Imaging Microstructure Dynamics using Synchrotron-Based Computed Tomography

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Outline

• X-Ray Imaging and CT
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- Synchrotron CT
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• Examples:
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• Examples:
  • Composites
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  • Devices and Batteries
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  • Devices and Batteries
  • Geological Samples
  • Fluid Dynamics
Radiography (X-Ray Projection Imaging)

- Projection imaging is the oldest x-ray technique
- Heavier elements and denser materials attenuate x-rays
- Resulting absorption image is essentially a map of electron density

Computed Tomography (CT)

- CT scans (aka CAT scans) are the 3D extension of x-ray projections.

Procedure:
- Take many projections while rotating the camera/detector around the patient.
- Reconstruct the projections into a digital 3D model.

X-ray Imaging in Industry

- Devices
- Defect/Failure Analysis
- Geological Core Analysis

Image sources: Wikimedia commons, Saskatchewan Research Council
Synchrotron-Based CT (SR-CT)
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• Advantages of SR-CT:
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  • Measurement speed
Synchrotron-Based CT (SR-CT)

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  - Better absorption contrast
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  - Large samples at high resolution
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  • Elemental Mapping
• Advantages of SR-CT:
  • Measurement speed
  • Better absorption contrast
  • Large samples at high resolution
  • Elemental Mapping
  • Large enclosures
Synchrotron-Based CT (SR-CT)
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• Well-suited to:
Synchrotron-Based CT (SR-CT)

- Well-suited to:
  - Low Contrast Samples
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  • In-Situ imaging
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  • Large samples with small features
  • Time-resolved experiments
• Well-suited to:
  • Low Contrast Samples
  • In-Situ imaging
  • Large samples with small features
  • Time-resolved experiments
  • Experiments that require large or complex equipment
The CLS has two beamlines that are dedicated for SR-CT experiments, which are known as the Biomedical and Imaging Therapy beamlines (BMIT).

The beamlines cover different energy ranges:

- **BMIT-BM**: low energy for small, low-density samples (15-40 keV)
- **BMIT-ID**: high energy range for large, high-density samples (30-140 keV)
• X-Ray Imaging and CT
• Synchrotron CT
• Examples:
  • Composites
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  • Geological Samples
  • Fluid Dynamics
Carbon Fiber Composites

1 mm

500 µm
Carbon Fiber Composites

0 hrs

0.73 hrs

2.23 hrs

4.23 hrs
Carbon Fiber Composites
Exploding Batteries
Exploding Batteries
Batteries and Devices

Interior of a “pouch cell” battery
Batteries and Devices

Interior of a “pouch cell” battery

Normal:
Batteries and Devices

Normal:

“Pillowed”:

Interior of a “pouch cell” battery
Batteries and Devices

Interior of a “pouch cell” battery

Normal:

“Pillowed”:

Difference:
Interior of an cylindrical commercial lithium ion battery

Water mapping of an in-situ hydrogen fuel cell (Bazylak et al.)
Geological Cores

Internal 2D cross section of a 1-inch core sample

Internal 3D pore network (highlighted in blue) of a core sample
Pore Network Analysis

CT scan of porous core sample

Results of pore analysis and fluid simulation (map of total flux along vertical axis)

Porosity = 26.1%
Tortuosity factor = 7.8
Connected fraction = 99.72%
Time-Resolved CT of Viscous Fluid

Bitumen core sample
Time-Resolved CT of Viscous Fluid

Bitumen core sample

X-ray-transparent pressure vessel
Time-Resolved CT of Viscous Fluid

Bitumen core sample

X-ray-transparent pressure vessel

Time-resolved experiment in progress
Time-Resolved CT of Viscous Fluid

Sand Grains

Bubbles
• SR-CT is:
Summary

- SR-CT is:
  - Fast
Summary

- SR-CT is:
  - Fast
  - High Contrast
Summary

• SR-CT is:
  • Fast
  • High Contrast
  • High-resolution for large samples
• SR-CT is:
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• SR-CT is ideal for:
Summary

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• SR-CT is ideal for:
  • In-situ imaging
Summary

- **SR-CT is:**
  - Fast
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- **SR-CT is ideal for:**
  - In-situ imaging
  - Time-resolved imaging
• SR-CT is:
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• SR-CT is ideal for:
  • In-situ imaging
  • Time-resolved imaging
  • Imaging materials with very similar composition/density
• Industry access is a core mandate of the CLS
• Independent legal status allows for flexible IP policies
• The Industrial Science Division exists to facilitate industry access
• The CLS has the highest rate of industrial utilization of any synchrotron in the world