NanoXCT

Laboratory X-ray tomography for non-destructive testing of specimens and materials at the nanoscale

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Yet it is not possible at the nanoscale to get a comprehensive representation of a specimen including internal and external 3D-structure analysis as well as a chemical analysis without destroying the sample.

Motivation
Targeted NanoXCT demonstration system specifications:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanning time:</td>
<td>~10 hours</td>
</tr>
<tr>
<td>Field of view:</td>
<td>1 mm</td>
</tr>
<tr>
<td>Probe size:</td>
<td>&lt;= 1 mm³</td>
</tr>
<tr>
<td>Voxel size:</td>
<td>50 nm</td>
</tr>
<tr>
<td>Analysis modes:</td>
<td>3D structural and chemical analysis</td>
</tr>
</tbody>
</table>

NanoXCT source

Compact X-ray computed tomography system for nondestructive characterization of nano materials
Grant Agreement No, NMP4-SE-2012-280987 • Duration 01.05.2012 - 30.04.2015 • www.nanoxct-project.eu
How to reach the source specifications?

**Source specification:**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray spot size</td>
<td>Down to 100 nm</td>
</tr>
<tr>
<td>Acceleration voltage</td>
<td>20-60 keV, optimized for 50 kV</td>
</tr>
<tr>
<td>Power density on target</td>
<td>0.5-1 W/µm</td>
</tr>
<tr>
<td>Focus to object distance</td>
<td>Below 300 µm</td>
</tr>
</tbody>
</table>

1. Generate a 100 nm e-beam spot

2. Have thin enough target to not spread the electrons
   (but still have to be thick enough to hold vacuum and transport heat)

E-beam design

**First generation correction optics**

Poor field homogeneity due to higher order coma and spot broadening

**First generation low aberration correction optics**

Good field homogeneity without spot broadening even with strong deflection.
Target design

- e-beam
- Thin tungsten layer on diamond substrate (good thermal conductor with poor X-ray conversion)
- Spot size simulations and thermal simulations

Some key concepts

- Integrated water cooling (temperature control) of source head
- Wedge shaped front to fit cone object holder
- Hard mounting close to target
Source results

- Initial spot size: 400 nm resulting in 200 nm (half pitch) resolution
- Second prototype: was reaching a spot size of 150 nm
NanoXCT – Detector

Photon-counting detector
- no dark noise
- spectral imaging

Small pixel size
- Timepix ASIC [1]
  - 55 µm pixel size
  - energy threshold
- Hexa modules (à 6 chips)

Large active area
- Array of 4 hexa modules
- 3072 x 512 pixels
- approx. 170 mm x 28 mm


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First imaging test (July 2014)

JIMA RT RC-04 test pattern, 200 nm line width
40 kV, 20 min acquisition, mean over 50 pixels

Detector results

First measurements (2014)
- spatial resolution 150 nm / 200 nm (line pattern)
- focal spot size around 300 nm
- detector performs very close to theoretical optimum (SNR)
System integration

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Design study
Measurement scenarios

<table>
<thead>
<tr>
<th>Different measurement scenarios</th>
<th>$D_a$ [µm]</th>
<th>$D_{10}$ [mm]</th>
<th>$M$</th>
<th>$D_v$ [nm]</th>
<th>$D_{10%}$ [µm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest Intensity</td>
<td>455</td>
<td>250</td>
<td>549</td>
<td>100</td>
<td>314</td>
</tr>
<tr>
<td>Highest Magnification</td>
<td>455</td>
<td>500</td>
<td>1100</td>
<td>50</td>
<td>165</td>
</tr>
<tr>
<td>Largest Field of View</td>
<td>50000</td>
<td>500</td>
<td>10</td>
<td>5500</td>
<td>18089</td>
</tr>
</tbody>
</table>

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Design of manipulator

Positioning device: stacked nano positioners
- high mechanical stability and low thermal sensitivity
- automatic movement with highest accuracy
- O.L.X: 50 mm range
- O.L.Y: 5 mm range
- O.L.Z: 5 mm range
- O.R.Z: 360° endless

Detector manipulation: stacked micro stages
- D.L.X: 300 mm range
- D.L.Y: 100 mm range

Design of Sample Holder

Demands:
- Low thermal sensitivity
- High mechanical strength
- Low X-ray scattering
- Low X-ray attenuation
- Low cost
- Possible / easy to machine
- Highest mechanical stability
- Detachable
- Easy and save
- Easy placement of samples
- Applicable for several sample sizes
Design of Positioning device

Demands on positioning device

- Place a (very small) sample on top of the sample holder
- Easy to handle

NanoXCT demonstrator

Design

- Platform and shielding cabinet with integrated climate control
- Manipulation system
- Sample holder
First prototype test

- Equipment used for the test

First CT test (October 2014)

- First CT test with NanoXCT Detector, NanoTube and manipulation system
- Half-sized detector (two Hexa modules instead of four)
- Image: gold particles in clay, sample provided by BAS
Fully integrated NanoXCT demonstrator (April 2015)

Head of a Mosquito. The compound eyes of the insect can be seen as well as parts of the sucker and a leg

Reconstruction and Data evaluation
NanoXCT Reconstruction

interpolated FBP, online
adapted SART, offline

SART reconstruction specially adapted to the detector geometry (gaps) maximizes image quality in the reconstructed images.

Introduction to K-edge tomography: Dependence on amount of material

Measurement of intensity at four energy thresholds:

- Two energy bins
- Ratio is dependent on transmitted thickness
K-edge results

Basic transmission images and resulting K-edge images of Ag and Mo wires with 700 nm pixel size

Data analysis and quantification platform

InSpectr module in Avizo software for data visualization, segmentation and quantification
Aggregated Spectrum
Global Analysis: Which materials?

- Minimum
- Average
- Maximum

Spectra Histogram
Global Analysis: How much of each element?
Spectral Transfer Function

Global Analysis: Where?

Selection in Spectrum

Global Analysis: Where?
Element Maps
Global Analysis: Where?

Spectrum & Concentration Probing
NanoXCT

- Ultra-bright nano focus X-ray source
- Wide field of view small pitch photon counting detector
- Integrated chemical characterization using MEXCT and/or KEA
- High precision manipulation and XCT system
- 3D visualization, data analysis, quantification, large data handling
- Combined structural and chemical analysis in a single device

Thank you for your attention!

NanoXCT
Compact X-ray computed tomography system for nondestructive characterization of nano materials

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