Multiscale 3-D X-ray Imaging for 3-D IC Process Development and Failure Analysis

W. Yun, M. Feser, J. Gelb, L. Hunter

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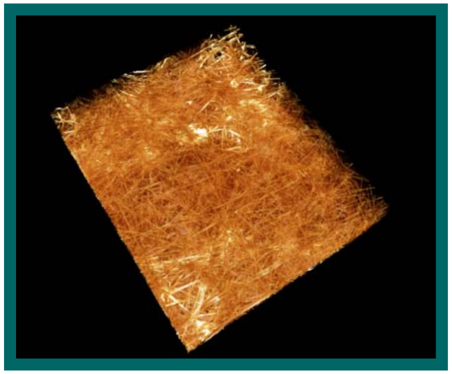
Xradia Inc.

Pioneer in Ultra-high Resolution 3D X-ray Microscopy

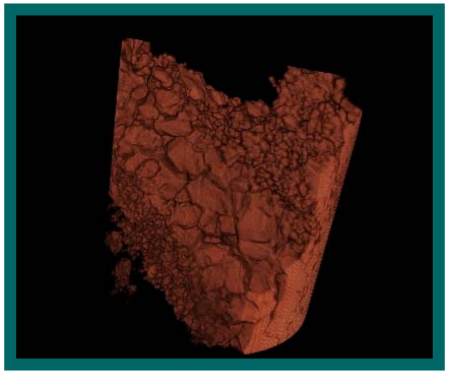
- Founded in 2000 by Wenbing Yun to commercialize high resolution x-ray imaging from synchrotron sources to the laboratory
- HQ in Pleasanton, CA
- Core competencies: x-ray optics/imaging, detectors, system architecture
- Comprehensive market focus
  - From Synchrotron – large installed base of synchrotron 3D microscopes
  - To Research and Industry Labs – Highest performance X-ray microscopes for:

Electronics

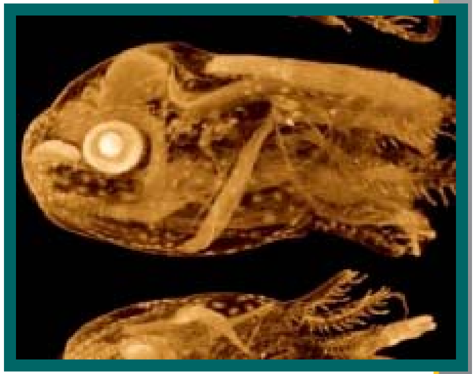
Materials Science



Geosciences



Life Sciences



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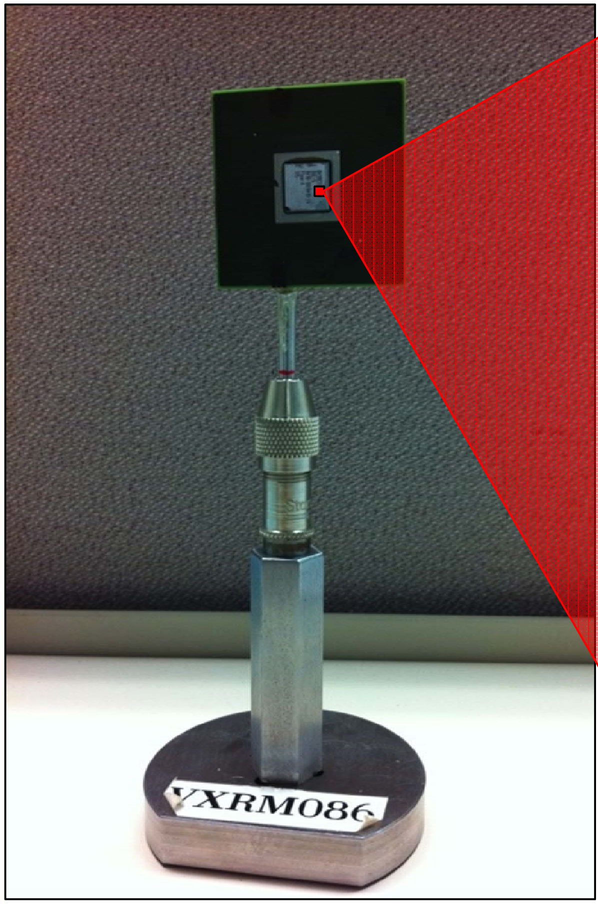
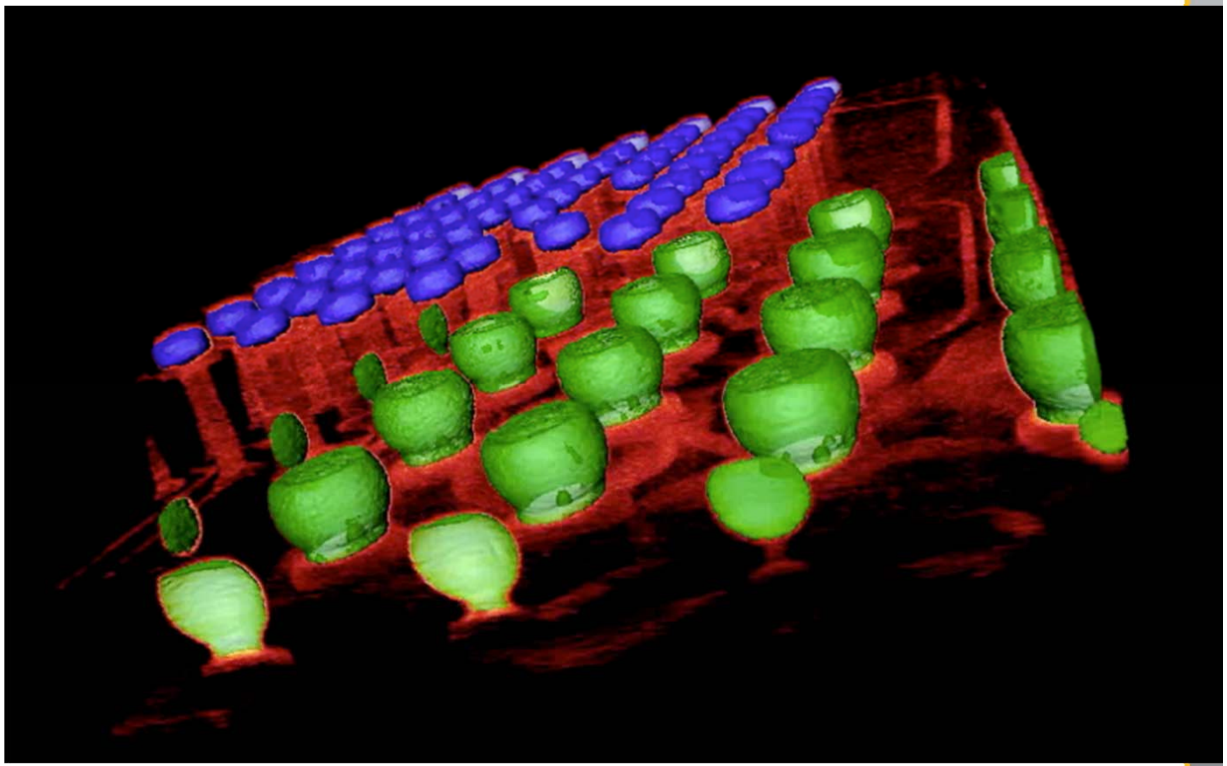
3D X-Ray Microscopy (XRM)

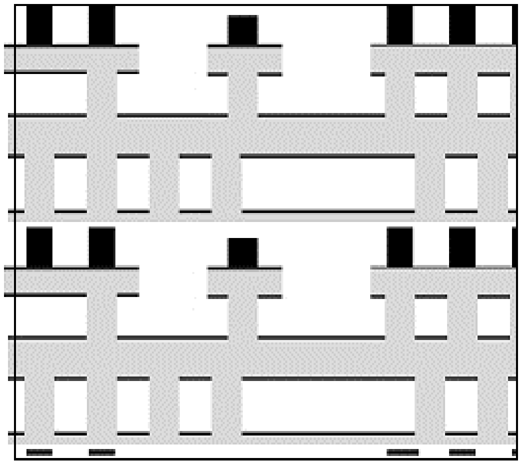
Fully packaged IC Sample



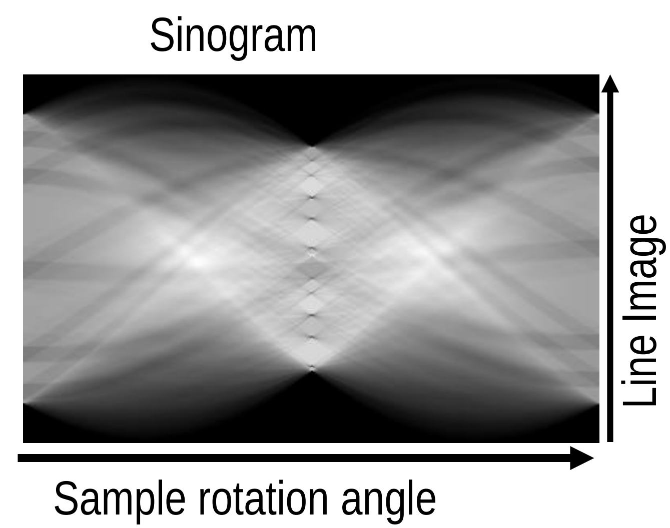
3D XRM Data Set



Computed Tomography



(1) Sample imaged at various angles to acquire tomographic projections.

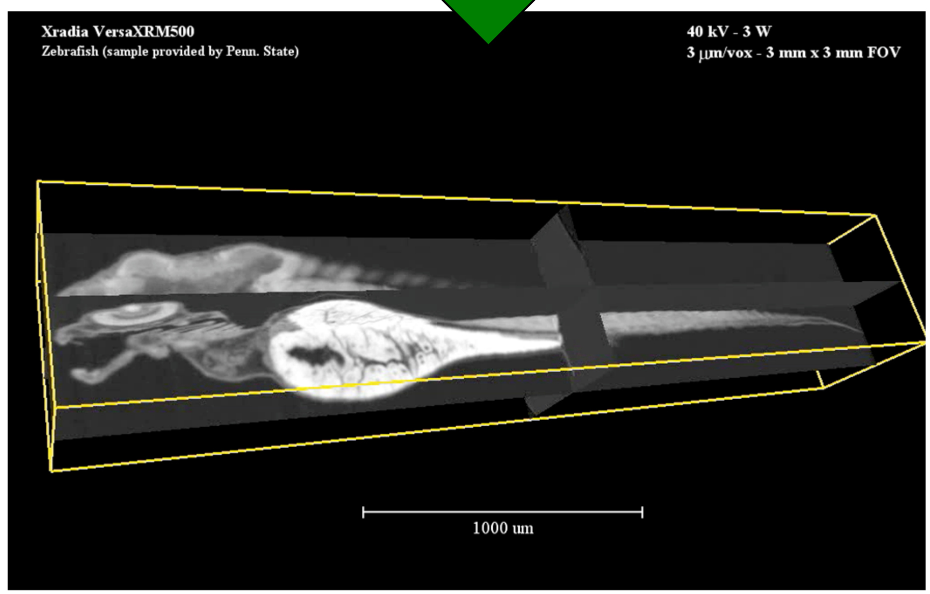


(2) 3D reconstruction by backprojection results in 3D image of the sample.

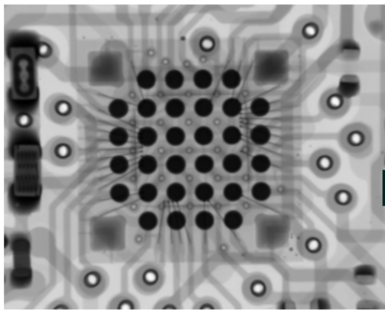
What Can You Do With a 3D XRM Dataset?

Non-Destructive

Virtual Cross Sections

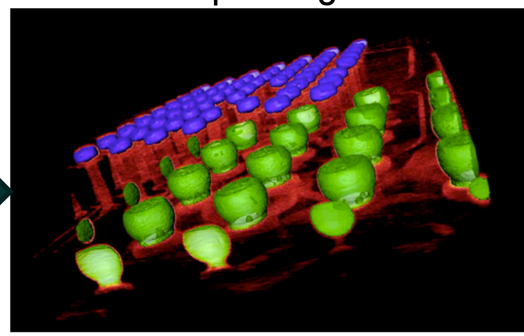


Evolution of X-ray Imaging Techniques in Electronics



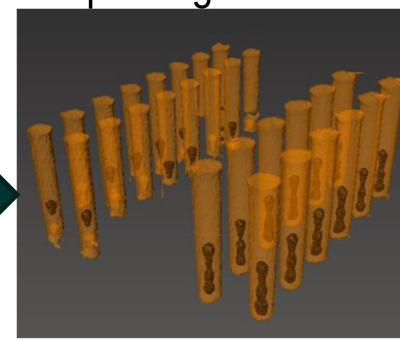
2-D PCB Inspection and traditional micro-CT

Intact 3-D packages



3-D sub-um X-ray Microscopy “VersaXRM”

Unpackaged IC

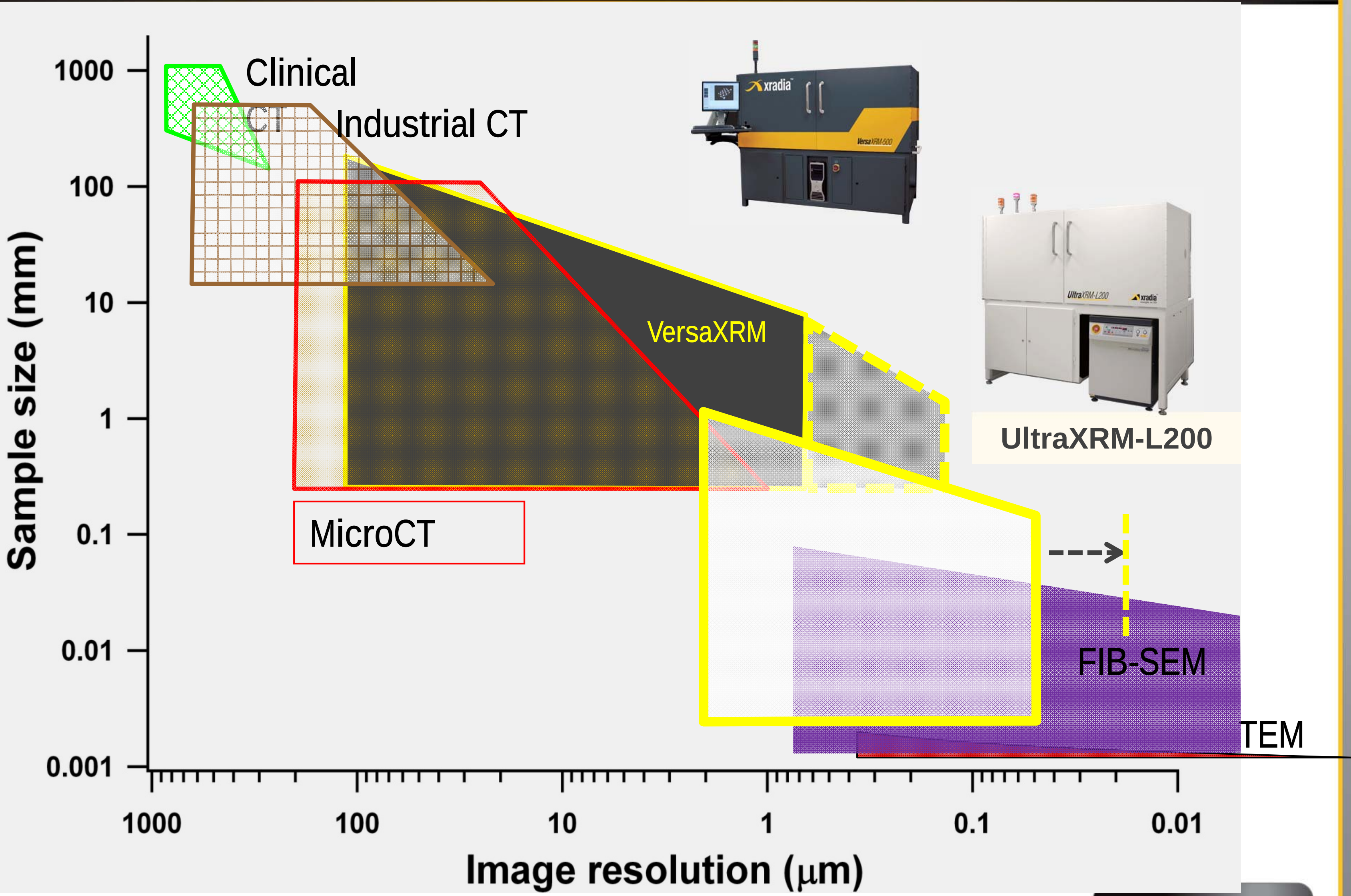


3-D sub-50nm X-ray Microscopy “UltraXRM”

Destructive (X-section/FIB)

- Complexity of 3-D integration on IC and package level drives the need for non-destructive 3-D imaging
- Mostly for FA and process development
- Enabled by development of x-ray detector and optics technology

Multi-scale 3-D Imaging



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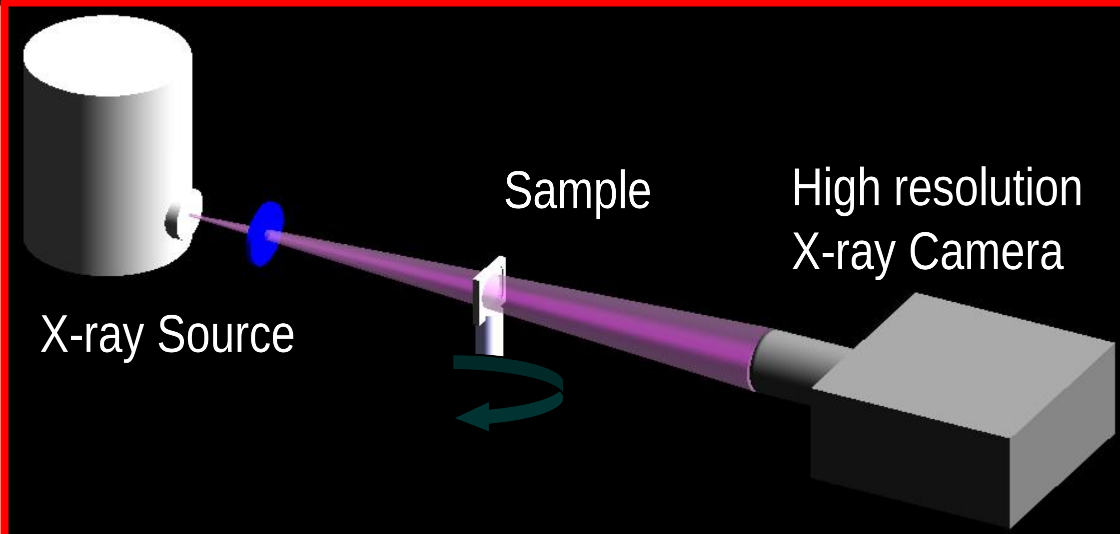
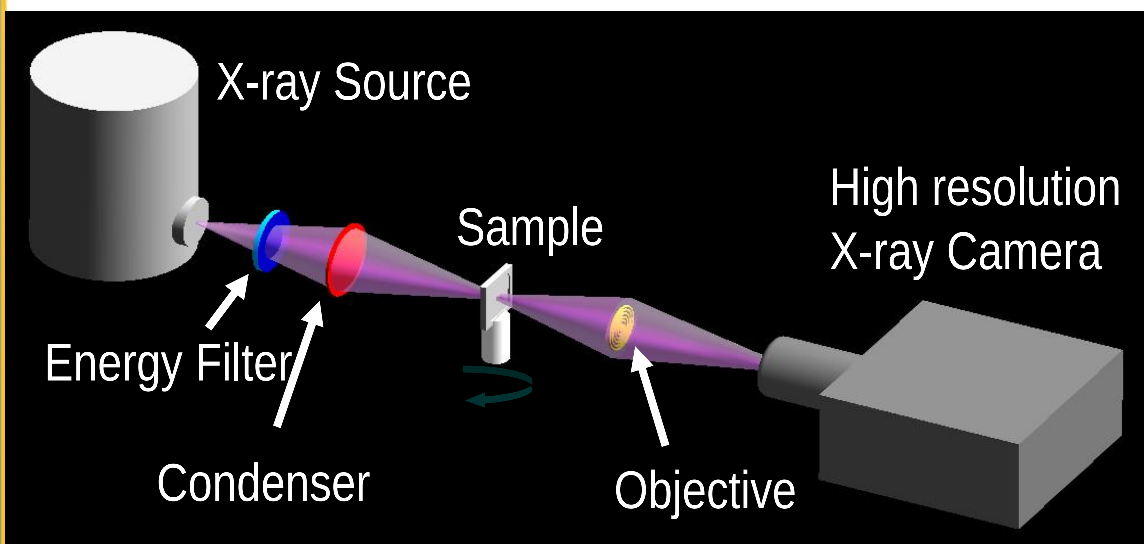
3-D X-ray Microscope Architectures



Point Projection Imaging
“VersaXRM”
0.7um spatial resolution



X-ray Lens Based Imaging
“UltraXRM”
50nm spatial resolution

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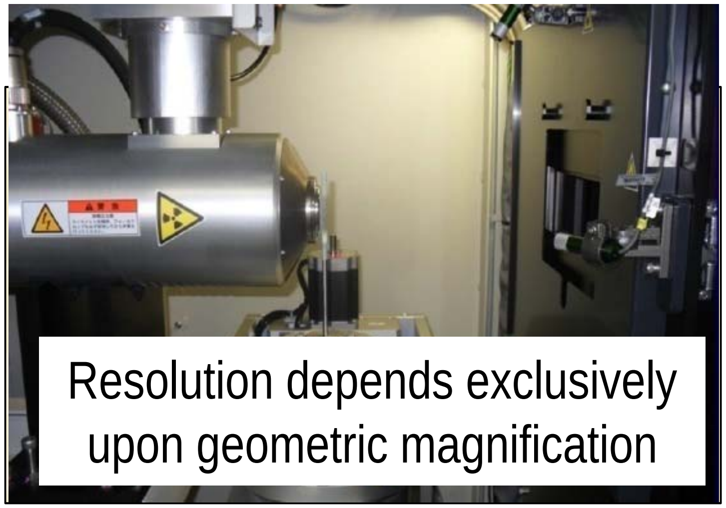
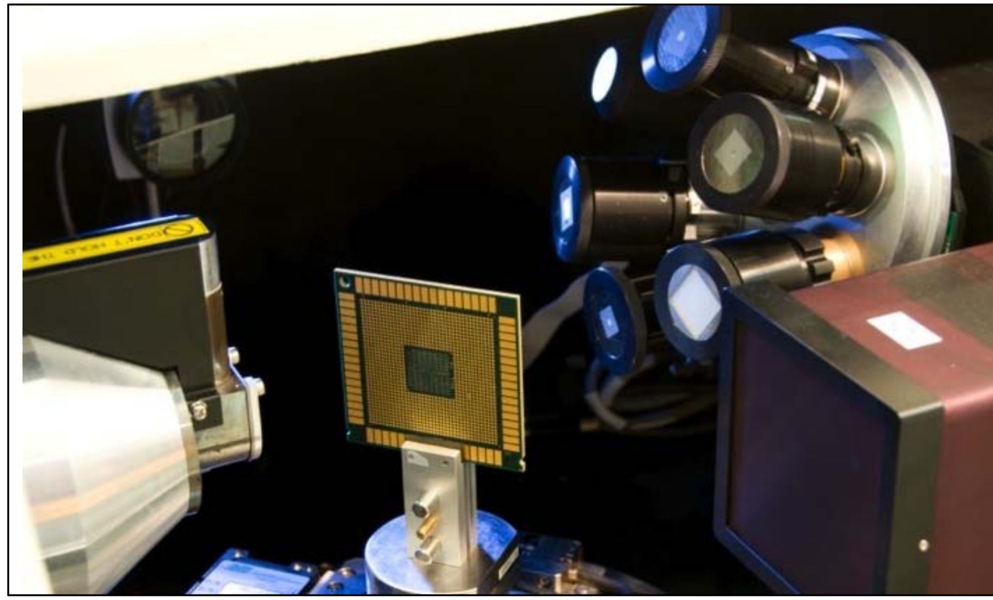
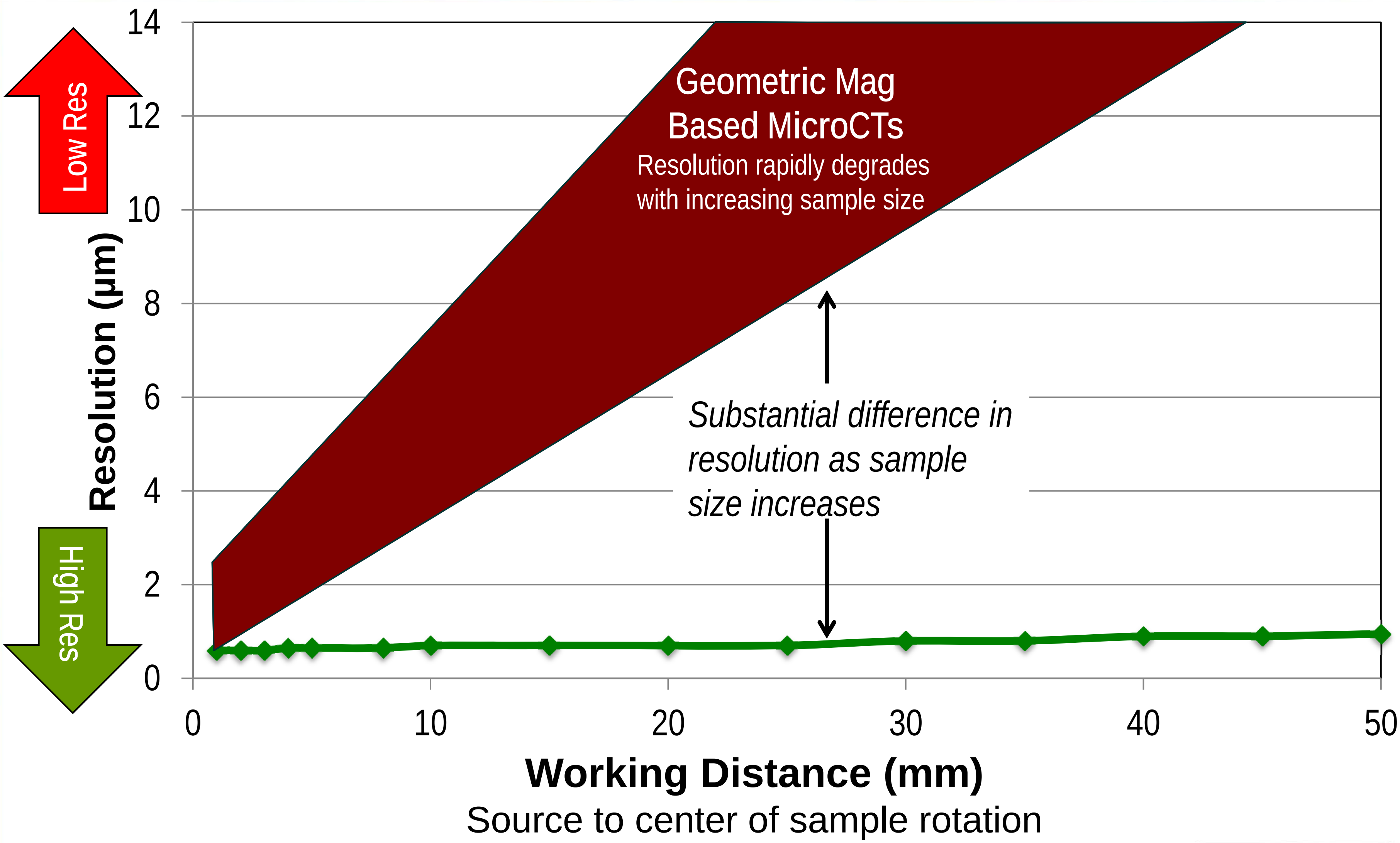
Micro CT vs. 3D X-ray Microscopy

	Traditional Projection based Micro CT	X-Ray Microscopy (XRM)
		
Res	▣ Highest resolution limited to < 1mm samples	▣ High resolution maintained for samples as large as 50 mm
Detector	▣ Large pixel size – no magnification	▣ Optically magnified x-ray detector with sub-um resolution
Working Distance	▣ Res. Degrades linearly with sample size	▣ **Resolution is maintained**, even for larger samples

Resolution depends exclusively upon geometric magnification

XRM Maintains High Resolution at Large Working Distances



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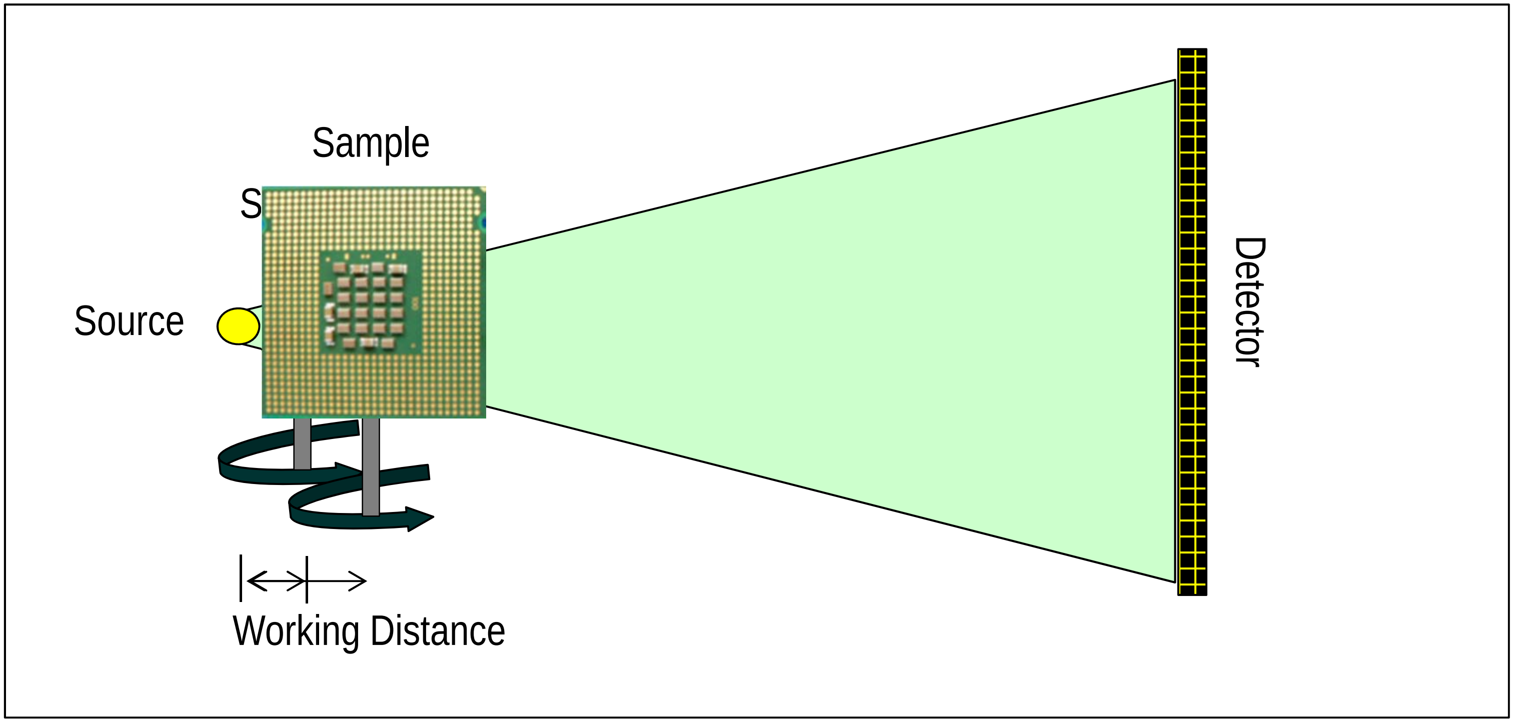
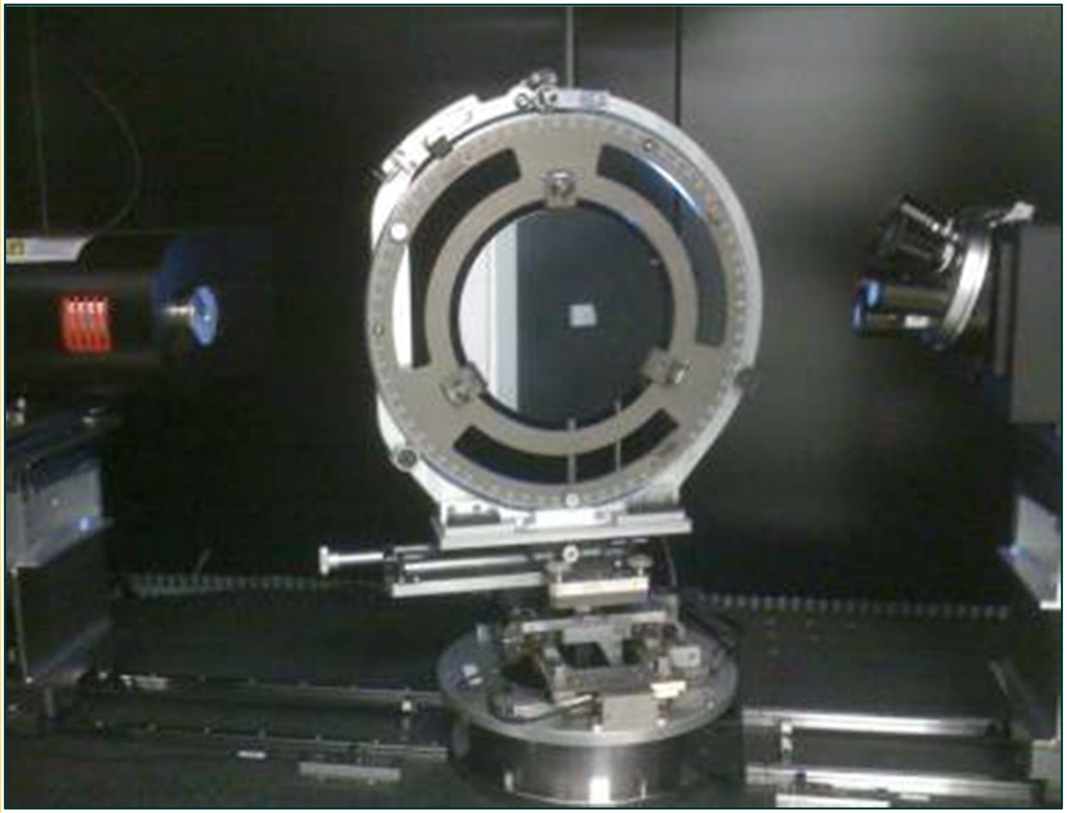
Implication of Increased Working Distance



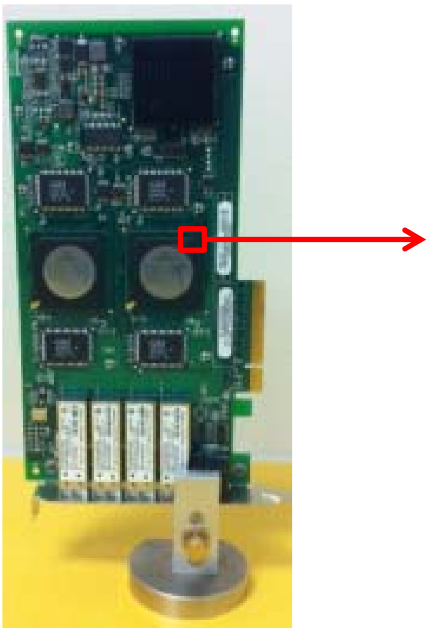
Working distance is pre-requisite to image larger samples relevant to electronics!

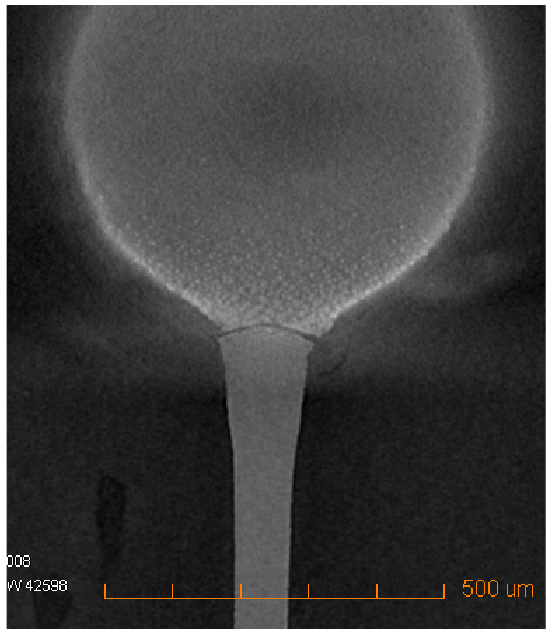
Working Distance Enabler

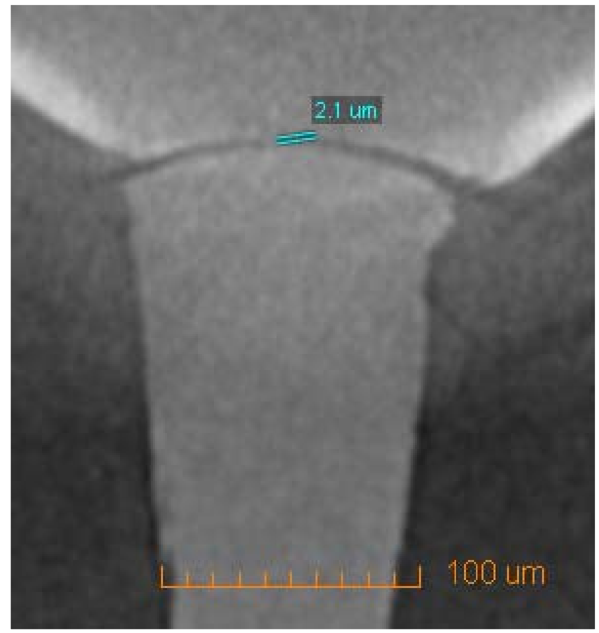


Even whole wafers can be imaged → TSV development / FA

Working Distance Enabler II





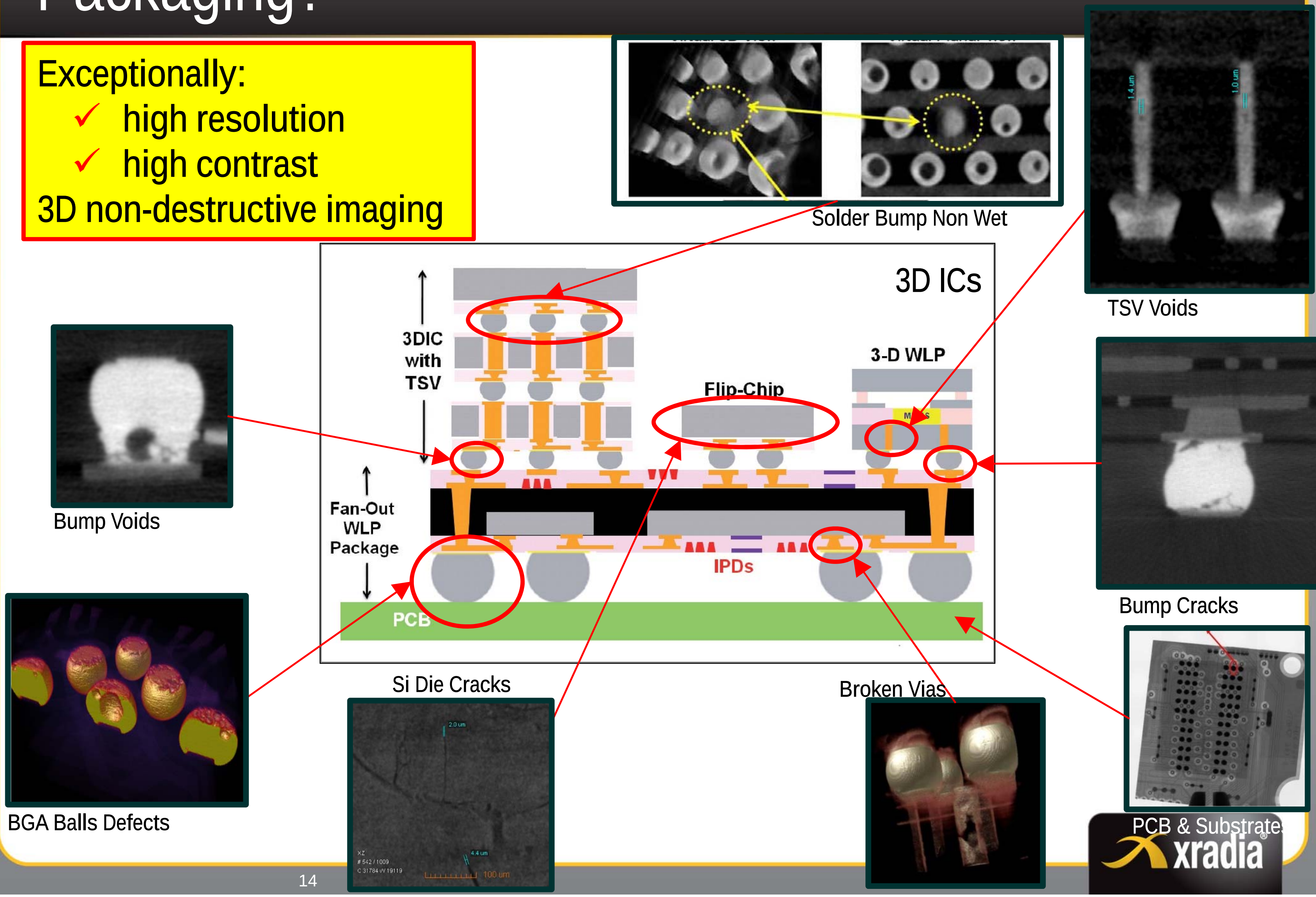


High resolution, even for large, completely intact samples

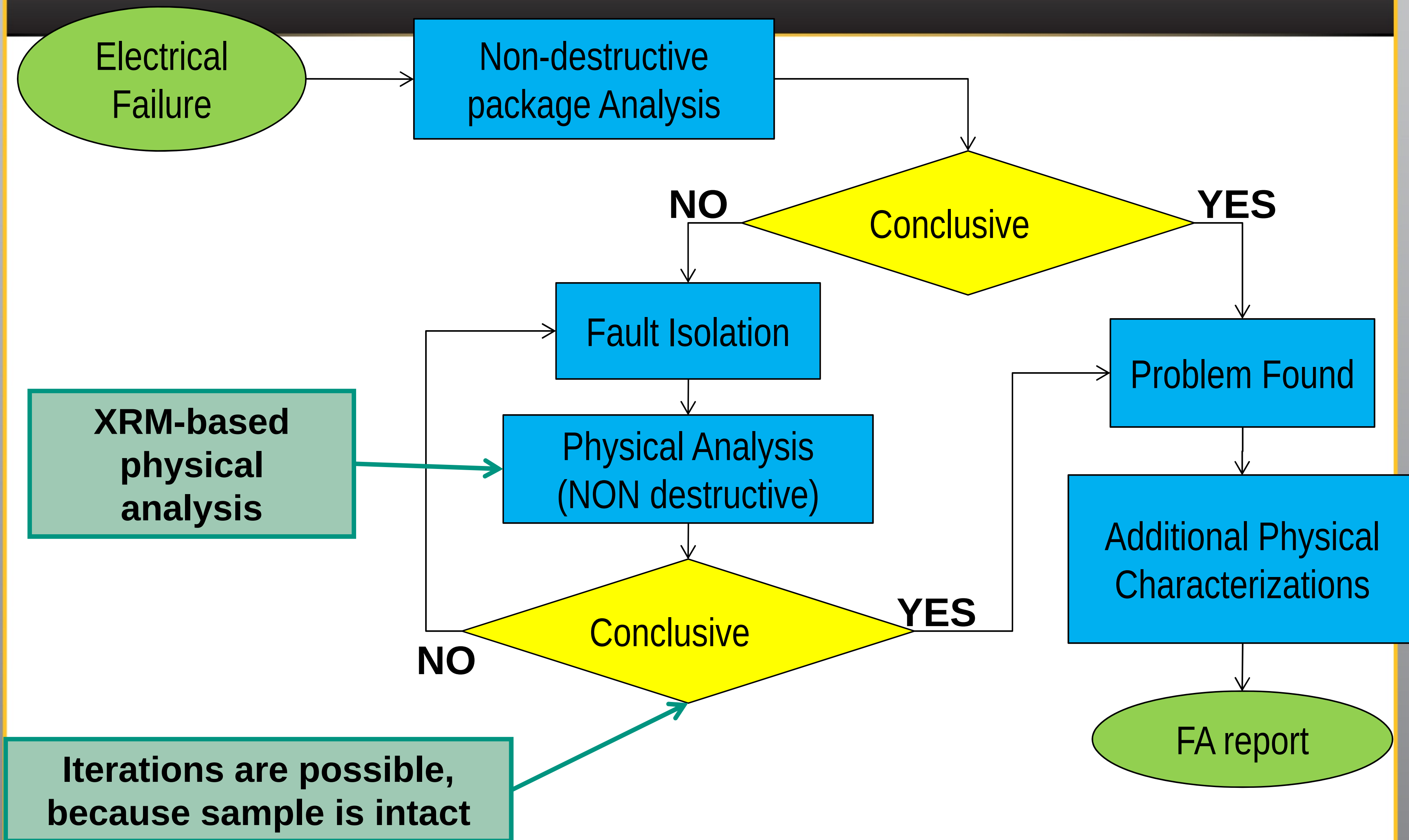
What Does XRM Offer to Advanced Semiconductor Packaging?

Exceptionally:
- ✓ high resolution
- ✓ high contrast

3D non-destructive imaging

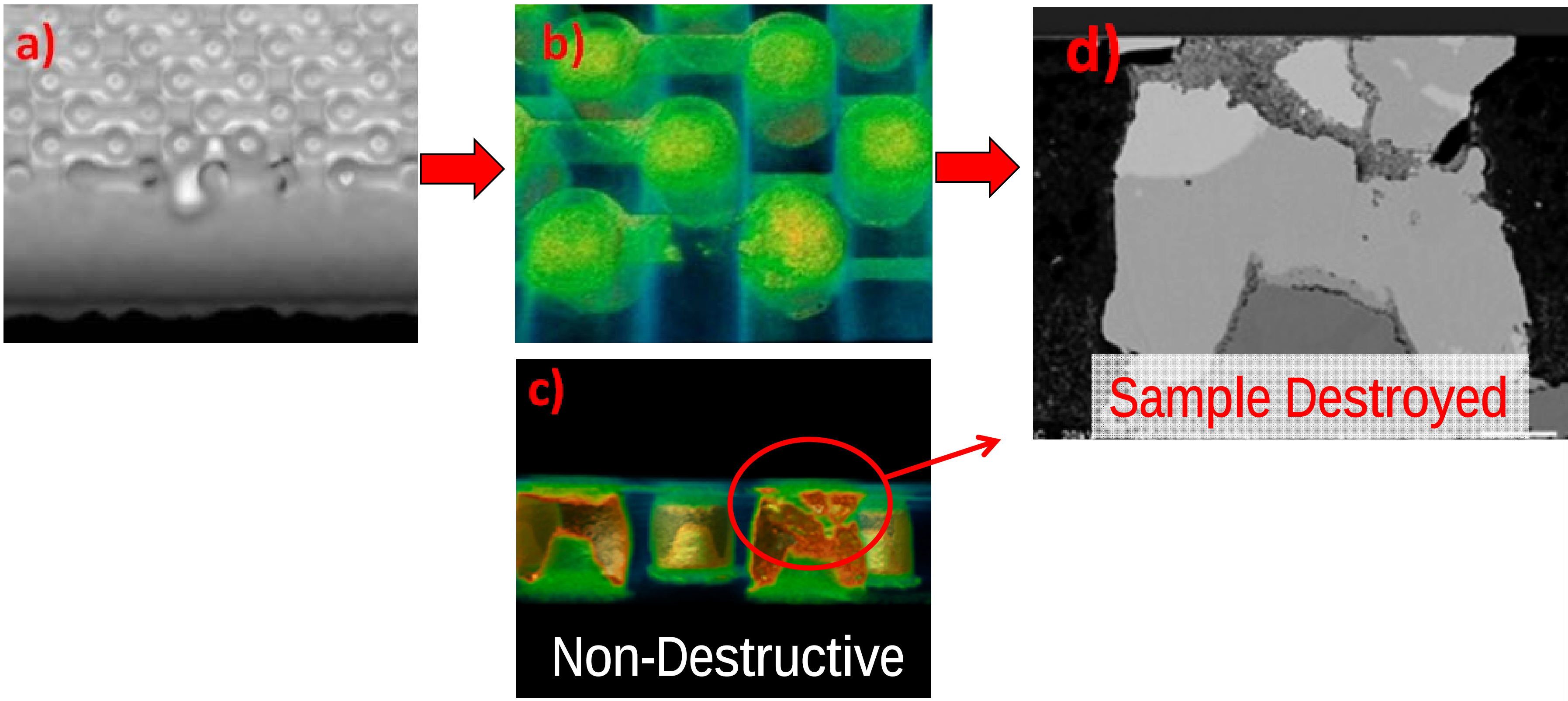


XRM-based FA flow (package failures)



Semi FA Example:
Electro Migration Related Failure

SAM | VersaXRM | SEM X-section



XRM for finding optimal location for physical cross section

Source: "Applications of 3D X-Ray Microscopy for Advanced Package Development", K. Fahey, R. Estrada (Xradia), L. Mirkarimi, R. Katkar, D. Buckminster and M. Huynh, Tessera Technologies, Inc, IMAPS Long Beach 2011

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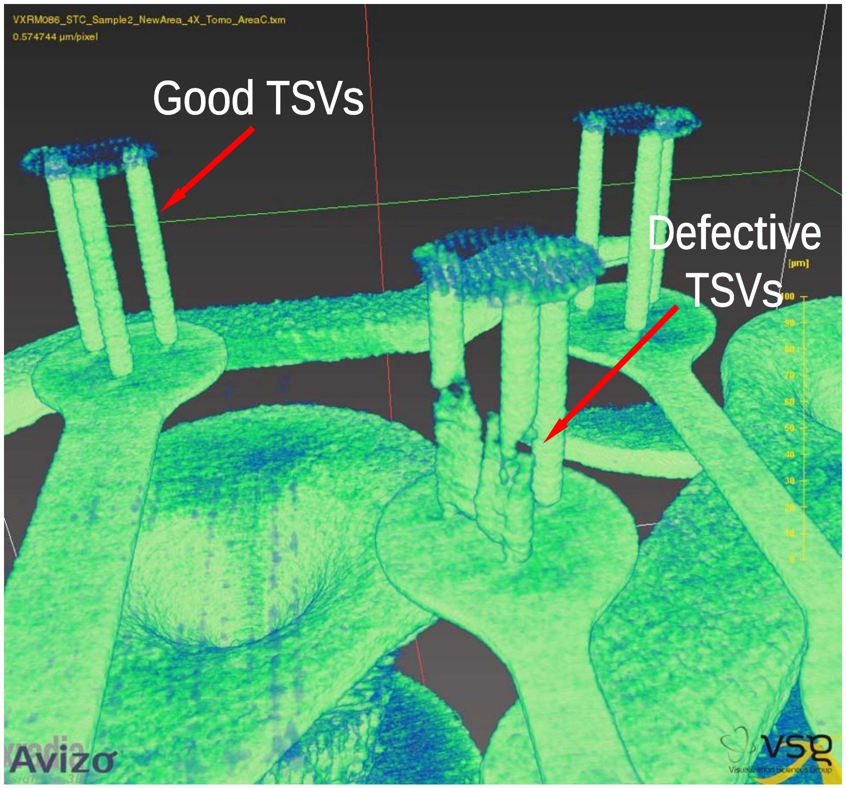
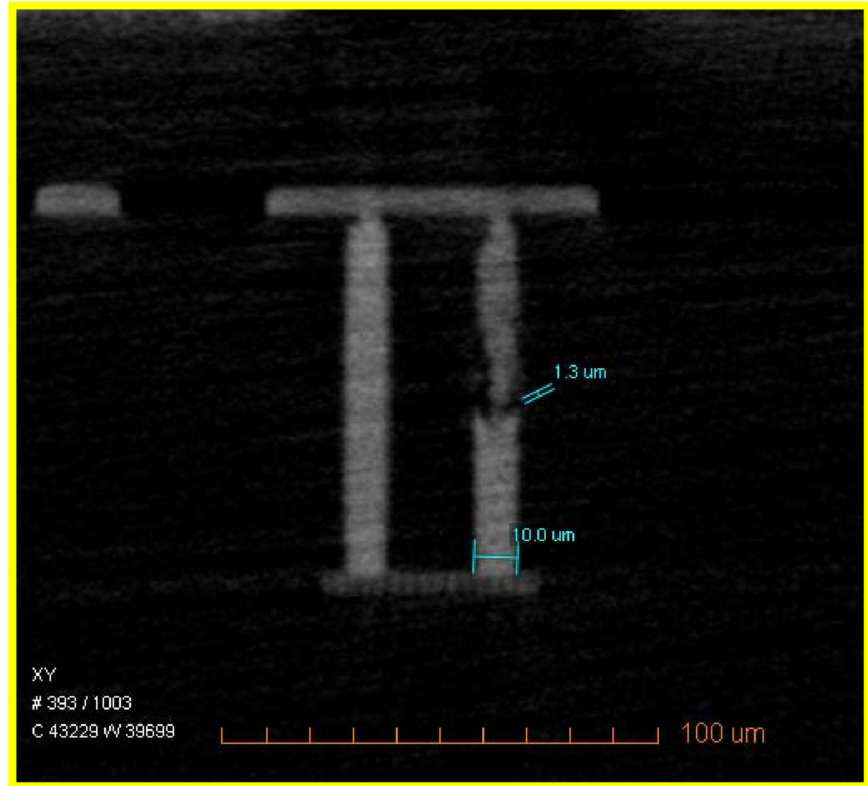
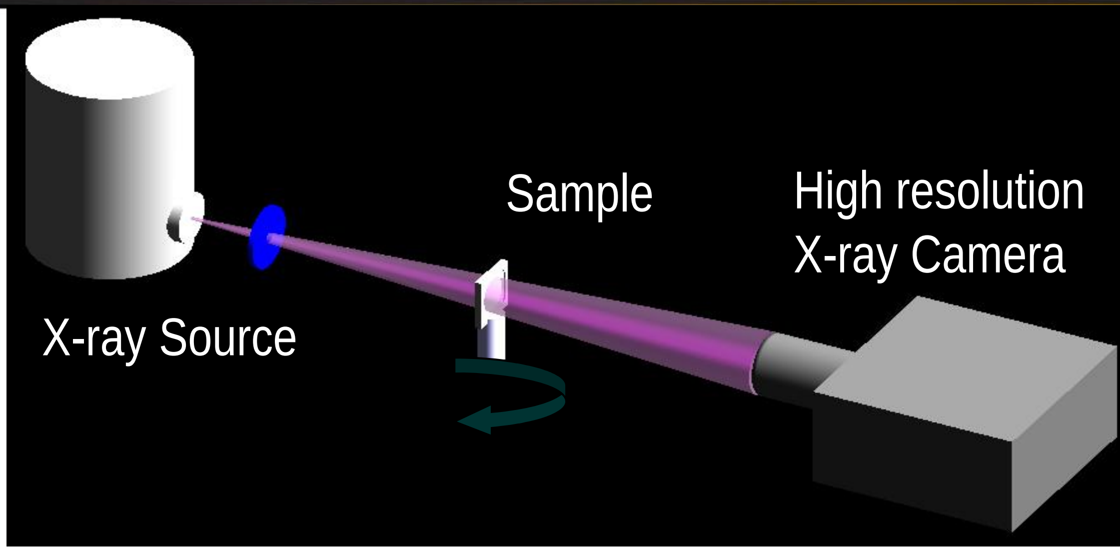
Non-Destructive High Res 3D for TSVs



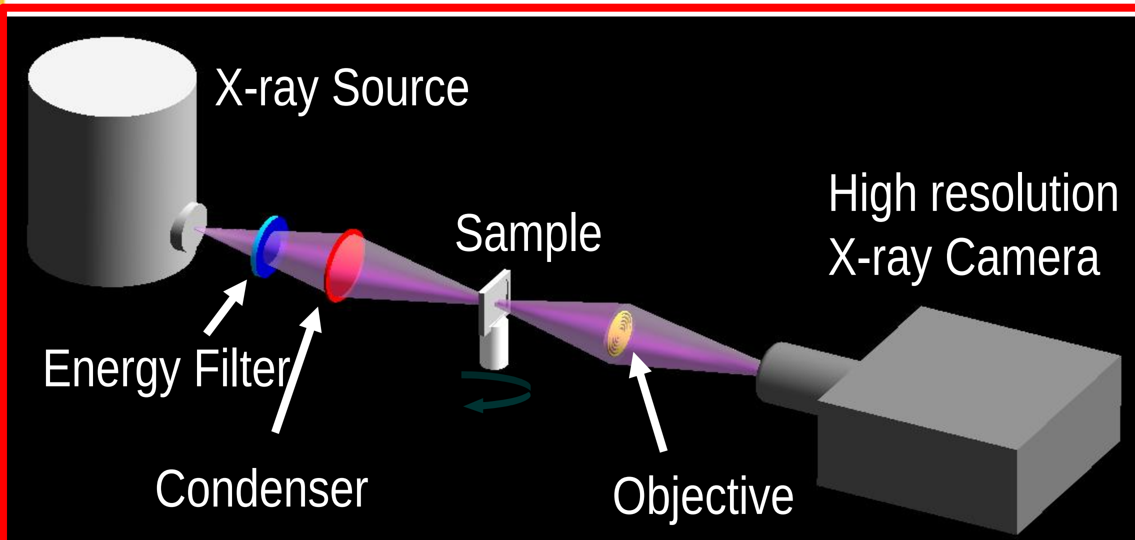


Ability to visualize TSV failure in intact package

3-D X-ray Microscope Architectures



Point Projection Imaging
“VersaXRM”
0.7um spatial resolution



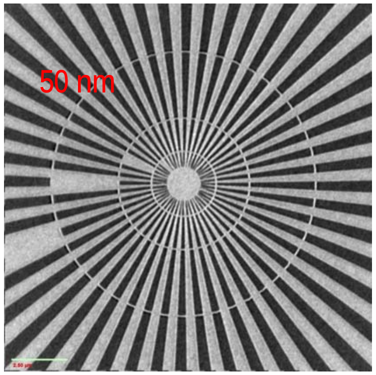
X-ray Lens Based Imaging
“UltraXRM”
50nm spatial resolution

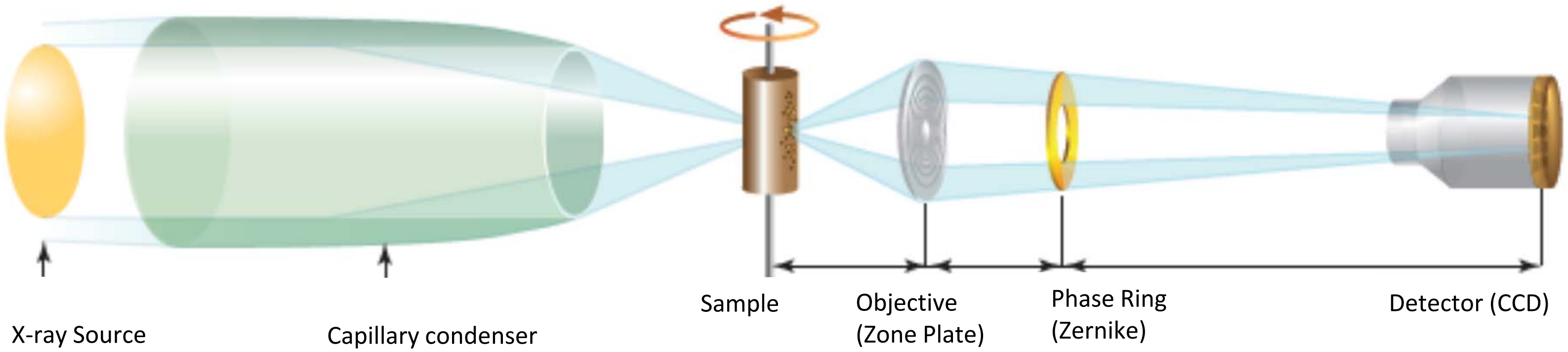
UltraXRM: 3D X-ray Microscope using X-ray Optics

50 nm spatial (16 nm pixel) resolution

- High brightness x-ray source (8kV)
- High efficiency reflective condenser
- High-resolution objective zone plate
- Zernike phase contrast optics
- Precision tomography system (auto-tomo!)

Mode	Mag	2D Res	Field of View
Large Field of View	200X	150 nm	65 µm x 65 µm
High Resolution	800X	50 nm	15 µm x 15 µm





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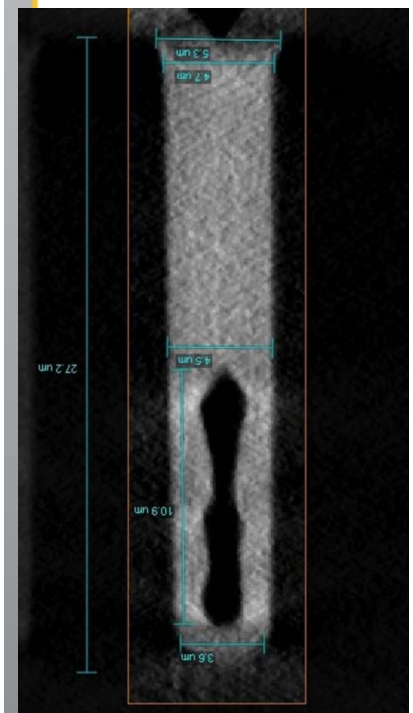
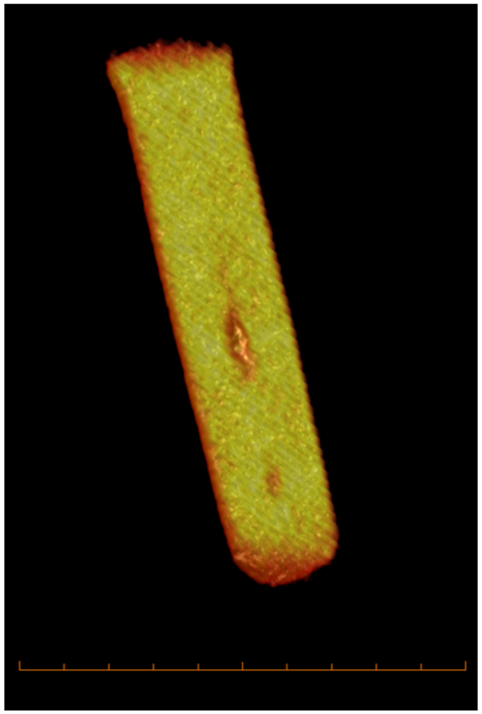
Post-metallization TSV – UltraXRM

Cross Sectioning

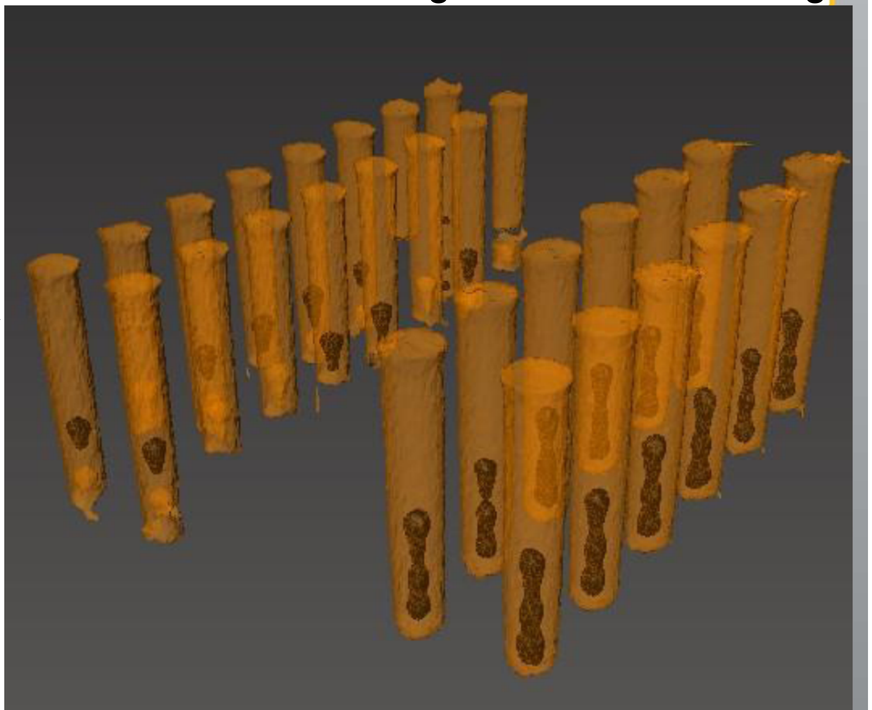
2D Virtual Cross Section



3D Isolated TSV

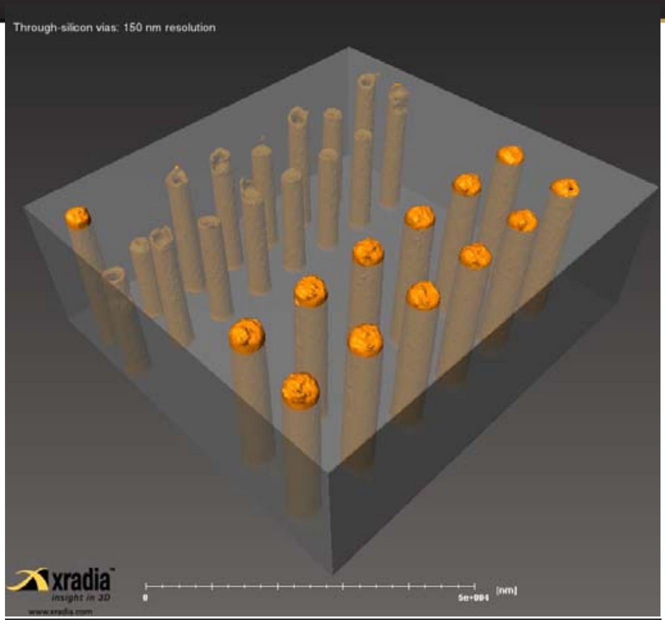


3D Rendered Large Field of View Image



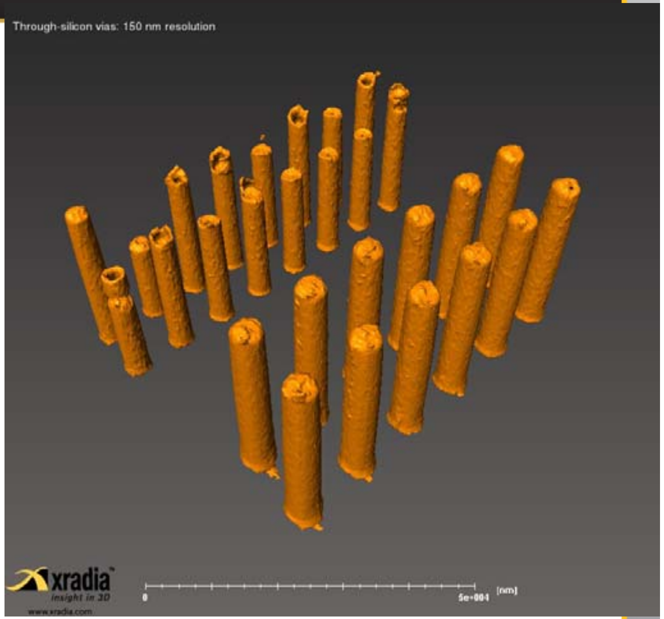
3D interconnects: Applying X-ray microscopy as a void inspection technique for Through Silicon Vias, Lay Wai Kong, CNSE Albany/NY, US
FRAUNHOFER WORKSHOP ON STRESS MANAGEMENT FOR 3D IC'S USING THROUGH SILICON VIAS Oct 20, 2010

Ultra: TSV Metallization – Quantitative Analysis



From images, to information, to data

Remove Si



Segment Voids

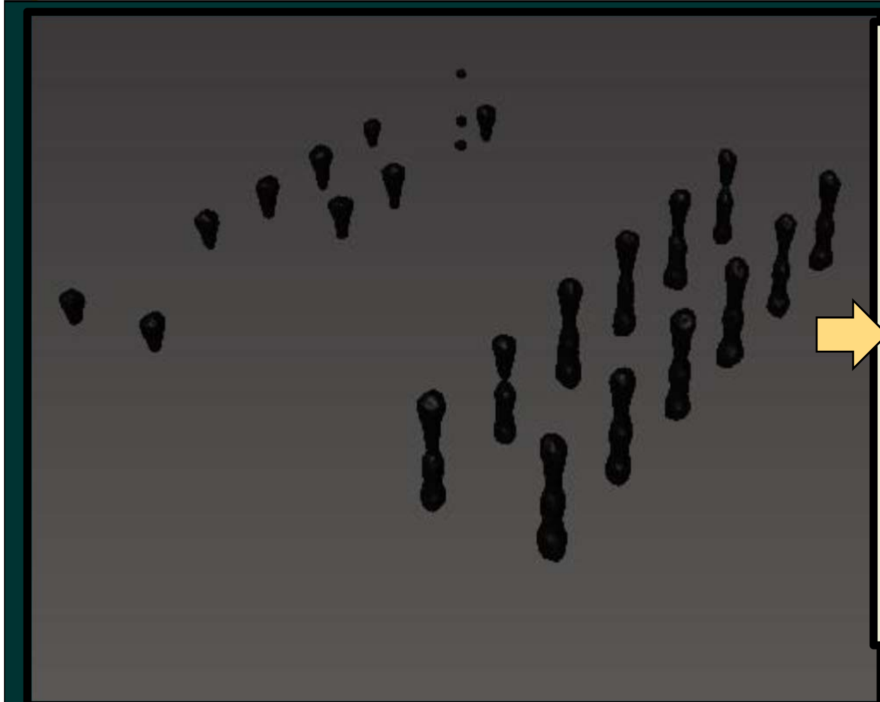
Remove Cu
(voids only)

Collaboratoion with Fraunhofer/Albany

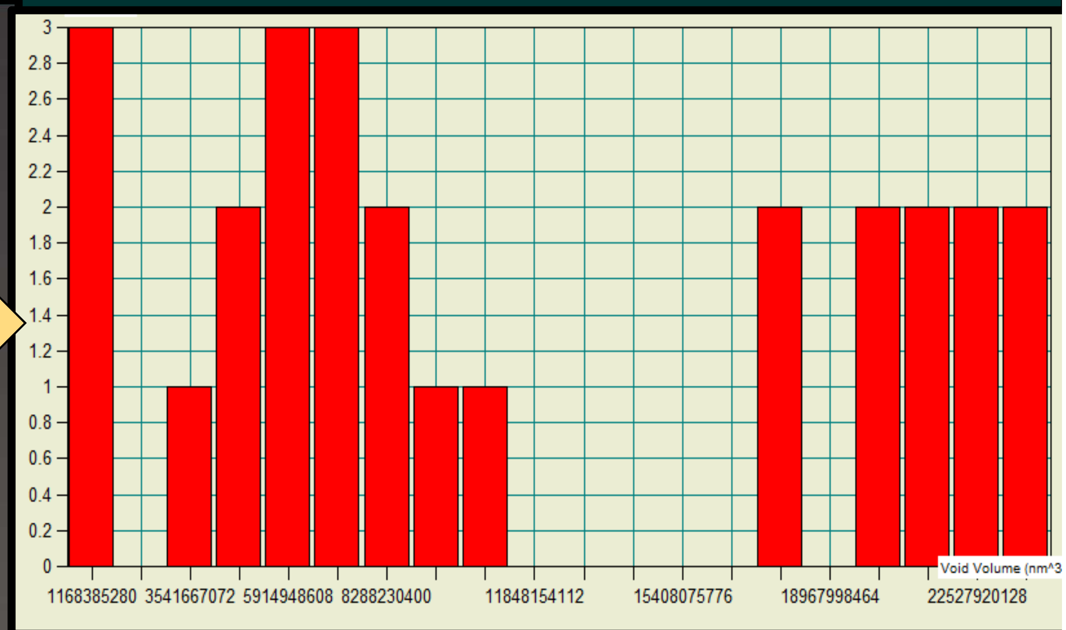
Quantifying Void Space / Volume

UltraXRM-L200 results: Segmentation enables Void Space Analysis

3D Rendered, Segmented Voids



Distribution Analysis of Void Space (nm^3)



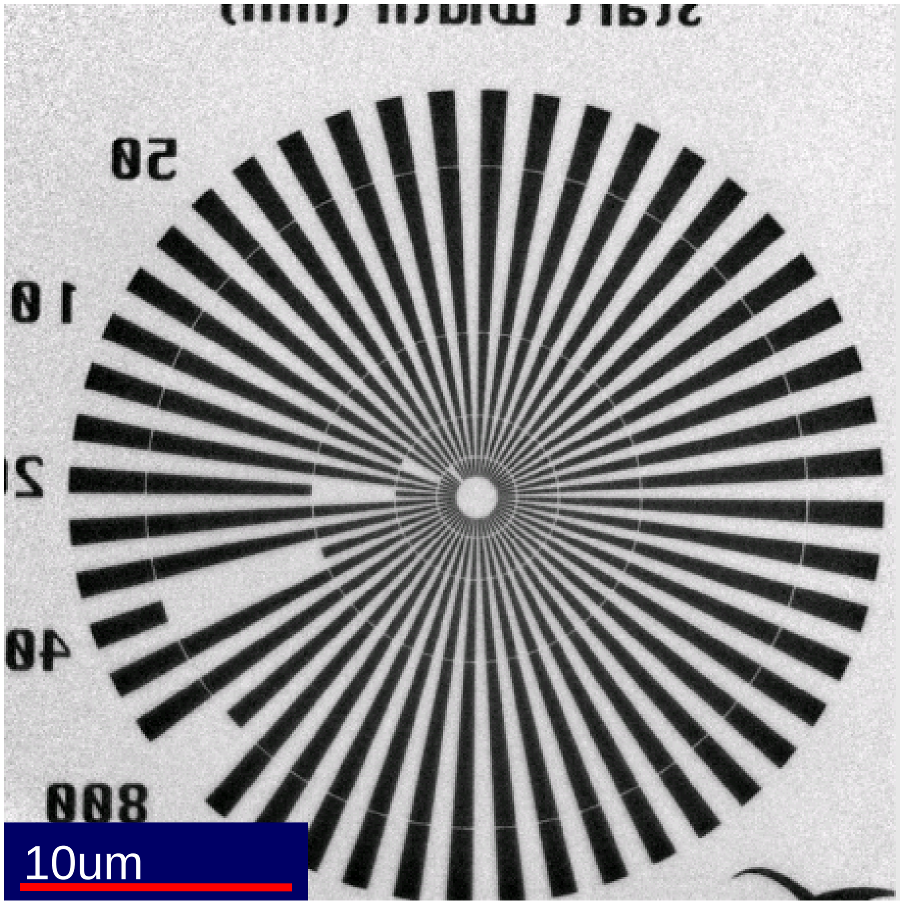
Segmentation of 3-D data allows objective, quantitative analysis of complex structures

Comparison with Other Imaging Modalities

	X ray UltraXRM	Optical	SEM	(S)TEM
Wavelength	0.1nm	100-1000	0.01	0.001-0.003
Spatial resolution	30 nm	200-300 nm	1-10 nm	0.1 nm
Contrast Mechanism	Absorption, Phase Contrast	Transmission, Reflectivity, Refractive Index, Labels	Secondary El., Backscattered El., EDS/WED	Electron Density, EELS EDS EBSD…
Max sample thickness	~50-500 μm	Optically transparent only	< 10 nm typical	<<200 nm
Vacuum requirement	No	No	Yes	Yes

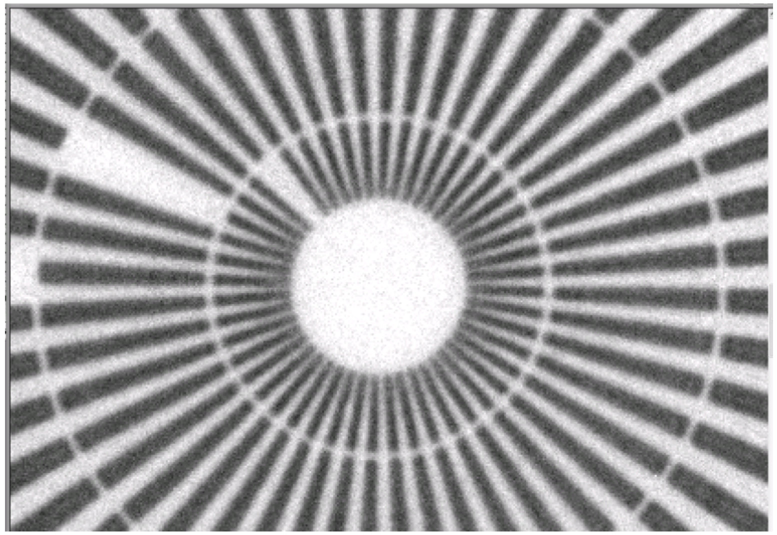
- Penetration of x-rays major advantage to nondestructively image a 3-Dimensional volume
- Resolution currently limited by optics (not physics) → single digit nm resolution should be reached for 3-D x-ray imaging eventually (not aberration limited like EM)

Resolution Better Than 50nm – FOV 32um



Field of View > 32x32um
2k x 2k (1s image time)

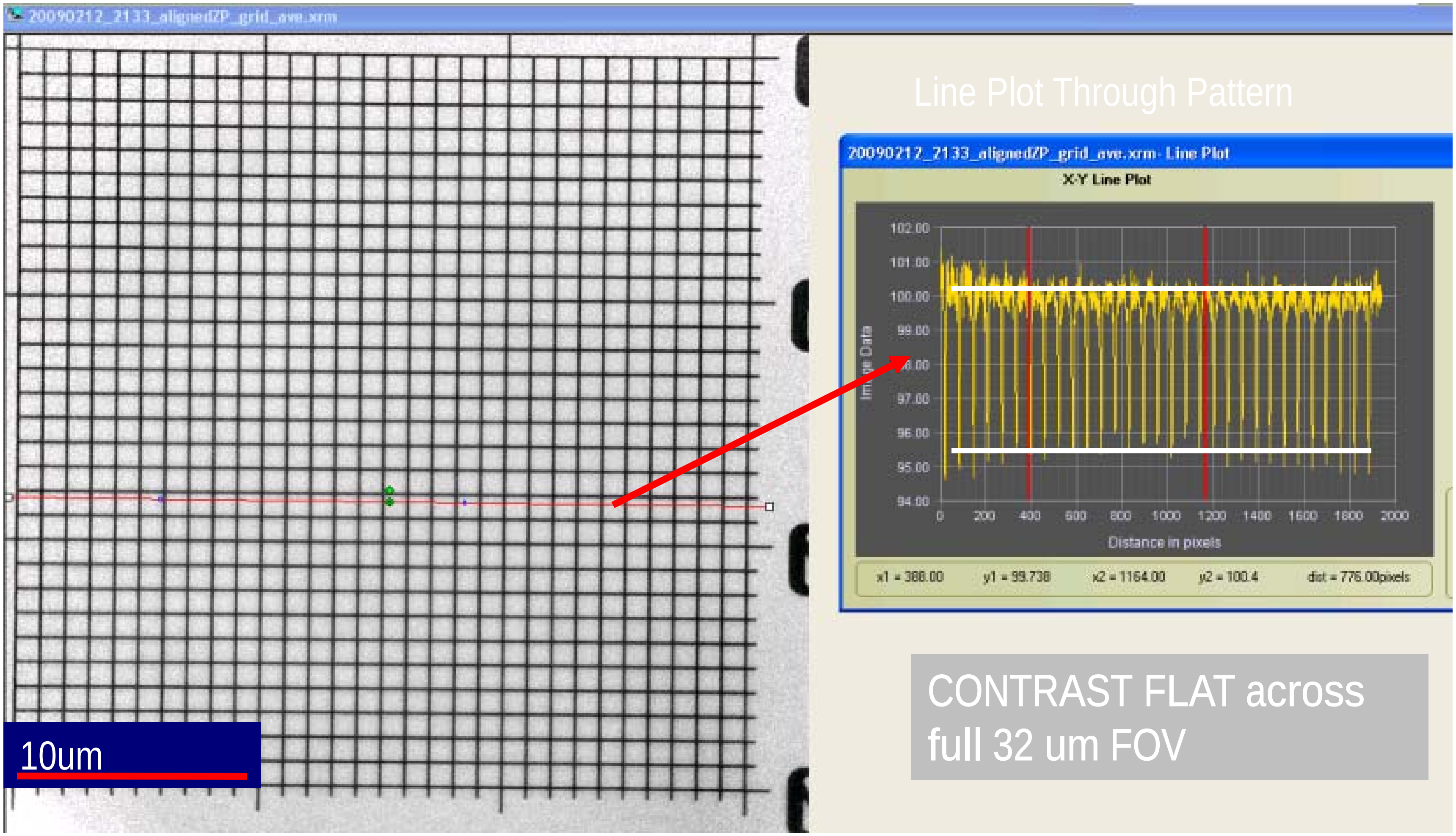
Same image zoomed in.
50nm smallest features



Resolution 30nm

Stanford Synchrotron SSRL
Beamline 6.2 Xradia UltraXRM

Contrast Uniformity

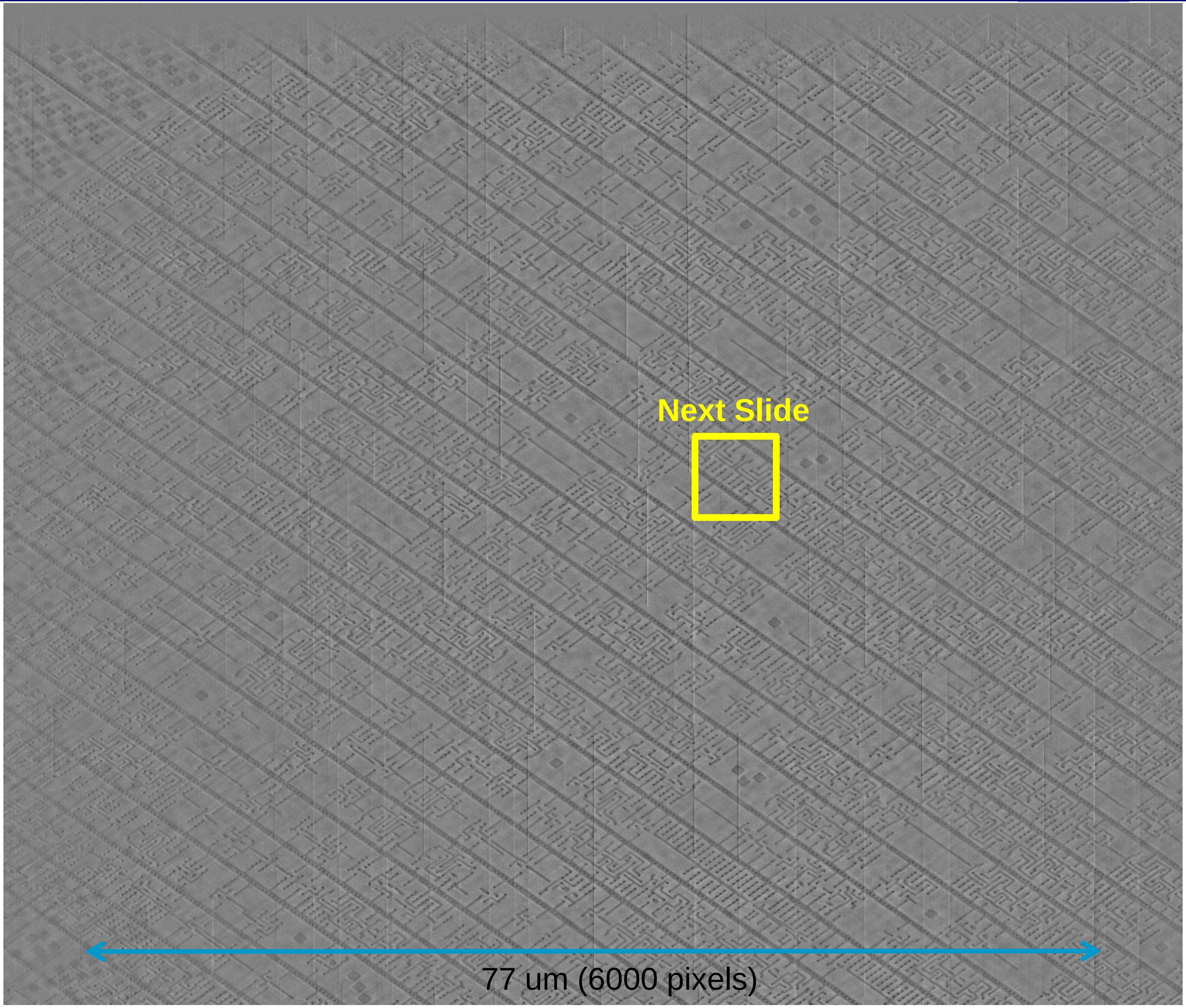


Line Plot Through Pattern

CONTRAST FLAT across full 32 um FOV

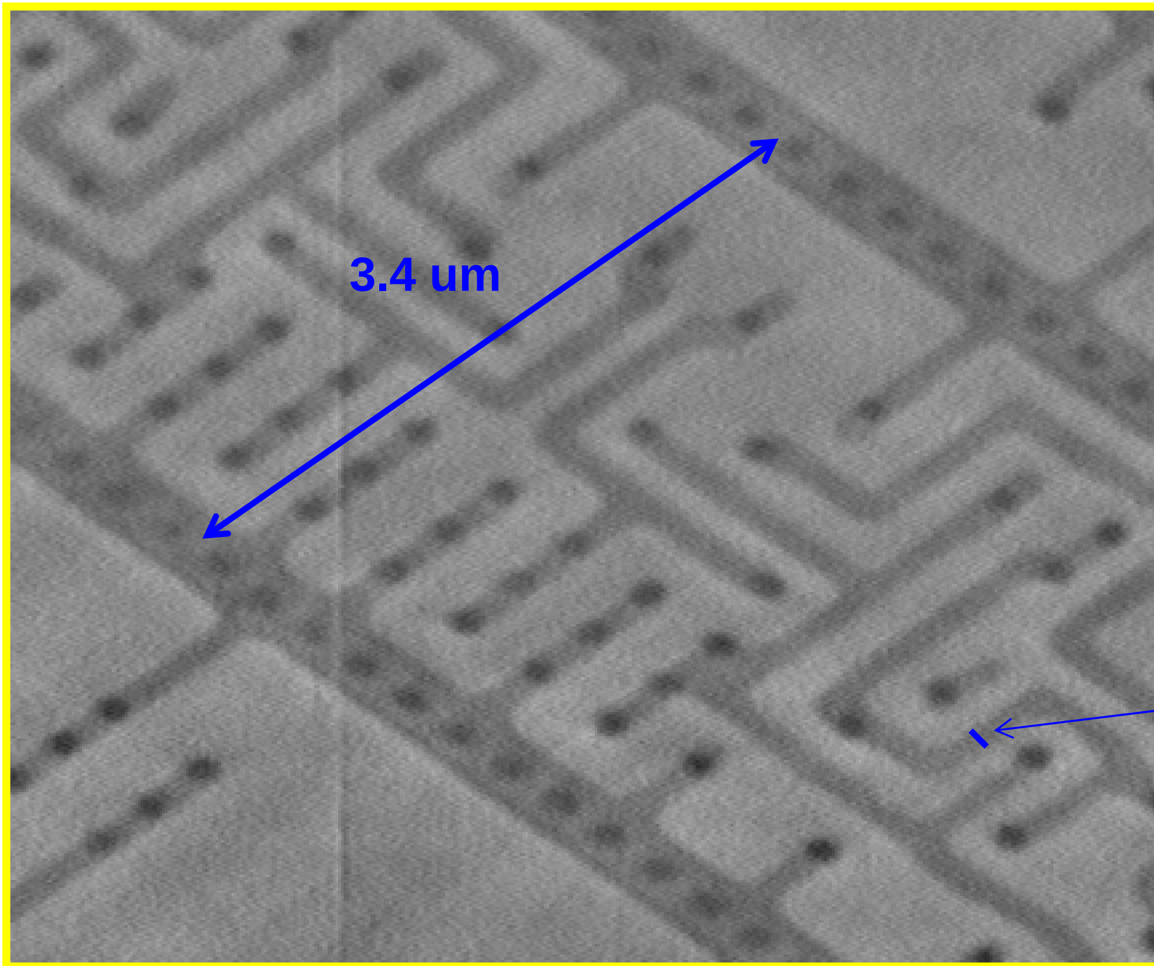
Automated Tomography of 70 um x 70 um M1 Slice – Still Image

77 um
(5100 pixels)



Automated Tomography
Closeup of Virtual Delayering M1

360 pixels



430 pixels

See outline in previous slide

90 nm process M1 Min. feature size 120 nm

Conclusion - What Makes XRM Unique?

Penetration, Large Working Distance at Highest Resolution

- X-ray microscopy (XRM) can bridge the gap between NDT and high resolution EM / FIB
- Address challenges of large, complex 3-D electronic packages
  - High Resolution
  - High Contrast
- **4D characterization** (before/after stress test or cycling)
- TSV imaging (UltraXRM)
- Design verification for TRUST on ICs (UltraXRM)

Not a Substitute for EM/FIB Microscopy for IC FEOL Imaging or smallest BEOL structures