# X-RAY TOMOGRAPHY FOR PROCESS DEVELOPMENT AND FAILURE ANALYSIS

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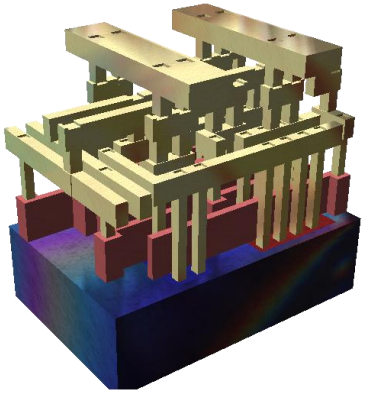
# Outline

- Introduction
- Application of laboratory based X-Ray Tomography
- Next generation of X-ray Optics

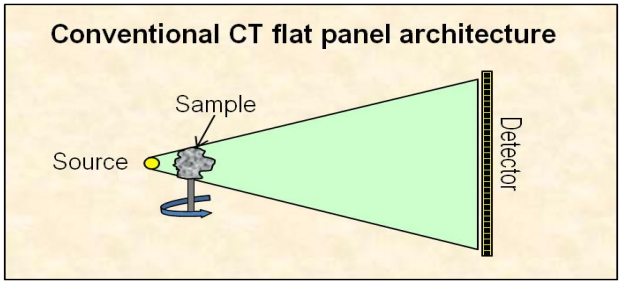
# Introduction

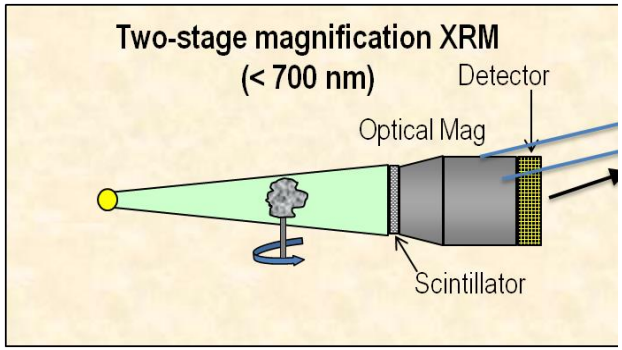
- New Era of microelectronic devices
  - Internet of things
  - Wearables, Cloud
  - Smart home, smart city, smart car, smart health, smart …
- Smaller devices with
  - Less power consumption (IoT, mobility)
  - Higher bandwidth (faster)
  - Integrated functionality (SoC, MEMS, memory…)

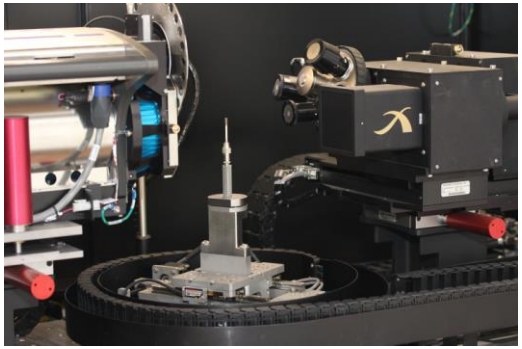


# Sub-Micron X-Ray-tomography: Zeiss Versa 520

Two stage magnification setup



- X-Ray magnification (fixed by geometry)
- Optical magnification (0.4x-40x)
- Large working distance for large samples or in situ experimentation
- Motorized filter wheel (beam hardening)
- Best resolution ~700nm

# Laboratory based X-Ray Tomography

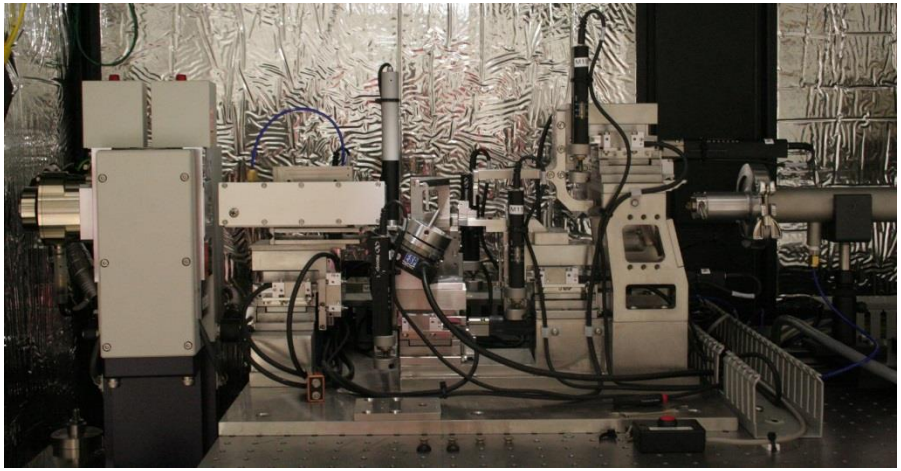
X-ray microscopy / tomography

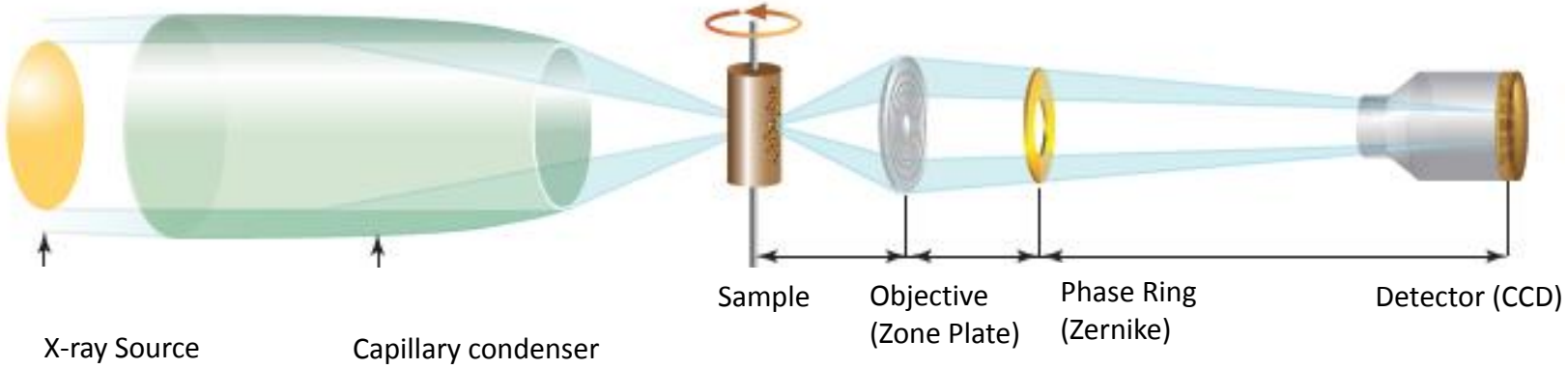
Xradia nanoXCT-100 (now Carl Zeiss Ultra)

Resolution: better than 50 nm

Tilt range: 360°

FOV (SR/HR): 65 µm / 16 µm Ø





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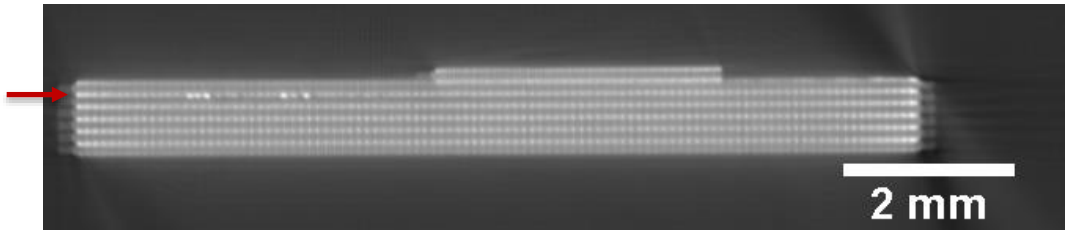
# Application of laboratory based X-Ray Tomography: *Multi-die stack*

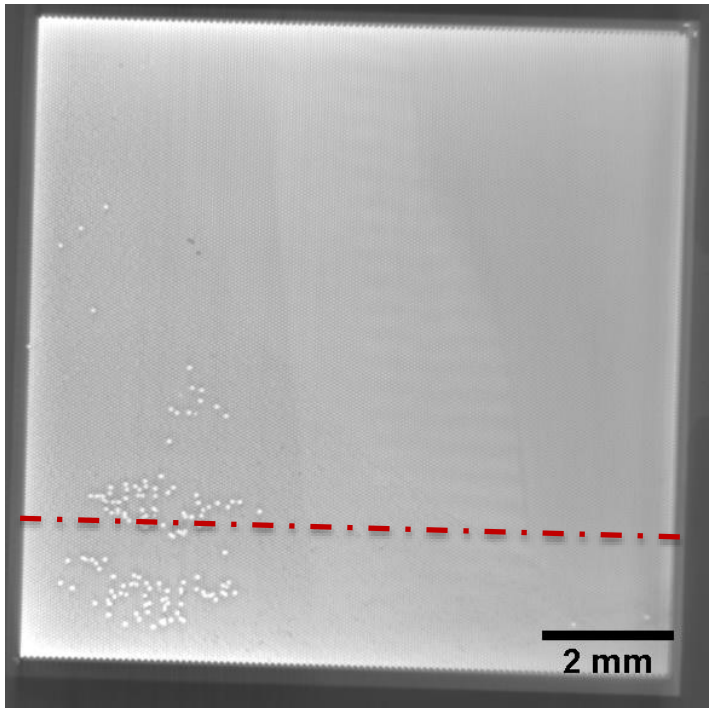
- Multi-die stack: 6 dies
- Cu TSVs, diameter: 10µm, ~65 000 TSV
- Lot-bumps: Cu, AgSn

- Overview by µ-CT:

  → CT of full chip to identify ROI




*Cross section*




*Plane view of second layer*



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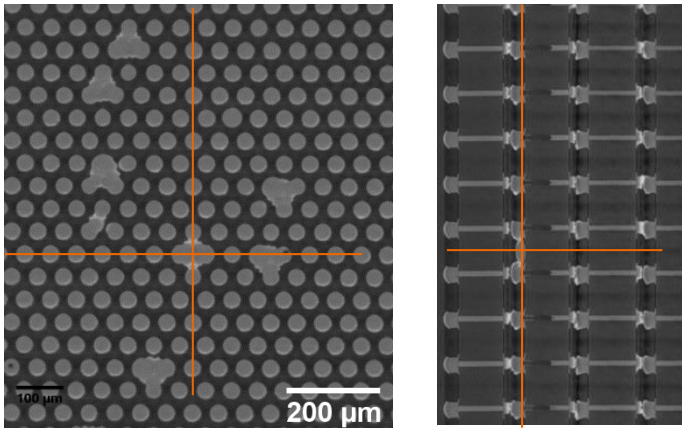
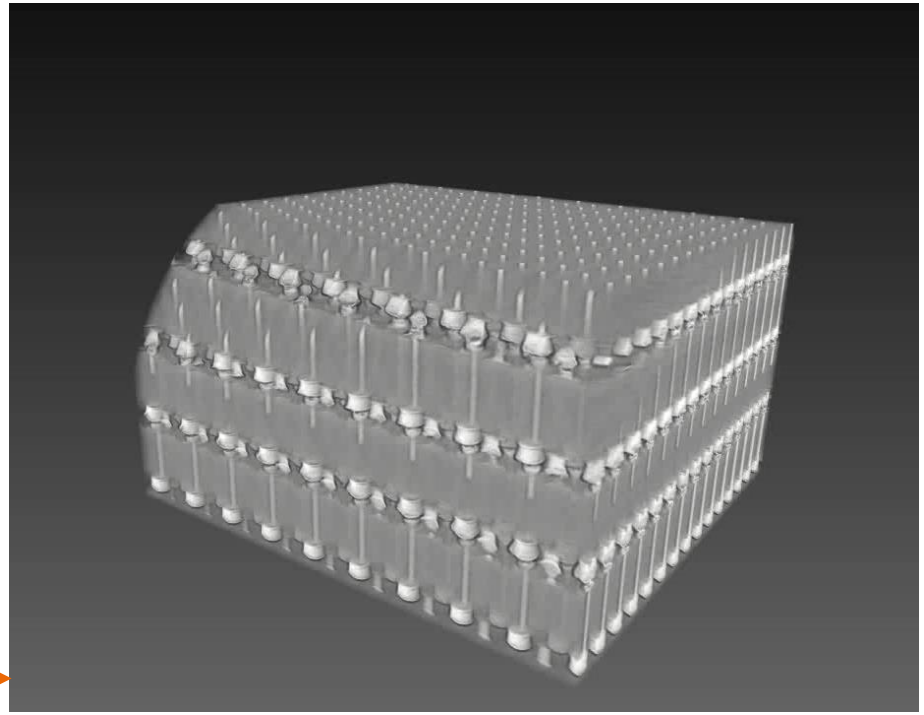
# *Multi-die stack* – Region of interest tomography

- Full-chip tomography, restricted to ROI
  - Bright spots correspond to short-circuiting solder bumps, darker layer corresponds to missing filling of the TSV in that layer



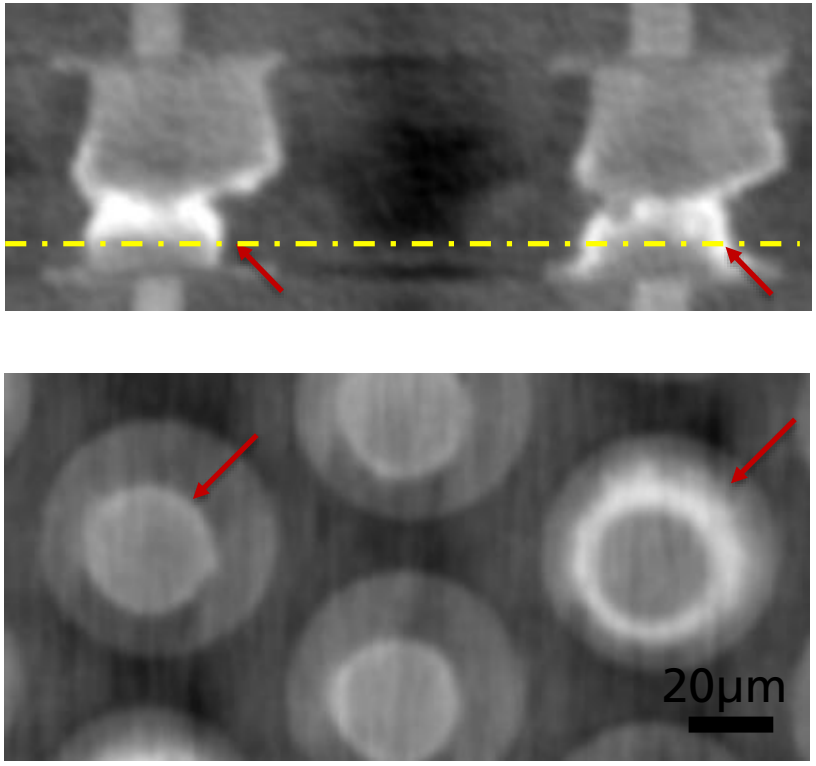

Orthogonal views

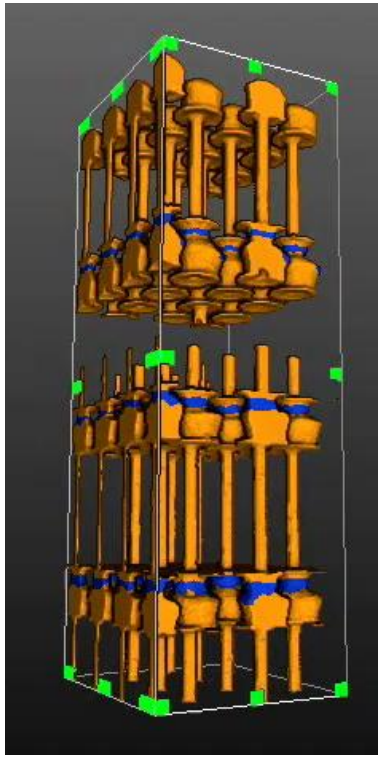
3D cut-away



# *Multi-die stack* – Region of interest tomography

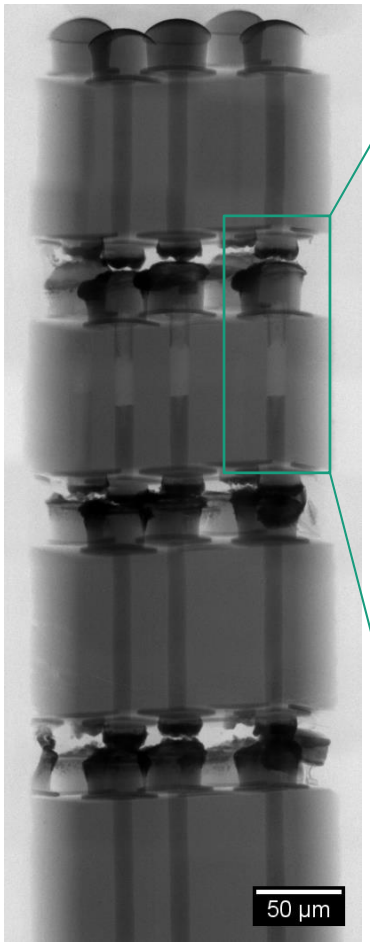
- AgSn solder (white) shows variable behavior in solder flow



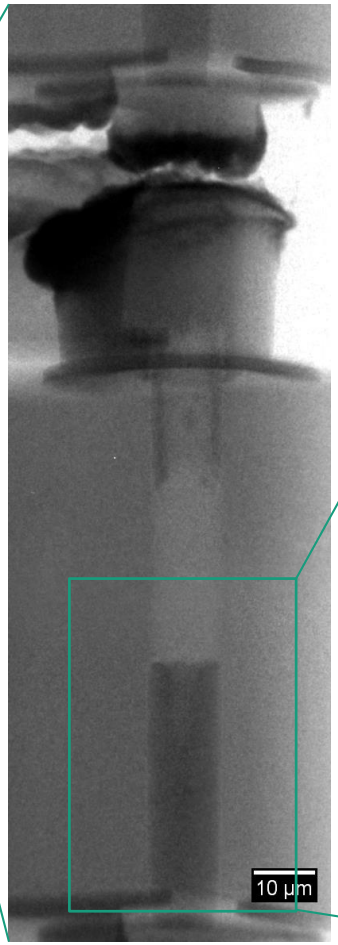



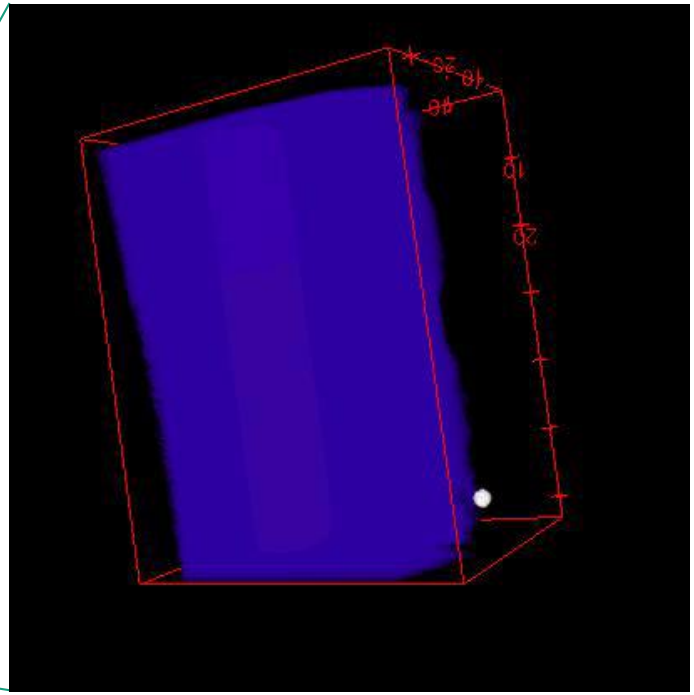
- Segmentation allows to identify Cu (orange) and AgSn solder (blue) in volume

# *Multi-die stack* – high resolution nano XCT




4x10 Mosaic



Tomography TSV



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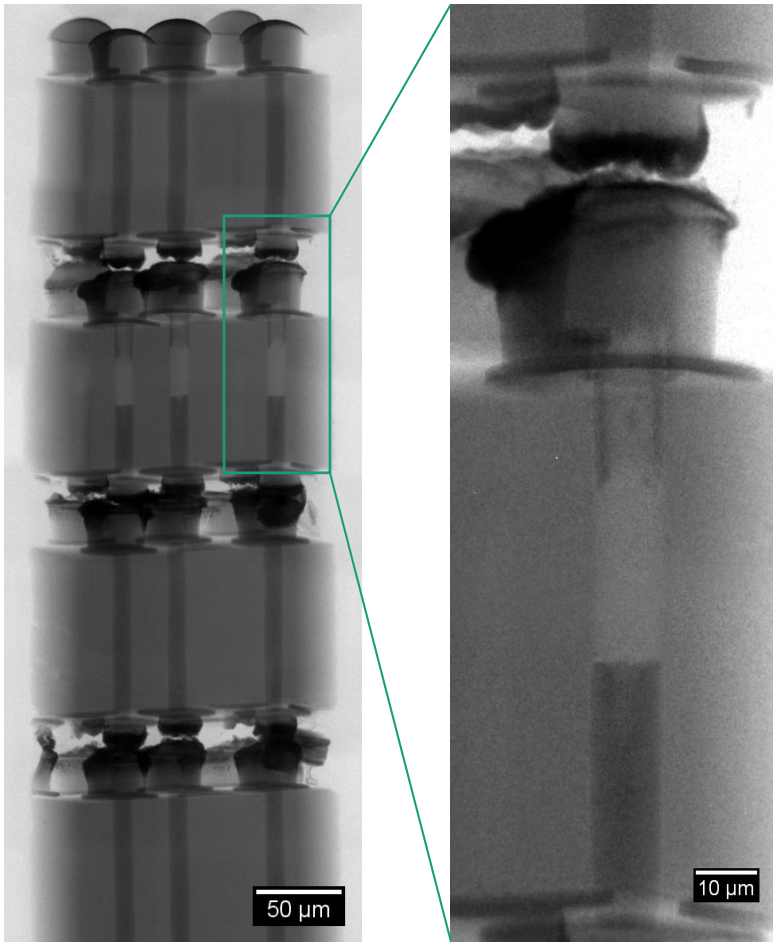
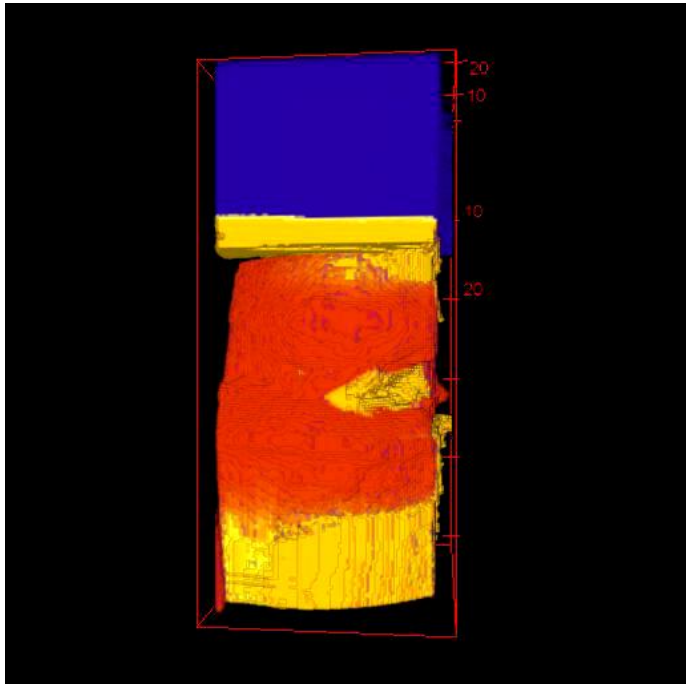
# *Multi-die stack* – high resolution nano XCT




4x10 Mosaic




Tomography solder bump



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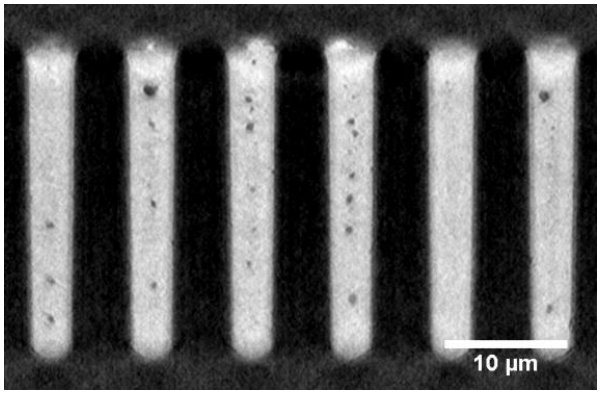
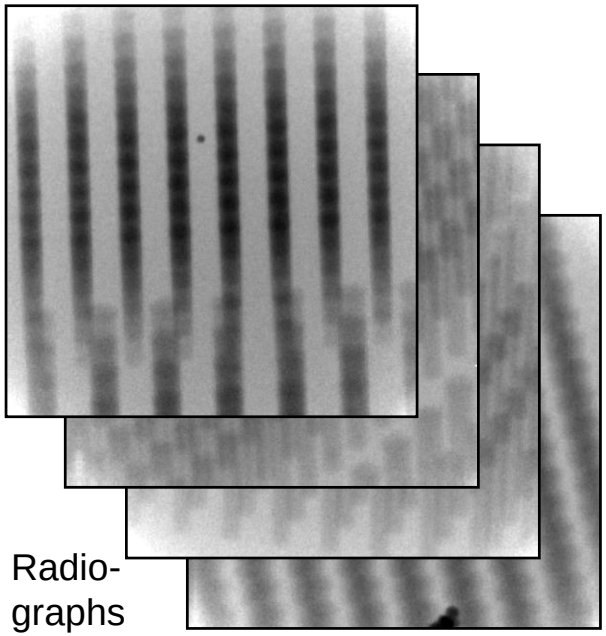
# Array of TSV´s

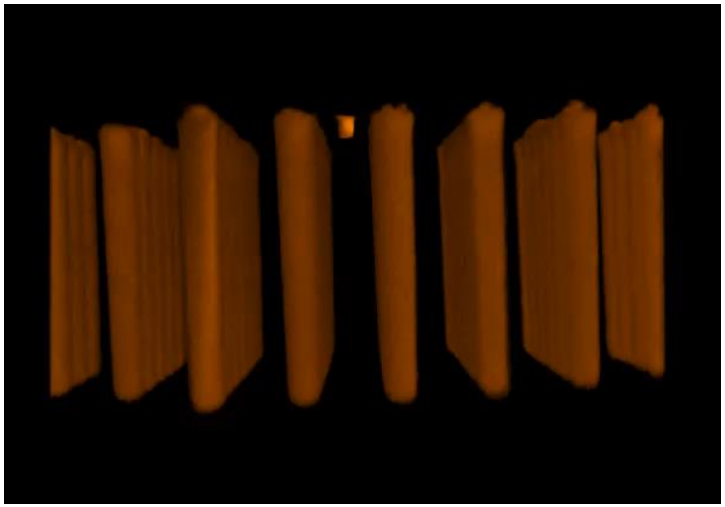
- Reconstruction of 3D volume by **Computed Tomography**
  - object rotation
  - projection acquisition
  - reconstruction and analysis




Virtual cross section



Radio-graphs



3D visualization



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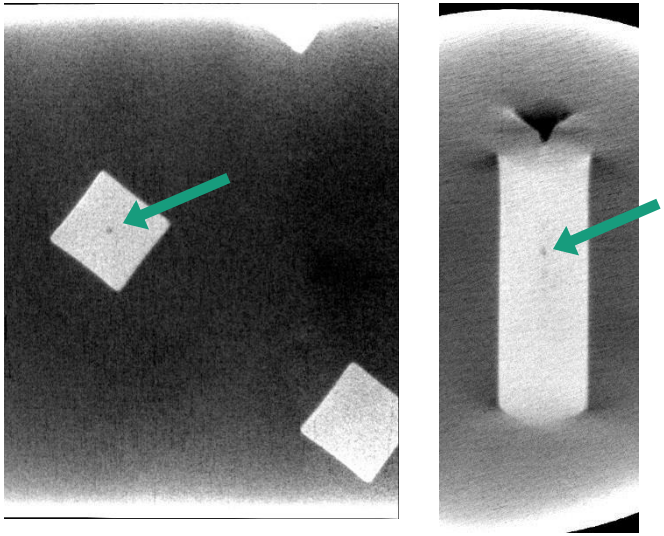
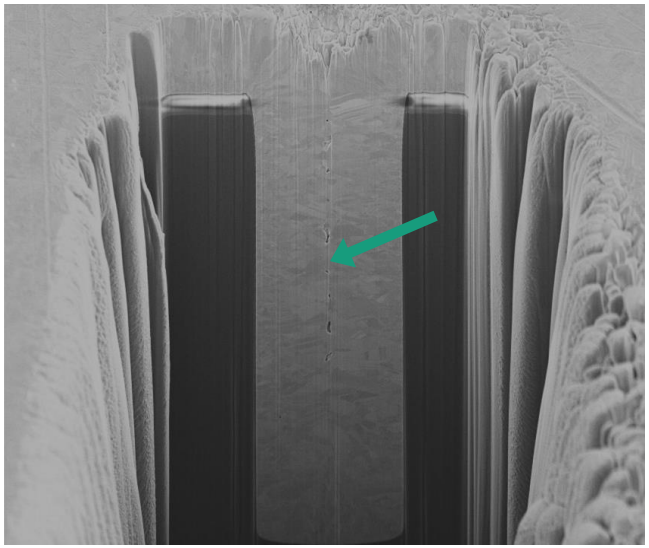
# Array of TSV´s

- TSV etch profiles and small voids in Cu TSVs are visualized



Nano-XCT: virtual cross section



SEM/FIB: detailed investigation

* J. U. Knickerbocker, S. Niese, et al. “3D Interconnect Technology” John Wiley & Sons Chichester, pp. 437-502 (2012)
* L. W. Kong, E. Zschech, et al., J. Appl. Phys. 110, 053502 (2011) DOI:10.1063/1.3629988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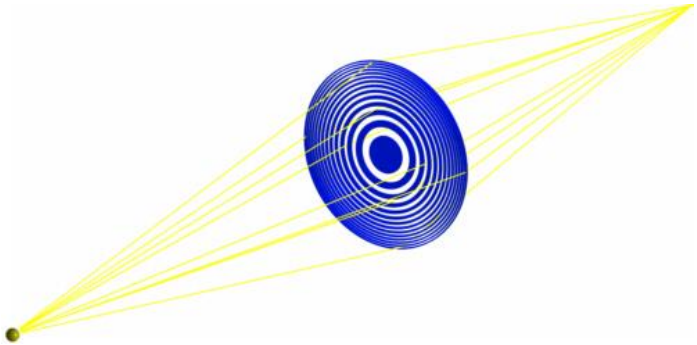
- Next generation of X-ray Optics

# Next generation of X-ray Optics
## *Multilayer-Laue-Lenses (MLL)*

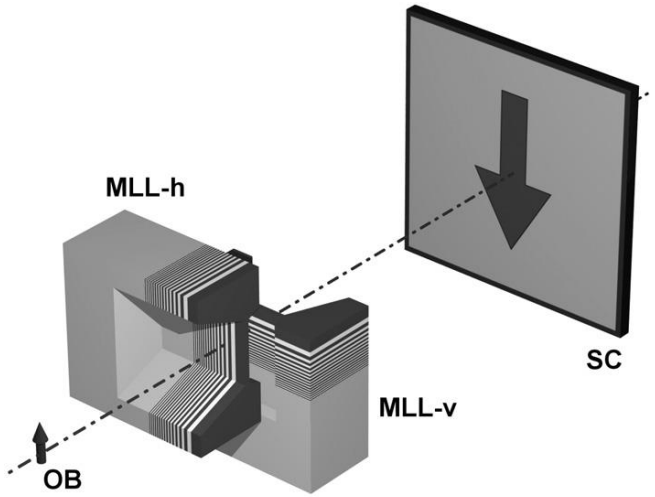
- Desired spatial resolution for XRM is 10 nm
- It is difficult to produce high resolution Fresnel-Zone-Plates for the hard X-ray (E > 10keV)



- The outermost rings determine the resolution
- High aspect ratio at outer zone

$$\delta = 1.22\,\Delta R_n$$

- No aspect ration limit for multilayer structures
- Magnetron sputter at flat substrate




Images: www.x-ray-optics.de, Sven Niese, Fraunhofer IKTS-MD, Dresden



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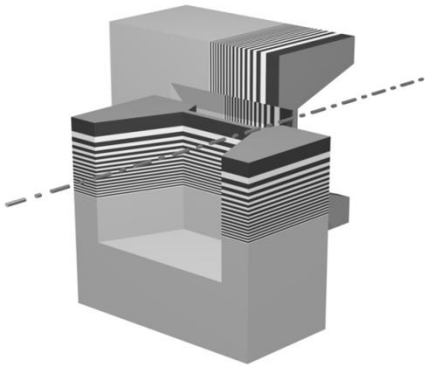
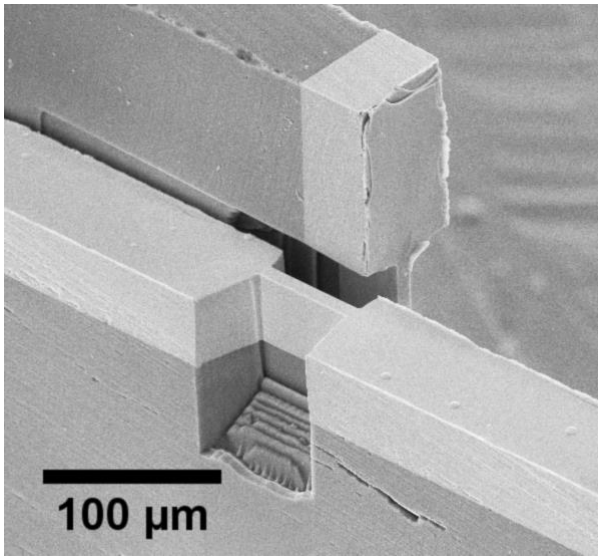
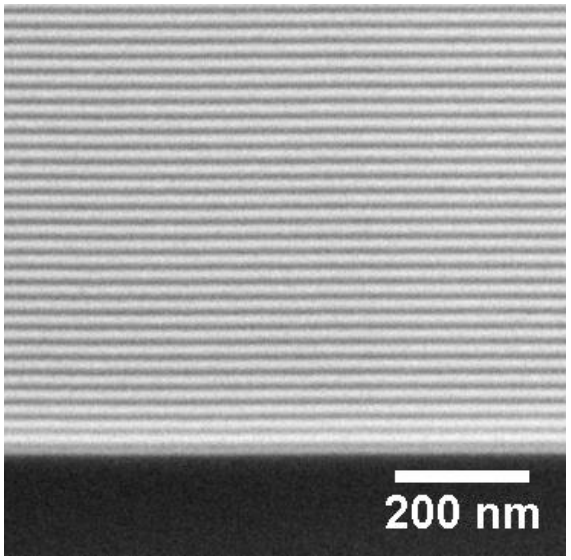
# Next generation of X-ray Optics
## *Multilayer-Laue-Lenses (MLL)*





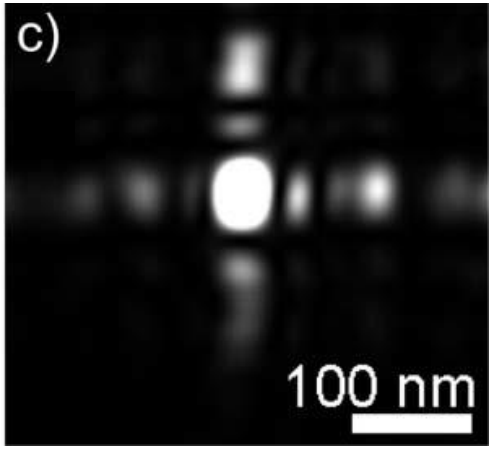




- 2451 alternating zones of WSi2 and Si

* S. Niese, et al., XRM 12th Int. XRM Conf., Melbourne (2014)

# Multilayer-Laue-Lenses (MLL)
## *Focussing Properties*

reconstructed wavefield
of crossed MLL




- central peak 39 nm x 49 nm

Reference:
Ptychography with multilayer Laue lenses
A. Kubec, S. Braun, S. Niese, P. Krüger, J. Patommel, M. Hecker, A. Leson and CG. Schroer
Journal of Synchrotron Radiation, (2014). 21, 1122–1127 DOI: 10.1107/S1600577514014556

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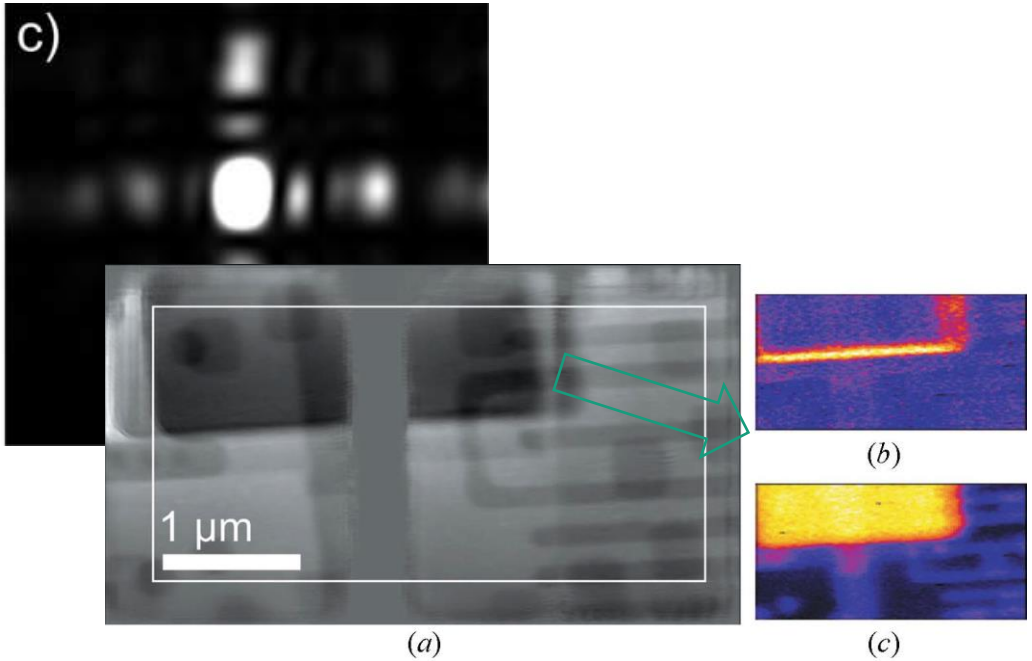
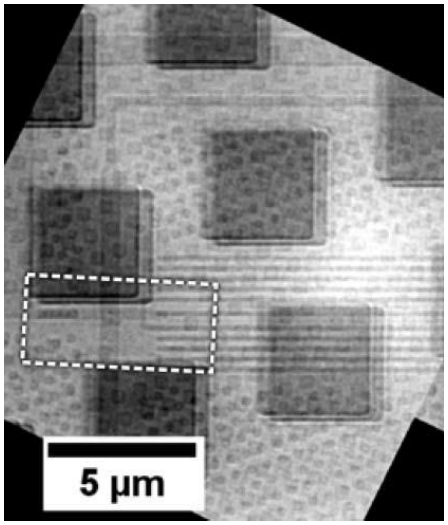


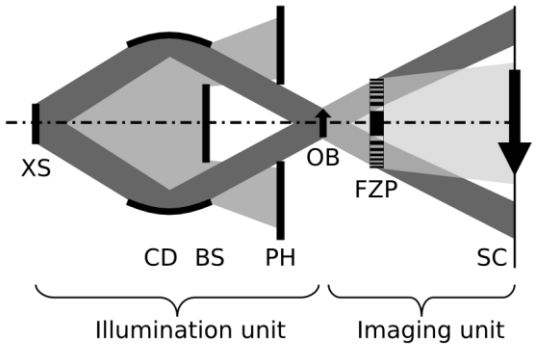

(a) Ptychographic reconstruction fluorescence maps (b) tantalum (c) copper

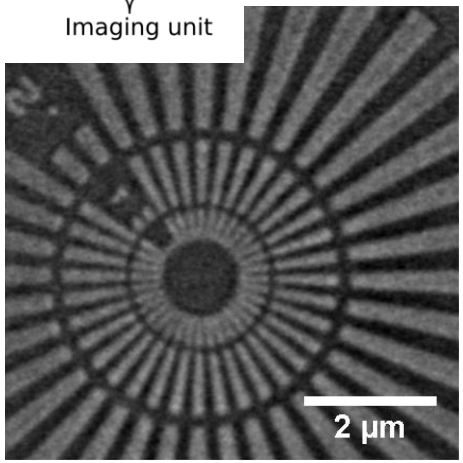



Overview: Xradia NanoXCT-100 (FZP)

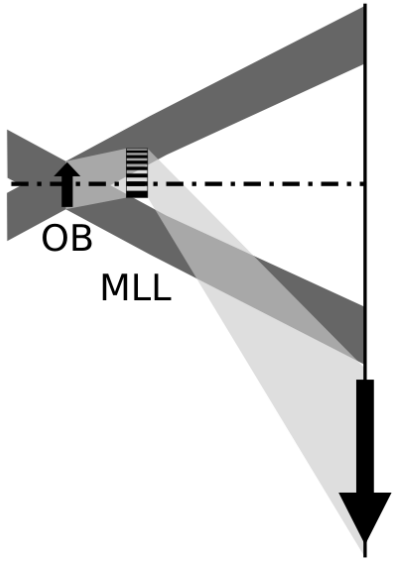
# Full field imaging with MLL

## Fresnel zone plate

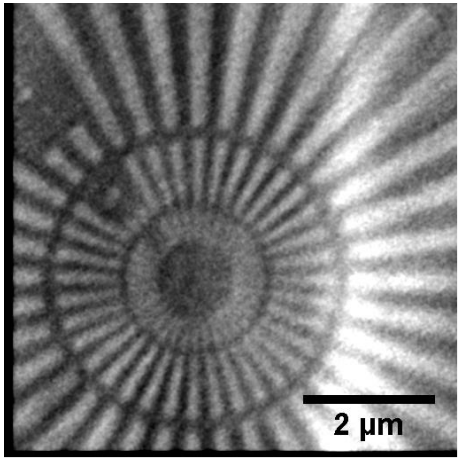



## MLL and Ni-Filter




- sub-100 nm resolution
- competitive contrast (8.8%)




Reference:

S. Niese, P. Krüger, A. Kubec, S. Braun, J. Patommel, C. G. Schroer, A. Leson, E. Zschech:
Full-field X-ray microscopy with crossed partial multilayer Laue Lenses
Optics Express, Vol. 22, Issue 17, pp. 20008-20013 (2014) DOI: 10.1364/OE.22.020008

# Summary

- 3D integration of microelectronics needs (non-destructive) characterization
- X-ray microscopy at different length scale to find and analyze ROI
- Hard X-ray microscopy to penetrate whole package / die
  - µ-CT for Overview
  - nano-CT for details
- Development of novel X-ray optics based on MLL

  will have improved resolution at higher X-ray energy

# Thank you

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Fraunhofer IZM

Fraunhofer IWS

TECHNISCHE UNIVERSITÄT DRESDEN

dcn dresden center for nanoanalysis

DRESDEN concept



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