University of Wisconsin-Madison
Materials Research Science and Engineering Center
Facilities Days Open House 2018

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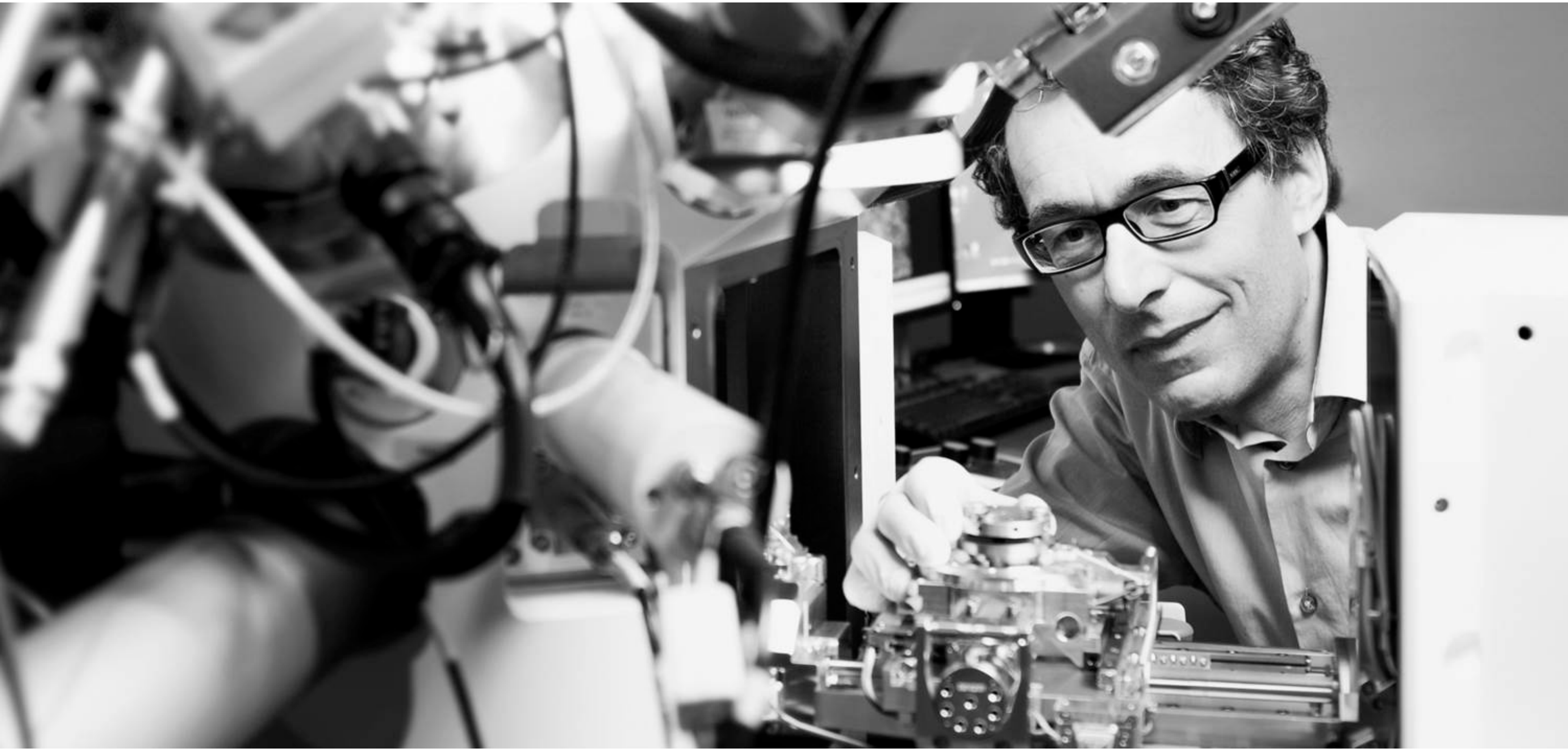
Two atoms were walking down the street when one *said*, "Oh my, I've lost *an electron*!" *The other said, "Are you* sure?" "Yes, I'm positive!".

Scanning Electron Microscopy and Energy-Dispersive X-Ray Spectroscopy

Facilities Days Open House 2018



Chris Santeufemio
Senior Applications Engineer
Thornwood, NY, 2018-04-09

Scanning Electron Microscopy and Energy-Dispersive X-Ray Spectroscopy

Facilities Days Open House 2018

Christopher Santeufemio
Senior Applications Engineer
Carl Zeiss Microscopy

Chris is a career-long Electron Microscopist, with 30 years of experience in Microscopy. First used a Zeiss TEM as undergrad. Has been a Zeiss customer for his whole career, and just recently joined Zeiss as Senior Applications Engineer in 2016.

He split his career between Biological and Material Science, working in Ultrastructural Pathology and Neuroanatomy at Hartford Hospital, St. Barnabas Medical Center, and McLean Hospital. Chris worked at Raytheon doing SEM, Metrology, Failure Analysis and Material Science, and at Epion Corporation where he helped develop the Gas Cluster Ion Beam system for Materials Applications.

At the University of Massachusetts, Lowell, Materials Characterization Lab, Chris managed the operation of 2 SEMs, 2 FESEMs, 3 TEMs, 3 AFMs, an E-Beam Lithography system and a FIB-SEM housed in a new, state of the art Emerging Technologies Center.

Gaining more business expertise, Chris worked with MicroVision Labs as Senior Analyst and VP of Business Development. He has extensive experience in TEM, SEM, STEM, FIB-SEM, AFM and Optical Microscopy.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GeminiSEM 500

Intro

The scanning electron microscope (SEM) is a type of microscope that produces images of a sample by scanning the surface with a focused beam of electrons.

The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition.

The electron beam is scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image.

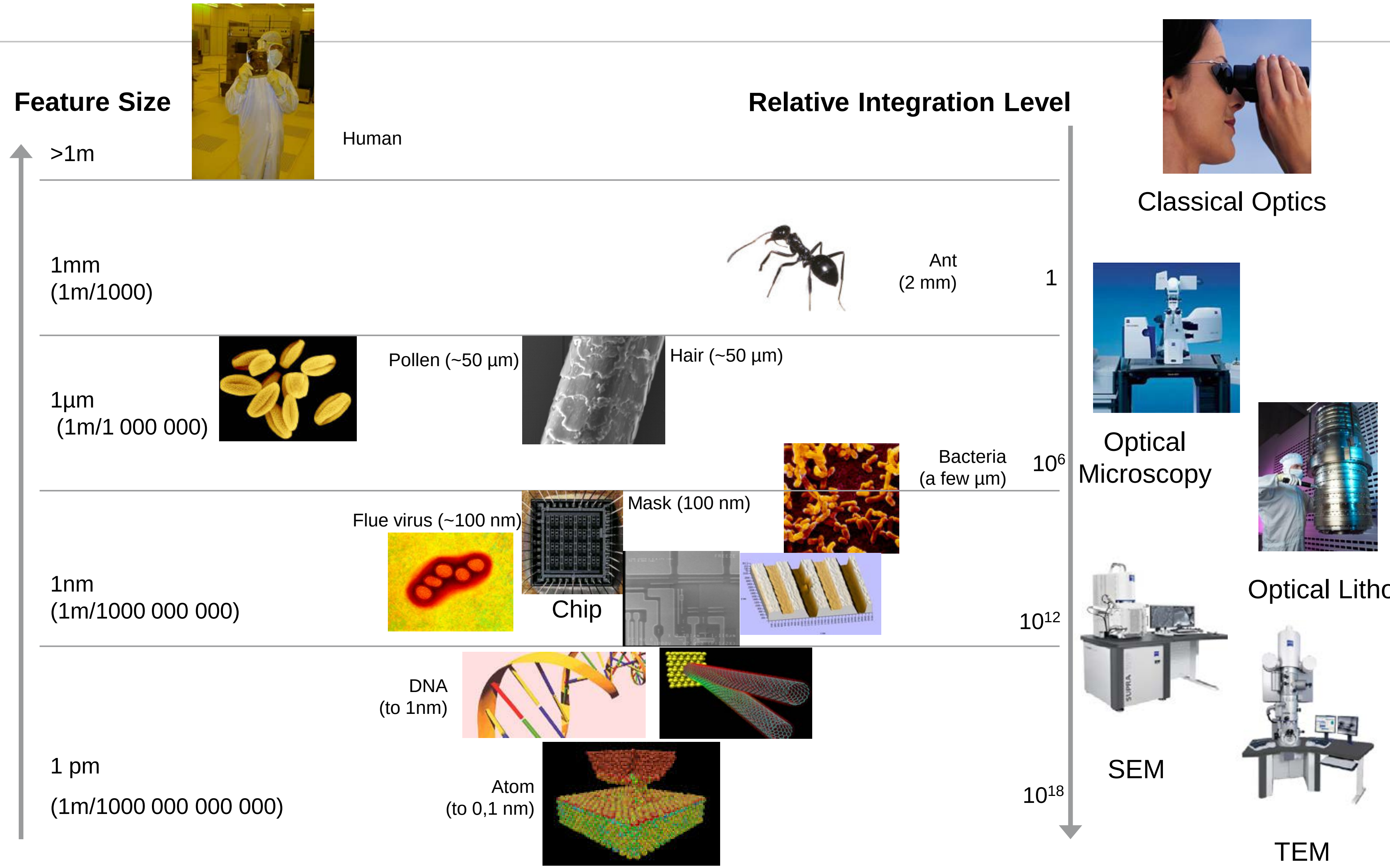
SEM can achieve resolution better than 1 nanometer, or $1\text{x}10^{-9}$ meters

Specimens can be observed in high vacuum in conventional SEM, or in low vacuum or wet conditions in variable pressure or environmental SEM, and at a wide range of cryogenic or elevated temperatures with specialized instruments.

Characteristic X-rays that are produced by the interaction of electrons with the sample may also be detected in an SEM equipped for energy-dispersive X-ray spectroscopy

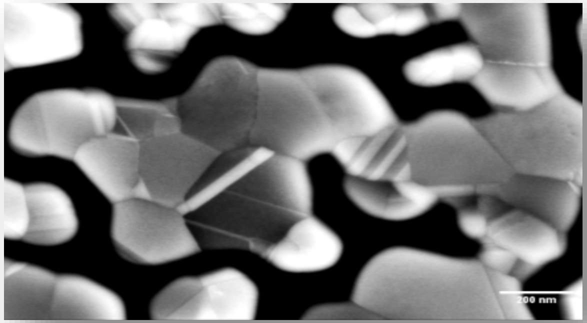
Analysis of the x-ray signals can be used to map the distribution and estimate the abundance of elements in the sample.

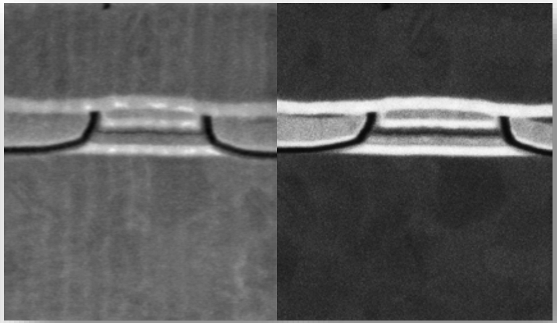
Overview of Micro and Nano Technology Solutions

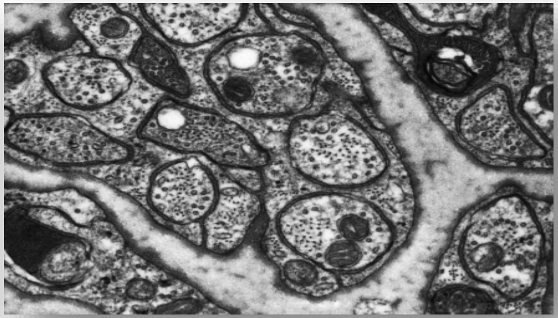


SEM offers Diverse Applications

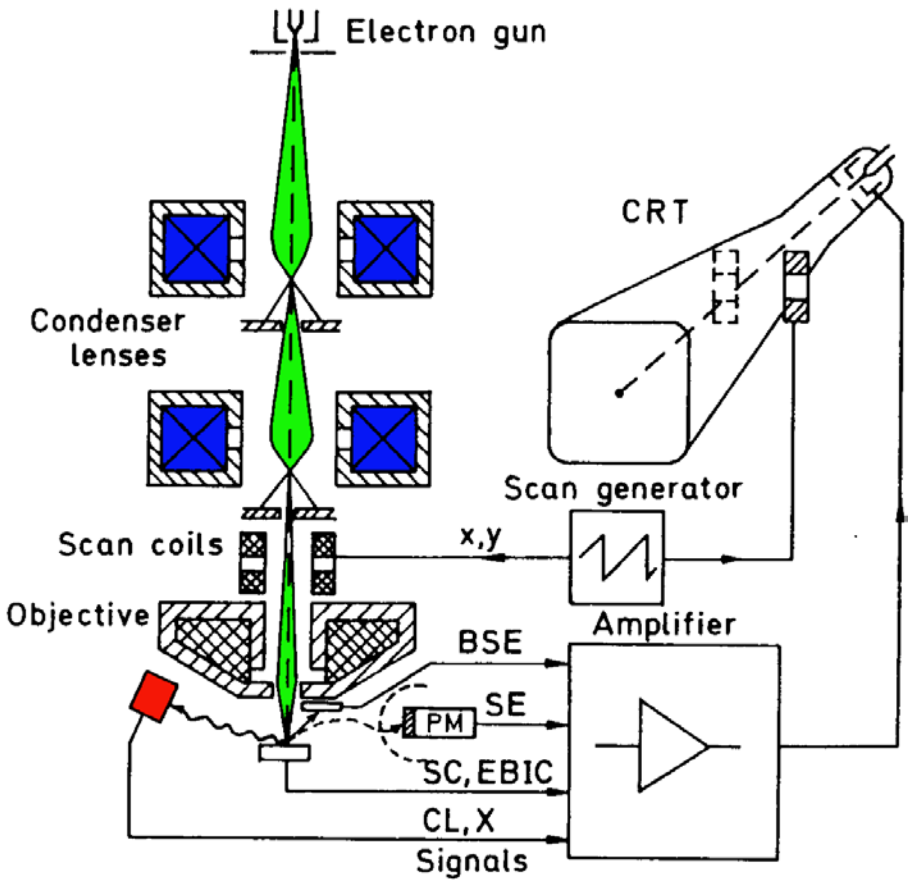
Materials Science	Industry	Life Science
Basic Materials, Functional Materials, Nanomaterials, 2D Materials Metals, Alloys Ceramics, Minerals, Polymers, Composites	Semiconductor Data Storage, Telecom, Flat Panel Electronics Battery, Solar Silicon, Resist, Metals, Particles, Catalyst	Bio, Pharma, Cosmetics, Medical Diagnostics, Brain Research Nano Bio Tech Drugs, Cells, Tissues

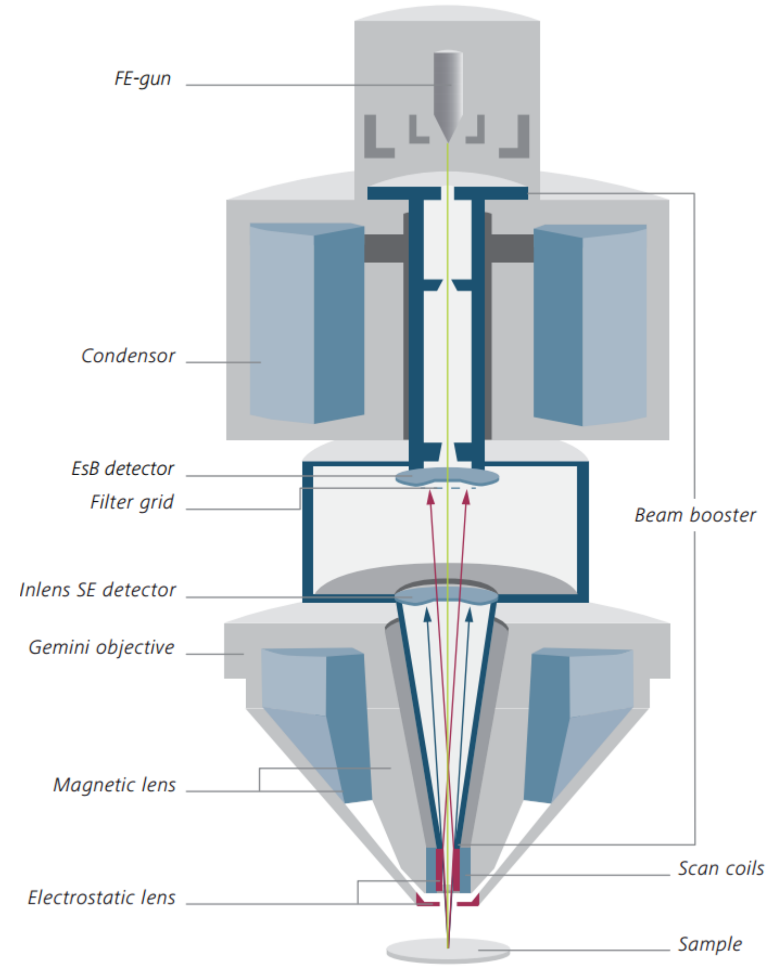






Scanning Electron Microscopes

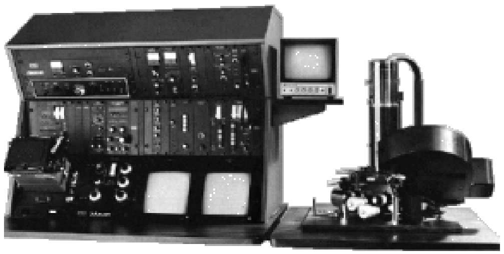




Schematic of a SEM

SEM & EDS

Recent Historical SEMs - 1900s


ETEC Autoscan


ETEC Bioscan


Bausch & Lomb Nanolab LE2100


Perkin Elmer Hitachi HFS-2


ISI Mini-SEM


Zeiss 982 Gemini


ISI Super 3A (40)


Cambridge 600


Amray 1000


Amray 1200

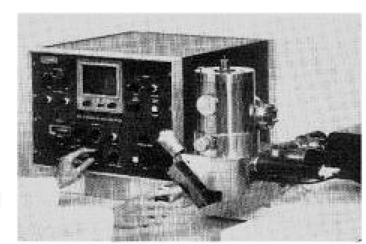

JEOL JSM-35


Cambridge 180

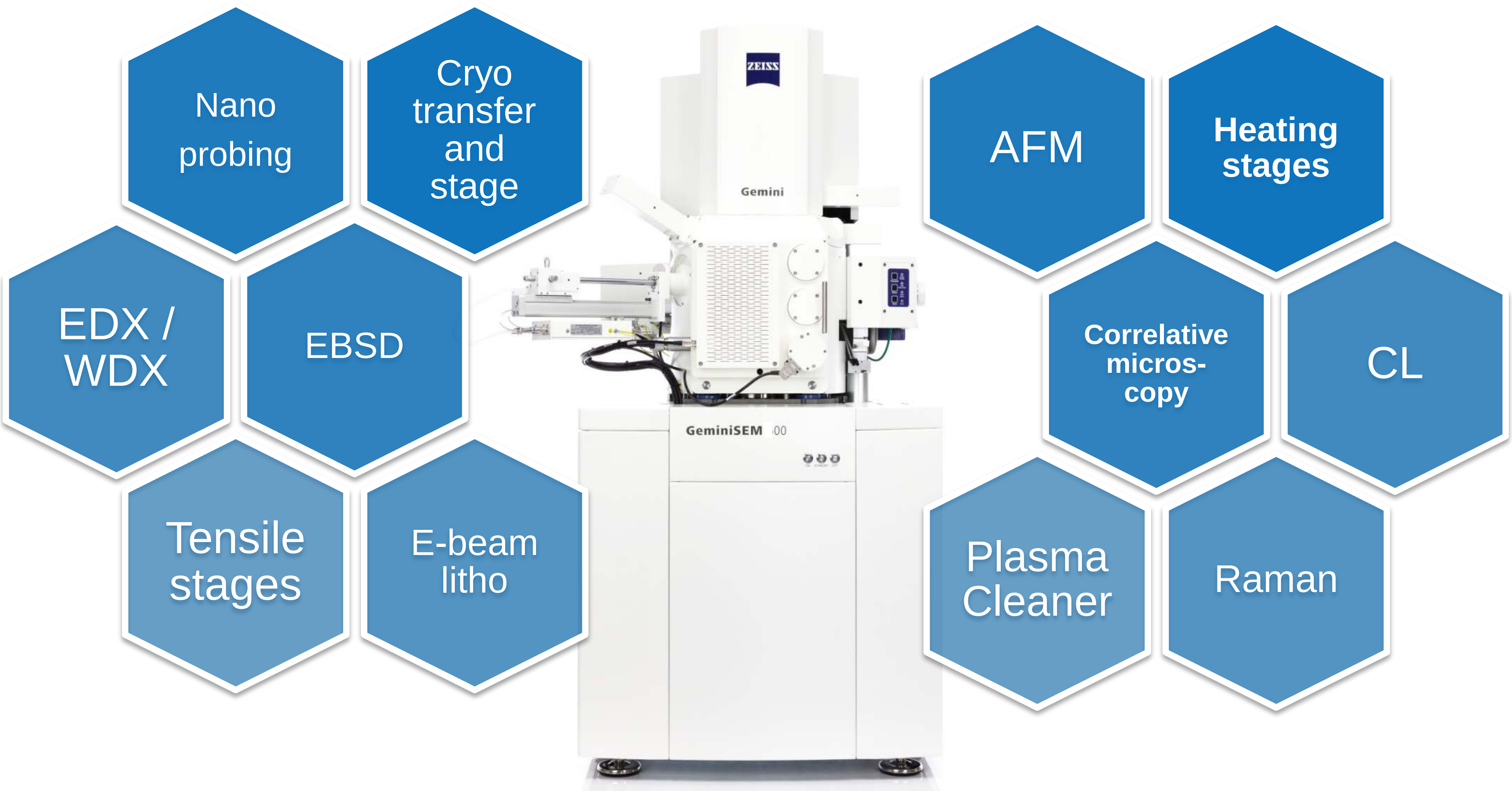

ISI DS-130


Hitachi S800

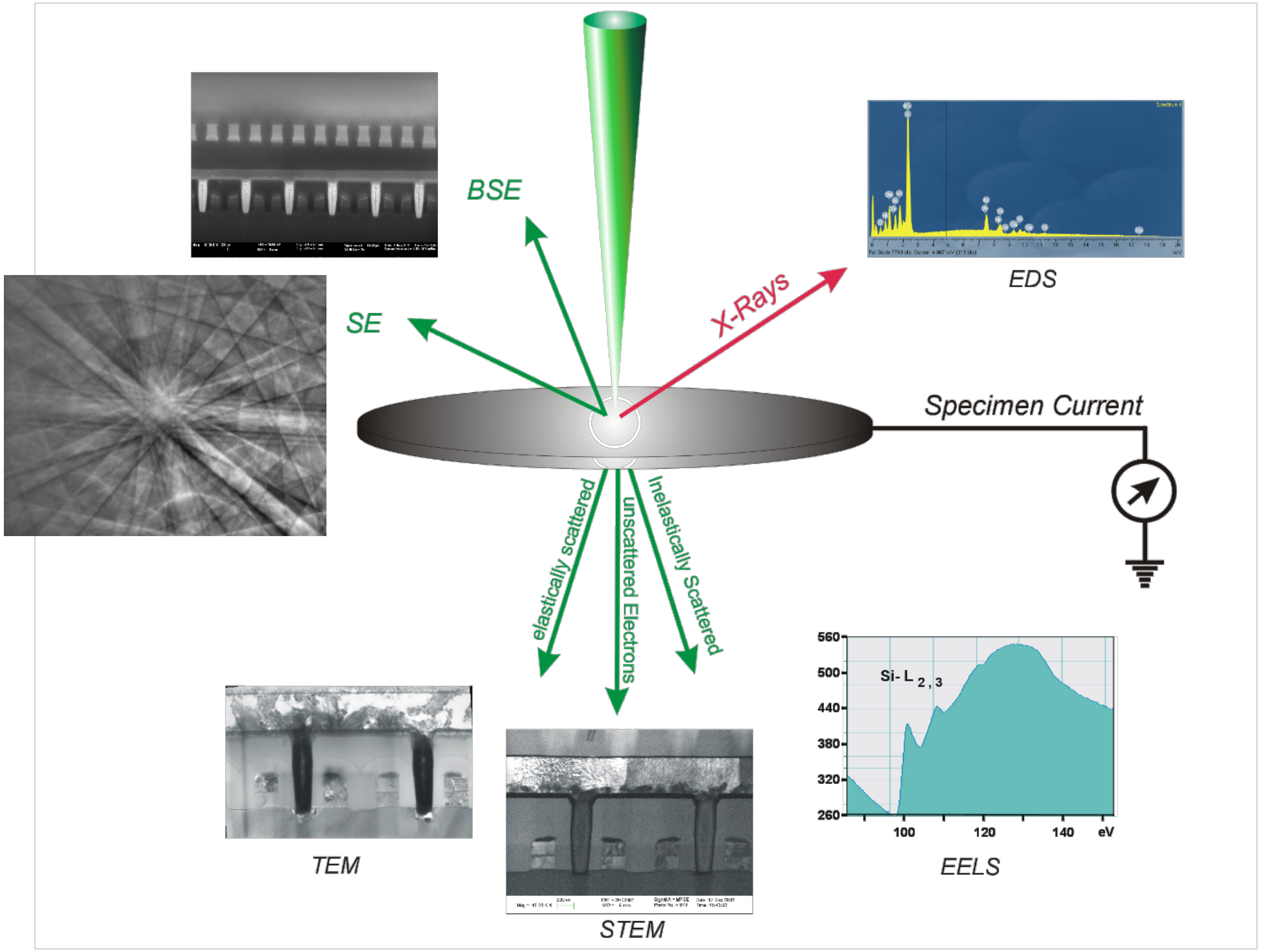

Hitachi TM-1000


Coates & Welter CWIKSCAN/100

State of the Art SEM systems offer Flexibility to Seamless Integration of 3rd Party Accessories and *in situ* Experiments

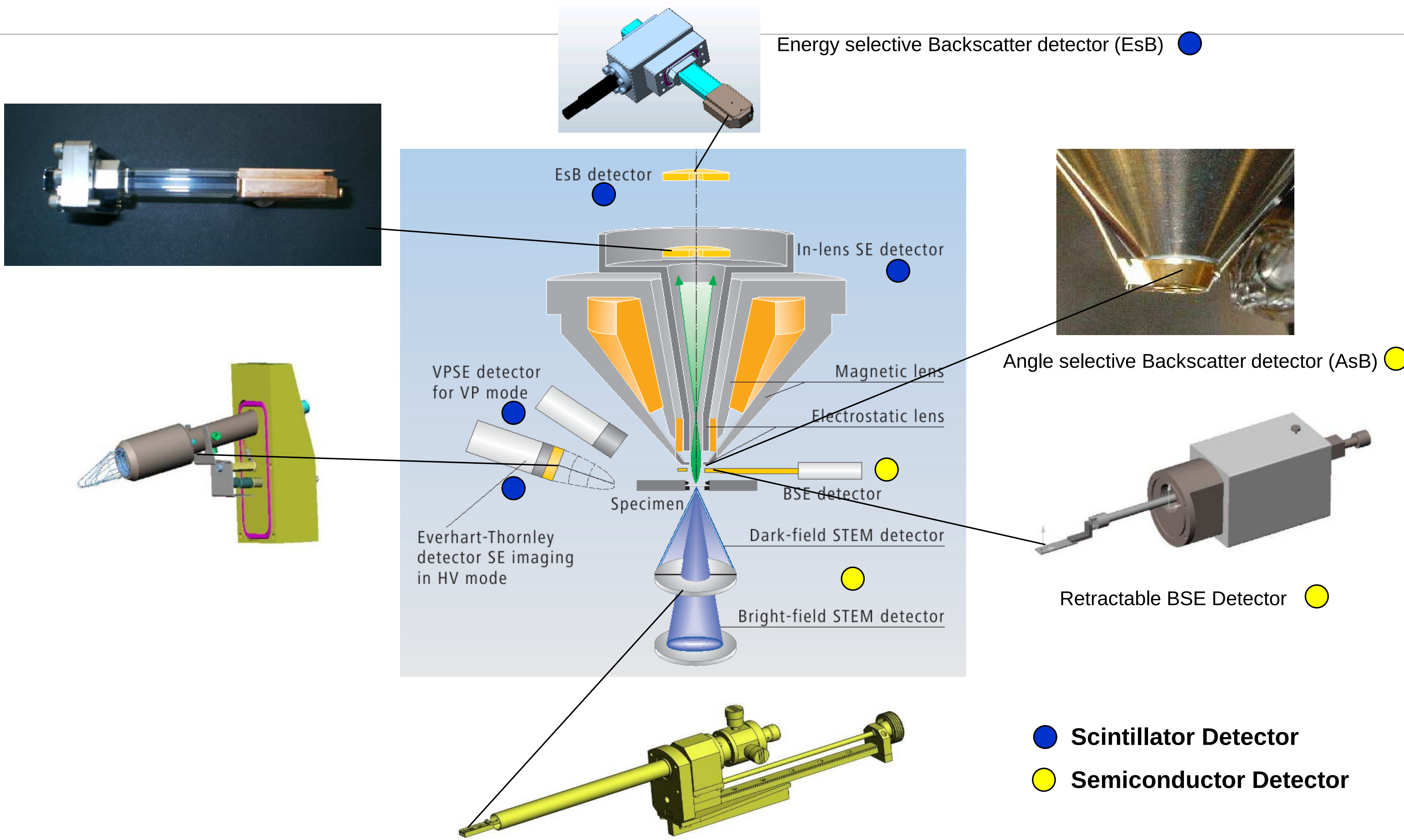


Scanning Electron Microscopy and Energy-Dispersive X-Ray Spectroscopy



Beam Sample interaction

Various Electron Detectors



Comparison of Various Microanalytical Techniques

Name	Enegy in	Energy out	Resolution		Detection Limit	Lightest Element	Imaging	Other Info	Comments
			Lateral	Depth					
SEM	e- (2 - 30 keV)	SE (50eV)	1 nm	5 nm	1000 ppm	Be	Yes		Routine, easy sample
EDS		BSE (Eo)	<0.1 um	<0.5 um			Yes		Prep good imaging
		X-rays (>108 eV)	<0.1 um	<0.5 um			Yes		and analysis
EPMA	e- (5 - 50 keV)	X-rays (>108 eV)	<0.5 um	<0.5 um	50 ppm	Be	Yes		Quantitaive surface
WDS									
TEM	e- (100 keV - 1MeV)	TE (Eo)	0.2 nm	<100 nm	1000 ppm	Be	Yes	SAED	High resolution,
									electron diffraction
AEM	e- (200 - 400 keV)	TE (Eo)	0.2nm	<100 nm		B	Yes	CBED	Analytical resolution
STEM		SE (50 ev)	3 nm	3 nm		B	Yes		
EDS		X-ray (>108 ev)	5 nm	<100 nm	1000 ppm	Be	Yes		
EELS		electrons	20 nm	<10 nm	1000 ppm	Li	Yes		
AES	e- (1 - 3 keV)	e- (<200 ev)	~0.2 um	<3 nm	1000 ppm	Li	Yes		Quantitaive surface
									analysis
XPS/ESCA	X-rays (1 - 1.5 keV)	e- (>10 ev)	0.5 nm	<3 nm	1000 ppm	He	No	binding	Chemical state
								energy	information
SIMS	ions (4 - 15 keV)	secondary ions	5 um	0.1 nm	1 ppb	H	some	depth profile,	Non-dedestructive depth
								mass	profile
PIXE	H+, He++ (~3 MeV)	X-rays	2 um		1 ppm	B	some		Analytical sensitivity
RBS	H+, He++	H+ He++ (<Eo)	2 mm	10 nm	1 - 1000 ppm	Li	No	depth profile,	Non-dedestructive depth
	(2 - 25 MeV							mass	profile
LIMA	UV (250 nm)	ions	~2 um	~2 um	1 ppm	H	Yes	mass	Analytical sensitivity,
LAMMA									mass spectrum
MicroRaman	visible light	visible light	~2 um				some	molecular	Phase identification
	~500 nm							spectrum	
MicroFTIR	IR light	reflected or	10 um				some	molecular	Phase and functional
		transmitted IR						spectrum	group identification
Micro-XRF	X-rays 1-100keV	> 1keV	25um-1mm	>1mm	50ppm	Na	Yes		Quantitative surface

The Four Basic Parameters

The Four Basic Parameters

- ✓ **Accelerating Voltage** **(EHT)**
- ✓ **Aperture Size** **(diameter)**
- ✓ **Spot Size** **(High Current mode)**
- ✓ **Working Distance** **(sample to lens distance)**

Accelerating Voltage

High kV

- Higher resolution
- Greater beam penetration
- Higher beam current
- Higher signal to noise
- More x-ray yield
- Good for VP

Low kV

- Lower resolution
- Less beam penetration
- Lower beam current
- Lower signal to noise
- Lower x-ray yield
- Not so good for VP

Aperture Size

Small Aperture

- Higher resolution
- Higher depth of focus
- Lower beam current
- Lower signal to noise
- Less x-ray yield
- May have smaller field of view (aperture cut-off)
- Not so good for VP

Large Aperture

- Lower resolution
- Less depth of focus
- Higher beam current
- Higher signal to noise
- Higher x-ray yield
- Good for VP

High Current Mode (Beam Current Adjustment)

Small Spot Size

- Higher resolution
- Lower beam current
- Lower signal to noise
- Less x-ray yield

Large Spot Size

- Lower resolution
- Higher beam current
- Higher signal to noise
- Higher x-ray yield
- Good for VP

Note: Spot size must be adjusted as a function of final field of view (magnification); i.e. the higher the magnification, the smaller the spot size and visa versa

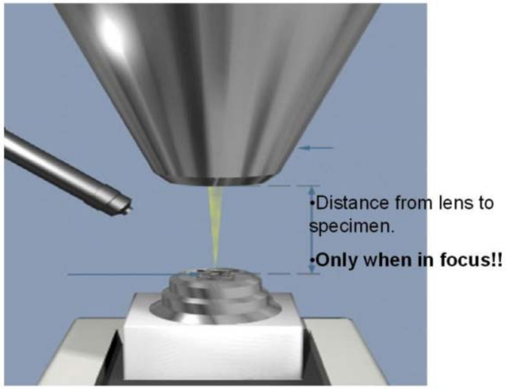
Working Distance

Short Working Distance

- Higher resolution
- Less Depth of Focus
- Better collection efficiency for In-Lens, AsB and EsB detectors
- Good for VP

Long Working Distance

- Lower resolution
- Greater Depth of Focus
- Better collection efficiency for In-Chamber SE
- Not so good for VP

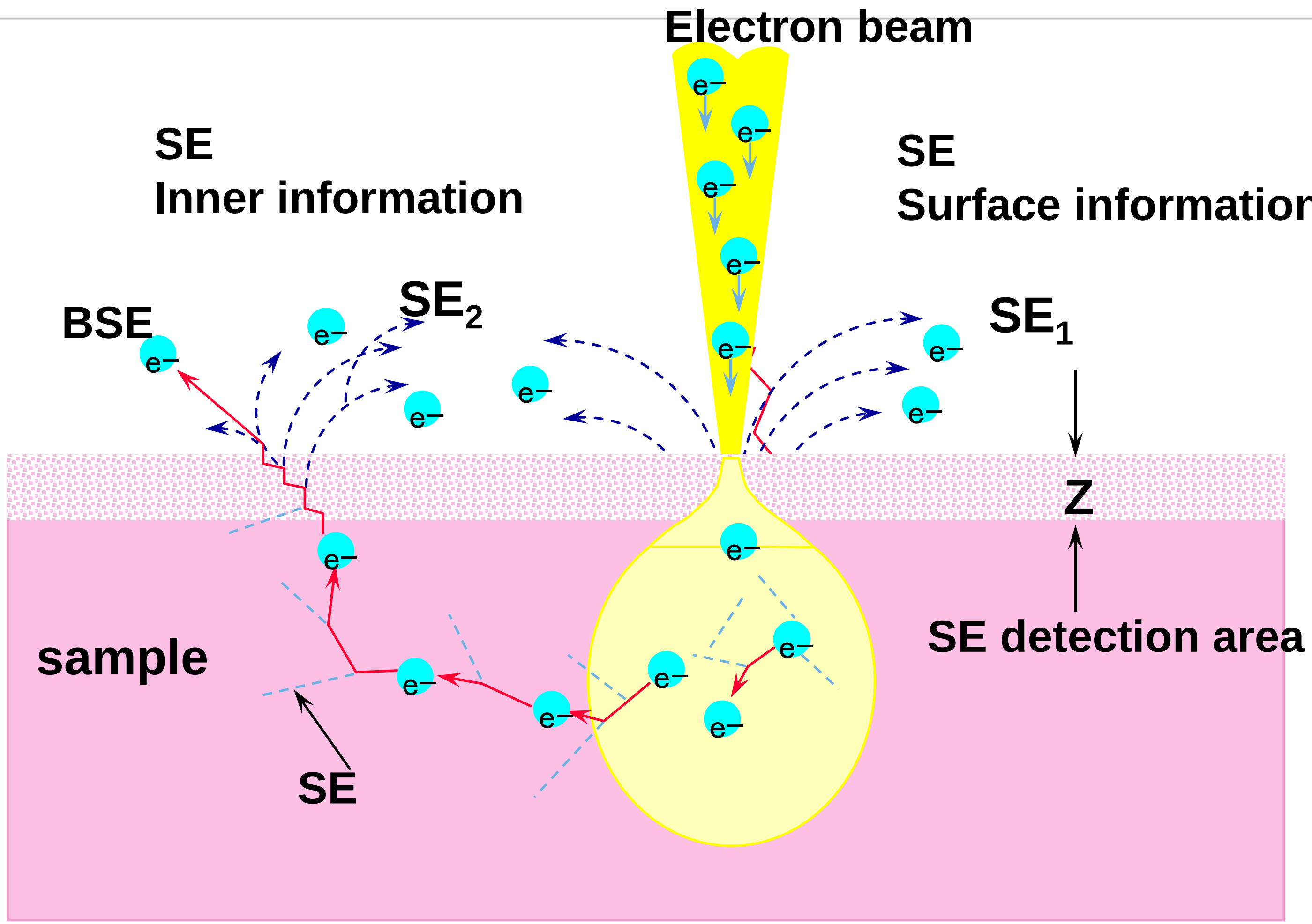


Variables Involved in Image Formation

- ✓ Acceleration Voltage (kV)
- ✓ Final Aperture (size)
- ✓ Probe Current (I probe)
- ✓ Working Distance (WD)
- ✓ Specimen
- ✓ Column/Aperture Alignment

- ✓ Detector
- ✓ Specimen geometry
- ✓ Scanning speed
- ✓ Signal processing
- ✓ Noise reduction
- ✓ Contrast / brightness
- ✓ Chamber pressure
- ✓ System cleanliness

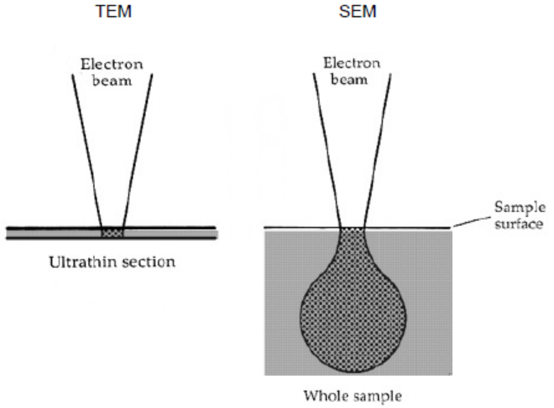
Electron Beam Interaction of SE and BSE

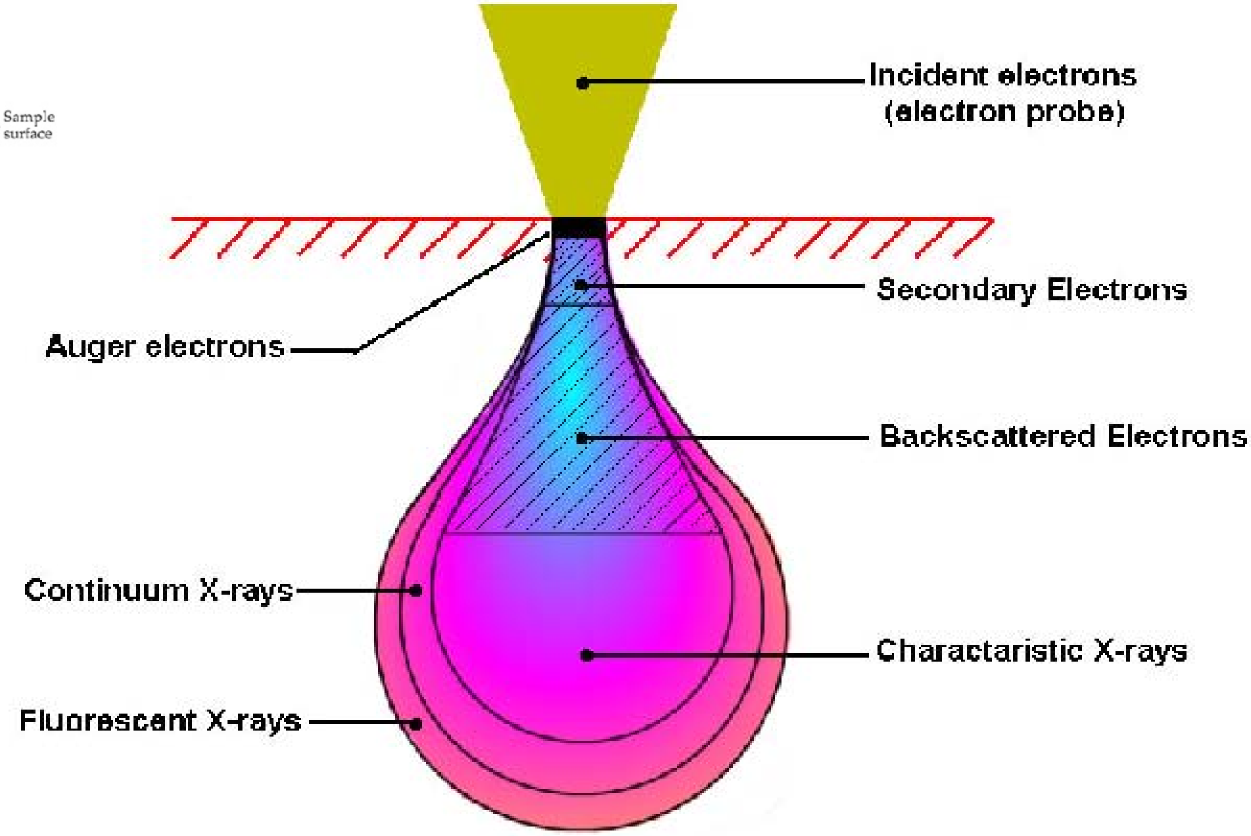


Secondary electrons are emitted from the top 10nm of the sample surface by initial interaction with the sample (SE1) and when a backscatter electron leaves the sample (SE2).

Courtesy Dr. David Joy – ORNL / UTK

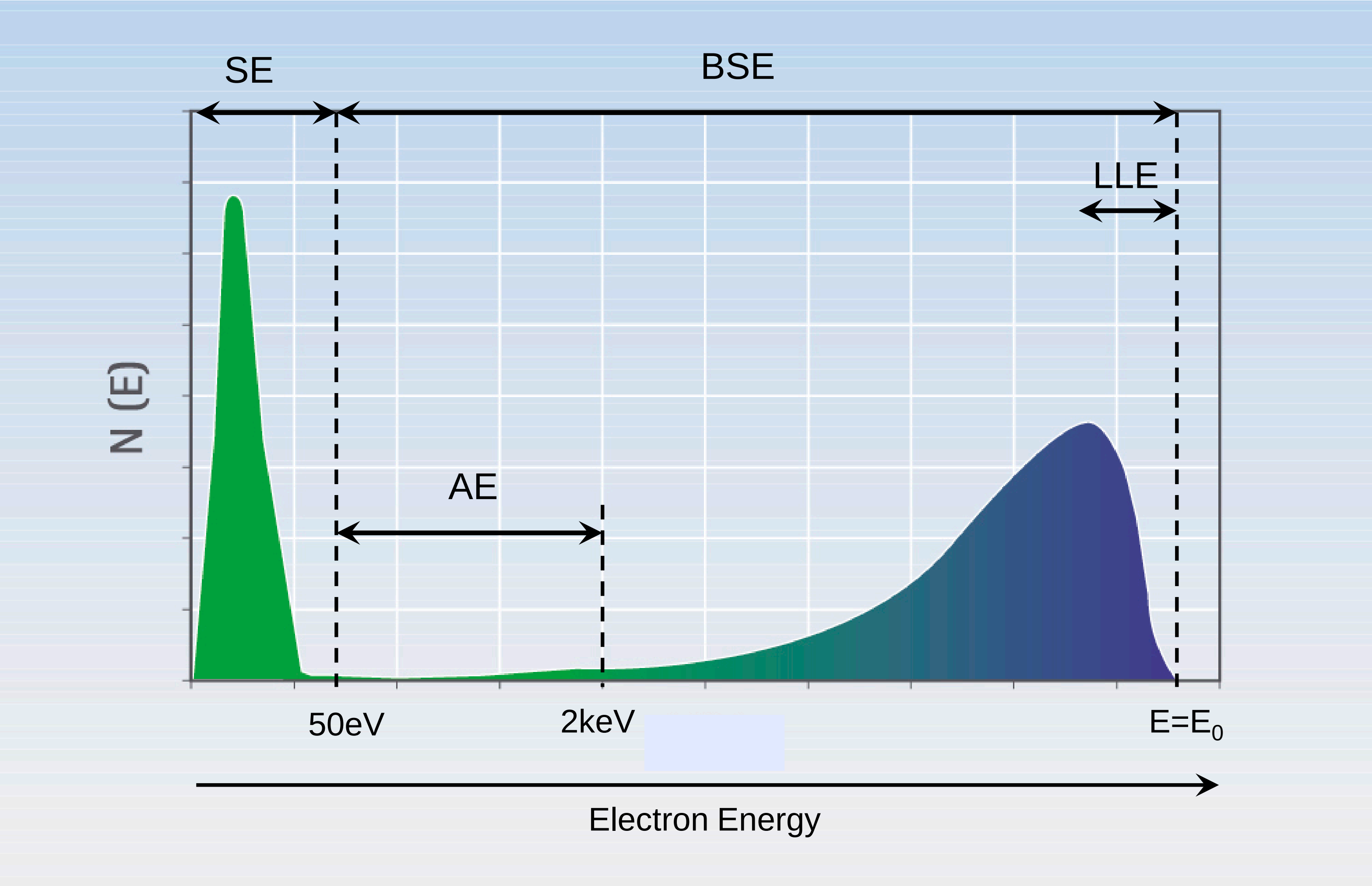
Beam Interaction Diagram





Electron Beam Interaction Diagram

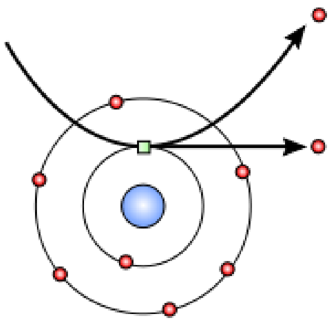
Beam Sample Interaction

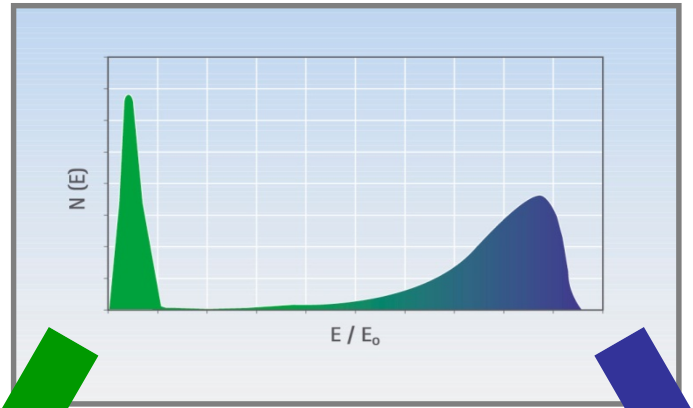


Energy distribution of electrons emerging from the specimen consisting of secondary electrons SE with $E_{SE} \leq 50eV$, low-loss electrons (LLE) with energy losses of a few hundred eV, back-scatter electrons (BSE) with $E_{BSE} \geq 50eV$ and Auger electrons (AE)

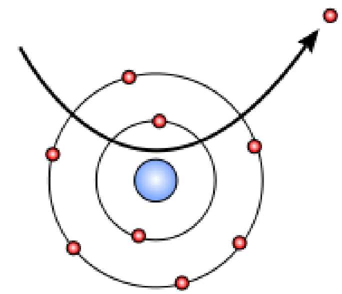
On-Axis In Column Detection System
Different electrons carry different information

Secondary electrons

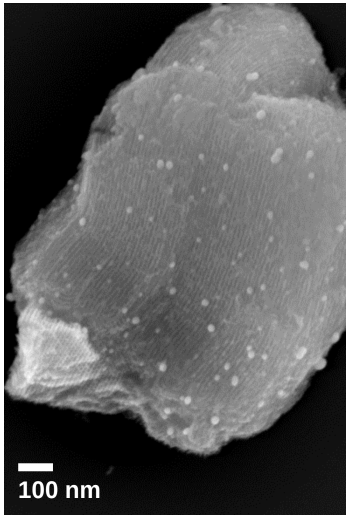


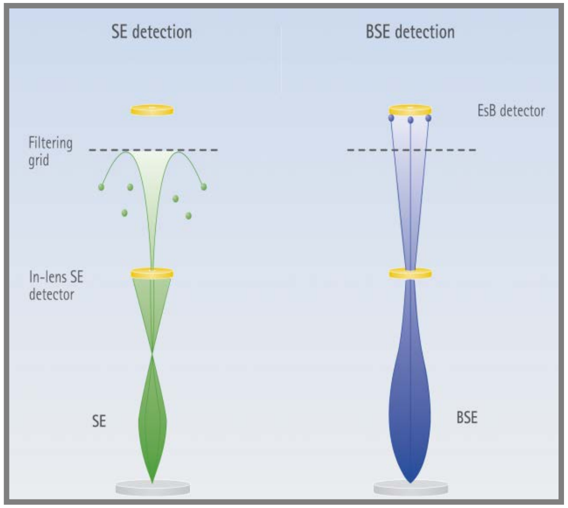


Backscattered electrons



Topographical information





Combined detection for maximum information!

Compositional contrast

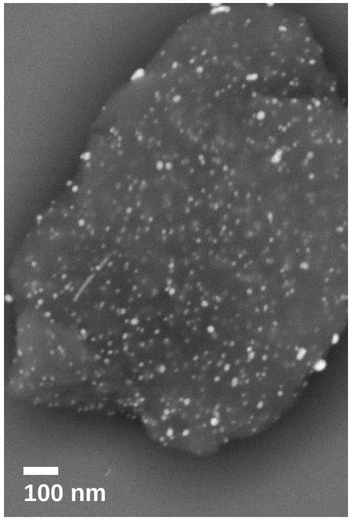


Image: Zeolite with Ag nanoparticles, 5kV. Sample curtesy of Fritz-Haber-Institute Berlin

Types of detectable electrons

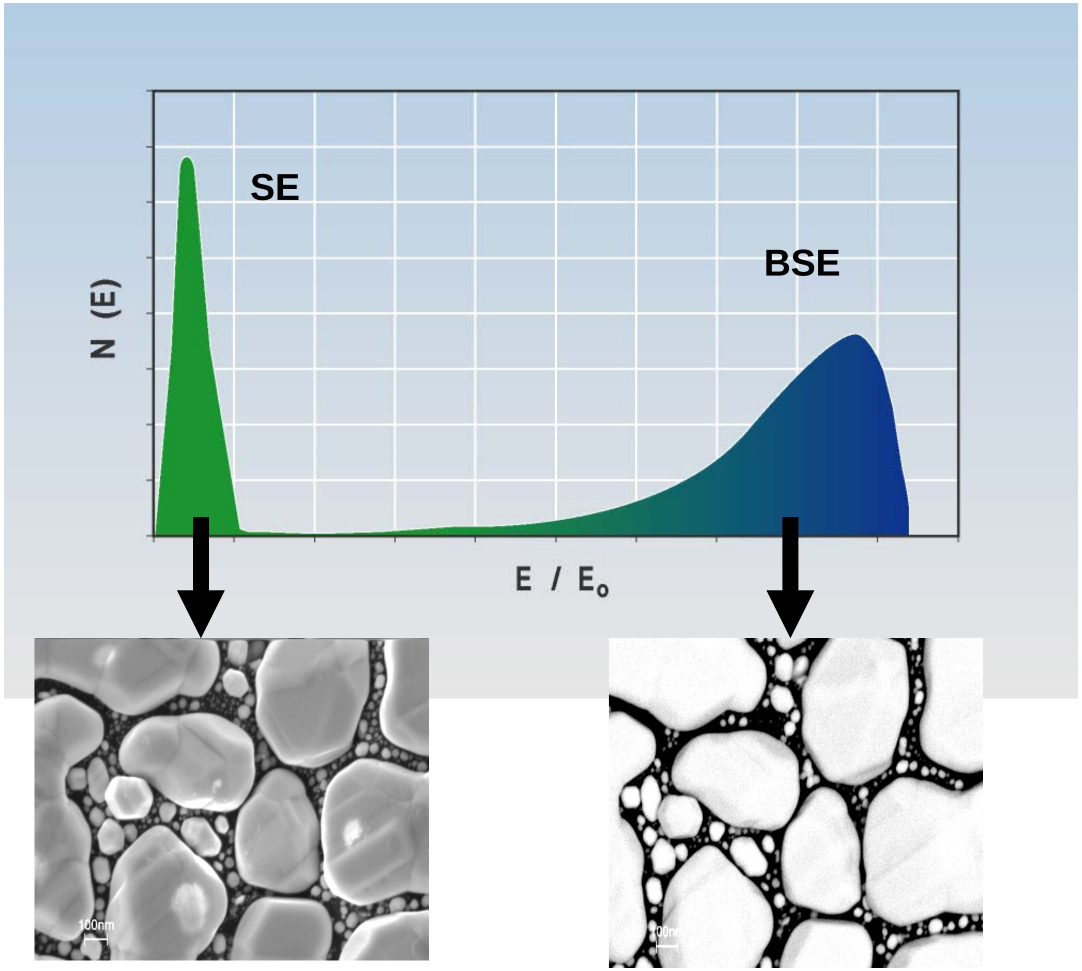
Interaction of primary electrons with sample

Secondary Electrons (SE):

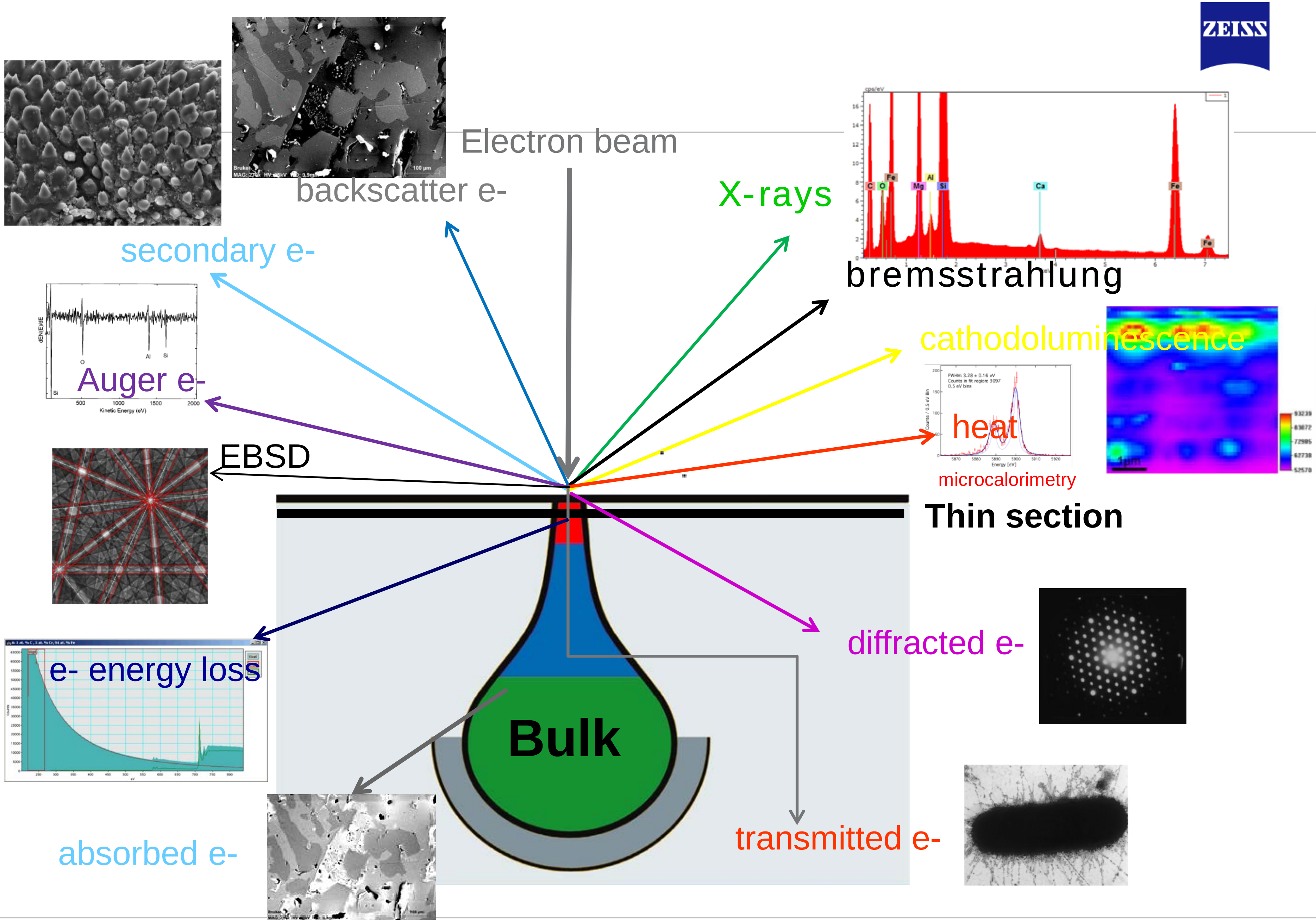
- Inelastic collisions,
- Interaction with surface
- Topographic information
- energy up to 50eV
- SE1:resulting from interactions with primary beam
- SE2: resulting from interactions with BSE in specimen
- SE3: resulting from interactions of BSE with metal parts

Backscatter Electrons (BSE):

- Often elastic collisions
- Interactions with bulk material
  ➔ material information
  (Density, Compositions,
  Z- Contrast, crystal structure)



Electron interactions



Electron Guns

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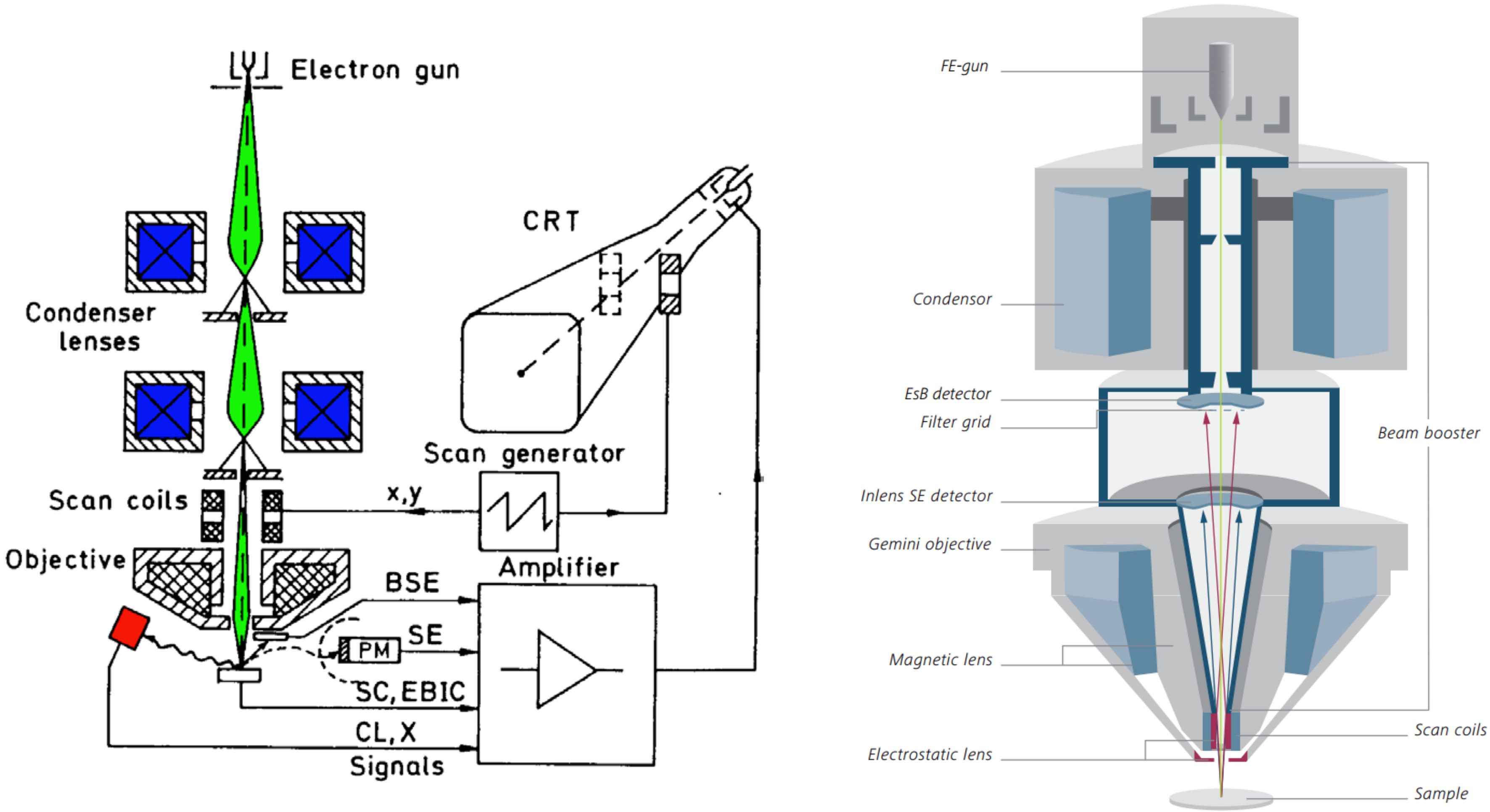
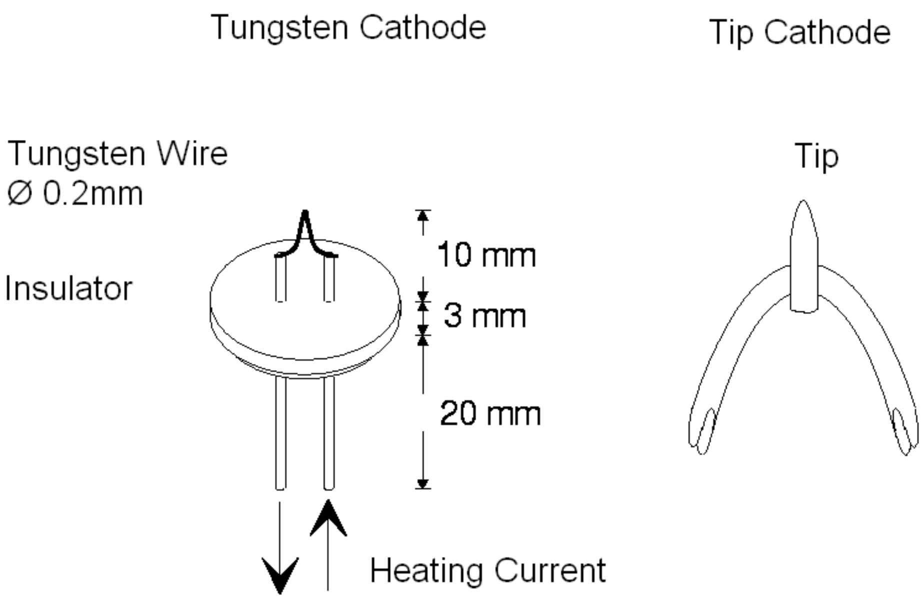
Gemini
GeminiSEM 500

Scanning Electron Microscopes

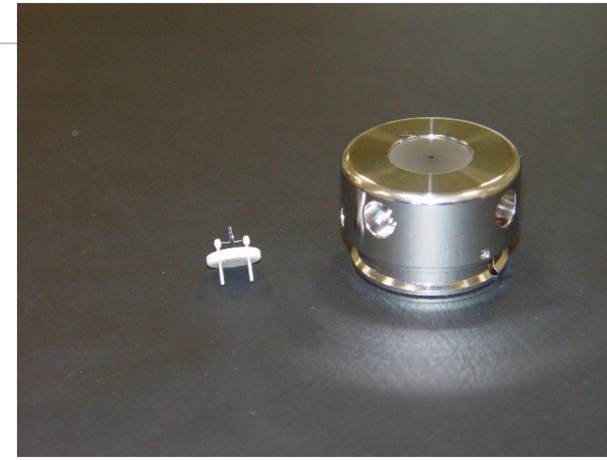


Schematic of a SEM

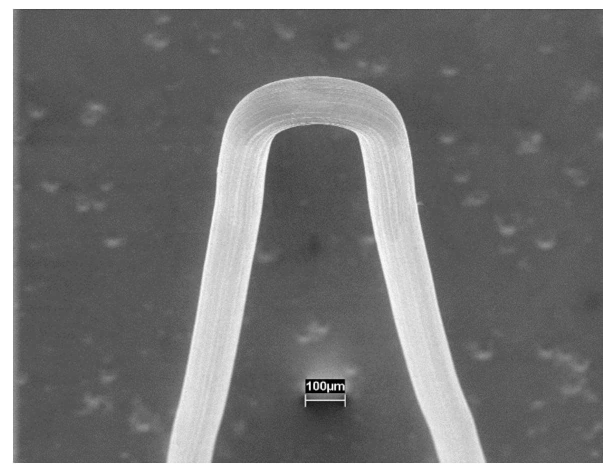
Emission Systems Thermionic Emitters



Schematic of tungsten emitter

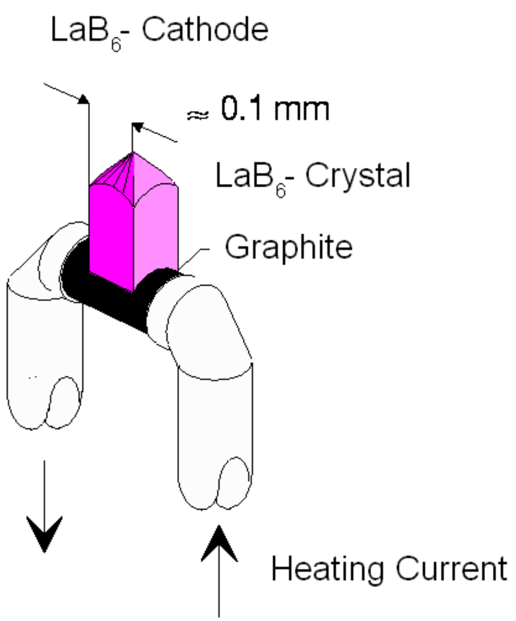


Emitter with Wehnelt assembly

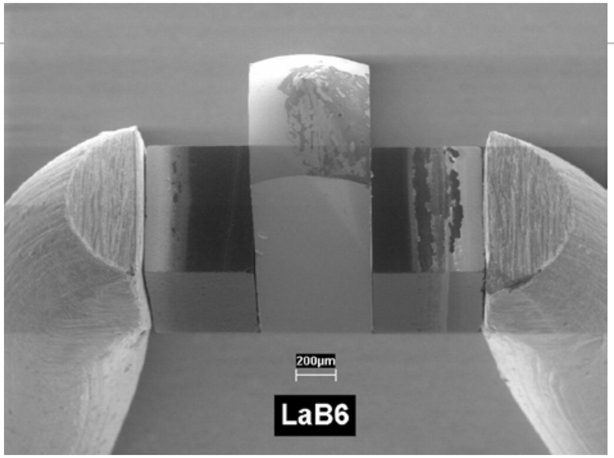


W – Emitter SEM Image

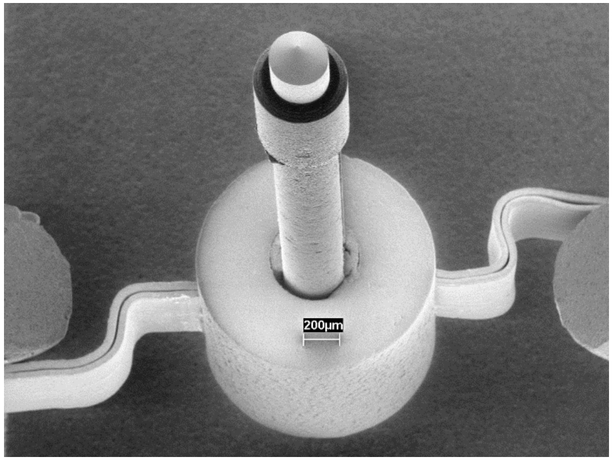
Emission Systems Thermionic Emitters – LaB_6



Schematic of a LaB_6 - Emitter

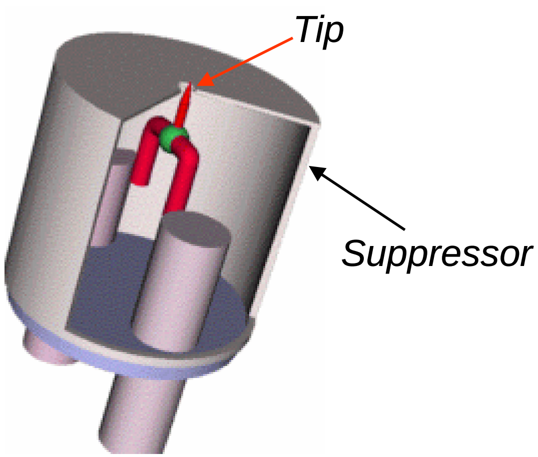


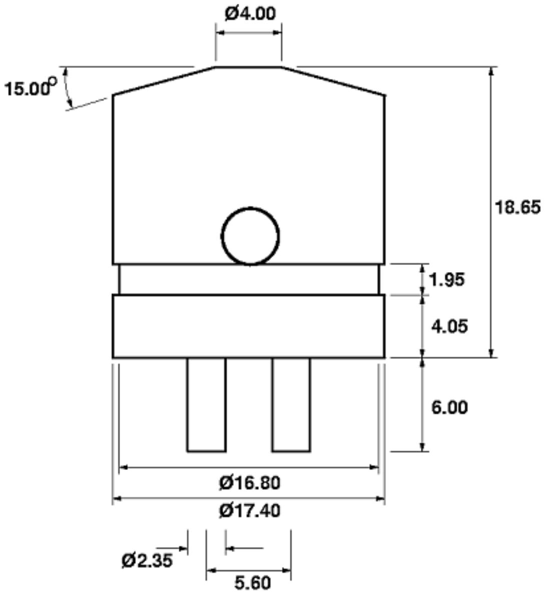
LaB_6 – Emitter SEM Image



LaB_6 – Emitter SEM Image

Emission Systems: Schottky - Field Emitters

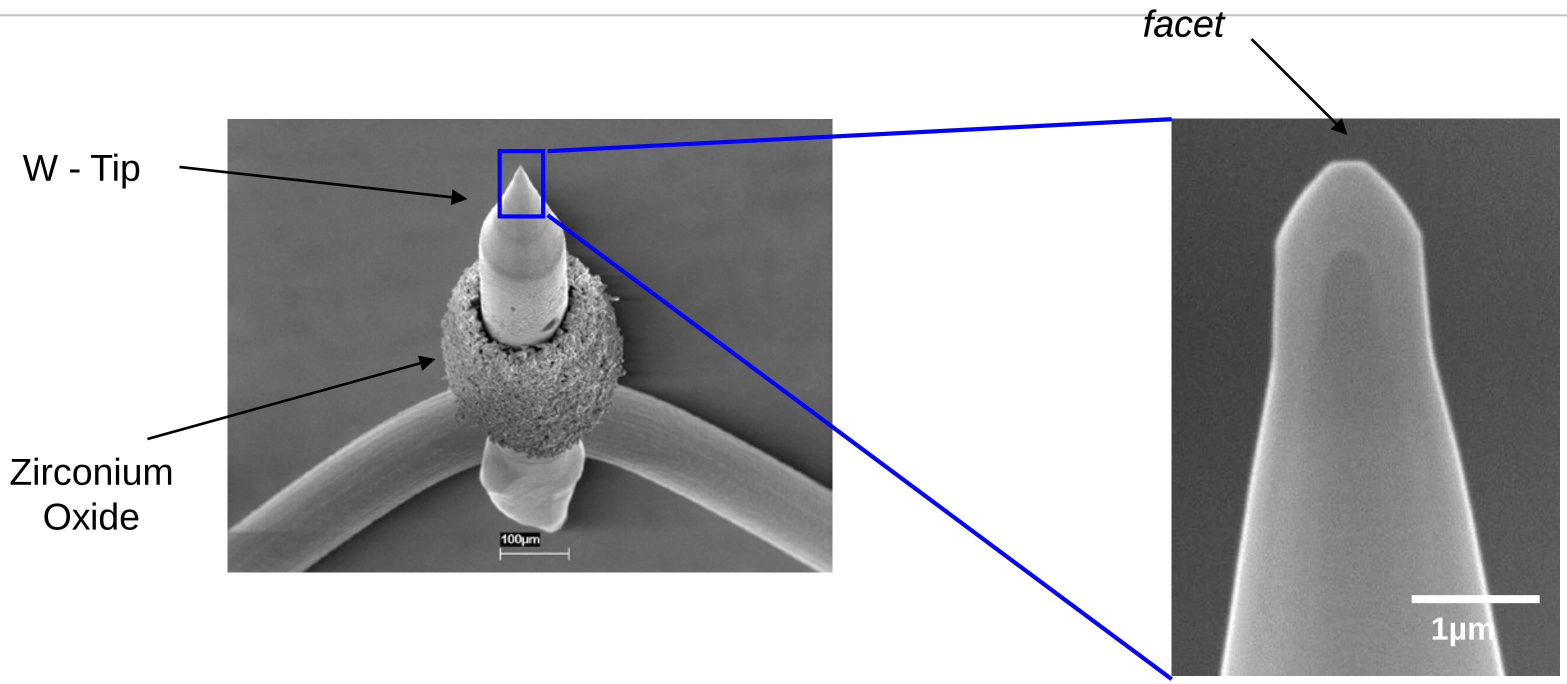




Schottky Emitter – Suppressor Cartridge

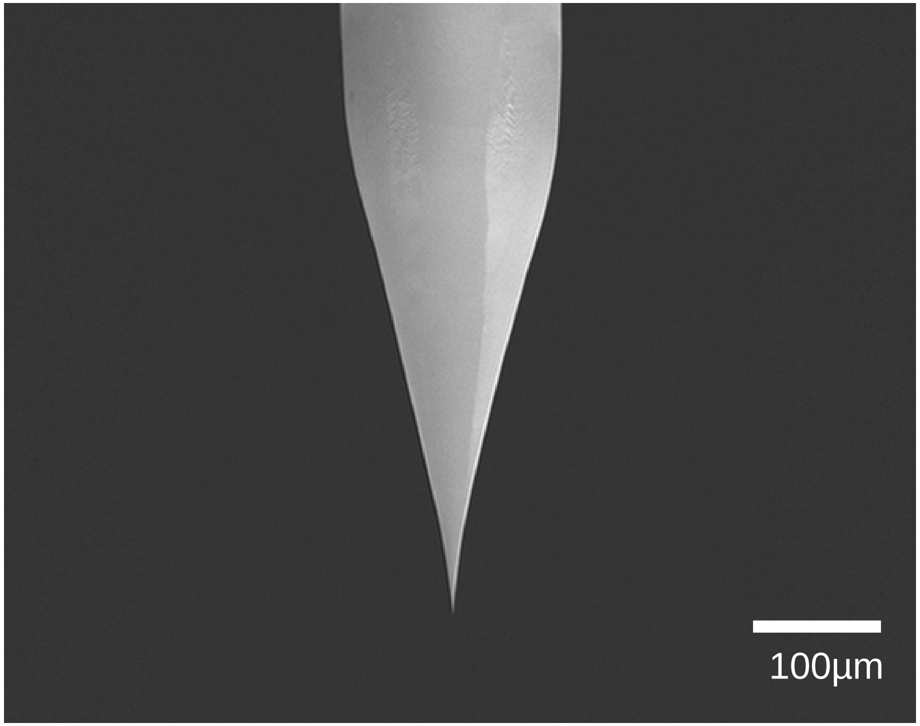
*A single crystal tungsten wire with a sharp end etched to a small radius (red in the sketch) is mounted on a tungsten hairpin (also red). A current through the filament is used to maintain the **tip** at a temperature of 1750 - 1850 K. The tip just penetrates a hole in a cylindrical **suppressor** electrode mounted around the assembly. Electrons are emitted from the tip due to both thermal excitation and the electric field at the tip due to the potential difference between it and an **extractor** electrode (not shown). Electrons from the filament are repelled by the potential on the suppressor.*

Emission Systems: Schottky - Field Emitters



SEM image of a Schottky tip.
Emission occurs from the crystalline facet (horizontal at the top) that is about 0.3 µm across.

Emission Systems: Cold Field Emitters



Cold Field Emitter - SEM Micrograph

Optics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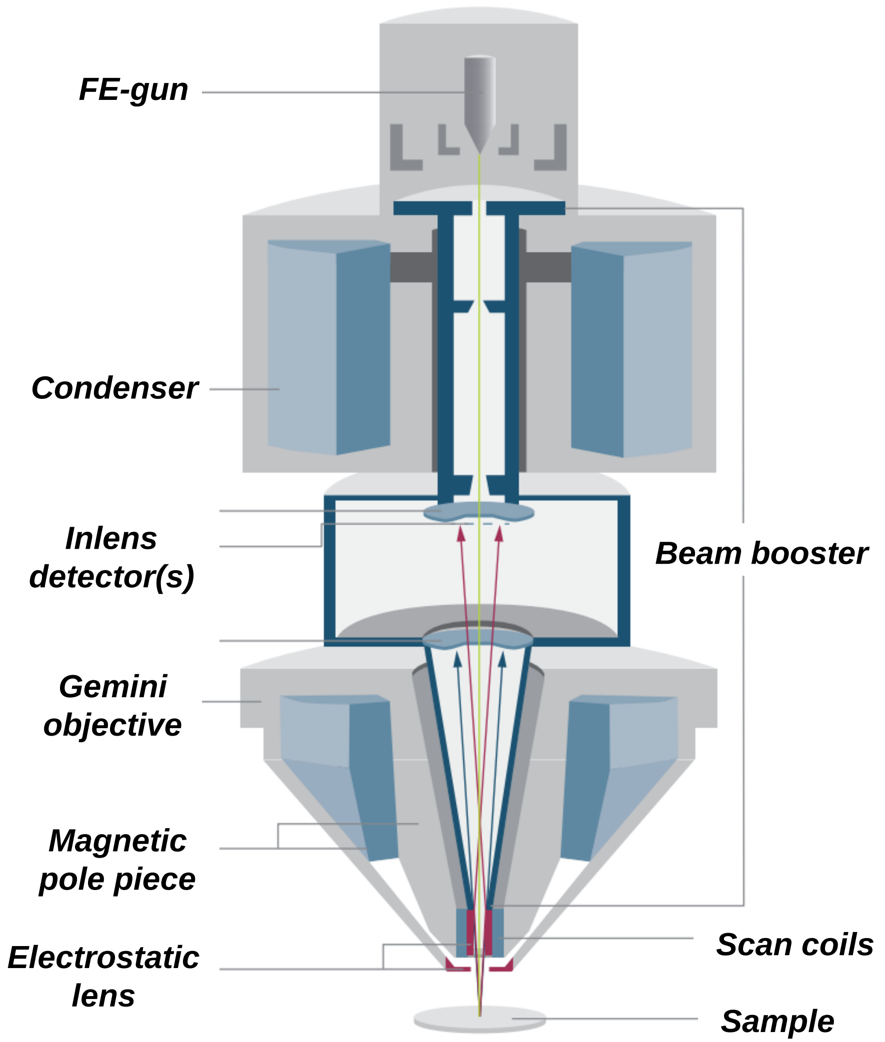
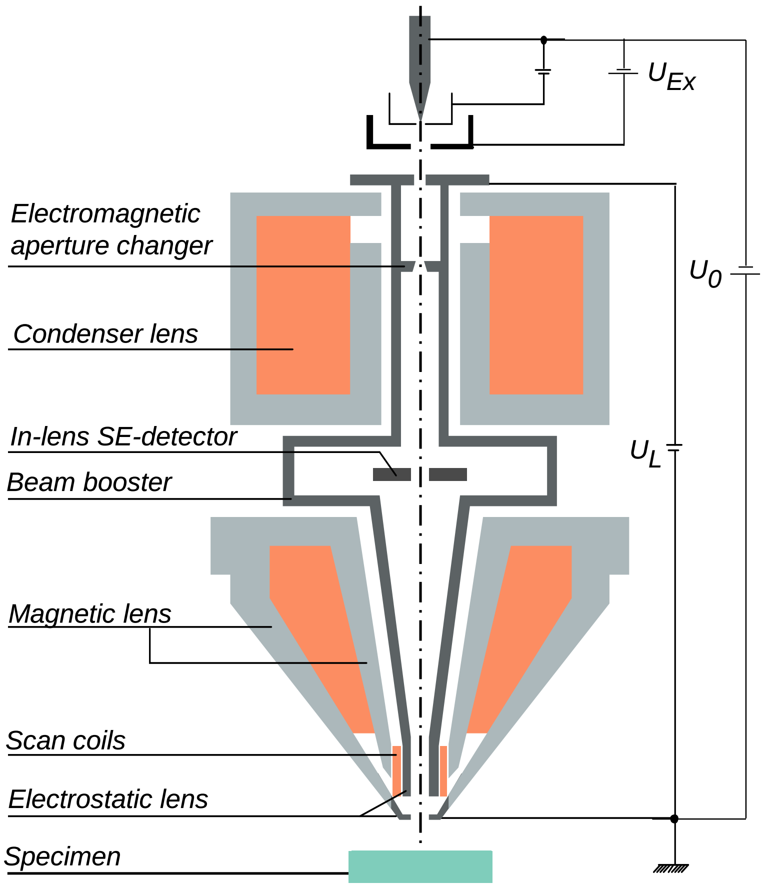
GeminiSEM 500

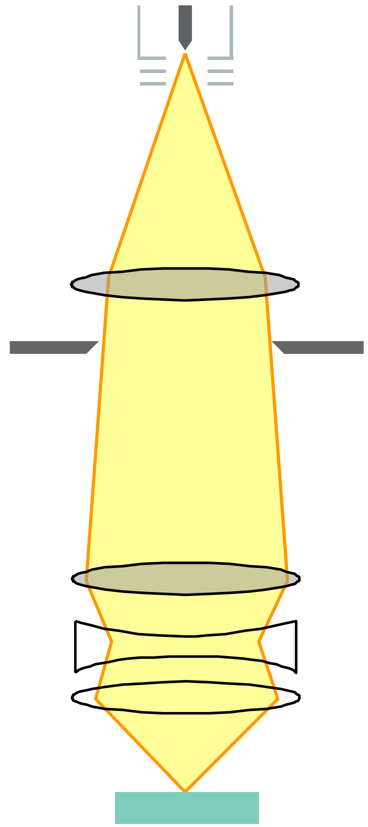
Scanning Electron Microscope Column



Electron Optics



Beam path with no intermediate cross over

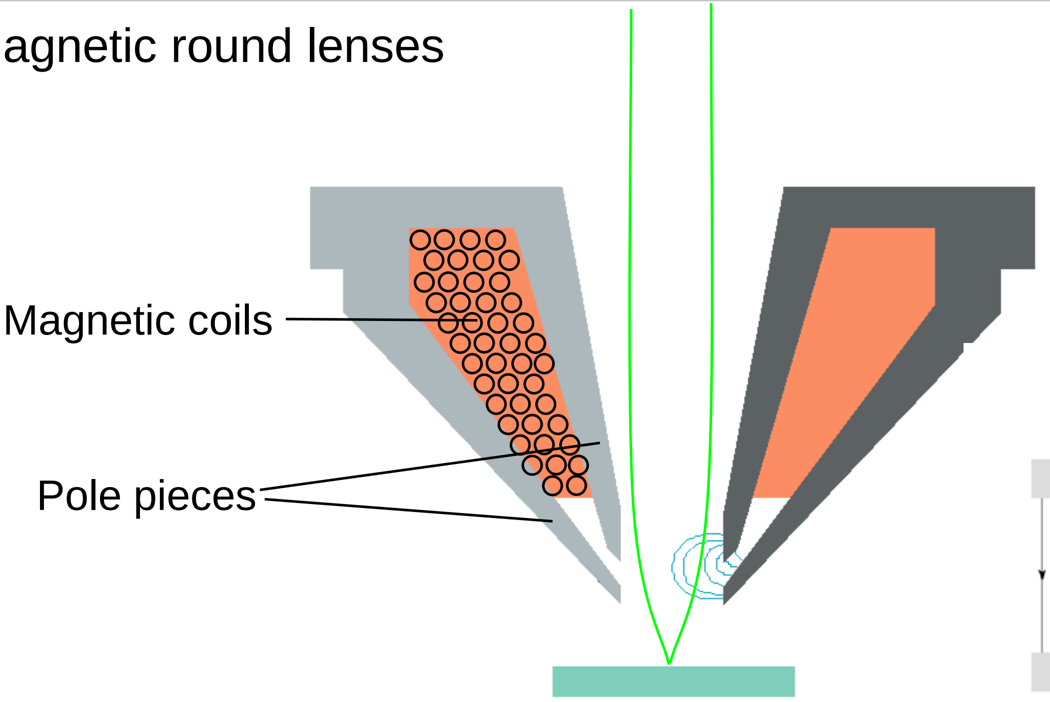


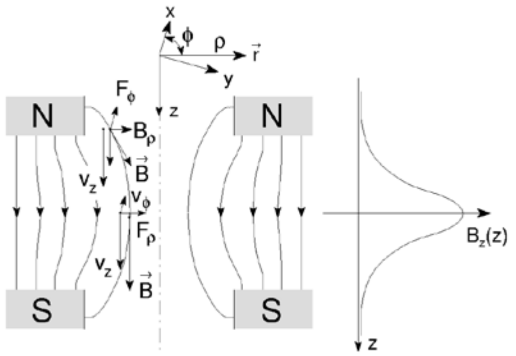
Features

- **highly stable thermal FEG**
  < 0.5 % /h variation
- **low beam noise**
  < 1 %
- **cross over free beam path**
  no significant Boersch effect, high depth of field
- **beam booster**
  superb image resolution throughout the whole beam energy range, particularly down to 100 eV.
  High resistance to ambient magnetic stray fields

Electromagnetic Lenses

Magnetic round lenses





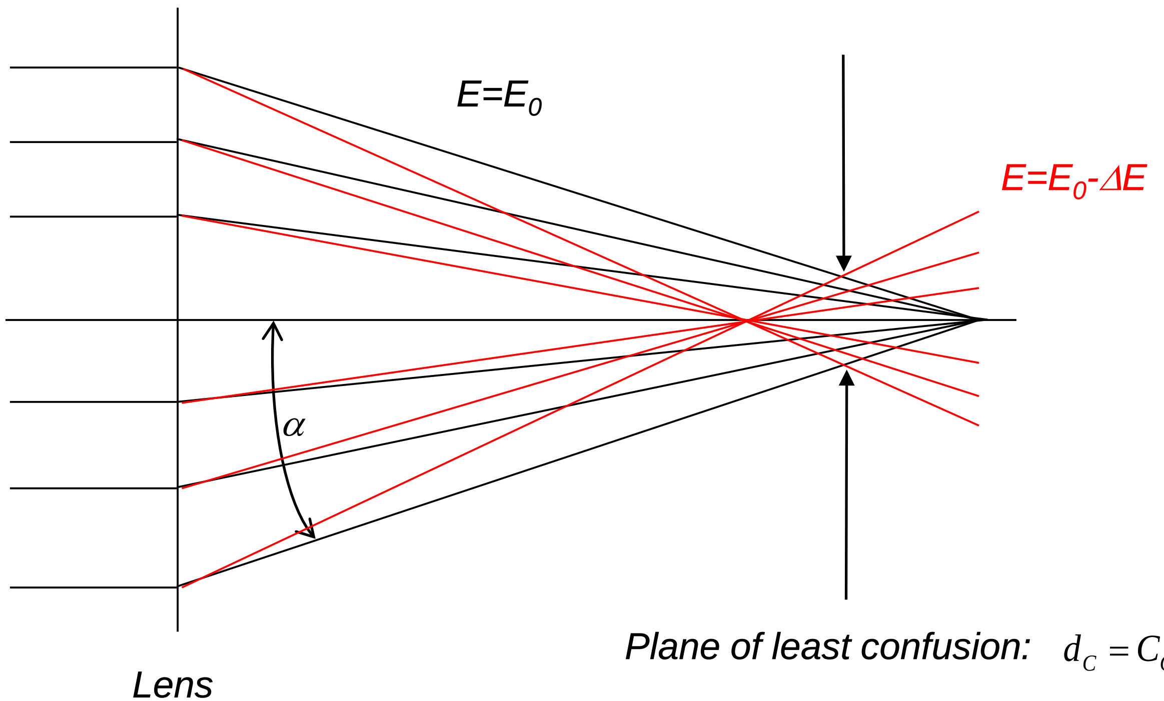
Lorentz Force: $\vec{F} = -e(\vec{E} + \vec{v} \times \vec{B})$

Focal length: $f = \dfrac{2a}{\pi k^2}$ $\qquad k^2 = \dfrac{eB_0^2 a^2}{8m_0 U^*}$

Electron Lenses: Aberrations

Chromatic aberration:

The focal length depends on the electron energy.
An energy spread of the electrons result in an aberration disc: $d_C = C_C \frac{\Delta U}{U} \alpha$

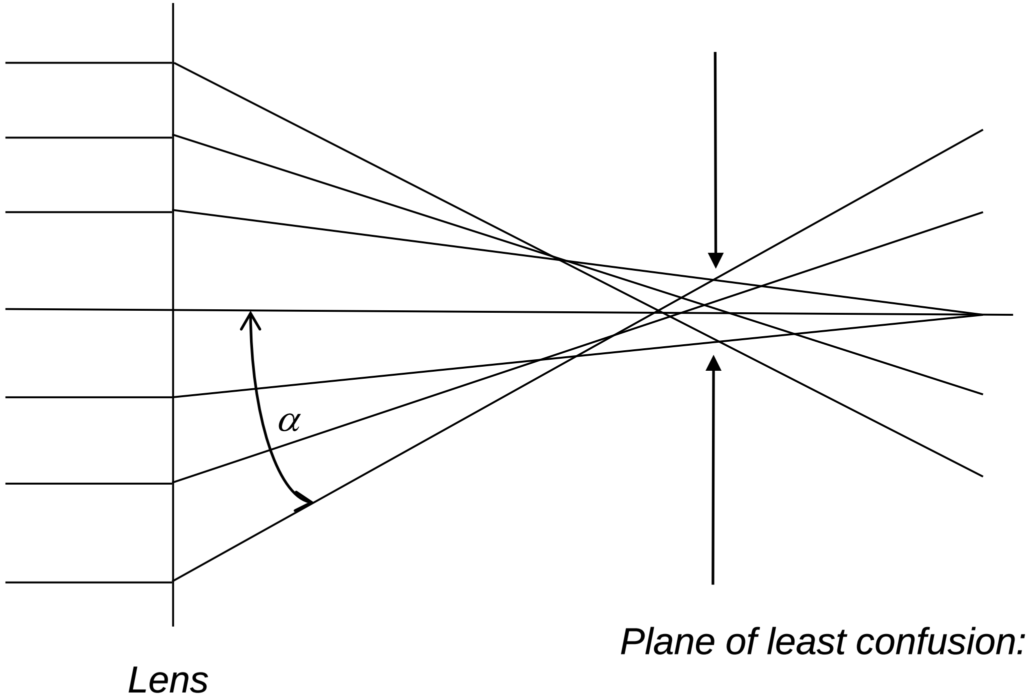


Plane of least confusion: $d_C = C_C \frac{\Delta U}{U} \alpha$

Electron Lenses: Aberrations

Spherical aberration:

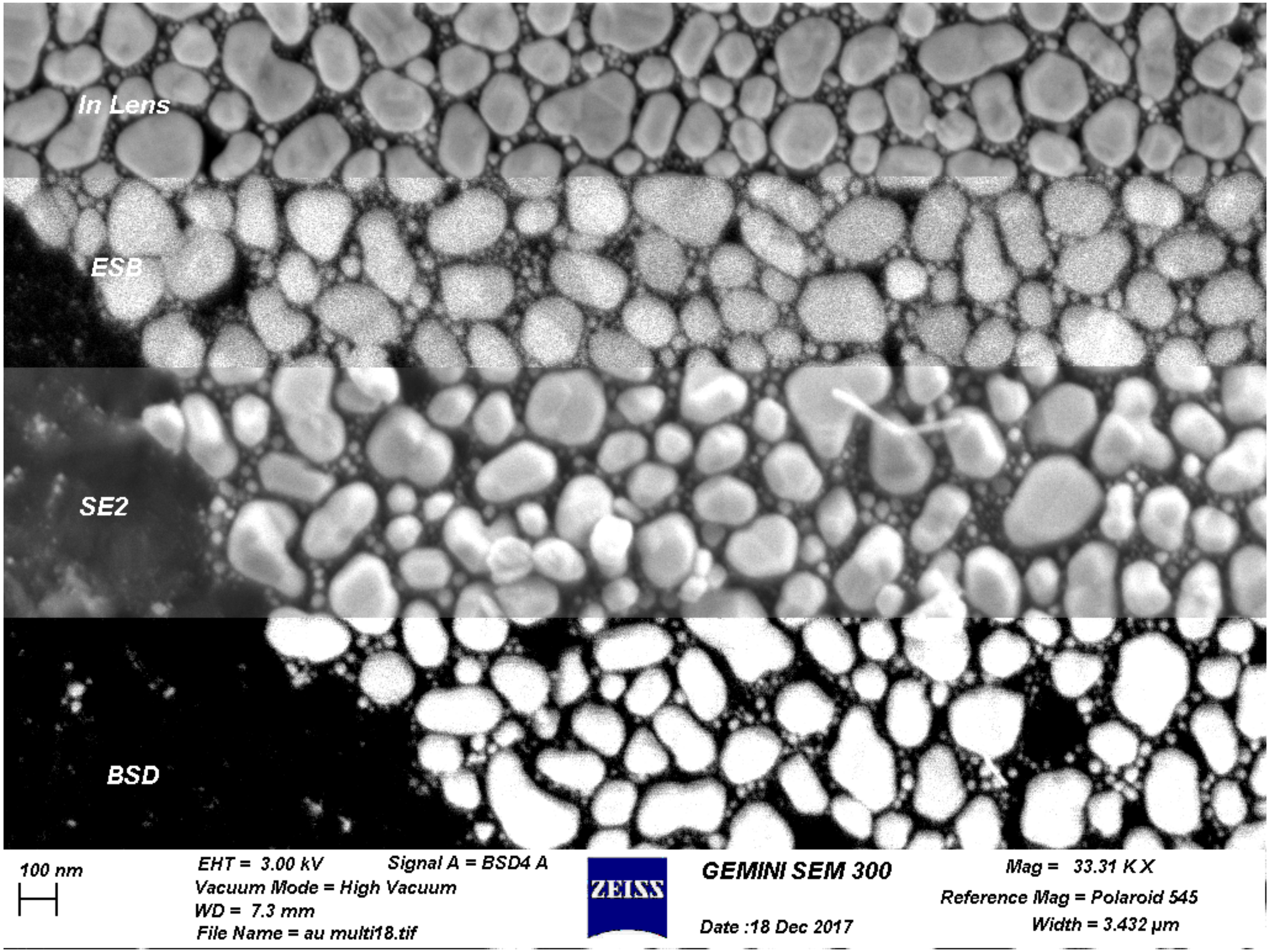
Rays further from the optical axis are focussed closer to the lens resulting in an aberration disc: $d_S = 0.5 C_S \alpha^3$



Plane of least confusion: $d_S = 0.5 C_S \alpha^3$

Detectors

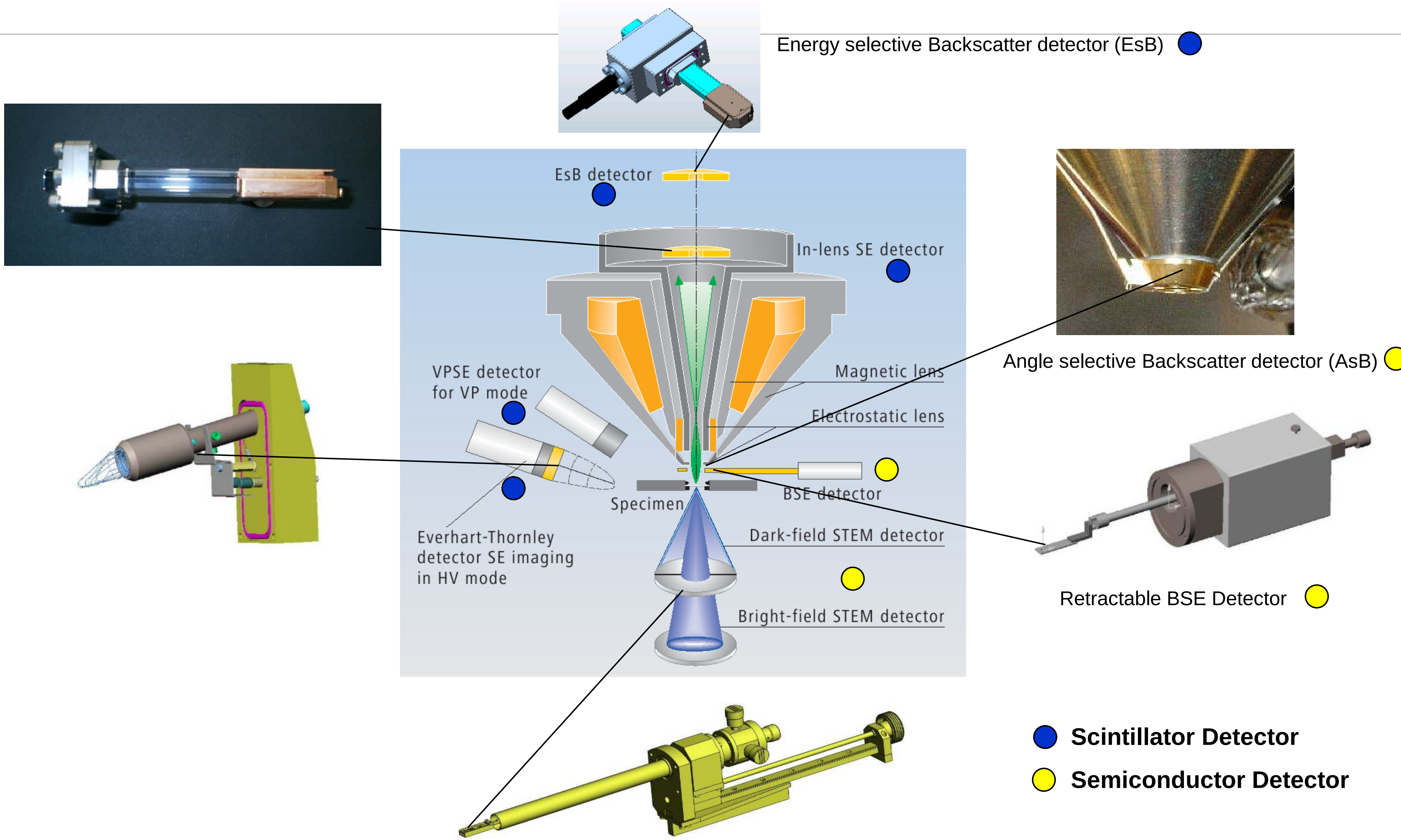
Detector comparison



Detectors Types

- ✓ **Secondary Electron Detector** (SED)
  - In-chamber Everhart Thornley
    - *Best for surface topography*
  - In-column (in-lens)
    - *Best for surface information (low energy)*
- ✓ **Backscattered Detector** (BSE)
  - AsB solid state (below objective lens)
    - *Best for channeling contrast (3kV and above)*
  - EsB in-column
    - *Best for Z contrast (3kV and below)*
- ✓ **Scanning Transmitted Electron Detector**
- ✓ **Variable Pressure and Extended Pressure Detectors**
  - Ionization Detectors used at 1Pa and below
- ✓ Energy Dispersive Spectrometer (EDS)
- ✓ Wavelength Dispersive Spectrometer (WDS)
- ✓ Cathodoluminescence Detector (CL)
- ✓ Electron Backscattered Diffraction Pattern (EBSD or EBSP)

Various Electron Detectors

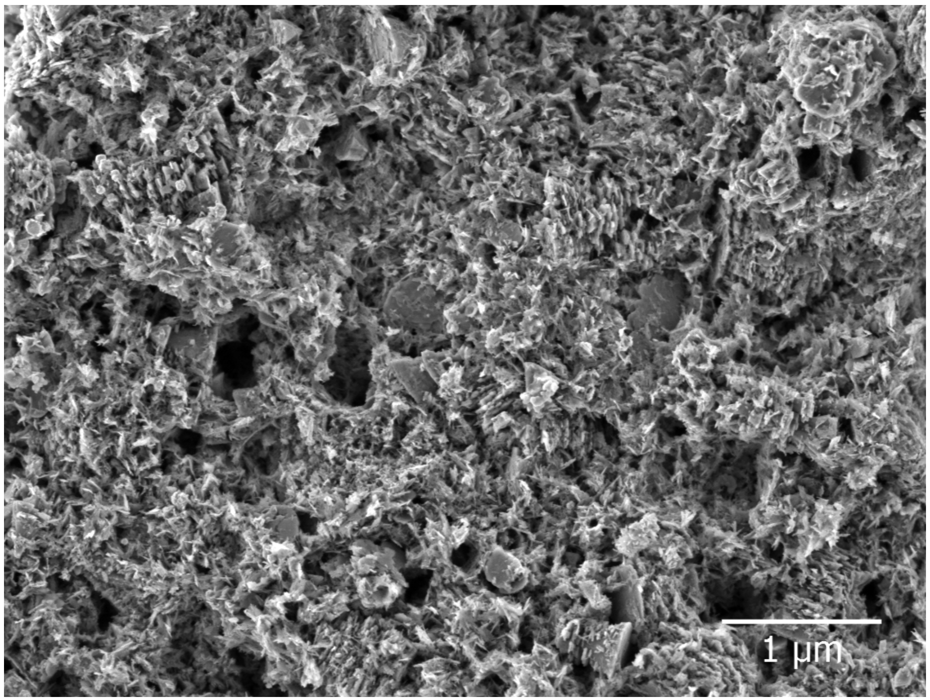


When to use which detector

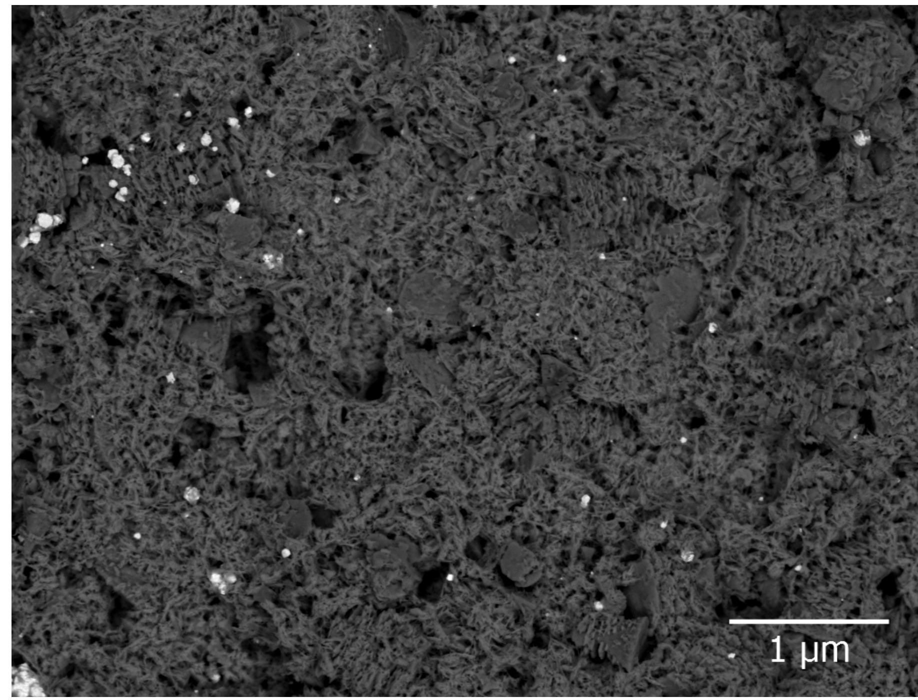
Detector	Information	Opt.Working Distance	Best Energy
Everhart-Thornley	Topographic surface information	5-12mm	0.02-30kV
InLens	Surface details, High Resolution Imaging	<5mm	0.02-5kV
AsB or SSBSE	Z-Contrast Channeling contrast (crystallographic information, strain, deformation)	5-10mm 2-5mm (material dependent)	>5kV
EsB	Z-Contrast (sharp due to energy filter) Low Loss BSE: Compositions, Bondings	<5mm	<1.5 kV

Applications

Pt Nanoparticles on Nonconductive Al_2O_3 matrix.

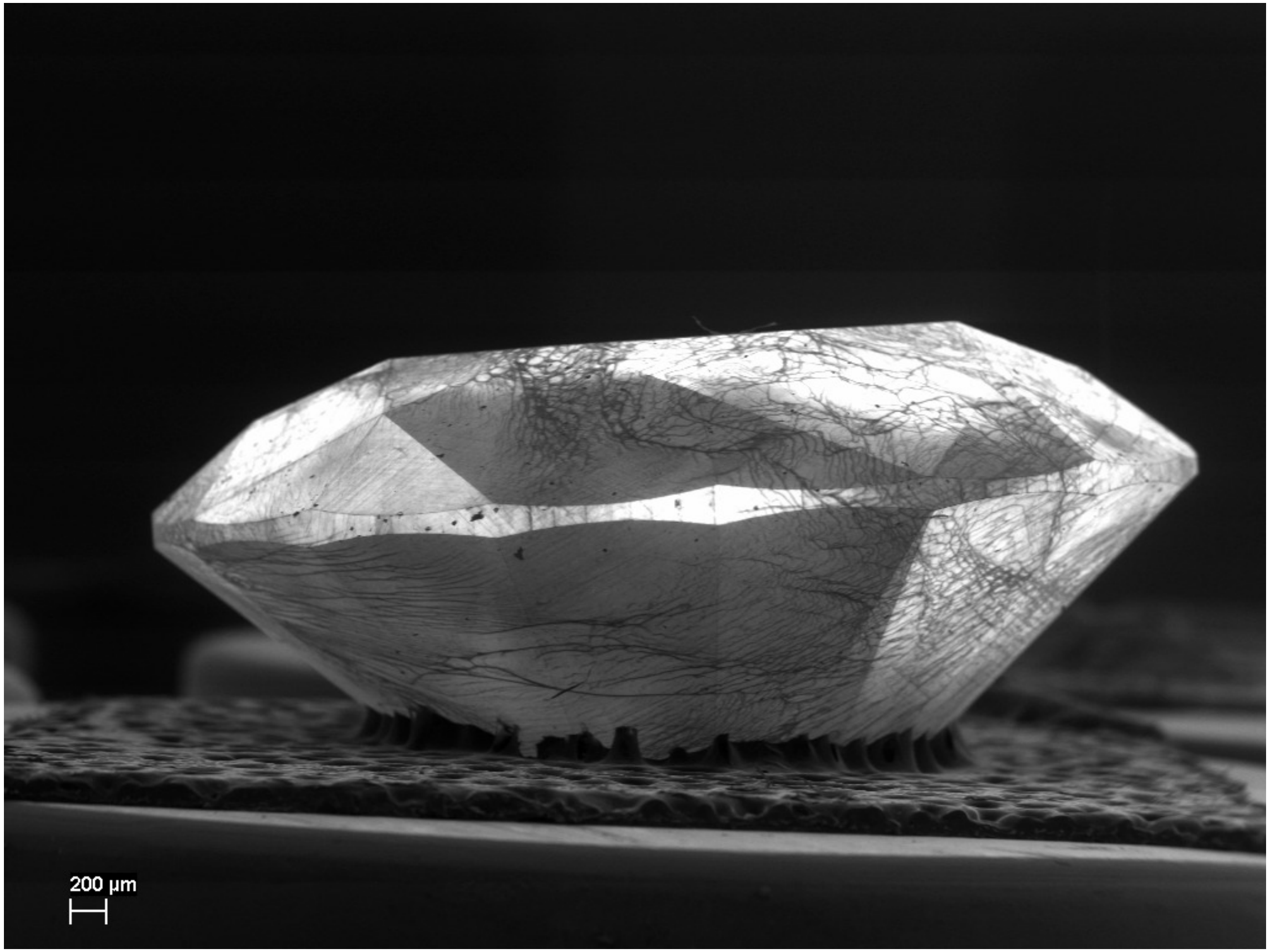


Inlens SE, 1 kV

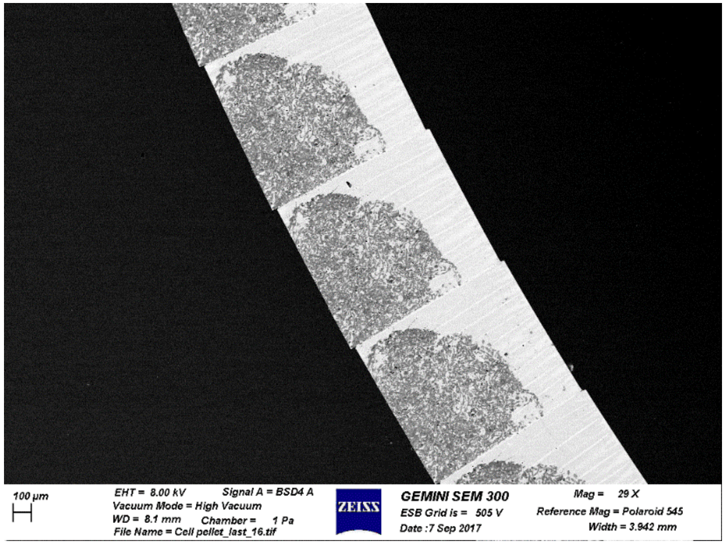


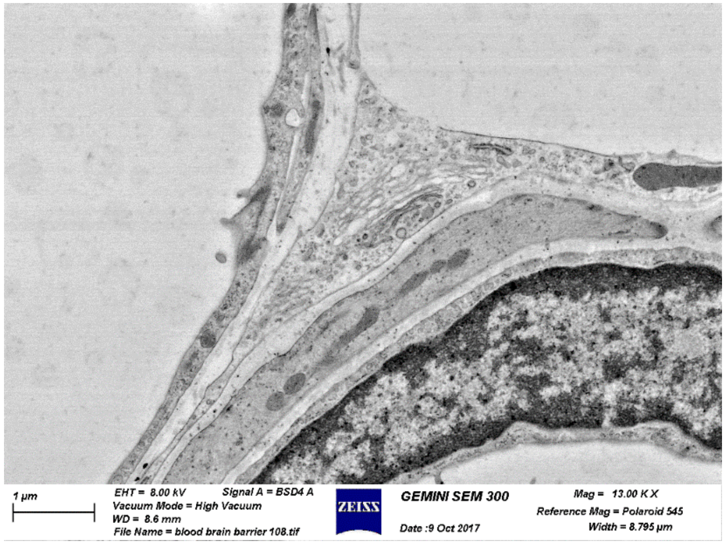
ESB1 kV

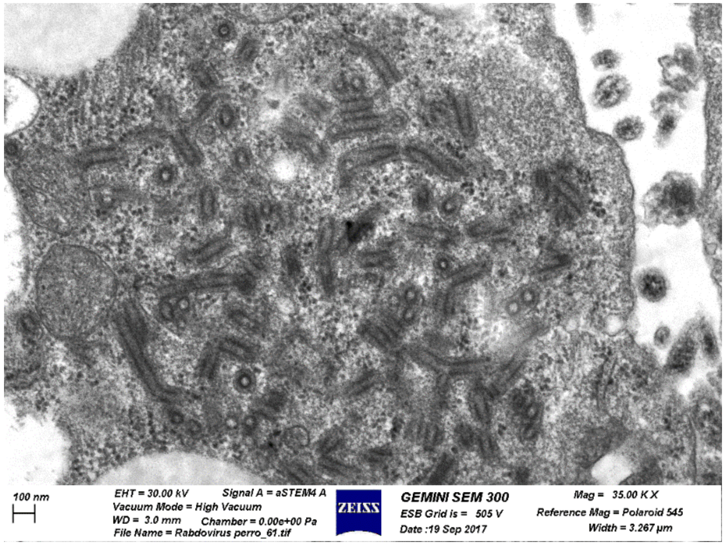
VP CL image showing dislocations

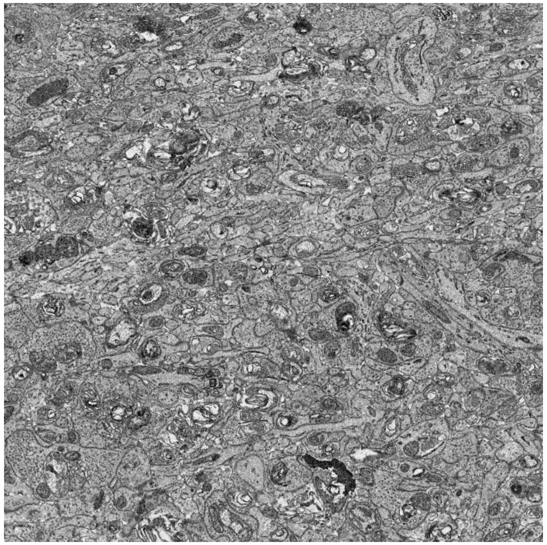


Bio applications with BSD

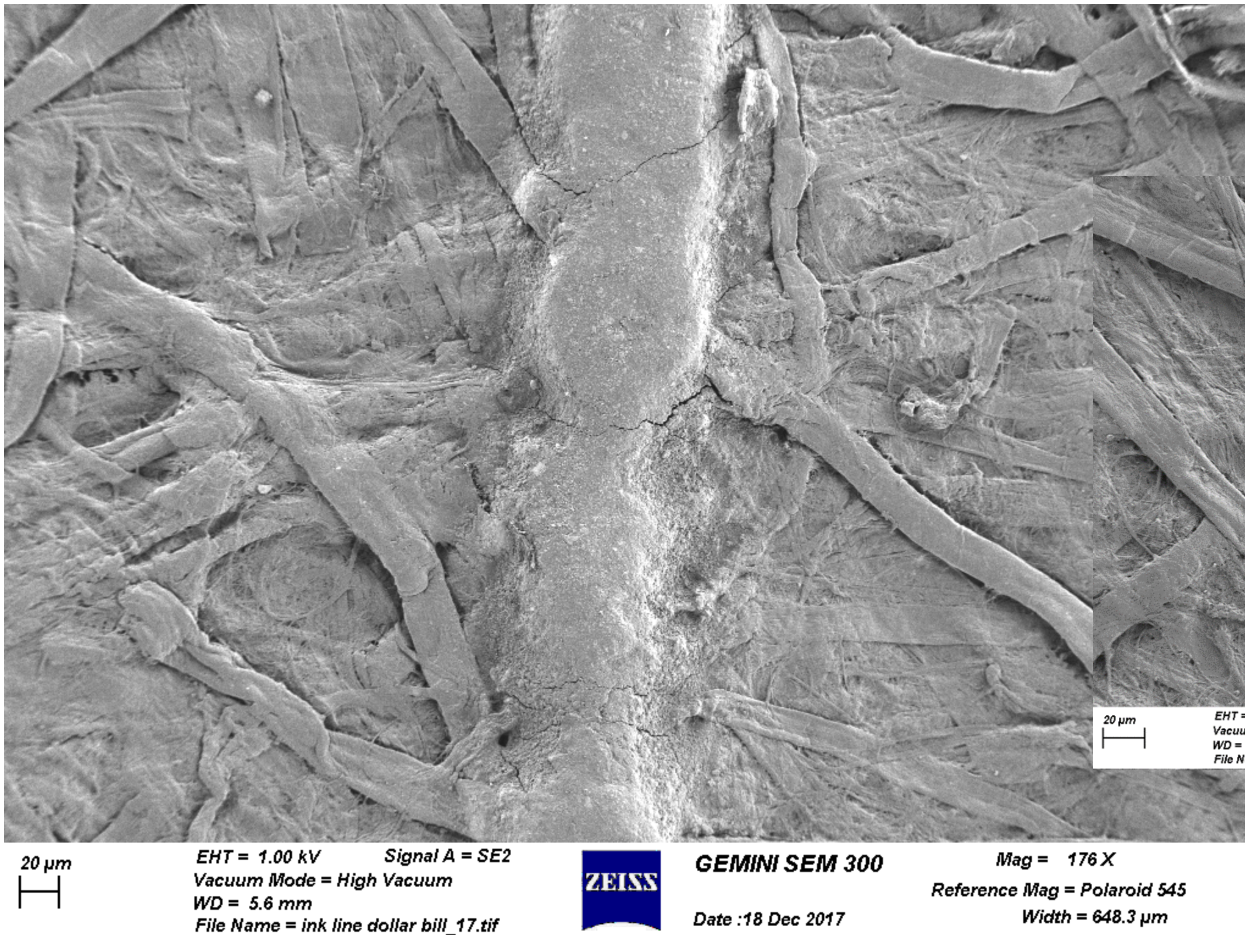


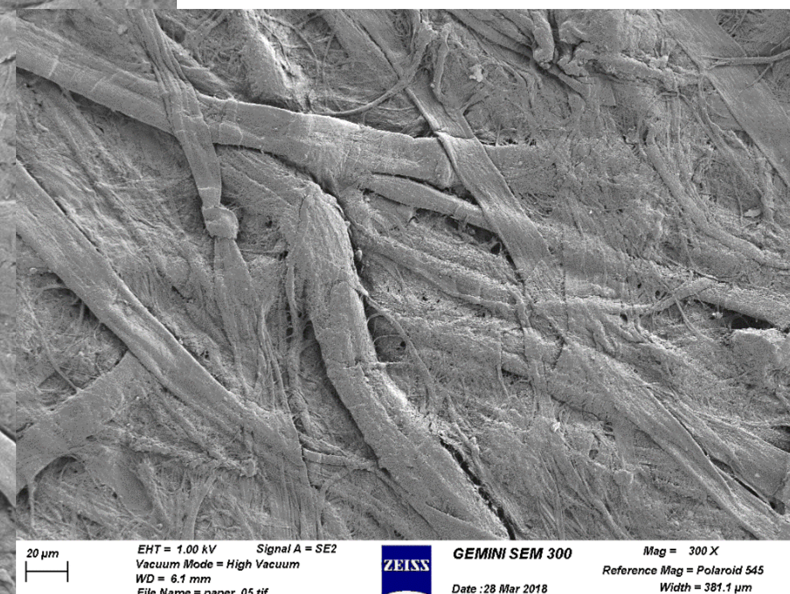






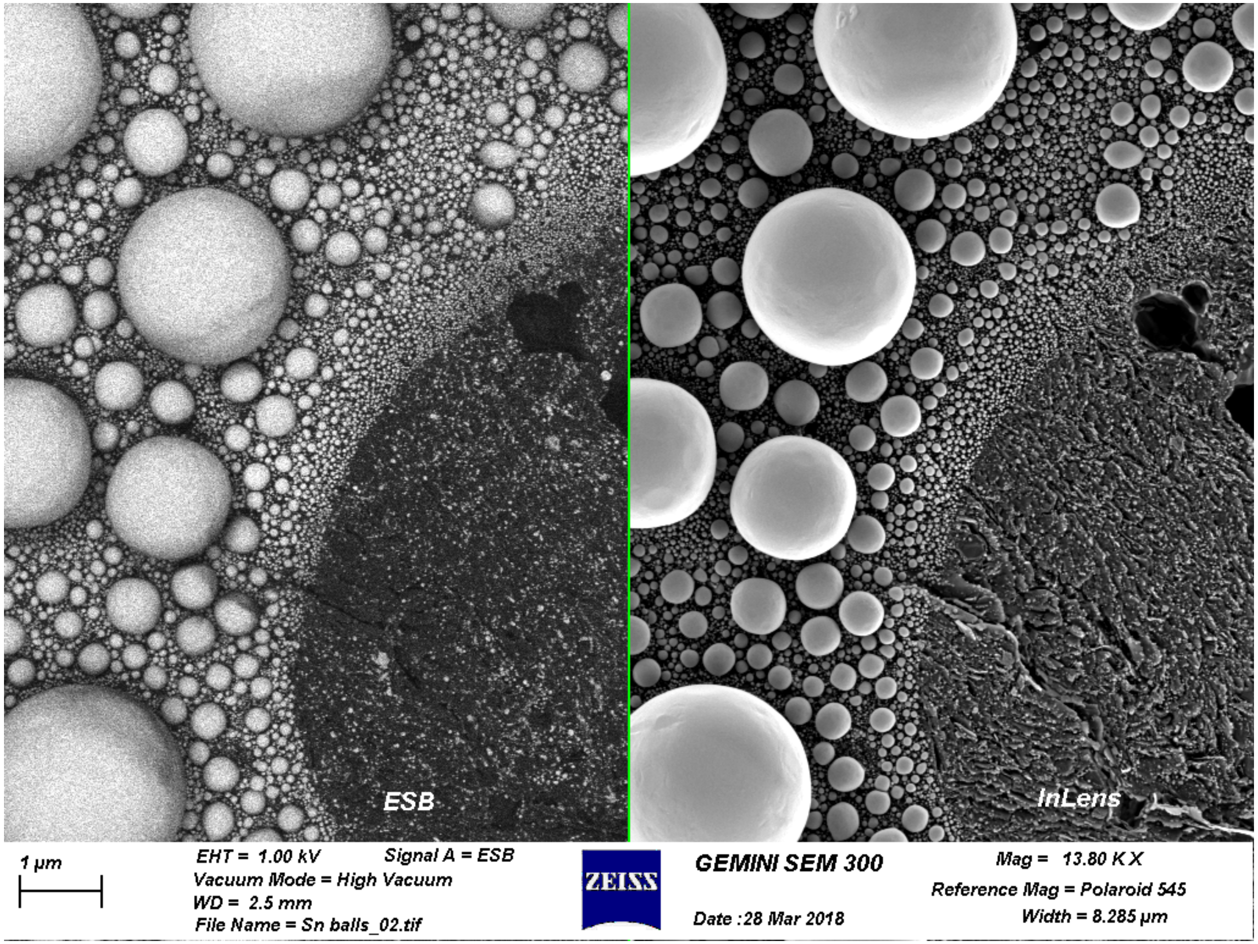
Low kV Imaging
Ink line on paper

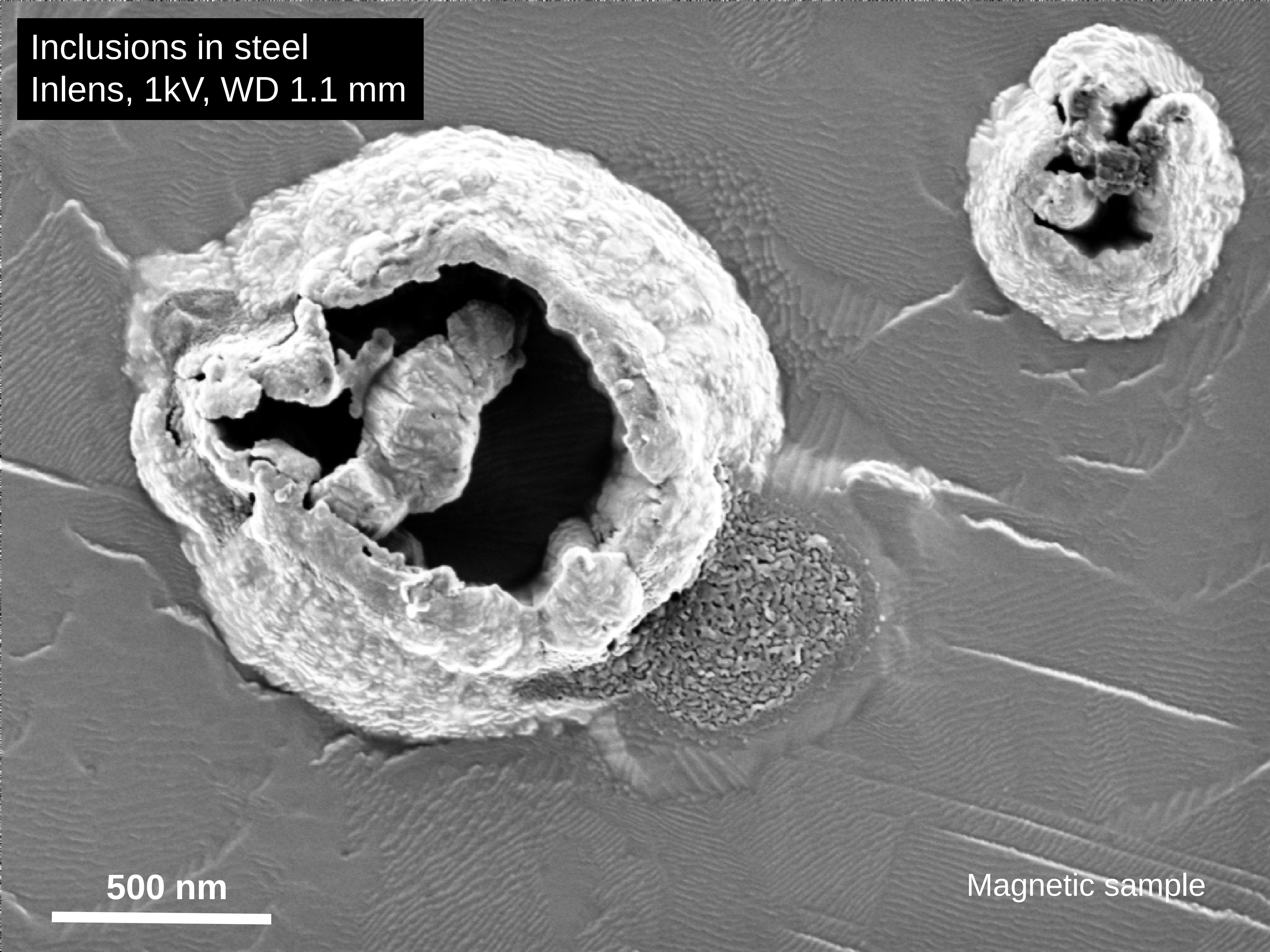




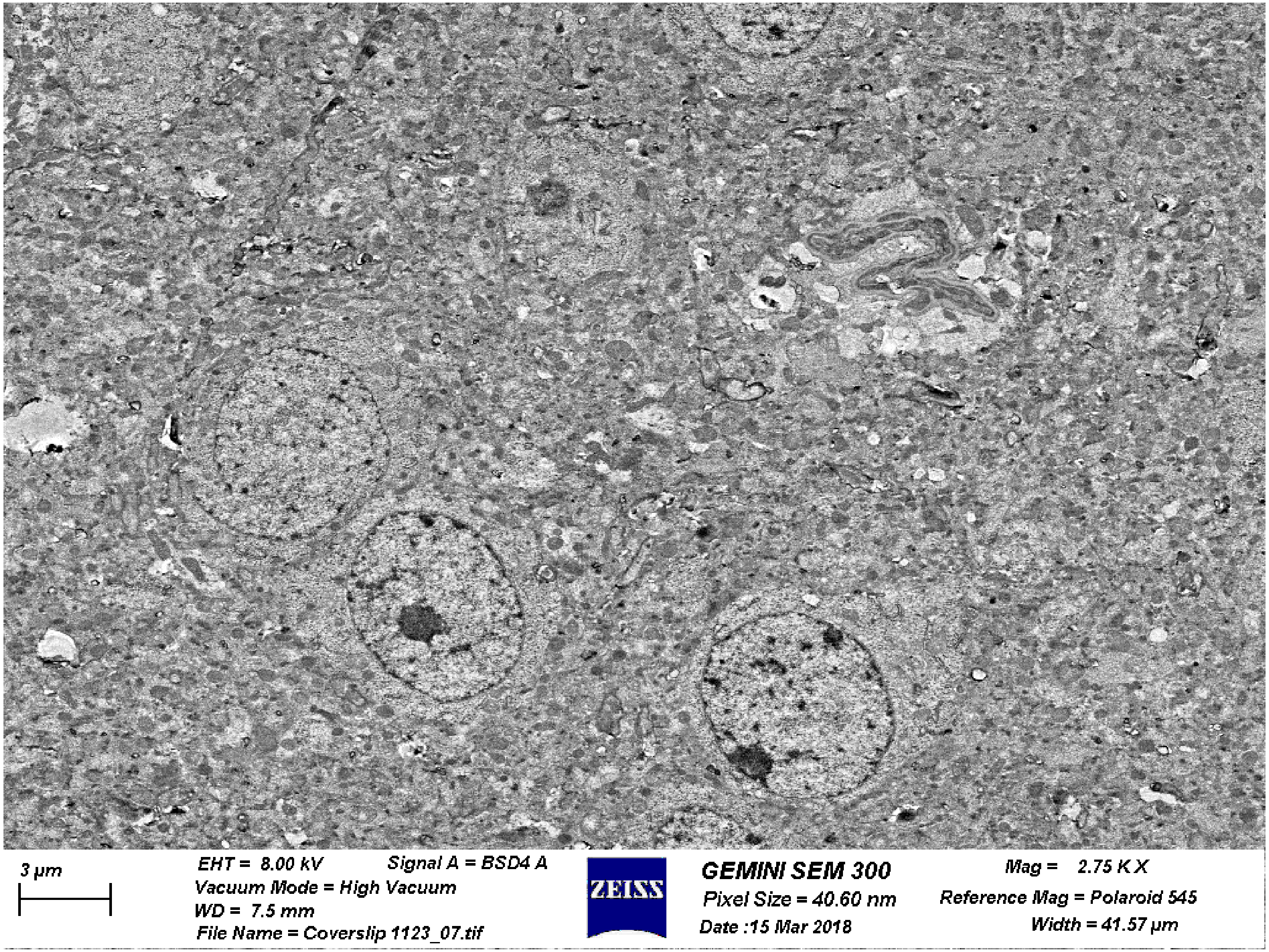
Tin balls

High resolution sample

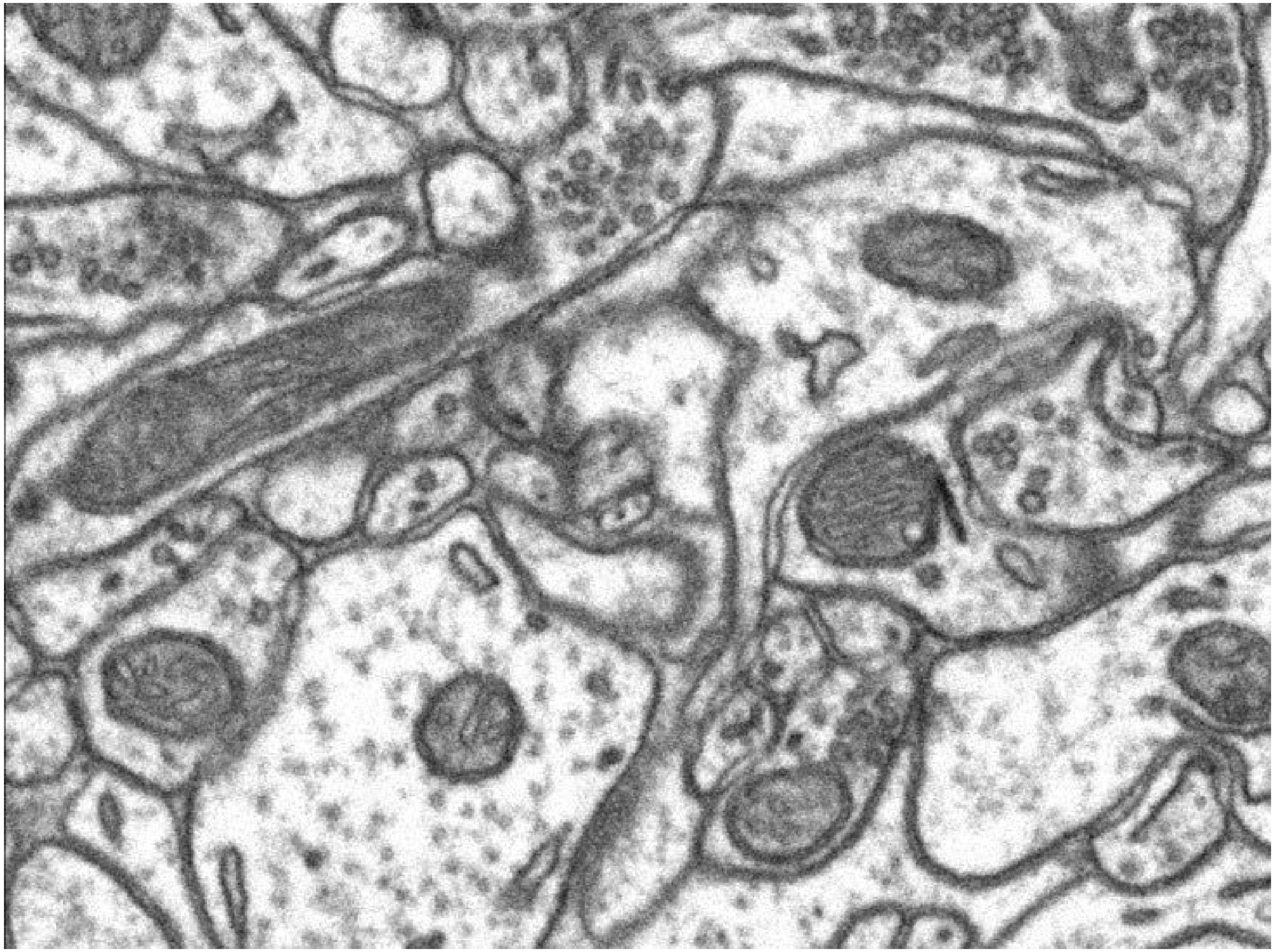



Inclusions in steel
Inlens, 1kV, WD 1.1 mm
500 nm
Magnetic sample

Using SEM to mimic TEM

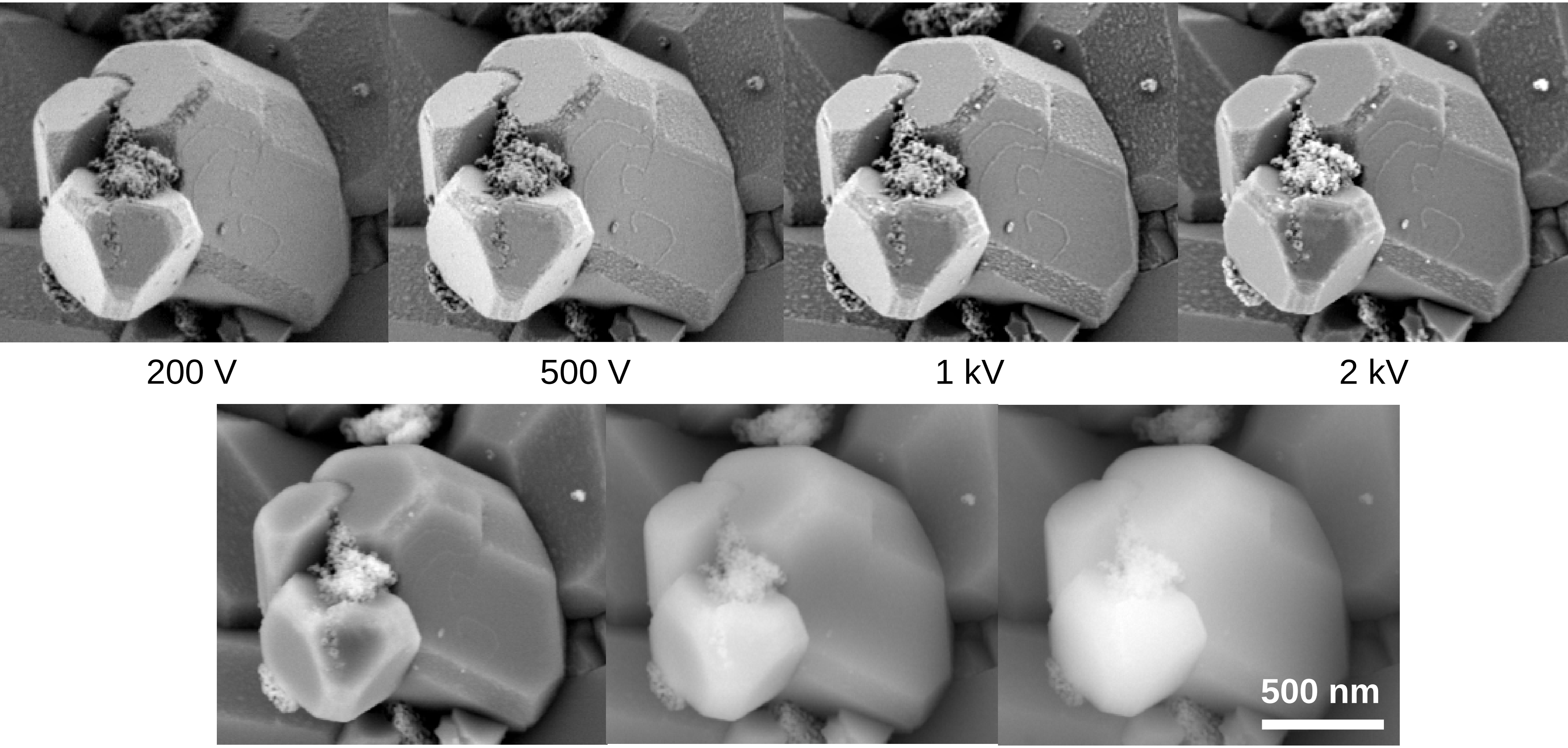


Brain Tissue - Low Voltage EsB Imaging



Courtesy Marco Cantoni EPFL Lausanne

Why low-kV imaging?
More surface sensitivity



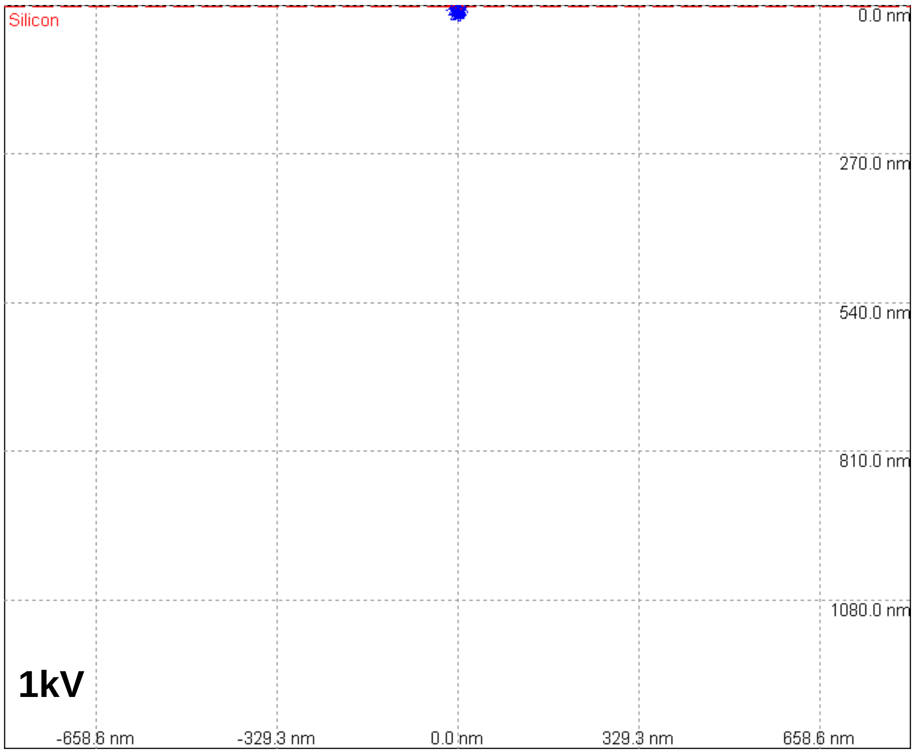
200 V 500 V 1 kV 2 kV

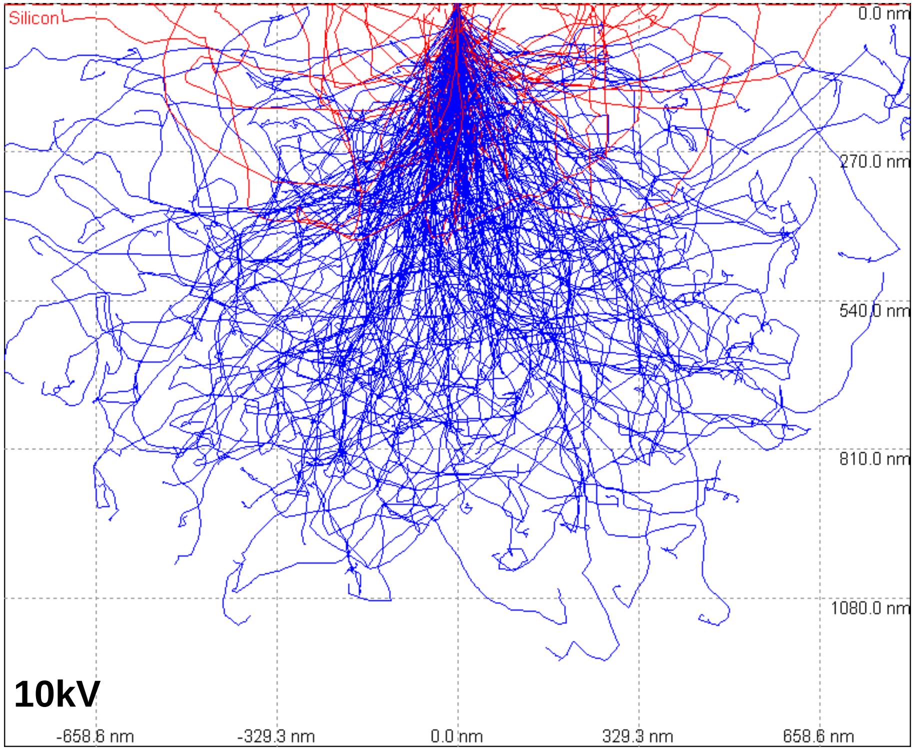
5 kV 10 kV 15 kV

Iron oxide/ Zirconium dioxide composite

Beam Sample Interaction – Influence of Beam Energy

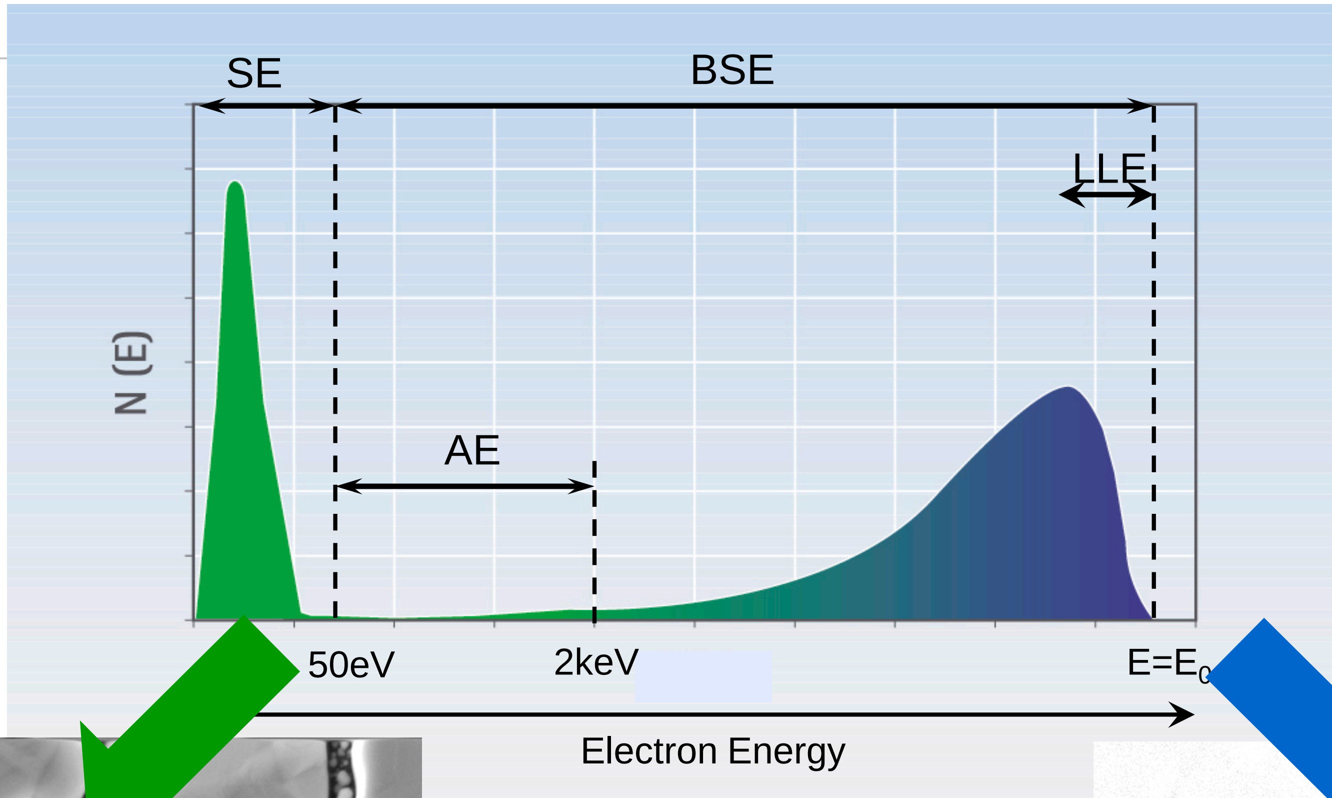
Monte Carlo Simulations

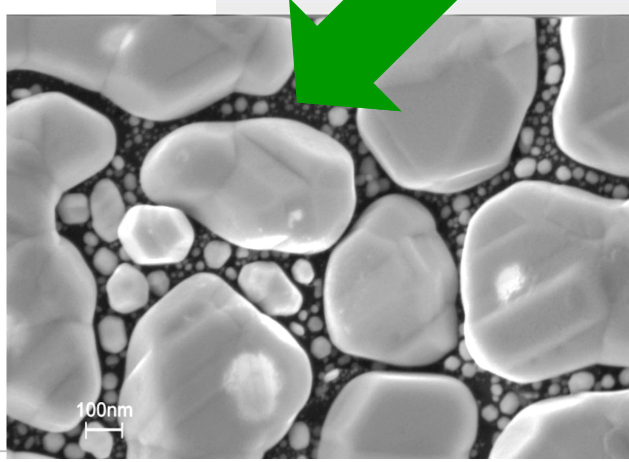




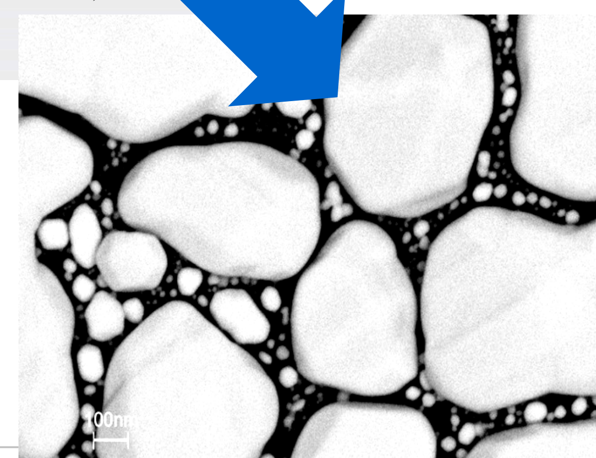
Monte Carlo simulation of the beam – sample interaction for a Si sample at 1kV and 10kV.

Beam Sample Interaction

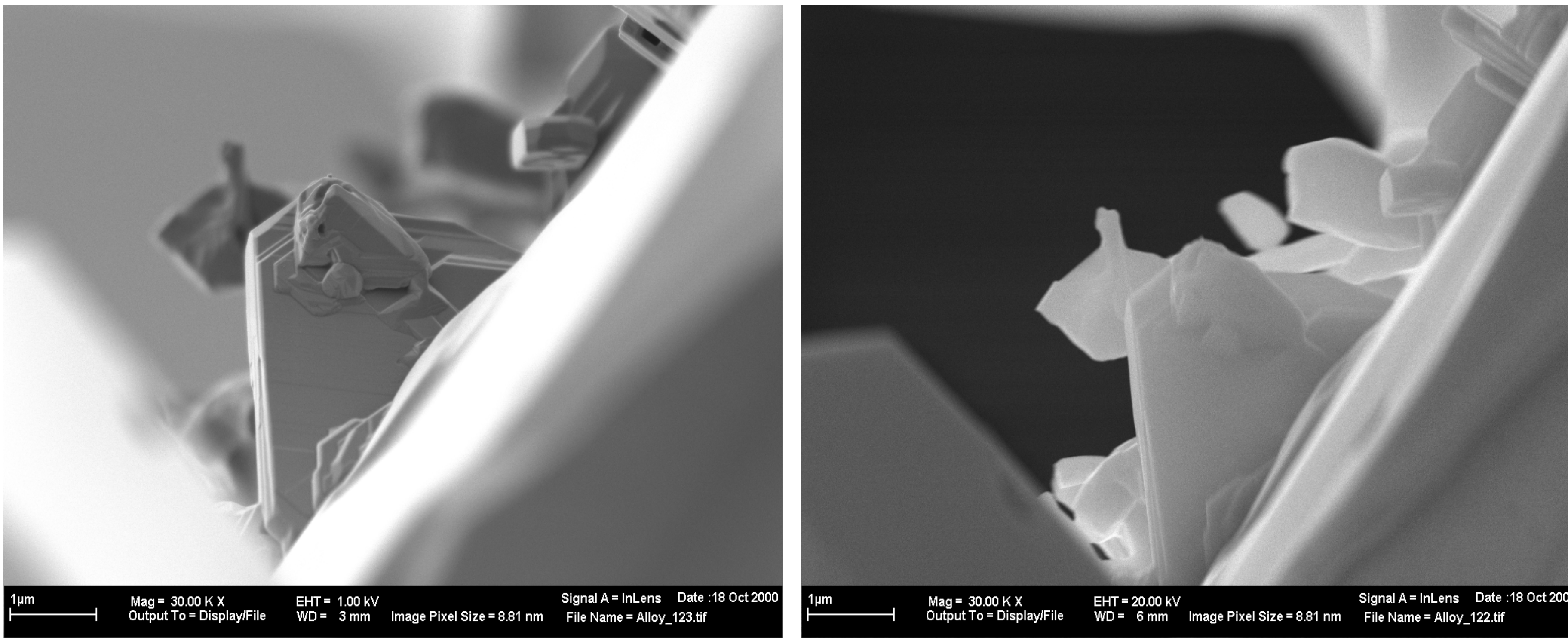




Target is to separate information

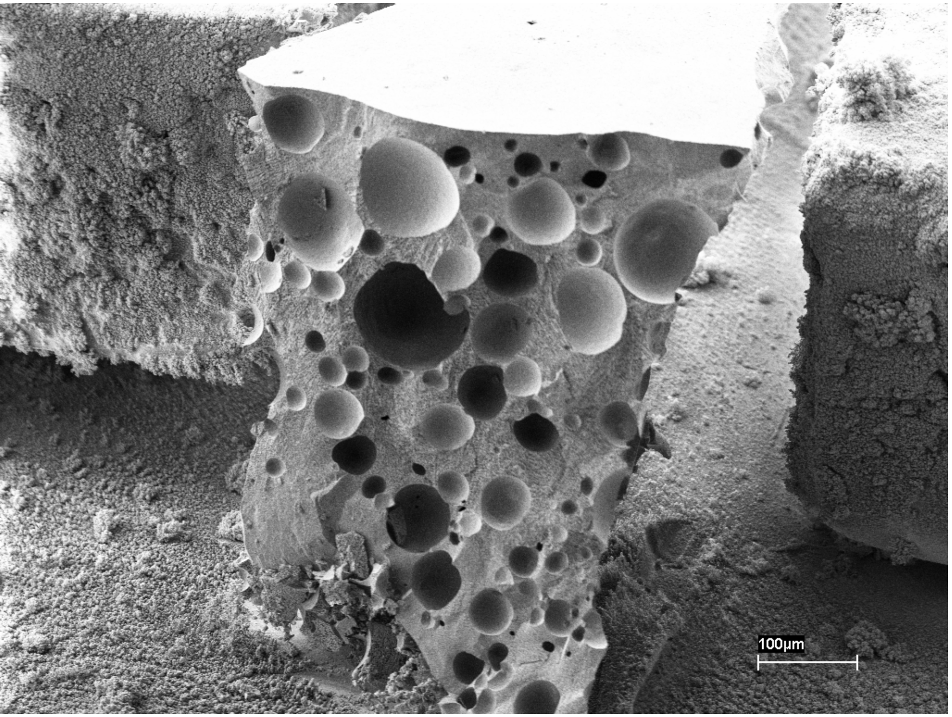


Beam Sample Interaction – Influence of Beam Energy

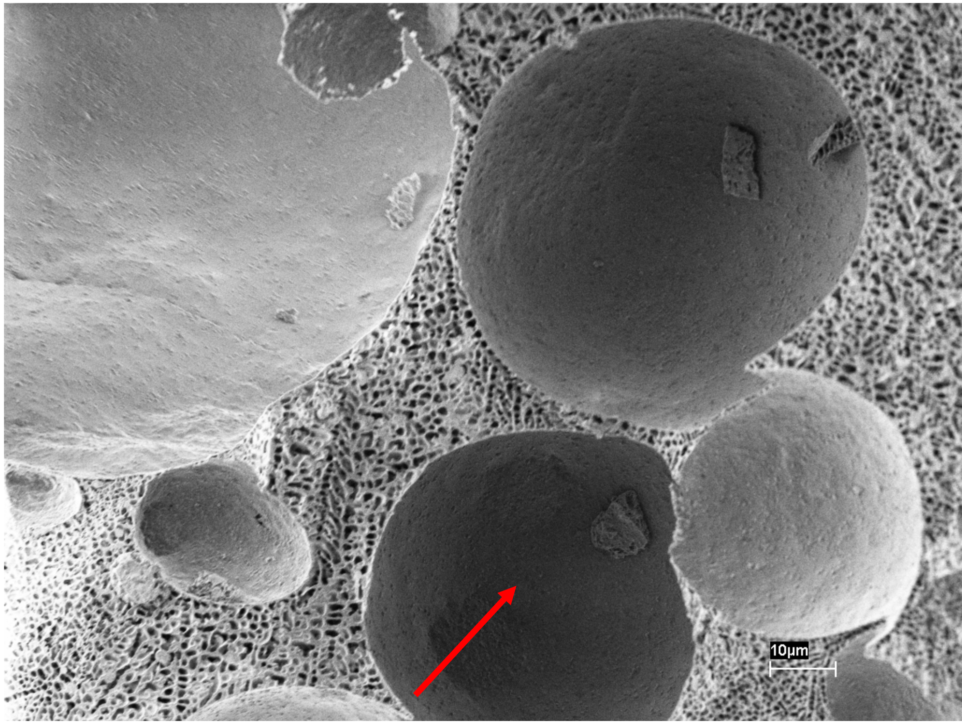


Platinum Rhodium Alloy Crystals at 1kV (left) and at 20kV (right)

Cryo SEM Applications

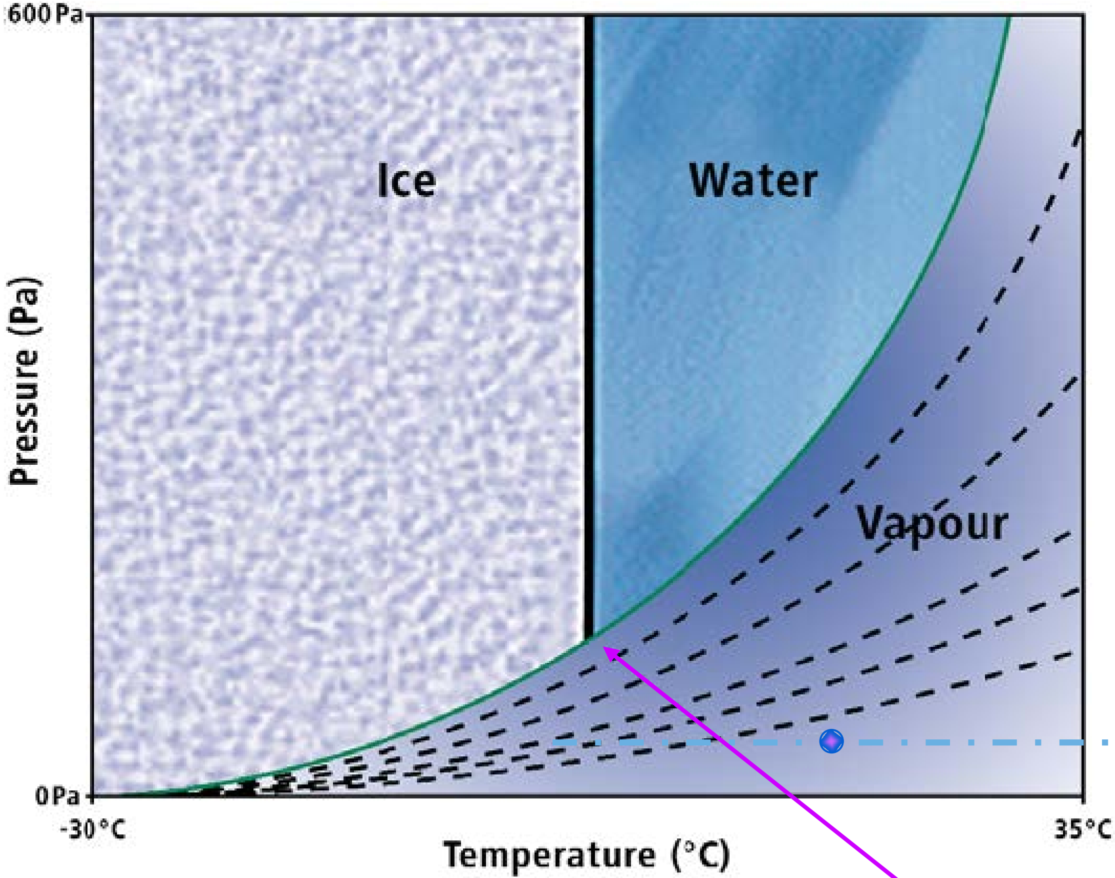


Freeze fracture,
(Temp. -130°C)



Fracture at the interface Fat - Water
fat droplets

Water Phase Diagram



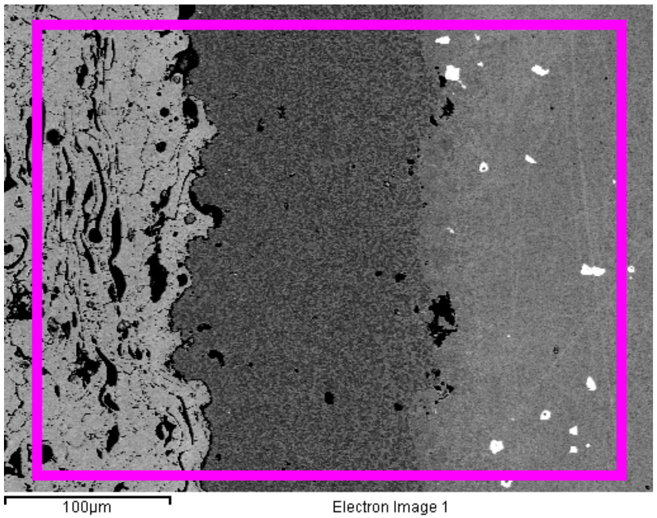
600 Pa - 750 Pa
Imaging liquid water; the specimen is cooled to just above 0 ºC (The water vapour pressure in the microscope is minimised).

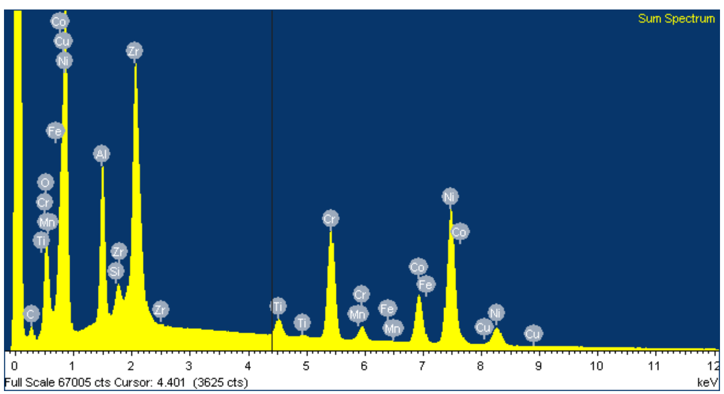
650 Pa – 3000 Pa
Imaging of liquid water close to room temperature; High water vapour pressure required to prevent dehydration and maintaining the structure of sensitive samples such as Fauna and Flora.

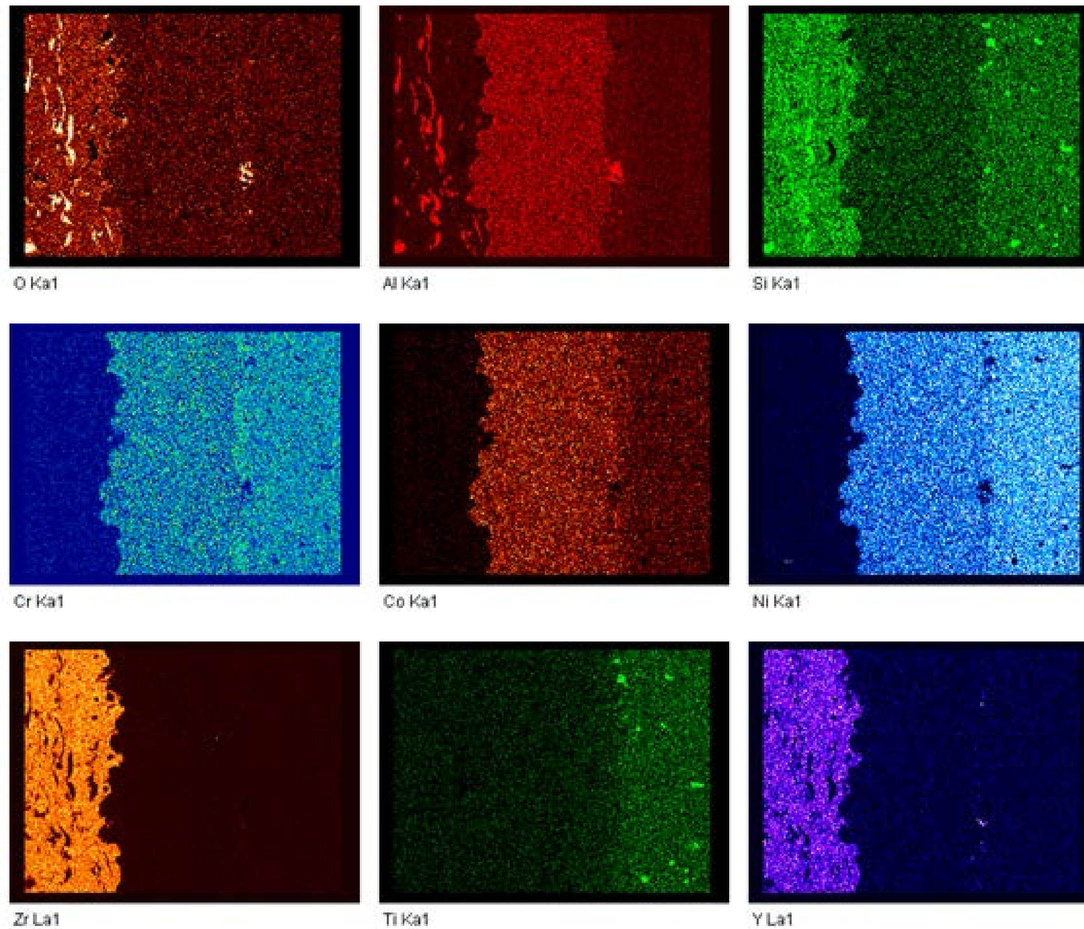
Triple point
0°C, 612 Pa (4.6 Torr)

Cryo-Technology

EDS Analysis – Turbine Blades







EDS Analysis at 15kV with charge compensation.

Energy-Dispersive X-Ray Spectroscopy

Energy-dispersive X-ray spectroscopy (**EDS**, **EDX**, **EDXS** or **XEDS**), sometimes called **energy dispersive X-ray analysis** (**EDXA**) or **energy dispersive X-ray microanalysis** (**EDXMA**), is an analytical technique used for elemental analysis.

EDS relies on the principle that all elements have unique atomic structures which are represented by unique peaks on their electromagnetic spectra.

To stimulate the emission of characteristic X-rays from a specimen, a high-energy electron beam is focused into the sample.

The incident beam may excite an electron in an inner shell, ejecting it from the shell while creating an electron hole where the electron was.

An electron from an outer, higher-energy shell then fills the hole, and the difference in energy between the higher-energy shell and the lower energy shell may be released in the form of an X-ray.

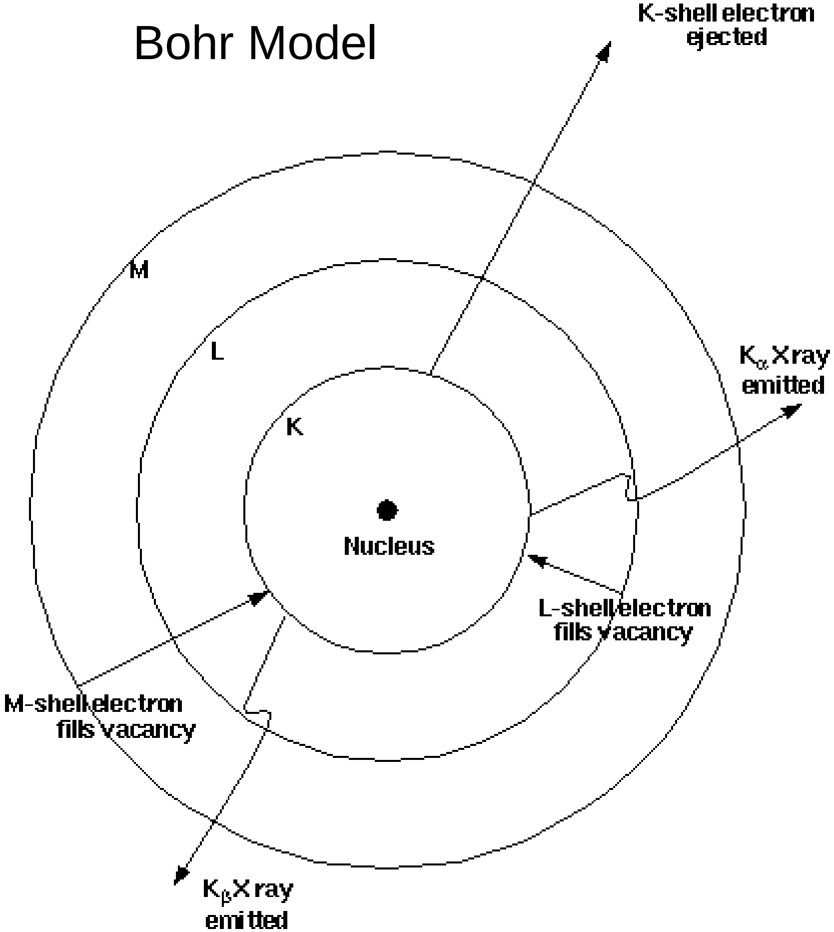
The number and energy of the X-rays emitted from a specimen can be measured by an energy-dispersive spectrometer.

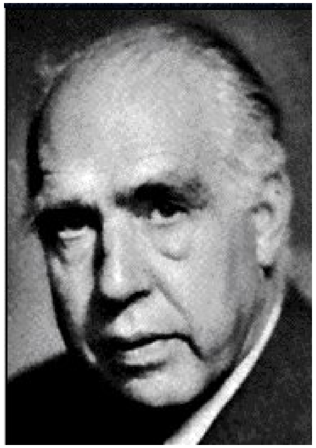
As the energies of the X-rays are characteristic of the difference in energy between the two shells and of the atomic structure of the emitting element, EDS allows the elemental composition of the specimen to be measured.

Inelastic Collision Summary
X-Ray Generation

Primary beam electron interacts with atom
There is an energy transfer
An electron from the atom is liberated
Creates a secondary electron (SE)
SE has low energy
The atom is excited and wants to return to a relaxed state
Characteristic X-ray is emitted

X-ray Generation

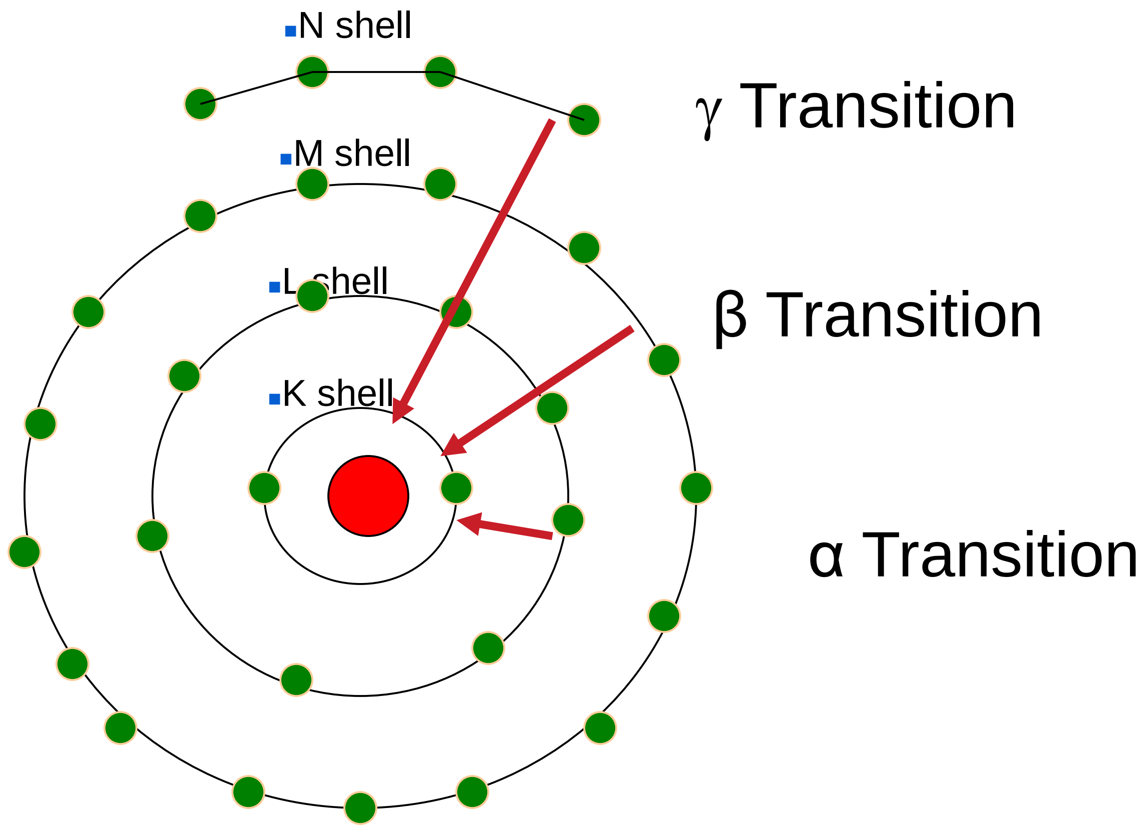




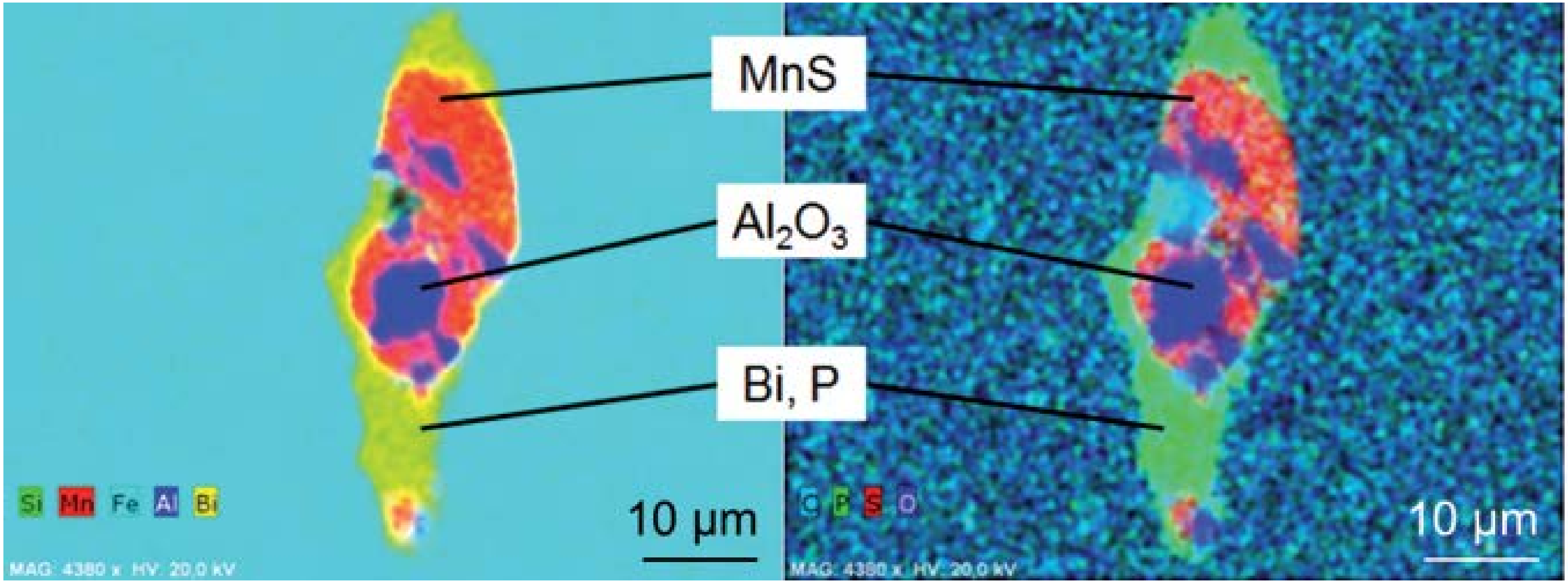
Niels Bohr
1885-1962
Danish
Nobel Prize 1922

Bohr, Niels (1913). "On the Constitution of Atoms and Molecules,
Part III Systems containing several nuclei". Philosophical Magazine; ***26*** *(155): 857–875*

Energy-Dispersive X-Ray Spectroscopy

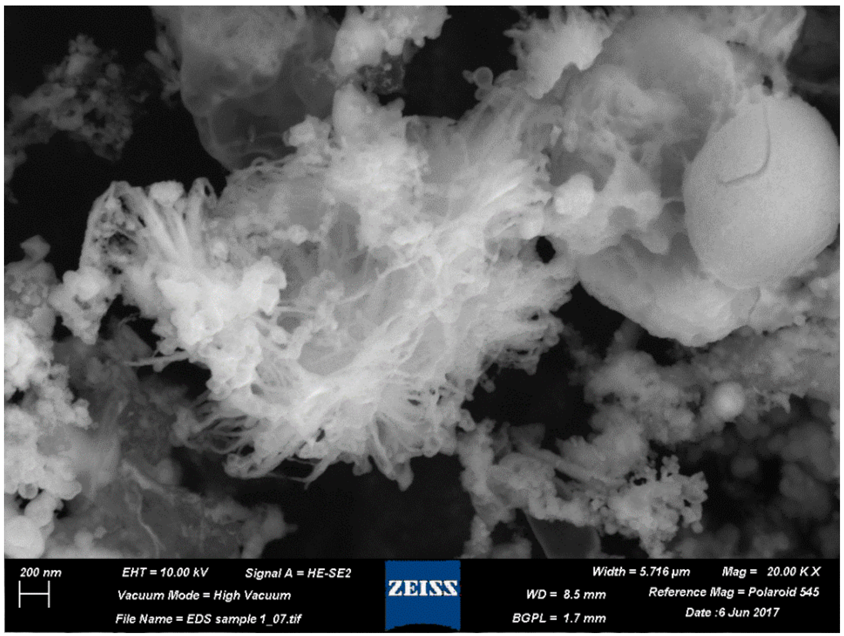


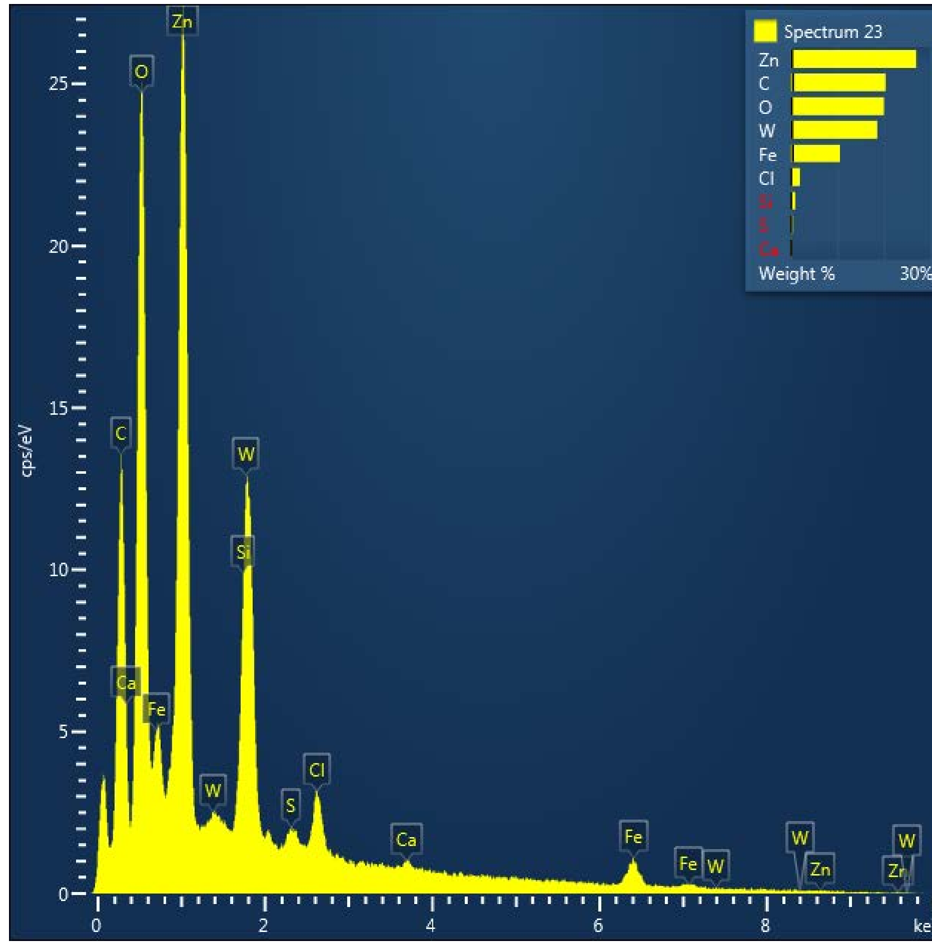
Characterization of Non-metallic Inclusions in Steel using EDS



EDS mapping of the conspicuous mixed inclusion in a mechanically polished steel sample (16MnCr5 grade). The core of the mixed inclusion consists of the "typical" inclusion types MnS (red) and Al2O3 (blue) whereas the surrounding bright phase contains the elements Bi (yellow) and P (green).

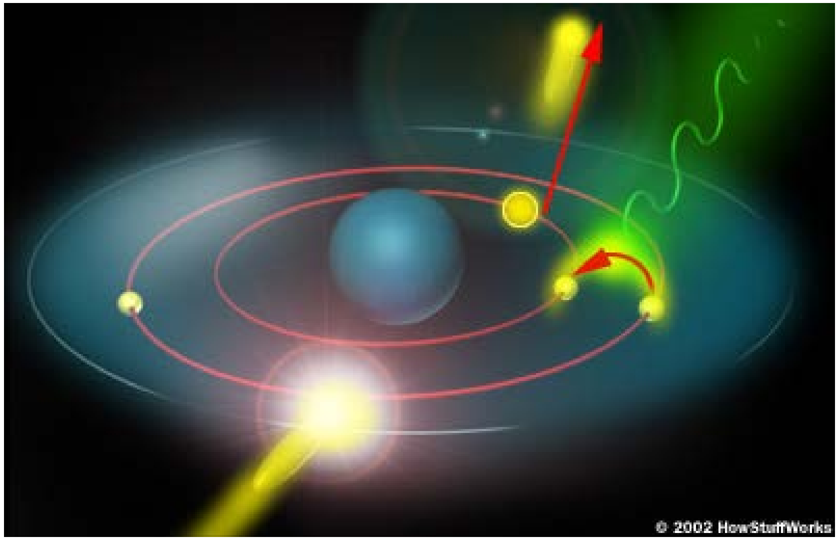
Energy-Dispersive X-Ray Spectroscopy



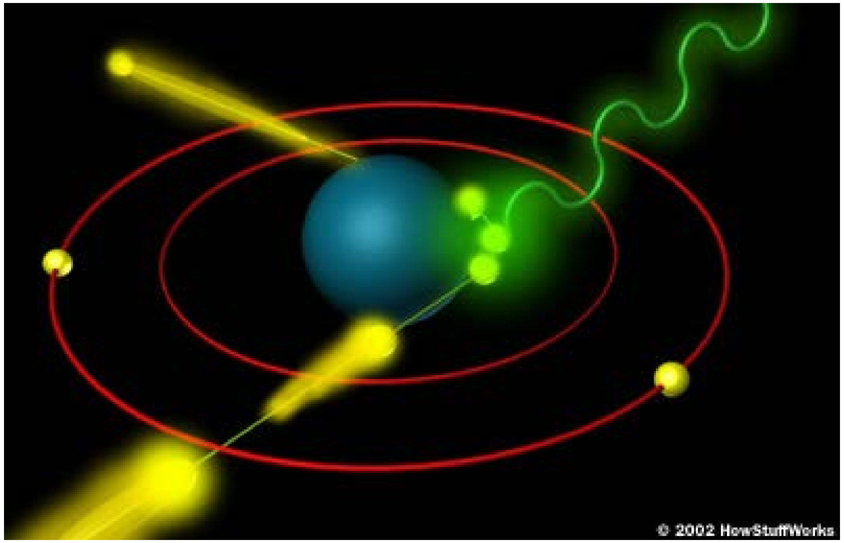


How X-rays (Photons) are Generated

Inelastic Scattering – Secondary Electron



Elastic Scattering – Backscattered Electron



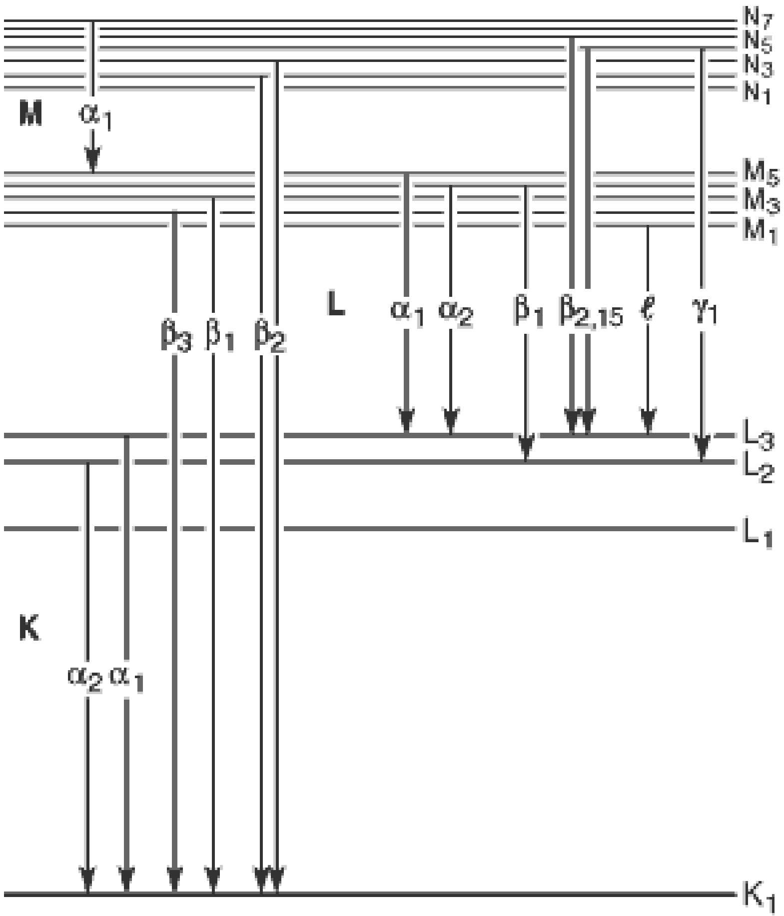
The primary electron interacts with the atom, knocking an electron out of a lower orbital. A higher orbital electron fills the empty position, releasing a (characteristic) photon of a known and measureable energy and wavelength

The primary electron is attracted to the atom nucleus. The electron course is altered as the electron passes the nucleus resulting a release of an X-ray photon (bremsstrahlung).

X-ray Line Nomenclature

Karl Manne Georg Siegbahn
1886 – 1978
Swedish
1924 Noble Prize

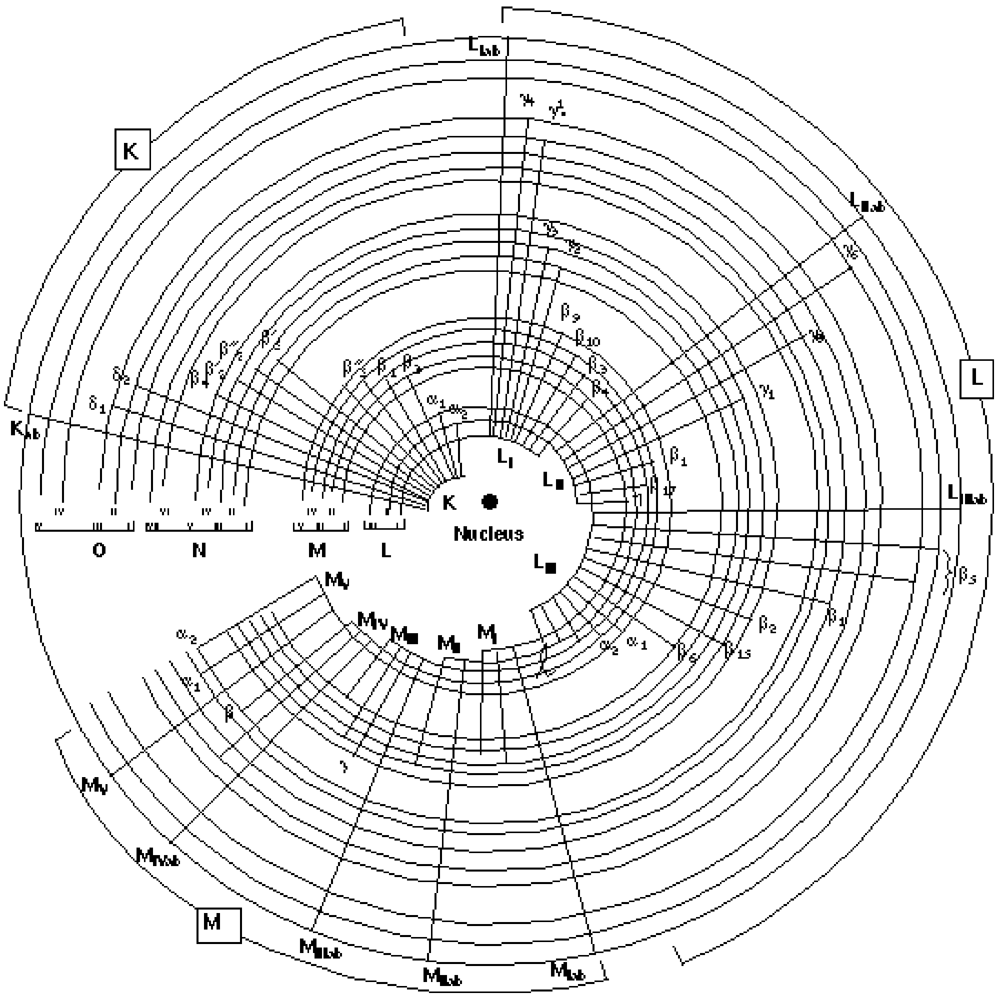
1. Atomic Symbol
2. Shell (KLMN)
3. Distance ($\alpha\beta\gamma\lambda$)



CaKα = Calcium, Kshell, L to K transition

Siegbahn Notation ARL

Energy Level Diagram of Electron Transitions



4. **CORRESPONDENCE BETWEEN THE SIEGBAHN AND IUPAC NOTATIONS**

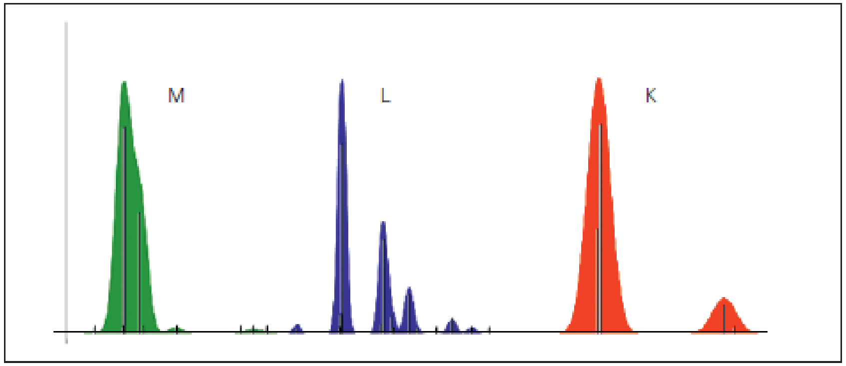
The IUPAC Notation is compared with the Siegbahn notation in the following table.

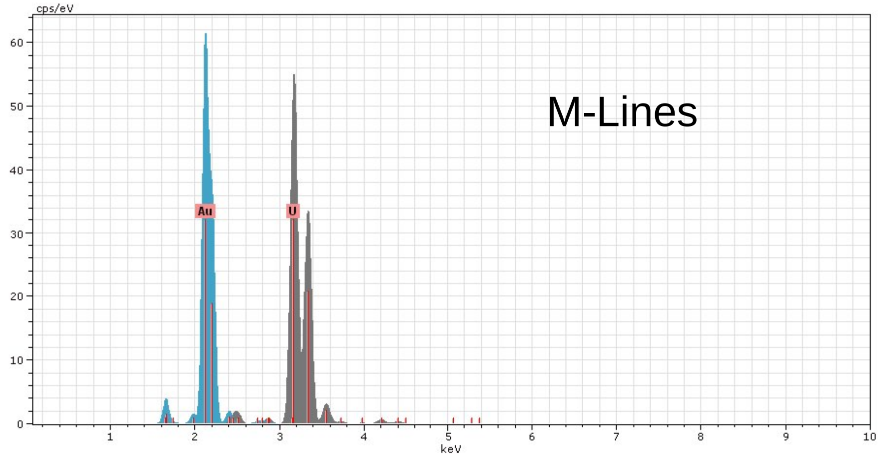
Table VIII.2. Correspondence between Siegbahn and IUPAC notation diagram lines

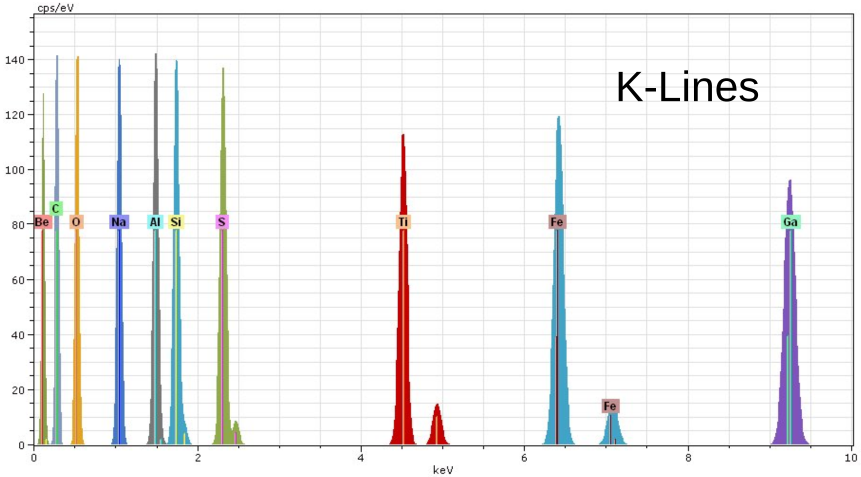
Siegbahn	IUPAC	Siegbahn	IUPAC	Siegbahn	IUPAC	Siegbahn	IUPAC
$K\alpha_1$	$K\text{-}L_3$	$L\alpha_1$	$L_3\text{-}M_5$	$L\gamma_1$	$L_2\text{-}N_4$	$M\alpha_1$	$M_5\text{-}N_7$
$K\alpha_2$	$K\text{-}L_2$	$L\alpha_2$	$L_3\text{-}M_4$	$L\gamma_2$	$L_1\text{-}N_2$	$M\alpha_2$	$M_5\text{-}N_6$
$K\beta_1$	$K\text{-}M_3$	$L\beta_1$	$L_2\text{-}M_4$	$L\gamma_3$	$L_1\text{-}N_3$	$M\beta$	$M_4\text{-}N_6$
$K^{I}\beta_2$	$K\text{-}N_3$	$L\beta_2$	$L_3\text{-}N_5$	$L\gamma_4$	$L_1\text{-}O_3$	$M\gamma$	$M_3\text{-}N_5$
$K^{II}\beta_2$	$K\text{-}N_2$	$L\beta_3$	$L_1\text{-}M_3$	$L\gamma_4'$	$L_1\text{-}O_2$	$M\zeta$	$M_{4,5}\text{-}N_{2,3}$
$K\beta_3$	$K\text{-}M_2$	$L\beta_4$	$L_1\text{-}M_2$	$L\gamma_5$	$L_2\text{-}N_1$		
$K^{I}\beta_4$	$K\text{-}N_5$	$L\beta_5$	$L_3\text{-}O_{4,5}$	$L\gamma_6$	$L_2\text{-}O_4$		
$K^{II}\beta_4$	$K\text{-}N_4$	$L\beta_6$	$L_3\text{-}N_1$	$L\gamma_8$	$L_2\text{-}O_1$		
$K\beta_{4x}$	$K\text{-}N_4$	$L\beta_7$	$L_3\text{-}O_1$	$L\gamma_8'$	$L_2\text{-}N_{6(7)}$		
$K^{I}\beta_5$	$K\text{-}M_5$	$L\beta_7'$	$L_3\text{-}N_{6,7}$	$L\eta$	$L_2\text{-}M_1$		
$K^{II}\beta_5$	$K\text{-}M_4$	$L\beta_9$	$L_1\text{-}M_5$	Ll	$L_3\text{-}M_1$		
		$L\beta_{10}$	$L_1\text{-}M_4$	Ls	$L_3\text{-}M_3$		
		$L\beta_{15}$	$L_3\text{-}N_4$	Lt	$L_3\text{-}M_2$		
		$L\beta_{17}$	$L_2\text{-}M_3$	Lu	$L_3\text{-}N_{6,7}$		
				Lv	$L_2\text{-}N_{6(7)}$		

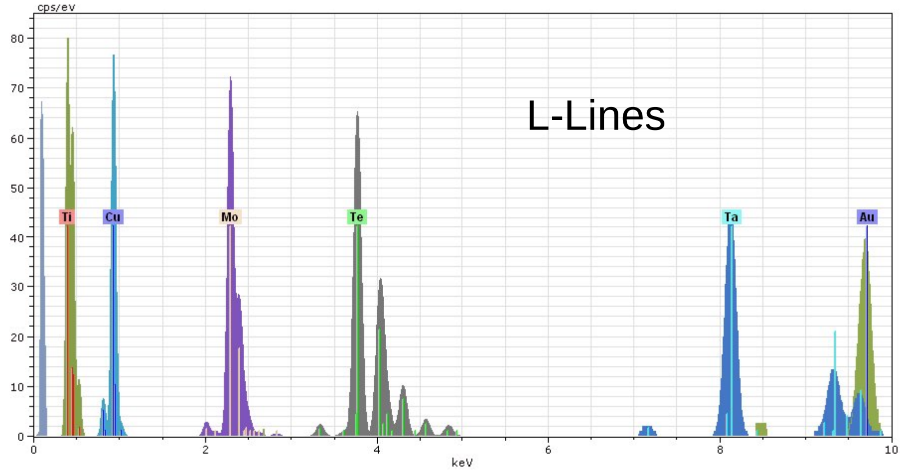
In the case of unresolved lines, such as $K\text{-}L_2$ and $K\text{-}L_3$, the recommended IUPAC notation is $K\text{-}L_{2,3}$

Typical X-ray Peak Shapes



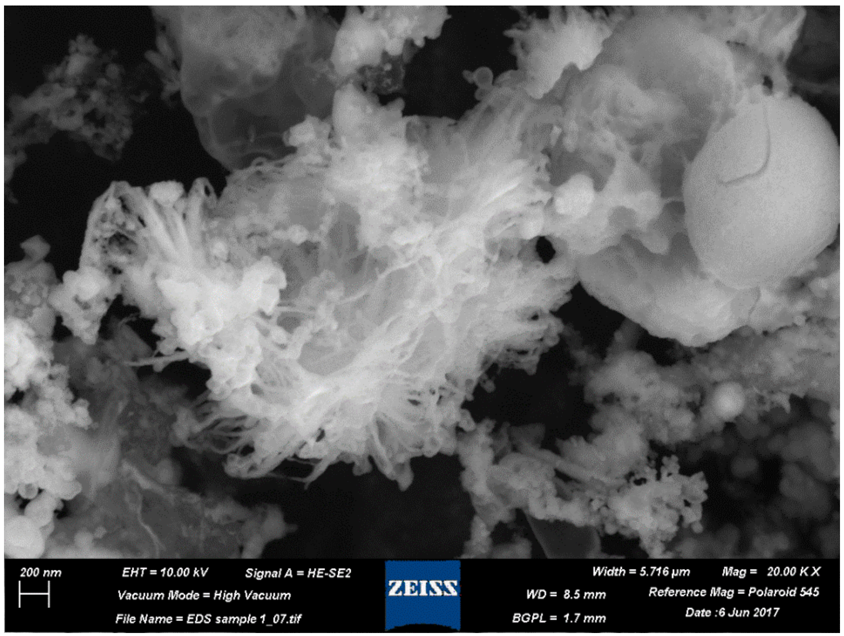


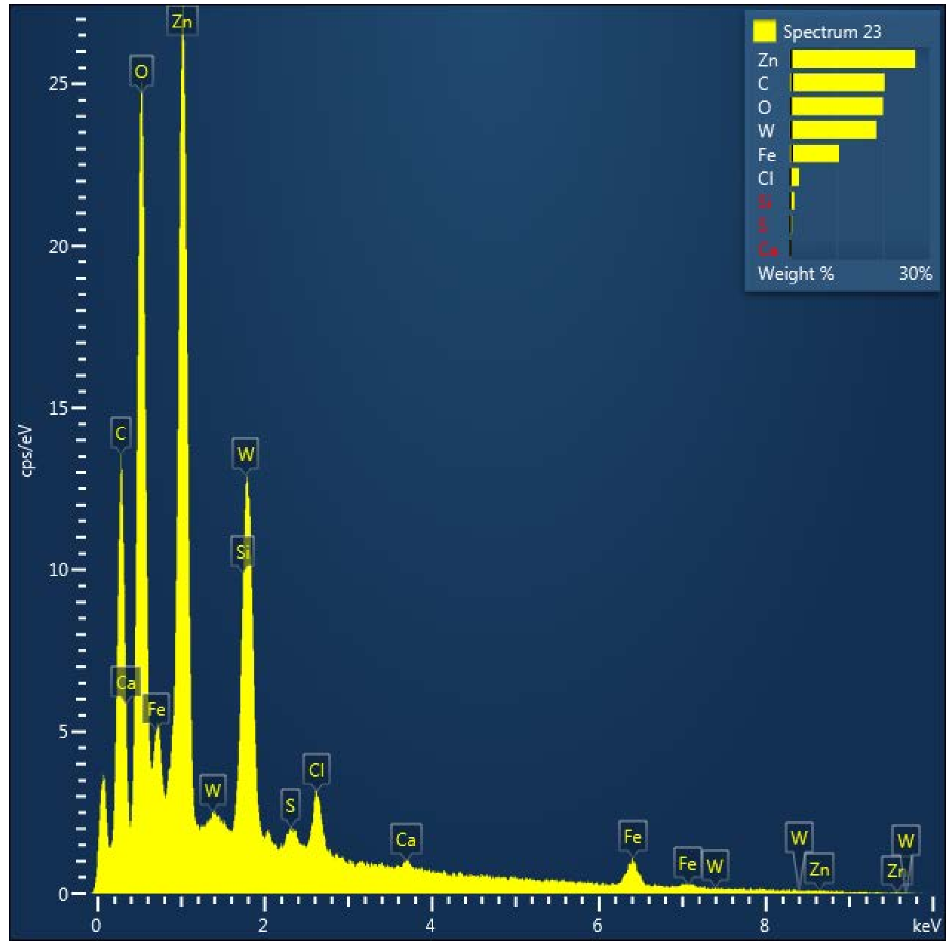




At 15kV accelerating voltage we can see the entire Periodic Table using K, L and M lines.

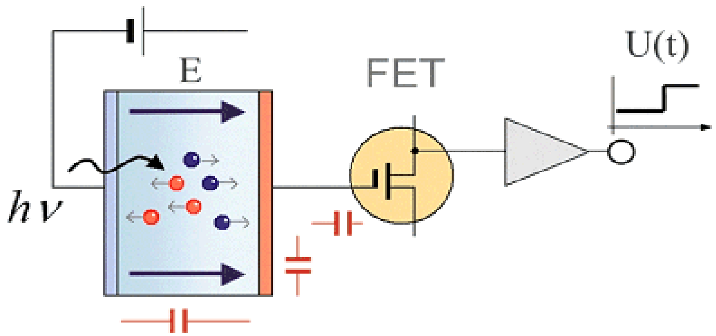
Energy-Dispersive X-Ray Spectroscopy





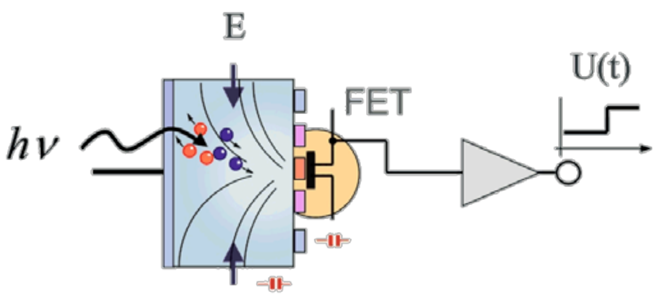
How Solid State Detectors Work

Si(Li)
or
HpGe

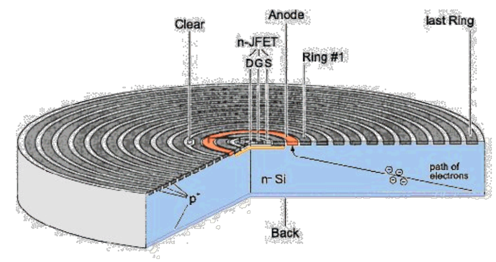


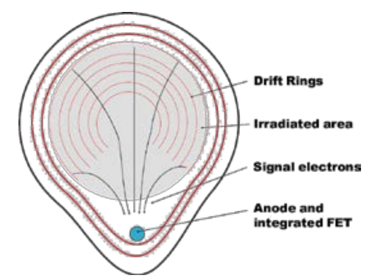
$$n_e = h\frac{\nu}{\varepsilon}$$

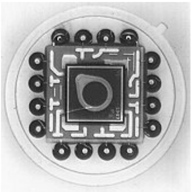
SDD



$$n_e = h\frac{\nu}{\varepsilon}$$







SEM & EDS

Summary

The scanning electron microscope (SEM) is an exceptionally versatile analytical tool, with resolution better than 1 nanometer.

The SEM produces images by scanning the surface of a sample with a focused beam of electrons.

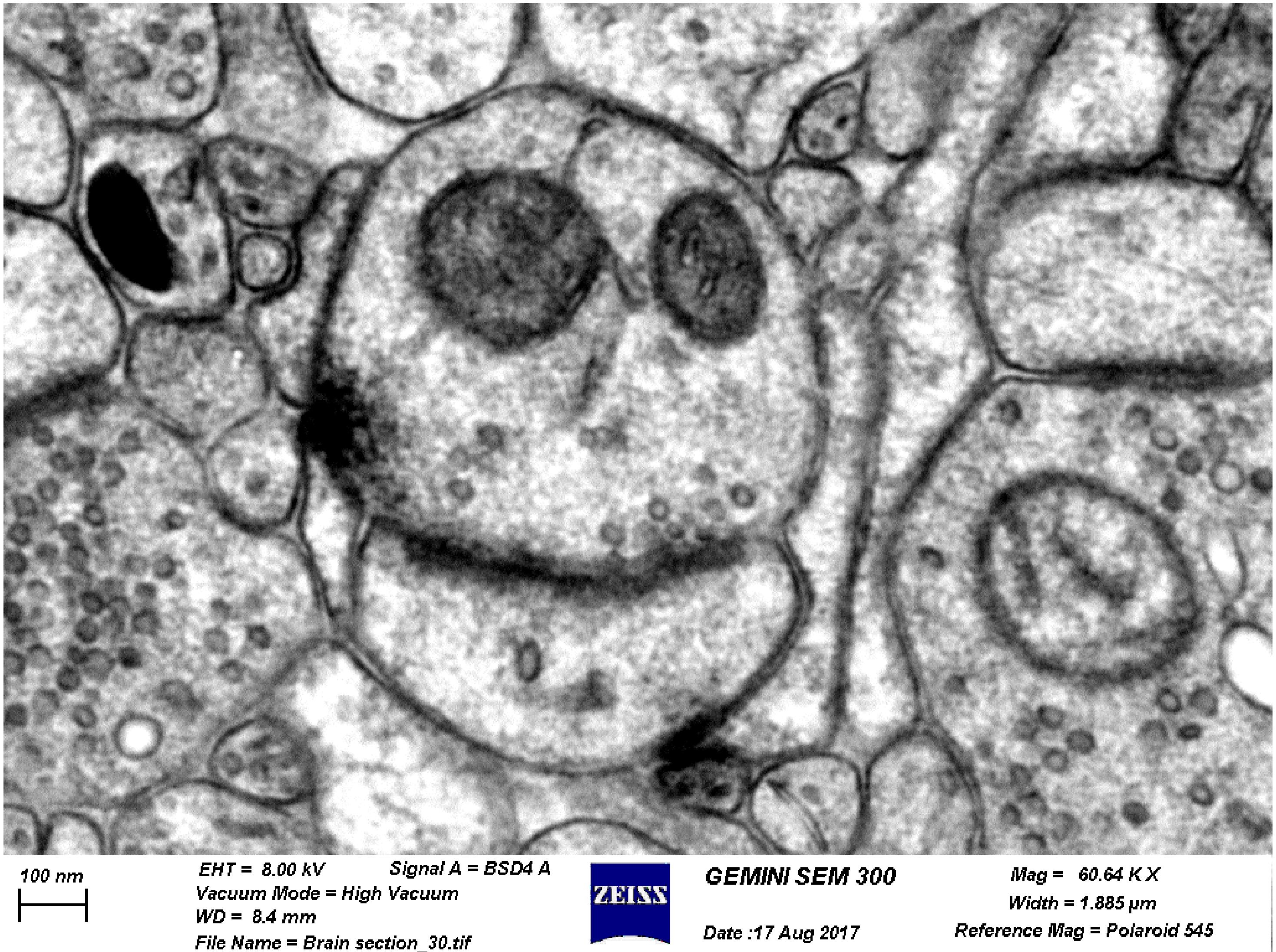
These electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition.

Characteristic X-rays that are produced by the interaction of electrons with the sample may also be detected in an SEM equipped for energy-dispersive X-ray spectroscopy, EDS

Analysis of the x-ray signals can be used to map the distribution and estimate the abundance of elements in the sample.

SEM/EDS systems are some of the most powerful and versatile analytical tools available.

SEM produces Happy, Stimulated Synapses



ZEISS