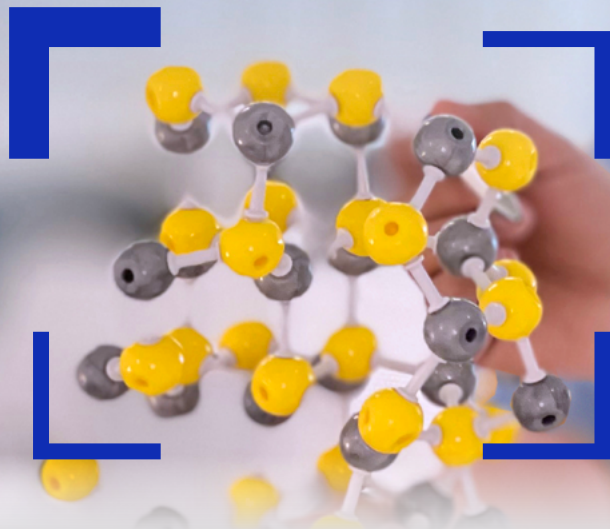# Unlock the crystallographic and microstructural secrets of your samples

ZEISS Xradia CrystalCT

Diverse. Innovative. Accessible.

www.zeiss.com/crystalct

ZEISS

Seeing beyond

# The world's first commercial implementation of diffraction contrast tomography on a microCT

ZEISS Research Microscopy Solutions and Xnovo Technology have partnered to deliver a revolutionary new laboratory diffraction contrast tomography (DCT) capability: ZEISS Xradia CrystalCT, the first commercial DCT system on a micro-computed tomography (microCT) platform. CrystalCT is faster, offers higher throughput, larger volume imaging, and a wider array of sample geometries than any previous commercially available system. Traditional X-ray tomography opens the door to non-destructive 3D investigation of samples, delivering information related to porosity, defects, and other microstructural features. Augmenting the already powerful technique of computed tomography with the ability to reveal crystallographic grain microstructure transforms the way in which polycrystalline materials can be studied, leading to newer and deeper insights into your materials research. Taking this capability out of the synchrotron and bringing it to your high-productivity lab enables you to benefit from the latest X-ray imaging advancement to propel your research to a new dimension.
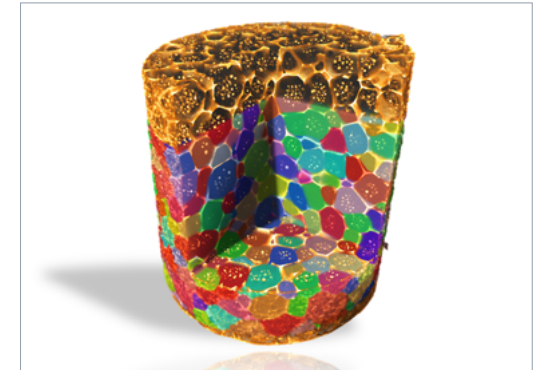
Aluminum copper alloy imaged in absorption and diffraction contrast tomography. Colors indicate grain orientation overlaid onto absorption data that discern the copper along grain boundaries.
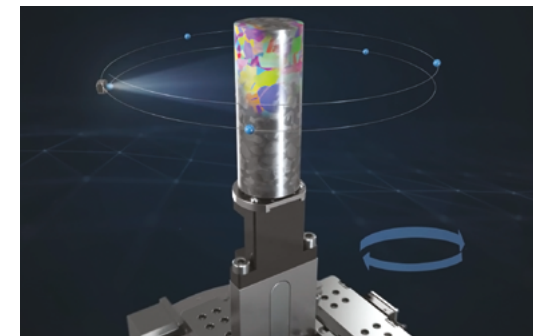
▶ Click here to view this video

ZEISS Xradia CrystalCT enables standard and three unique modes of advanced diffraction scanning capability: helical phyllotaxis, helical phyllotaxis raster, and helical phyllotaxis HART (high aspect ratio tomography)

Diverse. Innovative. Accessible.

Diffraction Contrast Tomography (DCT) for an Expanded Range of Research Possibilities

With its large field of view flat panel detector, CrystalCT is built to address a wide spectrum of imaging needs in research and industrial applications. Using 3D grain mapping, DCT on a microCT brings within the reach of technical and industrial research labs the ability to image single-phase polycrystalline materials, covering a wide range of metal, mineral, ceramic, semiconductor, and pharmaceutical samples in 3D. Non-destructive CT also enables in situ and 4D studies to understand practically the impact of varying conditions over time. Innovative DCT acquisition modes remove the limitations for larger sample sizes, providing you with the ability to research more sample types. Faster acquisition speeds enable you to run samples in a shorter time, increasing your productivity and profitability. Seamless large volume grain mapping enables scanning samples faster and with more accurate representation of data.
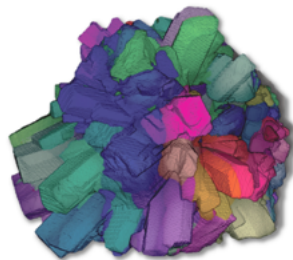
Removing the Limits on Contrast

X-ray tomography for 3D non-destructive imaging has been widely adopted and operated under two primary contrast mechanisms for quite some time: X-ray absorption and phase contrast. Both rely on differences in material properties within the sample. However, single-phase polycrystalline materials, e.g., steels, alloys, and ceramics, do not exhibit absorption contrast differences between neighboring grains, which is necessary to reveal the underlying grain microstructure. Synchrotron-based X-ray imaging methods such as DCT— which provides crystallographic information from the diffraction signals of single-phase polycrystalline samples— were the first to successfully demonstrate results in this class of materials almost two decades ago. Now, advancing non-destructive 3D X-ray imaging one step further, new 3D characterization methods and capabilities are available on laboratory-based DCT with CrystalCT, the world's highest performing microCT platform.
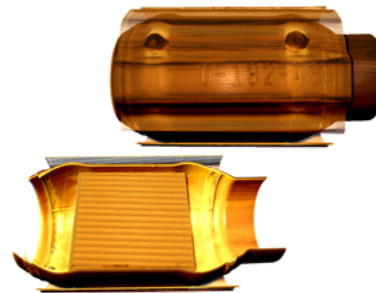
Built on a Powerful MicroCT Platform

ZEISS leverages its powerful Versa XRM technology to deliver world-leading performance on a microCT. With a robust stage, flexible software-controlled source/sample/detector positioning, and a large array detector, you can obtain high quality, high resolution scans with best-in-class contrast on entire objects or devices to reveal interior details in their full 3D context. The ZEISS Versa XRM imaging system combines its proven hardware architecture with state-of-the-art stability and drift compensation features. It is because of the superior stability of this renowned platform, that CrystalCT consistently surpasses one's comprehension of what a microCT can achieve.

# Your Insight into the Technology Behind It

A more advanced way of looking at crystallography

Virtual materials testing leads to rapid materials discovery, important for rapidly shifting industries like aerospace, automotive, energy, and construction. To enable this research, large volumes of real data are required to create high fidelity computational models, or data representivity. You can painstakingly image surface information and combine it with cross-sectioning to obtain volume data. But what if you could scan large representative volumes non-destructively to be used as a basis for your model?

2D optical and EM techniques provide surface-only measurements. When combined with destructive milling they do provide 3D information, but over limited smaller volumes with low sample representivity. Traditional DCT implementations at synchrotron and on early X-ray microscopy (XRM) solutions overcome these limitations.

CrystalCT delivers cutting edge, radically different diffraction scanning technology, uniquely offering the ability to image large sample volumes in their native state while targeting realistic sample geometries that suit the common requirements of research and industrial labs.
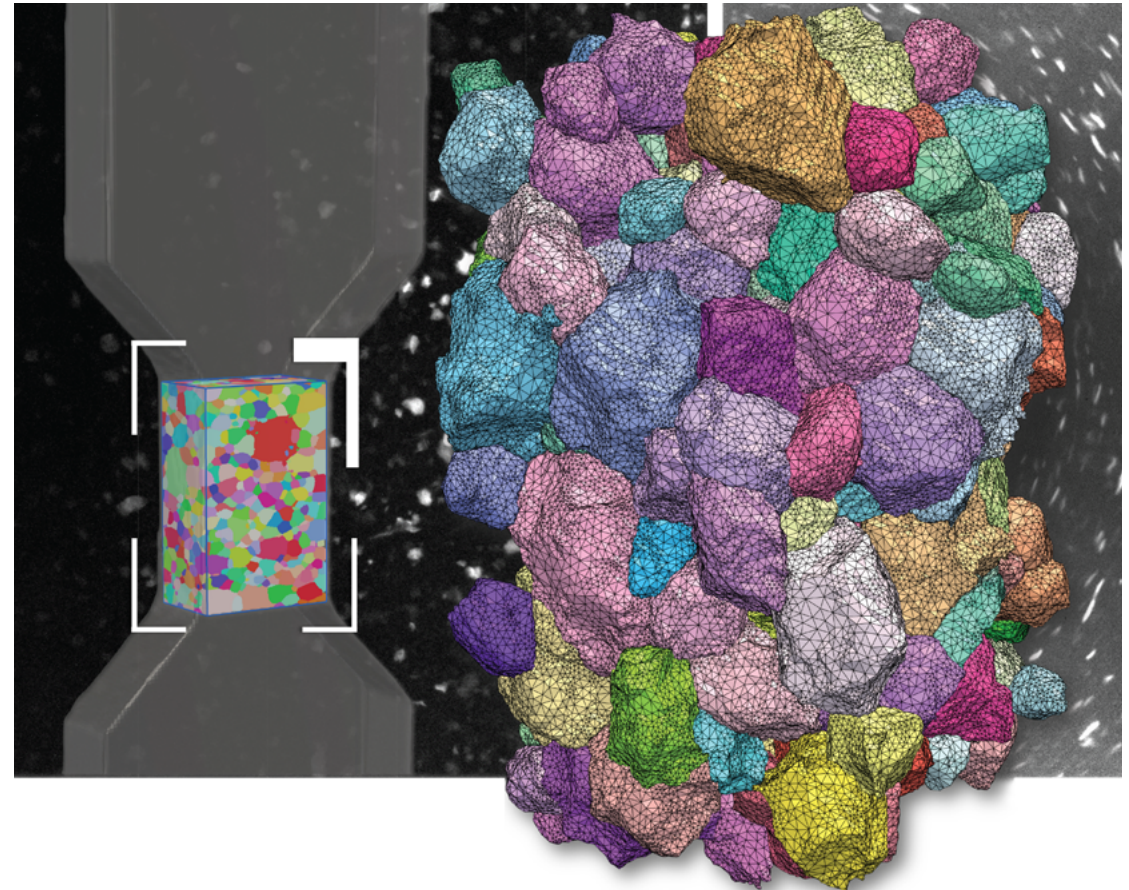
Unlike other grain mapping technologies, DCT enables non-destructive 3D grain imaging. And now CrystalCT allows you to map grain boundary surfaces over significantly larger volumes.

Your preserved sample enables additional and even correlative research: leverage in situ and 4D materials science in real-time or over-time to study the impact of temperature, mechanical loading, fracture mechanics, and other physical stimuli.

Your Insight into the Technology Behind It

**Diffraction Contrast Tomography Uniquely on a MicroCT**

The purpose-built CrystalCT leverages the robust design and high stability of the X-ray imaging architecture of ZEISS Versa XRM platforms, incorporating precisely designed aperture and beam stop assemblies. The divergent, polychromatic X-ray beam is constrained through the aperture to illuminate a region of interest (ROI) of the sample. The beamstop after the sample blocks transmitted X-rays on the detector to increase sensitivity towards the substantially weaker diffraction signals of polycrystalline samples.

The single CrystalCT platform delivers dual modalities: an absorption contrast tomography (ACT) scan to define the sample outline, and a diffraction contrast tomography (DCT) scan in which a specified number of diffraction contrast projections are collected as the sample rotates and translates.

Then the collected ACT and DCT data are imported into GrainMapper3D developed by Xnovo Technology for further processing and reconstruction. Information on grain morphology, crystallographic orientation, size, and centroid position is available from the reconstructed 3D grain map.

Projection Geometry
$L_{SS} < L_{SD}$
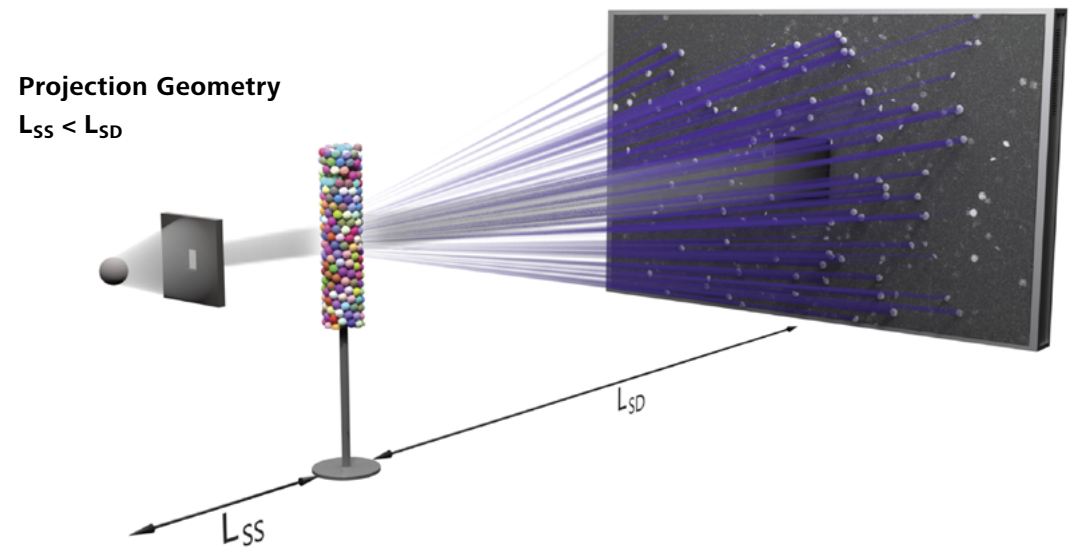
Schematic illustration of CrystalCT projection geometry. Exemplifying sample is sapphire spheres stacked in a tube.
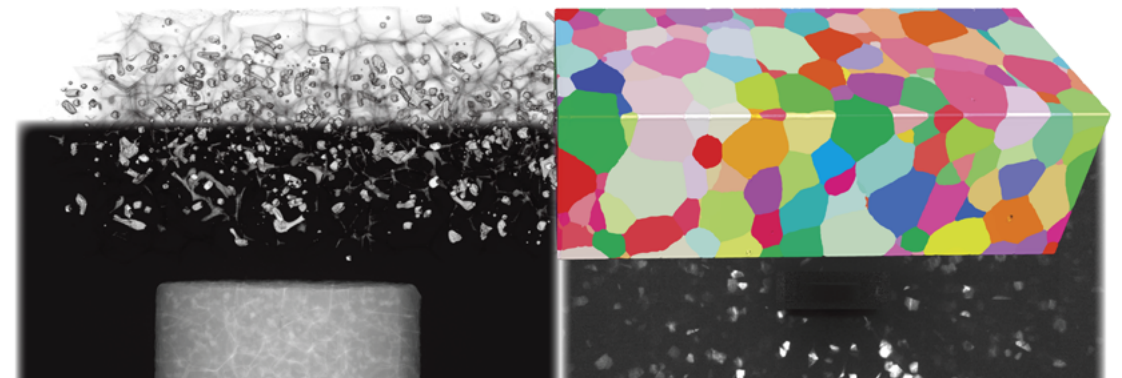
Aluminum alloy with copper-decorated grain boundaries. Foreground: left portion of the sample displays the copper inclusions and grain boundary decorations from absorption contrast data; right portion shows the grain map with colors representing crystallographic orientations reconstructed from diffraction contrast data. Background presents a raw absorption projection (left) and the corresponding diffraction projection (right).

Your Insight into the Technology Behind It

Superior Sample Representivity from Advanced Diffraction Scan Modes

CrystalCT advances materials characterization, modeling, and discovery through ground-breaking diffraction scanning modes that:

- Provide unprecedented sample representivity
- Enable scanning larger sample volumes
- Simplify sample prep, and handling of irregular/natural sample shapes
- Increase speed
- Address sample specificity

These advanced modes overcome some of the previous challenges of conventional DCT data collection, which assumes that the ROI in the sample is fully illuminated by the aperture field of view (FOV) for all rotational angles of the sample.

Inspired by nature's golden angle, advanced DCT scanning modes deliver helical phyllotaxis schema to manage a wide range of sample shapes and sizes.

Helical Phyllotaxis

Helical phyllotaxis rotation is used for long aspect ratio cylindrical samples.

Helical Phyllotaxis Raster

Helical phyllotaxis raster is used for samples that are typically wider than the field of view.

Helical Phyllotaxis HART

Phyllotaxis with high aspect ratio tomography, or HART, solves the problem of flat or plate-like sample imaging.

Non-destructive CrystalCT

Volume: >>$(1000)^3$ μm^3 and beyond

Isotropic voxels: Up to 2 μm

Voxel aspect ratio = 1

Prior Non-destructive DCT

Volume: $(1000)^3$ μm^3

Isotropic voxels: Up to 2 μm

Voxel aspect ratio = 1

PFIB + EBSD

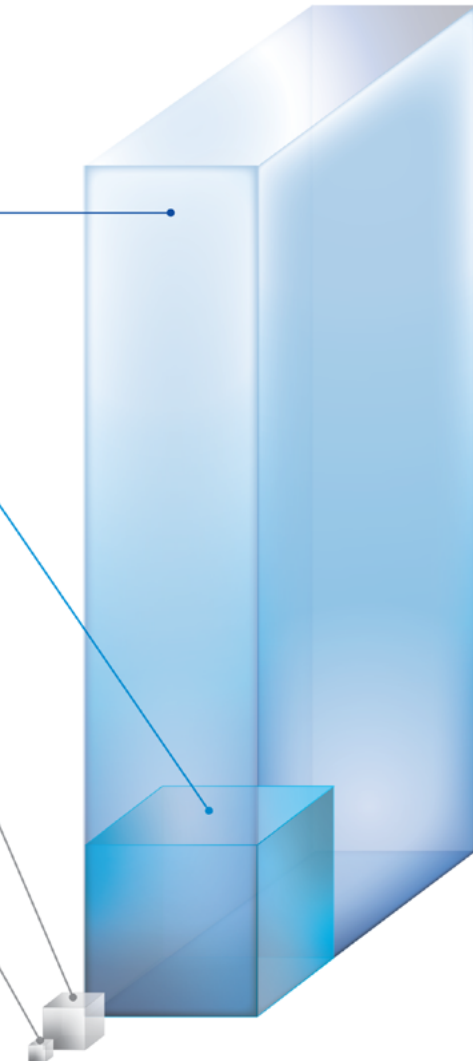Volume: $(250)^3$ μm^3

Slice thickness: 0.2-5 μm

Voxel aspect ratio ≥ 50

Ga-FIB + EBSD

Volume: $(100)^3$ μm^3

Slice thickness: 10 nm

Voxel aspect ratio ≥ 1

Your Insight into the Technology Behind It

**Image Quality Based on the Proven ZEISS Versa XRM Platform**

In addition to being a DCT platform, CrystalCT is also a full micro-CT imaging system enabling high-resolution, submicron or large field-of-view, non-destructive 3D X-ray microcomputed tomography in research and industrial applications.

Excellent Data Quality

Excellent data quality relies on several factors including source characteristics, beam energy tuning, detector geometry and sensitivity, environmental control, motion and vibrational stability, careful system calibration, and reconstruction accuracy.

To address these challenges, CrystalCT is built on the same platform as the proven ZEISS Versa X-ray microscope series, inheriting the stabilization mechanisms and data quality advancements that helped ZEISS Versa XRM set the standard in high performance 3D X-ray imaging in the laboratory. Experience excellent contrast and image clarity, enabling easy differentiation of phases and features to support downstream segmentation and quantification of your data.

Further extend your field of view with integrated vertical stitching functionality. Maximize geometric magnification with small samples to identify and characterize micron-scale structures with high contrast and clarity. From sample mounting to scan preparation, acquisition, multi-GPU reconstruction, and image processing and analysis, experience an efficient high throughput workflow that gets you to results quickly.
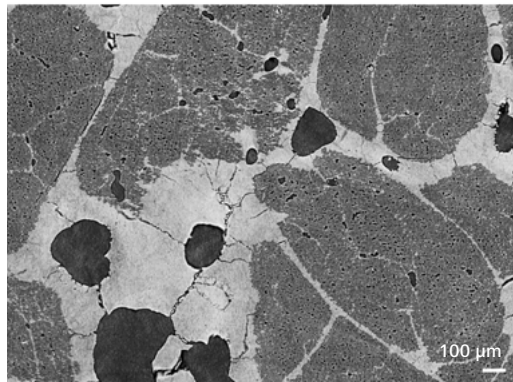
Woven ceramic matrix composite sample imaged after mechanical testing. Bright regions are the ceramic matrix, medium gray regions are fiber bundles at a crossover point, and dark regions are voids.
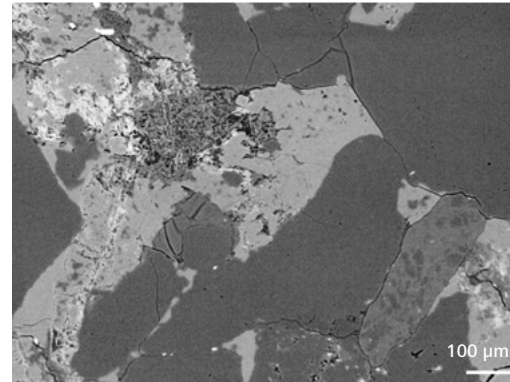
Tight sand rock specimen showing the carbonate and quartz content along with intergranular crack networks.
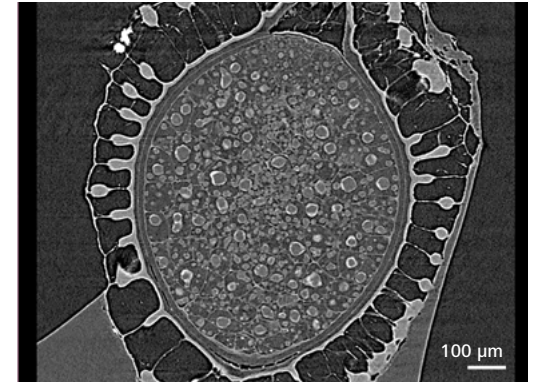
Virtual cross-section of a Cyclanthus Bipartitus seed, showing intricate internal details.

Your Insight into the Technology Behind It

A Closer Look at Spatial Resolution

ZEISS microCT and X-ray microscopy systems are specified on true spatial resolution, the most meaningful measurement of your instrument's performance.

Spatial resolution refers to the minimum separation at which your imaging system can resolve a feature pair. You would typically measure it by imaging a standardized resolution target with progressively smaller line-space pairs. Spatial resolution accounts for critical characteristics such as X-ray source spot size, detector resolution, magnification geometry, and vibrational, electrical and thermal stability.

Other terms such as "voxel," "spot size," "detail detectability," and "nominal resolution" do not convey your system's full performance.

CrystalCT specifies spatial resolution at short source-sample working distance indicative of results for a very small sample, as is practice in the industry. For larger working distances/samples, all CT and microCT systems relying on a projection-based architecture will have magnification that is strongly dependent on the working distance (in contrast to X-ray microscopy, where spatial resolution is not strongly dependent on working distance).

Therefore, to provide an indication of the operating space, ZEISS Xradia CrystalCT also specifies the achievable voxel size at different working distances.

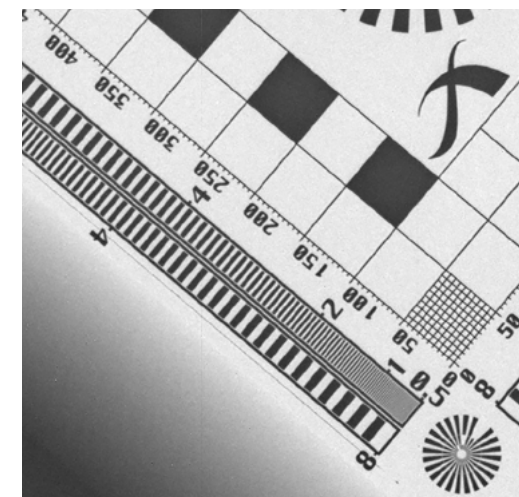As the leader in X-ray imaging, ZEISS provides this transparency to true system performance.

ZEISS resolution target, used to evaluate sub-micron spatial resolution. Minimum voxel size of 0.5 µm.

Imaging Specifications

Spatial Resolution [a]	0.95 µm
Minimum Achievable Voxel [b]	0.5 µm
Achievable Voxel at Working Distance [b,c]	0.5 µm / 0.5 mm
	0.8 µm / 2.5 mm
	2.5 µm / 12.5 mm
	4.0 µm / 25 mm
	12.1 µm / 100 mm

[a] Spatial resolution measured with ZEISS 2D resolution target.
[b] Voxel is a geometric term that contributes to but does not determine resolution, and is provided here only for comparison.
    ZEISS specifies resolution via spatial resolution, the true overall measurement of instrument resolution.
[c] Working distance defined as clearance around axis of rotation. This value can be interpreted as the radius of the sample.

Your Insight into the Technology Behind It

## Simple Control System to Create Efficient Workflows

All of the features of CrystalCT are seamlessly integrated within the Scout-and-Scan Control System, an efficient workflow environment that provides full control over the system hardware and allows you to easily position a region of interest, specify scanning parameters, and begin scans. The easy-to-use interface is ideal for a central lab-type setting where your users may have a wide variety of experience levels, enabling even novice users to begin collecting data quickly. The interface maintains the flexibility for which ZEISS XRM systems are known, enabling you to set-up scans with ease and with recipe-based repeatability, especially useful for your *in situ* and 4D research or repetitive sample scanning.

Advantages

- Internal camera for sample viewing
- Smart positioning sample navigation stage to easily position your region of interest on the tomography rotation axis
- Recipe control (set, save, recall) to enable multiple scans with different parameters allowing batch mode
- Easy set-up to stitch multiple scans of large objects with vertical stitching
- Automated reconstruction
- Collision avoidance for system set-up, custom models, and disable feature for highest resolution scans
- Integrated *in situ* recipe control for Deben chambers
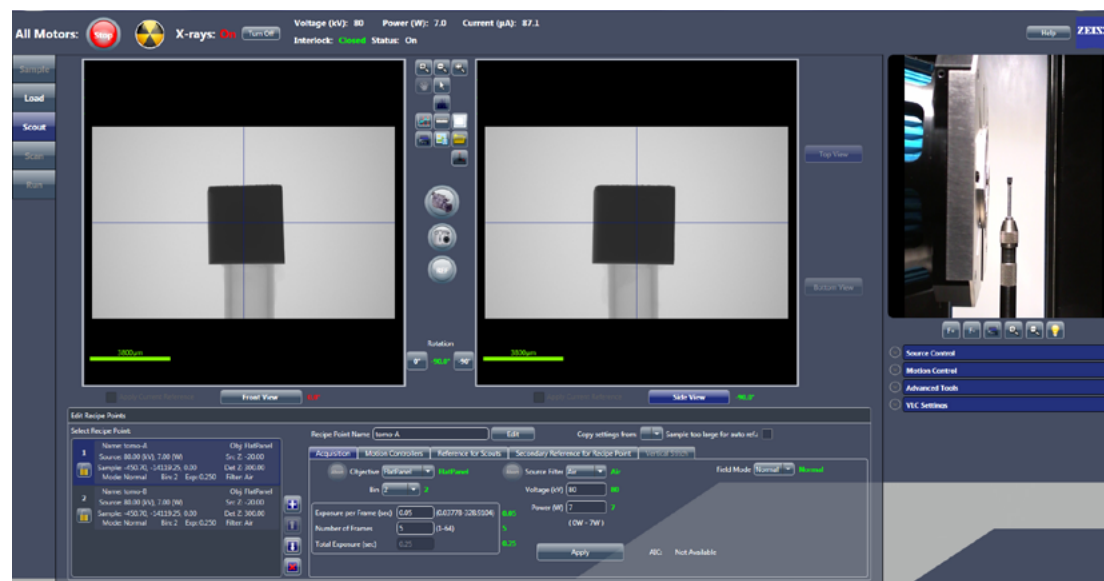

Workflow-based Scout-and-Scan control system
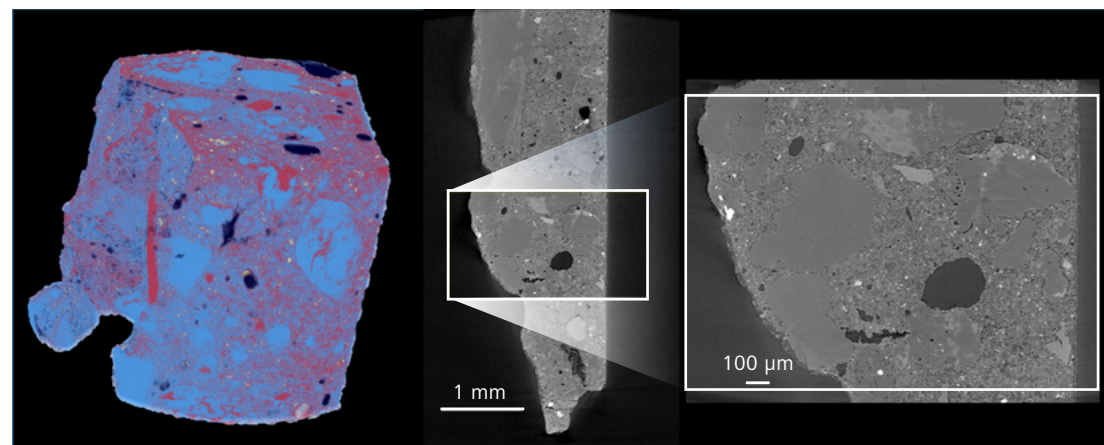
High resolution 3D imaging of a concrete sample: scout the sample and zoom to regions of interest for further analysis

Your Insight into the Technology Behind It

**ZEISS SmartShield – Protect Your Sample and Optimize Experiment Setup**

ZEISS SmartShield is a simple solution that protects your sample and your microscope, working within the Scout-and-Scan control system. SmartShield wraps a digital "envelope" around your sample with an easy click of a button. This automated solution allows you to confidently bring your sample even closer to the source and detector. With SmartShield, new and advanced users alike can experience an elegant sample setup workflow and efficient navigation of the CrystalCT system.

▶ Click here to view this video
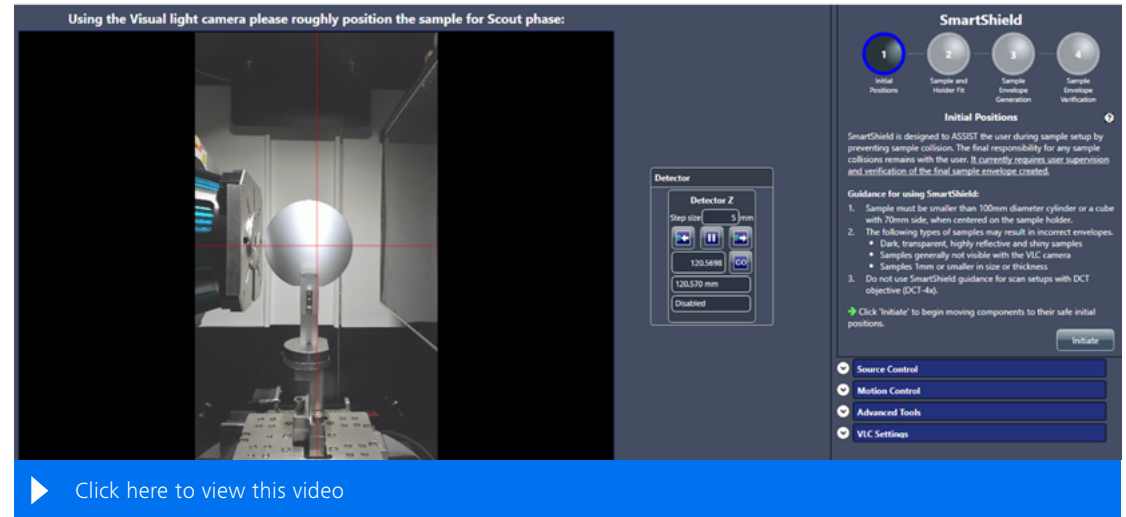
Watch this video and gain insights into the workflow guided by SmartShield.

What SmartShield Offers

- Fully integrated rapid envelope creation within Scout-and-Scan
- 3D awareness for sample and instrument safety
- Enhanced operator efficiency during setup
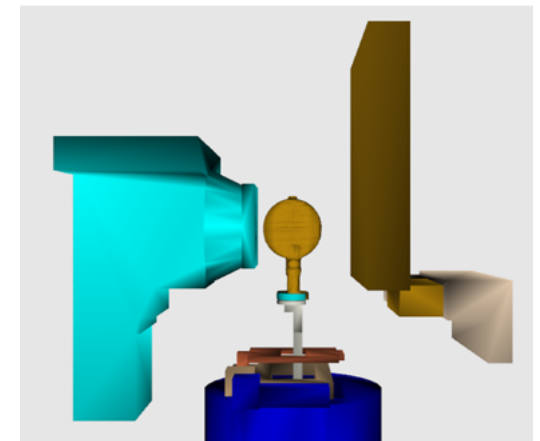
Digital safety envelope of the sample created by ZEISS SmartShield

Expand Your Possibilities

Increase Your Sample Handling Efficiency with ZEISS Autoloader

Maximize your instrument's utilization by minimizing user intervention with the optional robotic Autoloader available for all instruments in the ZEISS VersaXRM series of submicron 3D X-ray microscopes and microCT platforms. Reduce the frequency of user interaction and increase productivity by enabling multiple jobs to run.

Load up to 14 sample stations that can support up to 70 samples, queue, and allow to run all day, or off-shift. The software provides you with the flexibility to re-order, cancel, and stop the queue to insert a high priority sample at any time. Autoloader also enables a workflow solution for high volume repetitive scanning of like samples.
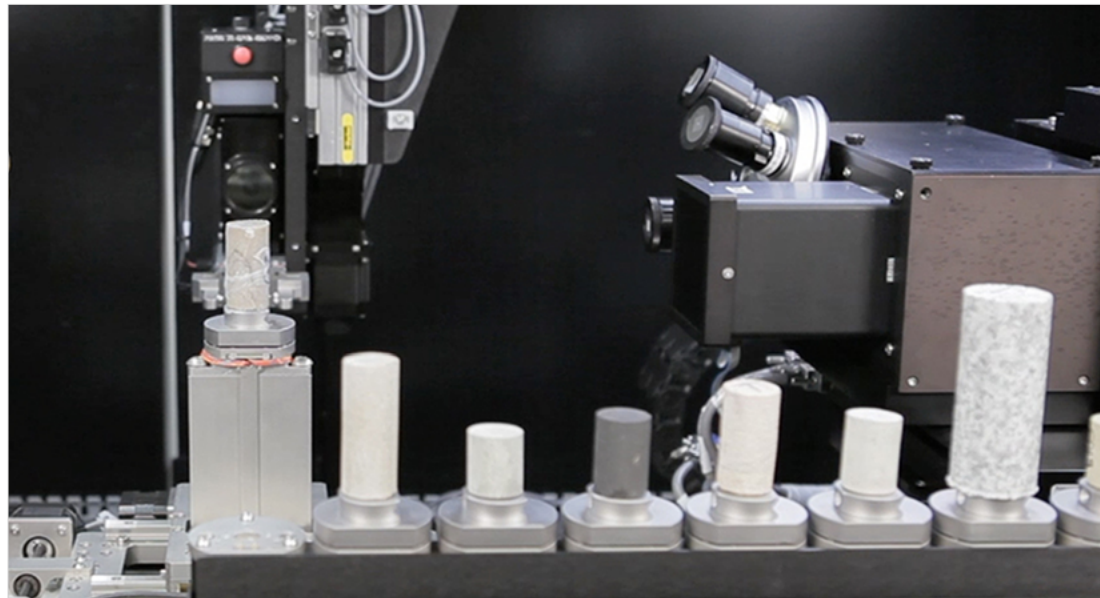
Autoloader option enables you to program up to 70 samples at a time to run sequentially.

Expand Your Possibilities

Add the ZEISS *In Situ* Interface Kit to Advance Discovery with 4D Imaging

Moving beyond the three dimensions of space, leverage the non-destructive nature of X-ray investigation to extend your studies into the dimension of time with 4D experiments. CrystalCT can accommodate a variety of *in situ* rigs, from high pressure flow cells to tension, compression and thermal stages, to user-customized designs. You can add the optional *In Situ* Interface Kit to your CrystalCT, which includes a mechanical integration kit, a robust cabling guide and other facilities (feed-throughs) along with recipe-based software that simplifies your control from within the Scout-and-Scan user interface. When your needs require pushing the resolution limits of your *in situ* experiments, convert your ZEISS Xradia CrystalCT to a ZEISS VersaXRM 730 X-ray microscope to leverage Resolution at a Distance (RaaD) with Performance technology for the maximum performance tomographic imaging of samples within *in situ* chambers or rigs.
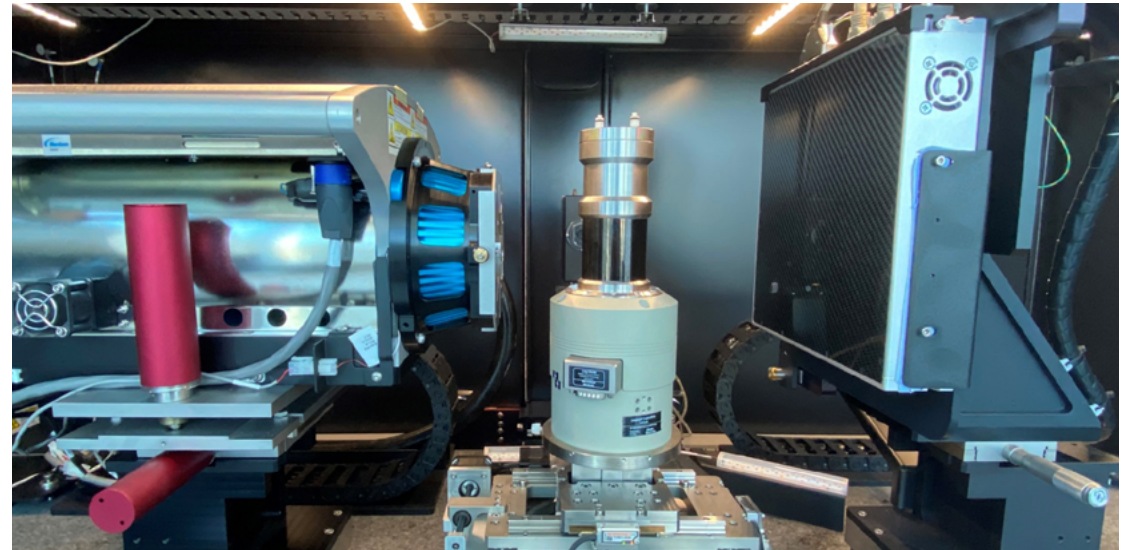
Making the industry's best in situ *solution even better:* in situ *kit tracking with Deben thermomechanical stage*

t_0 t_1 t_2

4D grain map of an Armco iron sample imaged at various annealing steps.
t0: initial state; t1: after annealing at 880 °C for 8 hrs; t2: after annealing at 880 °C for 16 hrs.
By imaging the sample at three temporal states, the abnormal grain growth of the top, pink-colored grain is captured.
*Courtesy of Prof. Burton R. Patterson, University of Florida, United States.*

Expand Your Possibilities

Correlative Microscopy

Drive correlative workflows starting with non-destructive X-ray imaging to seamlessly connect 3D X-ray, optical, and SEM analyses.

- Non-destructively scan your sample with ZEISS VersaXRM
- Drive your FIB-SEM analysis to the particular region of interest (ROI) guided by 3D tomography data
- Rapidly access deeply buried ROI with femtosecond laser milling
- Carry out TEM or atom probe sample preparation of deeply buried structures of interest
- Conduct FIB-SEM tomography with industry-leading 3D resolution
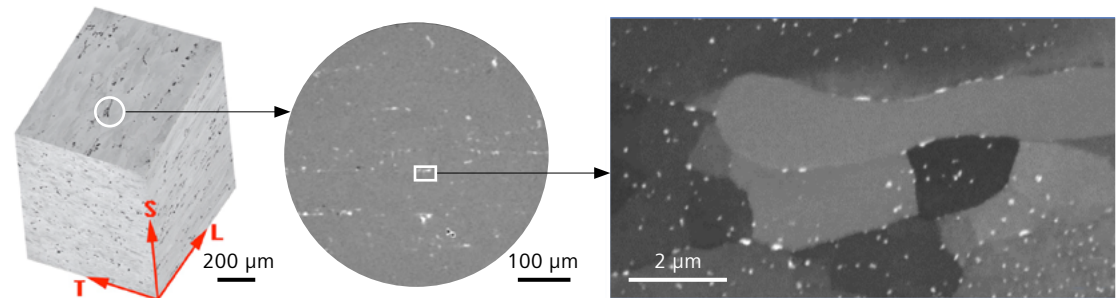
Multiscale analysis of an aluminum 7075 alloy. ZEISS Xradia Versa scan of the sample (left). XRM interior tomography of a 0.75 mm field of view with 750 nm voxel size (center). FIB-SEM tomography slice showing a silicon inclusion (right). In collaboration with S. Singh and N. Chawla, Arizona State University.

Prepare Site-specific Samples for Your High-resolution XRM Scans with ZEISS Crossbeam Laser

- Rapidly prepare site-specific small diameter pillars for microCT analysis on extremely dense samples with ablation rates of up to 15 mio. $\mu m^3/s$ (silicon)
- Reduce sample damage and heat affected zones to a minimum thanks to ultrashort femtosecond laser pulses
- Enjoy site-specific laser preparation with down to 2 µm targeting accuracy
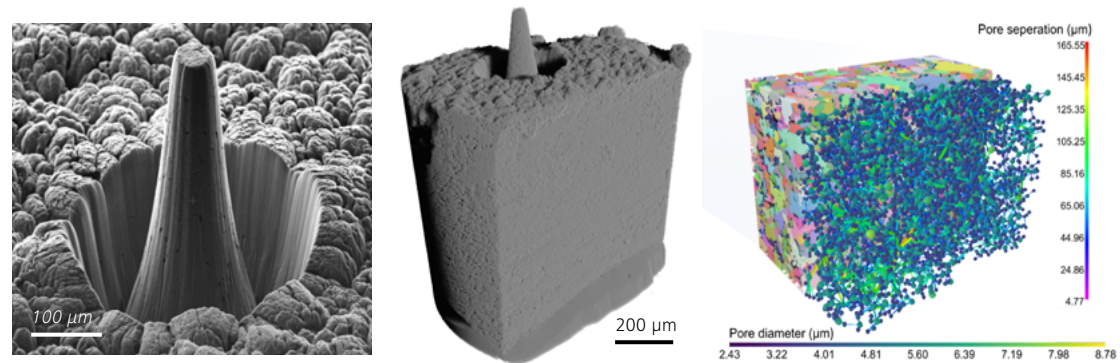
Pillar preparation of nuclear graphite with ZEISS Crossbeam laser (left); ZEISS Xradia Versa overview scan of the complete sample (center); 3D reconstructed and segmented data obtained with ZEISS Xradia Ultra XRM showing pore diameter and distances between pores (right).

Your Insight into the Software Behind It

ZEISS Advanced Reconstruction Toolbox

ZEISS Advanced Reconstruction Toolbox (ART) is an innovative platform through which you can continuously access state-of-the-art reconstruction technologies from ZEISS to enrich your research and increase the return on investment of your 3D XRM.

These unique offerings leverage AI and a deep understanding at ZEISS of both X-ray physics and customer applications to solve some of the hardest imaging challenges in new and innovative ways. These optional modules are workstation-based solutions that provide easy access and usability.

ZEISS DeepRecon Pro

DeepRecon Pro is an innovative AI-based technology bringing superior throughput and image quality benefits across a wide range of applications. DeepRecon Pro is applicable to both unique samples as well as semi-repetitive and repetitive workflows. Customers can now self-train new machine learning network models on-site with an extremely easy-to-use interface. The one-click workflow of DeepRecon Pro eliminates the need for a machine learning expert and can be seamlessly operated by even a novice user.

ZEISS DeepScout

ZEISS DeepScout uses high-resolution 3D X-ray microscopy datasets as training data for lower resolution, larger field of view datasets and upscales thelarger volume data using a neural network model.DeepScout, developed through continue algorithmic innovation enabled by the unique AI infrastructure from ZEISS, employs the unique Scout-and-Zoom capability to acquire richer information at higher resolution, including interior tomographies for large samples. Now you can take your large overview scan, feed it through the DeepScout reconstruction algorithm, and get resolution that approaches the resolution of a zoom scan, but over a much larger field of view. At its core, DeepScout relies on the ability to generate multiscale, spatially registered datasets and uses that ability to train neural networks to improve the reconstruction.

New capabilities, fueled by deep learning, mitigate the traditional trade-off between field of view and resolution.

ZEISS DeepRecon Pro and ZEISS DeepScout are offered as part of the AI Supercharger package for the Advanced Reconstruction Toolbox.

	FDK Standard Analytical Reconstruction	OptiRecon Iterative Reconstruction	DeepRecon Pro AI (Deep-Learning) based Reconstruction	DeepScout
Throughput	1×	up to 4×	up to 10×	up to 100×
Image Quality*	Standard	Better	Best	Unprecedented over LVOV, FVOV**
Ease-of-use	Minimal	Requires parameter optimization	One-click setup	Simple setup Familiar Scout-and-Zoom, user-friendly ZEN navx

* Image quality refers to the contrast-to-noise ratio and the relative performance of reconstruction technologies is shown.
** Large volume of view and full volume of view.

Your Insight into the Software Behind It

ZEISS PhaseEvolve

ZEISS PhaseEvolve is a patented* post-processing reconstruction algorithm that enhances the image contrast by revealing material contrast uniquely inherent to X-ray microscopy, which can often be obscured by phase effects in low-medium density samples or high-resolution datasets. Perform more accurate quantitative analysis with improved contrast and segmentation of your results.

ZEISS Materials Aware Reconstruction Solution (MARS)

ZEISS MARS is a reconstruction algorithm that is aware of the constituents within a reconstruction. A challenge in X-ray reconstruction in a lab setting is that imaging with a polychromatic source creates different X-ray energies to generate a phenomenon called beam hardening.

This effect is particularly challenging when your material is very dense and embedded in a relatively less dense material. MARS tells the reconstruction system how to compensate for the effect of extreme beam hardening in the regions between very dense objects.

This is important in applications like biomaterials, where you might be looking at implants next to bone or tissue. Or electronics where extremely dense solder balls appear next to other less dense materials on a printed circuit board, generating strong artifacts. MARS reconstructs your images to compensate for these effects.

ZEISS PhaseEvolve and MARS form the Artifact Reduction package of ART.

ZEISS OptiRecon

ZEISS OptiRecon is a fast and efficient algorithm-based technology that delivers iterative reconstruction from your desktop, allowing you to achieve up to 4× faster scan times or enhanced image quality with equivalent throughput.

OptiRecon is an economical solution offering superior interior tomography or throughput on a broad class of samples.

ZEISS OptiRecon bonds with ZEISS DeepRecon to create the Recon package of ART.

*US Patent 11645792B2

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Your Insight into the Software Behind It

ZEISS DeepRecon Pro – How It Works in Materials Science: Concrete
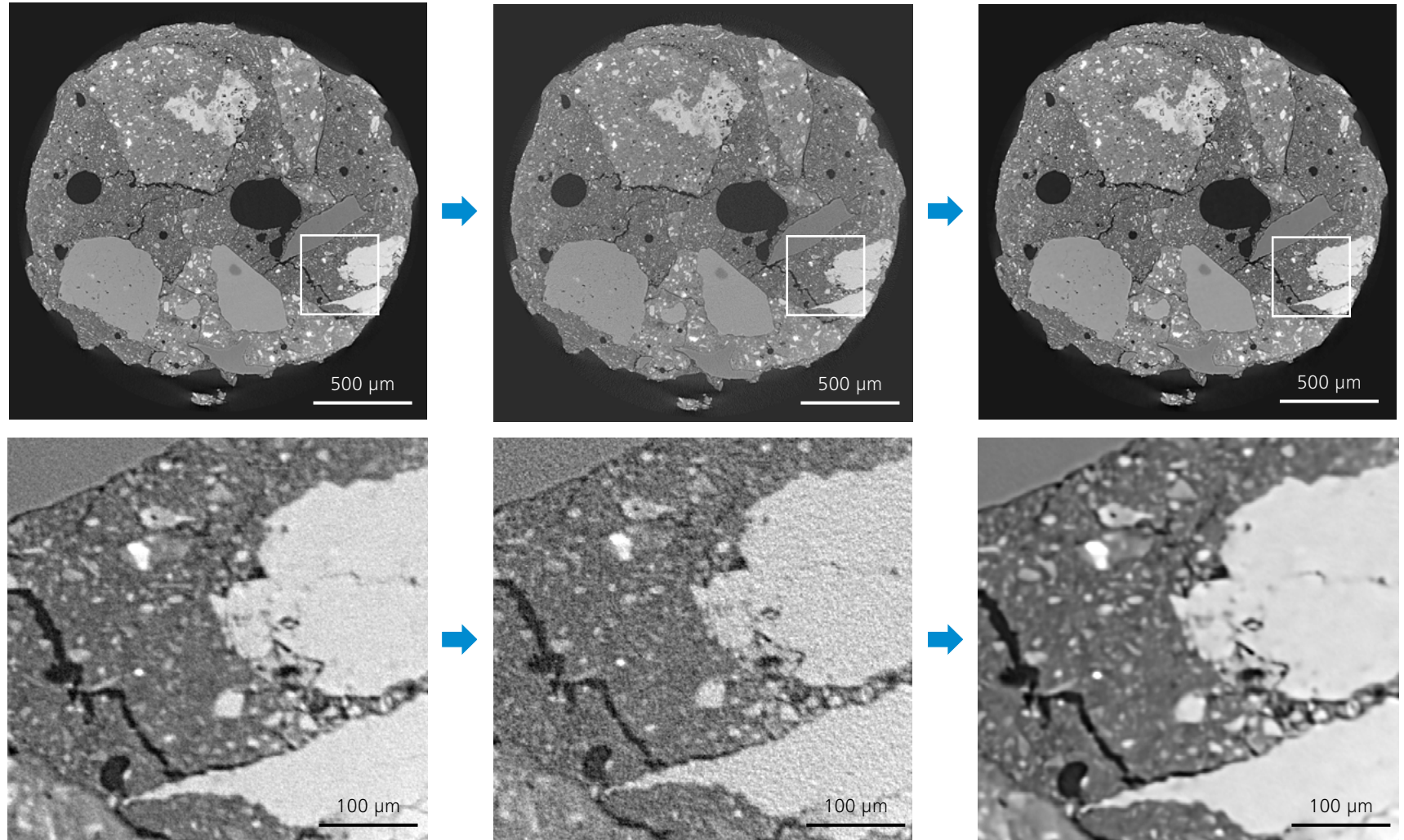
Standard Reconstruction (FDK): Scan time 7 hours

Standard Reconstruction (FDK): Scan time 1.4 hours

DeepRecon Pro: Scan timw 1.4 hours

Image concrete samples 5x faster with DeepRecon Pro while retaining the image quality needed to quantify phase distributions and the extent of crack networks.

Your Insight into the Software Behind It

ZEISS DeepRecon Pro – How It Works in Electronics: Printed Circuit Boards (PCB)
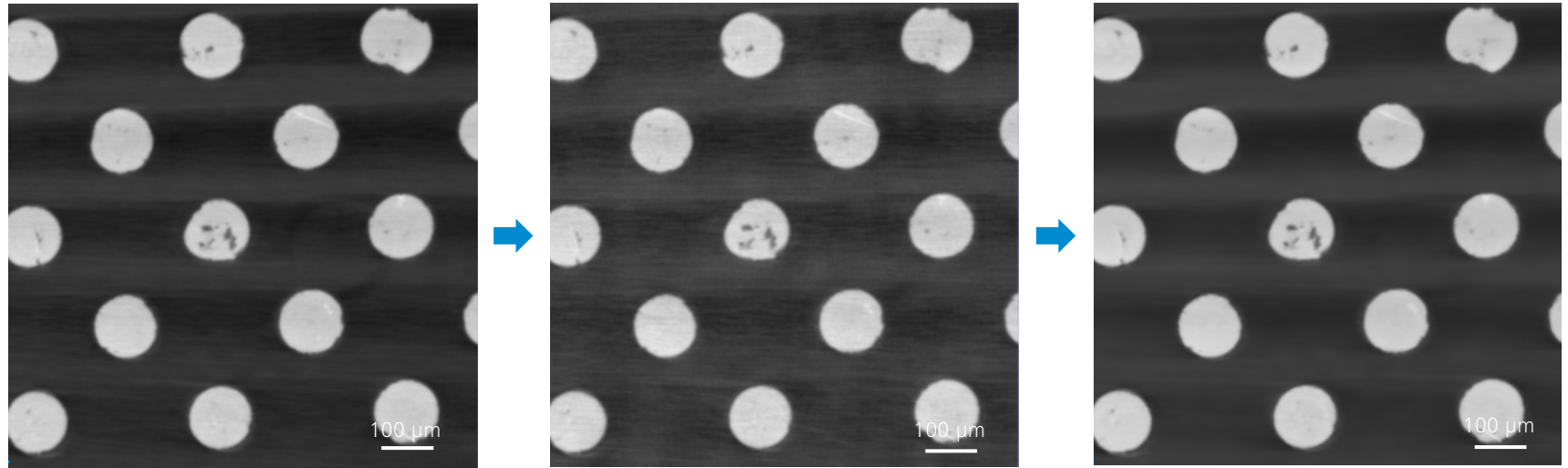
Standard Reconstruction (FDK): Scan time 70 minutes

Standard Reconstruction (FDK): Scan time 18 minutes

DeepRecon Pro: Scan time 18 minutes

Perform failure analysis tasks in electronics up to 4x faster with DeepRecon Pro while still retaining the image quality needed to observe fine cracks in detail.

Your Insight into the Software Behind It
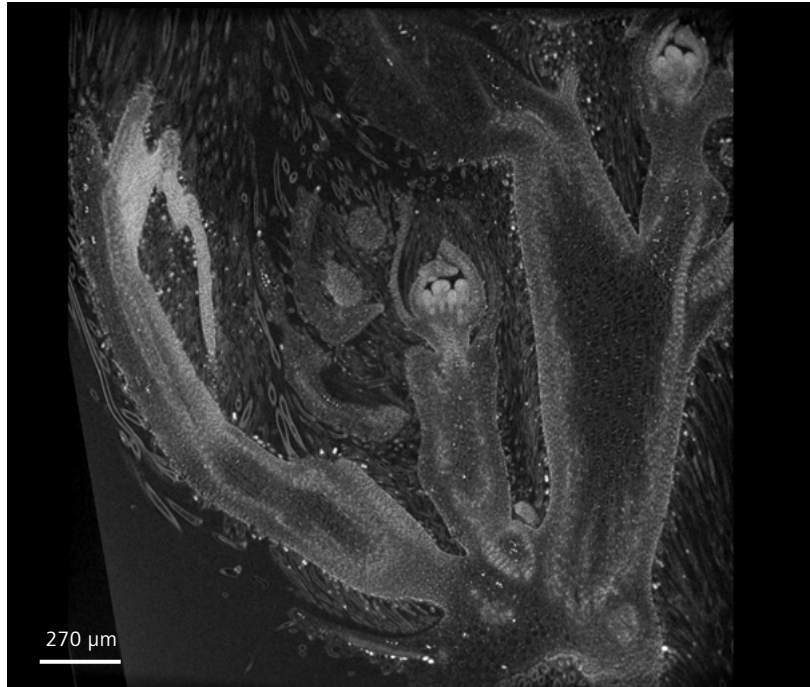
ZEISS DeepScout

Soybean flower: Without ZEISS DeepScout
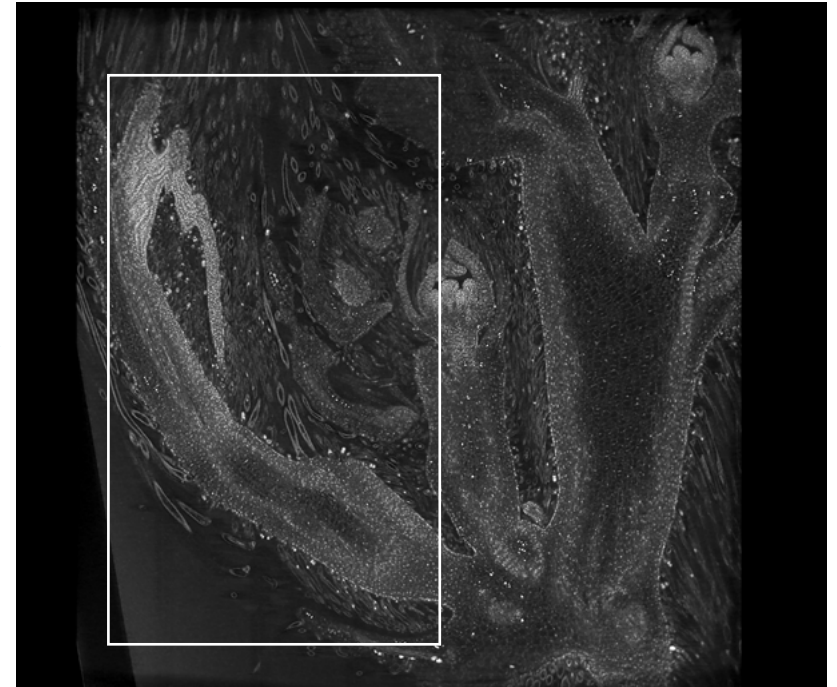
*Significantly more cellular information generated in flower sample using ZEISS DeepScout.
Sample courtesy of Keith Duncan, Donald Danforth Plant Science Center*

Your Insight into the Software Behind It
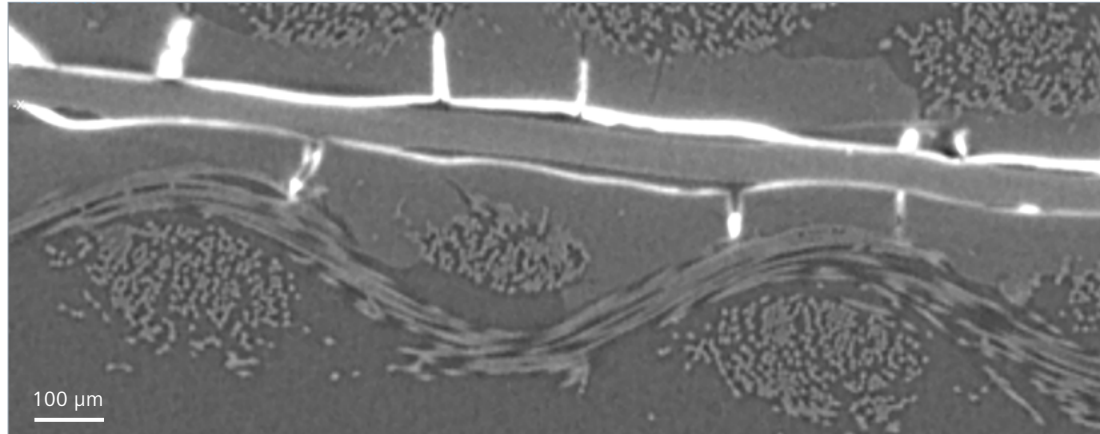
ZEISS DeepScout

Polymer electrolyte fuel cell (PEFC) membrane electrode assembly imaged without ZEISS DeepScout.
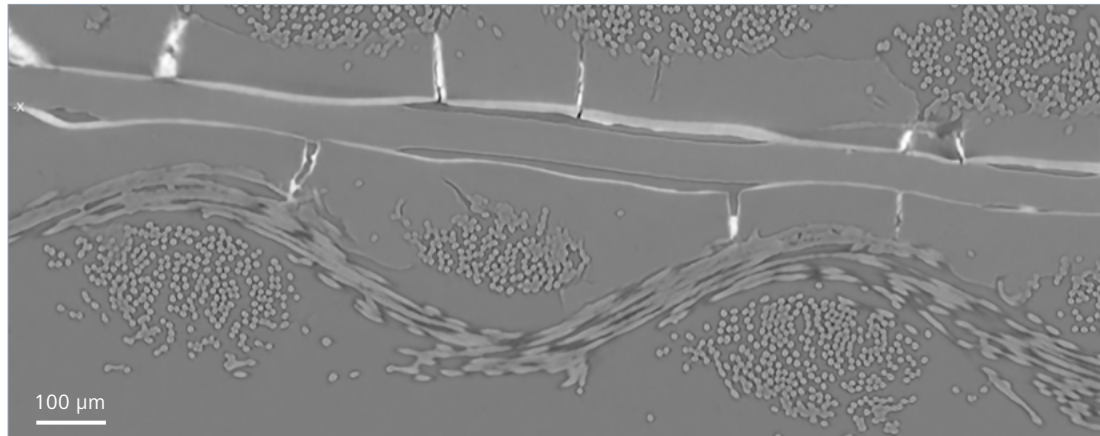
ZEISS DeepScout: Acquire high resolution data across entire sample image for a clear view of critical microstructural features that influence water formation and fuel cell performance.

Your Insight into the Software Behind It
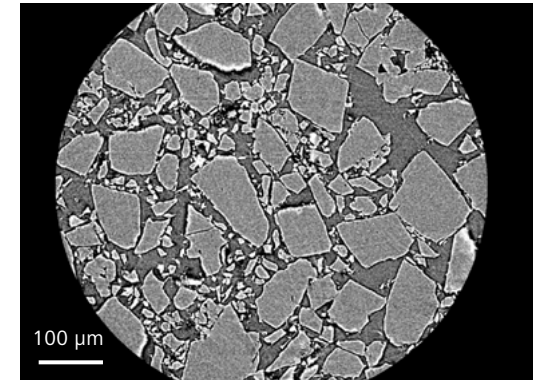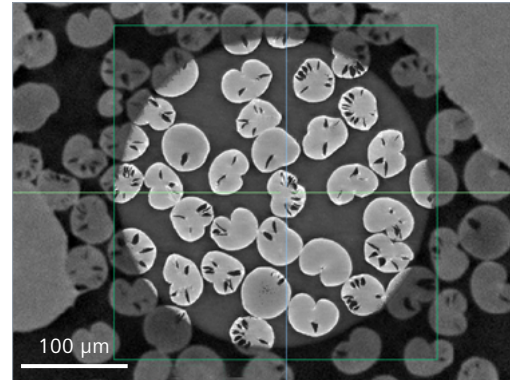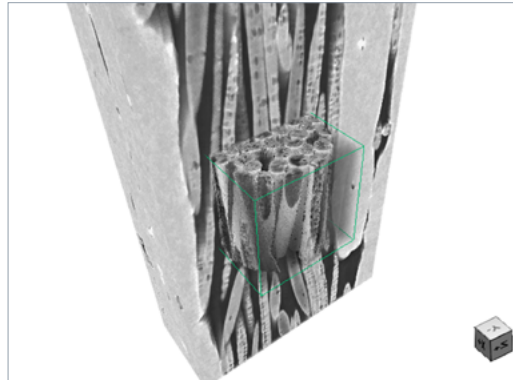
ZEISS PhaseEvolve

Standard reconstruction
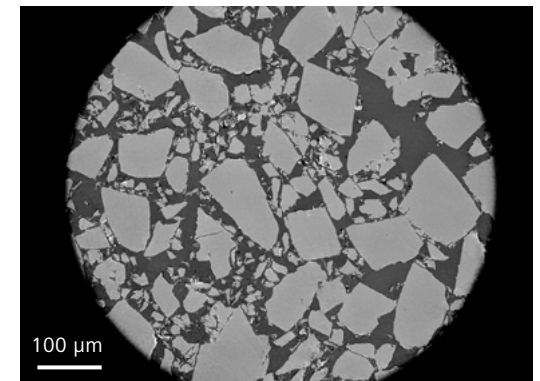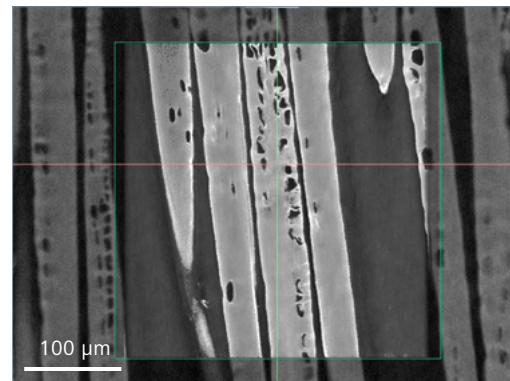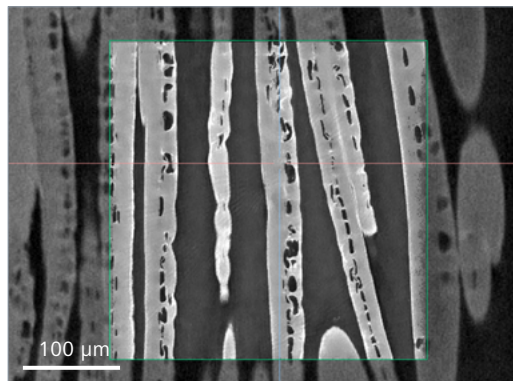
Rayon fibers were imaged at 1.5 µm/voxel resolution and processed using ZEISS PhaseEvolve revealing the large distribution of radial porosity along the length of the fibers. Sample courtesy Dr. Sherry Mayo & Dr. David Fox, CSIRO, Australia.

ZEISS PhaseEvolve applied to a pharmaceutical powder sample. High resolution or low kV imaging can result in inherent material contrast being obscured by phase contrast artifacts. PhaseEvolve effectively removes phase fringes to enhance image contrast and improve segmentation results. Sample courtesy of Dr. Parmesh Gajjar, TEVA Pharmaceuticals, UK.

Your Insight into the Software Behind It

ZEISS Material Aware Reconstruction Solution (MARS) for Reducing Beam Hardening

1 mm

Without MARS

100 µm

Without MARS

1 µm

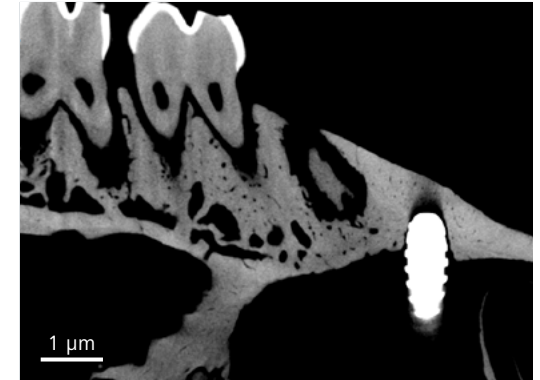*Without MARS*

1 mm
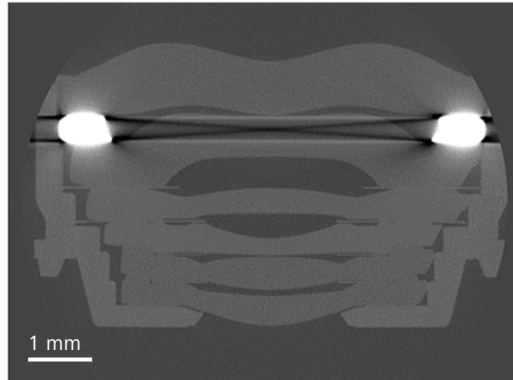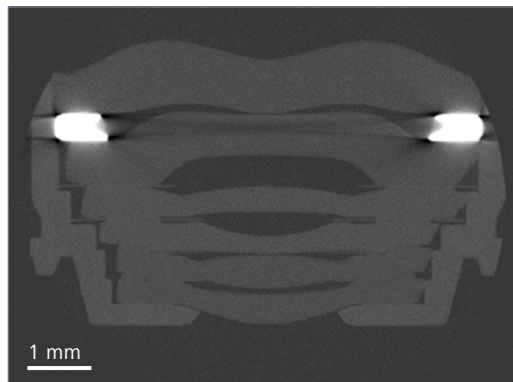
Camera module image using MARS.

100 µm
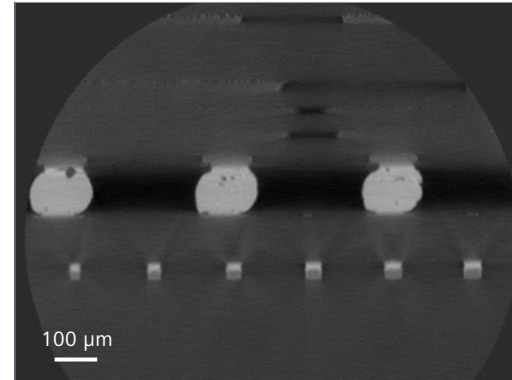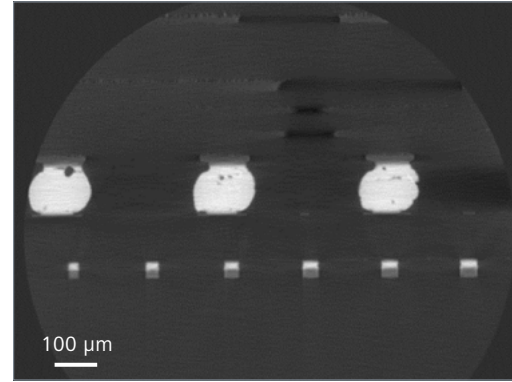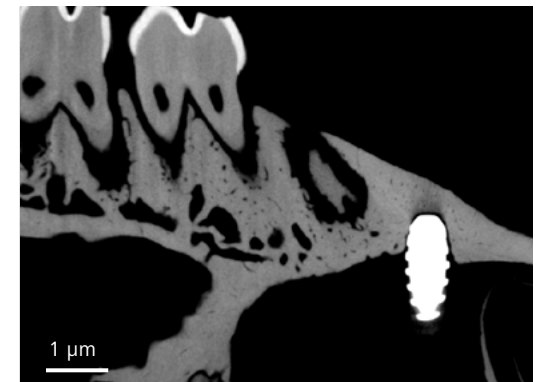
Semiconductor package image using MARS.

1 µm

Biomedical implant image using MARS.

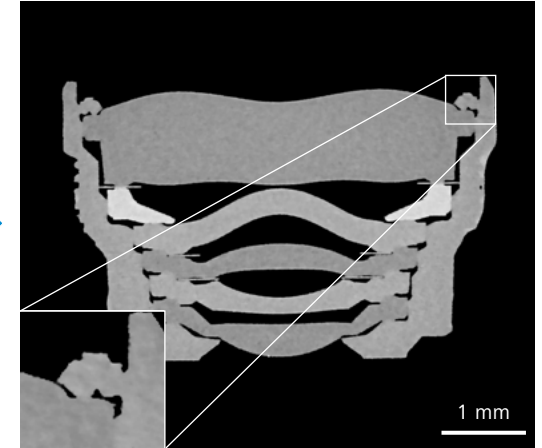# Your Insight into the Software Behind It
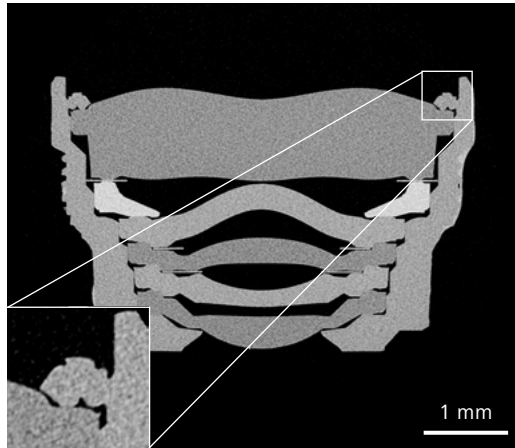
ZEISS OptiRecon

Standard reconstruction: Scan time 90 minutes (1200 projections)
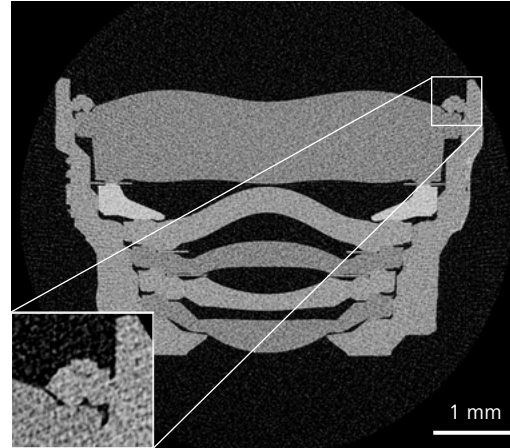
Standard reconstruction: Scan time 22 minutes (300 projections)

OptiRecon: Scan time 22 minutes (300 projections)

Observe the performance of ZEISS OptiRecon in a workflow performed on an electronics sample. Analyze integration issues in a smart phone camera lens, now 4× faster using OptiRecon.

Your Insight into the Software Behind It

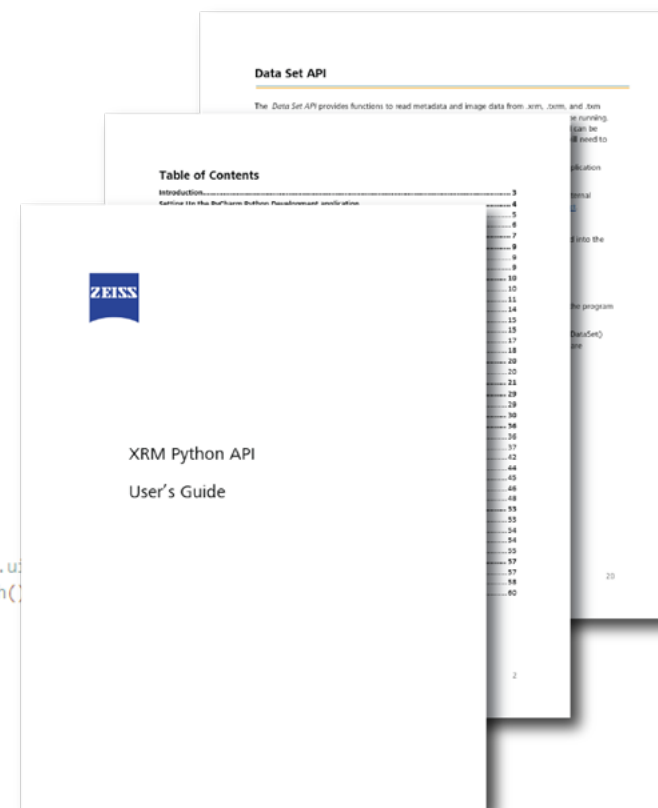**Python API for Your Custom Use Case**

The ZEISS XRM Python API provides additional capability to interact with ZEISS Versa X-ray microscopes and microCT platforms. There are three different APIs that can be used in Python scripts to interact with the microscope for different use cases.

- The Basic API module provides methods to interact with the microscope, such as moving motors and changing objectives.
- The Recipe API module contains functions that can modify and run recipes to acquire data.
- The Basic Data Set API module can be used to read the data generated by an acquisition or reconstruction.

With the seamless integration of Python API into the control system, you can expand instrument control capabilities and enhance the productivity and quality of your research.

```python
# main_txm.py
1    from XradiaPy import Data
2    import numpy as np
3    from PIL import Image
4    import os
5    import json
6    import csv
7
8    save_dir = '.\Images_txm'
9    data_dir = r"\\foo\\bar\\dir"
10   group_name_id = 6
11   tomo_name_id = 7
12
13
14   def choose_image(myDataset):
15
16       num_slices = myDataset.GetProjections()
17
18       data = np.array(myDataset.GetImageData(num_slices // 2), dtype=np.ui
19       data = np.reshape(data, (myDataset.GetHeight(), myDataset.GetWidth(
20       data = np.uint8(data / 256)
21
22       im = Image.fromarray(data)
23       #im.show()
24
25       return im
26
27
```

Data Set API

The *Data Set API* provides functions to read metadata and image data from .xrm, .txrm, and .txm

Table of Contents

XRM Python API

User's Guide

Your Insight into the Software Behind It

Flexible, End-to-End Image Analysis Pipelines

ZEISS arivis Pro empowers you to automate image analysis and visualization pipelines. Leverage traditional methods or AI models effortlessly to create pipelines for any image size, dimension, or modality without the need to code.

2 mm
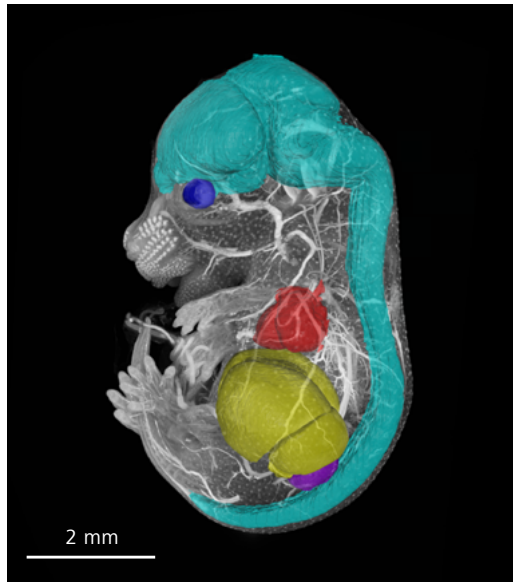
*Segmentation and visualization of a complete mouse embryo volume performed with ZEISS arivis software.*

The software supports and handles more than 30 commercial file formats. Efficiently process large files with ease. Pre-configured pipelines and standard assays are available for both simple and demanding analysis tasks. Or you can customize pipelines for your specific goals.

It takes just one click to repeat your analysis for consistent, quantitative results. Boost productivity and ensure reproducible results.

ZEN AI Toolkit including Intellesis

Machine learning can exponentially increase the throughput of image analysis and reduce the risk of human error. This toolkit contains solutions for image denoising, image segmentation, and object classification.

- Improve every step of the image analysis workflow
- Enable even new users to quickly gain proficiency
- Import third-party machine learning models
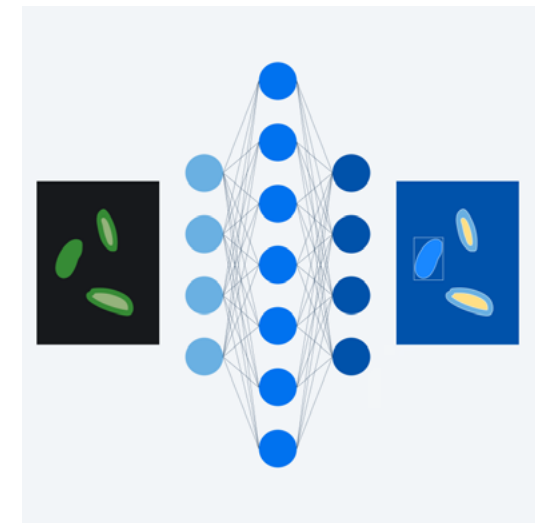
Your Insight into the Software Behind It

3D World ZEISS Edition – Your Visual Pathway to Quantitative Answers

3D World ZEISS Edition from Dragonfly is advanced 3D visualization and analysis software. It is offered exclusively by ZEISS for processing XRM, SEM, and FIB-SEM data. Combining advanced image processing algorithms and state-of-the-art volume rendering, 3D World enables high definition exploration and powerful quantitative analysis of your data. 3D World is distinguished by its ease of use, best-in-class image segmentation toolkit, and endless extensibility. Import your multi-scale, multi-microscope image studies, and you'll discover that 3D World is the most advanced correlative imaging platform available. Integrated with a suite of image processing tools for 2D and 3D image registration, resampling, and more, 3D World's cutting-edge image filters will make imaging artifacts disappear.

Your visual results will let your images speak for themselves. Capture and share insightful screenshots—as still images or 2D animations—or turn to 3D World's 3D Movie Maker for effortless high-impact 3D animations.

3D World's integrated machine learning engine solves segmentation of even the most challenging samples, while interactive painting and contouring tools make curation and fine edits a breeze. Record your workflows and replay them as needed or in batch. Even write custom Python code to drive the software to highly-customized and robust solutions.

Simple to use, but delivering the quantitative answers and visual impressions you demand, 3D World will accelerate your 2D/3D data productivity.

Key User Benefits
- Ease of use
- Image segmentation
- Multi-modal (XRM, SEM, FIB-SEM)
- Scripting robust and batching workflows
- Multi-scale
- Quantitative Analysis
- Movies
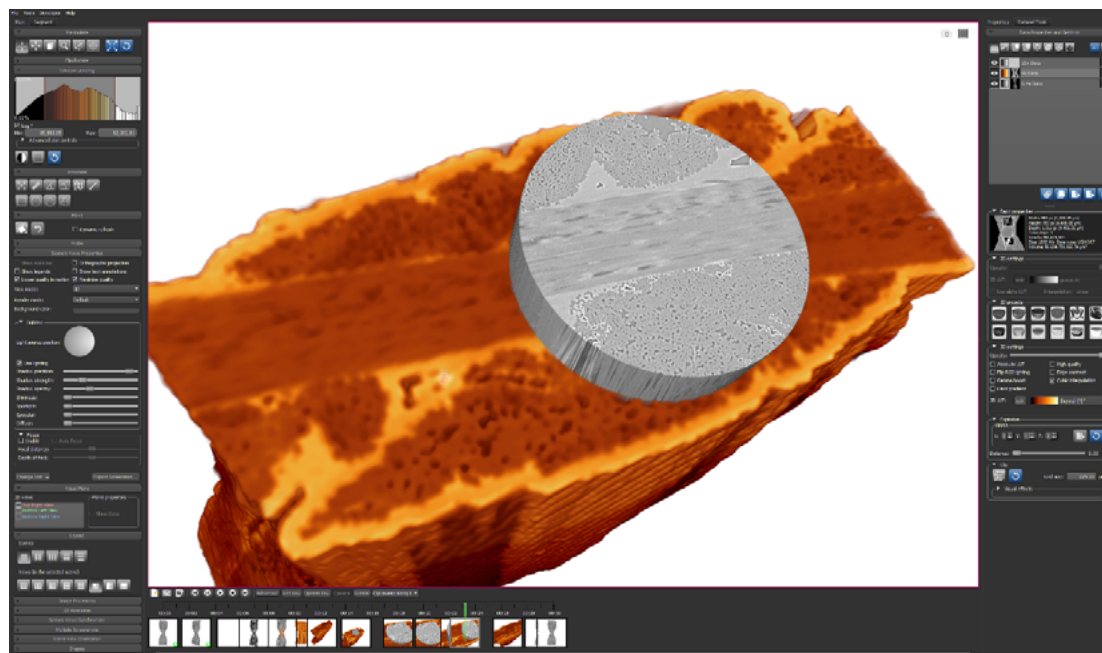
Tailor tools that are optimal to your workflow: choose plug-ins that allow you to control registration, map differences, and customize appearance. Ceramic matrix composite, imaged on a ZEISS VersaXRM microscope. Sample courtesy of Dr. David Marshall, University of Colorado, US.

Precisely Tailored to Your Applications

|	Task	ZEISS Xradia CrystalCT offers
Materials Research	Characterize crystallographic grain orientation and microstructural features including pores, cracks, voids, and other subsurface defects	Complementary information from high resolution absorption contrast tomography and non-destructive 3D grain mapping delivering size, shape, orientation and grain boundary information
	Analyze heterogeneity in composites and other multiphase functional materials	Non-destructive insights into interior microstructures and overlaid grain maps not visible by surface imaging methods such as optical or scanning electron microscopy
	Visualize and quantify microstructural change with 4D imaging	
	Use non-destructive 3D datasets to identify regions of interest for further investigation	
	Characterize particle size, shape, orientation and dispersion in 3D space within the pharmaceutical application space.	Ability to segment and analyze data to obtain quantitative, 3D descriptions of structures and particles
		4D imaging through ex situ or in situ experiments to see how materials evolve, e.g., through mechanical load or corrosion
Life Sciences	Perform virtual histology on a range of sample sizes from clusters of cells to whole animals	Image either stained or unstained hard and soft tissues and biological microstructure with high contrast
	Expand your views in developmental biology with high resolution, high contrast images of cellular structure	
	Image large intact samples such as brains, large bones, and whole animals	Quick and nondestructive verification of sample staining and location of features for subsequent imaging using 3D electron microscopy
	Explore 3D organization of plants, from seeds, root networks in soil to stem and leaf structure	
	Analyze 3D structure of biomaterials and implants	
Raw Materials	Characterize crystallographic orientation and texture of minerals, metals, and alloys	Understand grain size and phase evolution in 3D for insight into alloy performance and its dependence on thermal and mechanical processes
	Research the effect of processing variables to improve materials performance	
	Characterize heterogeneity at core plug scale and quantify pore structures	Export real 3D structures for physics simulations: predict materials properties (mechanical, thermal, etc.) or digital rock simulations using non-destructive 3D tomography data
	Perform failure analysis – identify the cause of failure and identify defects/inclusions for root cause identification	Imaging, characterization, and modeling of rock cores (up to 4") with high throughput
	Advance mining processes: analyze tailings to maximize mining efforts; conduct thermodynamic leaching studies; perform QA/QC of mining products such as iron ore pellets	High contrast 3D imaging for in situ flow studies or 3D mineralogy
Manufacturing and Assembly	Evaluate internal surface roughness of additive manufactured parts	Accommodate a range of sample sizes including large objects in their full 3D context, complementing with 3D grain maps in specific applications
	Image components and devices for inspection or failure analysis	Perform crystallography-based print quality assessment in 3D printed metal parts
	Optimize process development for electronics, automotive, and medical device industries	High throughput scanning of intact devices with fast time to results
		Complement or replace physical cross sectioning and eliminate the need to sacrifice your sample

CrystalCT at Work

3D grain map of an Al-4wt.%Cu sample with dimension of (diameter) 1.1 mm and (height) 5.1 mm. Sample scanned using helical phyllotaxis scheme.

3D grain map of a ß-Ti sample with dimension of (side length)1.0 mm and (height) 3.2 mm. Sample scanned using helical phyllotaxis scheme.
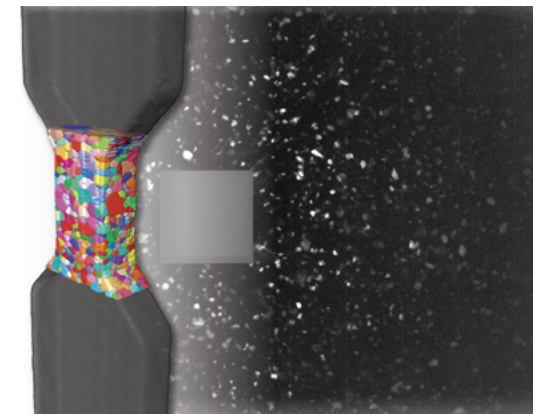

3D grain map of an armco iron sample with dimension of (diameter) 1.0 mm and (height) 3 mm. Sample scanned using helical phyllotaxis raster scheme. Sample courtesy of Prof. Burton R. Patterson, University of Florida, USA.
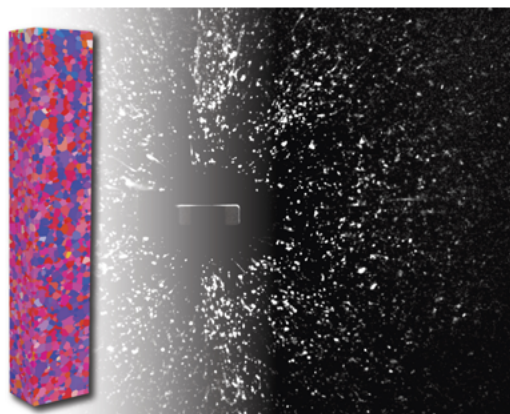
3D grain map of a low carbon steel sample with dimension of (side length) 0.4 mm and (height) 2.0 mm. Sample scanned using helical phyllotaxis scheme. Sample courtesy of Prof. Masao Kimura, KEK, Japan.

3D grain map of an austenitic stainless-steel sample with dimension of (side length) 0.66mm and (height) 4.4 mm. Sample scanned using helical phyllotaxis raster scheme. Sample courtesy of Prof. Grethe Wither, Technical University of Denmark.

3D grain map of an Al-4wt%Cu sample with gauge section dimension of (length) 1.25 mm, (width) 1.0 mm and (thickness) 0.5 mm. Sample scanned using helical phyllotaxis HART. Sample courtesy of Prof. Masakazu Kobayashi, Toyohashi University of Technology, Japan.
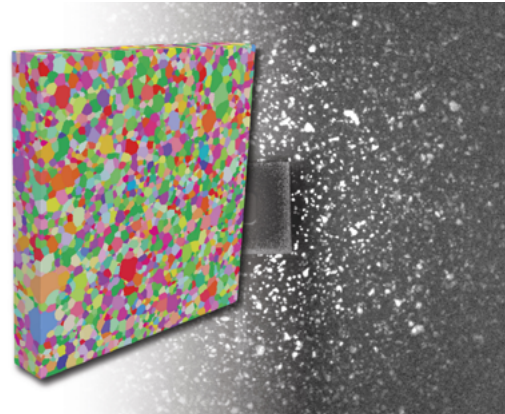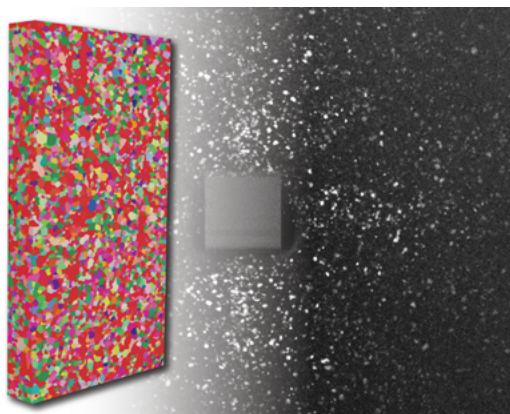
CrystalCT at Work
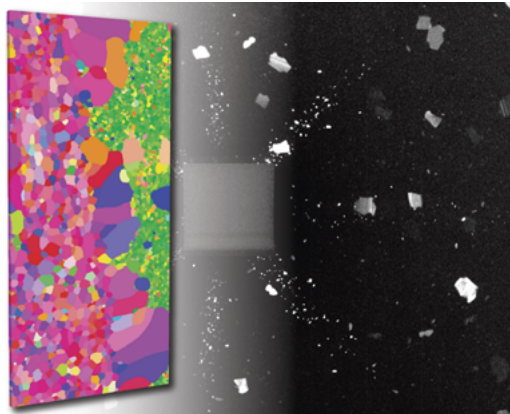
3D grain map of an ultra thin oriented electrical steel sample with dimension of (RD) 4 mm, (TD) 2 mm and (ND) 0.08 mm. Sample scanned using helical phyllotaxis HART scheme. Sample courtesy of Dr. Li Meng, China Iron and Steel Research Institute.
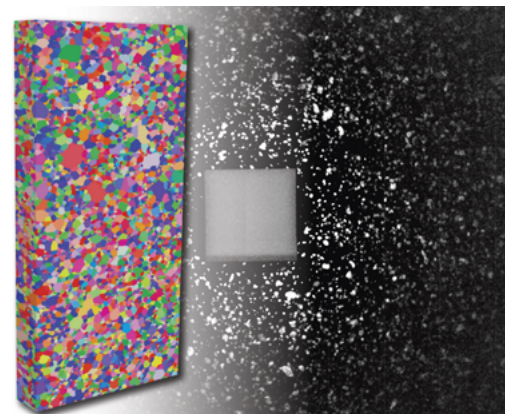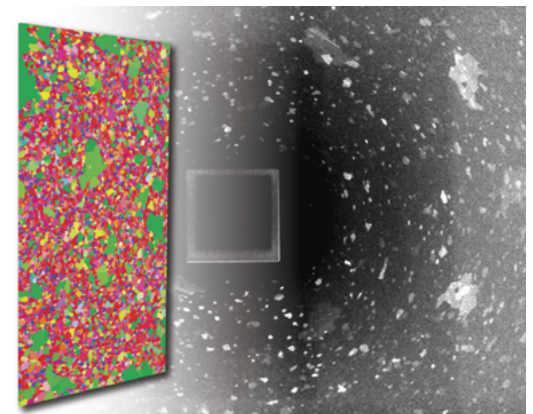

3D grain map of a 3% Si non-oriented electrical steel sample with dimension of (RD) 3 mm, (TD) 3 mm and (ND) 0.5 mm. Sample scanned using helical phyllotaxis HART. Sample courtesy of Dr. Ivan Petryshynets, Slovak Academy of Science, Slovakia.

3D grain map of an ultra thin oriented electrical steel sample with dimension of (RD) 4 mm, (TD) 2 mm and (ND) 0.08 mm. Sample scanned using helical phyllotaxis HART. Sample courtesy of Dr. Li Meng, China Iron and Steel Research Institute, China

3D grain map of an AA5657 sample with dimension of (RD) 4 mm, (TD) 2 mm and (ND) 0.5 mm. Sample scanned using helical phyllotaxis HART scheme. Sample courtesy of Dr. Robert Sanders, Novelis, USA

3D grain map of a Sb containing non-oriented electrical steel sample with dimension of (RD) 4.2 mm, (TD) 2.2 mm and (ND) 0.5 mm. Sample scanned using helical phyllotaxis HART scheme. Sample courtesy of Prof. Liuwen Chang, National Sun Yat-sen University, China
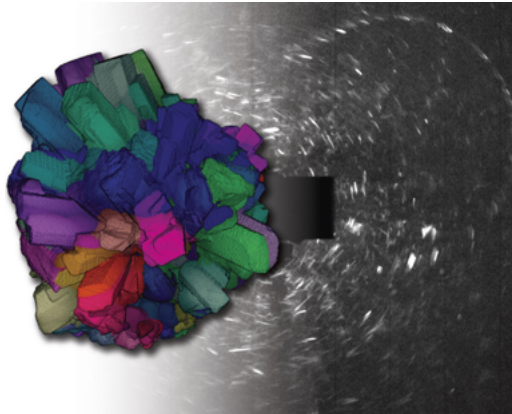

3D grain map of an oriented electrical steel sample with dimension of (RD) 40 mm, (TD) 20 mm and (ND) 0.2 mm. Sample scanned using helical phyllotaxis HART scheme. Sample courtesy of Prof Ping Yang, University of Science and Technology Beijing, China
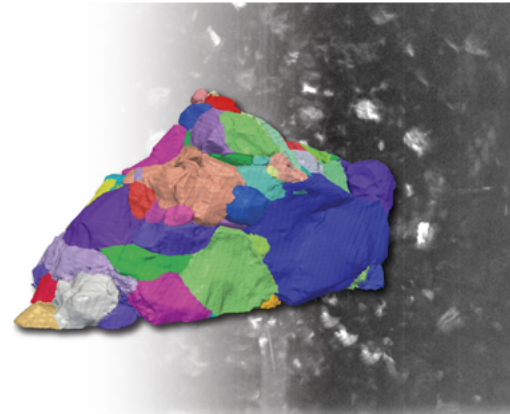
CrystalCT at Work

3D grain map of an aragonite sample with dimension of about 15 mm diameter. Sample scanned using helical phyllotaxis scheme.


3D grain map of a peridotite sample with height of about 3 mm. Sample scanned using helical phyllotaxis raster scheme.


3D grain map of stacked sapphire spheres with individual sphere diameter of 0.2 mm. Sample scanned using helical phyllotaxis scheme.
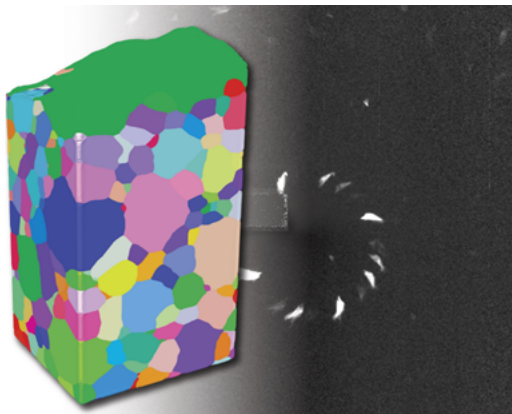
3D grain map of a SrTiO3 sample with side length of 0.8 mm. Sample scanned using helical phyllotaxis scheme. Sample courtesy of Prof. Amanda Krause, University of Florida, USA
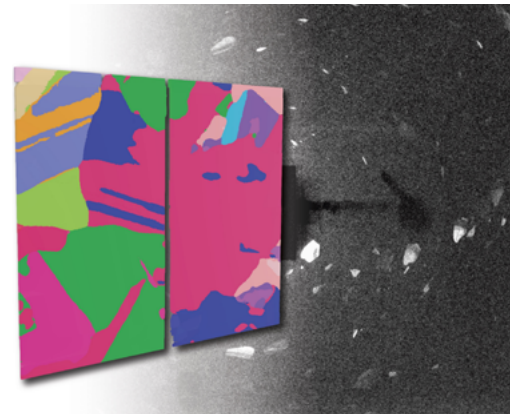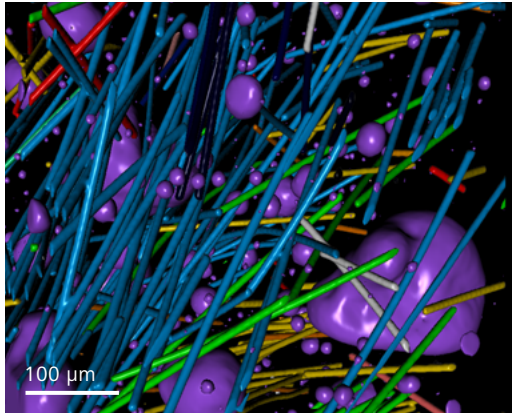

3D grain map of poly silicon materials from a solar panel with height of 30 mm. Sample scanned using helical phyllotaxis HART scheme.
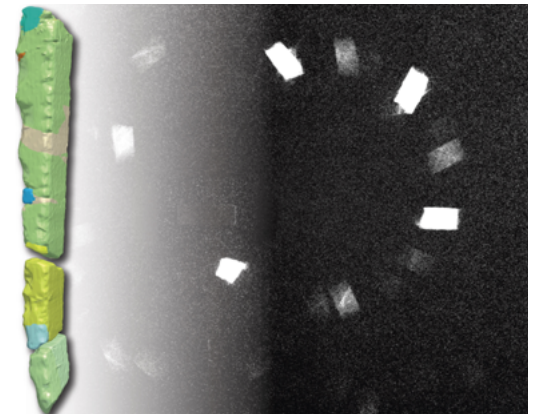

3D grain map of poly-silicon, sample height of 5.3 mm. Sample scanned using helical phyllotaxis scheme. Sample courtesy of Prof. Ashwin Shahani, University of Michigan, USA.
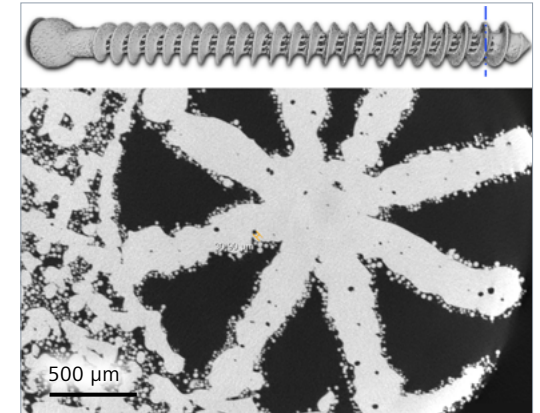
CrystalCT at Work

Quantitative volumetric analysis of a steel reinforced concrete specimen. Voids are rendered in purple. The rendering corresponds to a smaller volume imaged out of a large 350 x 100 x 50 mm concrete dogbone test specimen.
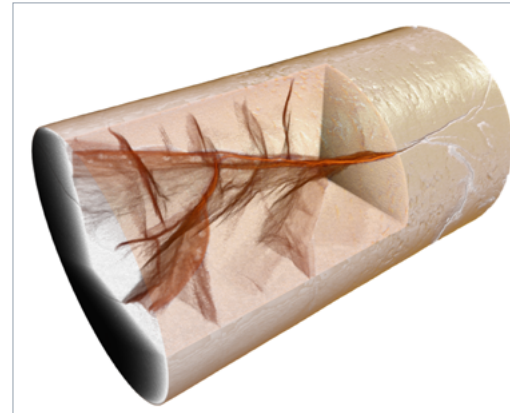

3D rendering of crack networks formed due to corrosion fatigue in the shank section of a load bearing steel bolt.


Volumetric rendering of a 3D printed Ti-6Al-4V screw (top). Blue dotted line indicates cross-sectional view from a region of interest scan (bottom), reveals local microstructure and defects such as voids and unsintered powder particles.
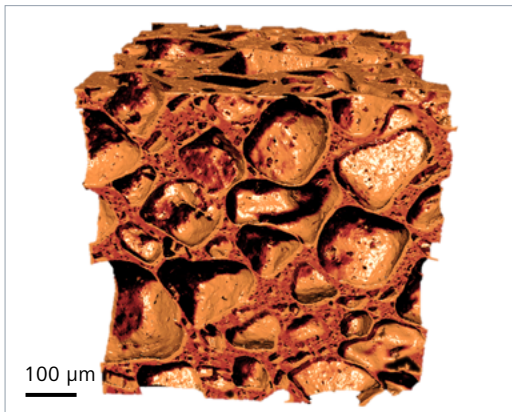
Microstructural view of a porous ceramic specimen with a closed pore cellular structure. 3D scans enable quantitative assessment of wall thickness and net porosity.
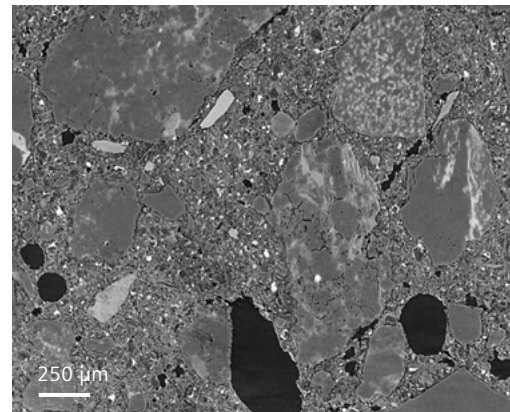
Cross-sectional view of a concrete sample scanned at 0.8 µm/ voxel resolution. Various phases of concrete can be observed in distinct contrast. Finer interfacial spacing between the large particles and aggregates can also be discerned.
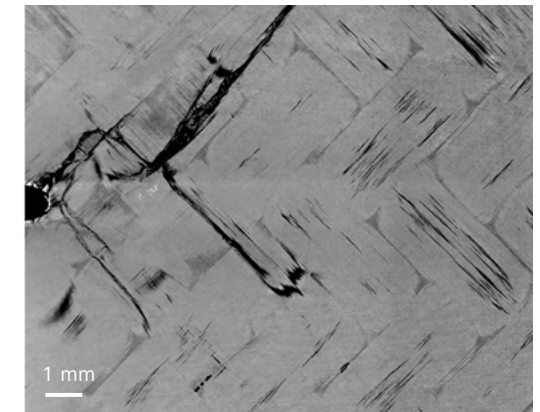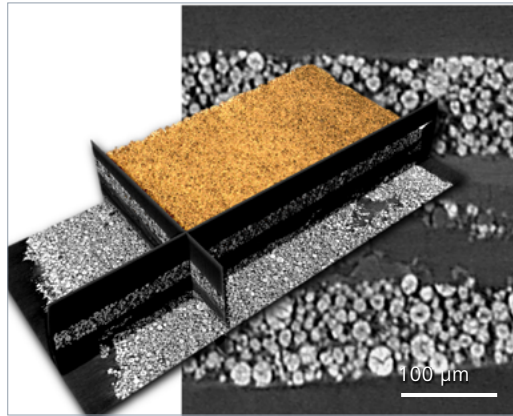

Cross-sectional view of a cascade of cracks initiating at a notch and propagating through a densely packed woven carbon fiber composite panel.
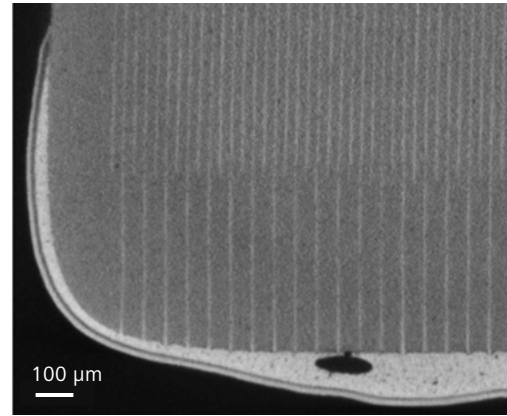
CrystalCT at Work

Lithium ion battery cathode. Degradation damage can be characterized by imaging the cathode material from a de-packaged battery after charge cycling.


Virtual cross section of a multi-layer ceramic capacitor. 3D imaging reveals the alternating layers of ceramic and thin metal electrodes. Also note the large defect (void) at the electrode contact layer.
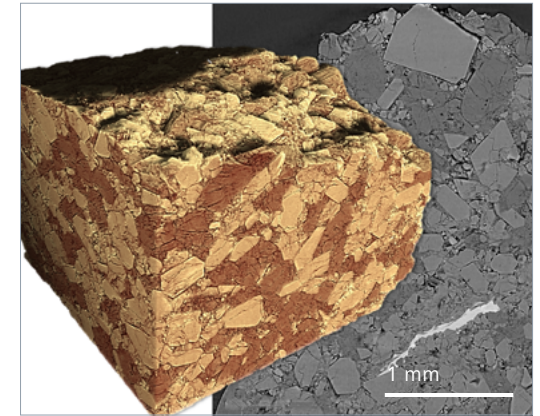

Pharmaceutical ingredient L-Glutamic acid, which has two polymorphs that are imaged. 3D rendering and 2D virtual cross-section show high contrast between the two phases and the interface crack network.
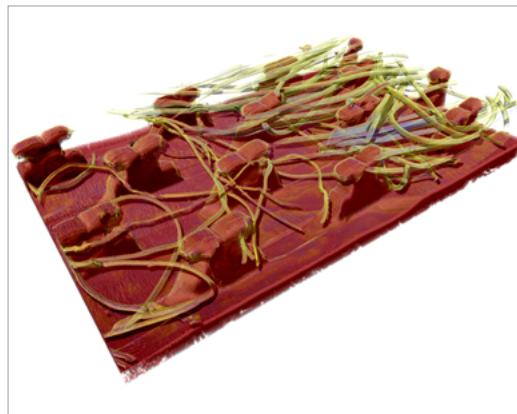
A patch of the microscopic hook and loop secure on disposable diapers imaged using CrystalCT reveals the loop structures of the fibers that engage with the rows of hooks. Both the fiber and hook structures are made of low-density polymers yet can be seen in excellent contrast and clarity.
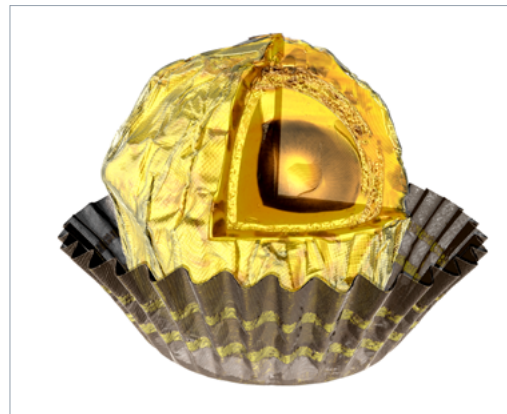
Full field of view imaging of a fine chocolate confectionery. The chocolate and wafer have been virtually sectioned to reveal the central hazelnut core. CrystalCT delivers superior contrast even for low absorbing samples.
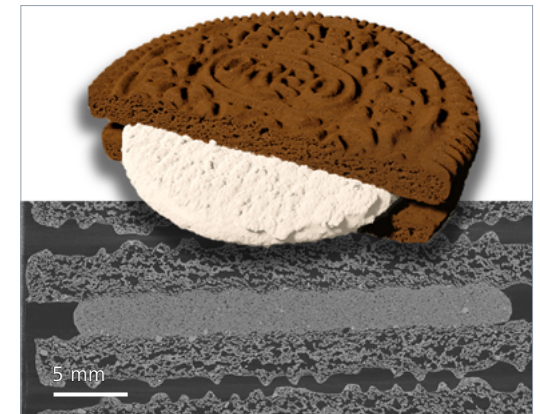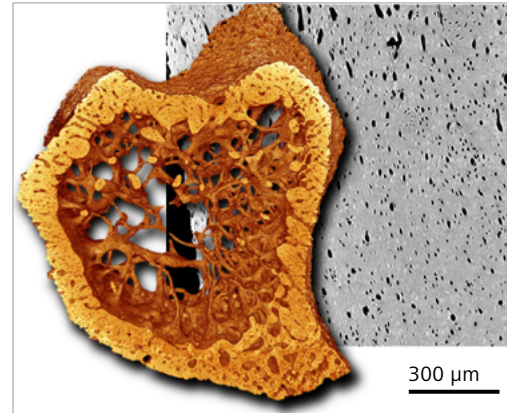

3D rendering and virtual cross-sectional view reveal the interior structure of an Oreo cookie. The cross section reveals the porous microstructure and different phases in the cream and cookie halves.

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CrystalCT at Work
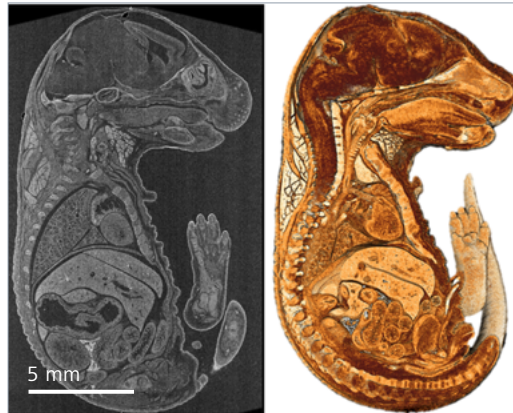
2D virtual cross-section and a cutaway view of 3D rendering of a mouse embryo embedded in paraffin. Internal structures are visible with high contrast. Sample courtesy of Massachusetts General Hospital.

3D rendering and 2D virtual cross-section of a mouse tibia showing the bone microstructure. 3D rendering shows the trabecular network.

3D rendering of a bear jaw. CrystalCT enables efficient large sample scanning.
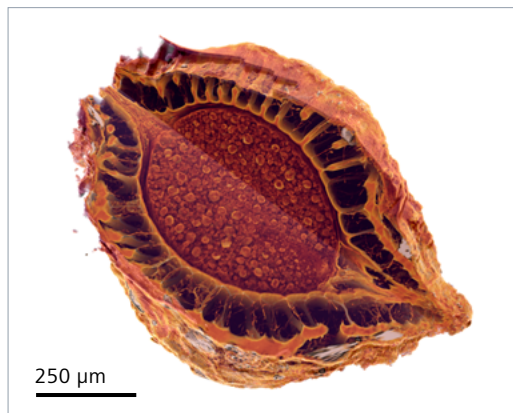
Microstructural view of a Cyclanthus Bipartitus seed using absorption contrast tomography. 3D microstructural features of the seed are discerned in high contrast. The example highlights the potential for use of CrystalCT as an excellent taphonomy tool due to its ability to deliver high resolution non-destructive virtual sections.
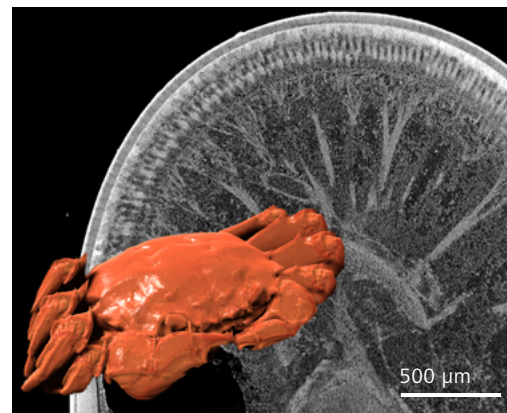
Virtual 2D cross section of the compound eye of a crab. Various microstructural details such as the corneal lens, crystalline cones and retinular cells along with the internal features are observed.
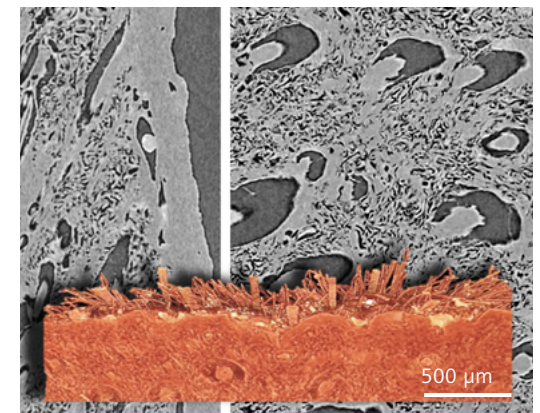
Microstructural details of mouse skin observed in 3D (foreground) and 2D virtual cross-sections (background). Various details of the dermal and epidermal layers can be observed.

CrystalCT at Work
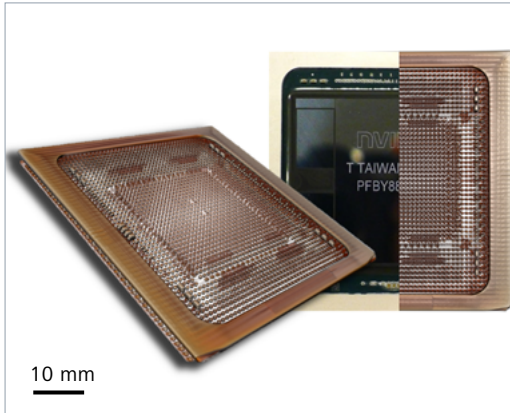
3D color-rendered image of a 2.5D interposer package – Nvidia Tesla v100.
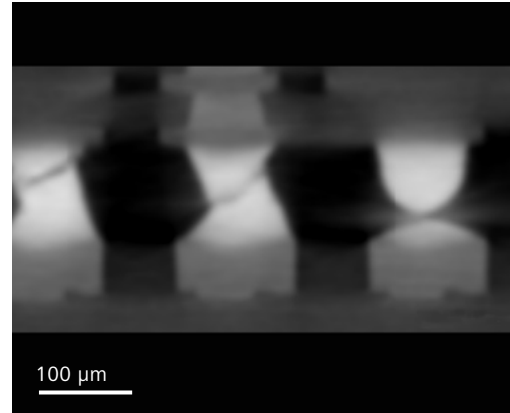
A virtual cross-section image visualizing the non-wet defect on C4 bumps in a semiconductor package.
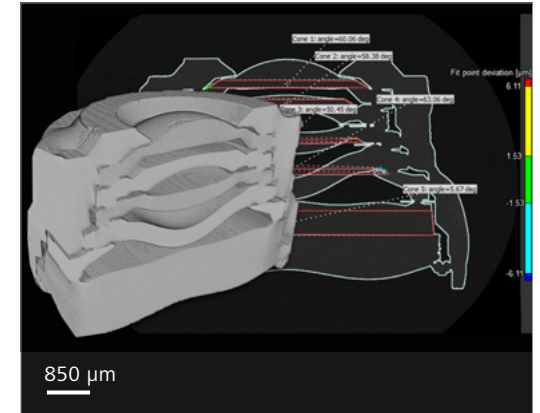
Smartphone camera lens assembly.

3D rendering image of smart watch imaged at 28 µm/vox. Image shows the entire watch assembly as well as the internal features such as motherboard and sound components.
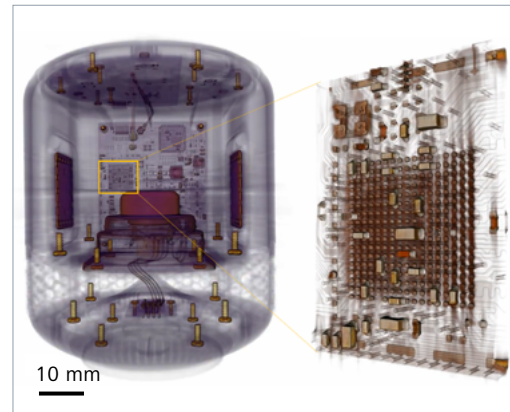
3D rendering images of intact smart speaker scanned at 39 (the left, vertically stitched data) and 7.5 (the right) µm/voxel resolutions. Various interior features of the sample can be observed in distinct contrast.
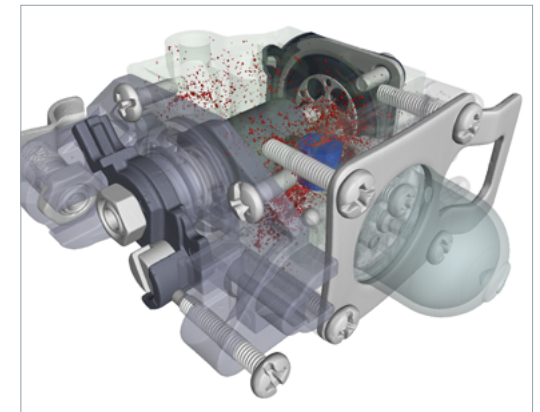
Semi-transparent view of a small carburetor assembly showing its internal components and assessing the porosity of the aluminum casting block.

ZEISS Xradia CrystalCT at Work
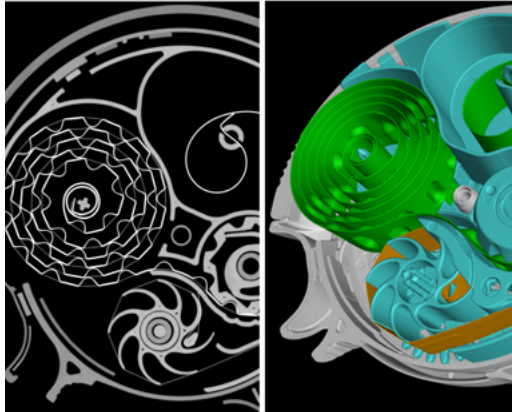
Respiratory drug delivery inhaler device. Left: 2D cross-section and Right: 3D rendering

10 mm
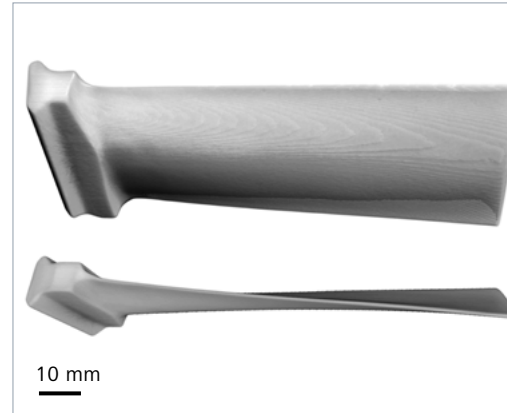
3D rendering of a turbine blade showing the airfoil geometry.

20 mm
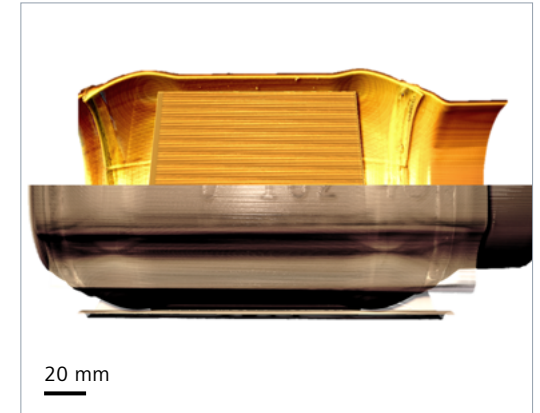
3D scan of an intact catalytic converter. Virtual cross sections allow investigation of the interior structure.
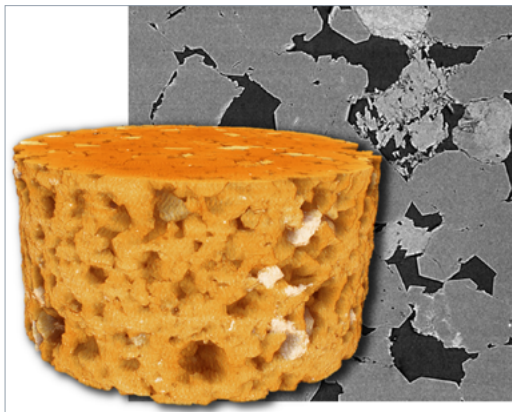
3D rendering of a high permeability Berea sandstone (foreground), 2D cross-section (background). Quartz, feldspar and pores can be clearly distinguished due to the high contrast.

1 mm
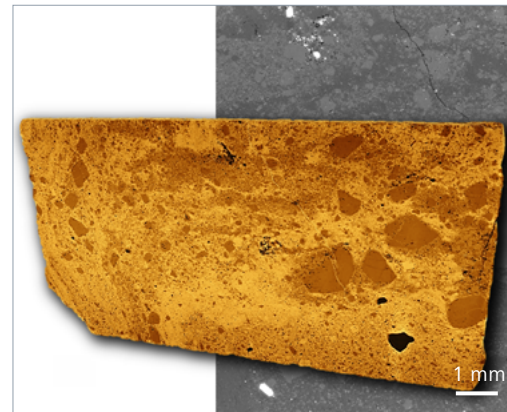
Diogenite sample from Vesta Asteroid. Sample courtesy of NASA.

5 mm
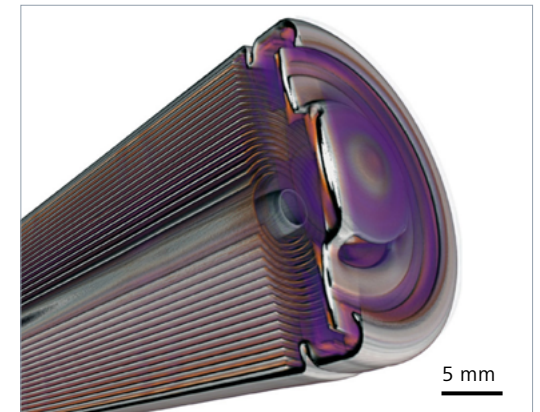
3D rendering of an intact lithium ion battery.

Your CrystalCT Imaging Solution
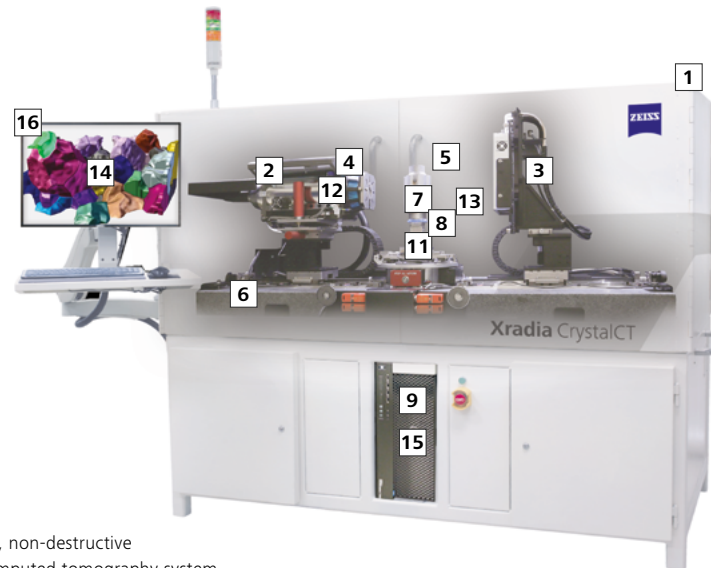
1 X-ray microCT
- Large field-of-view, non-destructive
  3D X-ray micro-computed tomography system

2 X-ray Source
- High performance, spot-stabilized sealed
  transmission source (30 - 160 kV, maximum 10 W)

3 Detector System
- High speed, large array CMOS flat panel detector
  (3072 x 1944 pixels) for large field of view and high
  throughput

4 Crystallography Acquisition Module
- Set of three DCT source-side apertures
- Set of six DCT zero-order detector-mountable beamstops

5 Crystallography Advanced Acquisition Modes
- For obtaining grain maps in diverse sample geometries
- Helical phyllotaxis
- Helical phyllotaxis-Raster
- Helical phyllotaxis-HART

6 System Stability for Highest Resolution
- Granite base vibrational isolation
- Thermal environment stabilization
- Low noise detector
- Advanced proprietary stabilization mechanisms

**7 System Flexibility for Diverse Range
of Sample Sizes in Absorption Mode**
- Variable scanning geometry
- Tunable voxel sizes
- Vertical stitching for joining multiple tomographies

**8 Smartshield for Sample Protection and
Setup Optimization**
- Fully integrated rapid envelope creation within
  Scout-and- Scan control system
- Sample and instrument safety in 3D
- Enhanced operator efficiency during experiment setup

**9 Advanced Reconstruction Toolbox
with Options for Enhanced Performance**
- ZEISS DeepRecon Pro with AI-based reconstruction technology
  for up to 10× throughput or superior image quality on
  unique, semi-repetitive, and repetitive sample workflows.
- ZEISS DeepScout for resolution and throughput at
 full field of view for reconstruction that is 100x faster
- ZEISS OptiRecon with iterative reconstruction for
  up to 4× throughput or enhanced image quality
- ZEISS Material-Aware Reconstruction Solution (MARS)
  for samples for highly attenuating samples, reducing
  the effects of beam hardening

- ZEISS PhaseEvolve for enhanced contrast and
  segmentation in low-medium density sample or
  high-resolution imaging applications

10 Autoloader Option *(not pictured)*
- Maximize productivity by reducing user intervention
- Programmable handling of up to 14 samples
- Automated workflows for high volume, repetitive scanning

11 Sample Stage
- 25 kg sample mass capacity

12 X-ray Filters
- Set of 13 filters to tune beam based on sample
  size and density

13 *In Situ* and 4D Solutions
- Integrated *in situ* recipe control for Deben stages
- *In Situ* Interface Kit option *(not pictured)*
- Custom *in situ* flow interface kit by special order

14 Instrument Workstation
- Powerful workstation with fast reconstruction
- Dual NVIDIA CUDA-based GPU / 128 GB RAM
- Multi-core CPU
- 27" display monitor

**15 Crystallography Reconstruction and
Visualization Secondary Workstation**
- Powerful workstation with fast reconstruction
- Dual NVIDIA CUDA-based GPU/ 128 GB RAM
- Multi-core CPU
- 27" 4K display monitor

16 Software
- Acquisition: ZEISS Scout-and-Scan Control System
- Standard CT Reconstruction: ZEISS XMReconstructor
- DCT Reconstruction: Xnovo Technology GrainMapper3D
- Viewer: TXM 3DViewer
- Compatible with wide breadth of 3D viewers and
  analysis software programs
- XRM Python API to expand instrument capabilities
- Optional ZEN AI Toolkit with Intellesis for image post-
  processing and segmentation using machine learning
- Optional ZEISS arivis Pro for automated image analysis
- Optional 3D World ZEISS edition visualization and analysis

Technical Specifications

X-ray Absorption Imaging

Minimum Achievable Voxel [a]	0.5 µm
Spatial Resolution [b]	0.95 µm
Achievable Voxel at Working Distance [a,c]	0.5 µm at 0.5 mm; 0.8 µm at 2.5 mm; 2.5 µm at 12.5 mm; 4.0 µm at 25 mm; 12.1 µm at 100 mm

[a] Voxel is a geometric term that contributes to but does not determine resolution and is provided here only for comparison. ZEISS specifies resolution via spatial resolution, the true overall measurement of instrument resolution.
[b] Spatial resolution measured with ZEISS Xradia 2D resolution target. [c] Working distance defined as clearance around axis of rotation. This value can be interpreted as the radius of the sample.

Crystallographic Grain Imaging (X-ray Diffraction Contrast Tomography)

Grain Detectability	20 µm
Grain Orientation Angular Resolution	0.1°
Crystal Symmetries	Cubic, Hexagonal, Trigonal, Tetragonal, Orthorhombic, Monoclinic, Triclinic
DCT Advanced Acquisition Modes	Three DCT modes, including Helical Phyllotaxis, Helical Phyllotaxis-Raster, and Helical Phyllotaxis-HART
DCT X-ray Source Apertures	Set of three self-aligning DCT apertures
DCT Detector Beamstops	Set of six zero-order beamstops
DCT Reconstruction and Visualization	GrainMapper3D powered by Xnovo Technology

X-ray Source

Type	Spot Stabilized, Sealed Transmission
Tube Voltage Range	30 – 160 kV
Maximum Output	10 W

Detector System

High Speed, Large Array CMOS Flat Panel	3072 × 1944 pixels
Single Field of View (diameter / height)	140 mm / 93 mm
Maximum Field of View (diameter / height)	140 mm / 165 mm

Xradia Platform Stability

Chassis	Proven stable Xradia Versa platform
Vibration Isolation	Granite base
Temperature Control	Temperature-stabilized interior
Drift Correction Capabilities	Adaptive Motion, Sample Drift, and Thermal tracking and compensation; plus, proprietary advanced methods
Artifact-Free Imaging Methods	Dynamic Ring Removal; Secondary Referencing; plus, proprietary advanced methods

Stages

Sample Stage (load capacity)	25 kg
Sample Stage Travel (x, y, z, θ)	50, 100, 50 mm, 360° motorized micro-positioning capability
Sample Region-of-Interest (ROI)	Intuitive 3D navigation for precise ROI positioning enabled by innovative sample stage architecture
Source Travel (z)	190 mm
Detector Travel (z)	475 mm

Technical Specifications

Additional Features

Scout-and-Scan Control System	▪
Vertical Stitching	▪
ZEISS SmartShield	▪
XRM Python API	▪
CT Reconstruction	Dual, CUDA-based GPU for instrument workstation; Automated parameter selection and unsupervised reconstruction
Crystallographic Reconstruction	Dual, CUDA-based GPU for offline analysis workstation
ZEISS Autoloader*	Optional
In Situ Interface Kit*	Optional

* Autoloader and *In Situ* Interface Kit cannot be installed simultaneously on the same system

Software

ZEISS Python API	Included
ZEISS arivis Pro	Optional
ZEN AI Toolkit with Intellesis	Optional
3D World ZEISS edition Powered by Dragonfly	Optional

Advanced Reconstruction Toolbox

Secondary High Performance Workstation	Optional
DeepRecon Pro (2-year license)	Optional
ZEISS ART AI Supercharger (DeepRecon Pro + DeepScout)	Optional
ZEISS ART Recon Package (DeepRecon Pro + OptiRecon)	Optional
ZEISS ART Contrast Package (PhaseEvolve + MARS)	Optional
ZEISS ART Premium (all modules)*	Optional

* All ART modules are also available individually.

Product Field Conversion

Field Conversion to ZEISS VersaXRM 730 with LabDCT and FPX	Optional field conversions to VersaXRM 730 with FAST mode

X-ray Safety and EMC Standards

|	
Safety Standards Compliance	UL/CSA 61010-1, SEMI S2-0712, SEMI S8-0712, EN 61326, CE Mark
Radiation Safety	< 1 µS/hr (equivalent to 0.10 mRem/hr) measured 25 mm above surface of enclosure

ZEISS Customer Focus: Continuous Improvement and Upgradeability

Protect Your Investment extends to ZEISS VersaXRM 730 microscopes – delivering unprecedented extendibility and unrelenting support to ensure you are not left behind.

Most ZEISS X-ray microscopes are designed to be upgradeable and extendible with future innovations and developments so that your initial investment is protected. This ensures your microscope capabilities evolve with the advancements in leading technology and is one of the key differentiators in the 3D X-ray imaging industry.

To make certain your system offers the latest capabilities and remains serviceable, you can field-convert your platform to the latest X-ray technology: your Context microCT can become a CrystalCT®, or higher performance Versa X-ray microscope. Your CrystalCT can become VersaXRM 730 with LabDCT. And every mid-tier Versa platform can be upgraded to the most advanced VersaXRM from ZEISS. In addition to instrument conversions at your facility, new modules are continuously developed that will enhance your instrument to provide advanced capabilities such as *in situ* sample environments, unique imaging modalities, and productivity-enhancing modules. Also, periodic major software releases include important new features that are made available to existing instruments, thereby enhancing and extending the capabilities of your research.

Context microCT   CrystalCT   510   515   520   610   620   630   615   730
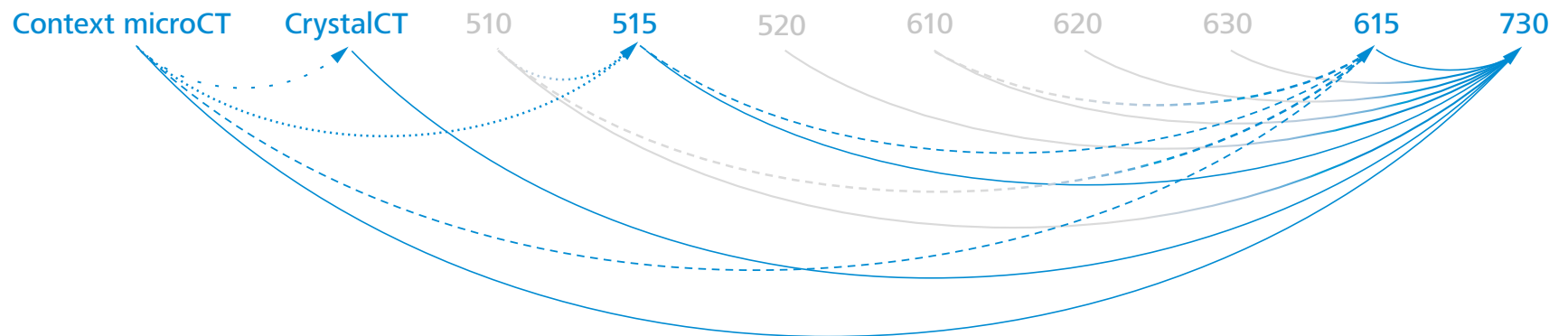
ZEISS Service – Your Partner at All Times

Your microscope system from ZEISS is one of your most important tools. For over 175 years, the ZEISS brand and our experience have stood for reliable equipment with a long life in the field of microscopy. You can count on superior service and support - before and after installation. Our skilled ZEISS service team makes sure that your microscope is always ready for use.

Procurement

- Lab Planning & Construction Site Management
- Site Inspection & Environmental Analysis
- GMP-Qualification IQ/OQ
- Installation & Handover
- IT Integration Support
- Startup Training

Operation

- Predictive Service Remote Monitoring
- Inspection & Preventive Maintenance
- Software Maintenance Agreements
- Operation & Application Training
- Expert Phone & Remote Support
- Protect Service Agreements
- Metrological Calibration
- Instrument Relocation
- Consumables
- Repairs

New Investment

- Decommissioning
- Trade In

Retrofit

- Customized Engineering
- Upgrades & Modernization
- Customized Workflows via ZEISS arivis Cloud

Please note: Availability of services depends on product line and location

www.zeiss.com/microscopy/service

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