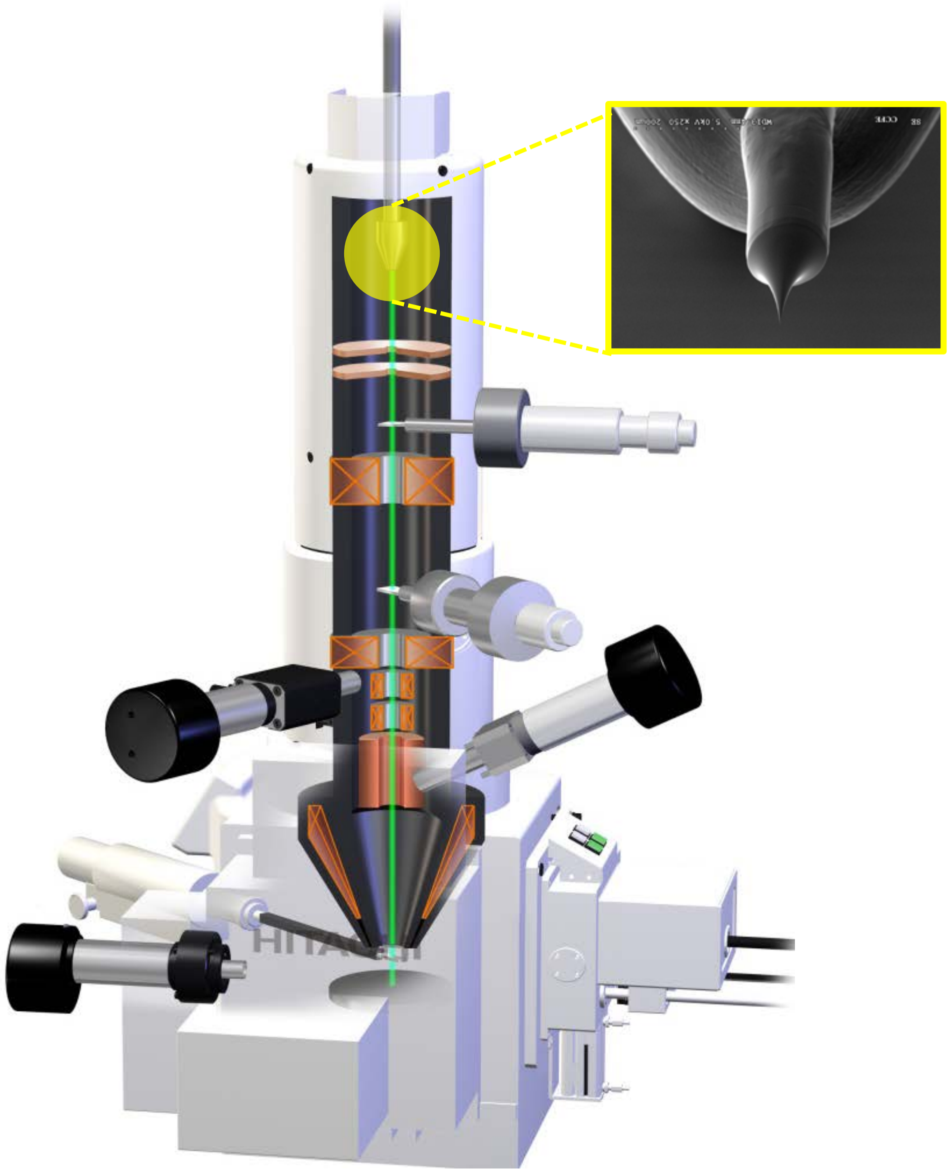
Hitachi SU8230 Cold Field Emission SEM

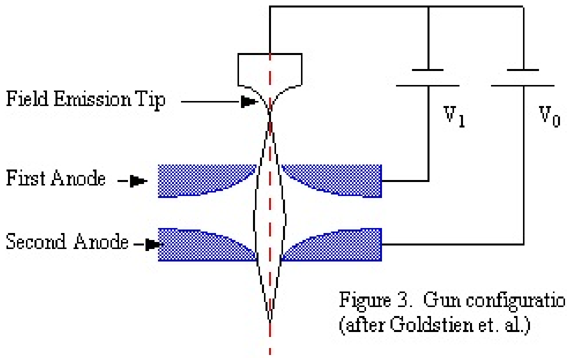
Core Policies

- **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).

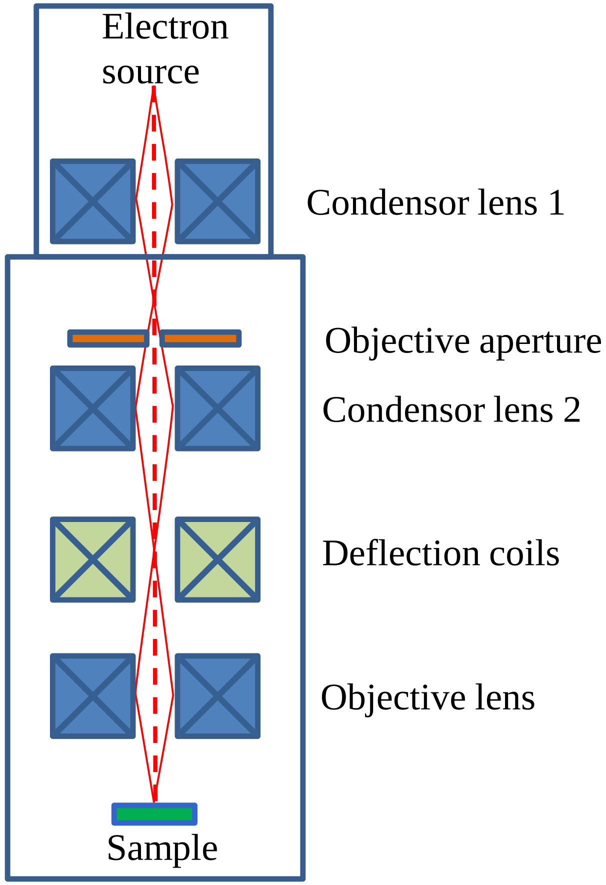
Scanning Electron Microscope (SEM)



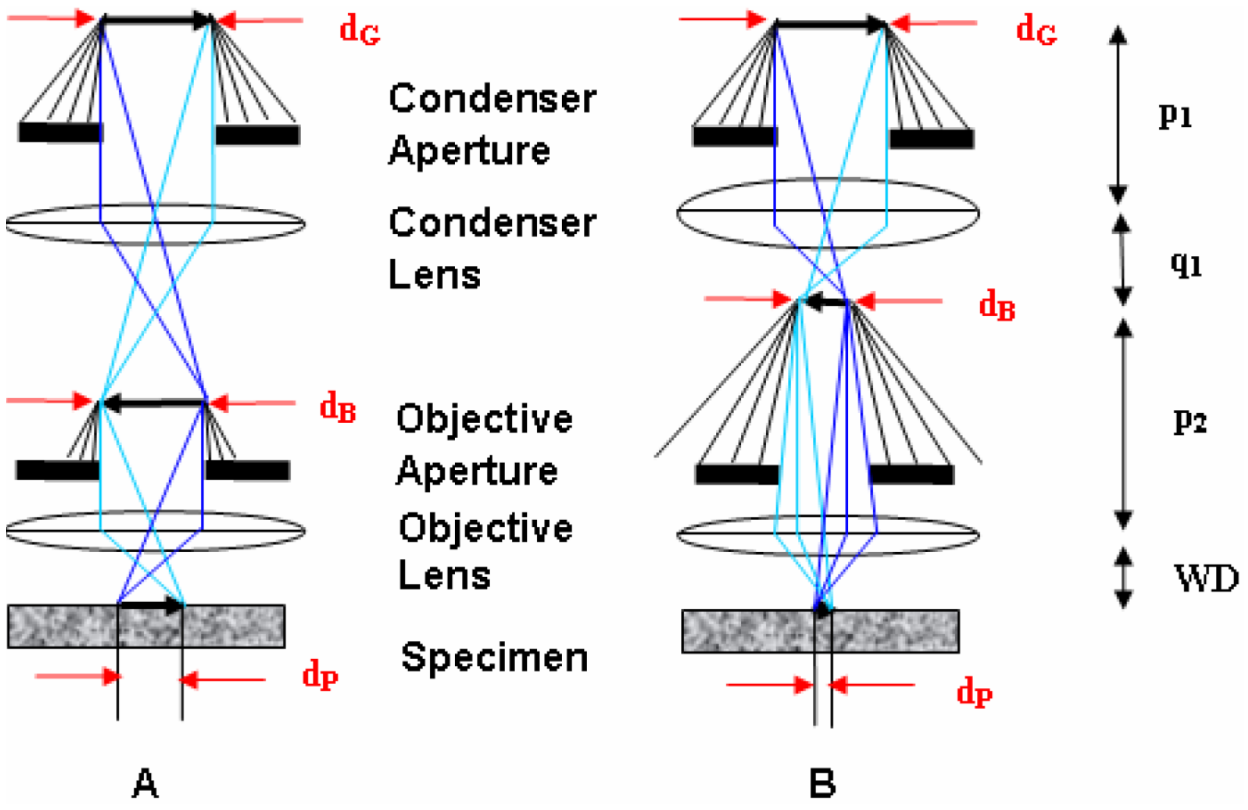
Cold Field Emission (CFE)



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



Demagnification Optics



- Demagnification → image resolution
- Resolution ←→ image intensity

Beam size at condenser lens focus plane

$$d_{\mathrm{B}} = d_{\mathrm{G}}/(p_1/q_1)$$

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

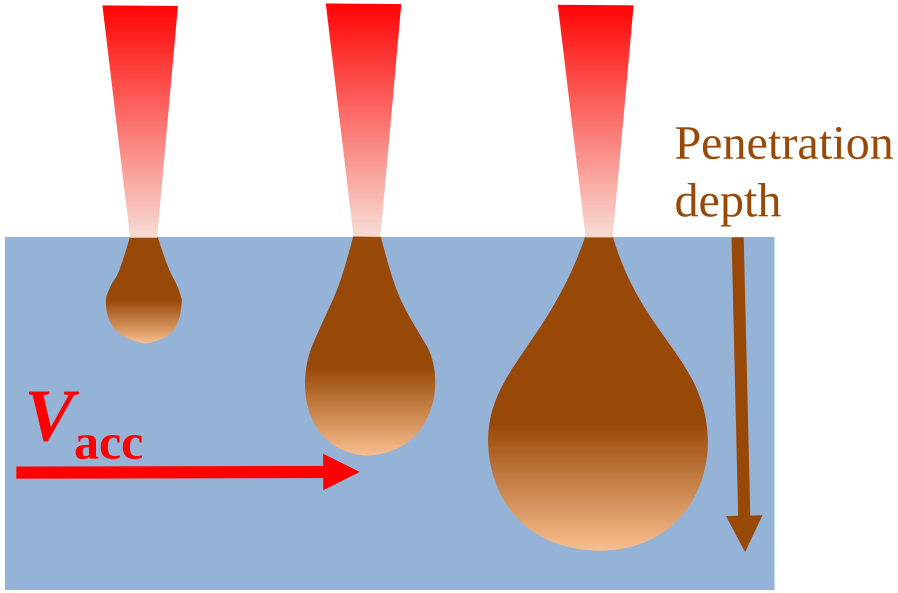
Beam size on specimen surface at objective lens focus plane

$$d_{\mathrm{p}} = d_{\mathrm{B}}/(p_2/WD)$$

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_{acc})

- Increasing accelerating voltage →
  - less spherical aberration → smaller probe diameter and better resolution
  - Increase beam penetration → 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

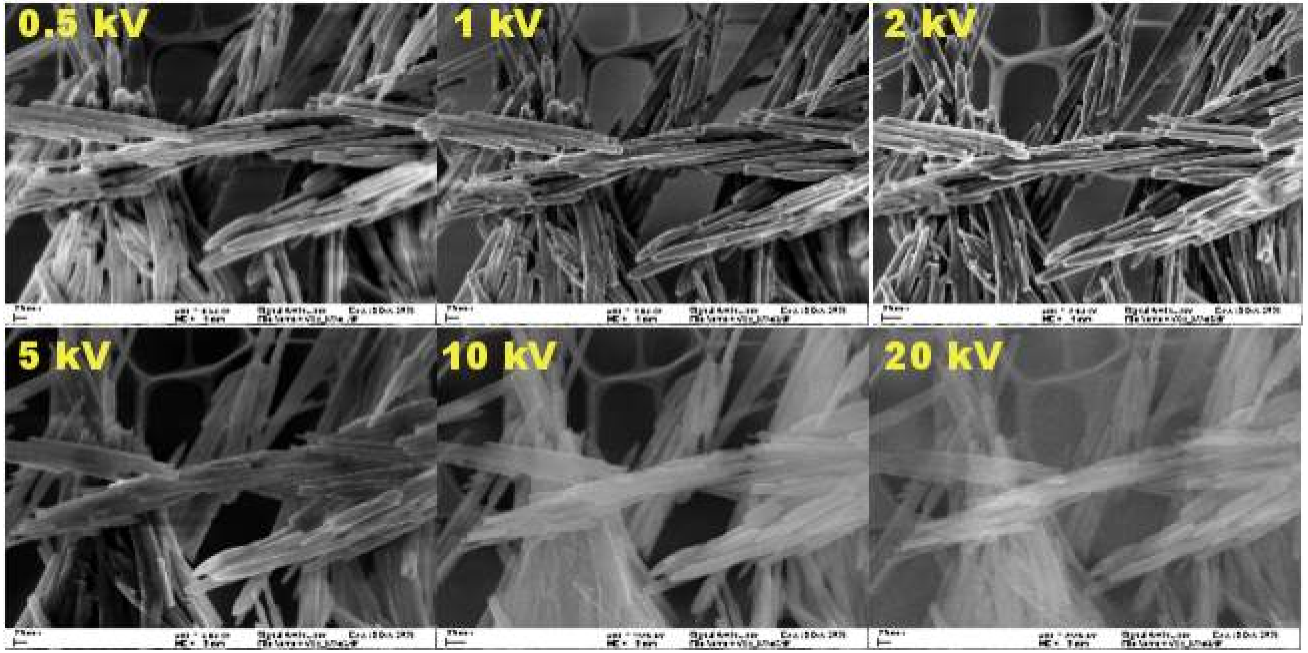
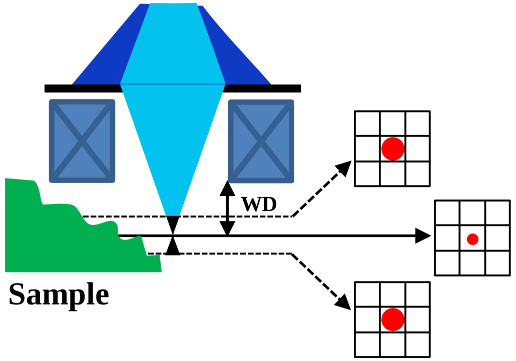
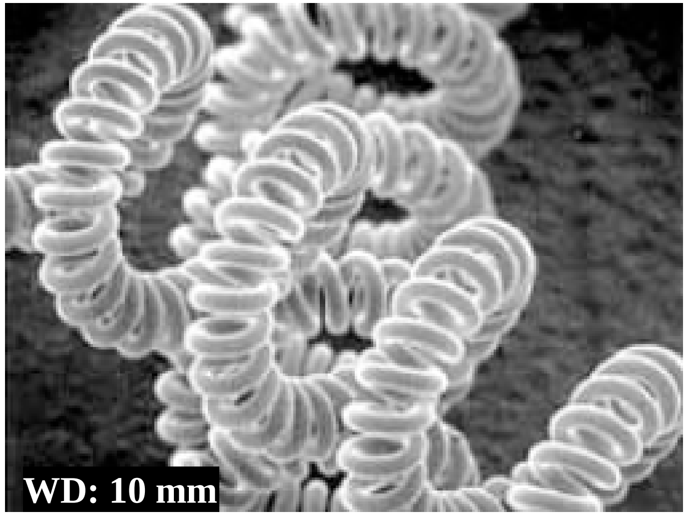
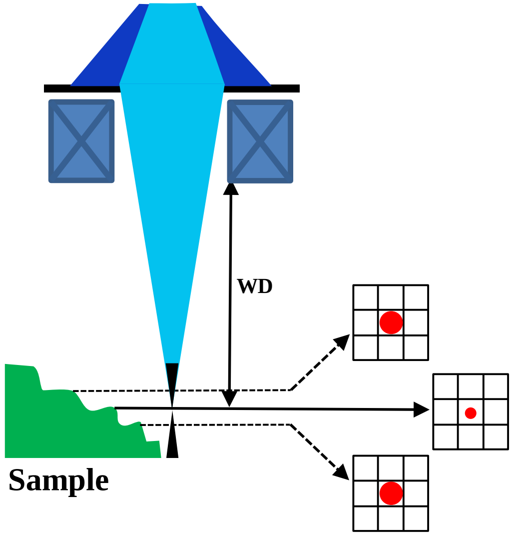


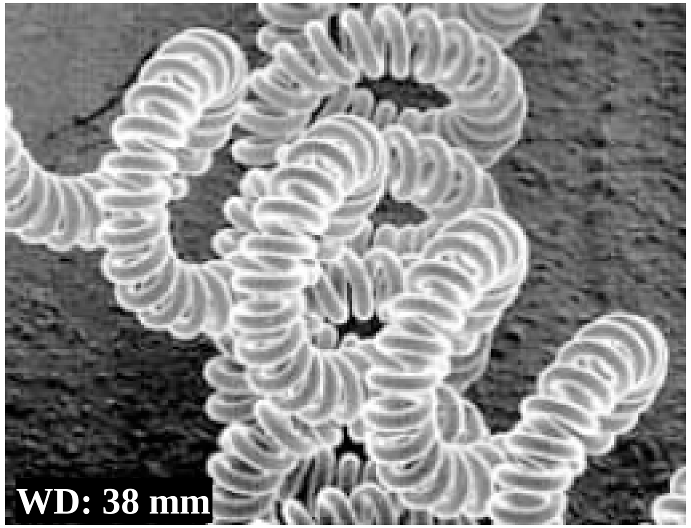
Image courtesy http://www.microscopy.ethz.ch/

Factors Affecting SE Emission: Working Distance (WD)







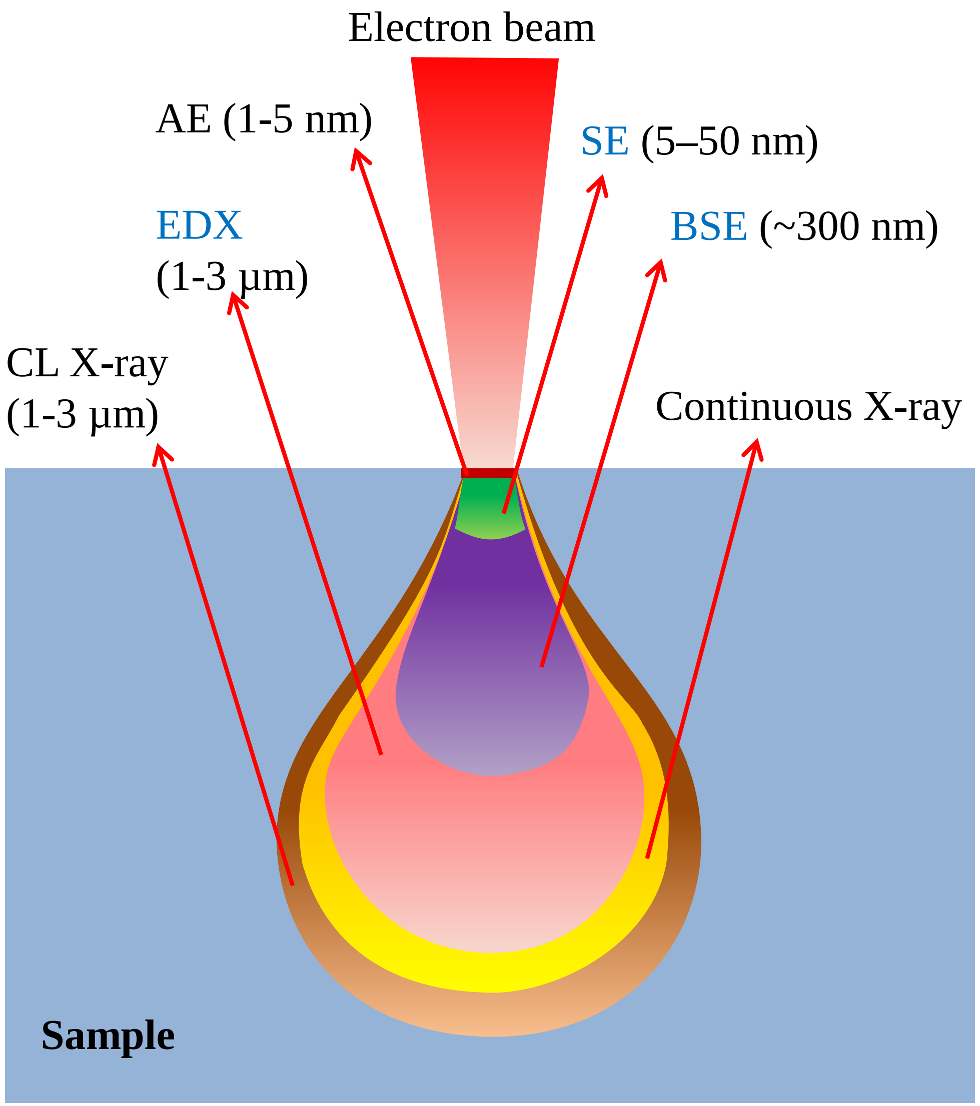


Working Distance: the distance between the bottom of the objective lens and the specimen

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

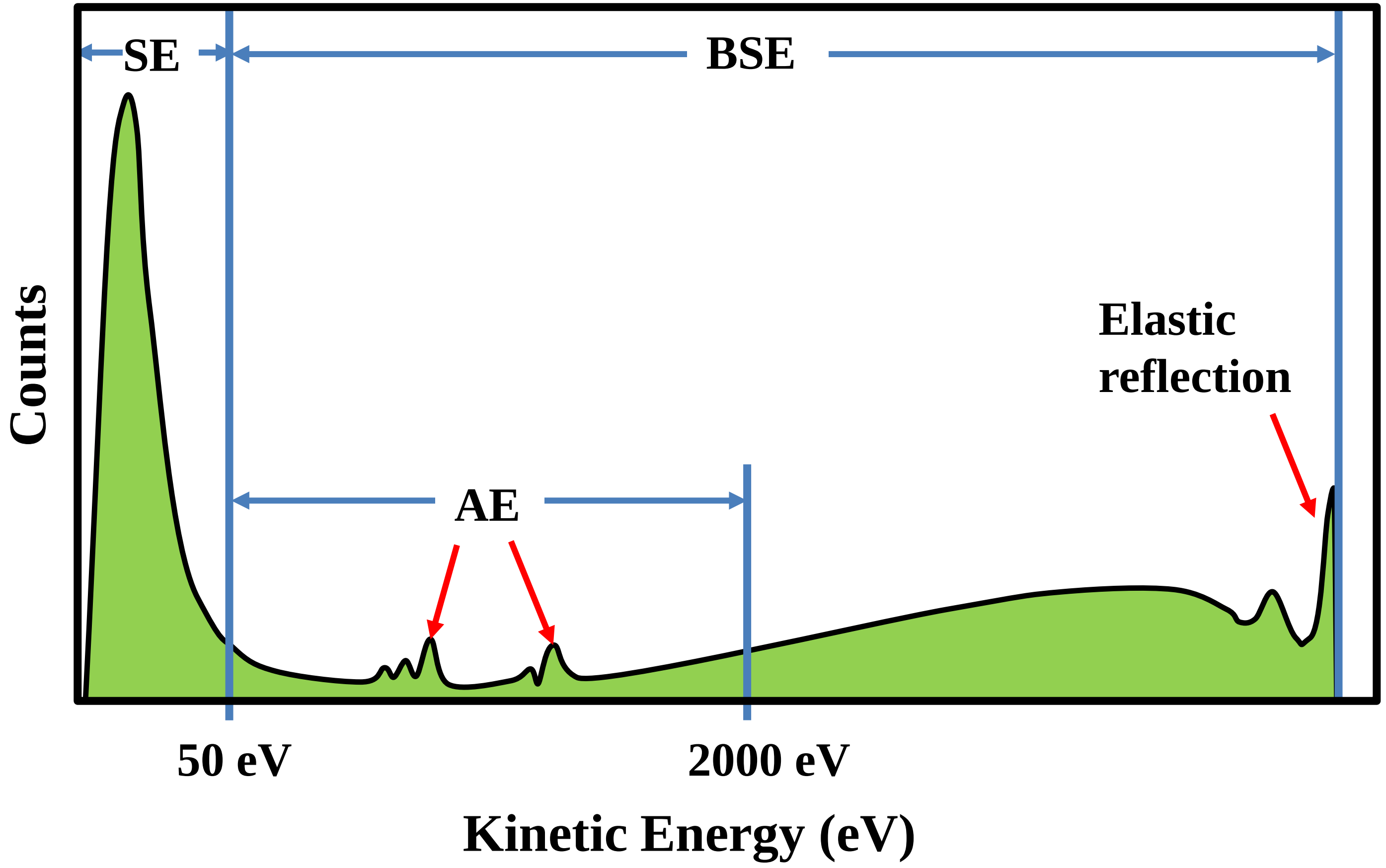


- **Secondary electrons (SE < 50 eV)→** Topographical information
- **Back-scattered electrons (BSE) →**
  Composition (atomic number) and topographical information
- **Characteristic X-ray (EDX)→** Composition information (Energy Dispersive X-ray Spectroscopy)
- **Auger electrons (AE)→**
  Surface sensitive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

Imaging resolution ← Interaction volume

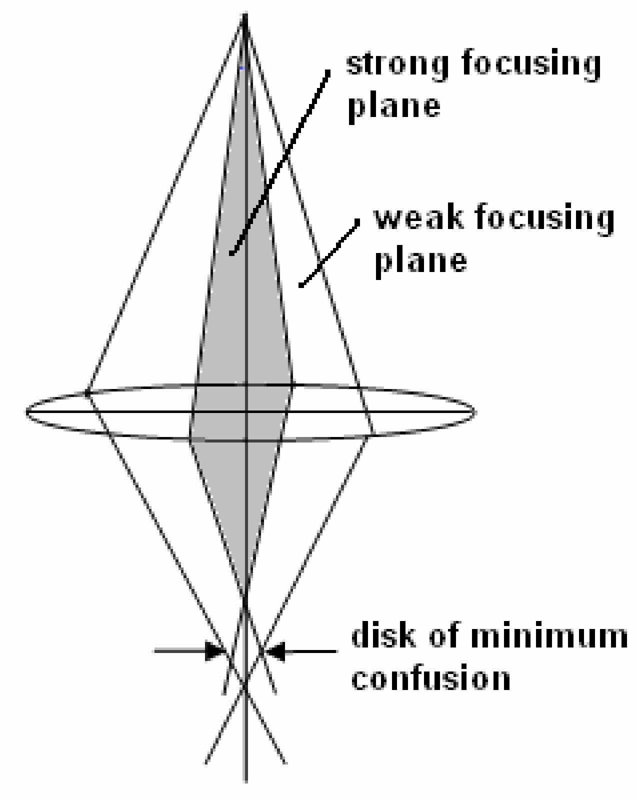
Schematic Electron Energy Spectrum

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

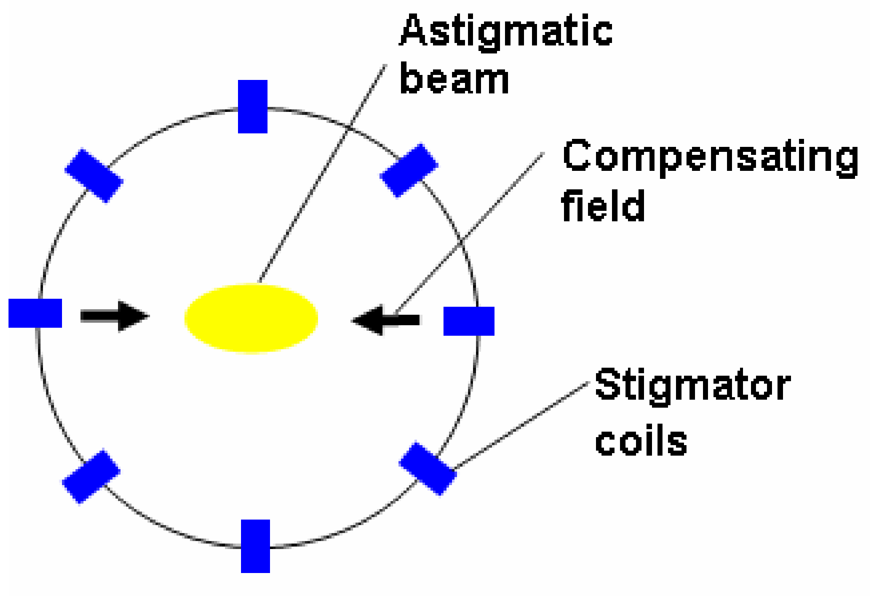


Goldstein et al. 1981

Lens Aberrations: Astigmatism

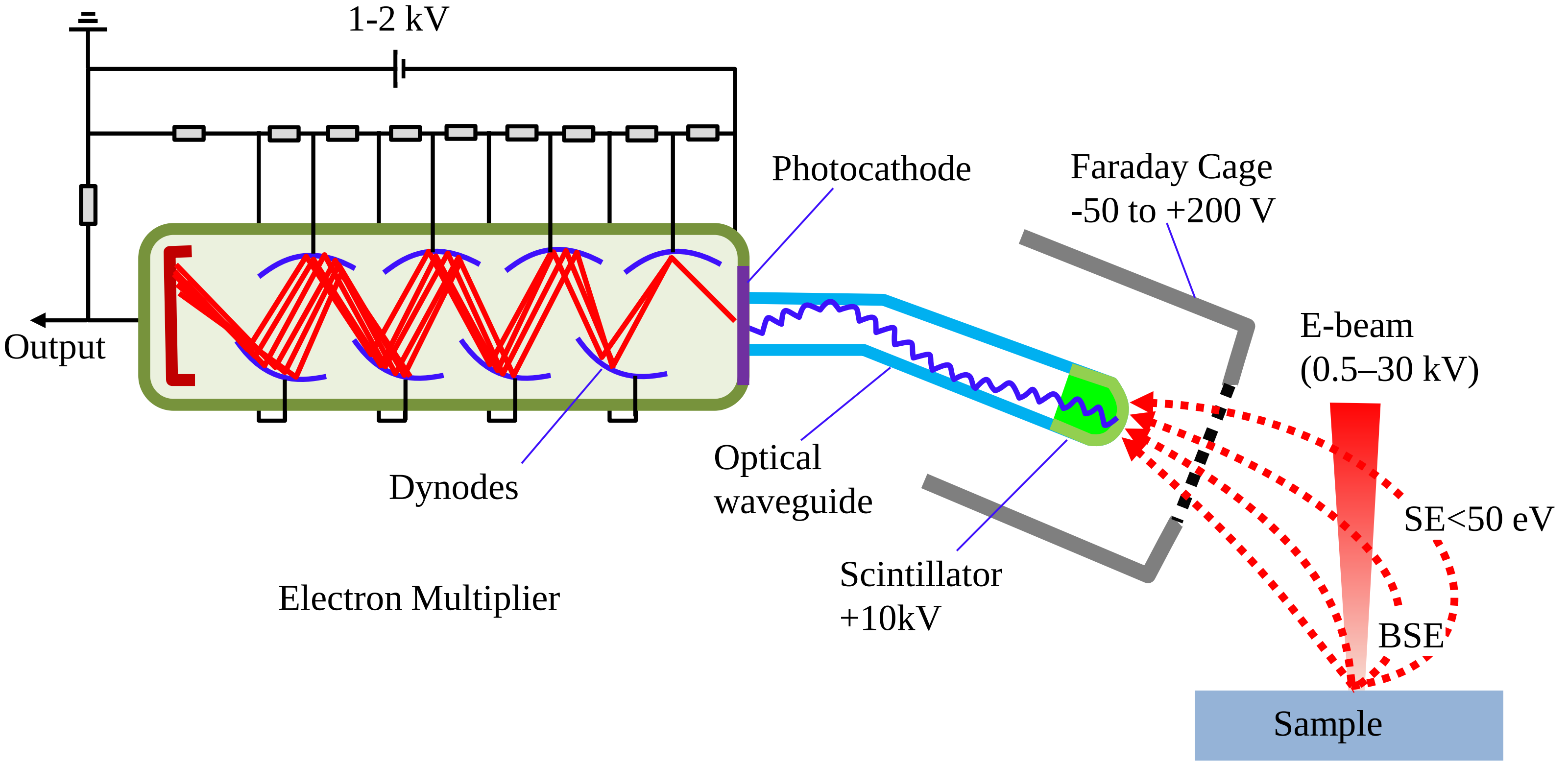


- The SEM electromagnetic lenses can not be machined to perfect symmetry.
- A lack of symmetry → an oblong beam: a disk of minimum confusion
  - stronger focusing plane → narrower beam diameter
  - weaker focusing plane → wider diameter



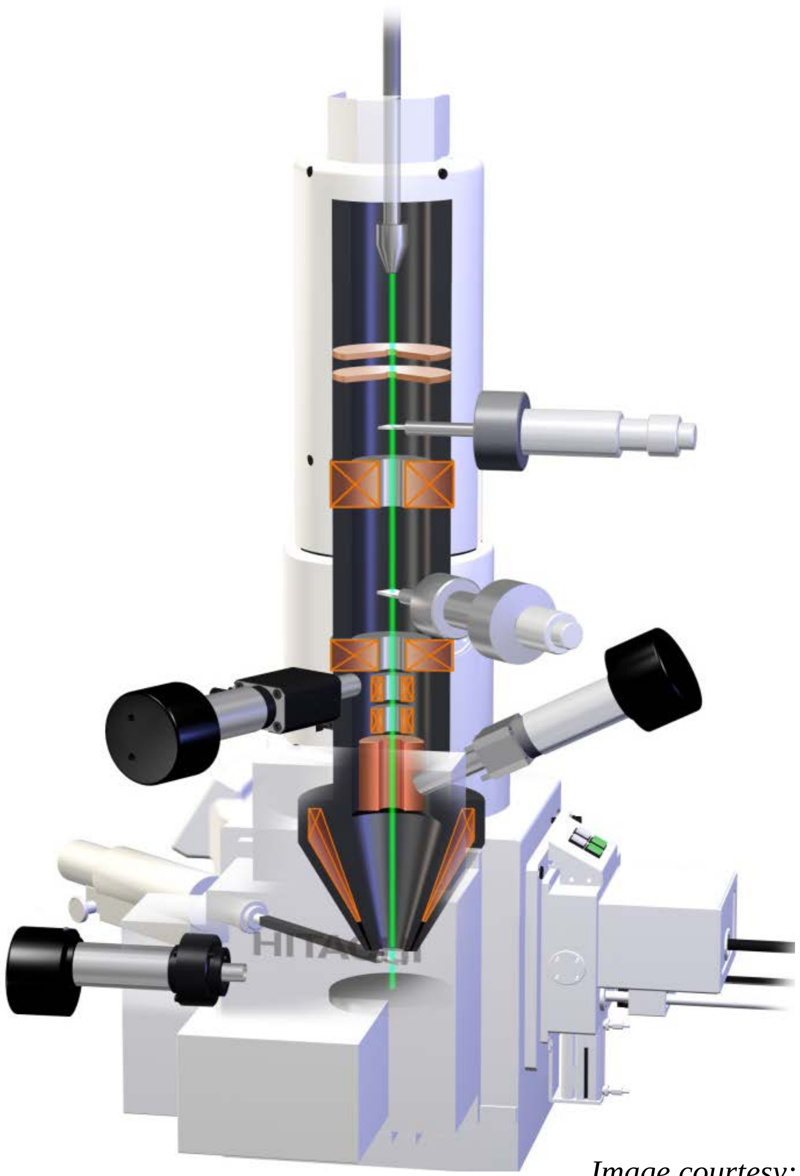
- Astigmatism correction
  - Apply current differentially to stigmator coils → circular beam

SE Detector: Everhart-Thornley (E-T) Detector



- 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



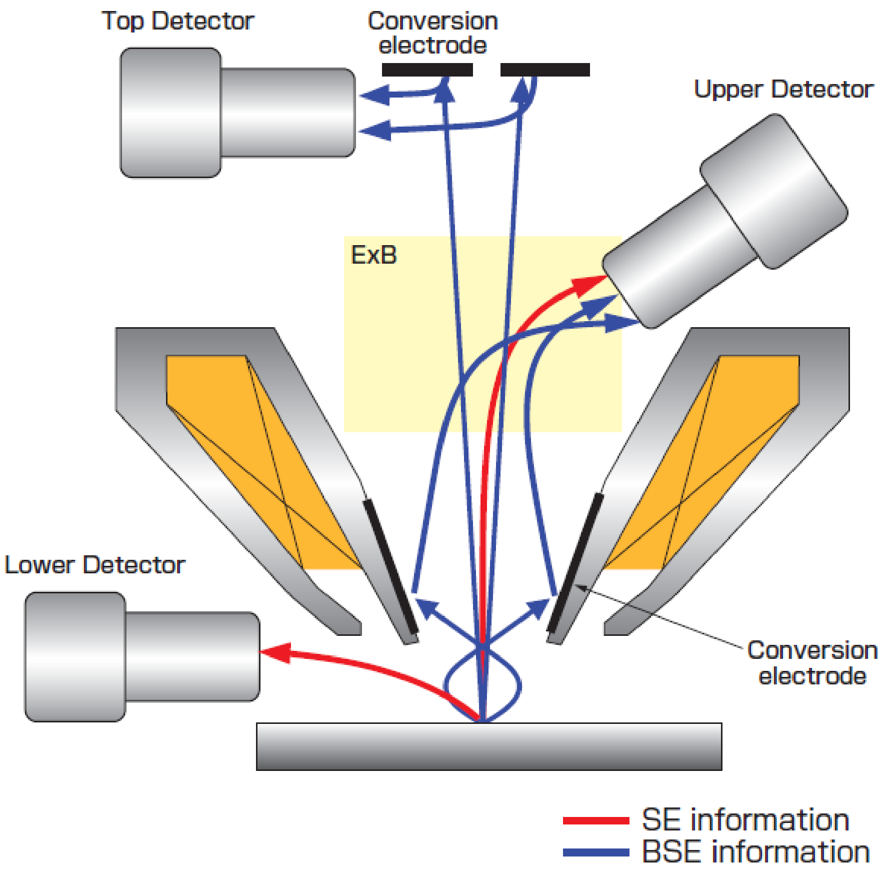
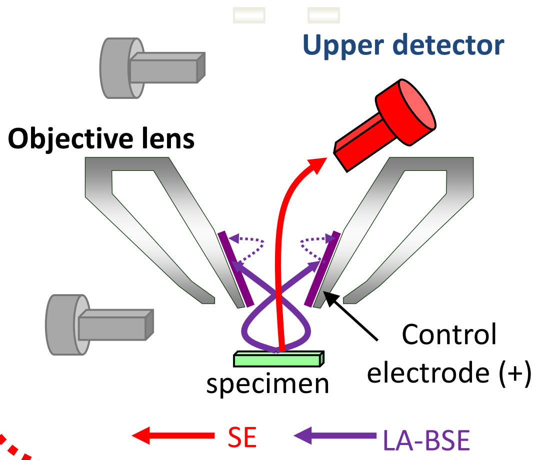


Image courtesy: Muto Atsushi, Hitachi

- 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

Multiple Detection Modes:

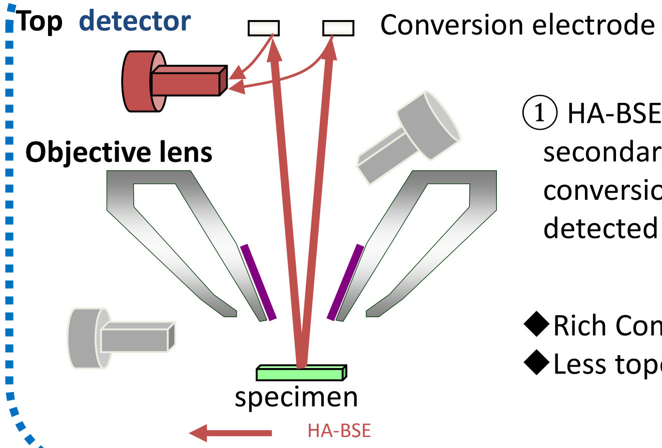
SE image : SE(U)



① SE is detected with the Upper detector through the objective lens.
② backscattered electron is not detected.

◆Rich Topographical information
◆High-resolution
◆Good voltage contrast

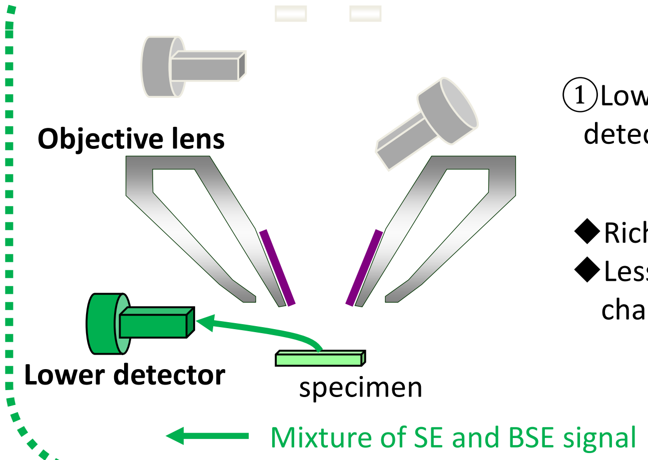
HA-BSE image : HA-BSE(T)



① HA-BSE is converted to secondary electron at the conversion electrode and detected with the Top detector.

◆Rich Compositional information
◆Less topographic information

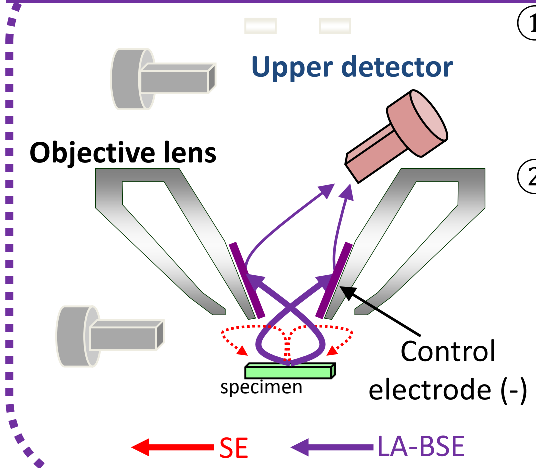
SE image : SE(L)



①Low angle BSE and SE are detected with the Lower detector.

◆Rich Topographic information
◆Less sensitive to specimen charging artifacts

LA-BSE image : LA-BSE(U)



① LA-BSE is converted to secondary electron at the control electrode and detected with the Upper detector.
② 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

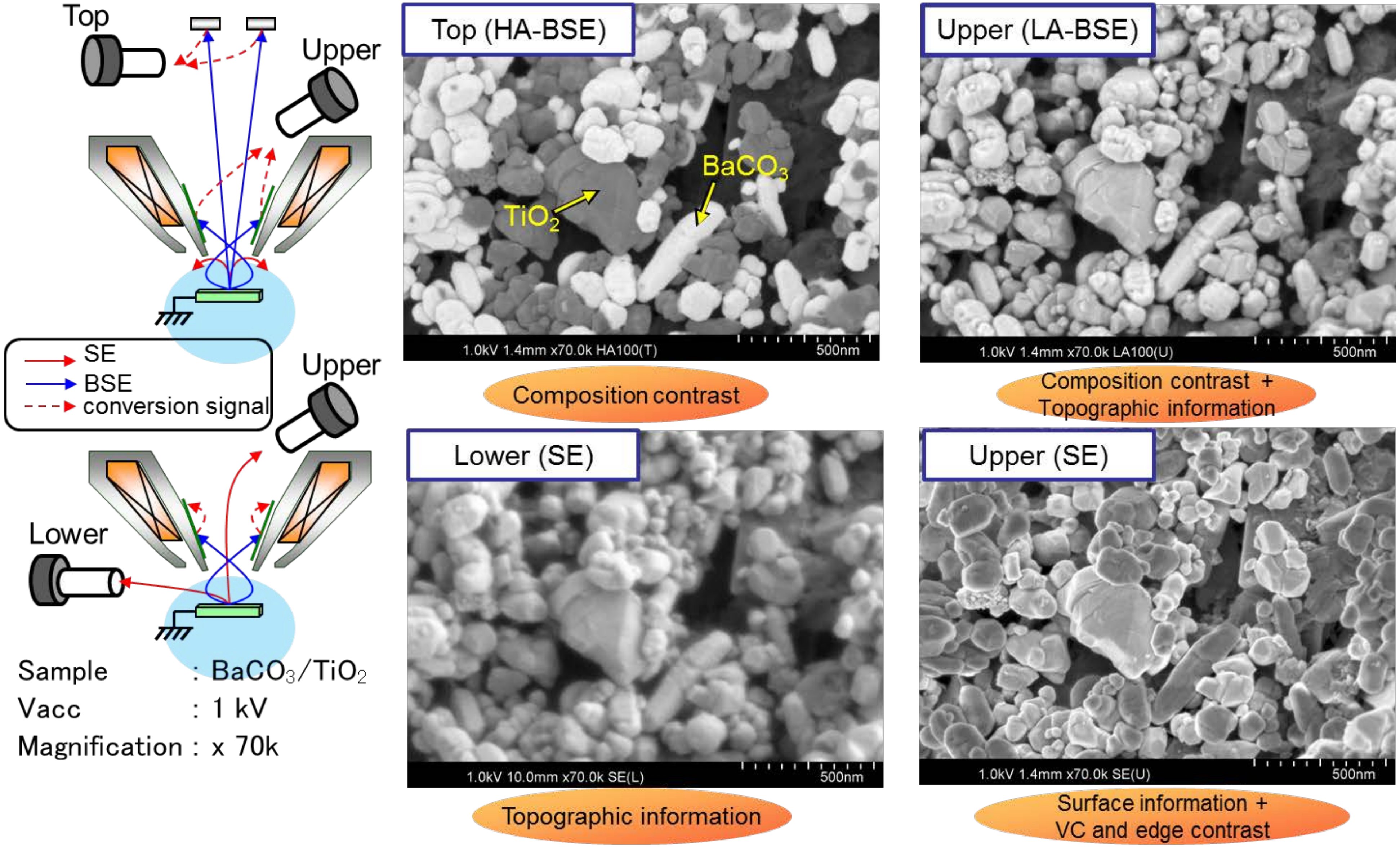
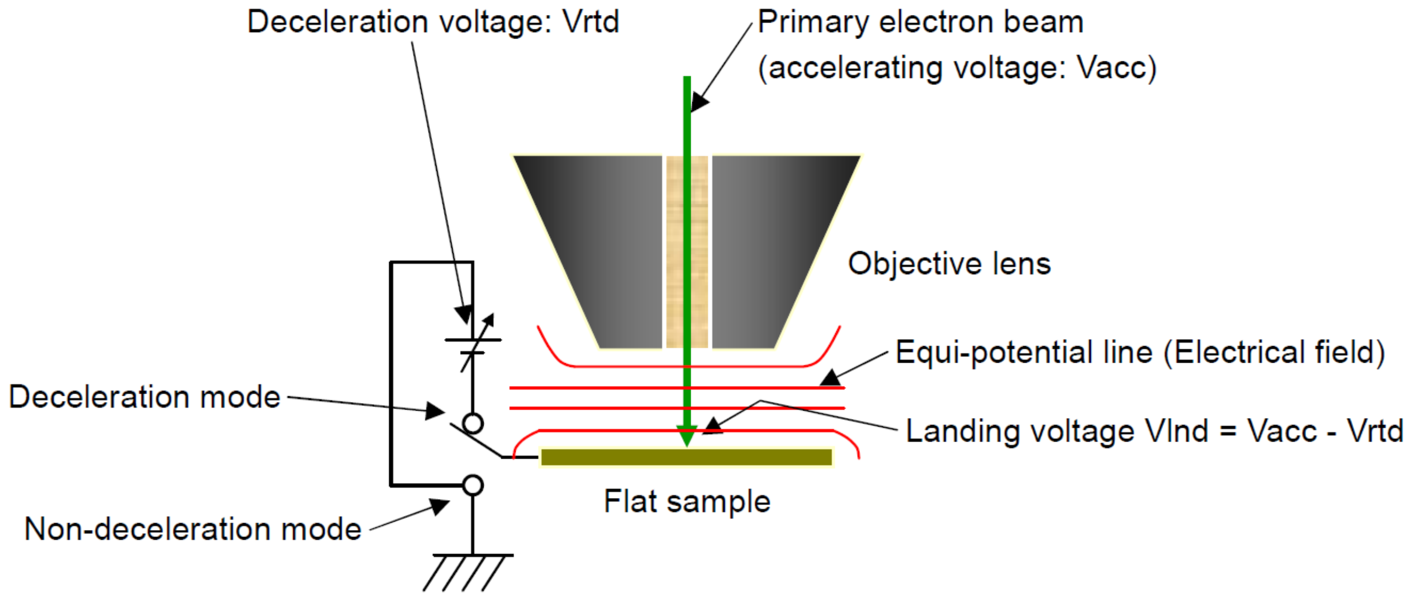


Image courtesy: Muto Atsushi, Hitachi

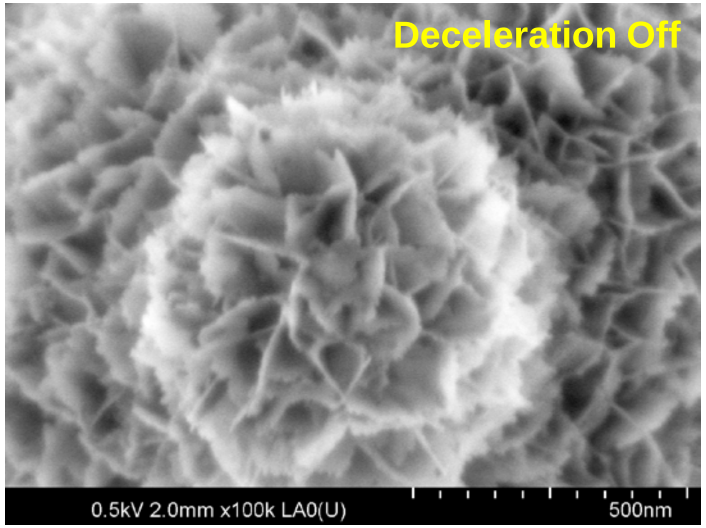
Beam Deceleration (Landing voltage 10 V ~ 2 kV)

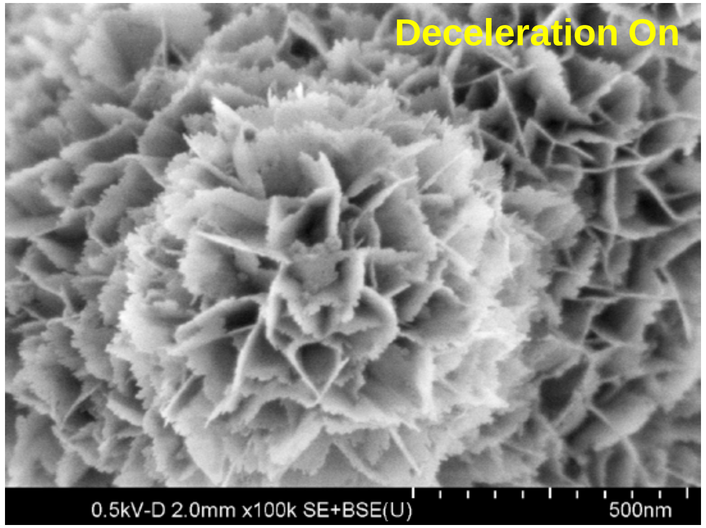


- A negative voltage (deceleration voltage, V_{rtd} up to 3.5 kV) applied to the specimen, thereby slowing down the primary electron beam to the desired landing energy.
- Landing voltage (10 V – 2 kV):

  $V_{lnd} = V_{acc} - V_{rtd}$;

  V_{rtd} : Deceleration voltage
- Resolution improved in deceleration mode



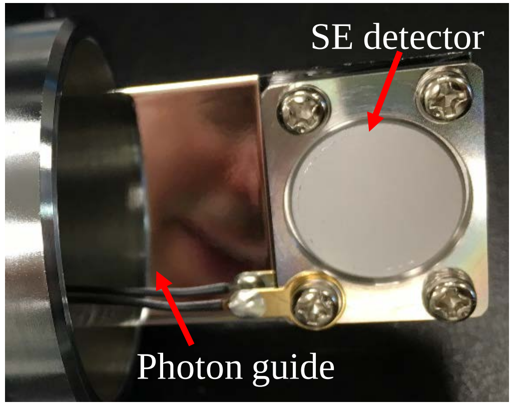


Al electrolytic capacitor

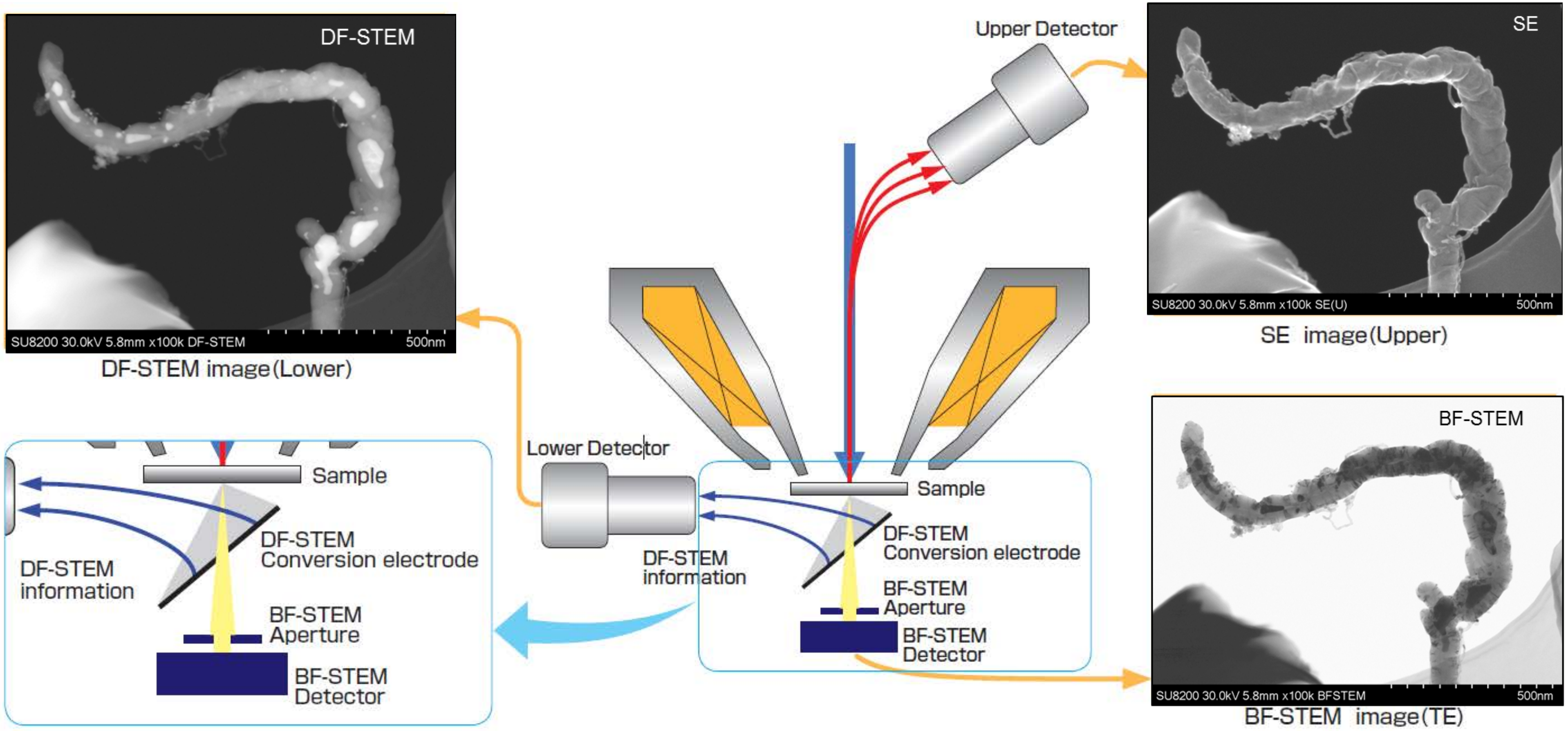
Image courtesy: Muto Atsushi, Hitachi

Scanning Transmission Electron Microscope (STEM) Mode

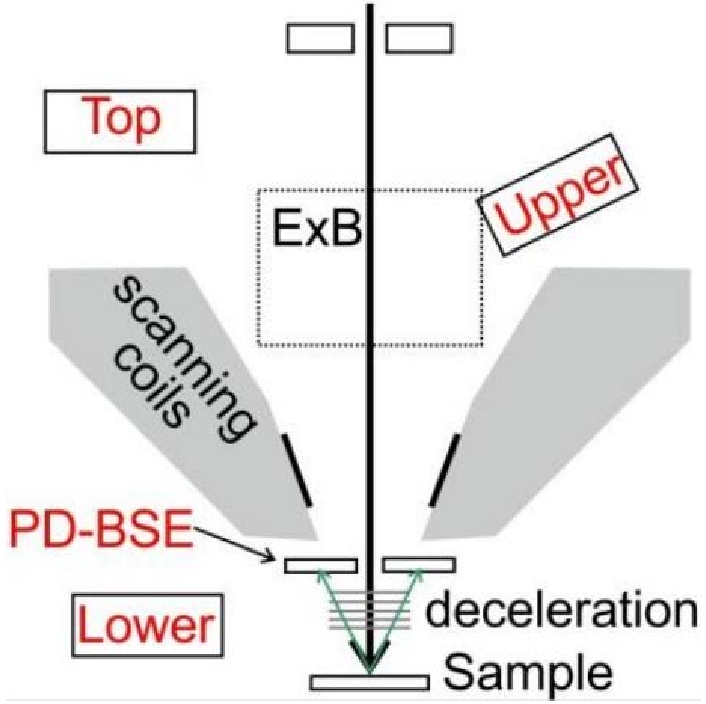
STEM detector

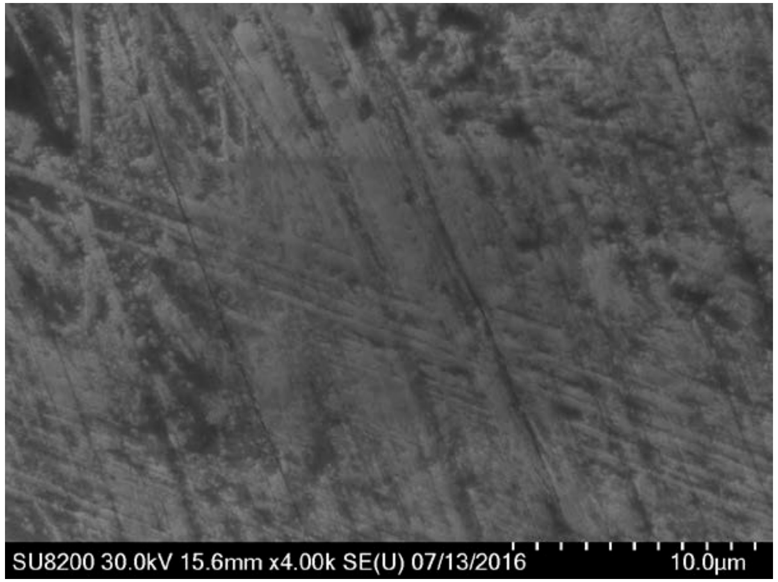


- STEM → internal sample information
- BT-STEM (Bright Field) → enhanced contrast
- DF-STEM (Dark Field) → surface details

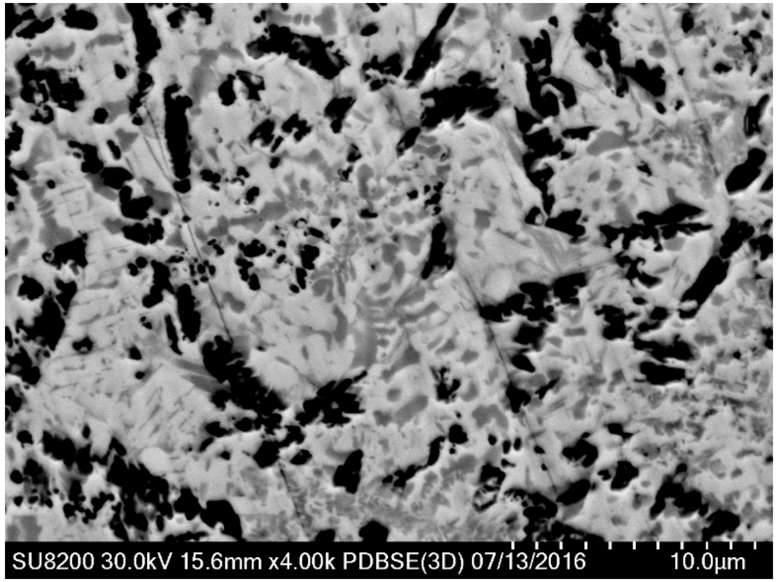


PhotoDiode (PD) - BSE Detector

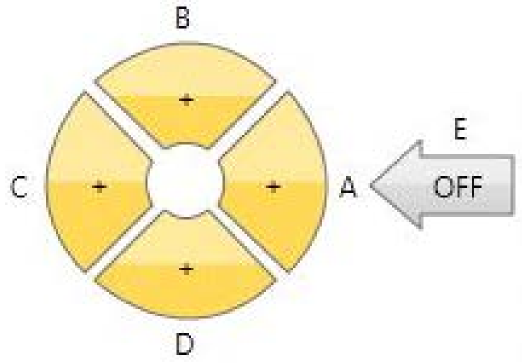


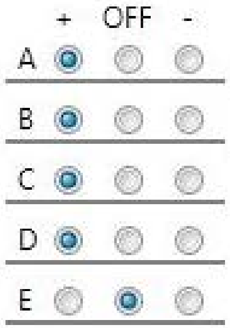


SE imaging



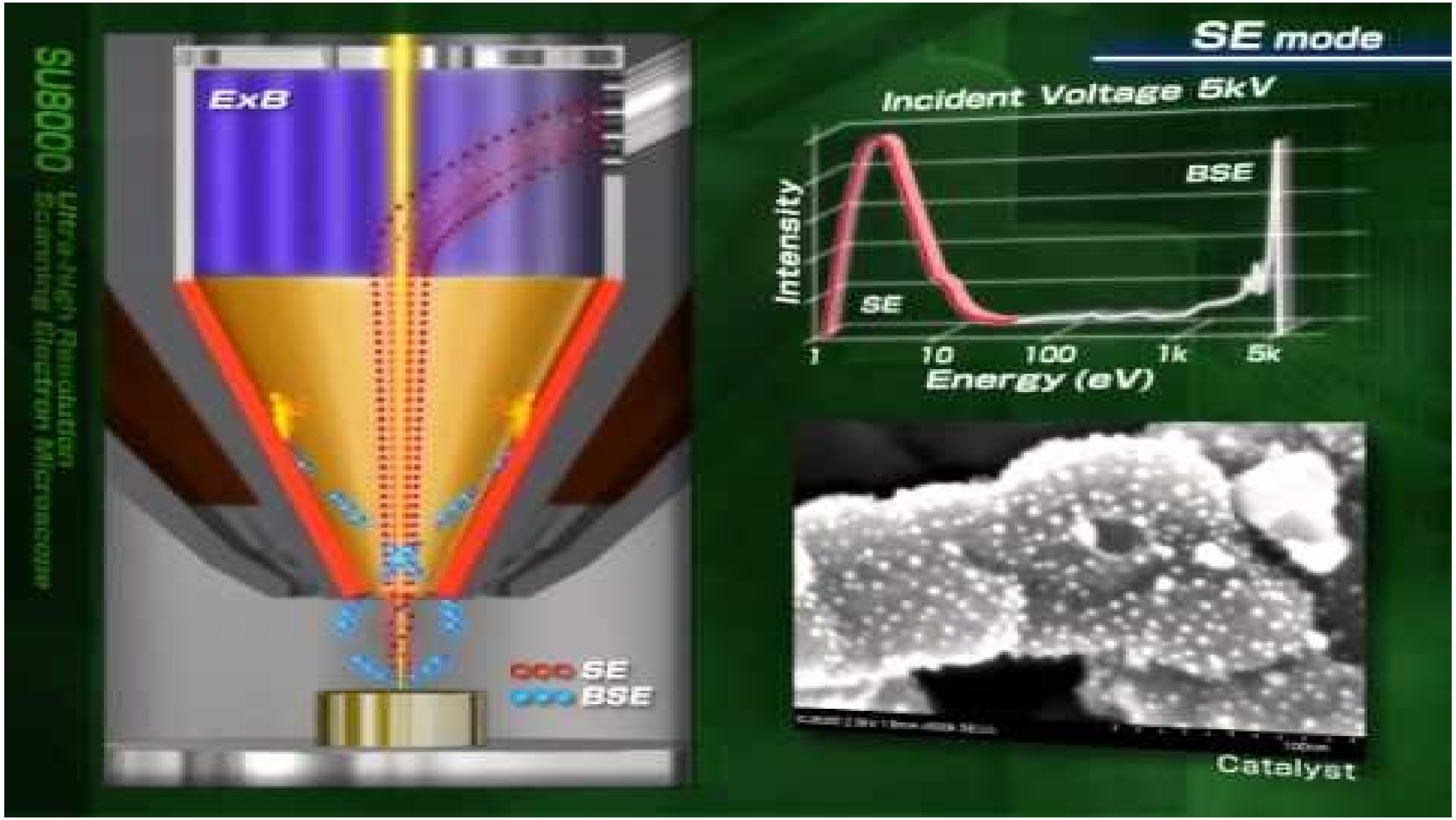
BSE imaging





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

Hitachi SU8000 – Video Summary



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