Electron Microscopy

SEM and TEM
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1. Motivation for EM

Resolution of light microscope is limited:

\[ \sin \Theta = 1.22 \cdot \frac{\lambda}{D} \]

- wavelength of visible light
- less diffraction for smaller wavelengths

➤ possible magnification: \(~ 2,000\)
1. Motivation for EM

Different approach: use electrons instead of light

- Access to much smaller wavelengths
  \[ \lambda = \frac{h}{p} \]  
  (3.7 pm for 100 keV)

- electrostatic/electromagnetic lenses instead of glass lenses

- possible magnification: \(~ 2000000\)
2. Interaction with matter

Backscattered electrons
Secondary electrons
Auger electrons
Transmitted electrons
X-Rays
phonons
2. Interaction with matter

Topography and composition ← Backscattered electrons

Topography ← Secondary electrons

Auger electrons

Structure and composition ← Transmitted electrons

Composition ← X-Rays

phonons
2. Interaction with matter

2 different approaches:

- Backscattered and secondary electrons
  - SEM

- Transmitted electrons
  - TEM
3. SEM

Scanning Electron Microscopy
3.1 Functional Principle

Electron source
Condenser lens
Scan coil
Objective lens
Specimen + Detectors

2-25 kV

$e^-$
3.1 Functional Principle

Electron gun

Condenser lens

Scan coil

Objective lens

Specimen + Detectors

e\-

coils

N

S
3.1 Functional Principle
3.1 Functional Principle

- Electron gun
- Condenser lens
- Scan coil
- Objective lens
- Specimen + Detectors
3.1 Functional Principle

- Electron gun
- Condenser lens
- Scan coil
- Objective lens
- Specimen + Detectors

Electron- and Light detectors
3.2 Examples

Photonic crystal in silicon substrate

Nanowires in silicon substrate

WSI, D. Dorfner

WSI, D. Pedone
3.3 Energy Dispersive Systems (EDX)

Bremsstrahlung → X-ray Continuum

Electron filling holes → Characteristic X-rays

Information about chemical composition
3.3 Energy Dispersive Systems (EDX)

Solid state X-ray Detector

- X-ray creates hole/electron pairs (3.8 eV necessary per pair)
- Number of pairs and current are a measure for X-ray energy
3.3 Energy Dispersive Systems (EDX)

Alloy of aluminum and tungsten
2 different approaches:

- Backscattered and secondary electrons
- Transmitted electrons

SEM

TEM
4. TEM

Transmission Electron Microscopy
4.1 Functional principles

Electron gun

Condenser lenses

Object

Objective lens
+ intermediate lens
+ projective lens

50-400 kV

$e^-$
4.1 Functional principles

Electron gun

Condenser lenses

Object

Objective lens
+ intermediate lens
+ projective lens
4.1 Functional principles

Electron gun
Condenser lenses
Object
Objective lens + intermediate lens + projective lens

~100nm specimen

e⁻ scattered direct beam

scattered direct beam
4.1 Functional principles

- Electron gun
- Condenser lenses
- Object
- Objective lens
  + intermediate lens
  + projective lens
4.2 Example

Crossectional analysis of a conductor nanogap device

WSI, S. Strobel

WSI, D. Pedone
4.3 Comparison of SEM and TEM

SEM: scans with a focused point

TEM: illuminates whole sample
4.4 High Angle Annular Dark-Field Imaging (HAADF)

- used in STEM (scanning transmission electron microscopy)
- rayleigh scattering at high angles
- Angle depends on the atomic number $Z$:
- electron intensity: $I \propto Z^2$

Ͼ by measuring the electron intensity, while scanning over the sample, information about the chemical composition can be acquired
Thanks for your attention.
- TUM chemie department:
  http://www.ch.tum.de/em/emlabor/methoden/rem.htm
  http://www.ch.tum.de/em/emlabor/methoden/tem.htm
- wikipedia:
  http://en.wikipedia.org/wiki/HAADF
  http://en.wikipedia.org/wiki/EELS
- Scanning electron microscopy and X-ray Microanalysis, G. Lowes
- electron microscopy in solid state physics, H. Bethge and J. Heydenreich