Tomography

Introduction to Tomography

TEM Tilt-Series Tomography in Life Science

STEM Tomography in Materials Science

Introduction to Tomography

• **Tomography** is imaging by sections or sectioning. A device used in tomography is called a **tomograph**, while the image produced is a **tomogram**.

• The method is used in **medicine**, **archaeology**, **biology**, **geophysics**, **oceanography**, **materials science**, **astrophysics** and other sciences.

• In most cases it is based on the mathematical procedure called **tomographic reconstruction**.

• The word "tomography" is derived from the **Greek** *tomos* (slice) and *graphein* (to write).

Wickipedia
Introduction to Tomography

- **Tomography** is a method in which a 3-D structure is reconstructed from a series of 2-D projections (images) acquired at successive tilts (Radon 1917).

- First developed for use in medical imaging (1963, Nobel Prize for Medicine in 1979) using X-rays, ultrasound and magnetic resonance (e.g. ‘cat-scans’).

- Found further application in geology, astronomy, materials science, etc...

P. Midgley, tomo workshop in Berlin

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**Recording**

- Series of 2D images
- Destructive: serial sectioning, FIB
- Non-destructive: X-rays, TEM

**Reconstruction and “viewing”**

- Registration (alignment of images)
- Back-projection, reconstruct (tilt-series)
- **Tomogram**
- Segmentation (image processing), extraction of the desired information
3D imaging in medicine

- Non-invasive methods are preferred!
- The disadvantage of conventional X-radiographs is its inability to discriminate between organs of close absorptivity or overlapping organs in the viewing direction.
- X-ray computed tomography overcomes that limitation:
  - X-radiographs are made in many different directions and combined mathematically to reconstruct cross-sectional maps.
  - reconstruction tomography or computer assisted tomography.

Tomograph
Radon 1917


Radon Transform

The paper defines the Radon transform $R$ as the mapping of a function $f(x,y)$, describing a real space object $D$, by the projection, or line integral, through $f$ along all possible lines $L$:

$$Rf = \int_L f(x,y) ds,$$

A discrete sampling of the Radon transform is geometrically equivalent to the sampling of an experimental object by some form of transmitted signal: a projection. The consequence of such equivalency is that the reconstruction of an object $f(x,y)$ from projections $Rf$ can be achieved by implementation of the inverse Radon transform.
Radon Transform

Object

Radon transform = Sinogram

-180°

9

180°
Back projection

(a) Projection recording

(b) Back projection reconstructing

Object 1 Proj. 3 Proj./40 deg.

5 Proj./20 deg. 13 Proj./10 deg. 25 Proj./5 deg.
back projection

Tomography in medicine
3D imaging in materials science

360 degree X-ray tomography
Milan Felberbaum
STI-IMX-LSMX

Cylinder of an Al-Cu Alloy
3D imaging in materials science

Reconstructed pore

Tomography with electrons

Stopping range for electrons (99% absorbed)

<table>
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<tr>
<th>Element (specific weight)</th>
<th>Element (atomic weight)</th>
<th>X-rays</th>
<th>Neutrons</th>
<th>Electrons</th>
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<td>Cu-Kα ( \lambda = 1.54 \text{ Å} )</td>
<td>Mo-Kα ( \lambda = 0.71 \text{ Å} )</td>
<td>( \lambda \approx 1.08 \text{ Å} )</td>
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<td>4-Be 1.84 g/cm³</td>
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<td>13-Al 2.7 g/cm³</td>
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<td>82-Pb 11.3 g/cm³</td>
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Bio-EM, Tomography

Tilt series, -60 … +60 degree tilt

Tomogram

Tomo workflow

3D object  Tilt series  Tomogram  3D Model

ACQUISITION  ALIGNMENT & RECONSTRUCTION  POSTPROCESSING & INTERPRETATION
resolution

GEOMETRICAL LIMIT, THE MISSING WEDGE

- There is a limit in the tilt angle we can reach ($\pm 70^\circ$) due to:
  - Design of the holder
  - Grid bars
  - Increasing thickness of the specimen with high tilt angles

- This is known as the missing wedge problem (missing information, loss of resolution)
Missing wedge

Weighted back projection WBP
projection requirement

- projection requirement: monotonically varying function of a physical property: mass-thickness dominant in biological samples!

Si-Ge multiple quantum well structure

Tomography in Electron Microscopy
**Tomography with HAADF (z-contrast)**

nanoparticle bimetallic catalysts supported on mesoporous silica

STEM HAADF: heterogeneous catalyst composed of Pd$_6$Ru$_6$ nanoparticles (~1 nm) on mesoporous silica support with mesopores of ~3 nm diameter.

Pd$_6$Ru$_6$ nanoparticles anchored to the wall of mesopore

**Emad Oveisi (CIME): STEM DF Tomography of Dislocations**

STEM-ADF tilt series (-35/+35°) of Mo pillar with [155] compression axis
Problems Associated with Tomography

- High tilt range required to acquire a tilt series (up to +/-70 degree)
  Increasing the effective thickness with tilt (2 times thicker at 60 degree!)
  No uniform focus: Dynamic focus package is required

- Misalignment between the tilt axis and diffraction axis;
  May change the excitation error during tilt series acquisition and results in inconsistent images

- Changes of diffraction contrast during tilting; e.g. close to zone axes

- 3D reconstruction is not always straightforward; e.g. missing wedge effect, complications due to surface artifacts, etc.

Algorithm for 3D observation of Dislocations

Developing an algorithm for 3D Reconstruction of Dislocations from TEM images

Microscopy

3D Reconstruction

Dr. M. Cantoni

Prof. C. Hebert

Prof. P. Fua

Dr. G. Lucas

Dr. A. Letouzey

CVLAB

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CVLAB
Algorithm for 3D observation of Dislocations

- Using state of the art curvilinear structures detection algorithm, the dislocation segments are extracted semi-automatically in ADF-STEM images.

- These 2D representations of dislocations are then automatically matched between images.

- 3D estimation of the dislocation structure is performed from these segments by taking into account the camera calibration and tilt angle for each image.


Second example: Dislocations in GaN

3D reconstruction using SIRT algorithm

STEM-ADF tilt series (-25/+25°) of GaN with [1-100] foil direction

Reconstruction using SIRT algorithm

Quentin Jeangros, SOFC