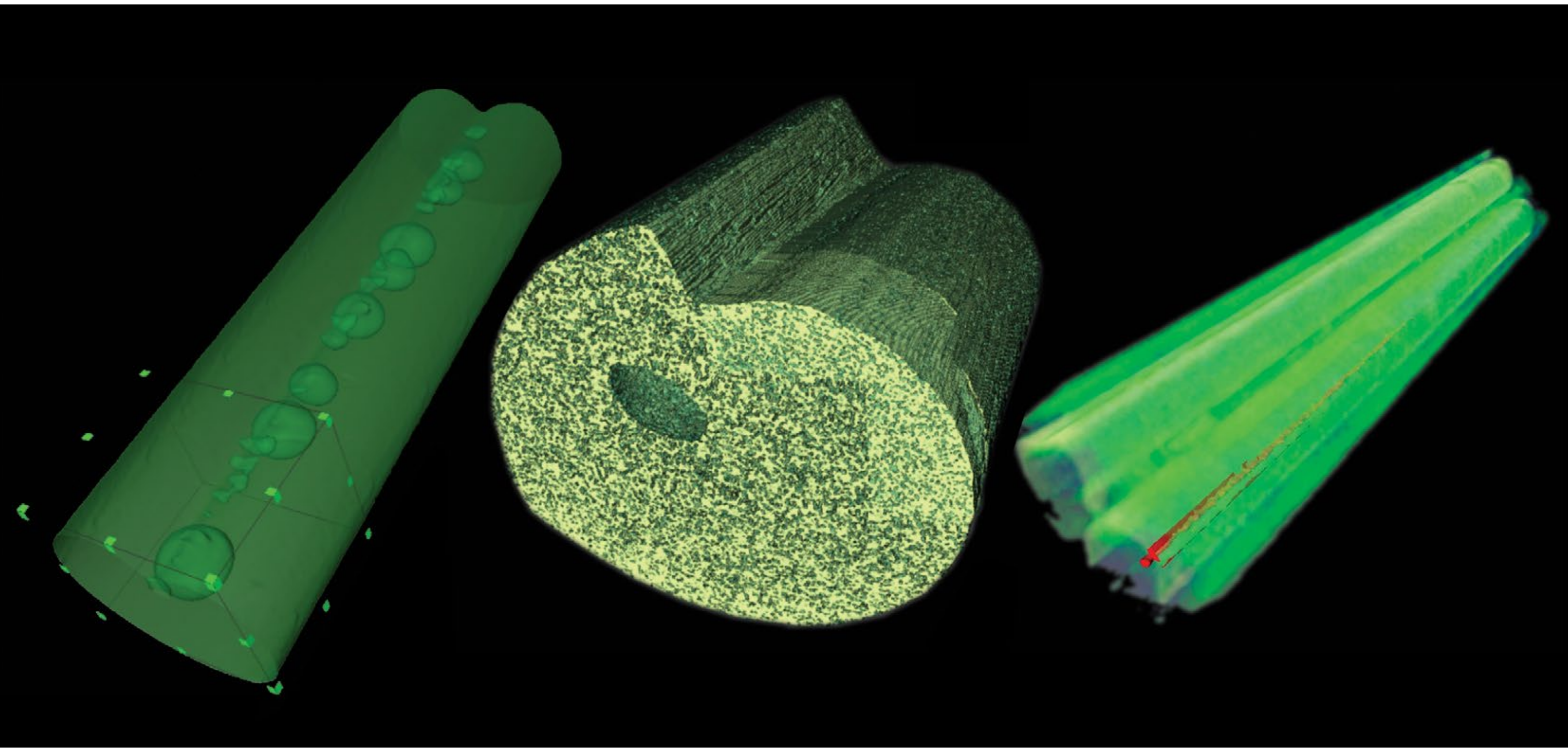
Technical Note



Multi-length Scale Imaging

Bridging the 3D Resolution Gap

We make it visible.

Multi-length Scale Imaging

Bridging the 3D Resolution Gap

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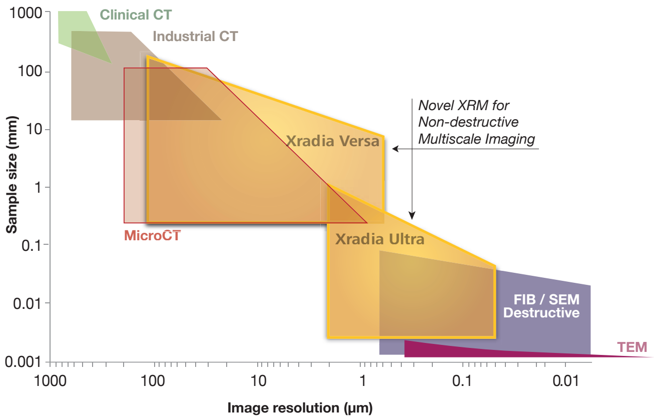
Between industrial CT and electron microscopy, a large sample size and resolution gap has remained unaddressed for volumetric imaging. ZEISS's 3D X-ray microscopes (XRM) provide non-destructive 3D imaging for quantitative analysis of samples at length scales within this gap to provide a complete solution for correlative multi-length scale investigations.

Both naturally occurring real world materials and a wide range of artificially constructed nanomaterials and composites typically have internal structures that vary in length scale, e.g.:

- Semiconductor chips and devices contain features ranging from nanometer scale transistors up to centimeter scale packages;
- Pore and crack structure in geological materials, such as those in rocks studied for oil and gas recovery or CO_2 sequestration, range from nanometers to millimeters;
- Biological tissues contain microscopic features from the subcellular level to large organs;
- Fractures and cracks in materials, in which a crack tip can measure on the order of angstroms while the crack opening profile and geometry can be substantially greater than millimeter scale;
- Engineered microstructures (fibers, matrix composites, sintered materials) can have complex features that must be observed at several length scales.

To gain true insight into the material, observation and quantification of structures are required at each length scale. Direct observation or correlation to 3D structure is critical.



No single microscopy solution is capable of imaging structures across an entire range of length scales in 3D. In response, new fields of correlative microscopy have emerged that use several imaging solutions to analyze one sample. However, there exists a significant gap between the two common 3D imaging methods:

1. *Low resolution, large sample size*
   Solutions such as clinical or industrial CT provide non-destructive 3D analysis of larger samples, but at coarse resolutions
2. *High resolution, small sample size*
   Electron microscopy-based techniques achieve high resolution, but are destructive and inefficient for samples beyond a limited size

The 3D imaging solution that fulfills this resolution and sample size gap must be non-destructive, so that the sample can be re-imaged at higher resolutions. ZEISS XRM provides the answer.

The ZEISS multi-length scale suite of X-ray microscopes – Xradia Versa and Xradia Ultra families – is the only solution that completely bridges the 3D resolution gap. The system suite provides variable magnification to non-destructively observe three-dimensional features across multiple length scales to offer flexible end-to-end X-ray imaging, allowing a wide range of structures to be studied:

- Sample sizes from sub-millimeter to inches with resolution down to 700 nanometers is possible on the Xradia Versa family;
- Samples up to a millimeter in size can be imaged with resolution down to 50 nanometers on the Xradia Ultra family.

The Xradia Versa family's unique multi-objective turret microscope design enables Scout-and-Zoom: surveying the entire sample at medium resolution (scout) to identify and isolate regions of interest before virtually sub-sampling (zoom), to scan the smaller ROI at the highest resolution.

Application Example (Bone)

Bone consists of complex hierarchical structures at a variety of different length scales. ZEISS multi-length scale imaging solutions enable bone investigations from the sub-millimeter trabecular level down to the nanometer canalicular level, providing unprecedented in-laboratory access to the 3D structures of inter-lacunar networks.

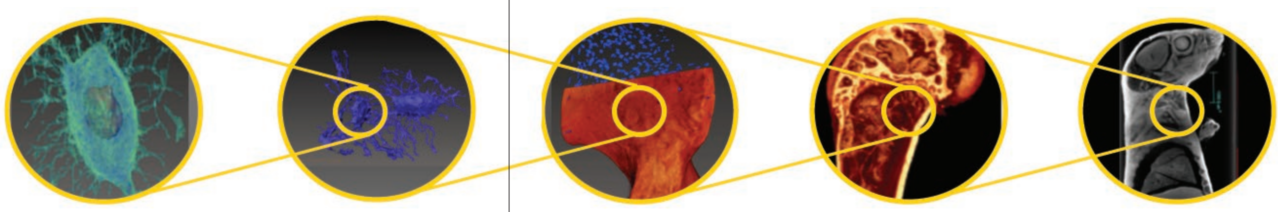
Application Example (Semiconductor)

The penetrative power and high resolution of ZEISS systems enable an effective new workflow for failure analysis. First, regions of interest (ROIs) are identified using conventional input from low-resolution failure analysis tools such as electrical TDR. Then, Xradia Versa can non-destructively perform virtual cross section of the ROI (without de-packaging) at high resolutions to gain 3D structural and coordinate information, providing defect localization and visualization for classification. Further testing can resolve inconsistencies (if any) between the first steps, strain the sample to failure, perform thermal analysis, or observe failure evolution *in situ*. Downstream, the package is ultimately consumed by a destructive electron microscopy technique that uses the fault isolation information provided by Xradia Versa to navigate to and characterize faults.

Bone

Xradia Ultra Family | *Xradia Versa Family*

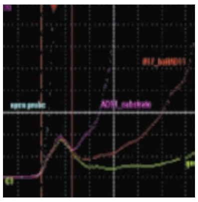
FOV: 15 µm Res: 50 nm	FOV: 65 µm Res: 150 nm	FOV: 1.5 mm Res: 1.3 µm	FOV: 7 mm Res: 7 µm	FOV: 50 mm Res: 60 µm



High Resolution Osteocyte Lacuna	*High Resolution Osteocyte Lacuna*	*Osteocyte Lacunae in Trabecular Bone*	*Rat Femur*	*Whole Rat*

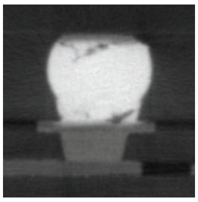
Semiconductor

1st



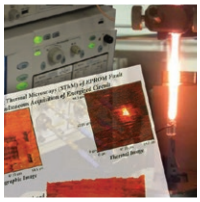
Testing: TDR (Electrical test)

2nd



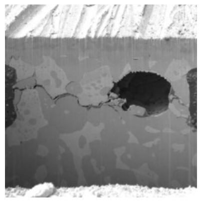
Xradia Versa Virtual Cross Section (non-destructive)

3rd



Further Testing (TDR, in situ *imaging on the Xradia Versa, thermal stress tests, etc.)*

4th

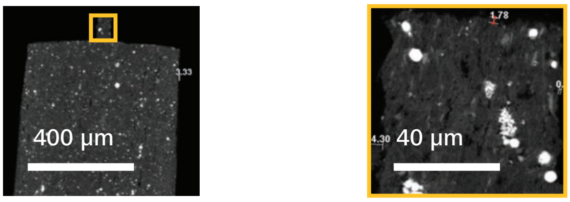


FIB SEM or Other Cross Section (destructive)

Application Example (Geo Materials)

Heterogeneous rock, such as sandstone, shale and carbonate, are characterized by microstructure that vary across length scales. ZEISS multi-length scale analysis of the porosity in these rocks provides the key input for virtual flow models to enhance special core analysis for oil drilling exploration and well feasibility studies.

Geo Materials



Shale sample, imaged with Xradia Versa (left) and Xradia Ultra (right)

Suggested Reading:

Lau SH, Tkachuk A, Chang H, Duewer F, Cui H, Feser M, Yun W. ICMAT 2007 Singapore.

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