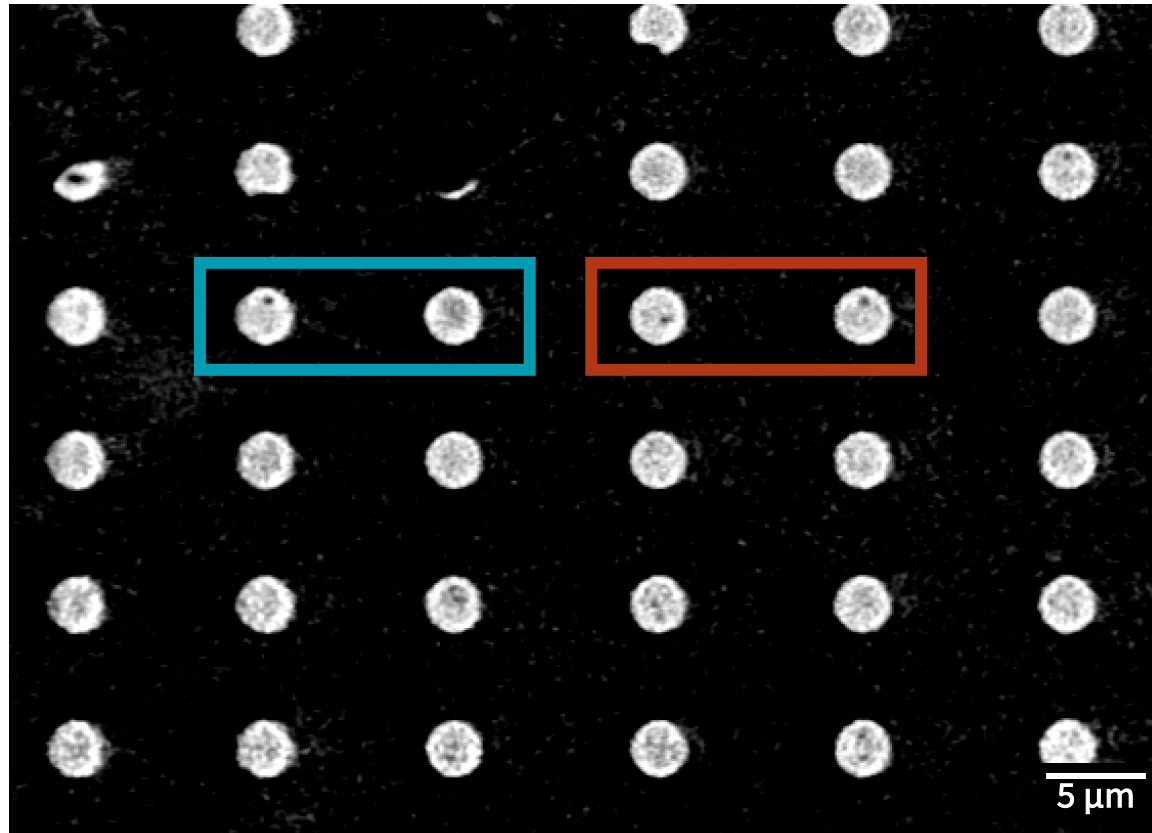
- Geometry
  - SOD = 1.0 mm
  - SDD = 440 mm
  - $p_{\text{eff}} = 150 \text{ nm}$
  - Voxel size = 200 nm
- Scan settings
  - Projections: 3000
  - Rotation: 360 degrees
  - Exposure time: 3.5 s
  - Scan time: 2.9 h
- Source settings
  - Voltage: 80 kV
  - Spot size: 700 nm



# Nano-CT

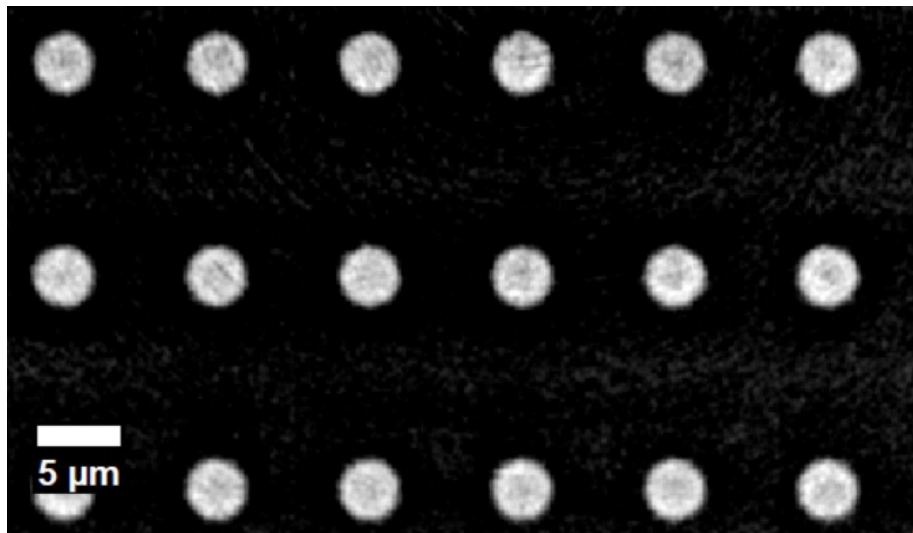
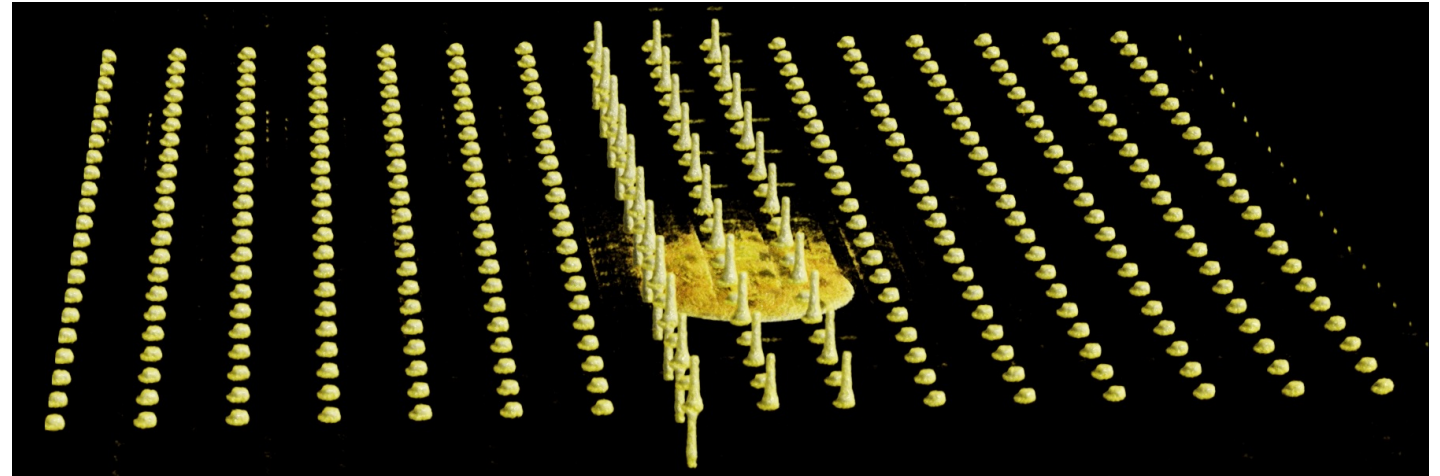


# Nano-CT – Void Inspection

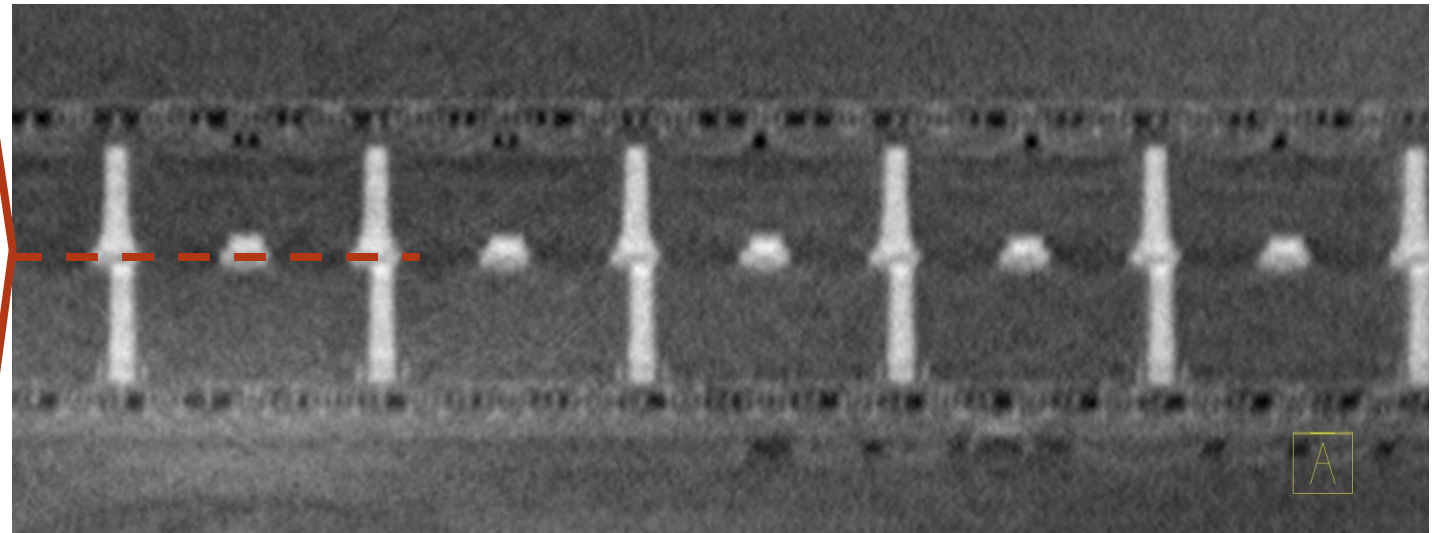


# Laminography

- Comparable image quality to Nano-CT
  - 70° detector angle → limited vertical artefacts
  - Contrast is slightly different
  - Similar resolution

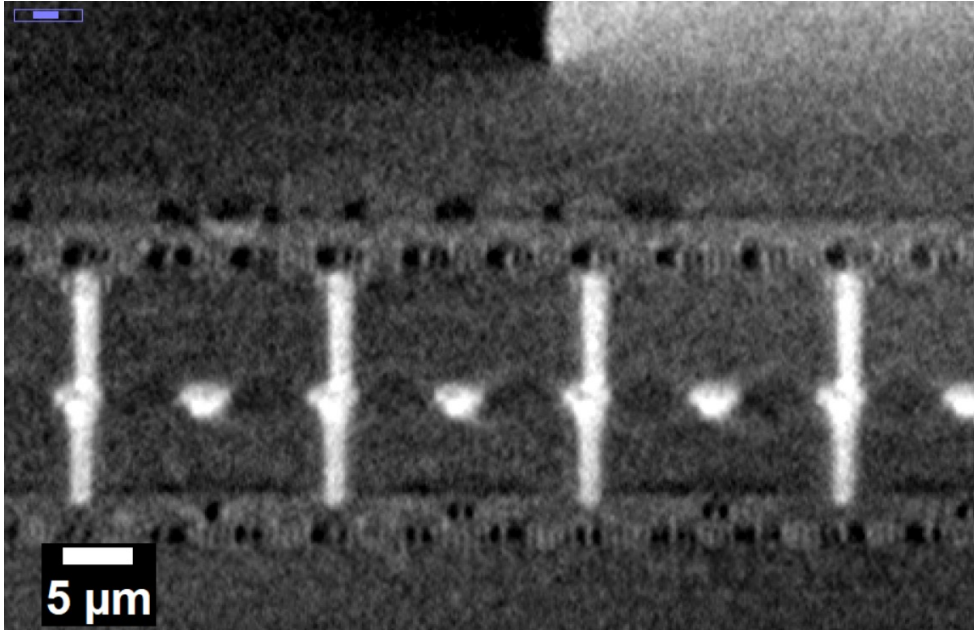


Horizontal slice



Vertical slice

# Laminography

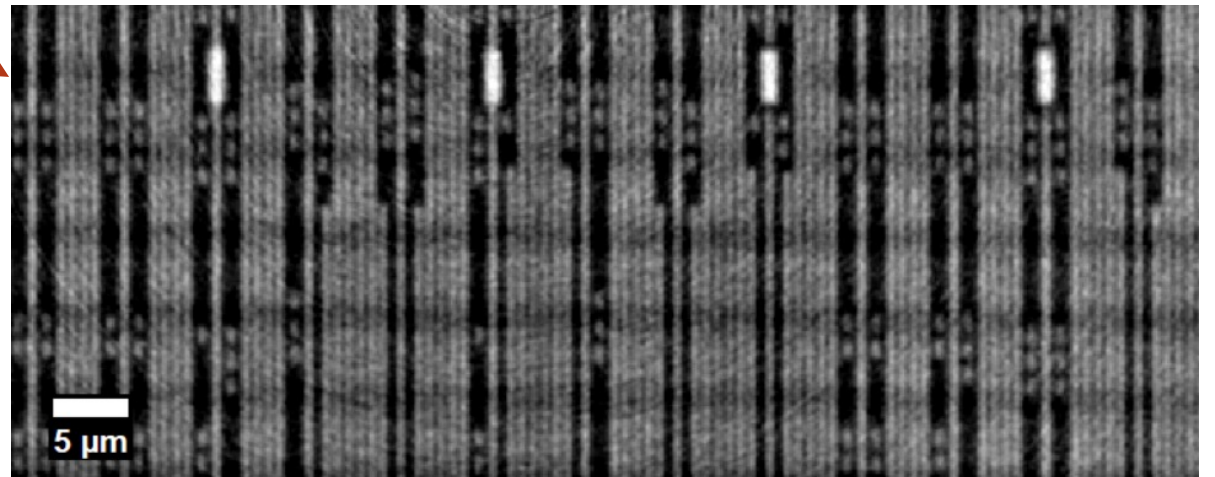
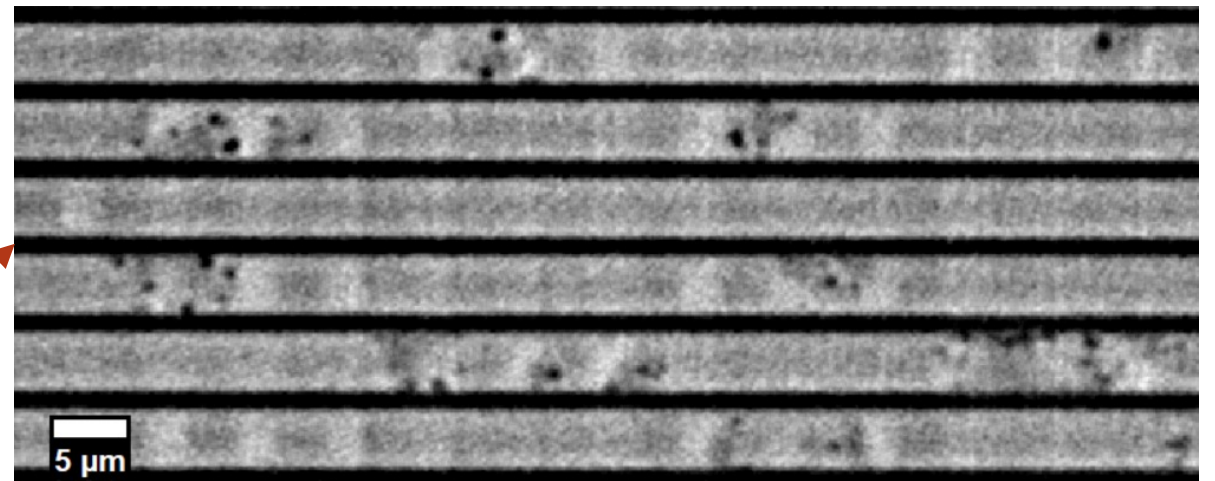
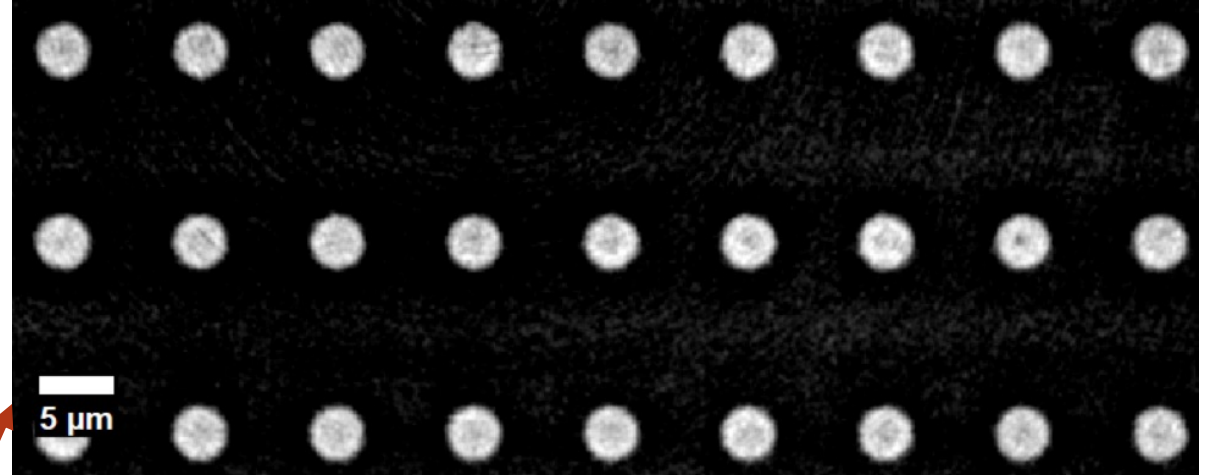
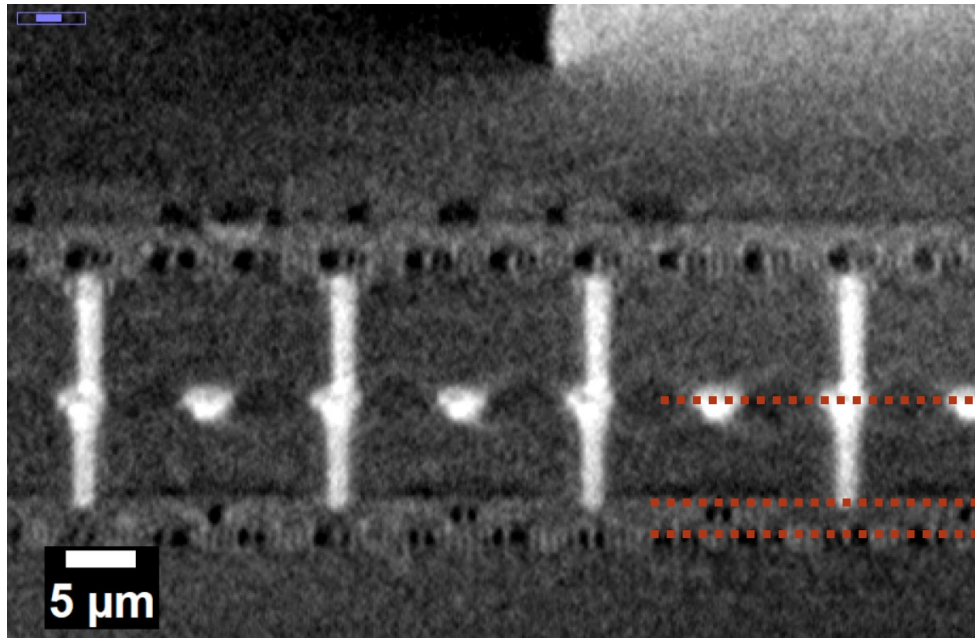


**excillum**

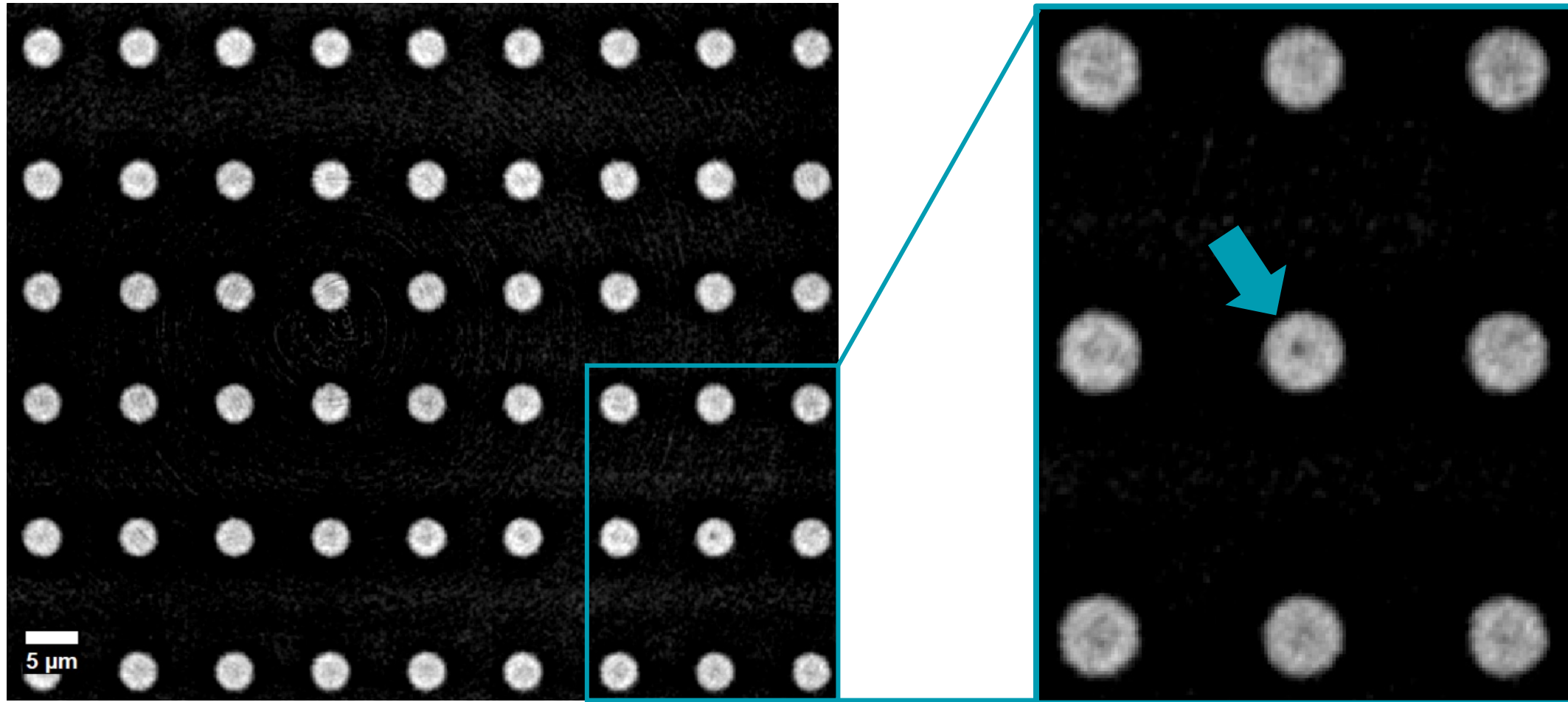
ICEP-HBS | Hiroshima, Japan | 2026

20 μm

# Laminography



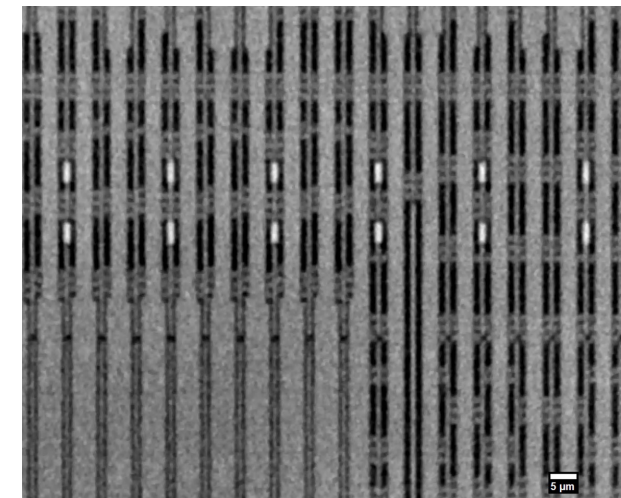
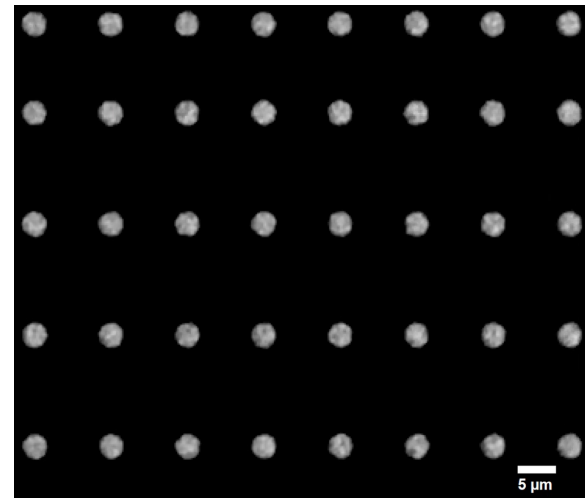
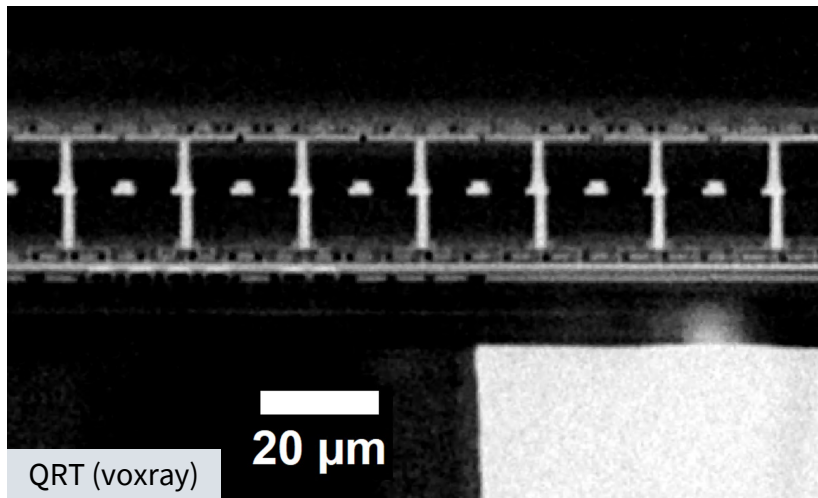
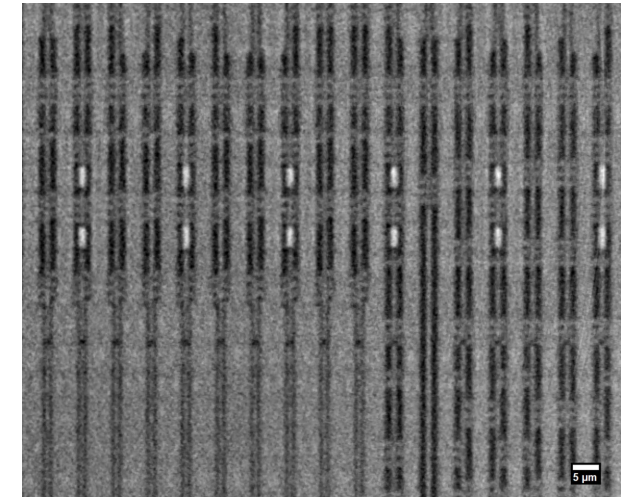
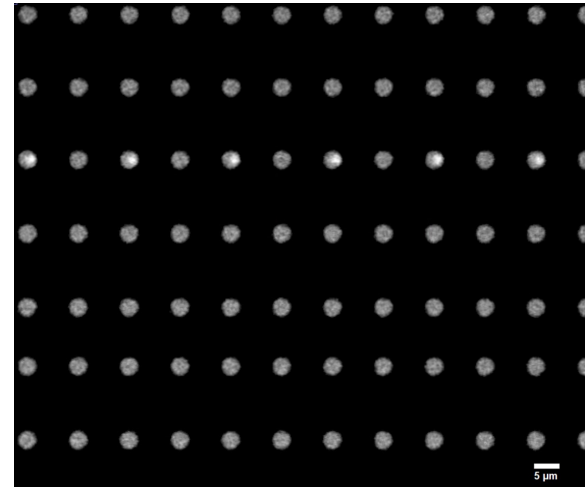
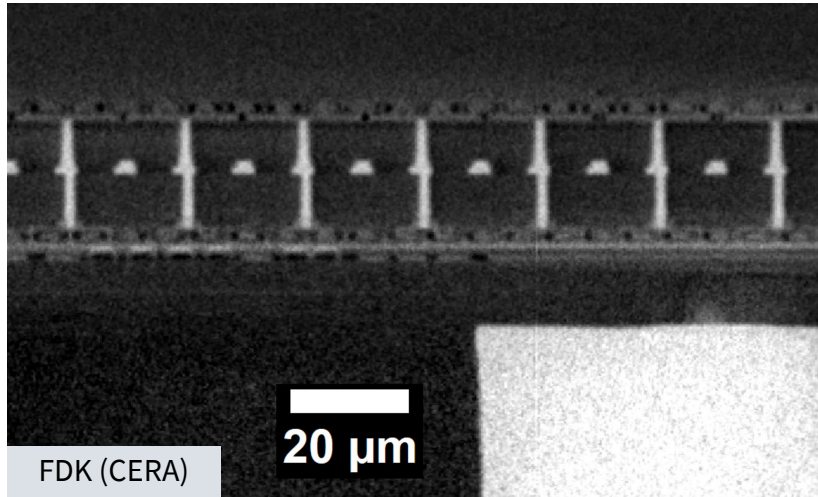
# Laminography – Void Inspection



# Iterative Reconstruction (Nano-CT)

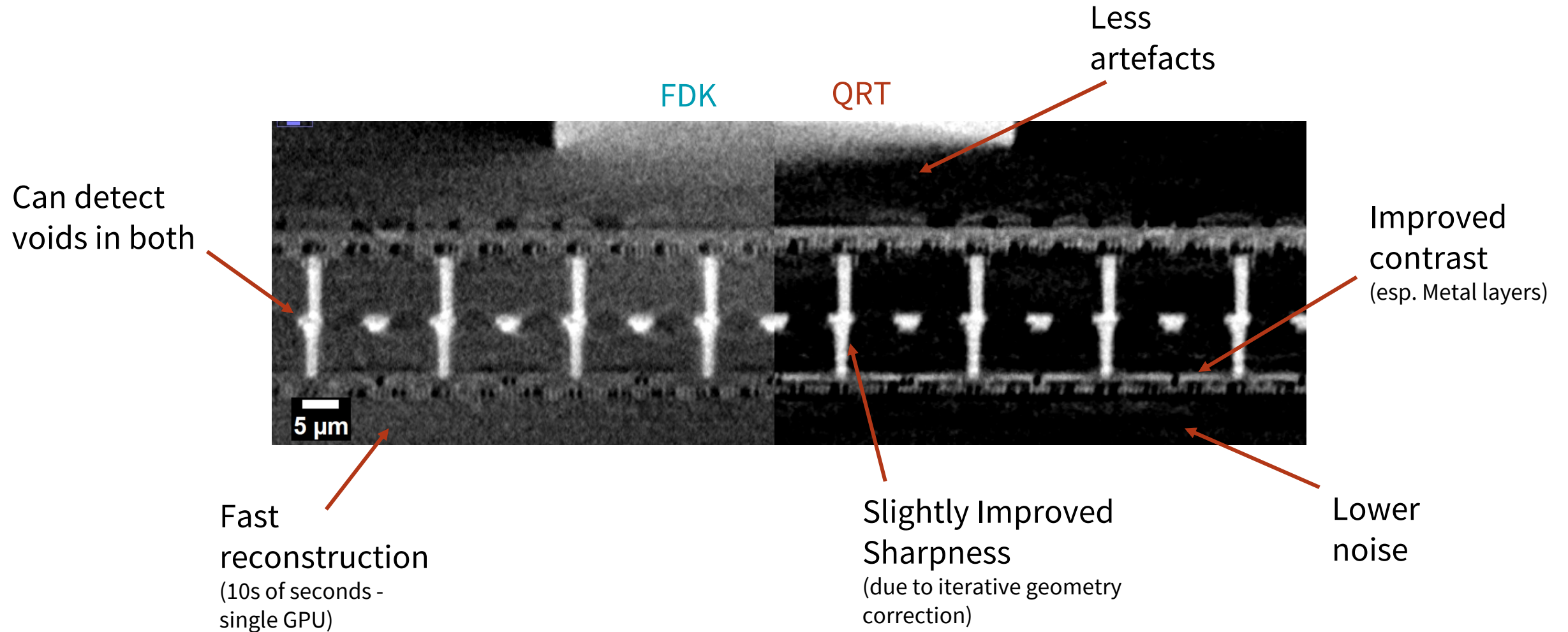
Hybrid Bonding Interface

Redistribution Layer



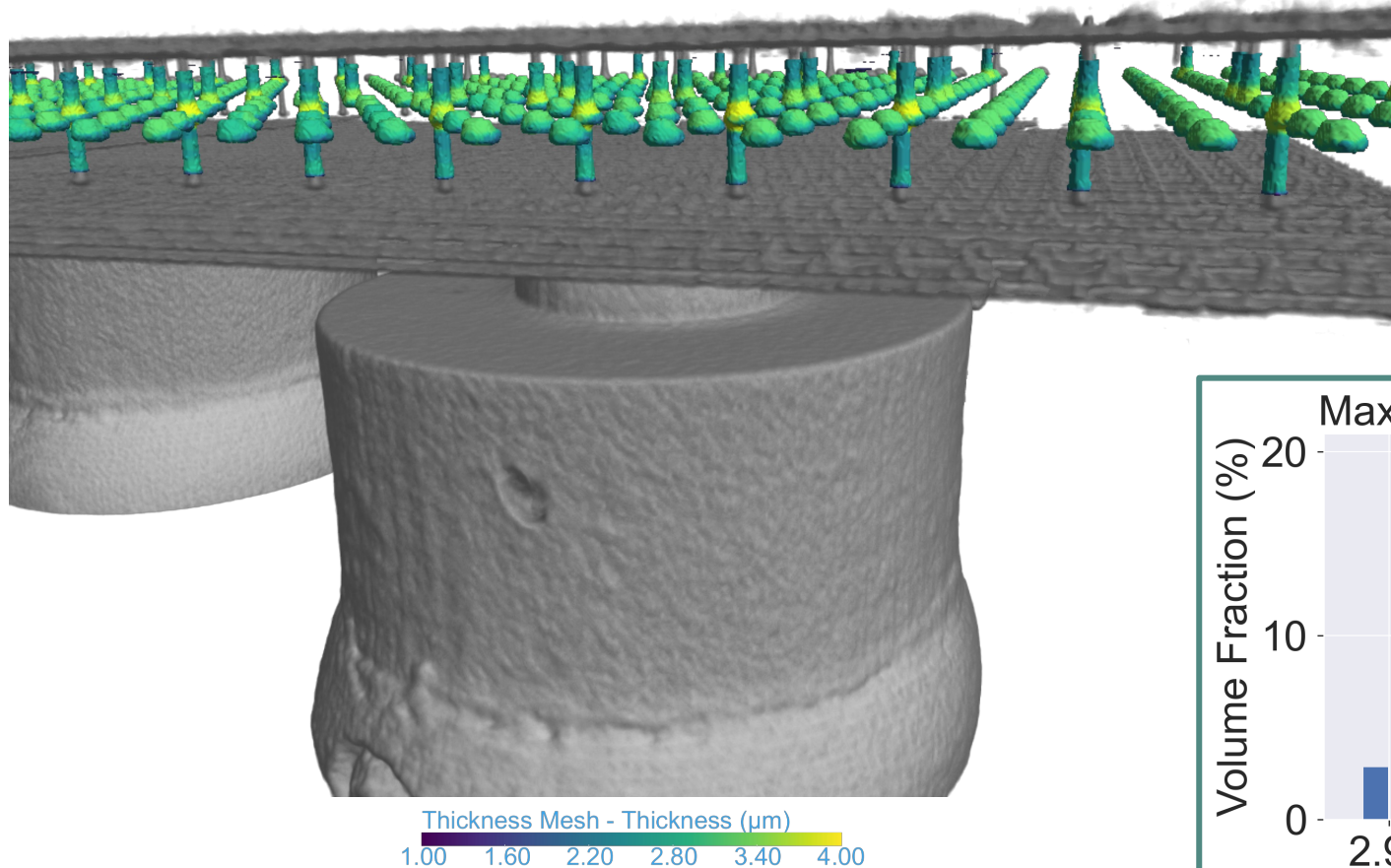
More details: T. Dreier et al., ECTC, Orlando, FL, USA (2026). *Accepted Manuscript*.

# Iterative Reconstruction (Laminography)

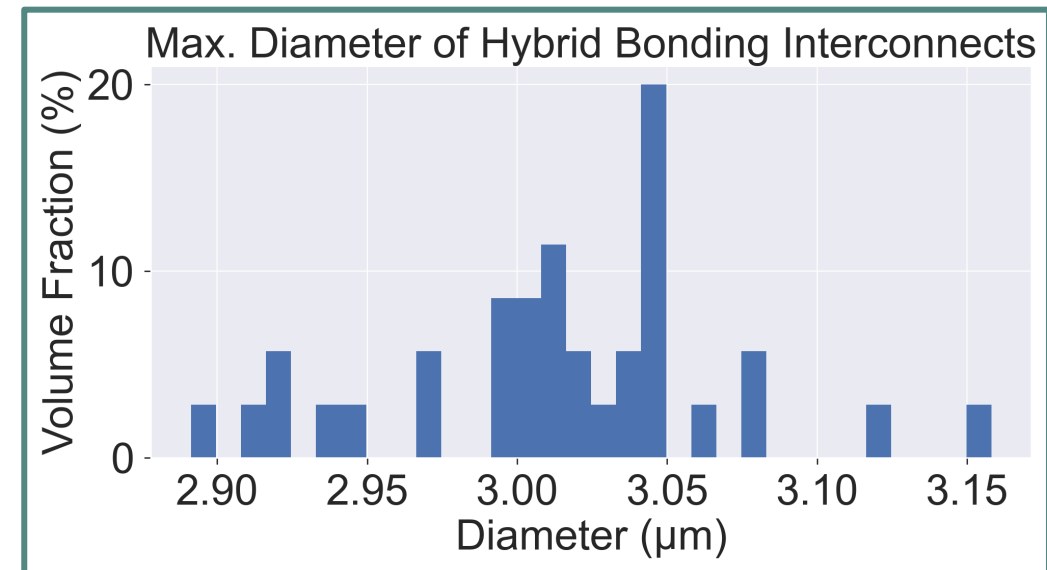


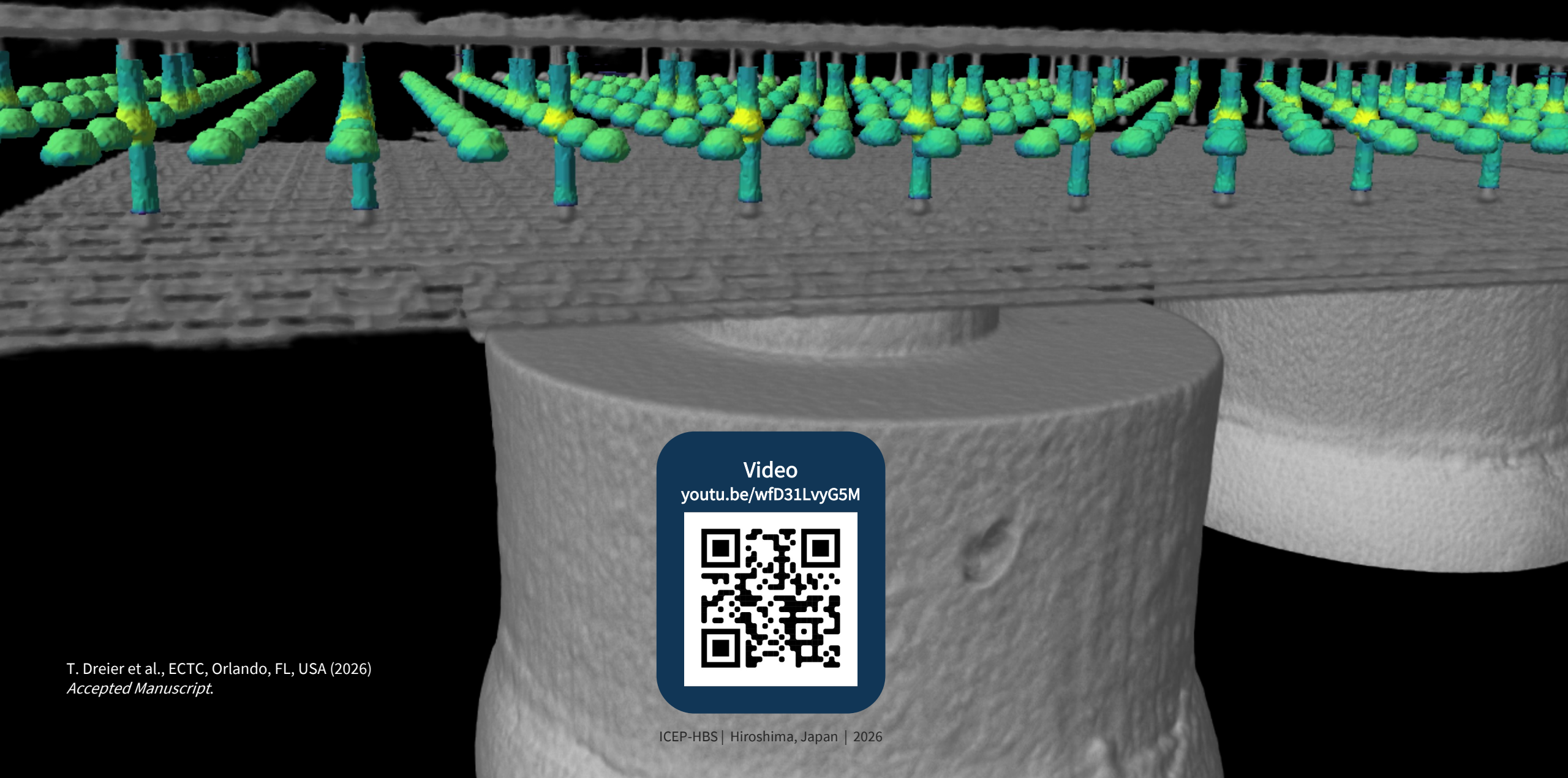
More details: T. Dreier et al., ECTC, Orlando, FL, USA (2026). *Accepted Manuscript*.

# Characterisation of Hybrid Bonds

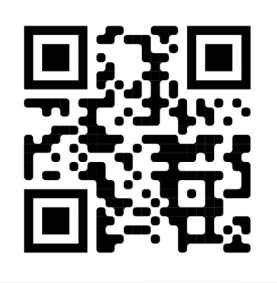


- Individual segmentation of hybrid bonds
  - Dimensional measurements of every bond
  - Distribution/variation of the individual bonds





Video  
[youtu.be/wfD31LvyG5M](https://youtu.be/wfD31LvyG5M)



# Conclusions

- High-resolution 3D X-ray imaging enables **inspection and metrology** of hybrid bonding.
- Nano-CT provides **highest quality**, but requires sample preparation to enable rotation within ~1 mm from the X-ray source
- Laminography enables **fully nondestructive** imaging at **comparable quality to Nano-CT** using high detector angles.
- Iterative reconstructions **can improve the image quality**, at the cost of significantly longer reconstruction times.

# Acknowledgements

SpectrumLogic

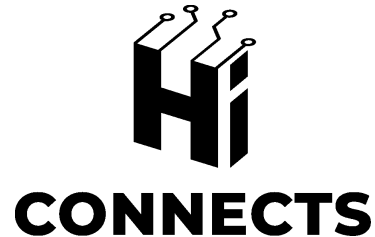
SIEMENS  
Healthineers



VOXRAY

dragonfly  
3D World

*Spectrum Logic is acknowledged for providing the used detector and their support. Siemens Healthineers is acknowledged for providing access to the CERA software. Voxray is acknowledged for providing access to their reconstruction software. Comet Technologies Canada is acknowledged for providing access to the Dragonfly software.*



ChipsJU

VINNOVA  
Sveriges innovationsmyndighet

*HiCONNECTS project has received funding from Chips Joint Undertaking (Chips JU) under grant agreement No 101097296. Chips JU receives support from the European Union's Horizon Europe research and innovation programme and Austria, Italy, Germany, Netherlands, Israel, Finland, Switzerland, Hungary, Sweden, Turkey, France, Denmark and Romania.*

# Innovation starts at the source

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Slides



[excillum.com/icep-hbs-2026/](https://excillum.com/icep-hbs-2026/)



# The source for X-ray innovation

- We push the limits of X-ray technology
  - Liquid metal-jet anode: World leading brightness
  - Precision electron beam: Exceptional resolution and stability
- We make (extreme performance) X-ray sources
  - MetalJet – the world’s brightest X-ray source
  - NanoTube – enabling world’s best X-ray resolution
- We inspire and share knowledge
  - Semiconductor & electronics manufacturing
  - Battery production & quality control
  - Material science, chemistry & life sciences research

## About Excillum

**Founded:** 2007

**Headquarters, development & production:** Stockholm, Sweden

**Employees:** ~100

**Revenue:** ~15 MEUR 2024

**Global footprint:** >280 X-ray sources shipped worldwide



# Our technology and product lines

## MetalJet

World's brightest microfocus X-ray source

Liquid metal-jet anode and advanced electron beam technologies



## NanoTube

World's smallest X-ray nanospot

Advanced electron beam technology

