Scanning Electron Microscopy
SEM

MASTER
Pharmaceutical sciences, drug innovation and health products

Analytical Sciences 1 - TU 09

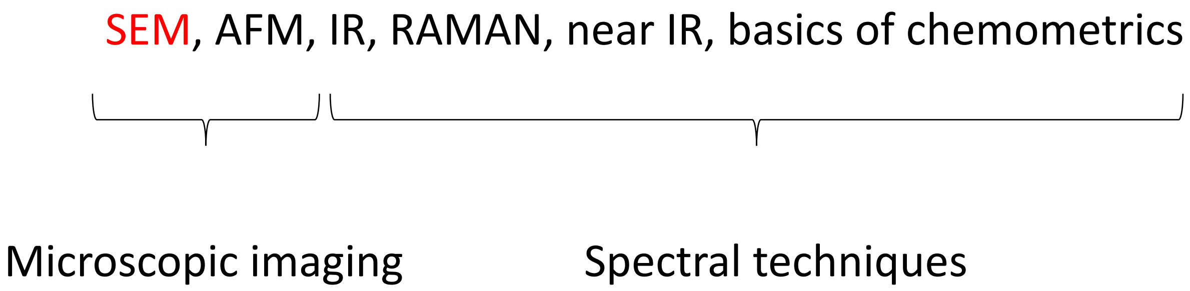
International Master Development of drugs and health products (D^2HP)

Caroline Aymes-Chodur
Lecturer (caroline.aymes-chodur@universite-paris-saclay.fr)

What are the learning objectives ?

- General background
- Technical Principle : different components of SEM
- SEM : where do the images come from ?
- Adjustment and optimization parameters

Spectral methods and analytical imaging:



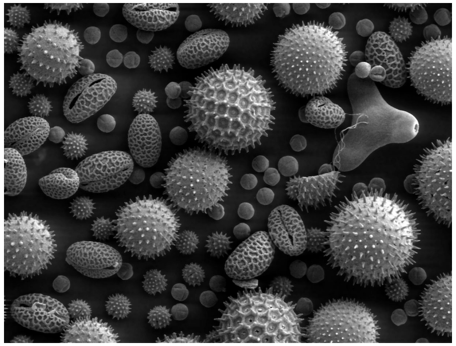
SEM, AFM, IR, RAMAN, near IR, basics of chemometrics

Microscopic imaging

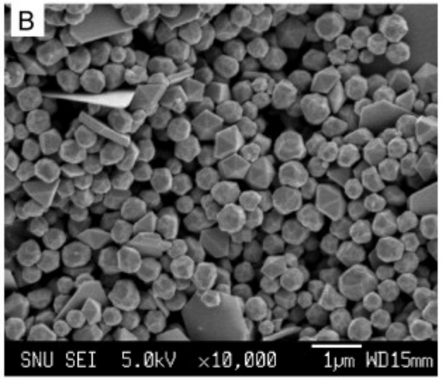
Spectral techniques

Spectral methods and analytical imaging:

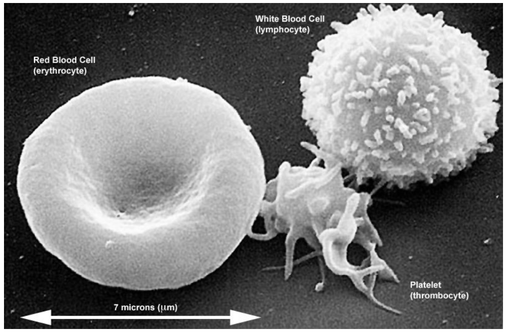
SEM, AFM, IR, RAMAN, near IR, basics of chemometrics



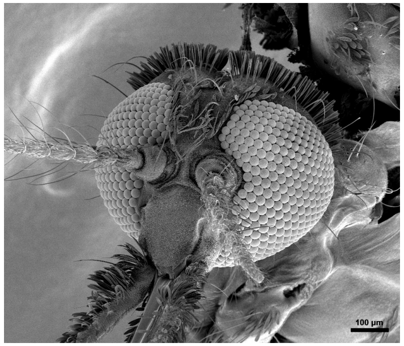
Pollen



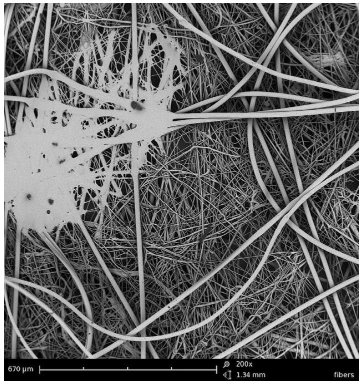
Zinc oxide tetrapods



Blood cells



Mosquito head



Melt blown fibers

Microscopy techniques :

- SEM : Scanning Electron Microscopy,
- TEM : Transmission Electron Microscopy,
- SPM : Scanning Probe Microscopy (AFM : Atomic Force Microscopy,
  STM : Scanning Tunnelling Microscopy)

Microscopy techniques :

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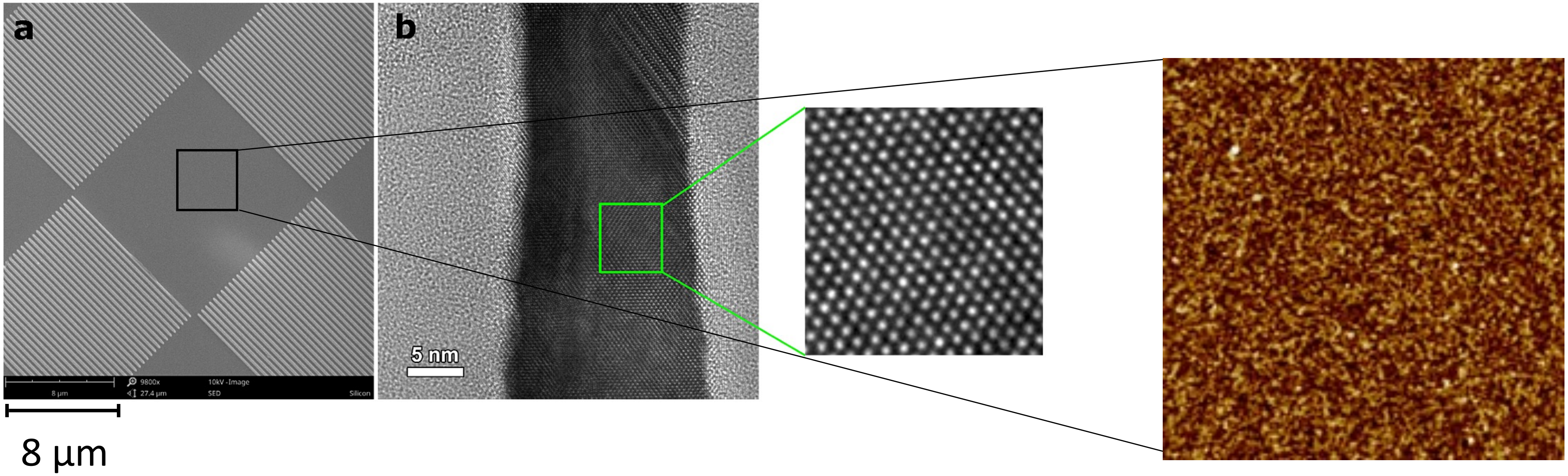
SEM, TEM and AFM images of a silicon



Scan size 1 µm.

SEM

Sample surface's **Morphology, composition**

TEM

Sample's **structural** information : electrons are passing through the sample

AFM

Sample surface's **topography**

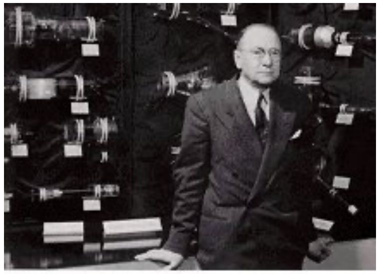
Short history of SEM

- **1926** : **Hans Busch** invented the first electromagnetic lens.
- **1931** : **Ernst Ruska and Max Knoll** created the first electron microscope. (Ruska was Awarded the Nobel Prize in 1986)
- **1937**: **Manfred von Ardenne** : developed the scanning transmission electron microscope (STEM).
- In the early **1940s Vladimir Zworykin** developed of the prototype of the modern SEM.
- In the **1950s-1965** : **Charles Oatley** developed the first commercial SEM produced by Cambridge Instruments in 1965 (Résolution = 50 nm).

Image: Replica from 1980 by Ernst Ruska of the first electron microscope with resolving power higher than that of a light microscope made by Ernst Ruska 1933. ©J Brew/ commons.wikimedia.org. Shared under: Creative Commons License.

C. Oatley

M. von Ardenne



Vladimir Zworykin, television pioneer

Course outline

- Technical Principle : different components of SEM
- SEM : Images from secondary / back scattered electrons detectors
- SEM : Images from back scattered electrons / Energy dispersive X-Rays detectors
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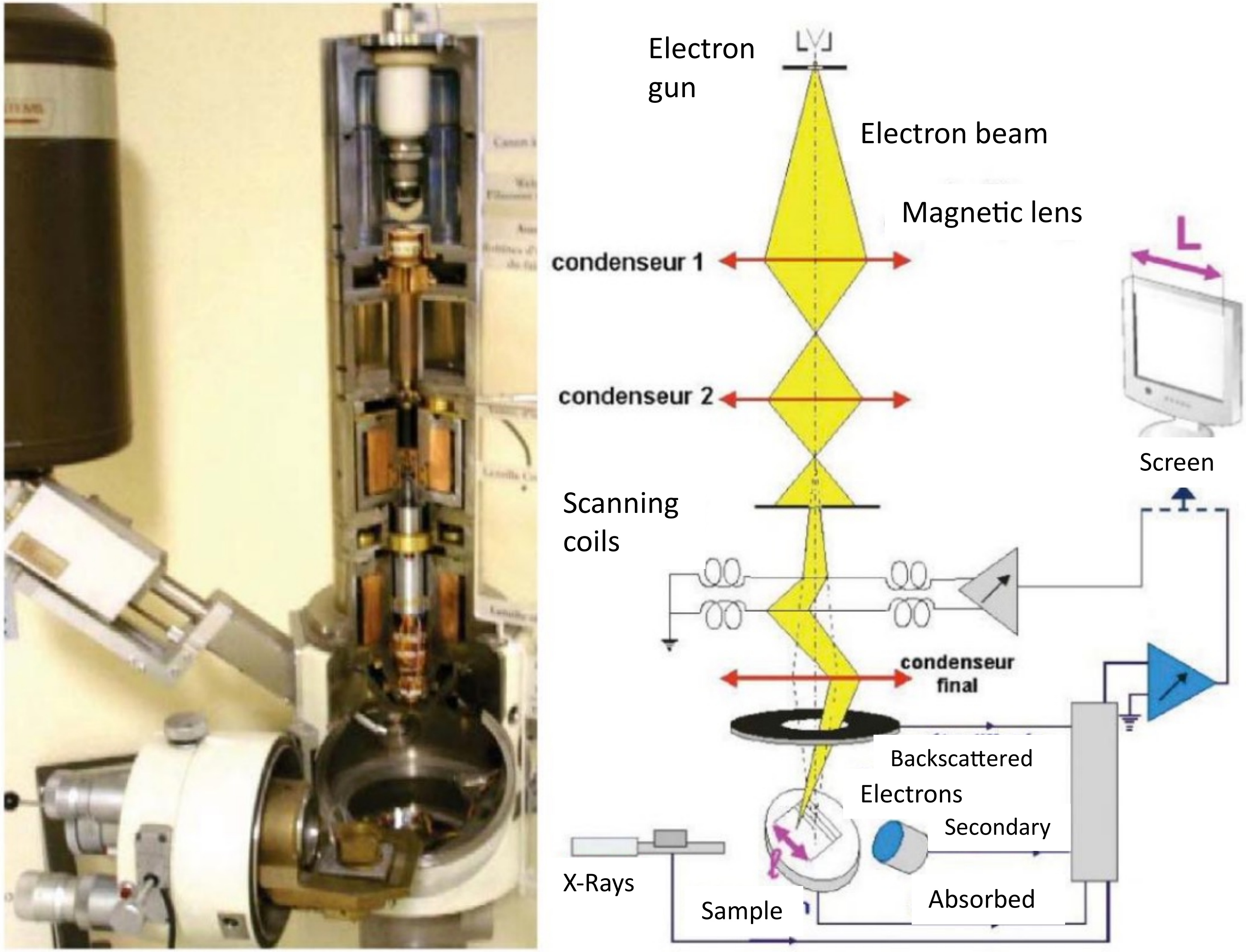
- Particular case : Environmental Scanning Microscope (ESEM)

Technical Principle : different components of SEM

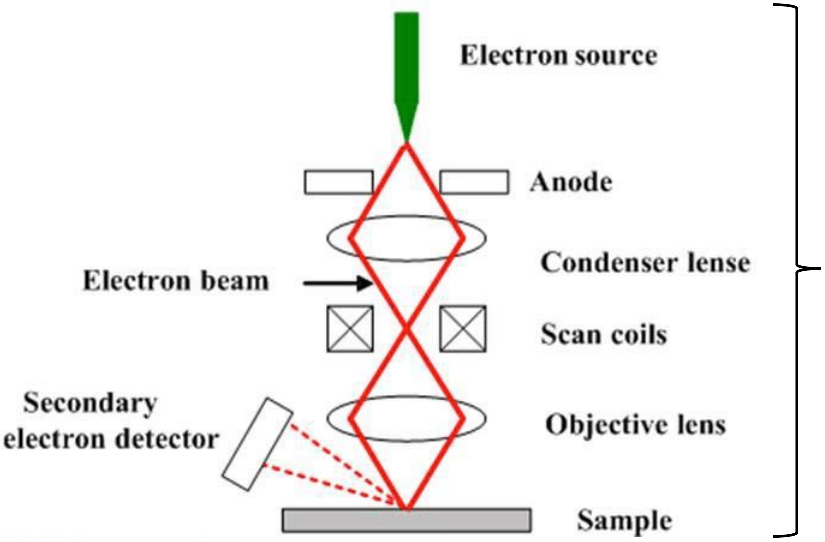
Vacuum : min 10^{-3} Pa



Cross-section of a SEM column (JEOL) and schematic layout of a SEM

Technical Principle : different components of SEM

The scanning electron microscope (SEM) uses **a focused beam of high-energy electrons.**



Column

Electron gun

Controlling the Path of Electrons

- Electromagnetic lenses
- Scanning coils
- Objective lens

Interaction of electrons with sample

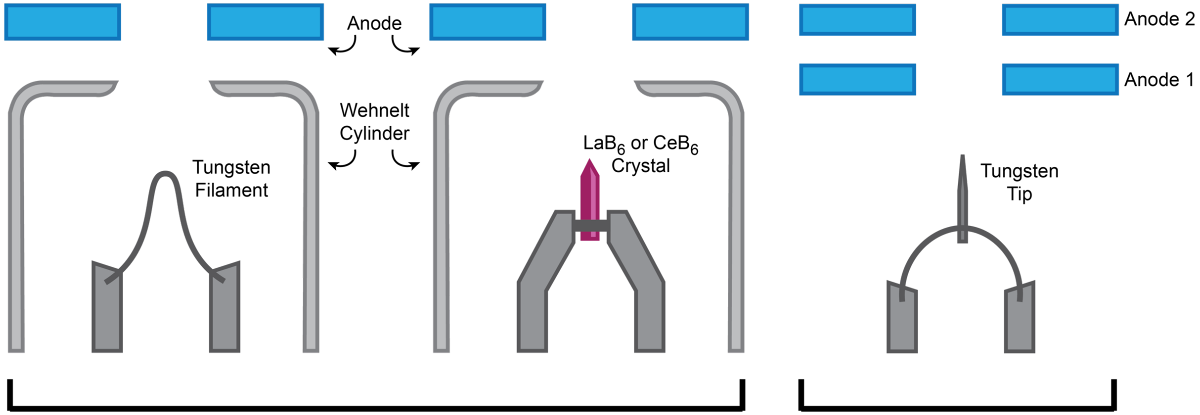
Column contains 3 important parts

Technical Principle : different components of SEM

Electron gun →

There are three main types of electron guns:

- Tungsten hairpin
- Lanthanum hexaboride (LaB6)
- Field emission



Source : www.thermofisher.com

Thermoionic emission source

Field emission source

« Traditionnal guns »
(Cheap, doesn’t require high vacuum)

« FEG-SEM »

Technical Principle : different components of SEM

Electron gun →

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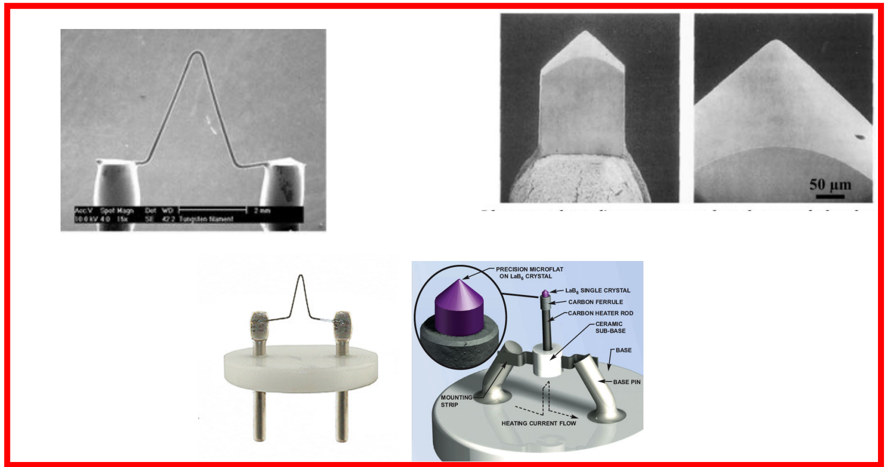
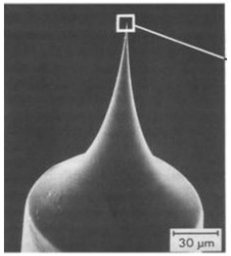
Thermoionic emission



Field emission



Sharp metal tip with a radius < 100 nm

	Tungsten	LaB_6	Thermal FEG	Cold FEG
Brightness ($A/cm^2 str$)	10^5	10^6	10^8	10^8
Lifetime (hrs)	40-100	200-1000	>1000	>1000
Source Size	30-100 um	5-50 um	<5 nm	<5 nm
Energy Spread (eV)	1-3	1-2	1	0.3
Current Stability (%hr)	1	1	5	5
Vacuum (Torr)	10^{-5}	10^{-7}	10^{-11}	10^{-11}

Technical Principle : different components of SEM

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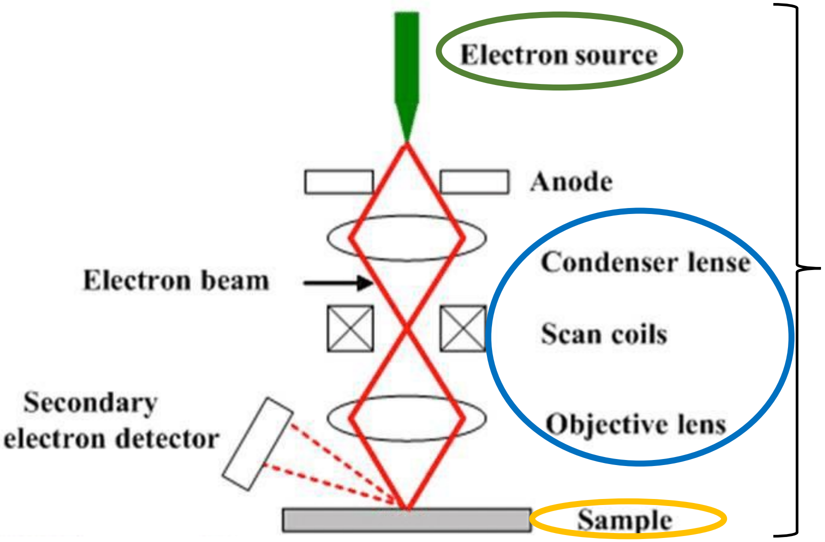


Electron gun

Column : ⚠ vacuum (min 10^{-3}-10^{-8} Pa)

Interaction of electrons with sample

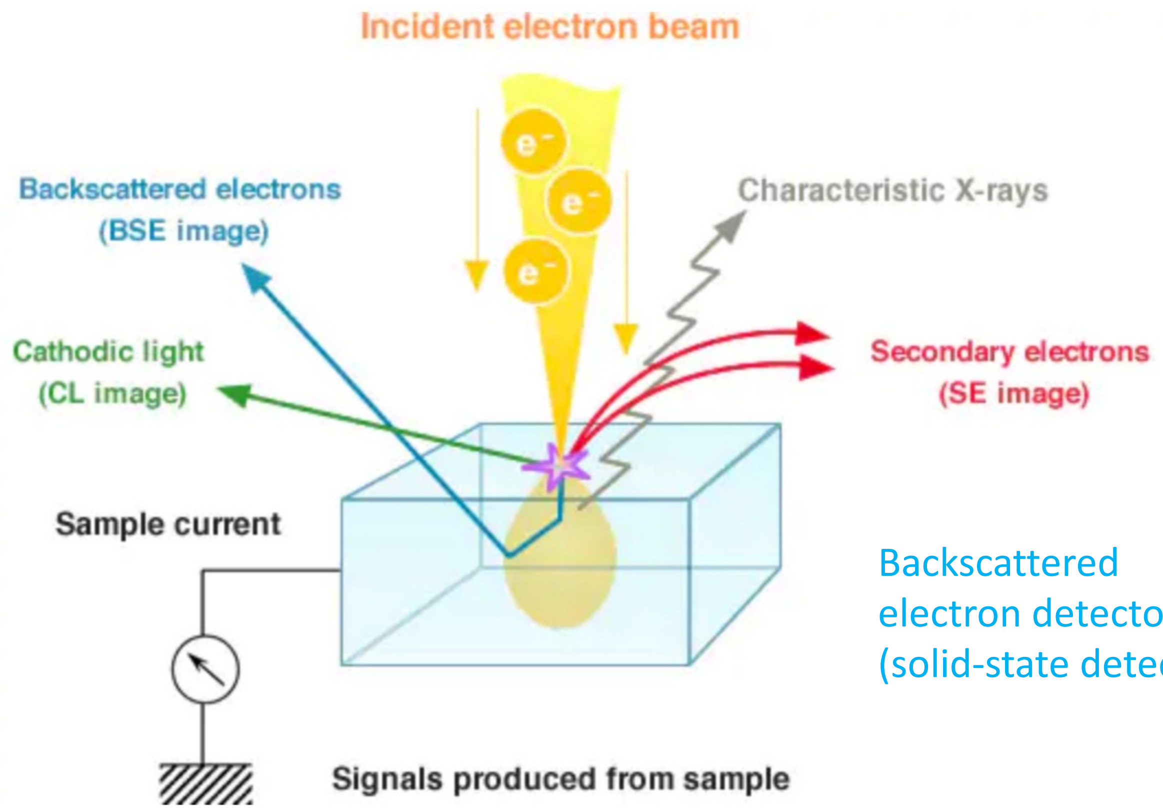
Controlling the Path of Electrons

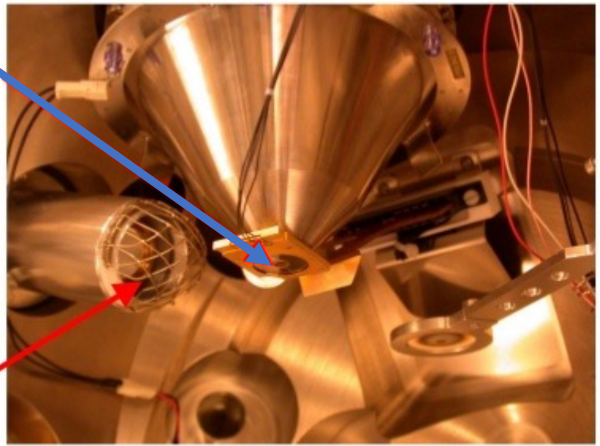
- Electromagnetic lenses : defines the size of the electron beam (resolution)
- Scanning coils : raster the beam on the sample
- Objective lens : focuses the beam on the sample

Technical Principle : different components of SEM

Interaction of electrons with sample

The principle of SEM lies on the interaction between electrons and matter. It gives rise to an interaction volume whose size depends upon the energy of the electron beam and the average density of the sample.



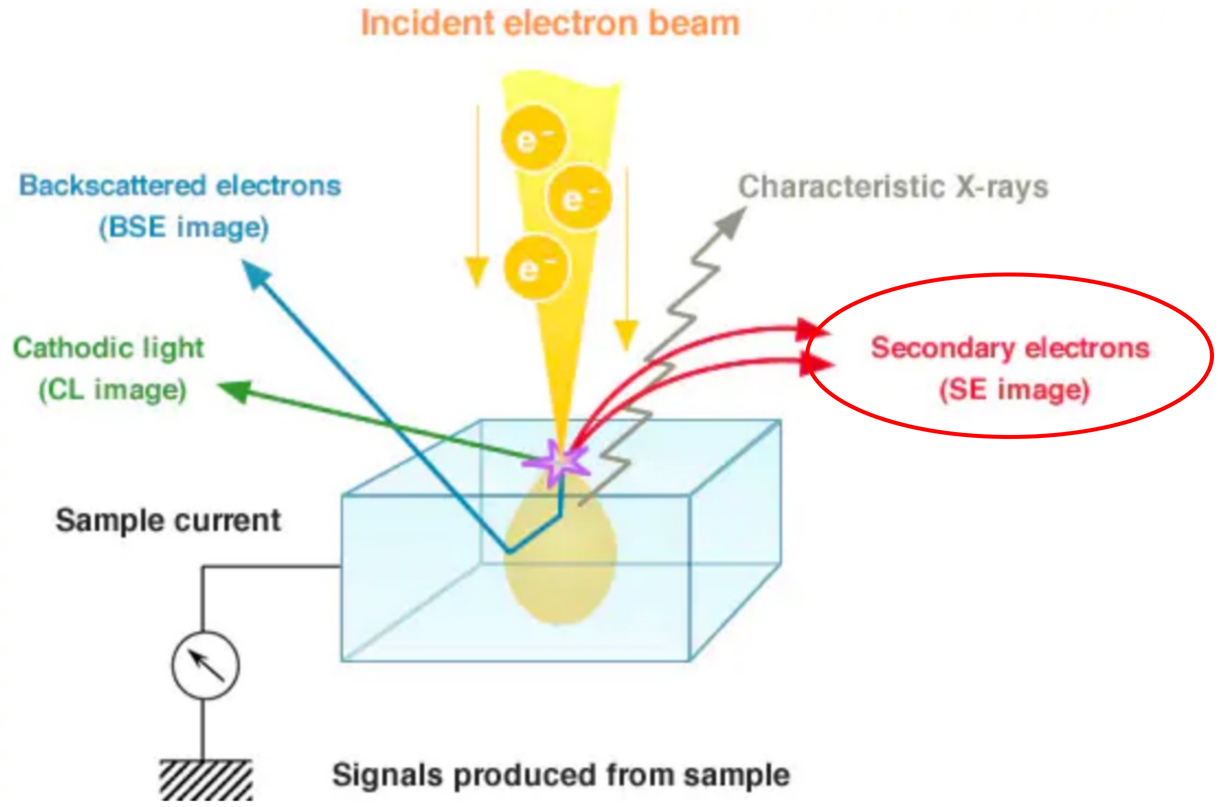


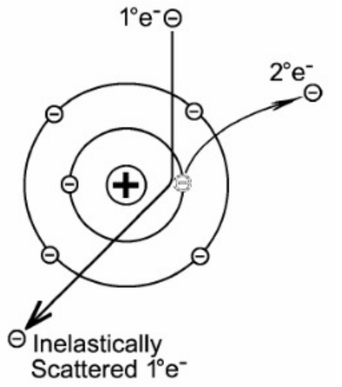
Backscattered electron detector (solid-state detector)

Secondary electron detector (Everhart-Thornley)

Technical Principle : different components of SEM

Interaction of electrons with sample

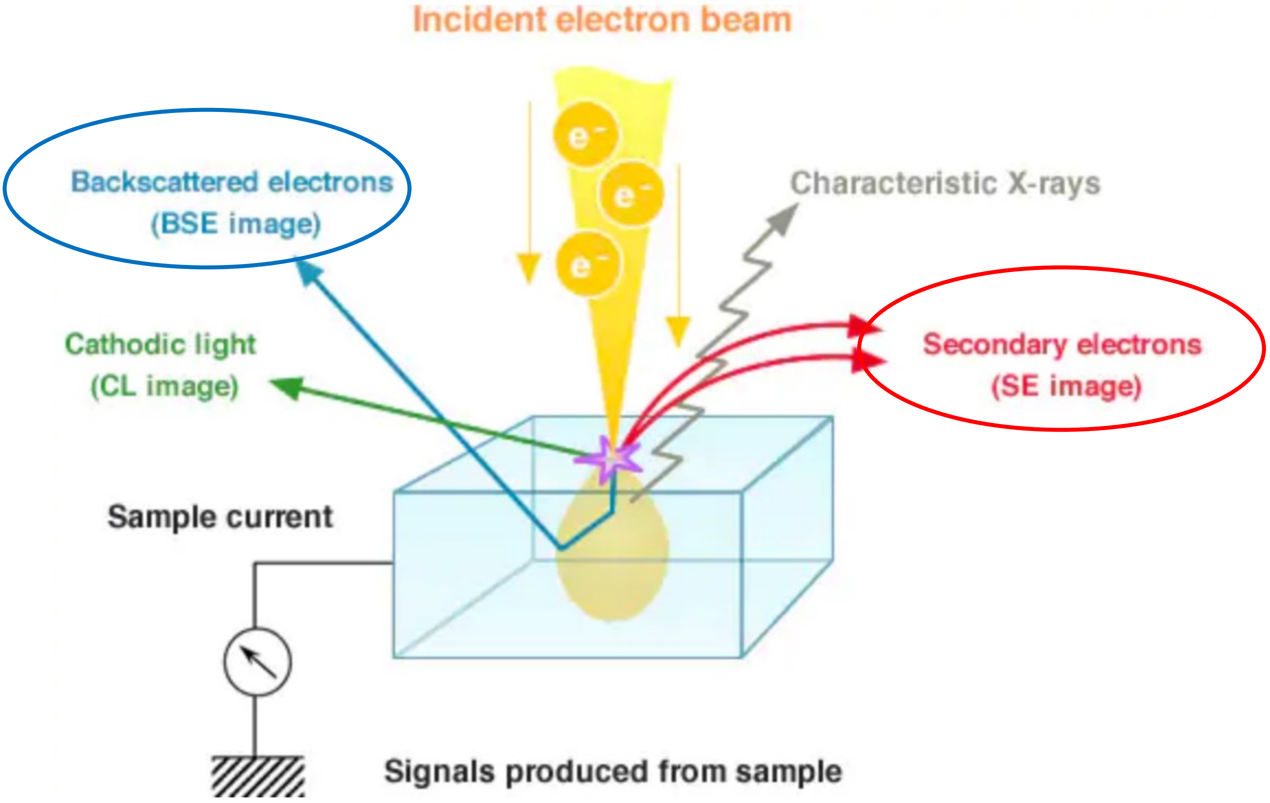




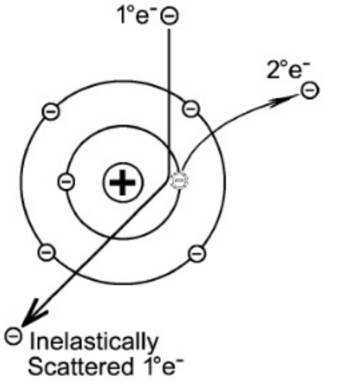
Inelastic events

Technical Principle : different components of SEM

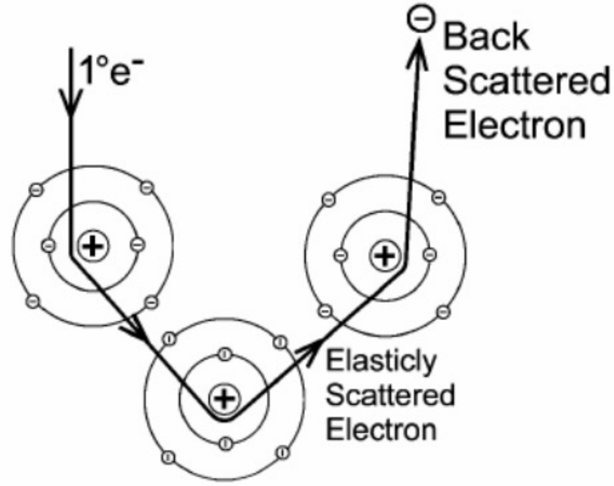
Interaction of electrons with sample



Signals produced from sample



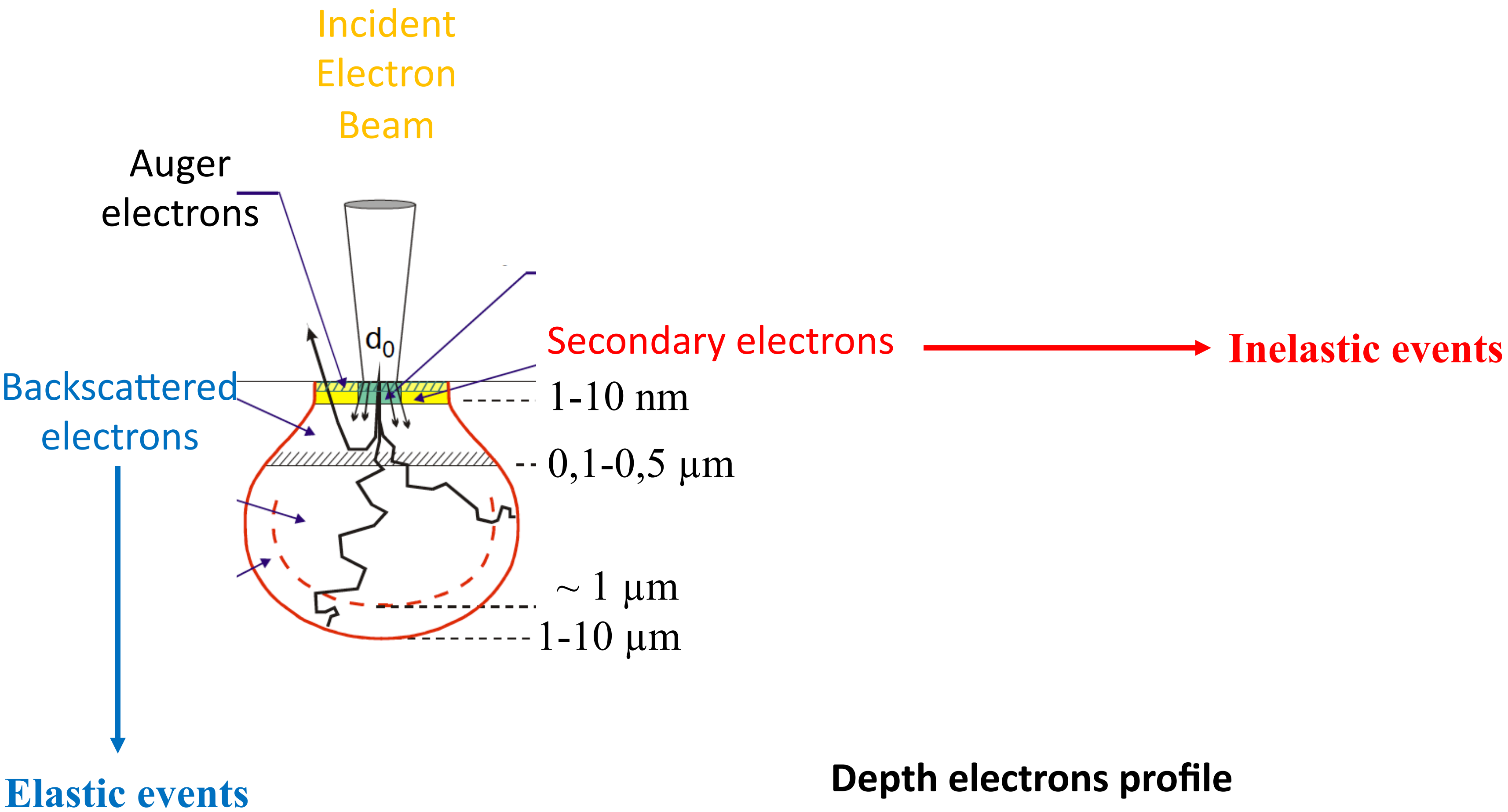
Inelastic events



Elastic events

Technical Principle : different components of SEM

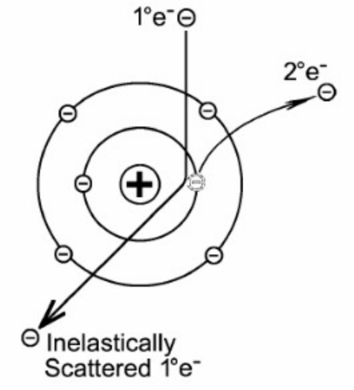
Interaction of electrons with sample



Depth electrons profile
« pear shaped » interaction volume

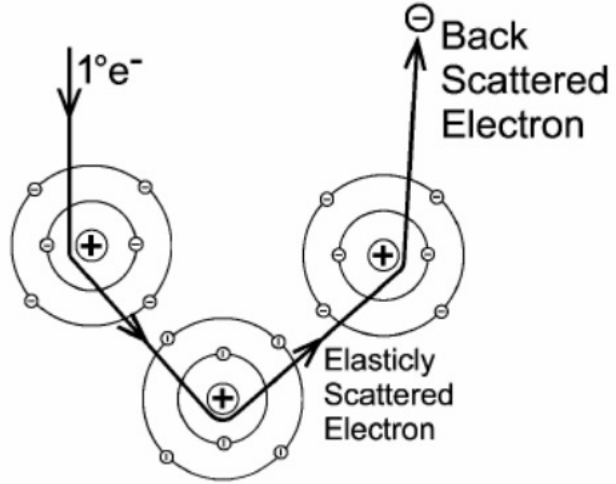
Technical Principle : different components of SEM

Interaction of electrons with sample

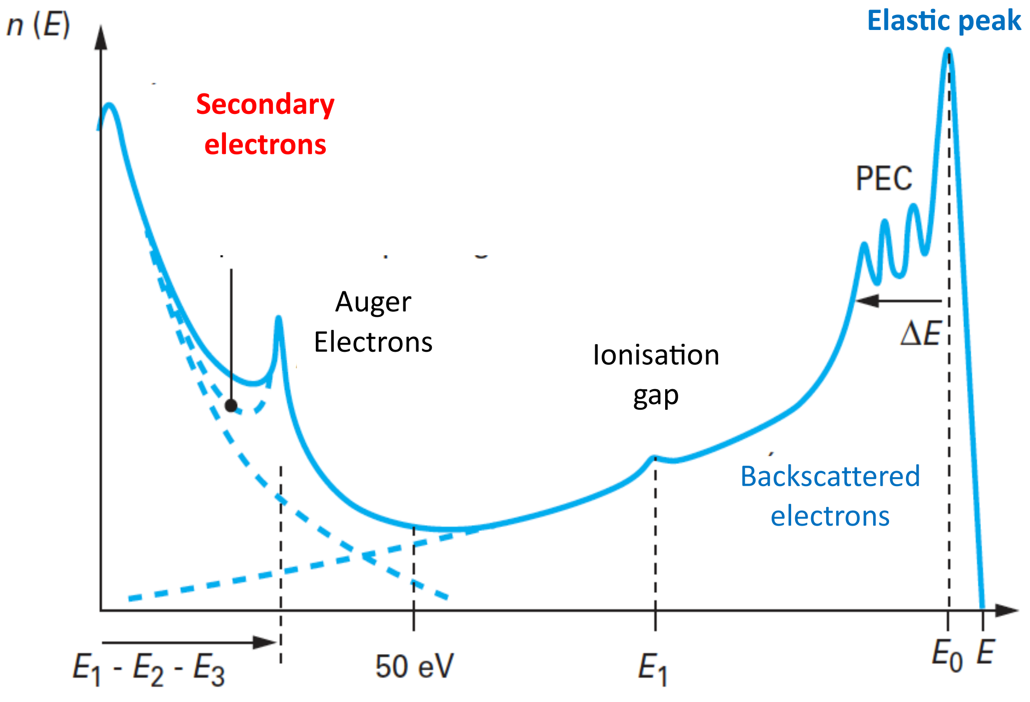


Inelastic events

Ejection of weekly bound valence electrons or conduction band electrons (< 50 eV)



Elastic events



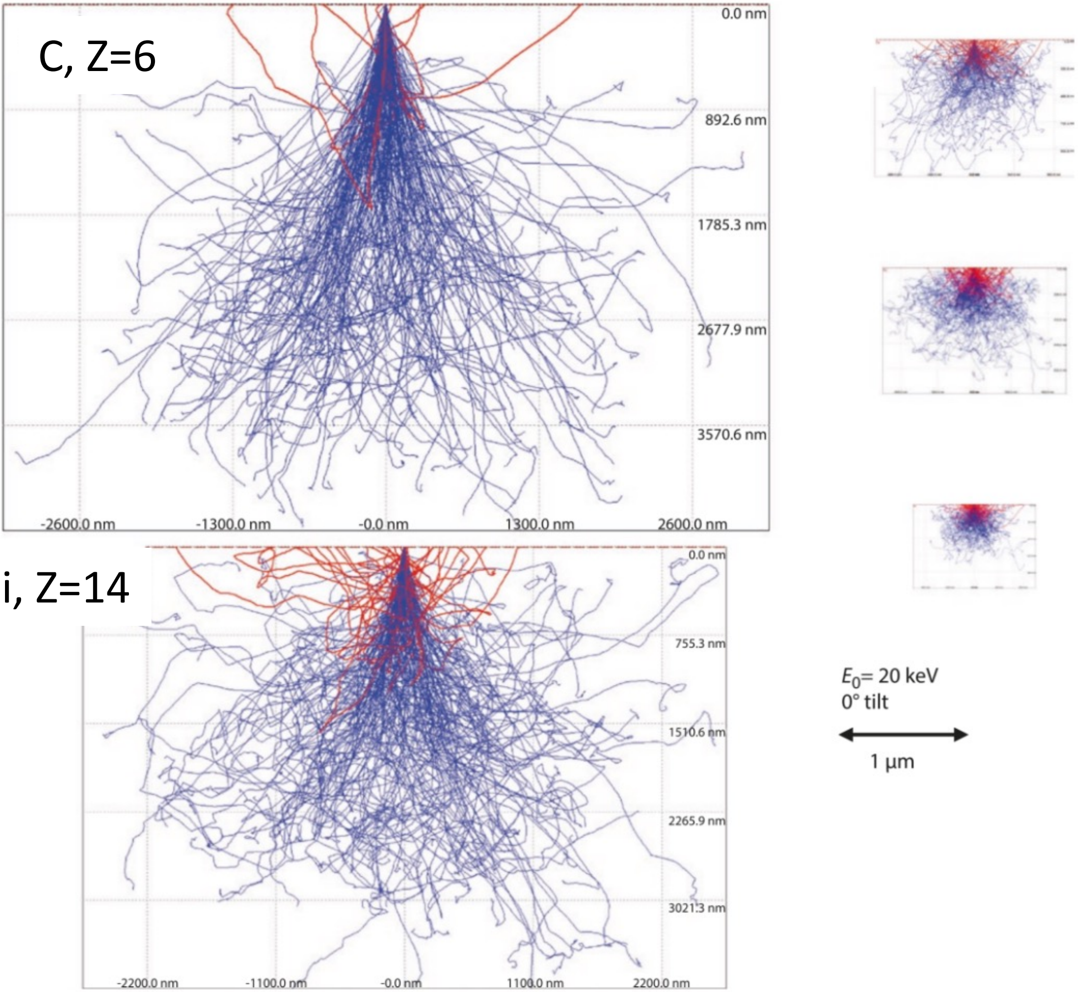
The negatively-charged electron will be attracted to the positive nucleus, will circle the nucleus and come back out of the sample.

Technical Principle : different components of SEM

Interaction of electrons with sample

Backscattered electrons

The size of the interaction volume depends upon the energy of the electron beam and the average density of the sample.



C, Z=6

Si, Z=14

Cu, Z=29

Ag, Z=47

Au, Z=79

Use of the **CASINO Monte Carlo simulation** software, to examine the dependence of electron backscattering on the atomic number of the specimen.

Fig. 1.8 Monte Carlo simulations for an incident beam energy of 20 keV and 0° tilt for C, Si, Cu, Ag, and Au, all shown at the same scale (CASINO Monte Carlo simulation)

From J. I. Goldstein et al., Scanning Electron Microscopy and X-Ray Microanalysis. Springer, New York, NY, 2018.

Technical Principle : different components of SEM

Interaction of electrons with sample

Backscattered
electrons

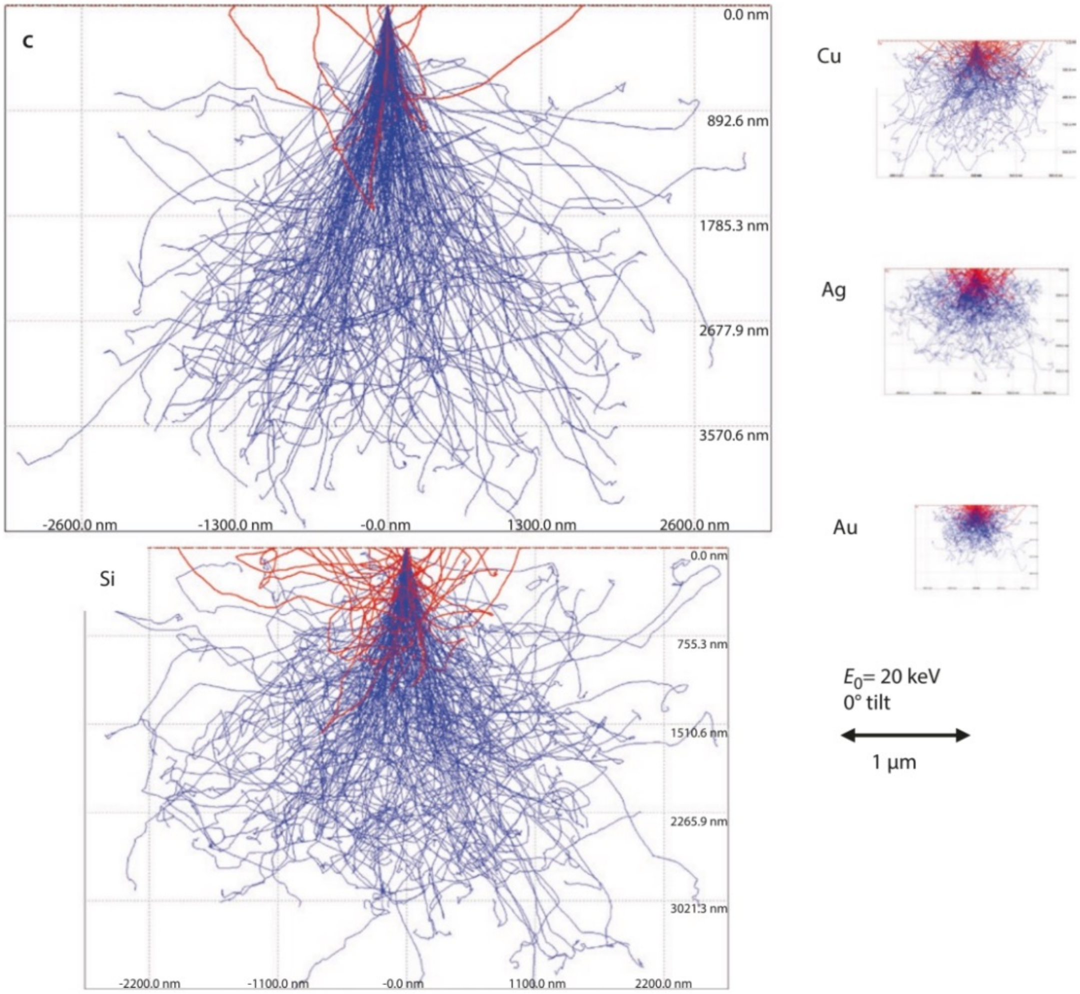
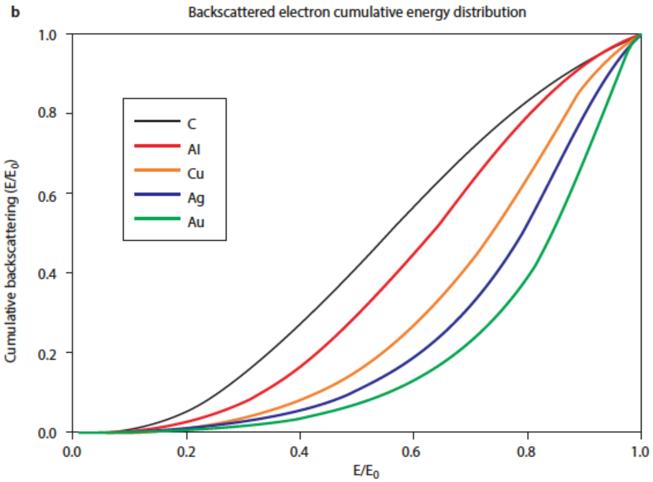


Fig. 1.8 Monte Carlo simulations for an incident beam energy of 20 keV and 0° tilt for C, Si, Cu, Ag, and Au, all shown at the same scale (CASINO Monte Carlo simulation)

Red trajectories
lead to backscattering events



Fractional energy retained

Absorbed Electrons
(lost all energy and are
absorbed within specimen)

From J. I. Goldstein et al., Scanning Electron Microscopy and X-Ray Microanalysis. Springer, New York, NY, 2018.

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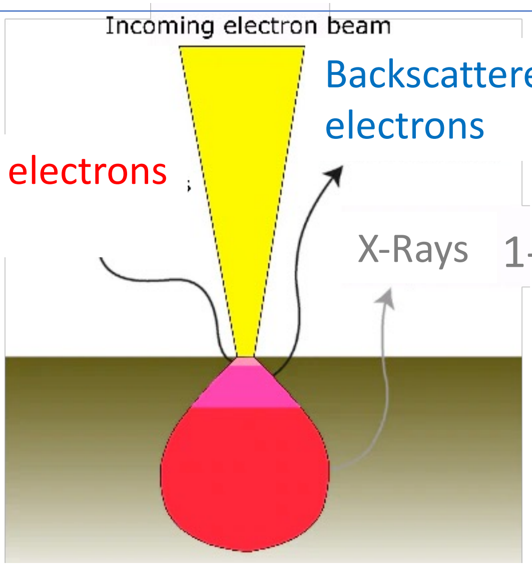
SEM : Images from secondary / back scattered electrons detectors



Backscattered electrons

0,1-0,5 µm

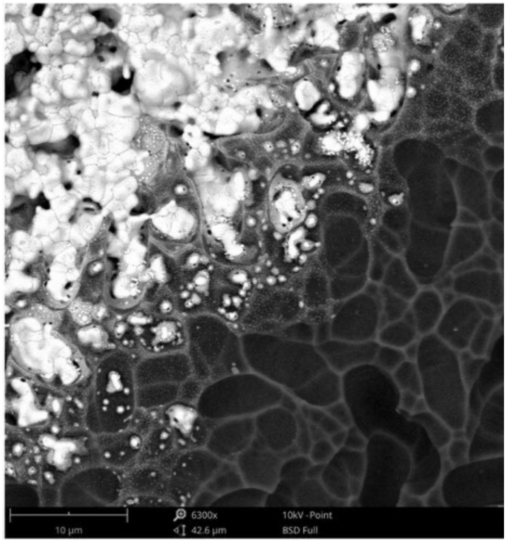
Secondary electrons

1-10 nm

X-Rays

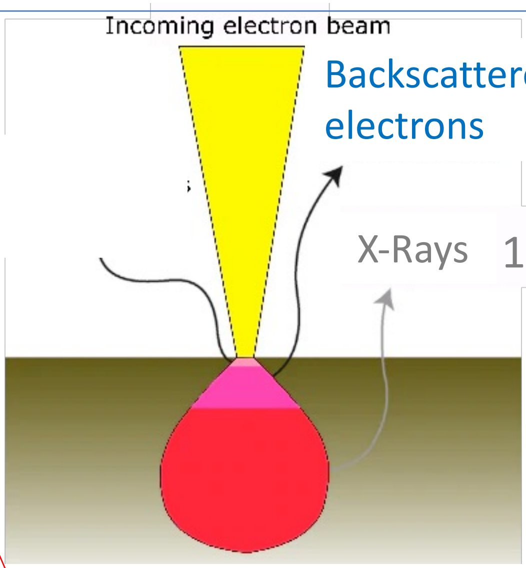
1-10 µm

Come from deeper regions :
⇨ high sensitivity to differences in atomic number : the higher the atomic number, the brighter the material



SEM image of a solar cell, where the white area is silver (Z_{Ag} =47) , and the dark area is silicon (Z_{Si} =14) .

SEM : Images from secondary / back scattered electrons detectors



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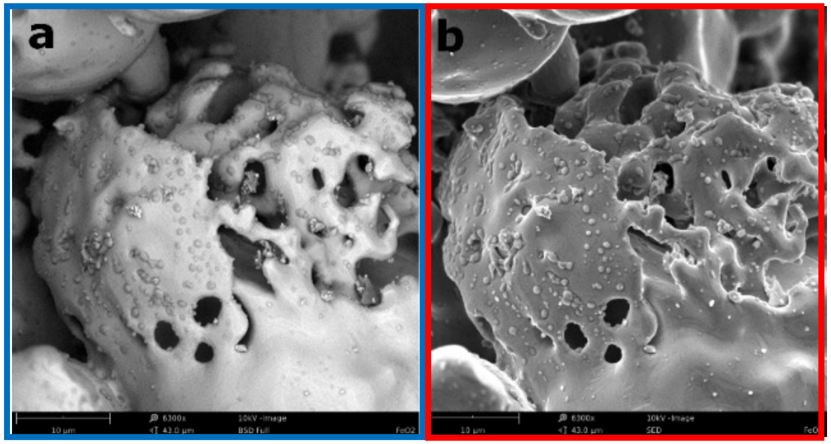
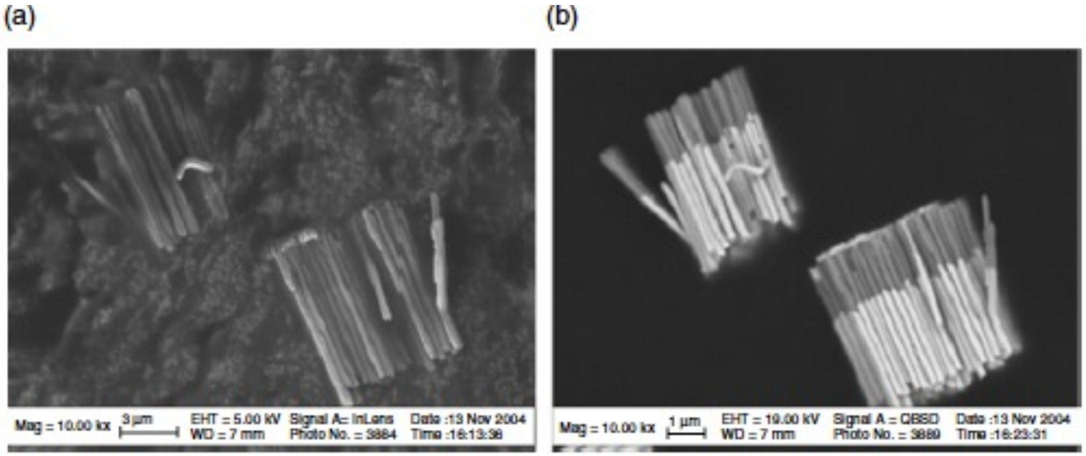


BSE (left) and **SE** (right) images of FeO2 particles.

Come from the surface : low energy (<50 eV)
⇨ detailed surface information :
topography, good resolution

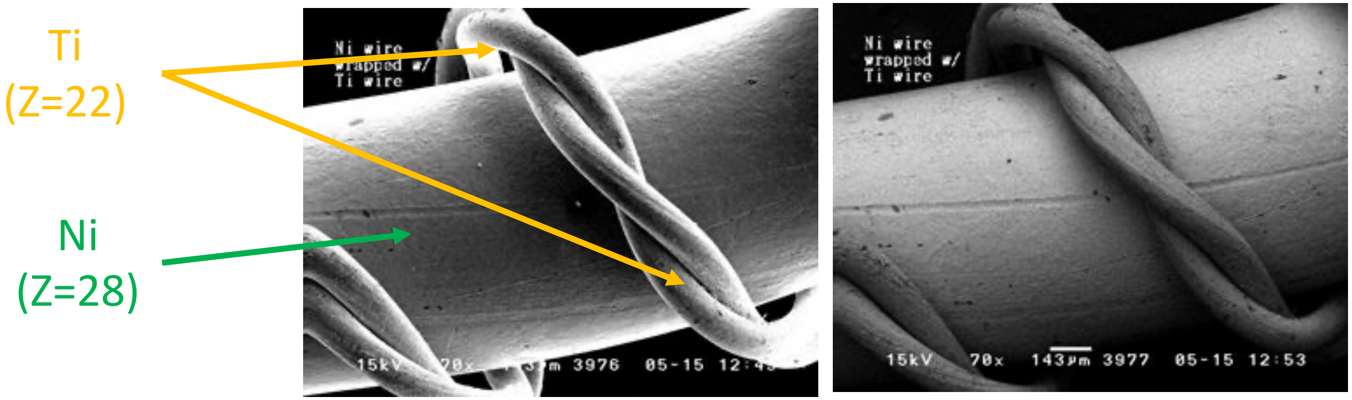
SEM : Images from secondary / back scattered electrons detectors

SE Ni/Au nanorods BSE



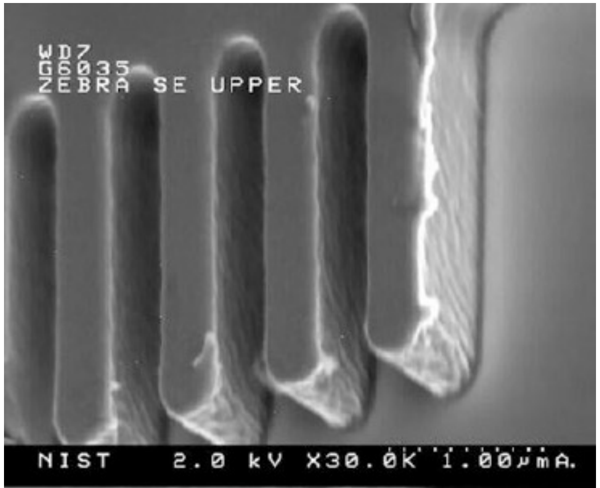
Contrast (BSE) / Topography (SE)

SE Ti wires wrapped around Ni wire BSE

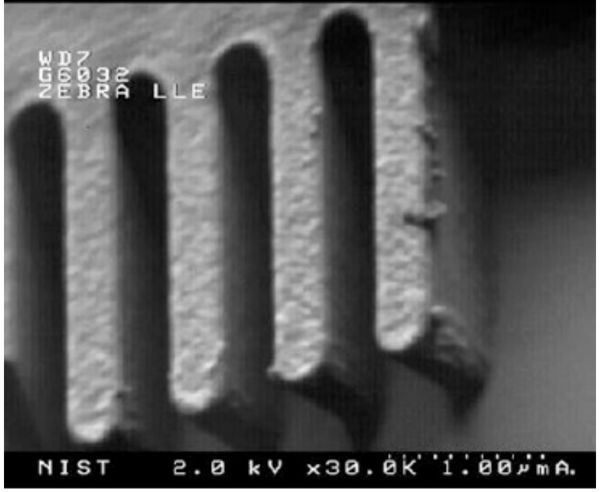


Elements of greater atomic mass (Ni) appear brighter in a back scattered electron image

SEM : Images from secondary / back scattered electrons detectors



SE



BSE

SE and BSE images of a photoresist at $E_0 = 2$ keV

The escape depth of backscattered electrons can be greater than that of secondary electrons, consequently resolution of surface topographical characteristics can suffer.

From M. T. Postek et al. *Scanning*, vol. 23, no. 5, pp. 298–304,(2001)

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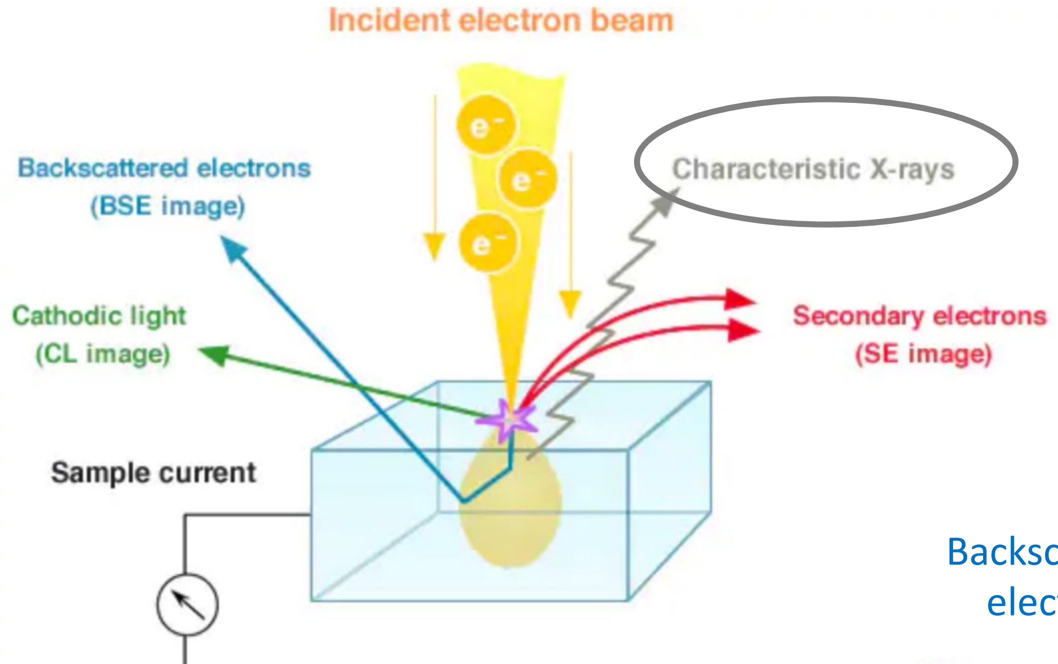


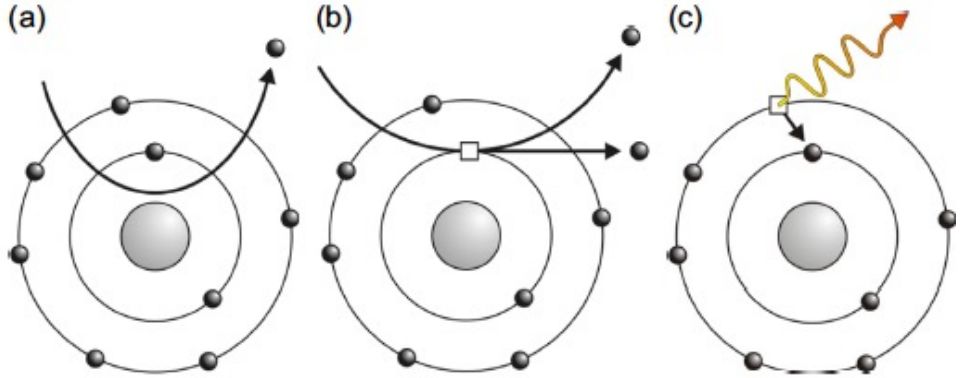
Signals produced from sample

Analysis of the X-ray signals are used to map the distribution and estimate the abundance of specific elements in the analyzed sample.

Backscattered electrons

Secondary electrons

X-Rays photoelectrons



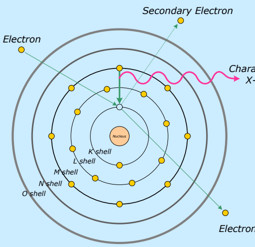
From A. R. Bunsell, in *Handbook of Properties of Textile and Technical Fibres (Second Edition)*, A. R. Bunsell, Ed. Woodhead Publishing, 2018, pp. 21–55.

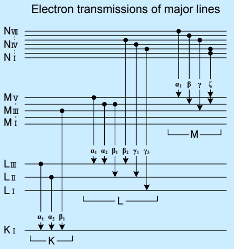
JEOL
ISO 9001 Certificated
ISO 14001 Certificated
High technology for quality assurance and the environment

Energy table for EDS analysis

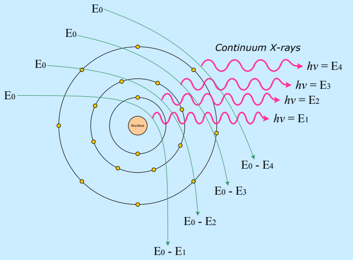
http://www.jeol.com/

Characteristic X-rays





Continuum X-rays

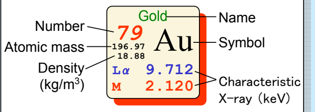


The electrons generated by the electron gun are accelerated and irradiate the sample. The electron has a kinetic energy proportional to the accelerating voltage. The kinetic energy dissipated within the sample generates characteristic signals from the specimen. The characteristic X-rays are the information used for EDS analysis.

If the incident electrons have sufficient acceleration and then have enough energy to strike an electron from the inner shell of the atom, it'll make an electron hole. An electron from the outer shell will fill up the hole and then, some characteristic X-rays will be emitted. The characteristic X-rays have different energy for each element, and the intensity will be proportional to the element concentration.

The continuum X-rays are emitted when the primary electrons are decelerated by the strong electric field existing close to atomic nucleus. The continuum X-rays have the energy of the kinetic energy lost during the deceleration. It will be observed as EDS spectrum background.

Hydrogen	1	H	1.01	0.08		
Helium	2	He	4.00	0.19		
Lithium	3	Li	6.94	0.53		
Beryllium	4	Be	9.01	1.85	Kα 0.110	
Boron	5	B	10.81	2.54	Kα 0.183	
Carbon	6	C	12.01	2.25 *	Kα 0.277	
Nitrogen	7	N	14.01	1.14	Kα 0.392	
Oxygen	8	O	16.00	1.57	Kα 0.525	
Fluorine	9	F	19.00	1.5	Kα 0.677	
Neon	10	Ne	20.18	1.20	Kα 0.848	
Sodium	11	Na	22.99	0.97	Kα 1.041	
Magnesium	12	Mg	24.31	1.74	Kα 1.253	
Aluminium	13	Al	26.98	2.70	Kα 1.486	
Silicon	14	Si	28.09	2.42	Kα 1.739	
Phosphorus	15	P	30.97	1.83 *	Kα 2.013	
Sulphur	16	S	32.06	2.07 *	Kα 2.307	
Chlorine	17	Cl	35.45	2.2	Kα 2.621	
Argon	18	Ar	39.95	1.65	Kα 2.957	
Potassium	19	K	39.10	0.87	Kα 3.312	
Calcium	20	Ca	40.08	1.55	Kα 3.690	
Scandium	21	Sc	44.96	2.99	Kα 4.088	Lα 0.395
Titanium	22	Ti	47.90	4.5	Kα 4.508	Lα 0.452
Vanadium	23	V	50.94	5.87	Kα 4.949	Lα 0.511
Chromium	24	Cr	52.00	7.14	Kα 5.411	Lα 0.573
Manganese	25	Mn	54.94	7.3	Kα 5.894	Lα 0.637
Iron	26	Fe	55.85	7.86	Kα 6.398	Lα 0.705
Cobalt	27	Co	58.93	8.71	Kα 6.924	Lα 0.776
Nickel	28	Ni	58.70	8.8	Kα 7.471	Lα 0.851
Copper	29	Cu	63.55	8.93	Kα 8.040	Lα 0.930
Zinc	30	Zn	65.38	6.92	Kα 8.630	Lα 1.012
Gallium	31	Ga	69.72	5.93	Kα 9.241	Lα 1.098
Germanium	32	Ge	72.59	5.46	Kα 9.874	Lα 1.188
Arsenic	33	As	74.92	5.73	Kα 10.530	Lα 1.282
Selenium	34	Se	78.96	4.82	Kα 11.207	Lα 1.379
Bromine	35	Br	79.90	4.2	Kα 11.907	Lα 1.480
Krypton	36	Kr	83.80	3.4	Kα 12.631	Lα 1.586
Rubidium	37	Rb	85.47	1.53	Kα 13.373	Lα 1.694
Strontium	38	Sr	87.62	2.60	Kα 14.140	Lα 1.806
Yttrium	39	Y	88.91	4.48	Kα 14.931	Lα 1.922
Zirconium	40	Zr	91.22	6.44	Kα 15.744	Lα 2.042
Niobium	41	Nb	92.91	8.4	Kα 16.581	Lα 2.166
Molybdenum	42	Mo	95.94	9.01	Kα 17.441	Lα 2.293
Technetium	43	Tc	(97)		Kα 18.325	Lα 2.424
Ruthenium	44	Ru	101.07	12.1	Kα 19.233	Lα 2.558
Rhodium	45	Rh	102.91	12.44	Lα 2.696	
Palladium	46	Pd	106.4	12.16	Lα 2.838	
Silver	47	Ag	107.87	10.49	Lα 2.984	
Cadmium	48	Cd	112.40	8.65	Lα 3.133	
Indium	49	In	114.82	7.28	Lα 3.286	M 0.368
Tin	50	Sn	118.69	7.30 *	Lα 3.443	M 0.691
Antimony	51	Sb	121.75	6.62	Lα 3.604	M 0.733
Tellurium	52	Te	127.60	6.25	Lα 3.769	M 0.778
Iodine	53	I	126.90	4.94	Lα 3.937	
Xenon	54	Xe	131.30		Lα 4.109	
Cesium	55	Cs	132.91	1.87	Lα 4.286	
Barium	56	Ba	137.34	3.5	Lα 4.465	M 0.972
Lanthanoid	57-71					
Hafnium	72	Hf	178.49	13.3	Lα 7.898	M 1.644
Tantalum	73	Ta	180.95	16.6	Lα 8.145	M 1.709
Tungsten	74	W	183.85	19.3	Lα 8.396	M 1.774
Rhenium	75	Re	186.21	20.53	Lα 8.651	M 1.842
Osmium	76	Os	190.2	22.5	Lα 8.910	M 1.914
Iridium	77	Ir	192.22	22.42	Lα 9.174	M 1.977
Platinum	78	Pt	195.09	21.37	Lα 9.441	M 2.048
Gold	79	Au	196.97	18.88	Lα 9.712	M 2.120
Mercury	80	Hg	200.59	14.19	Lα 9.987	M 2.195
Thallium	81	Tl	204.37	11.86	Lα 10.267	M 2.267
Lead	82	Pb	207.2	11.34	Lα 10.550	M 2.342
Bismuth	83	Bi	208.98	9.78	Lα 10.837	M 2.419
Polonium	84	Po	(209)		Lα 11.129	
Astatine	85	At	(210)		Lα 11.425	
Radon	86	Rn	(222)		Lα 11.725	
Francium	87	Fr	(223)		Lα 12.029	
Radium	88	Ra	226.03	5	Lα 12.340	
Actinoid	89-103					
Lanthanum	57	La	138.91	6.17	Lα 4.650	M 0.833
Cerium	58	Ce	140.12	6.66	Lα 4.839	M 0.883
Praseodymium	59	Pr	140.91	6.77	Lα 5.033	M 0.929
Neodymium	60	Nd	144.24	7.02	Lα 5.229	M 0.978
Prometium	61	Pm	(145)		Lα 5.432	
Samarium	62	Sm	150.4	7.54	Lα 5.635	M 1.081
Europium	63	Eu	151.96	5.25	Lα 5.845	M 1.131
Gadolinium	64	Gd	157.25	7.90	Lα 6.056	M 1.185
Terbium	65	Tb	158.93	8.25	Lα 6.272	M 1.240
Dysprosium	66	Dy	162.50	8.56	Lα 6.494	M 1.293
Holmium	67	Ho	164.93	8.80	Lα 6.719	M 1.347
Erbium	68	Er	167.26	9.06	Lα 6.947	M 1.405
Thulium	69	Tm	168.93	9.32	Lα 7.179	M 1.462
Ytterbium	70	Yb	173.04	6.96	Lα 7.414	M 1.521
Lutetium	71	Lu	174.97	9.84	Lα 7.654	M 1.581
Actinium	89	Ac	(227)	10.07	Lα 12.650	
Thorium	90	Th	232.04	11.00	Lα 12.967	M 2.991
Protactinium	91	Pa	231.04		Lα 13.288	M 3.077
Uranium	92	U	238.03	18.7	Lα 13.612	M 3.164
Neptunium	93	Np	237.05		Lα 13.942	M 3.260
Plutonium	94	Pu	(244)		Lα 14.276	M 3.348
Americium	95	Am	(243)		Lα 14.615	M 3.437
Curium	96	Cm	(247)		Lα 14.953	M 3.539
Berkelium	97	Bk	(247)		Lα 15.304	M 3.634
Californium	98	Cf	(251)		Lα 15.652	M 3.731
Einsteinium	99	Es	(254)			
Fermium	100	Fm	(257)			
Mendelevium	101	Md	(258)			
Nobelium	102	No	(255)			
Lawrencium	103	Lr	(262)			



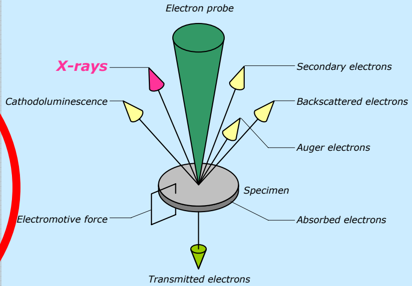
Note: Density
* ‘C’ as (graphite), ‘P’ as (white),
‘S’ as (alpha), ‘Sn’ as (white)

Minimum accelerating voltage

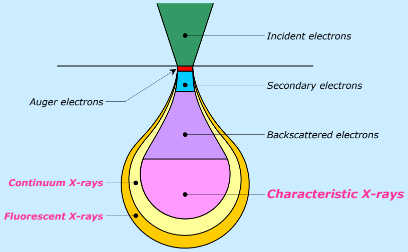
Unable to detect
5kV or higher
10kV or higher
15kV or higher

The colors mean to detect the characteristic X-ray of the lowest energy for each element

Information from specimen



Generation depth and space resolution



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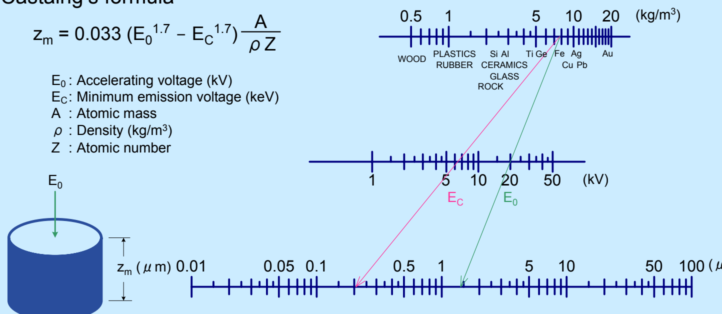
Analytical area

Castaing’s formula

$$z_m = 0.033\,(E_0^{1.7} - E_C^{1.7})\,\frac{A}{\rho Z}$$

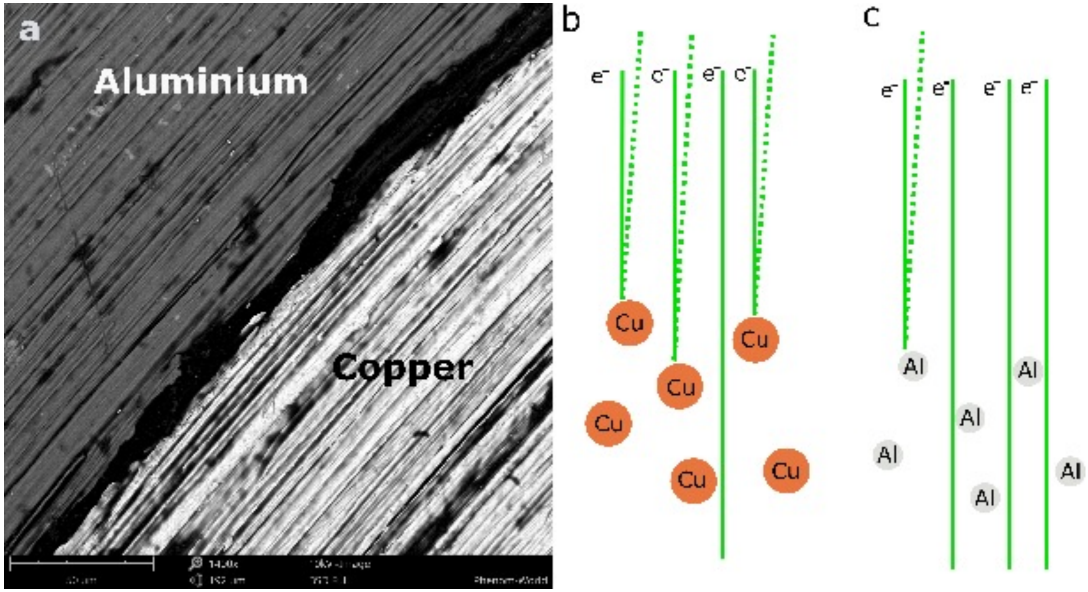
E_0 : Accelerating voltage (kV)
E_C : Minimum emission voltage (keV)
A : Atomic mass
ρ : Density (kg/m3)
Z : Atomic number



Analytical area of iron in 20kV ≒ 1.5 – 0.2 = 1.3 (μm)

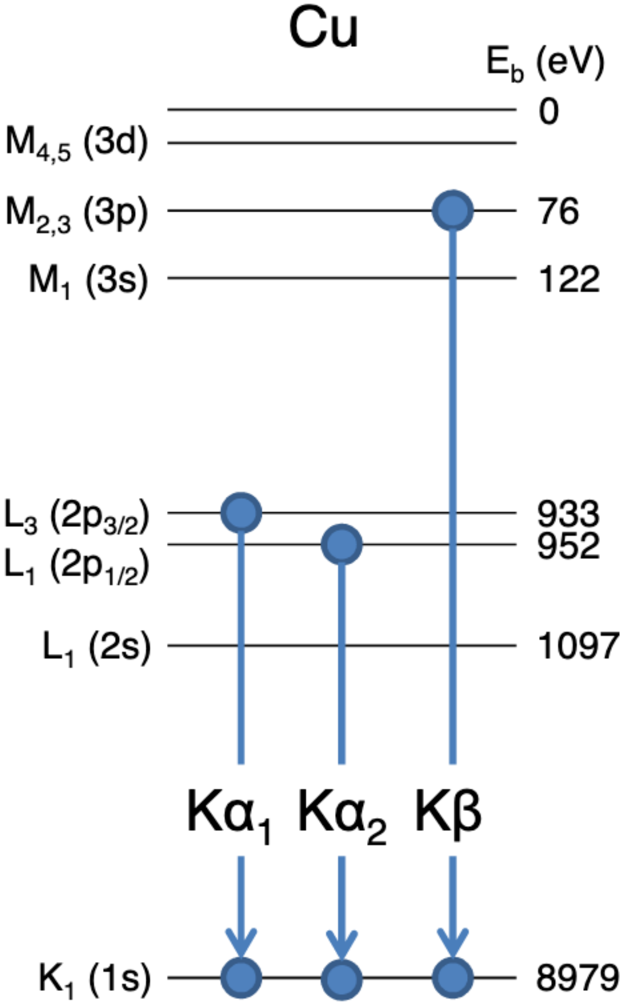
SEM : Images from back scattered electrons / Energy dispersive X-Rays detectors

Energy-dispersive X-ray spectroscopy (EDX)
(*syn. EDS, EDXS or XEDS*).

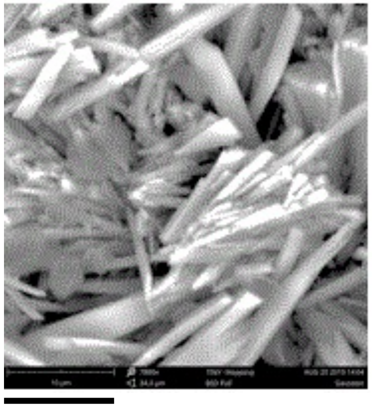


SEM image of an Al/Cu sample where the white area is copper (Z_{Cu} =29) , and the dark area is Aluminium (Z_{AL} =13)

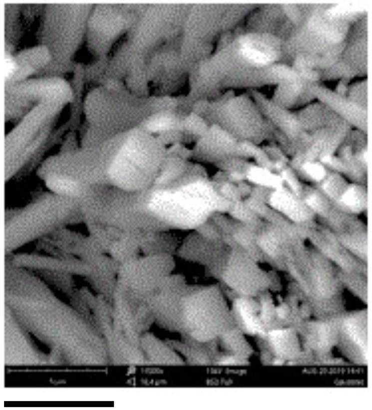
X-ray spectrum : characteristic and continuum X-rays



SEM : Images from back scattered electrons / Energy dispersive X-Rays detectors



10 µm



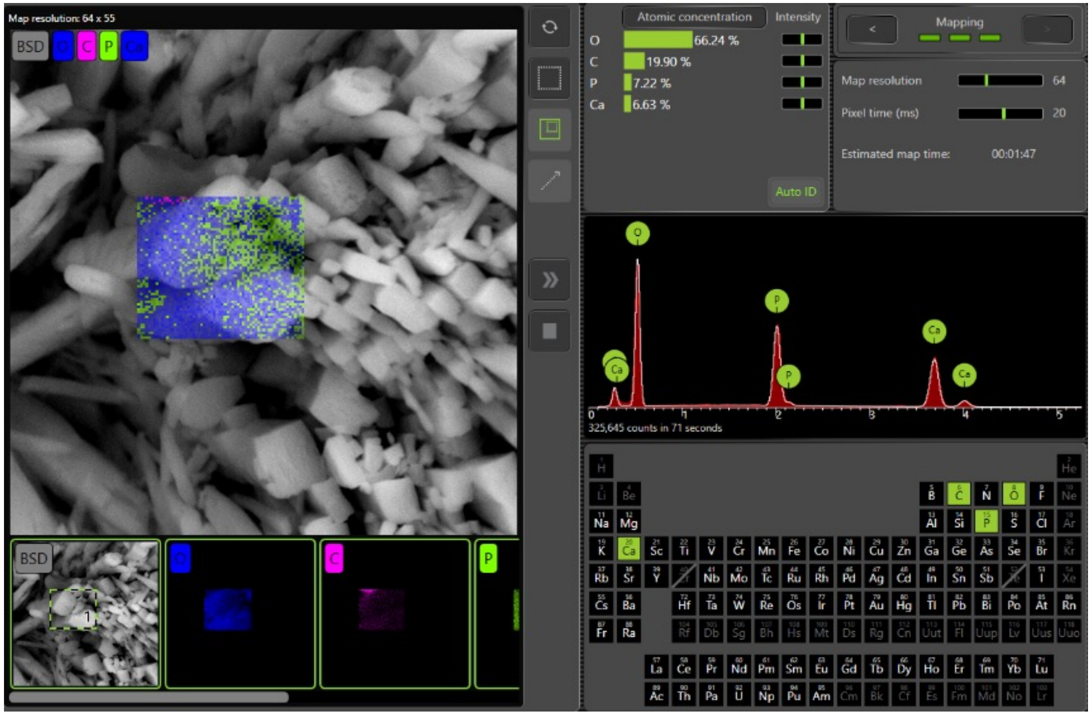
5 µm

3 µm

Crystal aggregates of calcium phosphates (Ca^{2+} combined with PO_4^{3-},$H_2PO_4^-$, and/or HPO_4^{2-}) at different magnifications

Chemical Composition analysis via EDX

EDX spectrum is shown with peaks for the identified elements.



Map resolution: 64 x 55

Atomic concentration		Intensity
O	66.24 %	
C	19.90 %	
P	7.22 %	
Ca	6.63 %	

Map resolution 64

Pixel time (ms) 20

Estimated map time: 00:01:47

325,645 counts in 71 seconds

Course outline

- Technical Principle : different components of SEM
- SEM : Images from secondary / back scattered electrons detectors
- SEM : Images from back scattered electrons / Energy dispersive X-Rays detectors
- Adjustment and optimization parameters
- Specimen damage and contamination
- Particular case : Environmental Scanning Microscope (ESEM)

Adjustment and optimization parameters

Image disturbances can be due to :

- Images lacking sharpness and contrast
- Unstable images
- Generally poor-quality images
- Noisy images
- Images showing jagged edges

- Unusual-contrast images Contamination
- Distorted or deformed images.

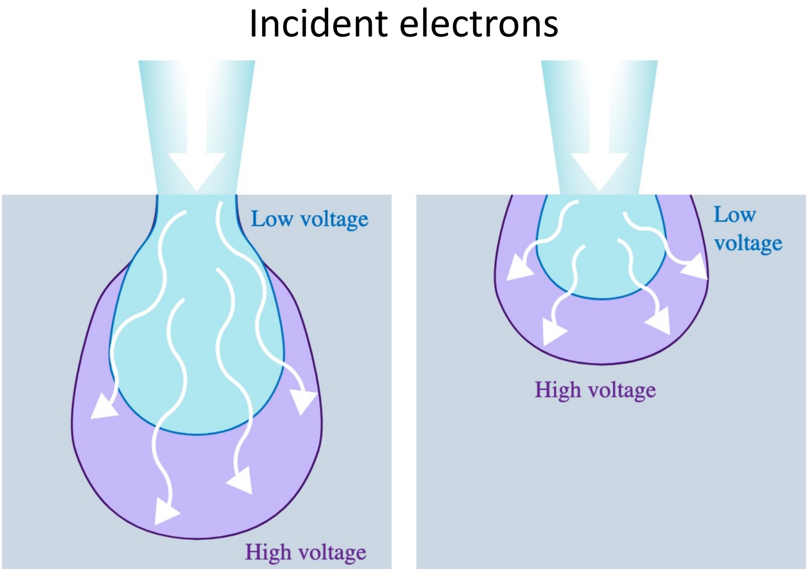
Causes

- Influence of accelerating voltage
- Probe current, probe diameter
- Influence of charge-up
- Working distance and objective aperture
- Influence of astigmatism

- Specimen damage by electron beam
- Contamination

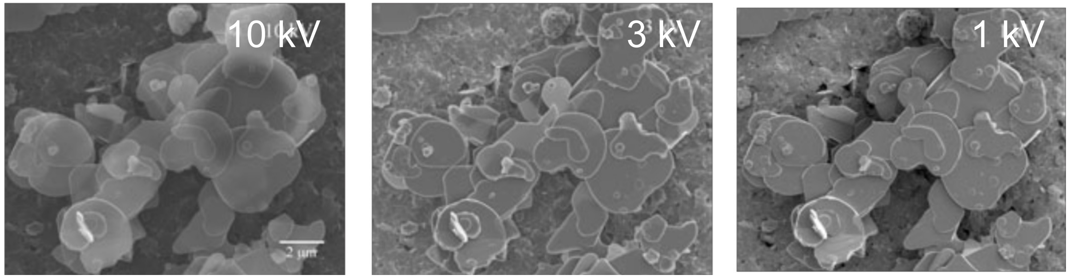
Adjustment and optimization parameters

- Influence of **accelerating voltage** (kV or keV) = voltage difference between the filament and the anode



Low atomic number **High atomic number**

When the accelerating voltage is changed (0-30 kV), the penetration depth of the incident electrons changes : the greater the power of penetration by the beam into the sample. Unnecessary signals generated in ths specimen, reduce the image contrast and veils fine surface structures.



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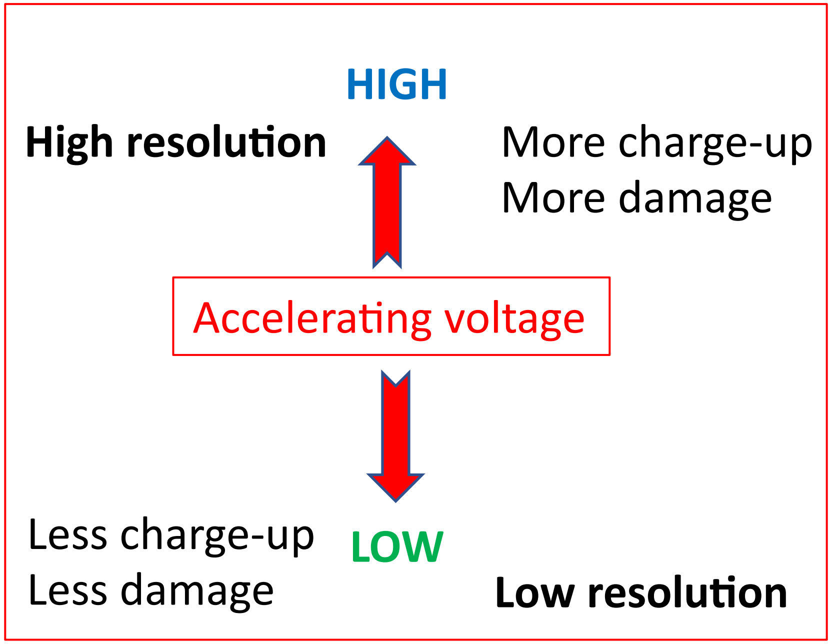
Adjustment and optimization parameters

- Influence of **accelerating voltage** (kV or keV) = voltage difference between the filament and the anode



HIGH

High resolution

More charge-up
More damage

Accelerating voltage

Less charge-up
Less damage

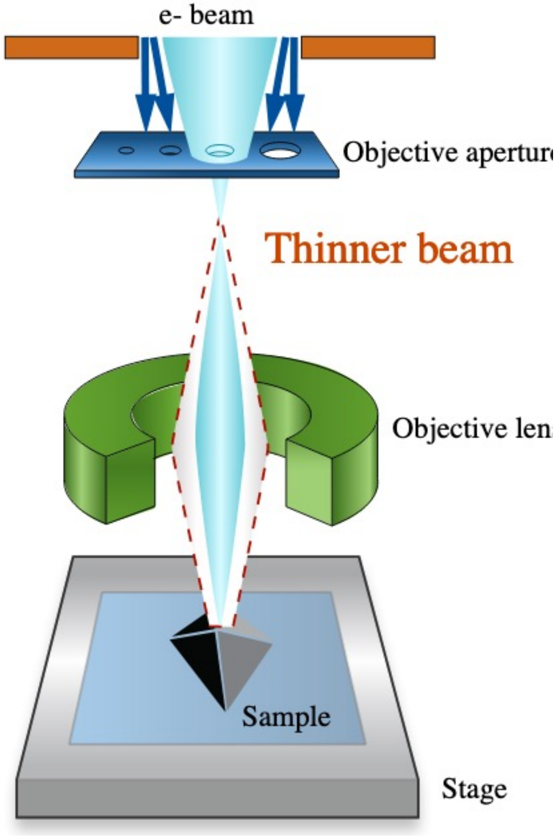
LOW

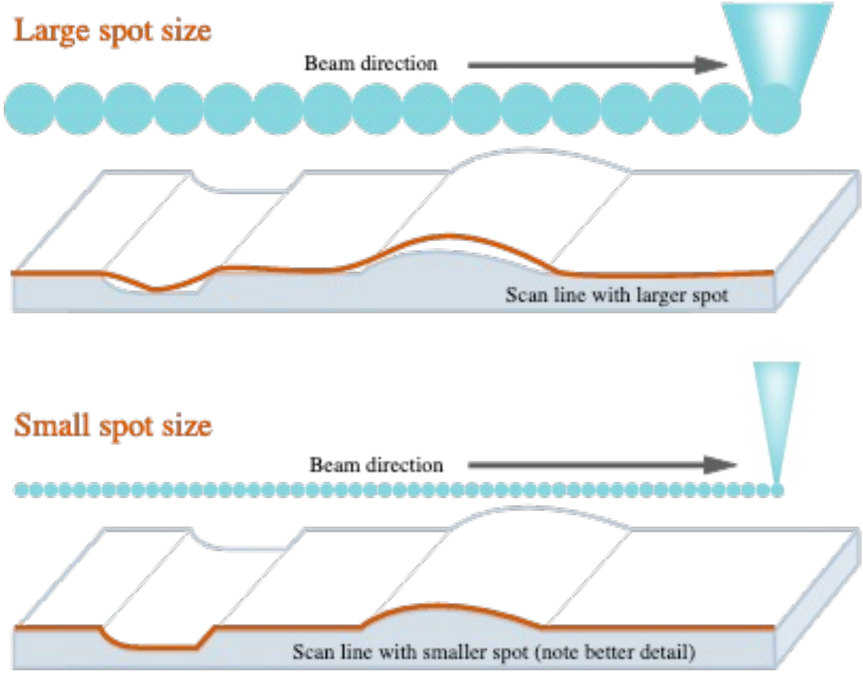
Low resolution

keV range	Application
1-5 kV	Delicate or uncoated specimens
5-10 kV	Coated biological samples
10-30 kV	Physical science samples

Adjustment and optimization parameters

- Influence of **probe current**, **probe diameter**



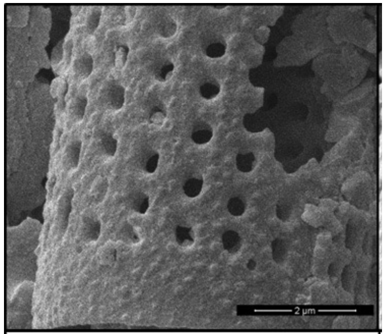


The beam scans across the sample.
The size (cross sectional diameter) that the cone of the beam makes on the surface of the sample affects :

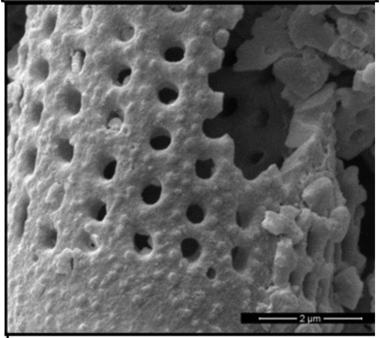
- The resolution of the image
- The number of electrons generated and therefore the graininess of the image.

Adjustment and optimization parameters

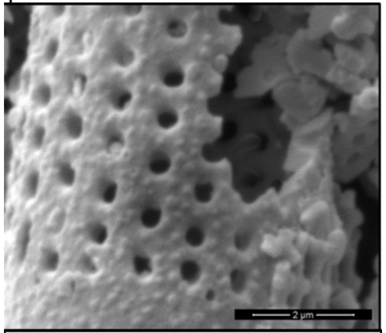
- Influence of **probe current**, **probe diameter**



Spot 1



Spot 3



Spot 5

Details ↗
Brightness ↘

Spot size ↗

LARGE

Smooth image

- Deteriorated resolution
- More damage

Probe current

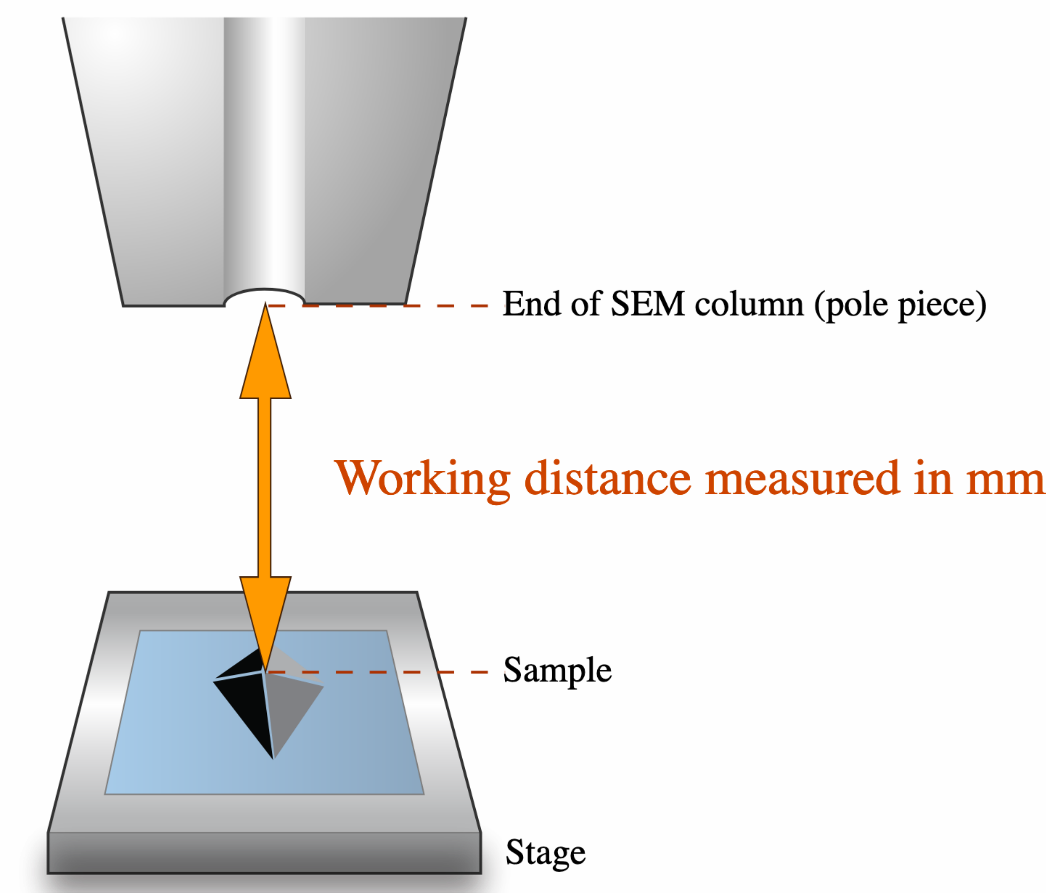
SMALL

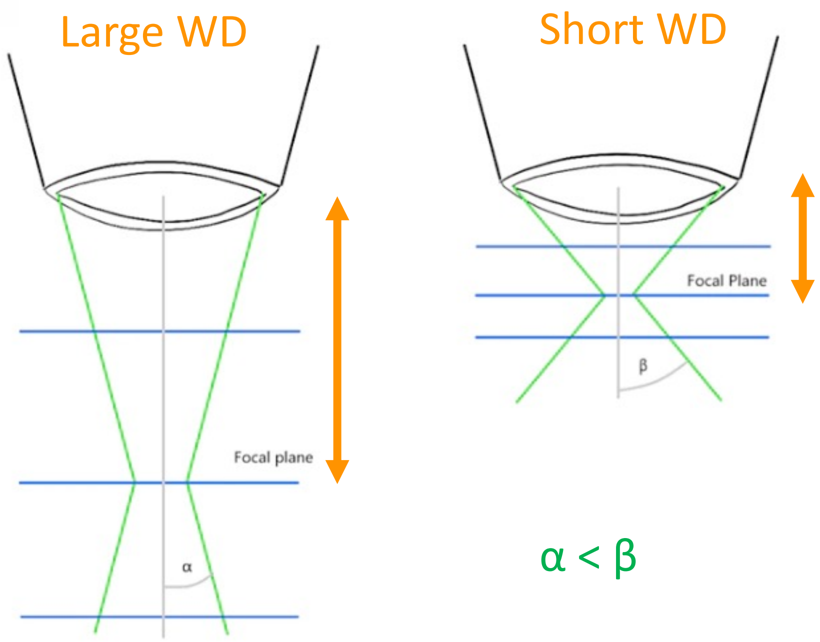
- High resolution obtainable
- Less damage

Grainy image

Adjustment and optimization parameters

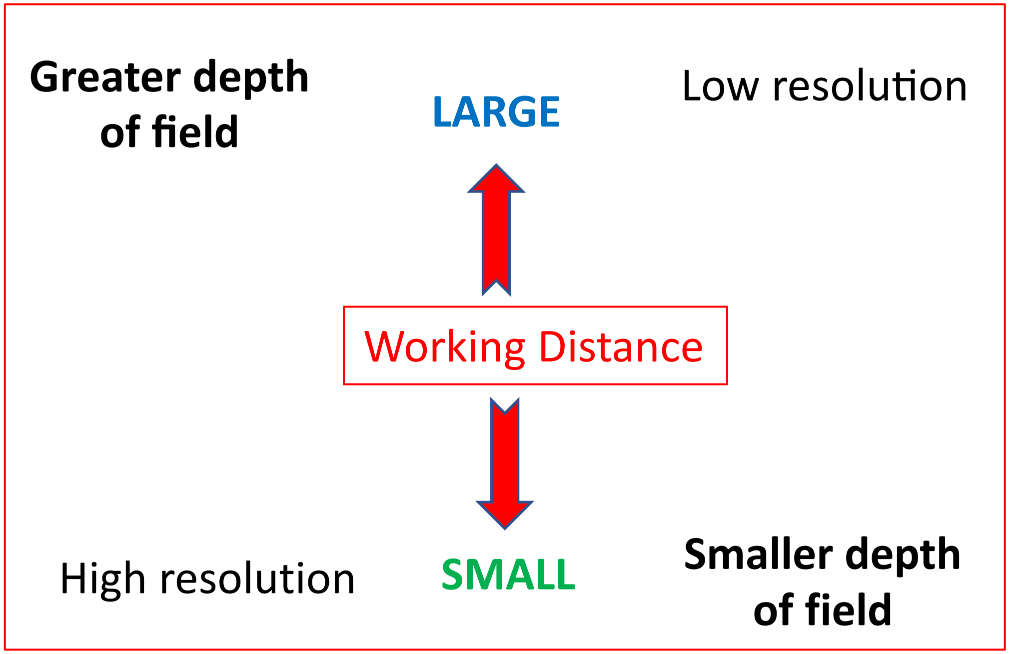
- Influence of **working distance** (WD) refers to the distance between the bottom of the SEM column and the top of the sample





Adjustment and optimization parameters

- Influence of **working distance**



Greater depth of field

LARGE

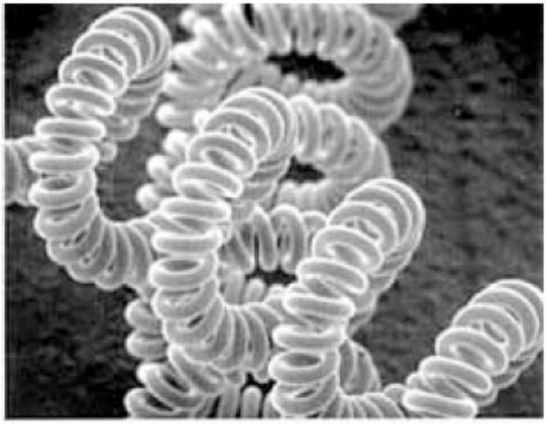
Low resolution

Working Distance

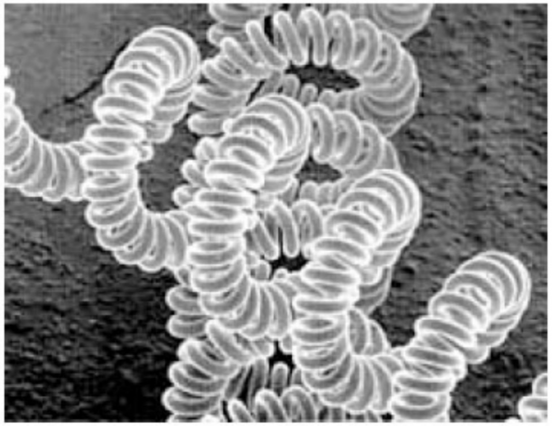
High resolution

SMALL

Smaller depth of field



10 mm Working Distance



38 mm Working Distance

Depth of field increases with WD
→ Bluriness decreases

Course outline

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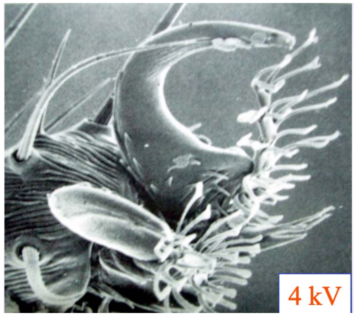
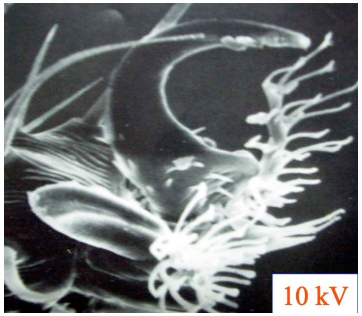
Specimen damage and contamination

- **Charging** : due to low conductivity of sample

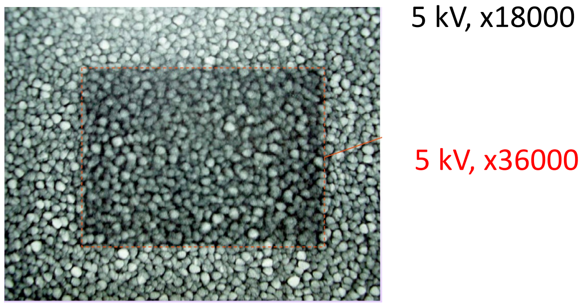
  - ➢ Need of coating with a conducting material to avoid charging
  - ➢ Need to reduce voltage, probe current and tilt
  - ➢ Fix the sample on a conductive stub.



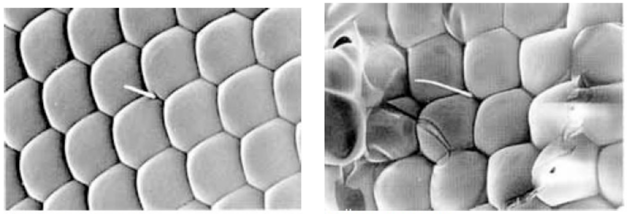


- **Contamination** : due to residual gas in vicinity of the electron probe.

  - ➢ Leads to reduced contrast and loss in image sharpness
  - ➢ Usually caused by scanning a small region for long time



- **Damage** : heat generation at the irradiated point


(a) Undamaged specimen (b) Damaged specimen

  - ➢ Need to reduce accelerating voltage, scanning area and time
  - ➢ Need a coating with a conducting material

Course outline

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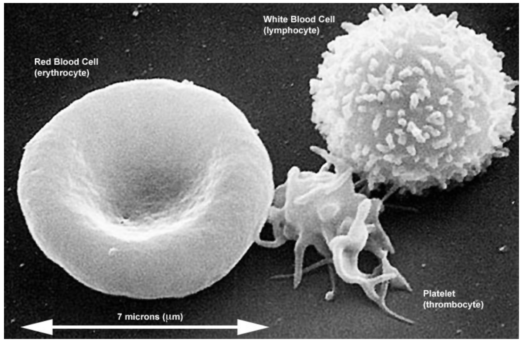
Particular case : Environmental Scanning Microscope (ESEM)

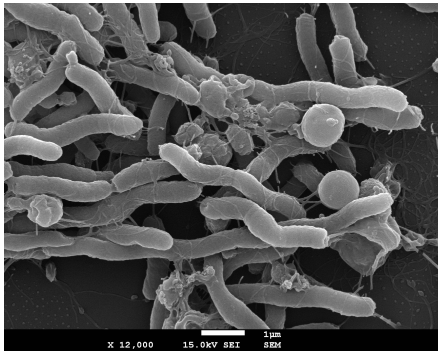
ESEM is a modified version of SEM which can image samples in either :

- the wet state
- or contained in low vacuum
- or in a gas with adequate resolution and quality.

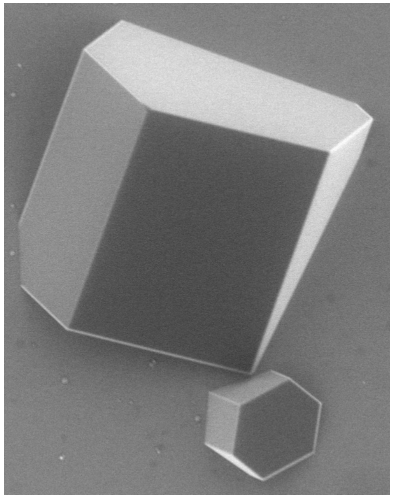
This is particularly useful in producing images from biological specimens that cannot withstand conventional electron microscopy because of its high vacuum.



Blood cells



Bacteria



Crystalline ice prism

In classical SEM : Biological samples must be first fixed chemically, then dehydrated and embedded in a resin polymer so that they are stable enough for such thin sections to be prepared (vacuum of ~ 10^{-3} to 10^{-4} Pa).

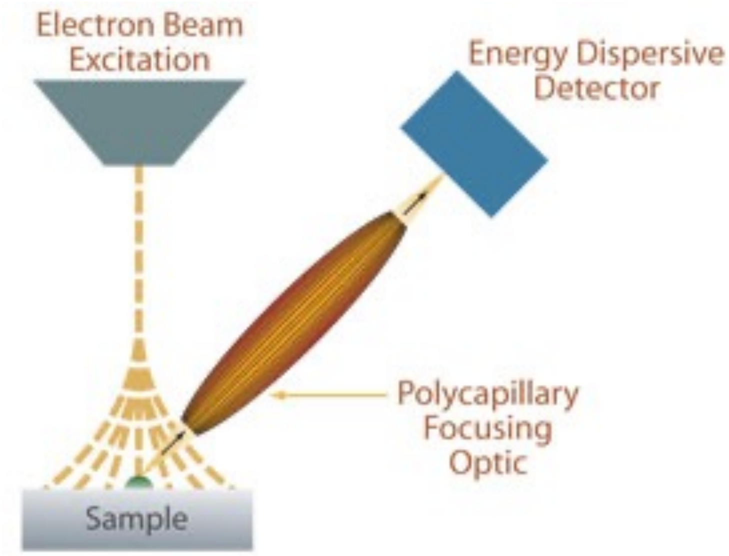
In ESEM : imaging uncoated, non-metallic or biological specimens. Argon or other gases are typically present around the specimen so that a pressure higher than 500 Pa can be achieved.

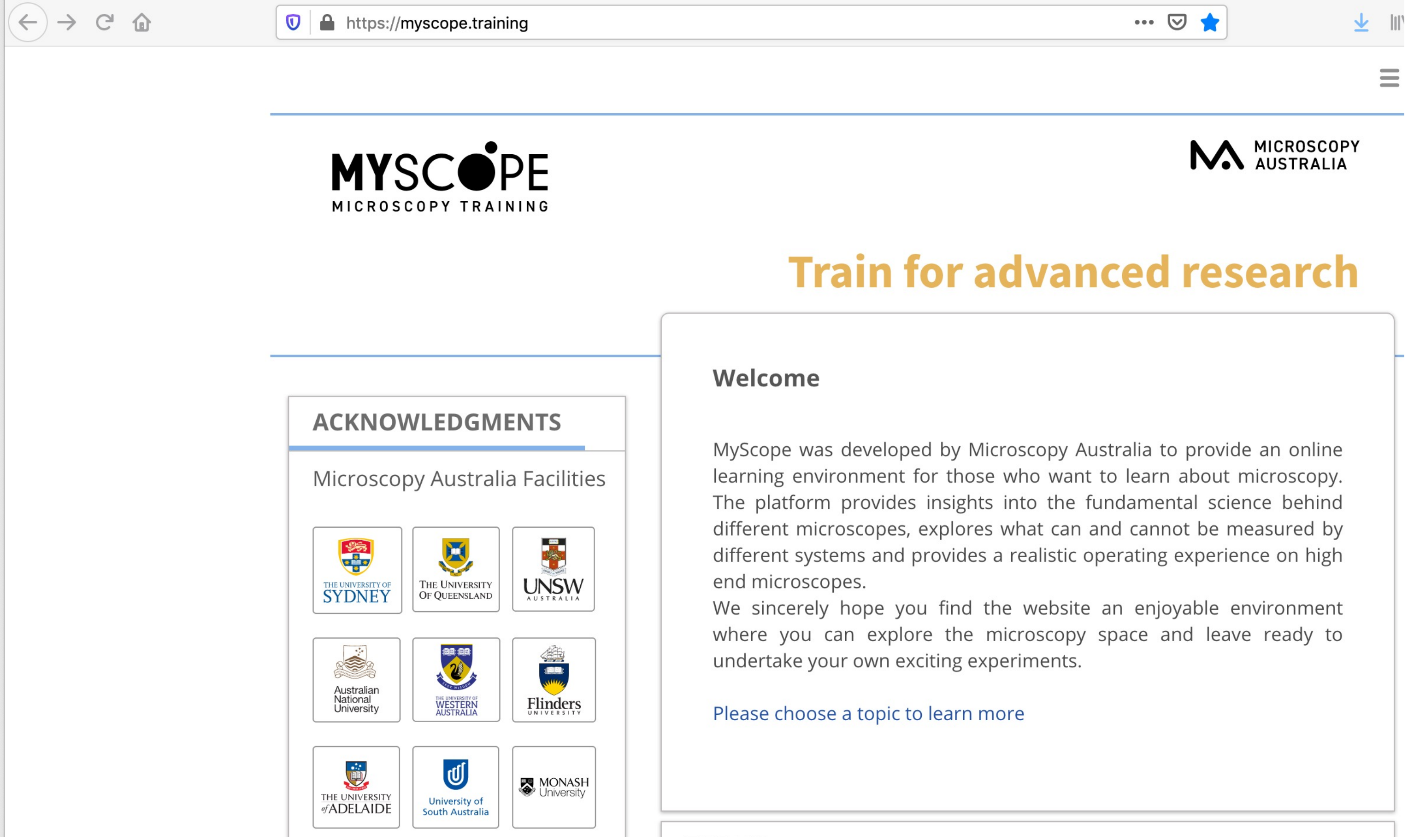
Particular case : Environmental Scanning Microscope (ESEM)

Advantages of ESEM : - Without destruction and additional specimen preparation procedures.
- Dynamic experiments (drying or crystallization) are also possible
- Wet imaging

Main disadvantage of ESEM : Reduced image contrast.

The electron beam spreads in the high-pressure environmental chamber and excites fluorescent X-rays from the entire specimen, not just from under the electron beam. The fluorescent X-rays generated outside the area of interest are detected, therefore reducing the background and enhancing the image contrast.





Train for advanced research

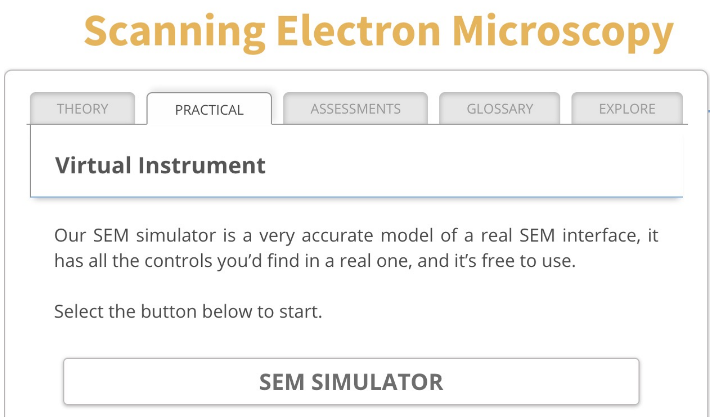
ACKNOWLEDGMENTS

Microscopy Australia Facilities

Welcome

MyScope was developed by Microscopy Australia to provide an online learning environment for those who want to learn about microscopy. The platform provides insights into the fundamental science behind different microscopes, explores what can and cannot be measured by different systems and provides a realistic operating experience on high end microscopes.
We sincerely hope you find the website an enjoyable environment where you can explore the microscopy space and leave ready to undertake your own exciting experiments.

Please choose a topic to learn more



Scanning Electron Microscopy

Virtual Instrument

Our SEM simulator is a very accurate model of a real SEM interface, it has all the controls you'd find in a real one, and it's free to use.

Select the button below to start.

https://myscope.training/SEM_simulator.html

Bibliographic references

[1] François Brisset, Monique Repoux, GN-MEBA, *Microscopie électronique à balayage et microanalyses*. EDP Sciences, 2009.

[2] P. J. Goodhew and F. J. Humphreys, Eds., *Electron Microscopy and Analysis*. England, 1988.

[3] P. S. Turner, Ed., *Electron Microscope Techniques for Surface Characterization*. Germany: Springer Series in Surface Sciences - 23, 1992.

[4] Joseph I. Goldstein, Dale E. Newbury, Joseph R. Michael, Nicholas W.M. Ritchie, John Henry J. Scott, and David C. Joy, *Scanning Electron Microscopy and X-Ray Microanalysis*. Springer, New York, NY, 2018.

[5] Techniques de l'Ingénieur, références R 6 710, PE 865, P 866, P865.

[6] A guide to Scanning Microscope Observation - JEOL

Web sites

- https://www.slideshare.net/fellowbuddy/materials-characterization-technique-lecture-notes
- https://www.thermofisher.com/fr/fr/home/global/forms/industrial/tungsten-ceb6-electron-source.html
- http://www.globalsino.com/EM/page4587.html
- https://myscope.training/
- https://serc.carleton.edu/research_education/geochemsheets/techniques/SEM.html

What to take home at the end of the lesson ?

- The most important parts of the SEM device
- What is the general process to get SEM images ?