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nano3DX

X-ray microscope

Sub-micron computed tomography (CT) for life science

Rigaku
POWERING NEW PERSPECTIVES

High-resolution, high-contrast X-ray microscope

What is X-ray microscopy?

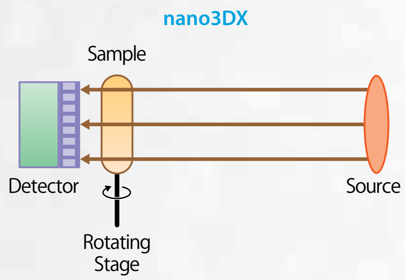
Tomography is the study of the three dimensional-structure of an object by slicing it into thin sections. Microtomography implies that the slices are very thin; thin enough to be viewed by an optical microscope. Classical tomography is a tedious and time-consuming process, and can also result in significant perturbations to the sample. In X-ray tomography, the entire sample is imaged at multiple rotation angles. This multitude of images is processed by sophisticated computer algorithms to provide a three dimensional reconstruction that can be sliced in any direction, providing new insights into the internal features of the object. X-ray microscopy provides this visualization at a resolution better than a micrometer (μm).

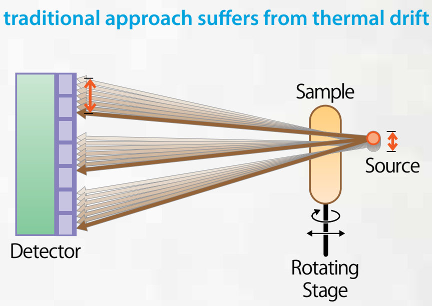
What is the nano3DX?

The nano3DX is a true X-ray microscope (XRM) with the ability to measure relatively large samples at high resolution. This is accomplished by using a high-power rotating anode X-ray source and a high-resolution CCD imager. A rotating anode X-ray source provides for fast data acquisition and the ability to switch anode materials easily, to optimize the data acquisition.

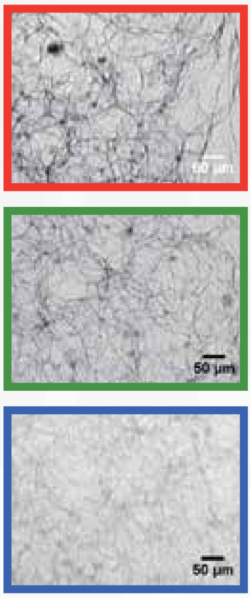
How does the nano3DX work?

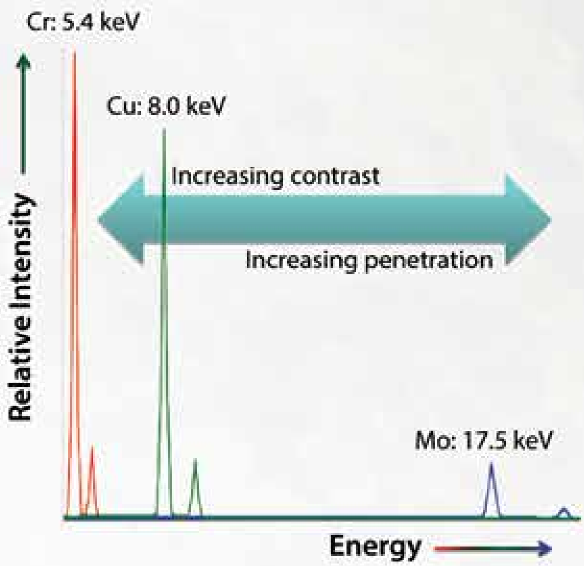
In the nano3DX, the magnification takes place in the detector using true microscope elements. This design places the sample close to a high-resolution detector, allowing for a quasi-parallel beam experiment. This means greater instrument stability and shorter data collection times, providing the highest resolution of any X-ray microscope in its class. The nano3DX design is a vast improvement over older implementations that use a small source and a long sample-to-detector distance. Traditional geometric magnification requires a very small source and extreme stability to prevent smearing.

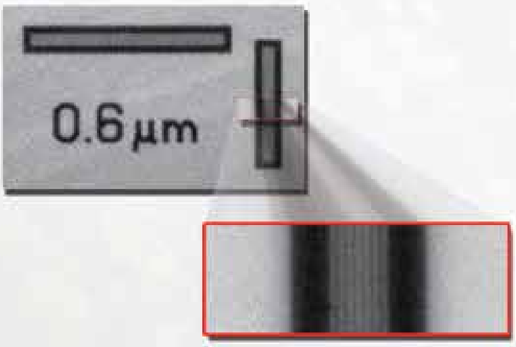




The graph at right illustrates the three primary anode materials available for use in the nano3DX: chromium (Cr), copper (Cu) and molybdenum (Mo), and the effects they have on the experiment. As the energy of the X-ray radiation rises, penetration increases but contrast for low atomic weight materials goes down. For tablets and capsules, Mo is preferred but for smaller objects, Cu or Cr is preferred. This flexibility is essential to obtaining high-quality, high-contrast images quickly.



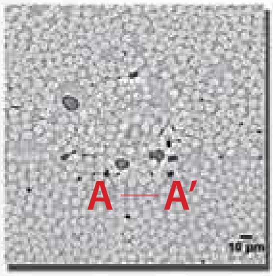


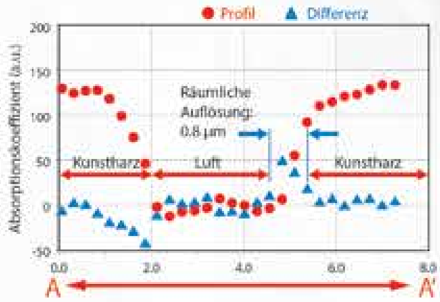


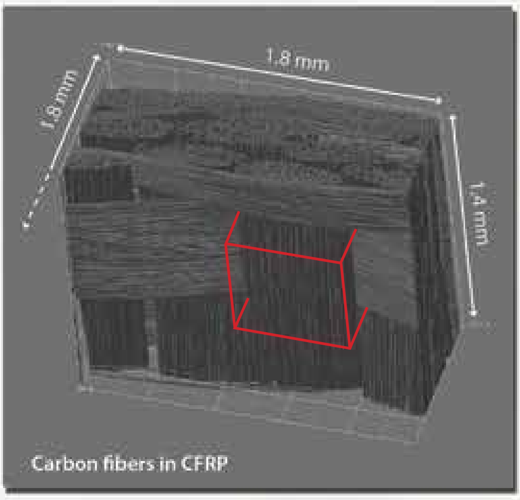
The two dimensional resolving power is shown directly in the images above with a transmission image of a test pattern at 0.27 µm per pixel in which lines at 0.6 µm are resolved.

High resolution

To the left below, a slice was extracted from a 3D tomogram of a carbon fiber reinforced polymer (CFRP). A profile across an air defect in the CFRP sample was examined by difference analysis. The FWHM of the difference curve is less than 0.8 µm at 0.27 µm per voxel demonstrating high resolution in 3D.



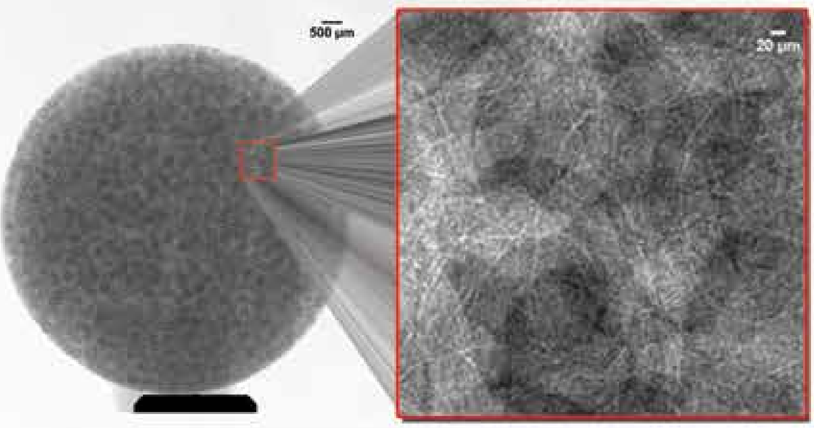




Carbon fibers in CFRP

Ultra wide field of view

To the left is shown a reconstruction of a CRFP composed of 7 µm fibers in a polymer matrix imaged at 0.54 µm per voxel. The volume is a 1.8 mm x 1.8 mm x 1.4 and is represented by 3330 x 3300 x 2500 voxels. The volume is more than 25 times larger than the volume imaged in a single scan from conventional X-ray microscopes at this resolution and data collection time. A typical volume for a conventional XRM is highlighted in the center of the nano3DX volume.



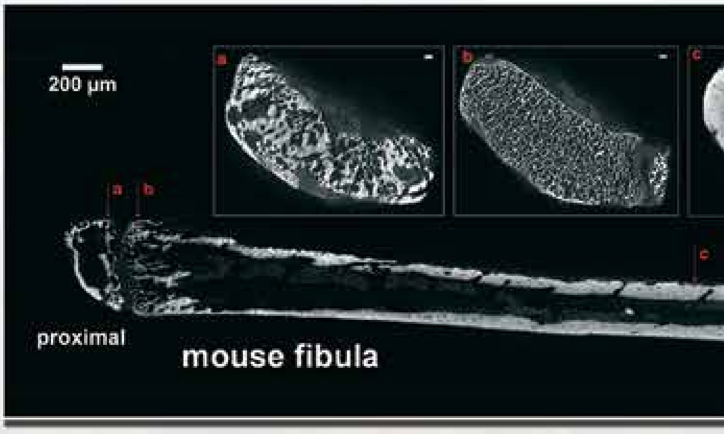
Rapid large field inspection

To the left is a transmission image of a tablet preparation demonstrating both high-resolution and a large field of view obtained with automated image stitching: overall image 10 mm x 10 mm at 0.54 µm per pixel representing 42 (6x7) separate images for a total of 18500 x 18500 pixels.

Sub-micron resolution computed tomography for lif

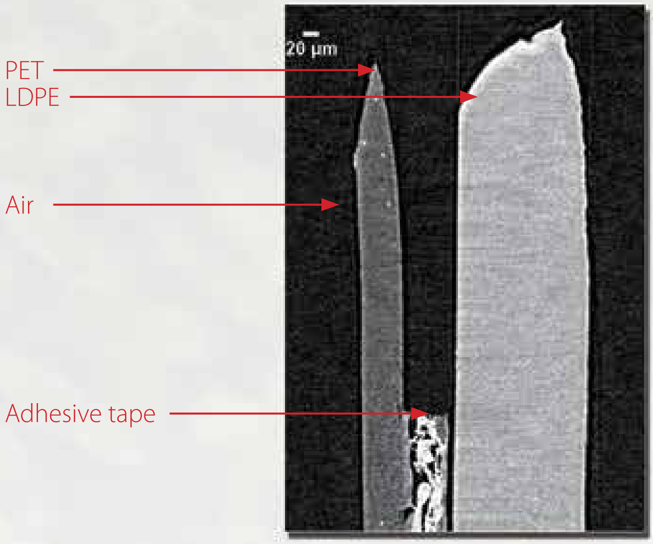
High resolution studies of large objects

The nano3DX is ideally suited to the analysis of bone samples at submicron resolution. One of the important features of the nano3DX is the ability to look at large samples at high resolution. In the example to the right, an entire mouse fibula was analyzed with the nano3DX, the first time a whole bone analysis has been performed.



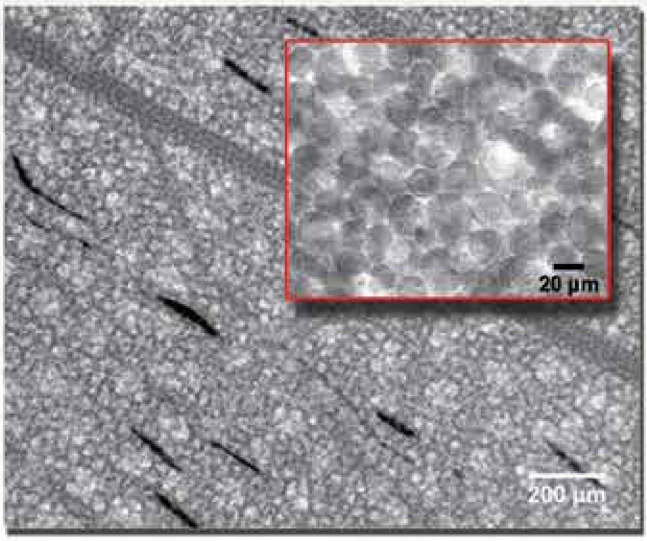
High contrast

The picture at right shows a transmission image collected with Cu radiation. Rapid absorption contrast imaging of very light materials is possible in minutes without the artifacts inherent in phase contrast imaging. Ultra light materials are typically invisible to standard CT systems or require long data acquisition times in other XRMs. The difference in density between low density polyethylene (LDPE) and polyethylene terephthalate (PET) is clearly shown in the differing gray levels.



High contrast at high speed

The image at far right shows a transmission image of a leaf from a house plant, taken with Cu radiation at 0.27 µm per pixel in 60 seconds. Note the ability to see individual cells and features less than 1 µm in size.



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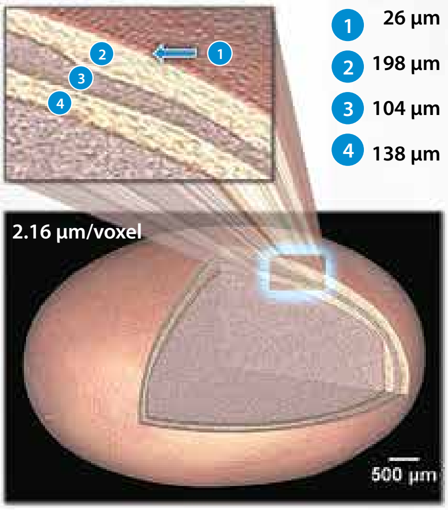
X-ray microscope

Coatings

Below is a is a reconstruction of a coated tablet with multiple layers, each clearly distinguished and measurable. The data were collected at 8.64 µm per voxel with molybdenum radiation. In the bottom visualization a light source is placed inside the tablet and the brightest areas on the surface indicate the places where the coating is thinnest.

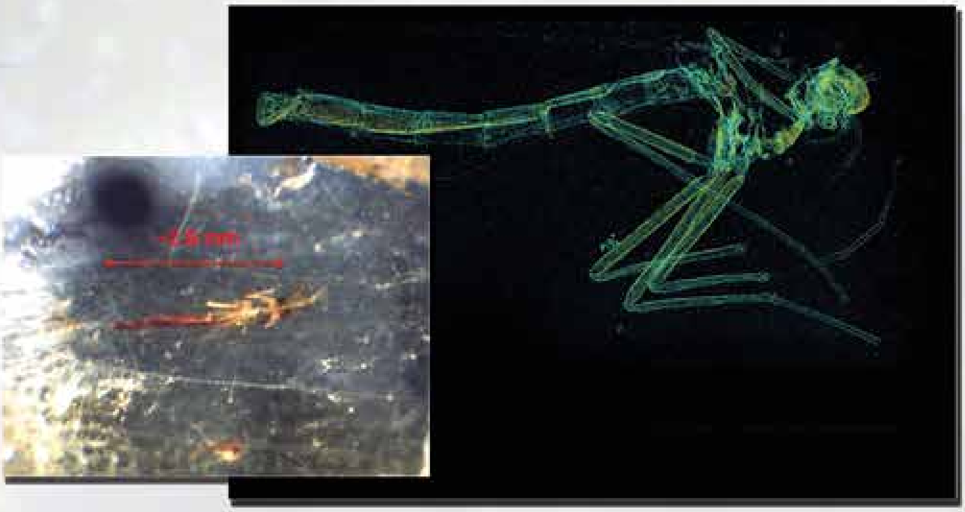


Multilayer-coated tablet

nano3DX application examples

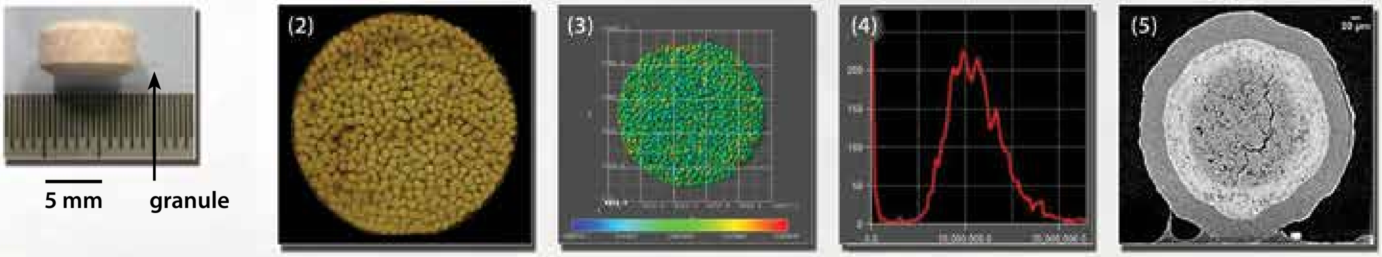
Fossils

In this example, a fossilized dragonfly was studied *in situ* in amber of undetermined age. The data were collected at 4.32 µm resolution in less than four hours. Fine features including the wings are clearly visible.



Formulations

Below is a an orally disintegrating tablet (left) from which a single active pharmaceutical ingredient (API) granule has been excised (right). The whole tablet (2) was imaged at 8.64 µm per voxel. The excipients have been made transparent so only the API granules are visible. nano3Dcalc was used to select the granules so that a particle size map (3) and distribution (4) were generated. The excised granule was imaged at 0.54 µm per voxel and is displayed the far right (5).



Plant seeds

A reconstruction of a hard red winter wheat berry is shown at the right. The data were collected at 4.32 µm per voxel in less than one hour using molybdenum radiation.

nanoBDX

X-ray microscope

Specifications

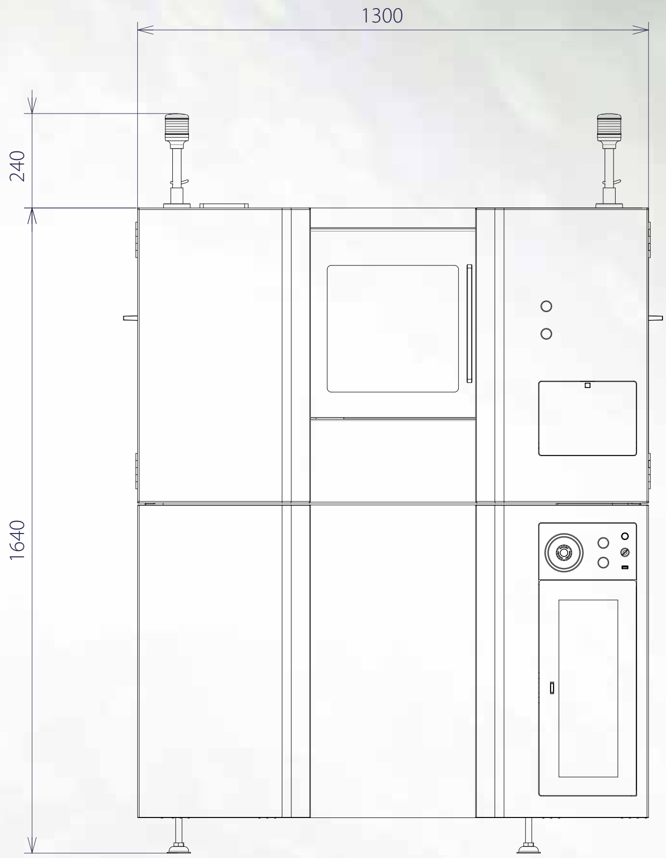
X-ray source	High-brightness rotating anode	
Voltage / current	20 – 50 kV (60 kV optional), ≤30 mA	
Anode targets	Cr, Cu, Mo, W	
Detector type	CCD	sCMOS
Area	3300 x 2500 pixels	2100 x 2100 pixels
Resolution	0.27 to 4.32 µm/pixel	0.325 to 5.2 µm/pixel
Field-of-view	0.9 x 0.7 to 14 x 10 mm	0.66 x 0.66 to 10 x 10 mm
Dynamic range	16 bit	16 bit
Sample stage	5-axis automatic	
Computer		
CPU	Intel Xeon	
HDD	512 GB SSD + 2 TB HDD	
Memory	128 GB	
Monitor	24 inch	
Operating system	Windows® 10 64 bit	

Dimensions	1300 (W) x 655 (D) x 1640 (H) mm
Weight	600 kg
Cooling system	External water chiller (standard)
External radiation leakage	≤1 µSv/h

Water supply*	6 L/min at 25°C or 13 L/min at 32°C	
Power	Main unit	200 VAC, 3-phase, 15 A
	Computer	100 – 240 VAC, 15 A
	Water chiller	100 – 240 VAC, 3-phase, 20 A
Environment	Requires a low humidity air conditioning facility	

*An air-cooled type water supply device may be used instead of the standard water-cooled type water chiller.

Layout



Units: mm

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Since its inception in 1951, Rigaku has been at the forefront of analytical and industrial instrumentation technology. Today, with hundreds of major innovations to our credit, the Rigaku Group of companies are world leaders in the field of analytical X-ray instrumentation. Rigaku employs over 1,400 people worldwide in operations based in Japan, the U.S., Europe, South America and China.

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