X-Ray Microscopy for Interconnect Characterization

Frontiers of Characterization and Metrology for Nanoelectronics

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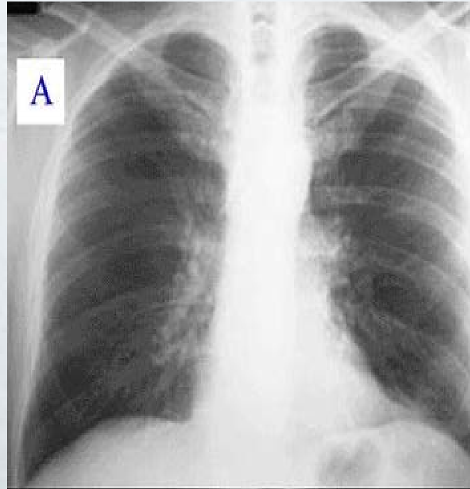
President, CTO, Founder

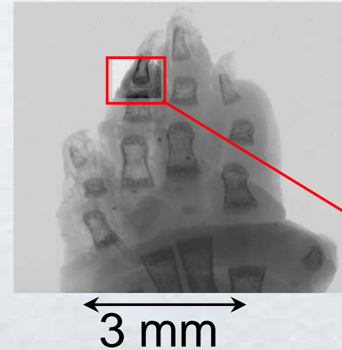
,May 13, 2009

X-ray Imaging Advantages

1896, Rontgen



Chest x-ray



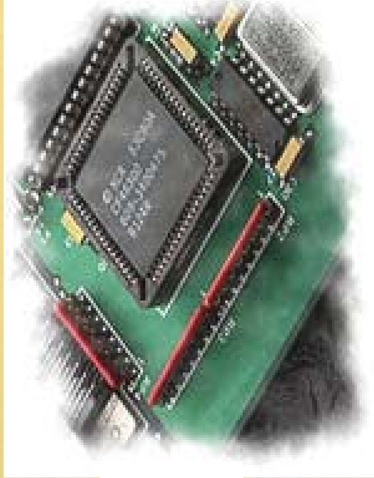
newborn mouse paw

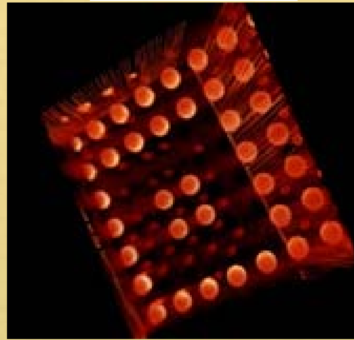
microfocus x-ray sources and high resolution CCDs

- Nondestructive and 3D
- Resolution is Not diffraction limited (8 keV x-rays = 1.5A wavelength!)
- No need for conductive coating (Photons don't have charge)
- Minimal and no sample preparation
- No vacuum required. Fully hydrated thick samples (hard x-rays)

Multi-Length Scale Capabilities : Semiconductor

MicroXCT

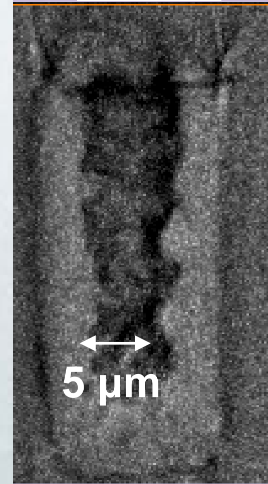

Board

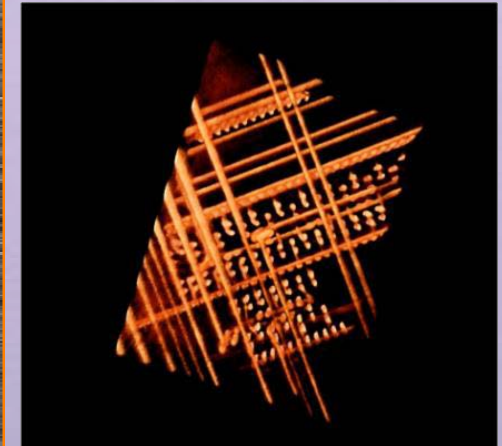
Flip Chip


20 μm   1 μm

Applications::
- Advanced package development
- Through silicon vias (>20 um)
- Failure and reliability analysis
  - Solder ball crack
  - C4 bump crack

nanoXCT

TSV


Interconnect


150 nm   50 nm

Applications::
- Advanced interconnect development
- Through silicon vias (<20 um)
- Failure and reliability analysis
  - Open & short
  - Static discharge

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Nanoscience needs nanoimaging (Seeing is believing)

- Nondestructive
- High resolution
- Element specific
- Magnetism
- Proving chemical and electron states

X-ray nano-imaging

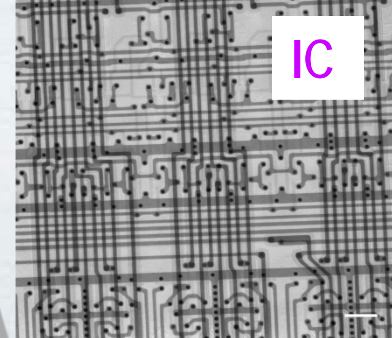
Nondestructive 3D imaging at Nanometer scale

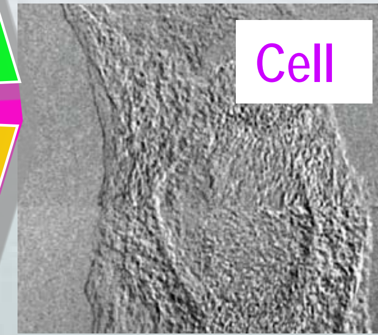
IC Manufacturing

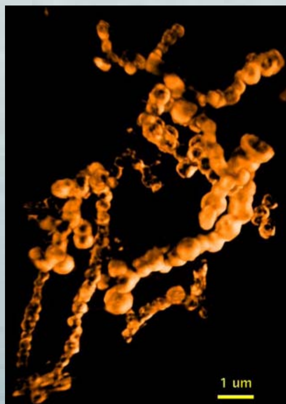
Biotechnology

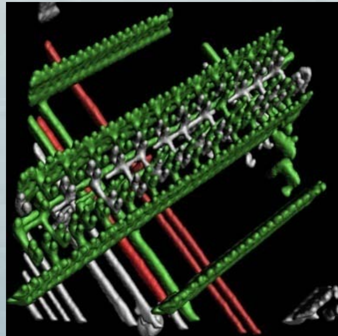
Nanotechnology

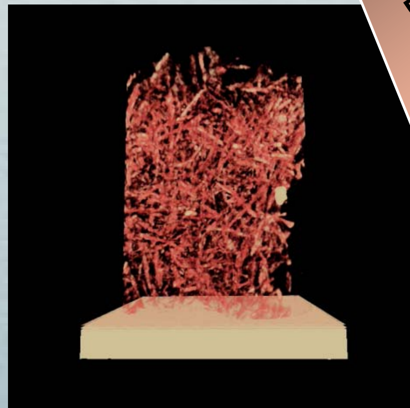
R&D Centers

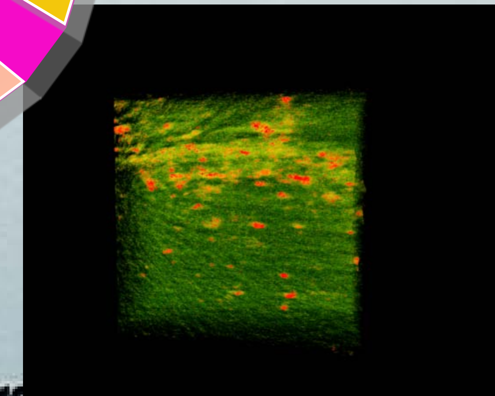












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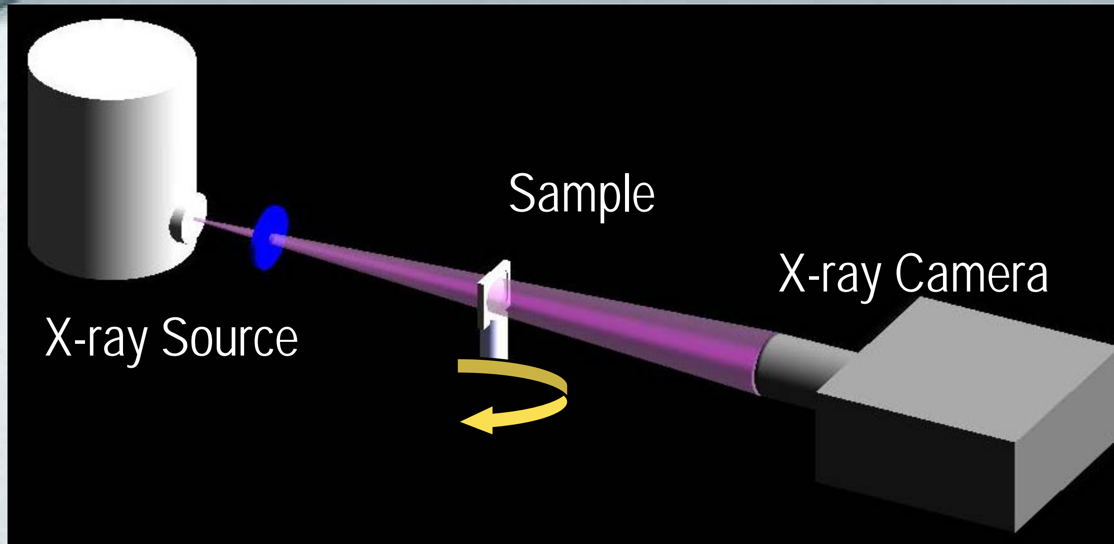
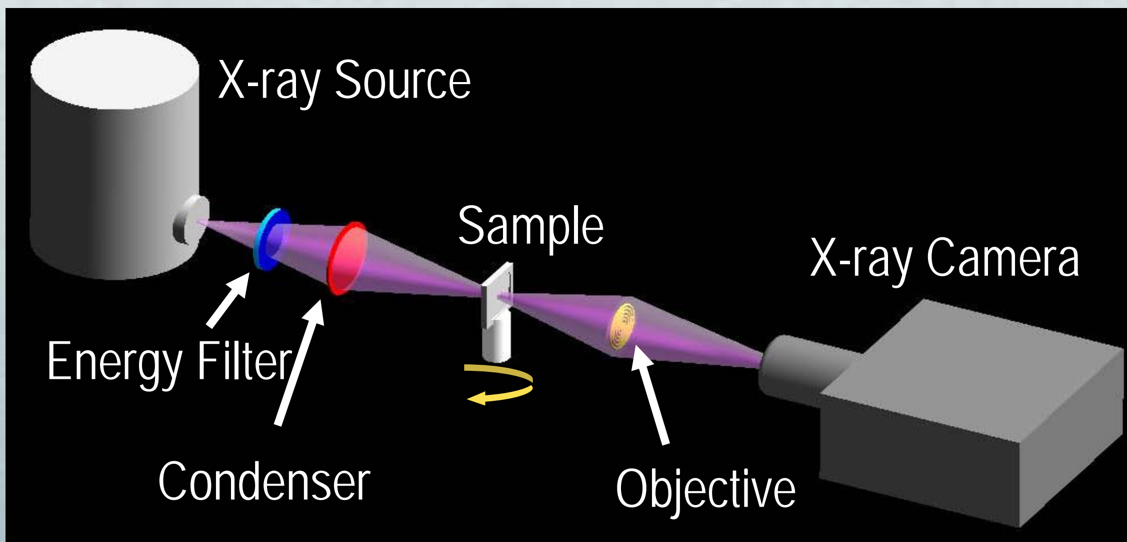
Competitive Analysis: Other Imaging Tools

	X ray	Optical	SEM	(S)TEM
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, spectroscopy
Probing depth	~100-1000 μm	Optically transparent only	< 10 nm typical	<200 nm
Sample preparation	Minimal	Minimal	Medium	Extensive
3D imaging	Yes	Yes	No, needs FIB or other preparation	Yes Very small vol.
3D image volume	10-60 μm up to 50mm	> 50 μm	No, needs FIB or other preperation	< 0.5 μm
Material class	All	Optically Transparent	Conductive path required > Charging	Conductive path required > Charging
Vacuum requirement	No	No	Yes	Yes

Full Field X-ray Imaging Methods



Point Projection Imaging



Lens Based Imaging

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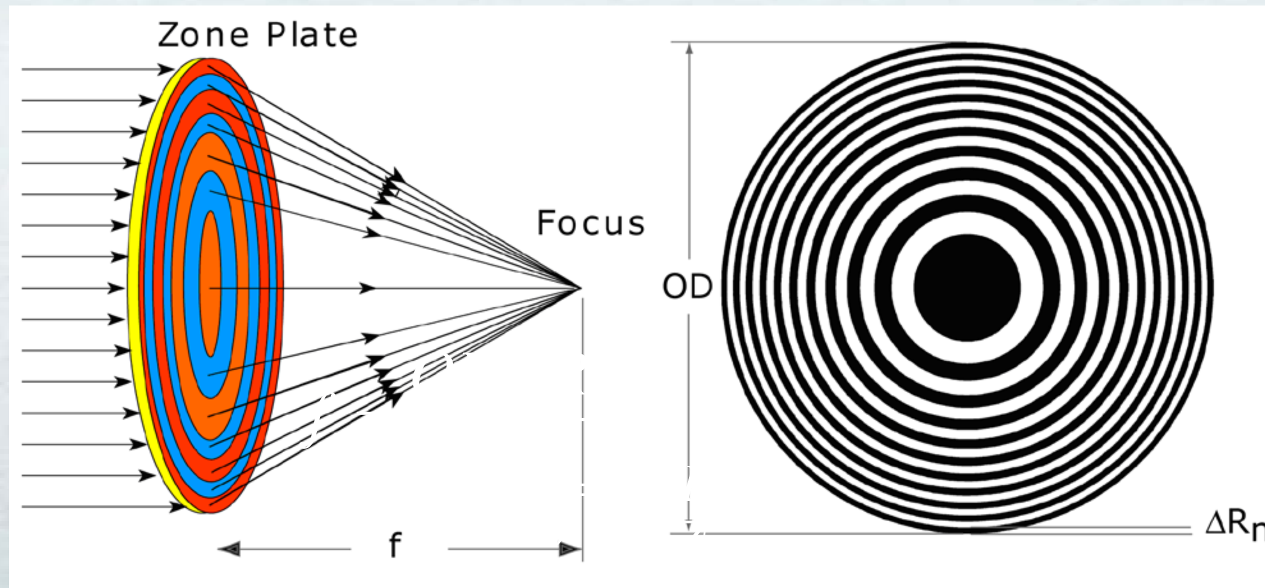
Highest Resolution X-ray Optics: Zone Plate Lenses



- Zone plates are diffractive x-ray lenses with high resolution (<30nm)
- Circular grating with radially varying pitch focuses x-rays to a point
- Focal length with **strong wavelength dependence**:

- Zone plates enable wavelength specific imaging

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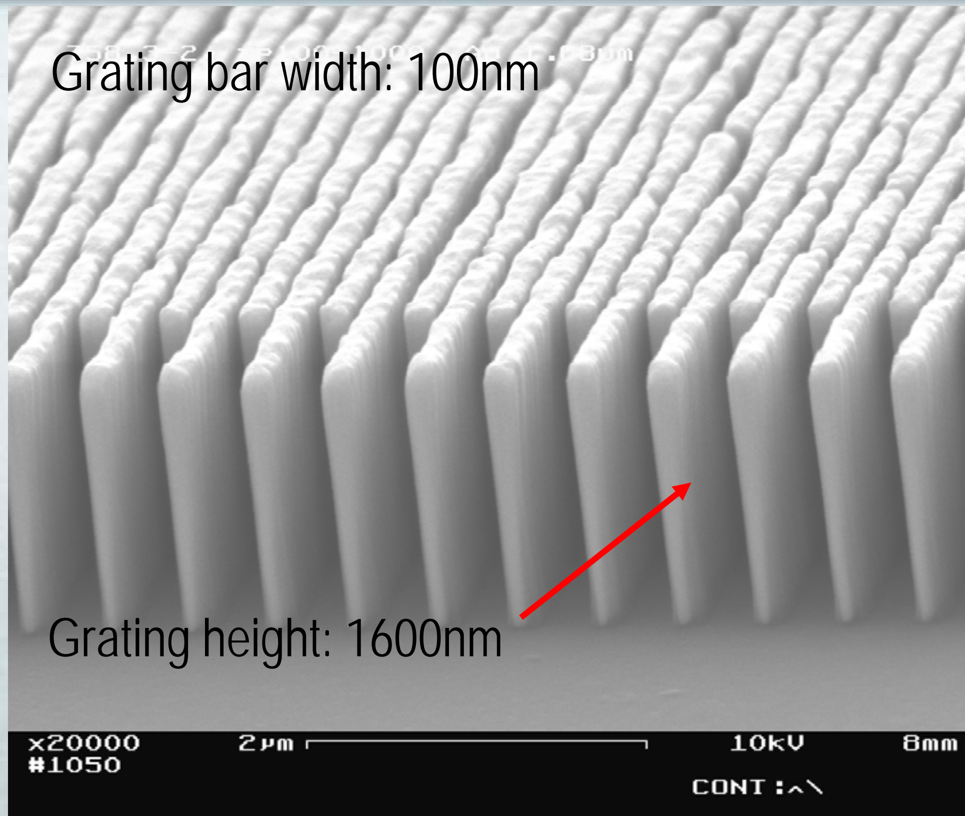
Scanning Electron Micrographs of Gold Zone Plates



- Zone plates are fabricated out of high-Z (typically gold) material using electron beam lithography, reactive ion etching and electroplating
- Focusing efficiencies 10-30% currently achievable

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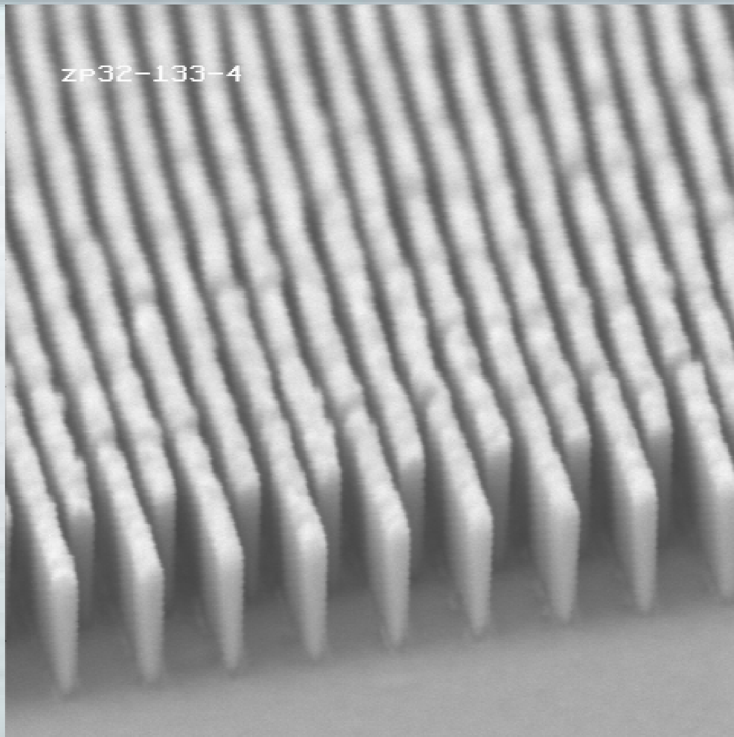
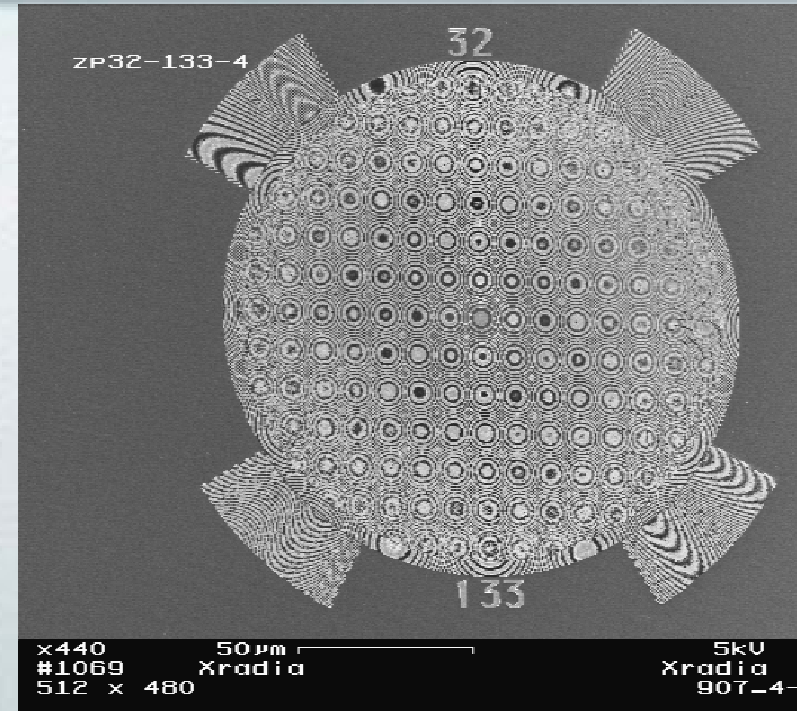
Recent Fabrication Highlights



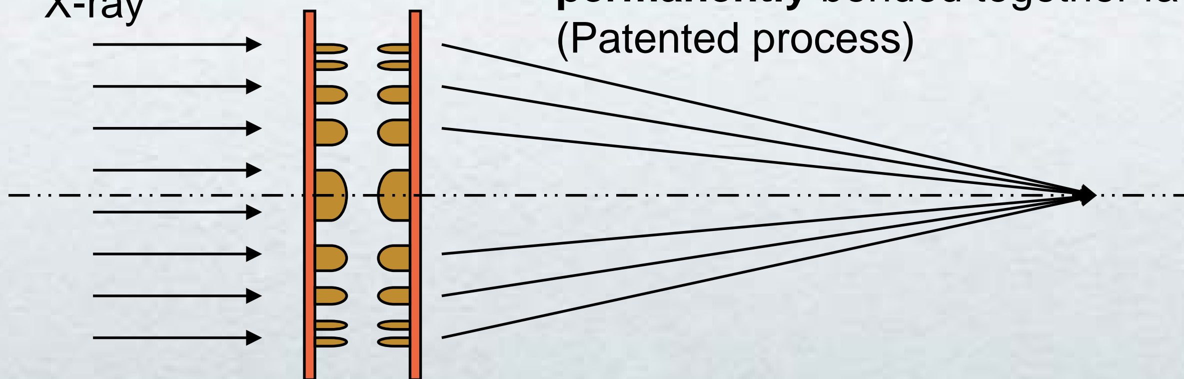
Cross section view of control structure
450nm zone height
32nm structure width



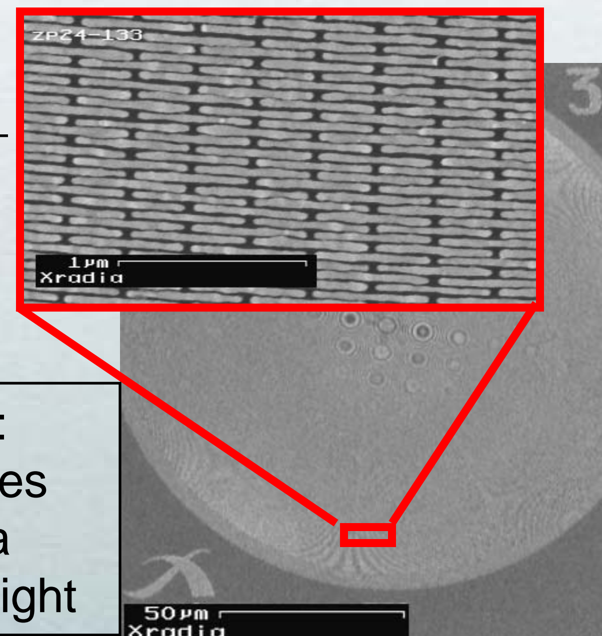
32nm zone width, 133um diameter
450nm thickness

- 32nm gold zone plates, 450nm thick fabricated for CNM nanoprobe project (Xradia under contract), AR=14
- 24nm gold zone plate, 300nm fabricated recently, aligned to produce an effective thickness of 600 nm

High-resolution, High-efficiency Zone Plates



Two zone plates are aligned and **permanently** bonded together face-to-face. (Patented process)



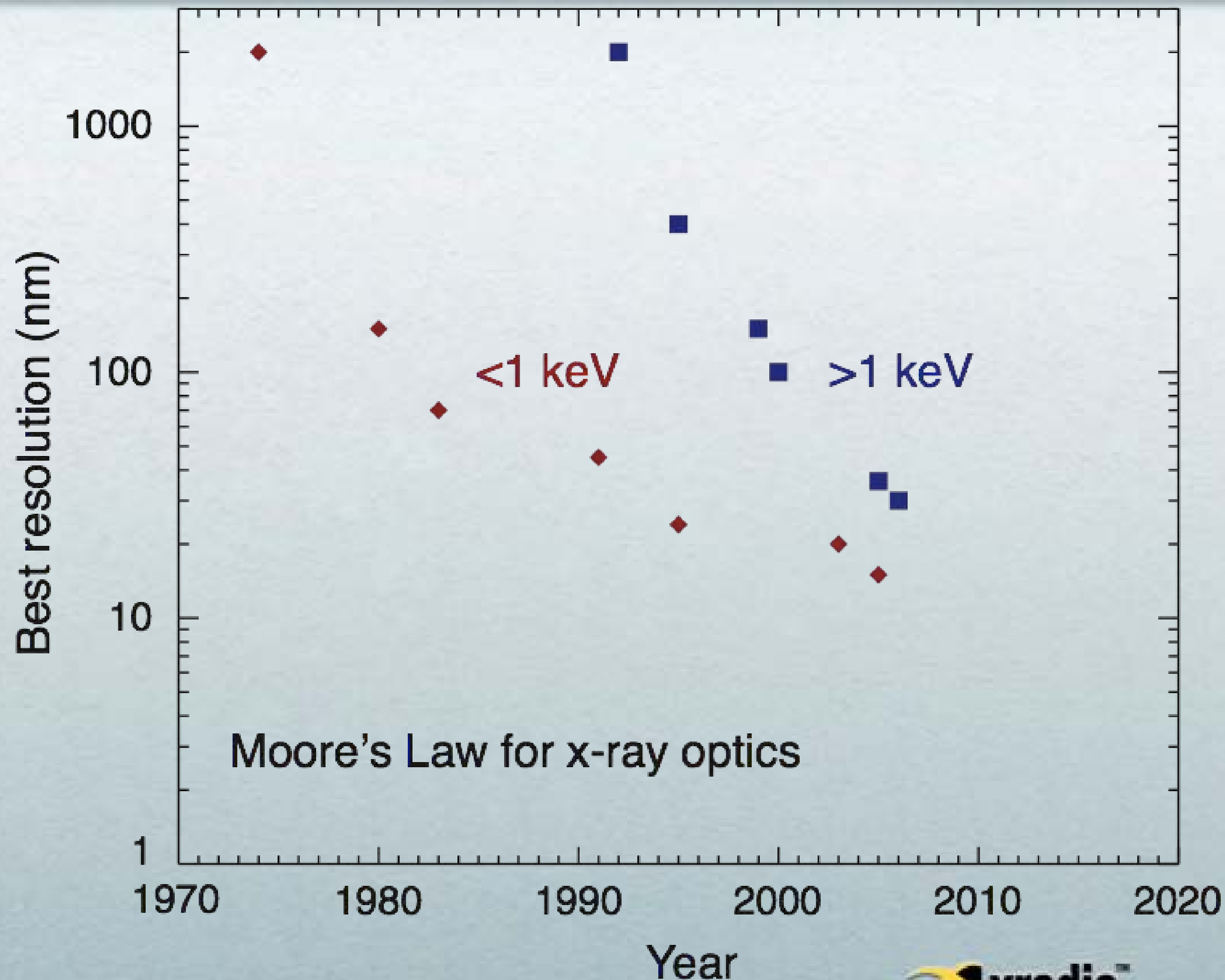
Two zone plates act effectively as one diffractive element if aligned precisely laterally and in very close proximity (within depth of focus of lens)

Single ZP:
24nm zones
133um dia
300nm height

- High-resolution zone plates usually low efficiency
- Alignment to increase zone height increases efficiency
- 24nm zone width zone plates with combined 600nm height in use at ANL ID-26 nanoprobe.

Y. Feng, et al., *Journal of vacuum science and technology B*, 25 (6), 2008

X-ray optics: best resolution



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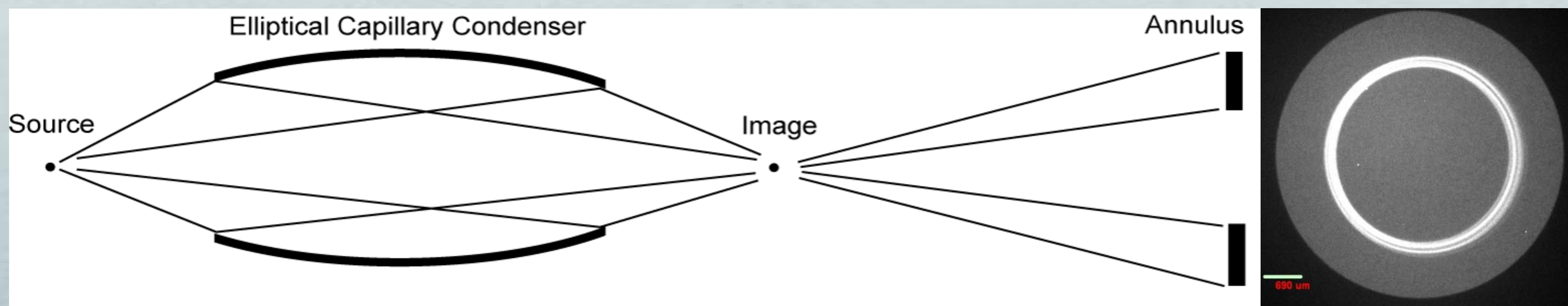
Elliptically Shaped Mono-Capillary Focusing Optics

- <3um focusing achieved (using full aperture)
- Axially symmetric optic with high reflection efficiency (>90% for most energies), limited by critical angle
- Specific designs to match the numerical aperture (illumination angles) for zone plate objectives in full-field x-ray microscope



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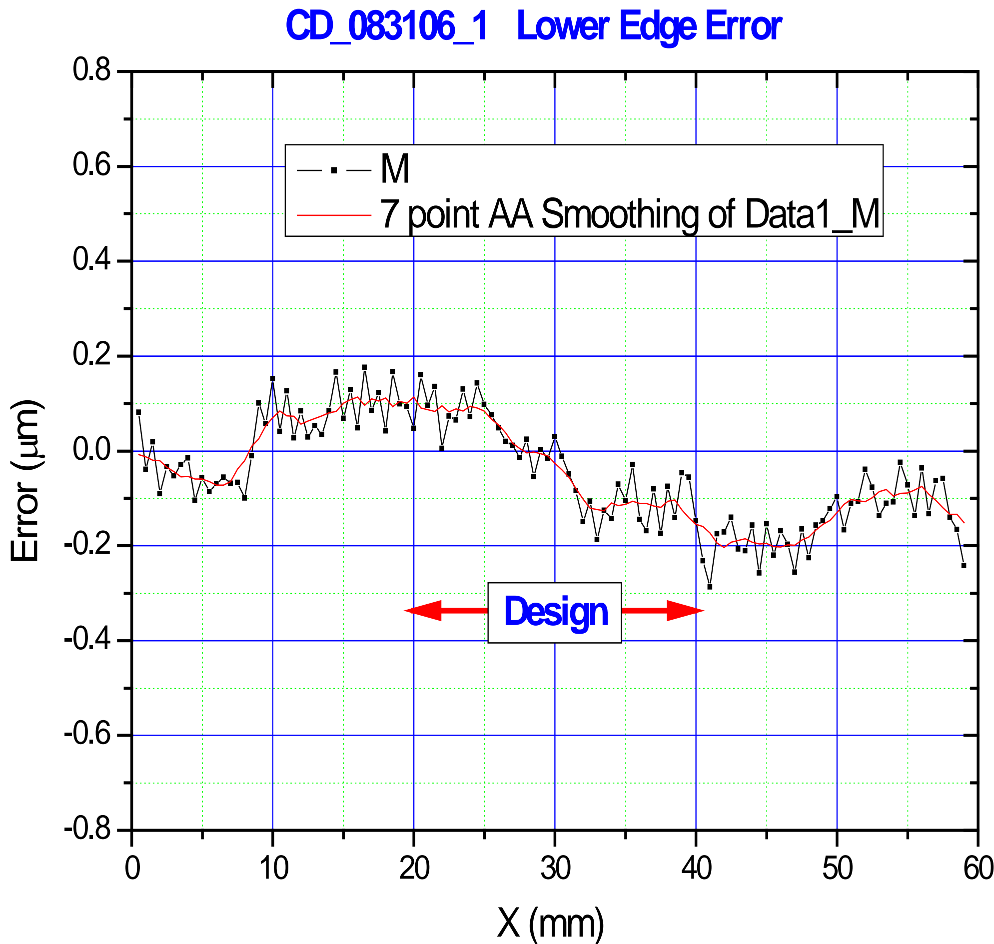
Mono-capillaries Quality Measurements



- Elliptical figure shape is controllable to few 100nm
- Optical metrology system developed by Xradia

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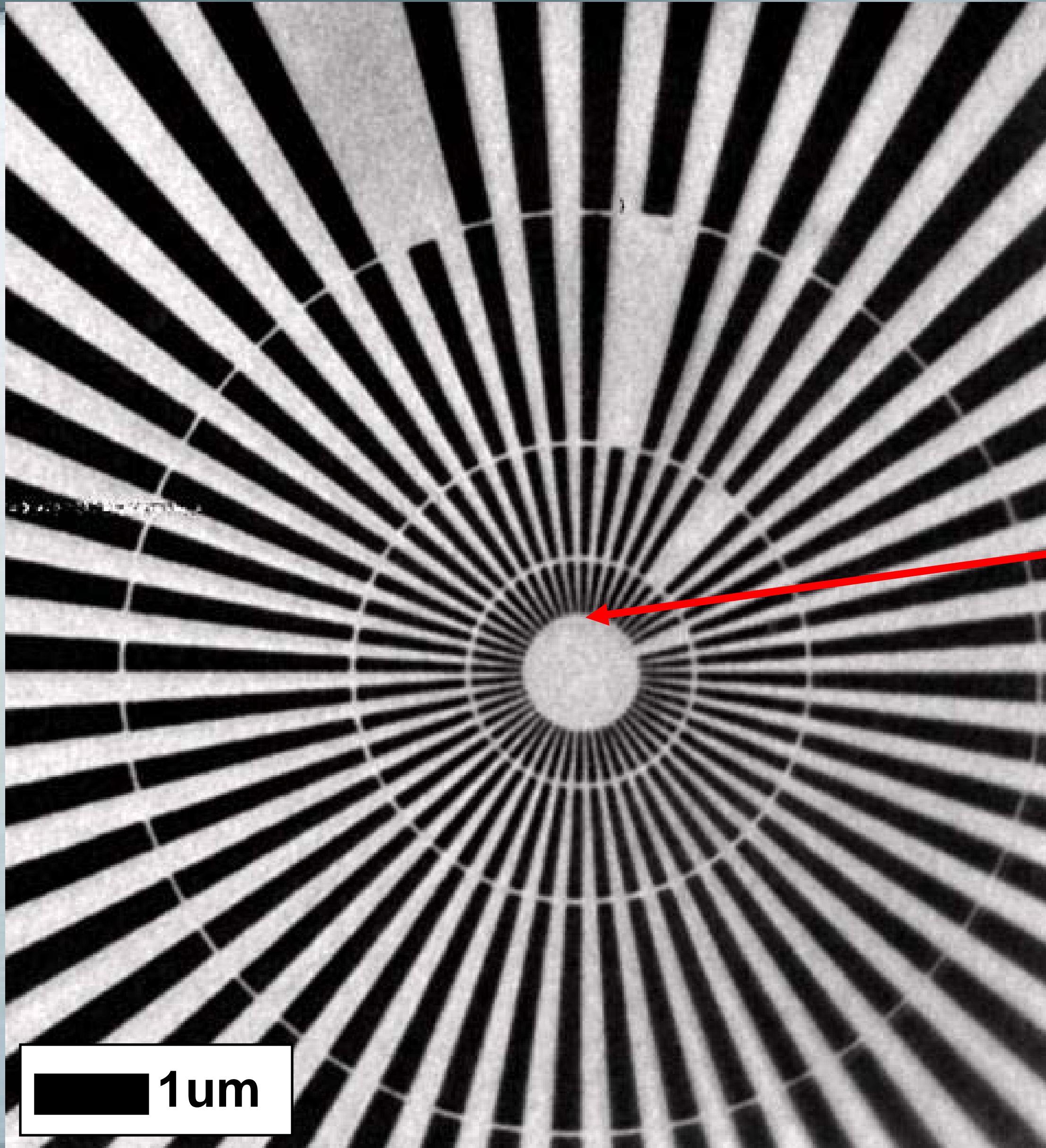
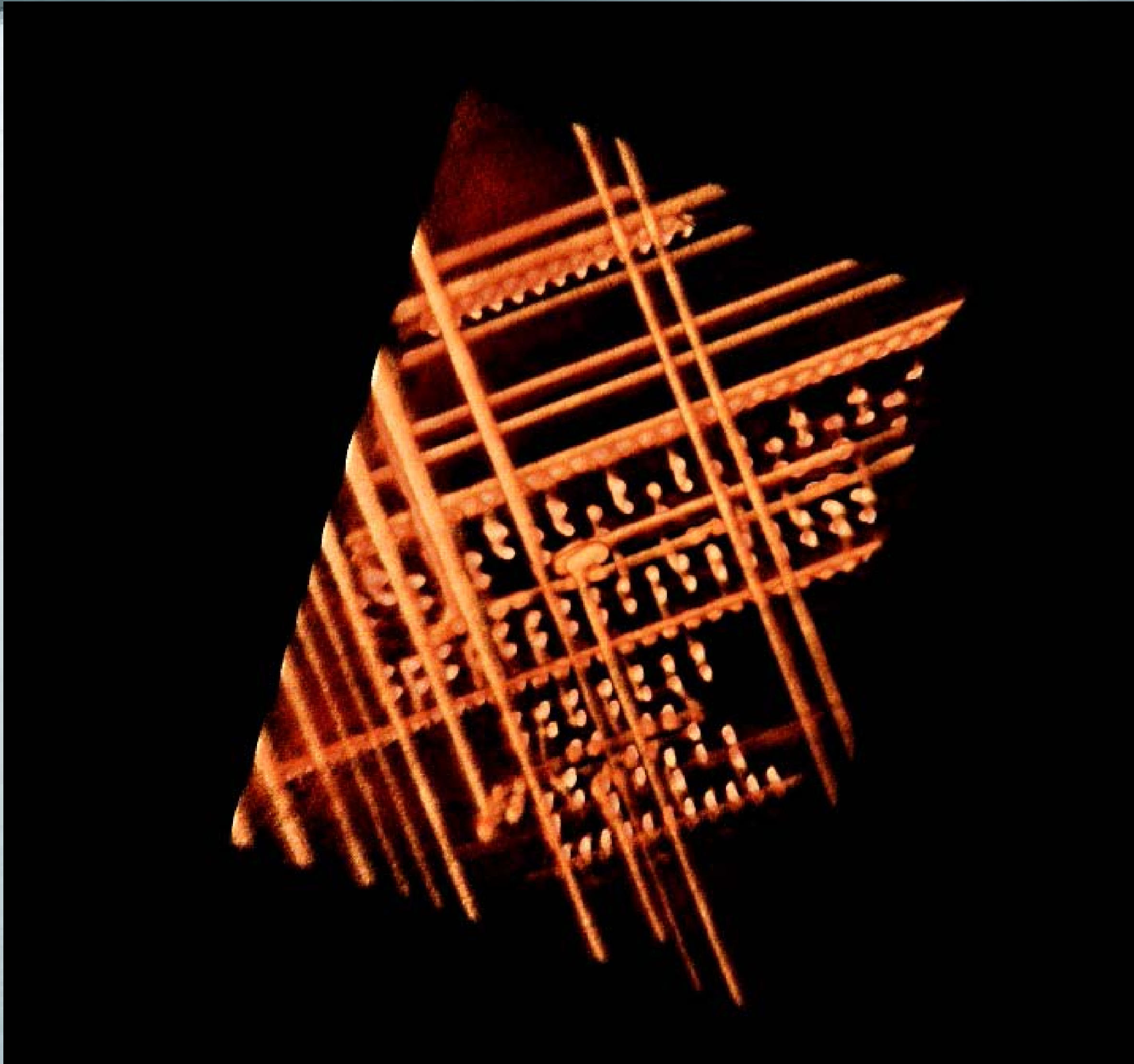
Sub-50 nm Laboratory X-ray Image



Xradia nanoXCT 5-50
- Cr (5.4kV)
- 35nm zone plate optic

Xradia Resolution & Calibration Test Pattern X50-30
- 50 nm minimum line
- 100 nm mini. period
- 150 nm thick Au

Volume Rendering of a 90nm Technology Node IC



20min exposure at SSRL synchrotron

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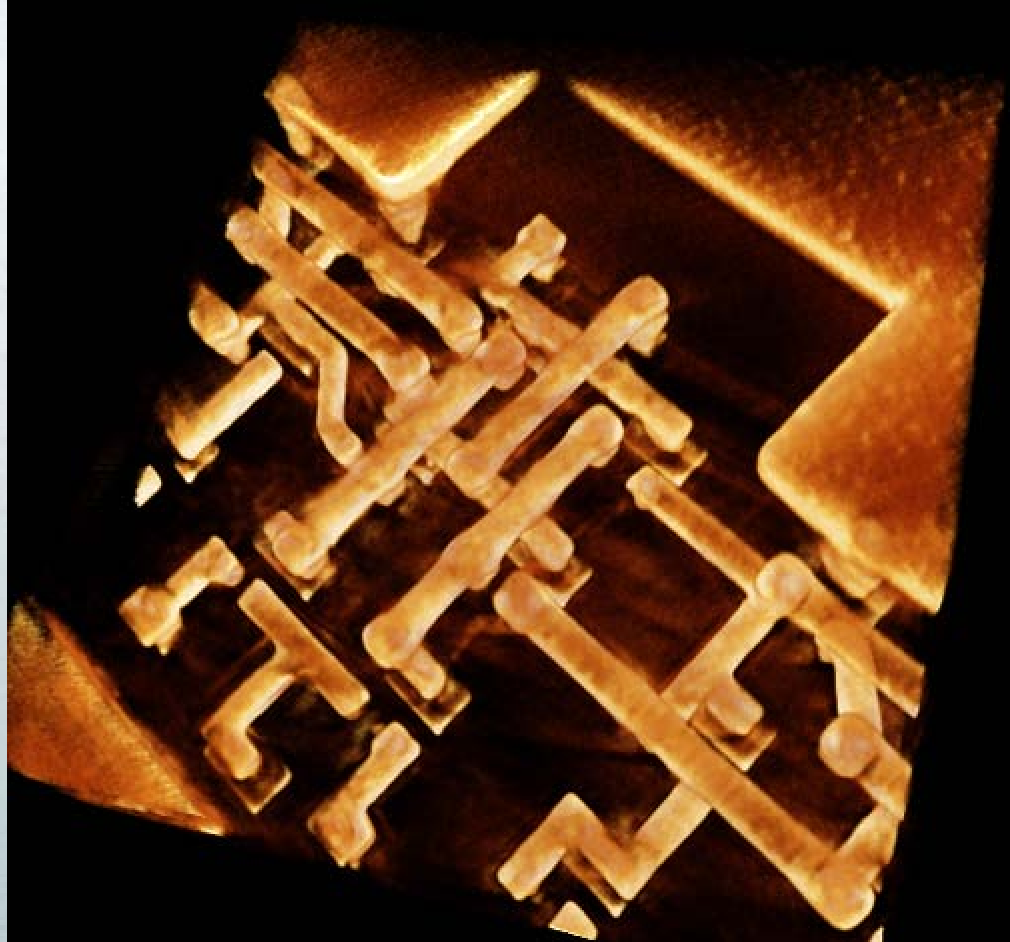
X-ray Tomography of IC Device Up to 100 μm Thick



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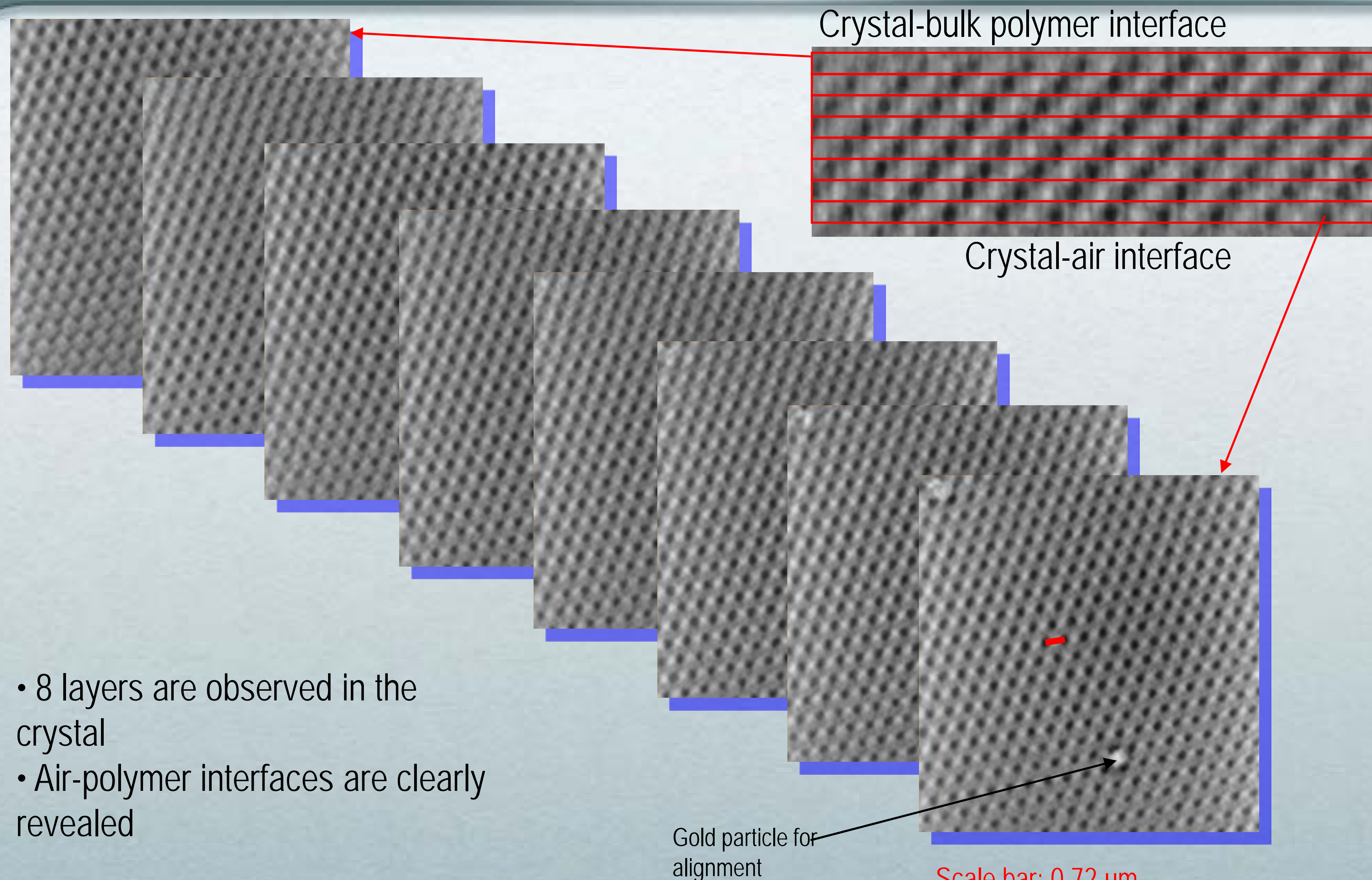
X-ray Tomography of Polymer Photonic Crystal 2D Slices



- 8 layers are observed in the crystal
- Air-polymer interfaces are clearly revealed

* See attachment for slice movies

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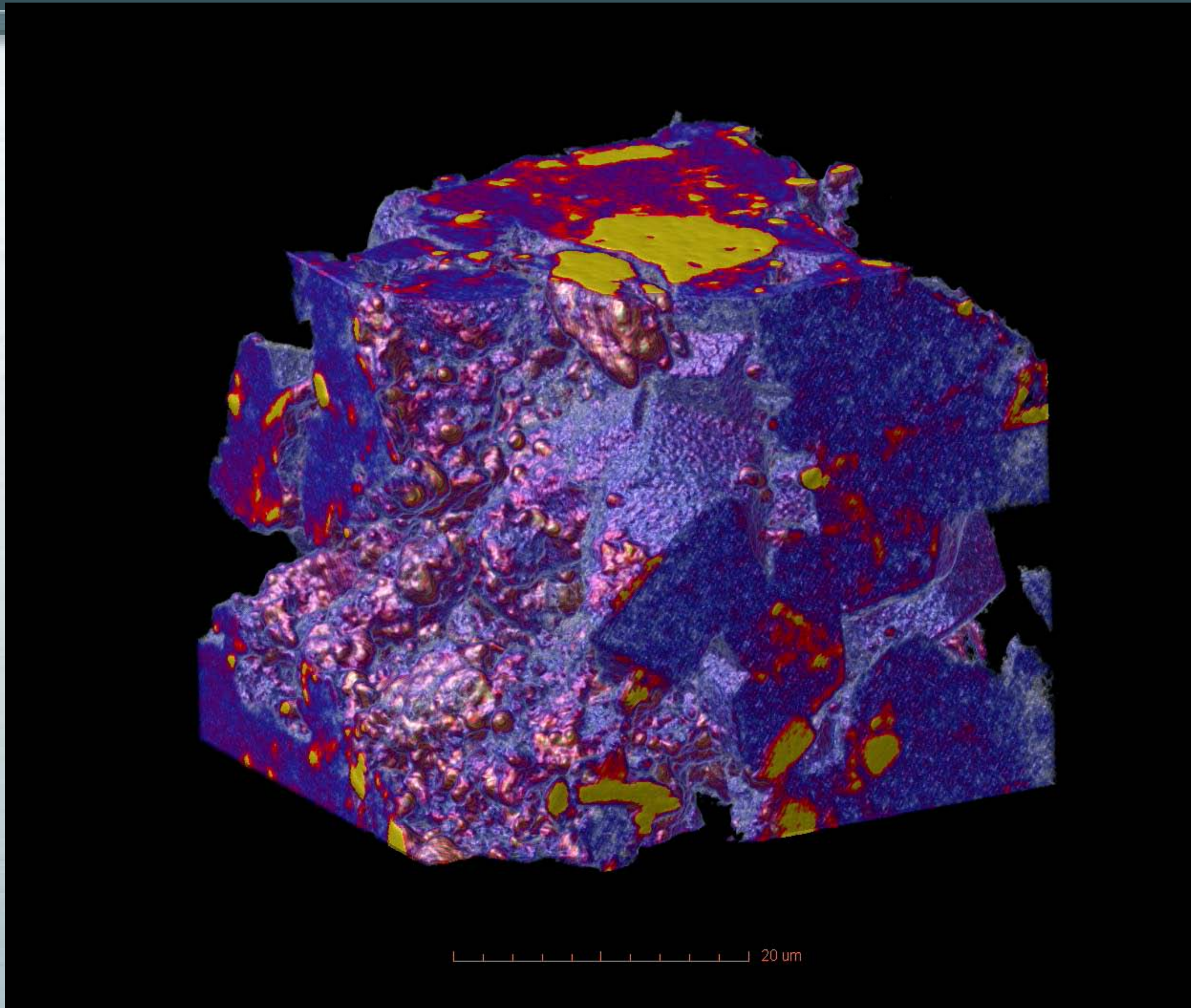
X-ray Tomography of an Alumina Particle



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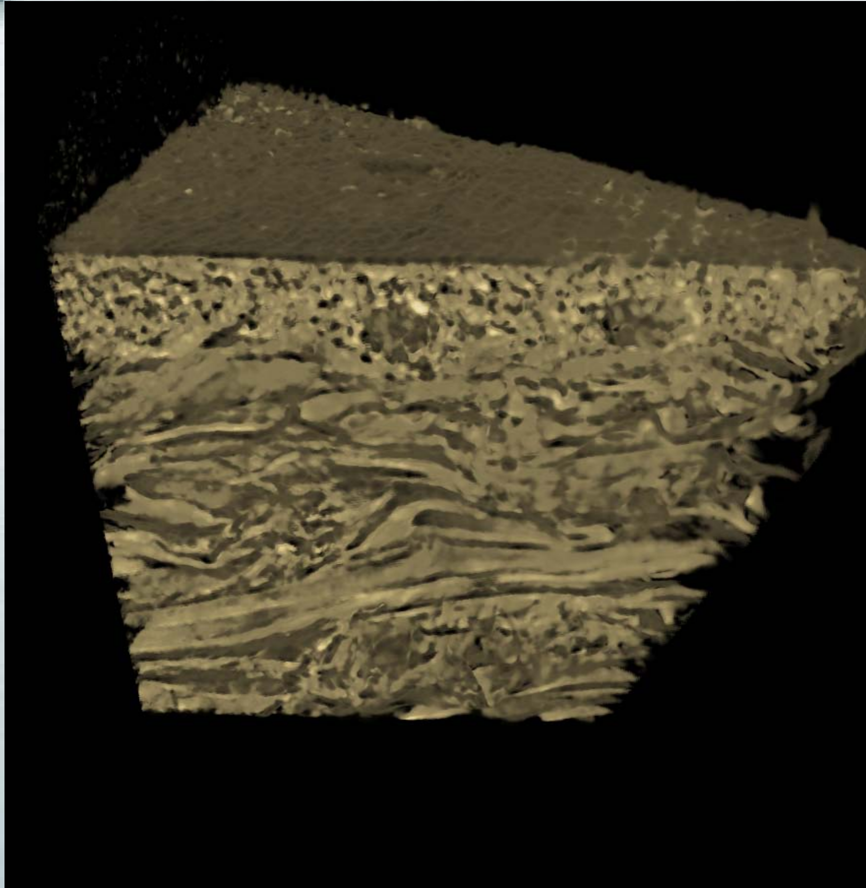
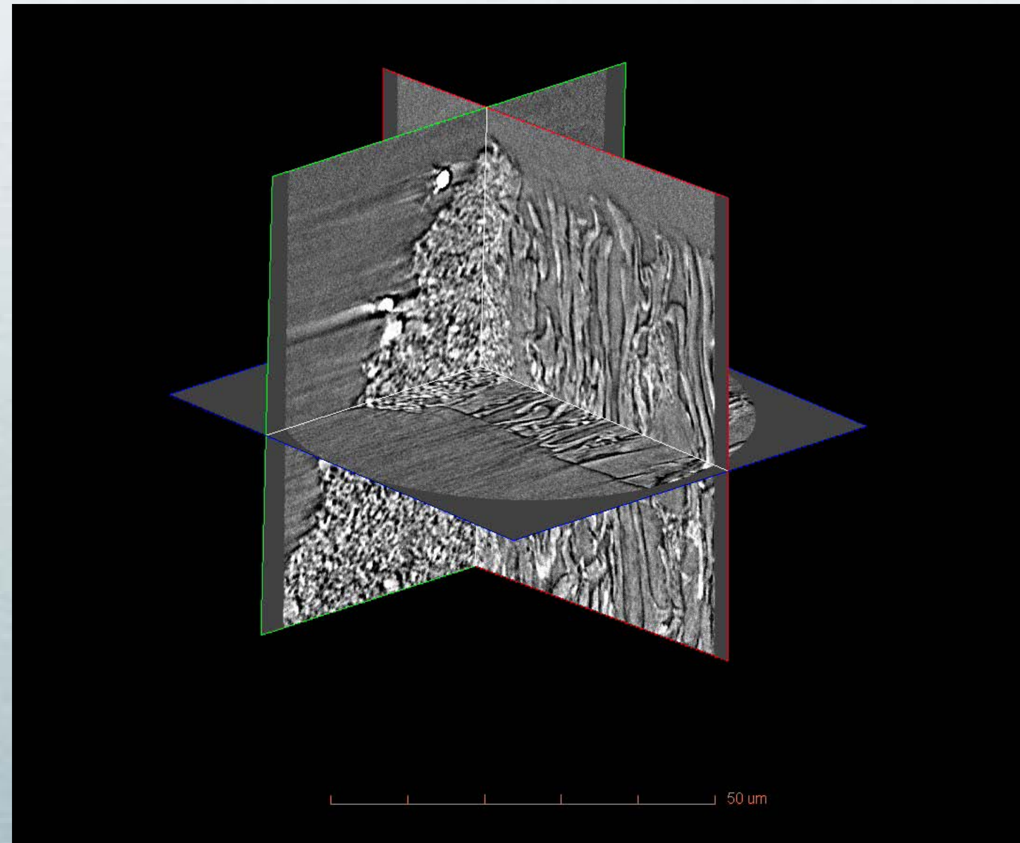
X-ray Tomography of Paper





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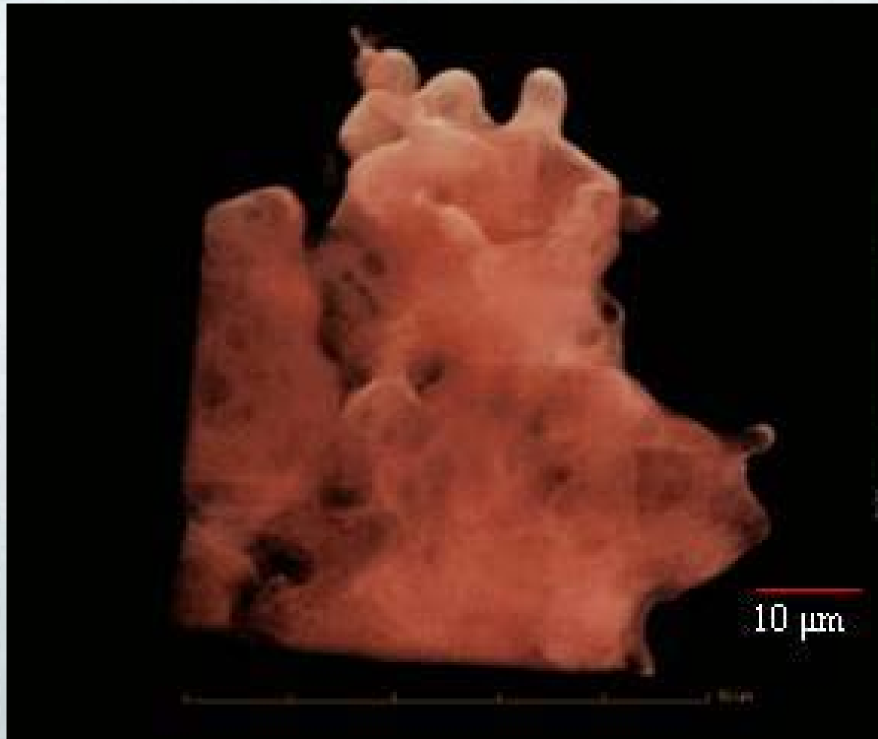
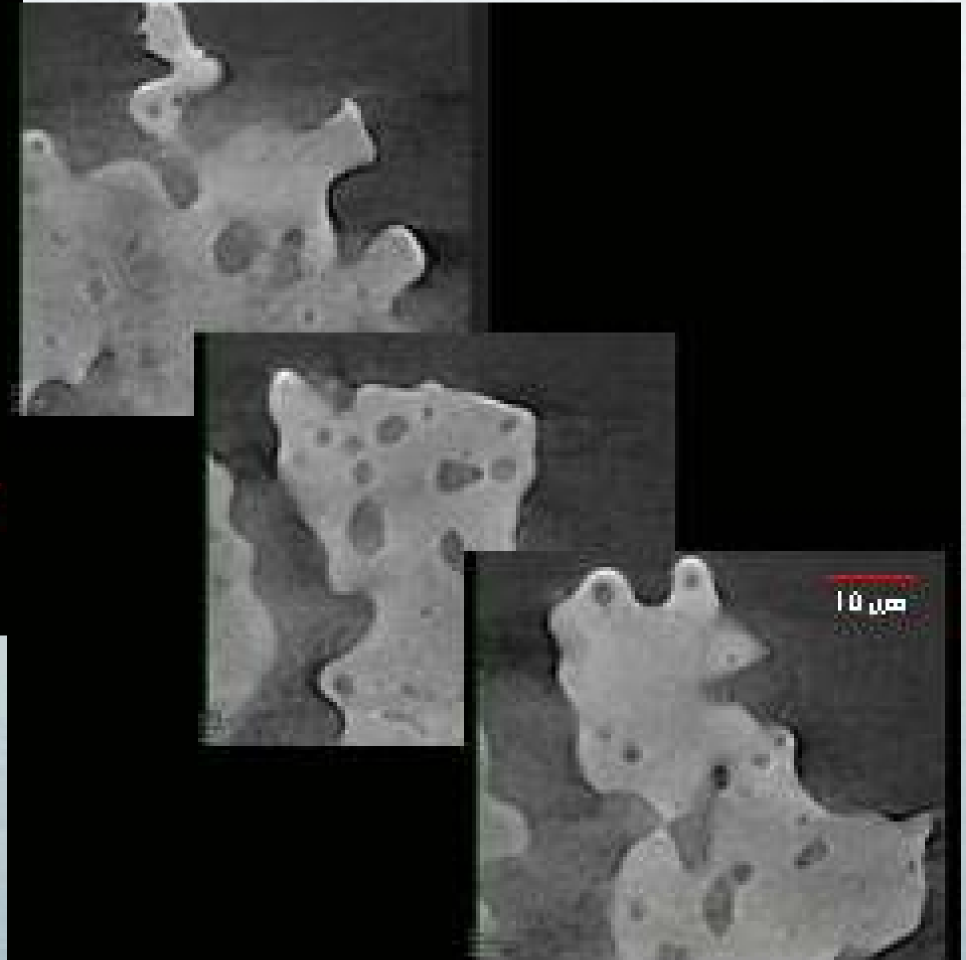
3D Imaging of Titanium Oxide Foam at 150 nm Resolution

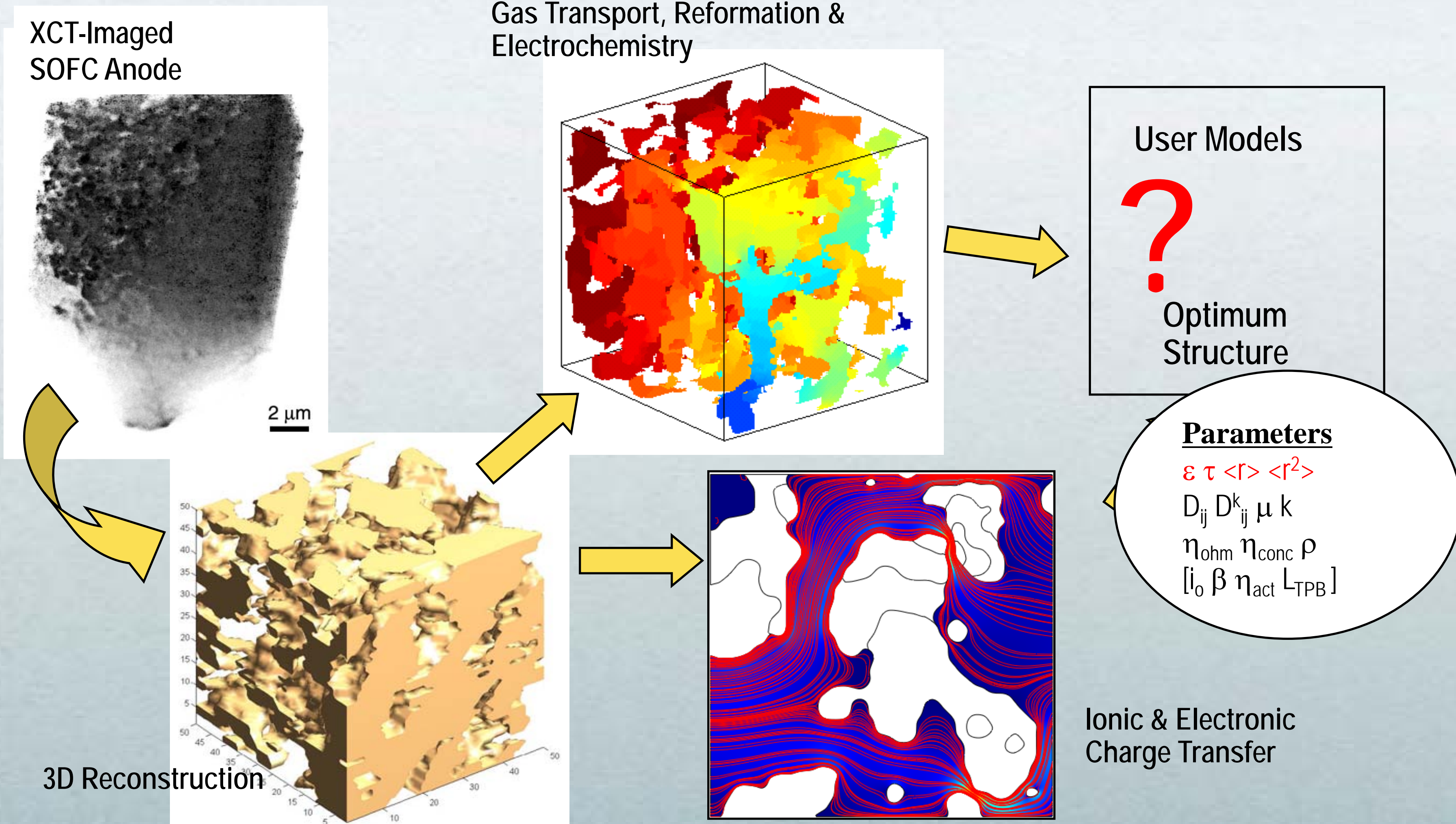


3D Rendered Image

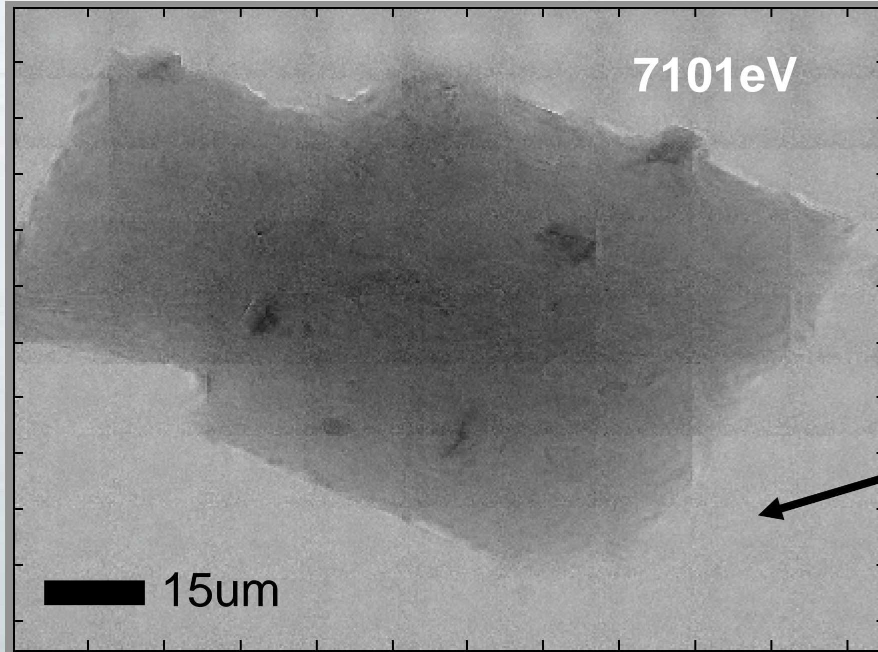
Virtual Cross Sections

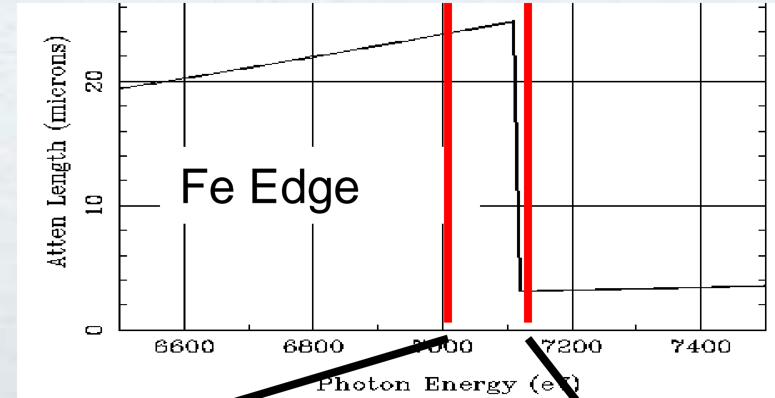


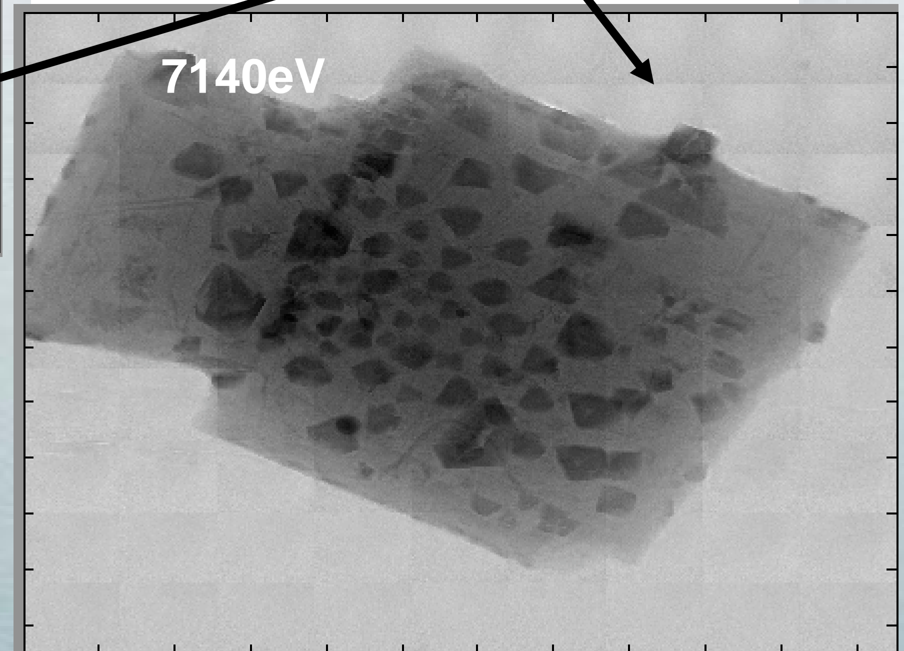
Putting It All Together



Spectroscopic X-ray Imaging and Tomography: Meteorite







Identification of Fe-phases inside the Silicate matrix

Xradia nanoXCT-S100 at Stanford **Synchrotron** Radiation Center, SLAC, USA

Data courtesy of P. Pianetta, S. Brennan SSRL Xradia nanoXCT, unpublished

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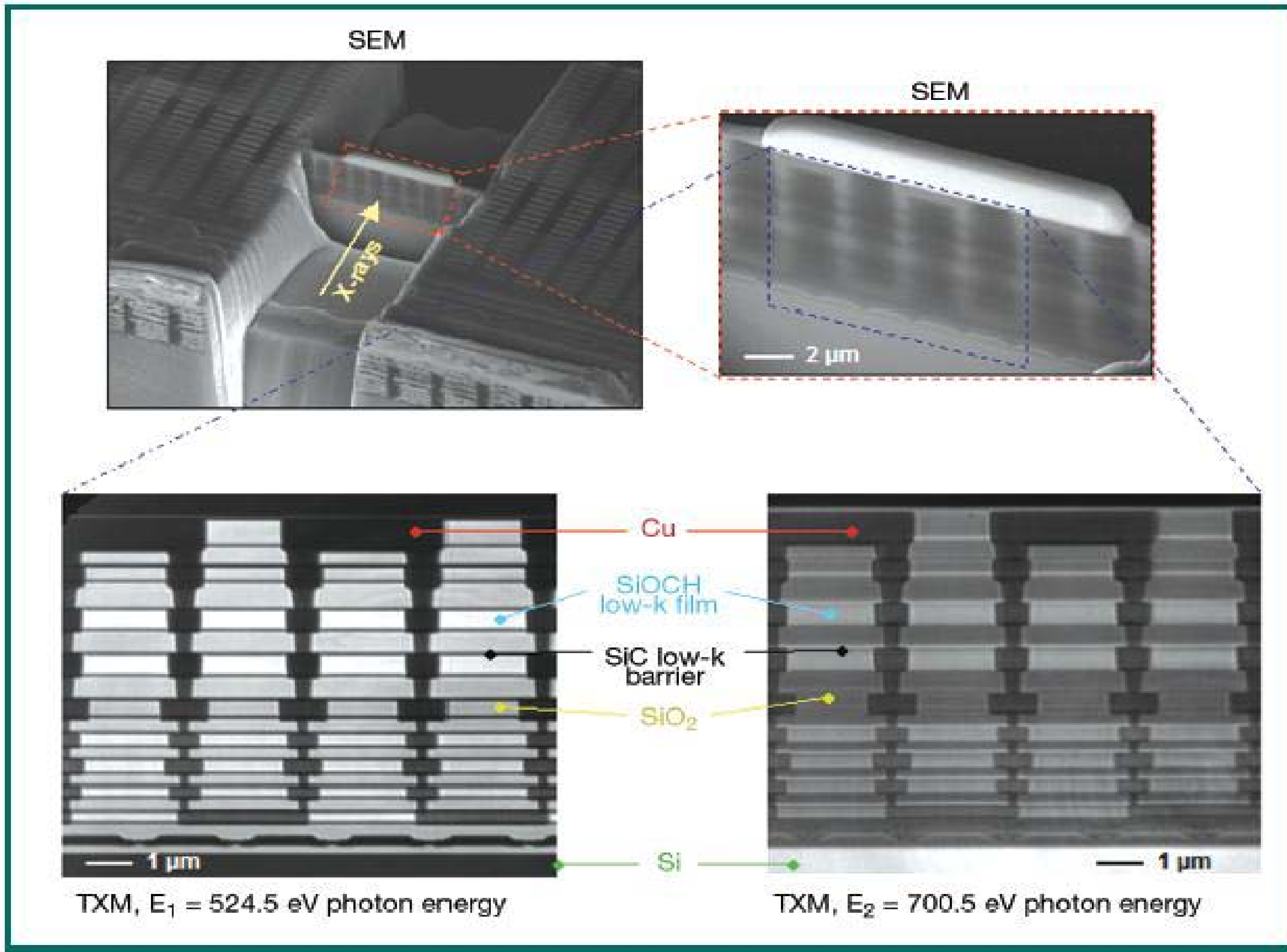
Some published TXM data from Synchrotron : Cu-low k



High Resolution & High Contrast

Sneider et al, Future Fab Vol 19, section 8

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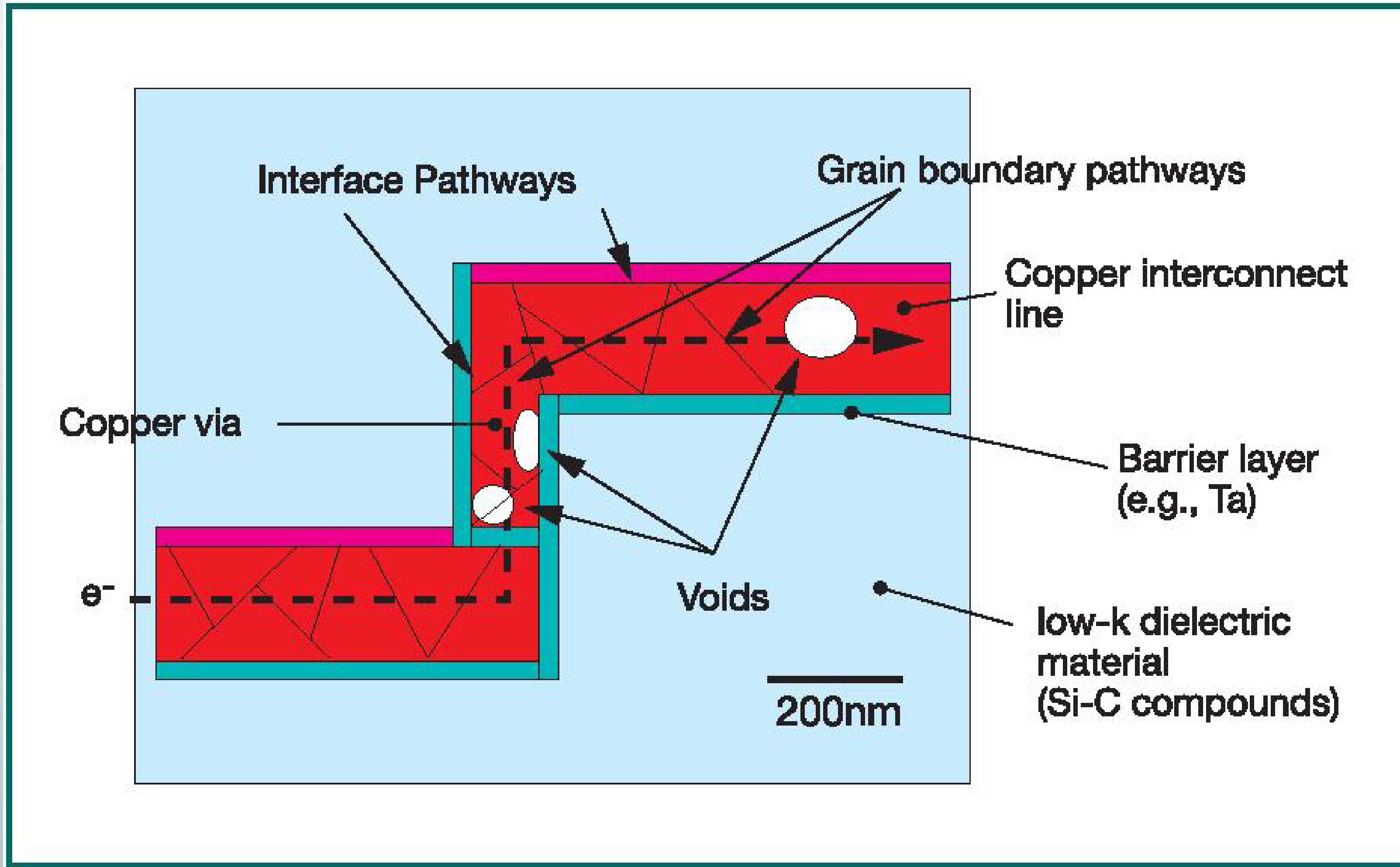
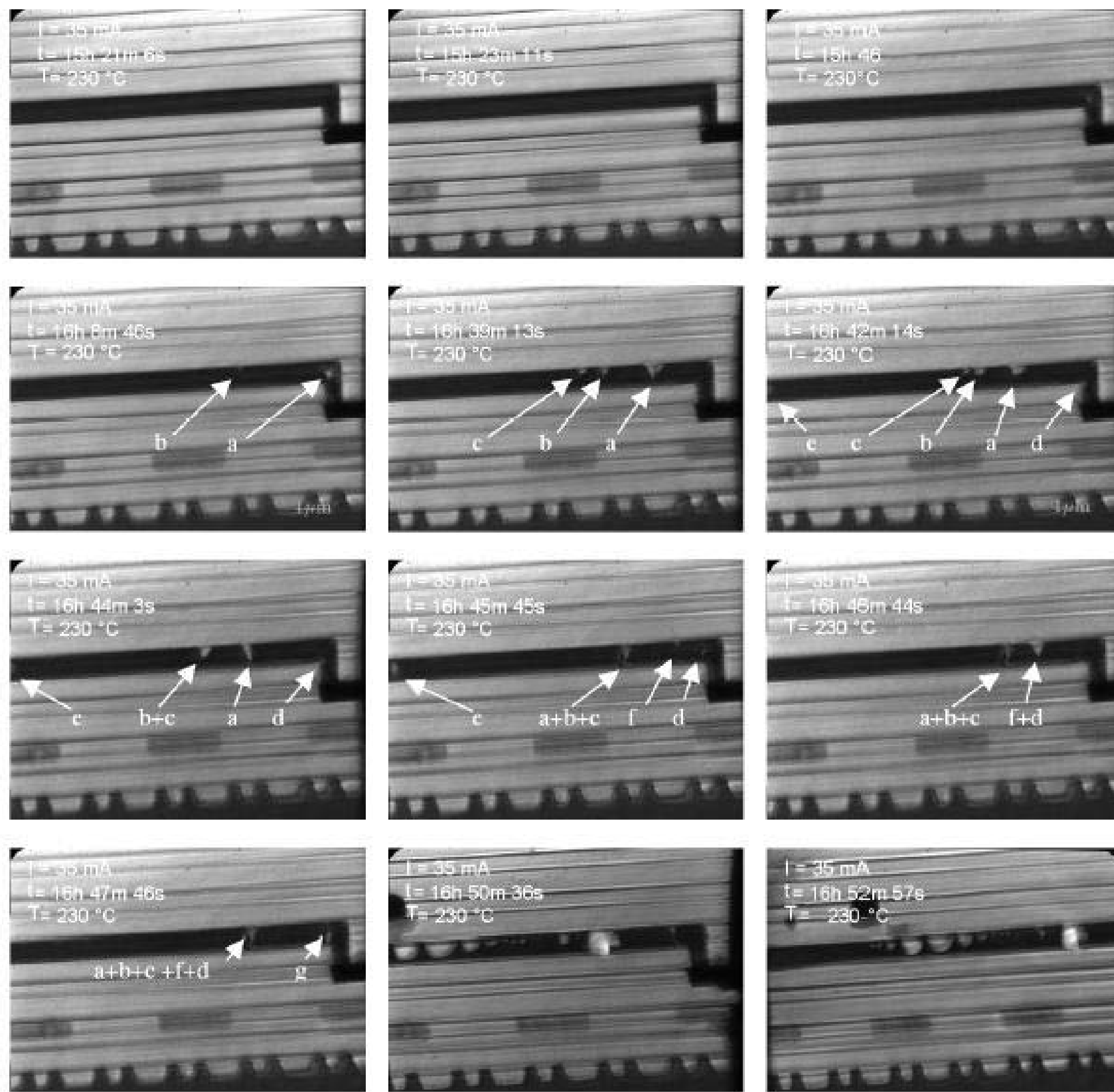
Application : Electromigration- insitu



Cu via line test segment

Sneider et al, Future Fab Vol 19, section 8

Application : Electromigration- insitu



Passivated Cu interconnect. Thickness 350 nm, line width 600nm.

Via stressed at temp 230 deg C

Current densities increased up to 10e7 A/cm3 during 16 hrs, 52 min

Sneider et al, Future Fab Vol 19, section 8

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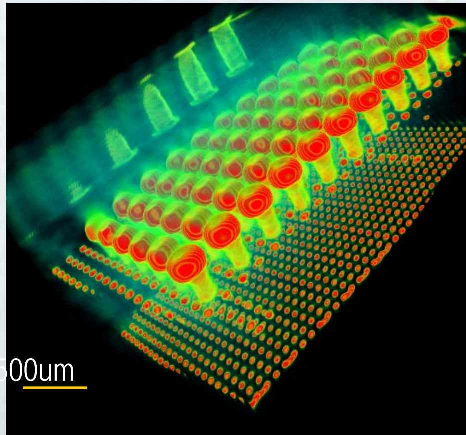
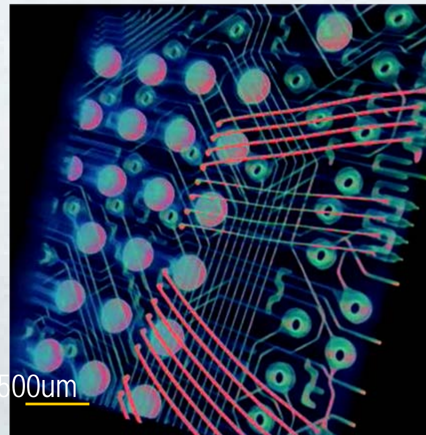
Selected Imaging Applications for IC Packaging (MicroXCT)

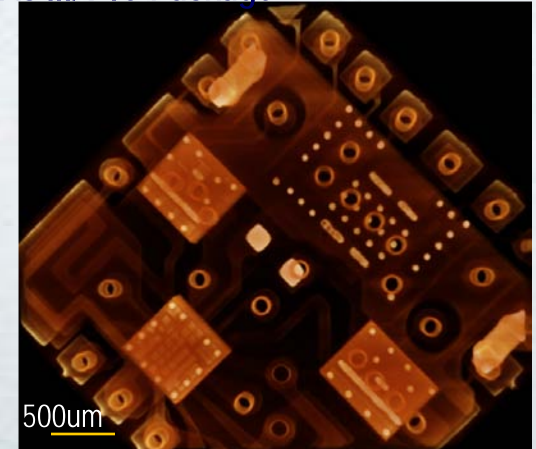
C4 Bump on Flip-chip



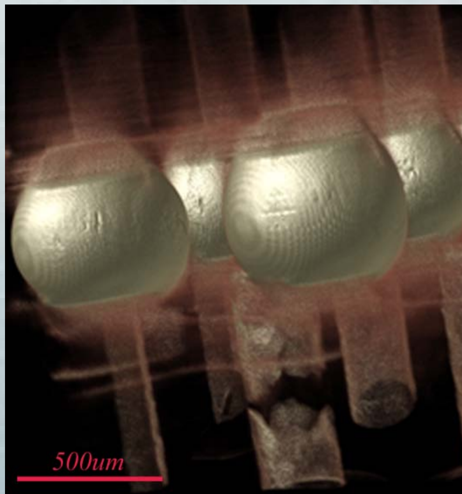
Wire bond packaging



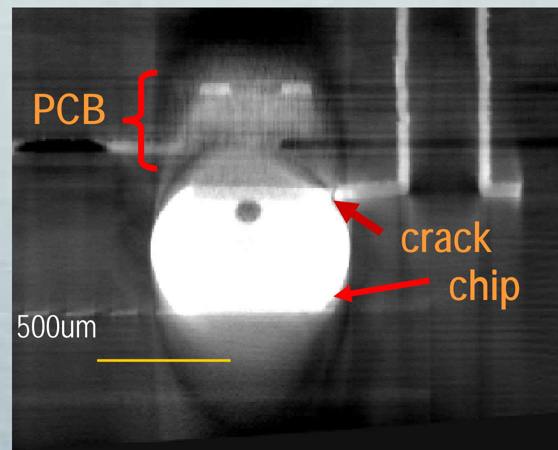
GaAs III/V IC Package



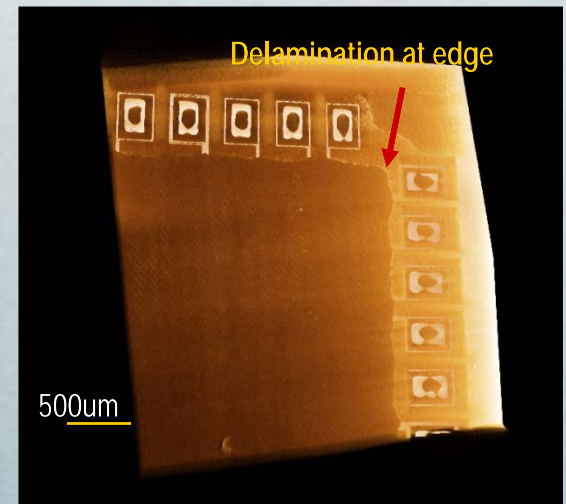
Solder Balls and Via Crack



Solder Balls and Via Joint Crack



Delamination on Thin Die



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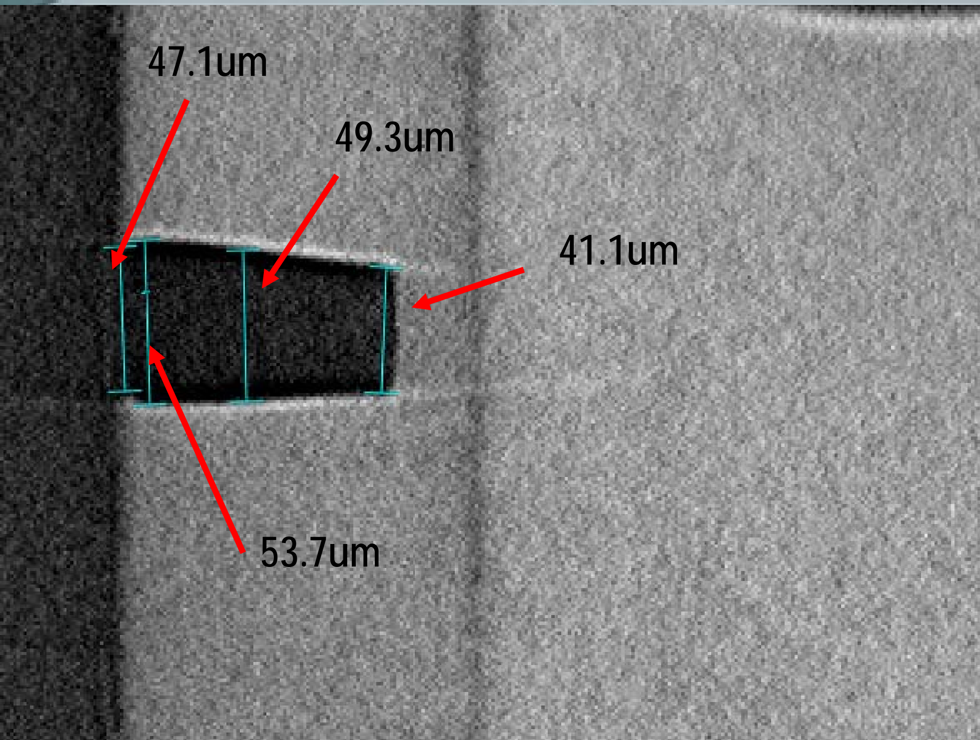
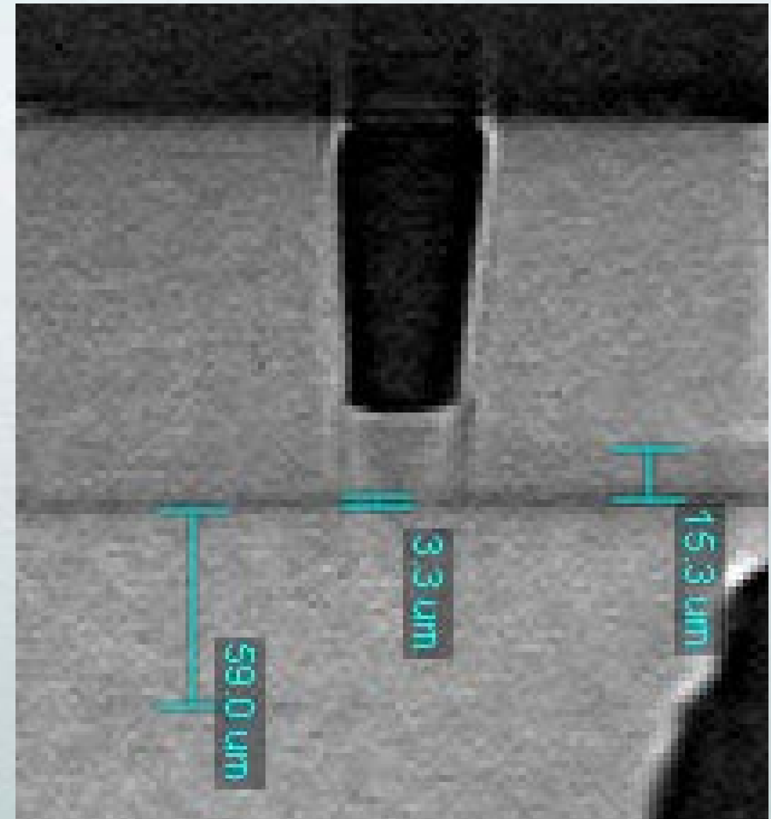
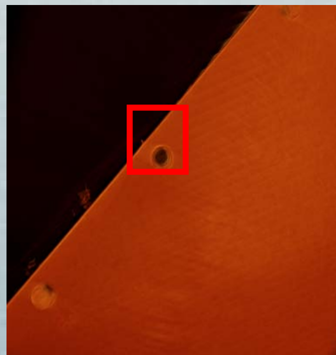
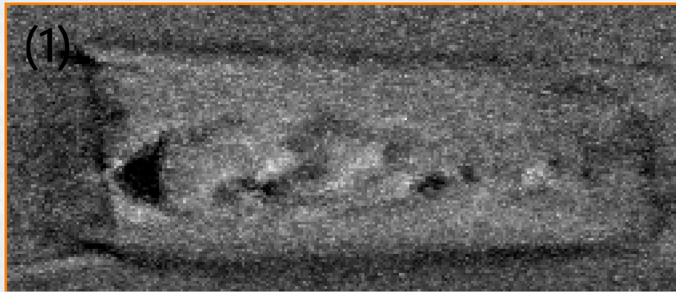
Etched Through Si Via on glass carrier imaged at 1 um resolution with MicroXCT

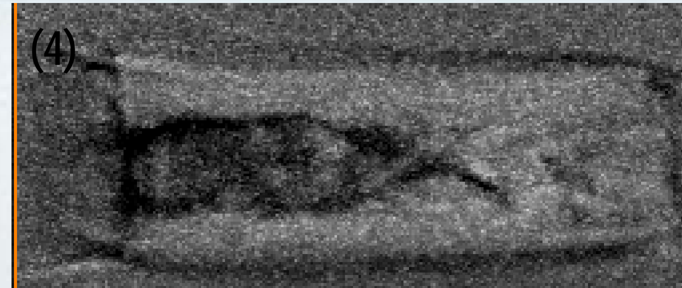


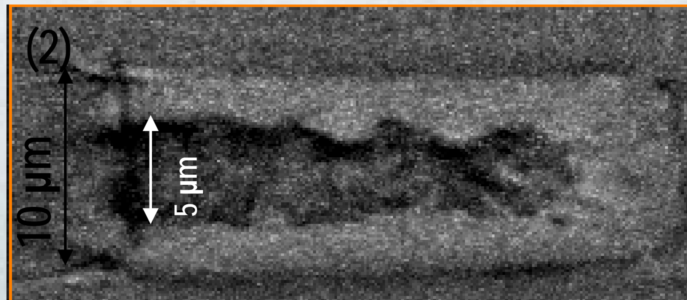


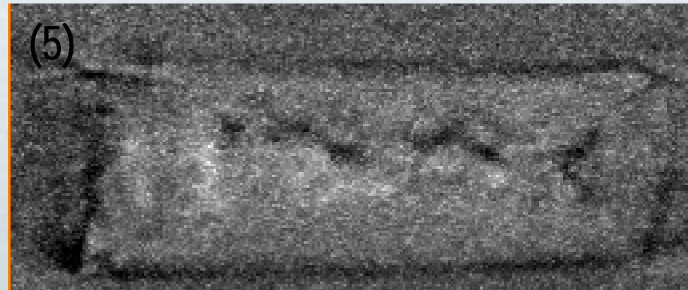


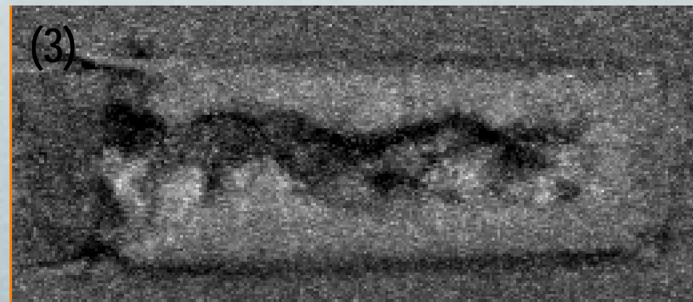
Non invasive void characterization: CT slices at 50 nm











Virtual slices from a 10 µm via. The via has a ~ 5 µm void in the center

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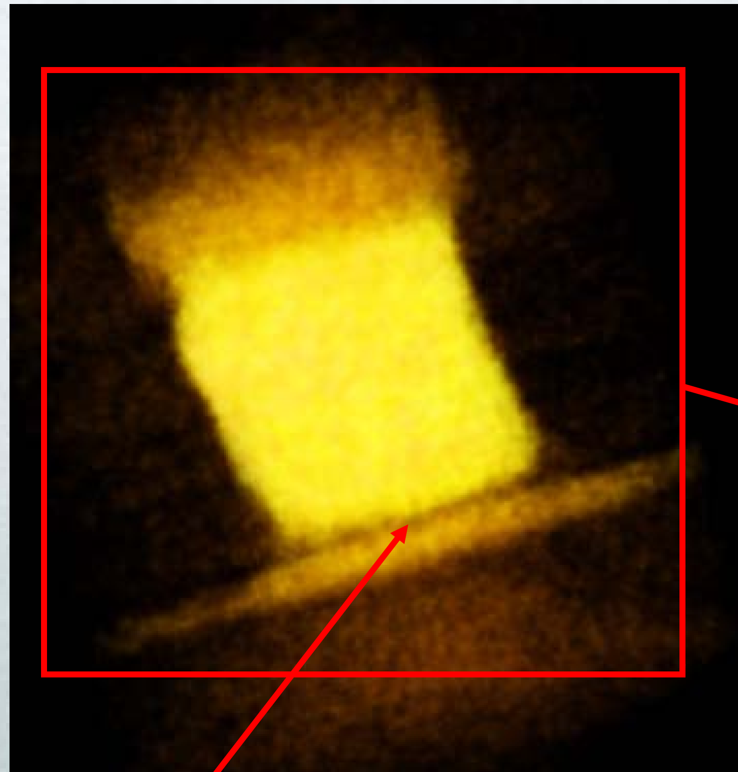
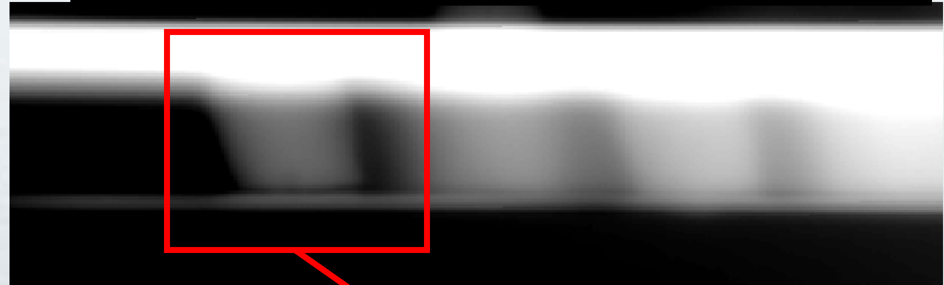
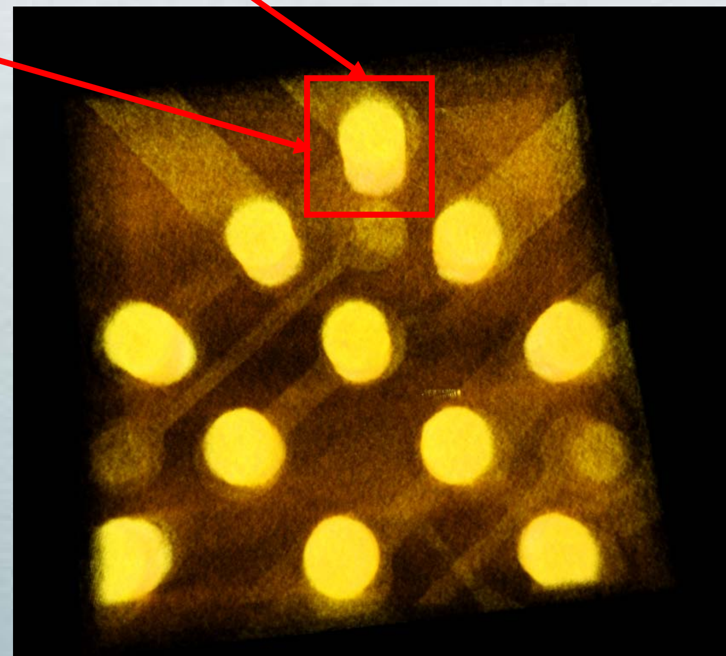
1. Solder non wet



Complete non wet
taken from entire tomography

Cracked ball taken from 20s scan, limited angle





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Conclusions

- X-ray nondestructive 3D imaging with 30nm resolution has been developed for Cu interconnect characterization
- X-ray nondestructive 3D imaging offers good capability for TSV development and FA applications
- Time lapse imaging using x-rays can be used to study reliability issues

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