Hitachi SU8230 Cold Field Emission SEM
Core Policies

• **DO NOT** let other people use the facility under your account.
• **DO NOT** try to fix parts or software issues by yourself!
• **DO NOT** surf web using instrument computer!
• **Follow checklist** and SOP! **DO NOT** explore program!
• **Facility usage time** at least twice a month, **OR** receive training again (two practice sessions within one week).
Cold Field Emission (CFE)

- Brightness: **1000 x**
- Beam size = **30 - 50 Å**
- Operation temperature: **300 K**
- Vacuum: **10^{-11} Torr**
- Lifetime: > **10000 hrs**
Demagnification Optics

- Demagnification $\rightarrow$ image resolution
- Resolution $\leftrightarrow$ image intensity

Beam size at condenser lens focus plane

$$d_B = \frac{d_G}{p_1/q_1}$$

- $d_G$: Beam size exiting the gun
- $p_1$: Object distance of condenser lens
- $q_1$: Image distance of condenser lens

Beam size on specimen surface at objective lens focus plane

$$d_p = \frac{d_B}{p_2/WD}$$

- $p_2$: Object distance of objective lens
- $q_2$: Image distance of objective lens
- $WD$: Working Distance between the bottom of the objective lens and sample surface
Accelerating voltage ($V_{\text{acc}}$)

- Increasing accelerating voltage $\rightarrow$
  - less spherical aberration $\rightarrow$ smaller probe diameter and better resolution
  - Increase beam penetration $\rightarrow$ obscure surface detail
  - Increase the probe current at the specimen. A minimum probe current is necessary to obtain an image with good contrast and a high signal to noise ratio.
  - Potentially increase charge-up and damage in specimens that are non-conductive and beam sensitive.

SEM images of vanadium oxide nanotubes at different acc voltages

Image courtesy http://www.microscopy.ethz.ch/
**Factors Affecting SE Emission: Working Distance (WD)**

**Working Distance**: the distance between the bottom of the objective lens and the specimen

Increasing WD →
- increased depth of focus
- Increased probe size → lower resolution
- increased effects of stray magnetic fields → lower resolution
- increased aberrations due to the need for a weaker lens to focus.
SEM: Electron-Specimen Interactions

- **Secondary electrons (SE < 50 eV)** → Topographical information
- **Back-scattered electrons (BSE)** → Composition (atomic number) and topographical information
- **Characteristic X-ray (EDX)** → Composition information (Energy Dispersive X-ray Spectroscopy)
- **Auger electrons (AE)** → Surface sensitive composition information
- **Cathodoluminescence (CL)** → Electric states information
  - Fluorescence
  - Phosphorescence
- **Continuous X-ray (Bremsstrahlung)** → Insulator charging

**Imaging resolution ↔ Interaction volume**
- **SE** forms a large low-energy peak < 50 eV
  - Shallow depth of production $\rightarrow$ topography information
  - Small interaction volume $\rightarrow$ high imaging resolution, comparable to e-beam size
- Auger Electron (**AE**) produces relatively small peaks on the **BSE** distribution

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**Table:**

<table>
<thead>
<tr>
<th>Kinetic Energy (eV)</th>
<th>SE</th>
<th>BSE</th>
<th>AE</th>
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</thead>
<tbody>
<tr>
<td>50 eV</td>
<td></td>
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<tr>
<td>2000 eV</td>
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**Graph:**

- **SE**
- **BSE**
- **AE**
- Elastic reflection

**Goldstein et al., 1981**
The SEM electromagnetic lenses cannot be machined to perfect symmetry.

- A lack of symmetry $\rightarrow$ an oblong beam: a disk of minimum confusion
  - stronger focusing plane $\rightarrow$ narrower beam diameter
  - weaker focusing plane $\rightarrow$ wider diameter

- Astigmatism correction
  - Apply current differentially to stigmator coils $\rightarrow$ circular beam
E-T detector: low-secondary electrons are attracted by +200 V on grid and accelerated onto scintillator by +10 kV bias;

The light produced by scintillator (phosphor surface) passes along light pipe to external photomultiplier (PM) which converts light to electric signal.

Back scattered electrons also detected but less efficiently because they have higher energy and are not significantly deflected by grid potential.
Schematic of SU8200: Optics and detection system

- SE detectors:
  - SE(L): SE lower detector
  - SE(U): SE upper detector
  - LA(U): LA-BSE upper detector
  - HA(T): HA-BSE top detector
- Control/filtering electrode: ExB
- Conversion electrode

Image courtesy: Muto Atsushi, Hitachi
Multiple Detection Modes:

**SE Image: SE(U)**
- SE is detected with the Upper detector through the objective lens.
- Backscattered electron is not detected.
- Rich Topographical information
- High-resolution
- Good voltage contrast

**SE Image: SE(L)**
- Low angle BSE and SE are detected with the Lower detector.
- Rich Topographic information
- Less sensitive to specimen charging artifacts

**HA-BSE Image: HA-BSE(T)**
- HA-BSE is converted to secondary electron at the conversion electrode and detected with the Top detector.
- Rich Compositional information
- Less topographic information

**LA-BSE Image: LA-BSE(U)**
- LA-BSE is converted to secondary electron at the control electrode and detected with the Upper detector.
- Amount of SE is controlled by variable negative electrode voltage.
- Compositional + Topographic information (LA100(U))
- Mixture of SE and LA-BSE image (LA0(U) ~)
- Less sensitive to specimen charging artifacts

Image courtesy: Muto Atsushi, Hitachi
Multiple Detection Modes

Sample: BaCO₃/TiO₂
Vacc: 1 kV
Magnification: x 70k

**Top (HA-BSE)**
- Composition contrast
- BaCO₃
- TiO₂

**Upper (LA-BSE)**
- Composition contrast + Topographic information

**Lower (SE)**
- Topographic information

**Upper (SE)**
- Surface information + VC and edge contrast

Image courtesy: Muto Atsushi, Hitachi
Beam Deceleration (Landing voltage 10 V ~ 2 kV)

- A negative voltage (deceleration voltage, $V_{\text{rd}}$ up to 3.5 kV) applied to the specimen, thereby slowing down the primary electron beam to the desired landing energy.
- Landing voltage (10 V – 2 kV):
  $V_{\text{Ind}} = V_{\text{acc}} - V_{\text{rd}}$;
  $V_{\text{rd}}$: Deceleration voltage
- Resolution improved in deceleration mode
STEM detector

- STEM → internal sample information
- BT-STEM (Bright Field) → enhanced contrast
- DF-STEM (Dark Field) → surface details
PhotoDiode (PD) - BSE Detector

- 4+1 segment retractable below-lens semiconductor type BSE detector

SE imaging

BSE imaging
Hitachi SU8000 – Video Summary

Video link: https://youtu.be/F9qwfYwwCRM