High resolution
Scanning Electron Microscopy

CENTRE D'ETUDES
ET DE RECHERCHES
TECHNOLOGIQUES EN
MICROELECTRONIQUE
(CERTeM)

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UNIVERSITÉ FRANÇOIS - RABELAIS TOURS

GREMAN
matériaux microélectronique acoustique nanotechnologies
UMR 7347 - Université de Tours / CNRS

cnrs advancing the frontiers

Outline

1. Overview
2. HR imaging
3. Analytical capabilities
4. CERTeM 2020 AO4 investment

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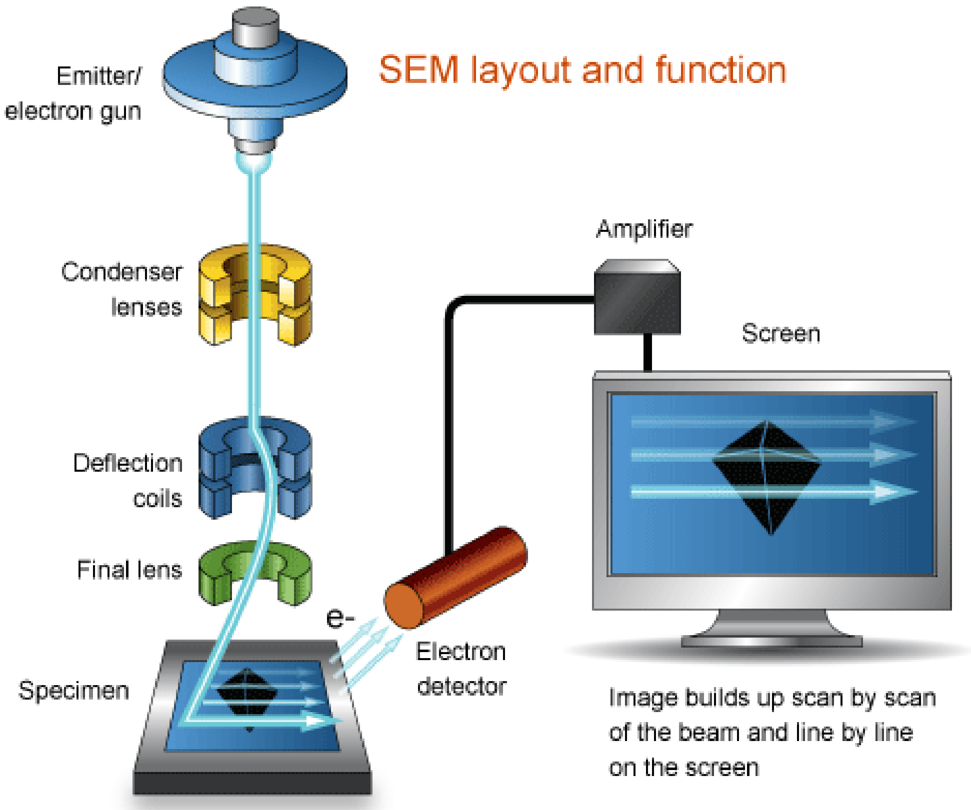
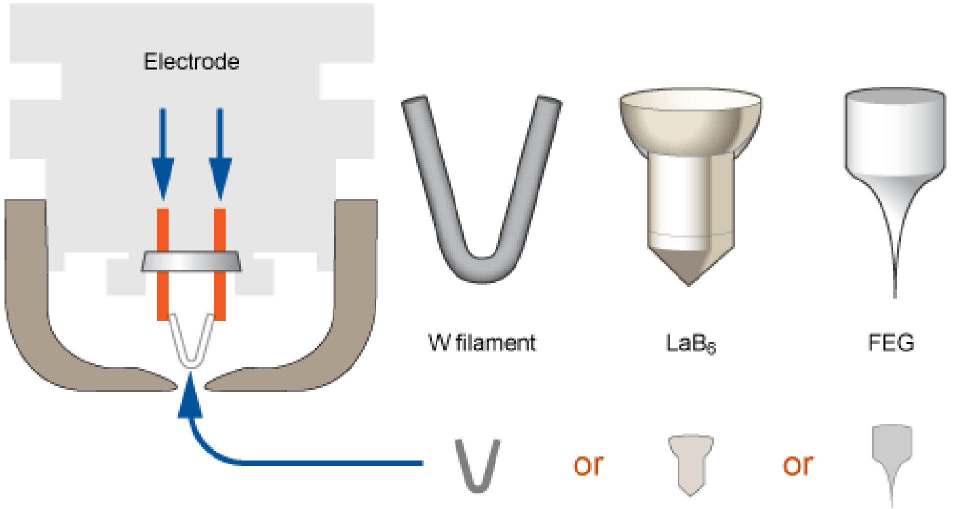
What is needed for High Resolution SEM?

- A small probe size
- High beam current
- A mechanically stable microscope and a quiet lab environment
- A skilled operator



Electron gun

3 commonly used types of electrons sources:



Emission	Thermionic		Field Emission
	W	LaB6	FE
Size (nm)	1 x 10^5	2 x 10^4	0.2
Brightness (A/cm2.steradian)	10^4 - 10^5	10^5 - 10^6	10^7 - 10^9
Energy Spread (eV)	1 - 5	0.5 – 3.0	0.2 – 0.3
Operating Lifetime (hrs)	>20	>100	>300
Vacuum (torr)	10^{-4} – 10^{-5}	10^{-6} – 10^{-7}	10^{-9} – 10^{-10}

Which FEG source for HR ?

- Cold FE
  - Highest resolution (energy spread)
  - Low running cost
  - Max probe current : ≤20 nA
- Schottky FE
  - better beam current stablility
  - less vacuum requirements
  - no need for periodic emitter flashing
  - Higher probe currents : ≥ 200nA

Electromagnetic lens system

- **Condenser lens**

controls the intensity of the electron beam reaching the specimen

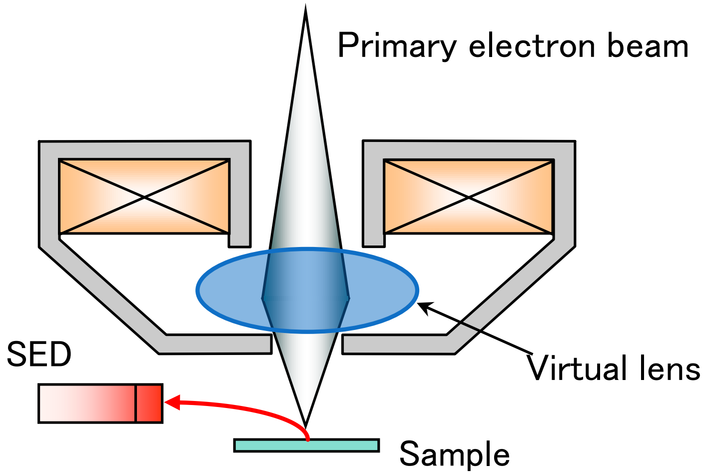
- **Deflection coils**

Deflect the beam in the *x* and *y* axes

- **Final/objective lens**

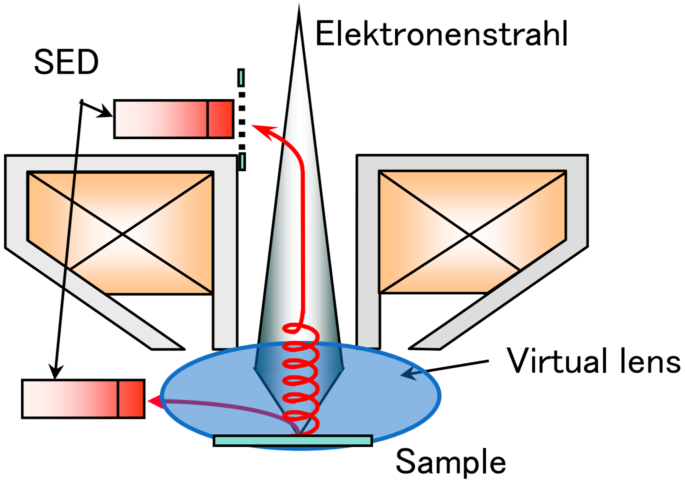
Brings the electron beam into focus (de-magnifies) on the specimen

Conventional Lens



Semi in-lens

Magnetic Immersion Lens, “Snorkel lens”



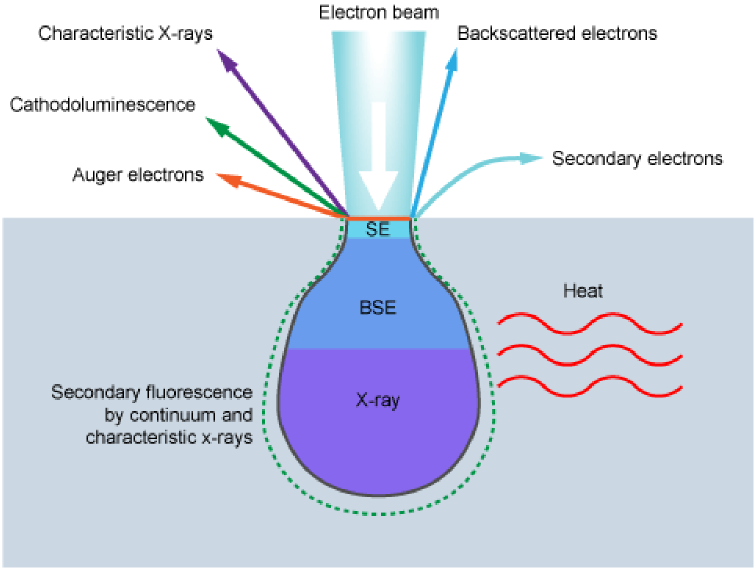
Electron-matter interactions

When high energy electrons impinge on the specimen, a number of signals are generated :

- **Secondary electrons**
  - low energy electrons (~2 to 50 eV)
  - Topographical info
  - High spatial resolution

- **Backscattered electrons**
  - High energy (> 50eV)
  - Atomic number and compositional info
  - Less charge up effect and edge contrast

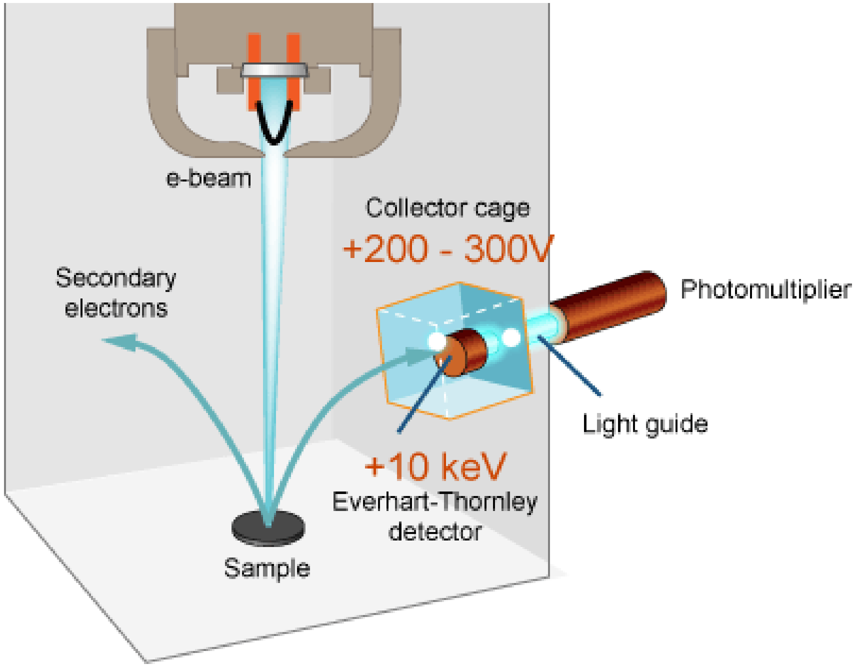
- **X-rays**
  Elemental composition information



Detectors

Secondary Electron Detector (SED) – Everhart-Thornley Detector

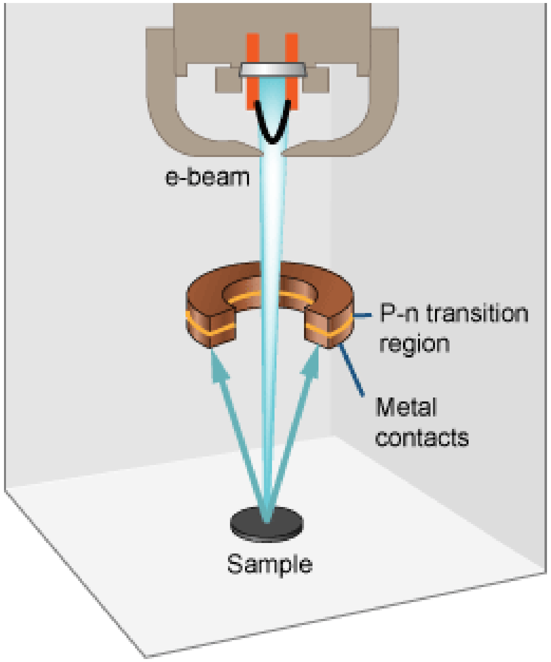
- A scintillator emits photons when hit by high-energy electrons.
- The emitted photons are collected by a light guide and transported to a photomultiplier for detection.
- A metal grid known as a Faraday cage surrounds the scintillator, and is usually held at a positive potential to attract the secondary electrons.



Detectors

BackScattered Electron Detector (BSED) – solid state diode detector

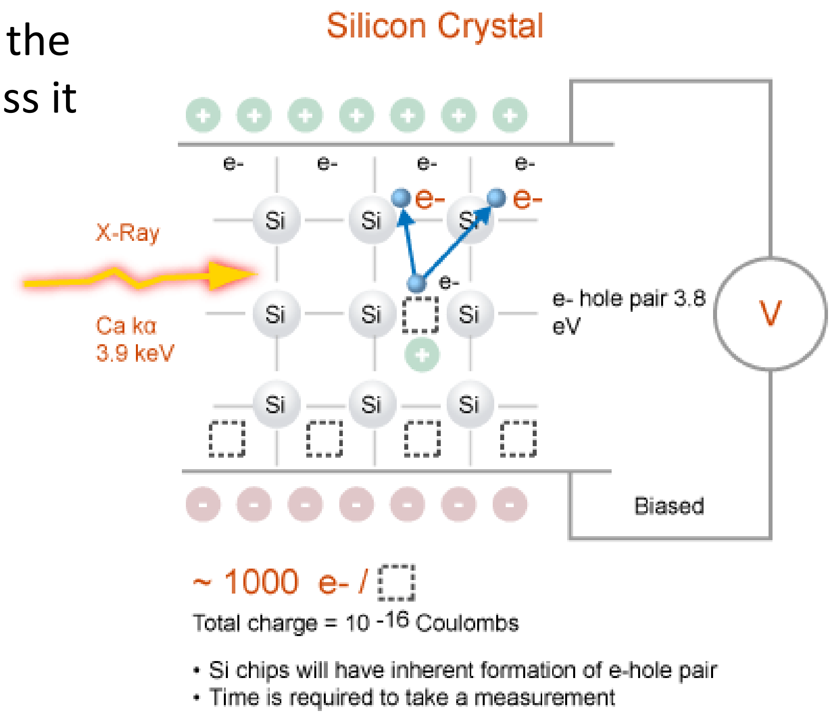
- The BSED is mounted below the obj. lens pole piece and centered around the optic axis.
- Both compositional or topographical backscattered electron images can be recorded depending on the window of electron energies selected for image formation.



Detectors

X-ray detection by EDS* – silicon drift detector

- A collimator ensure that only X-rays generated from where the primary electron beam interacts with the sample will be collected.
- An electron trap ensure no electrons enter the detector, just X-rays
- A semiconductor crystal detector
- Electronics to detect the charge recorded by the detector, convert it to a voltage pulse and pass it to the pulse processor



*Energy Dispersive Spectroscopy

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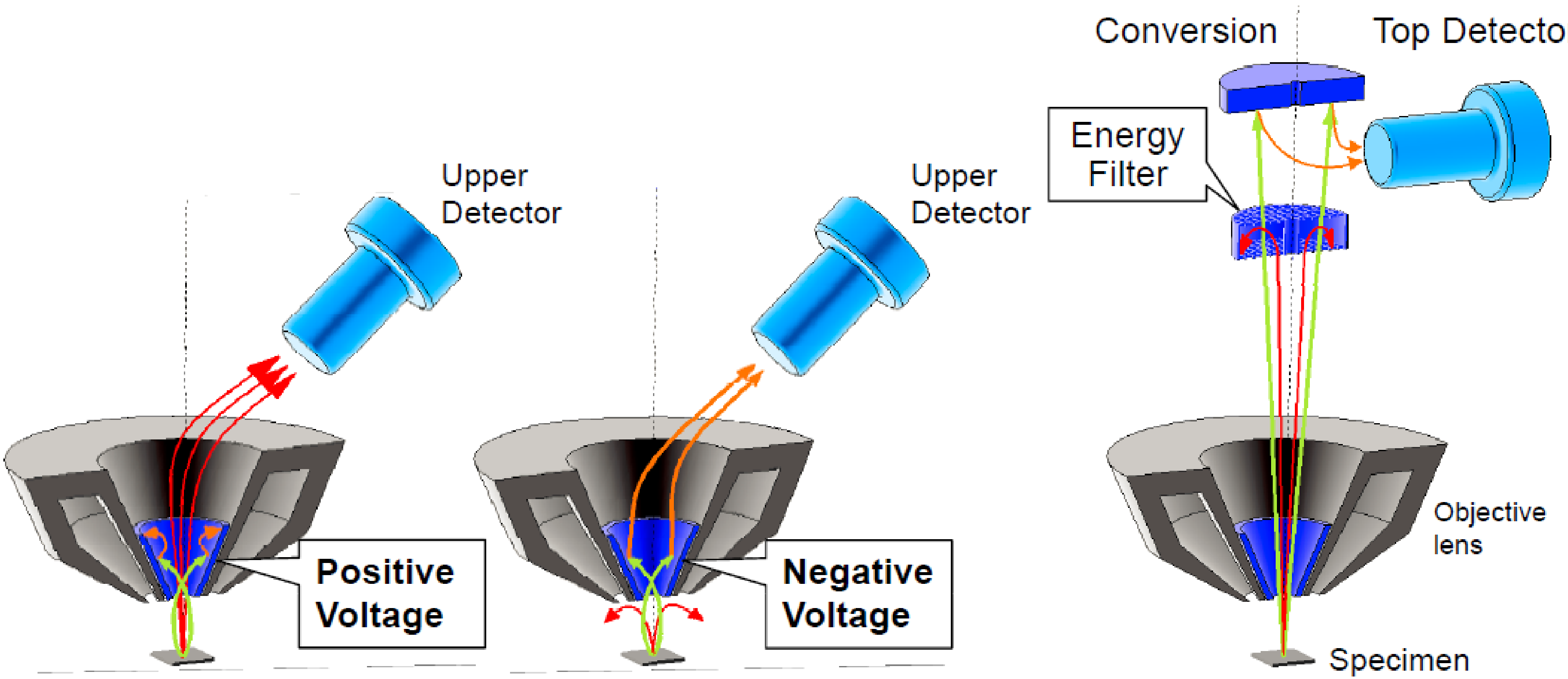
Hitachi - in column twin detector system



SE mode

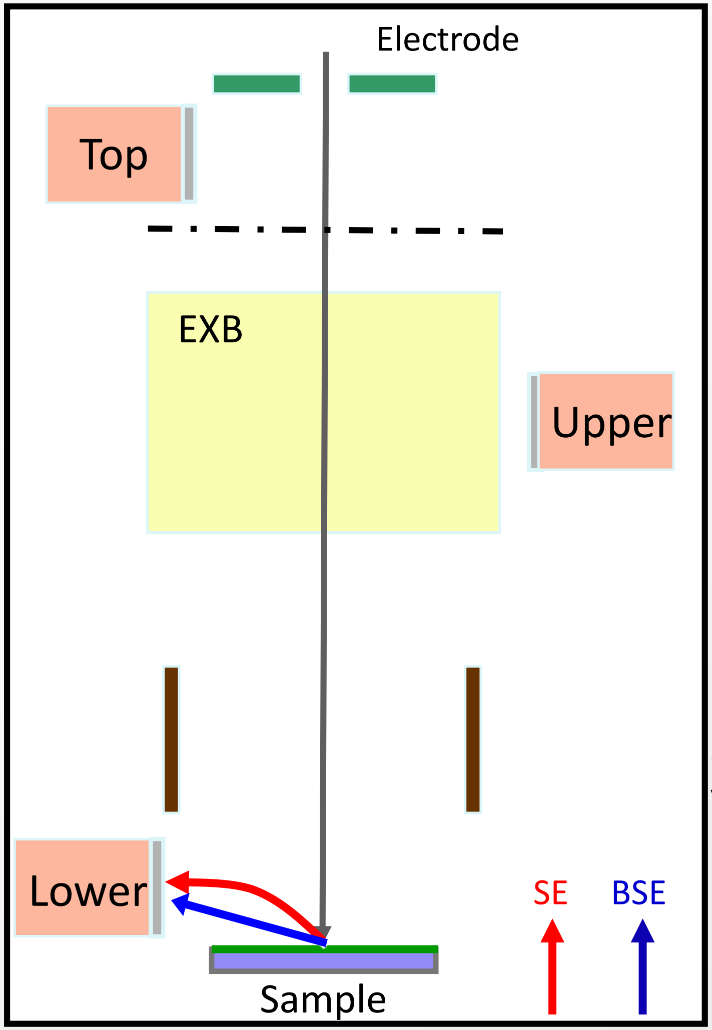
Low Angle BSE mode

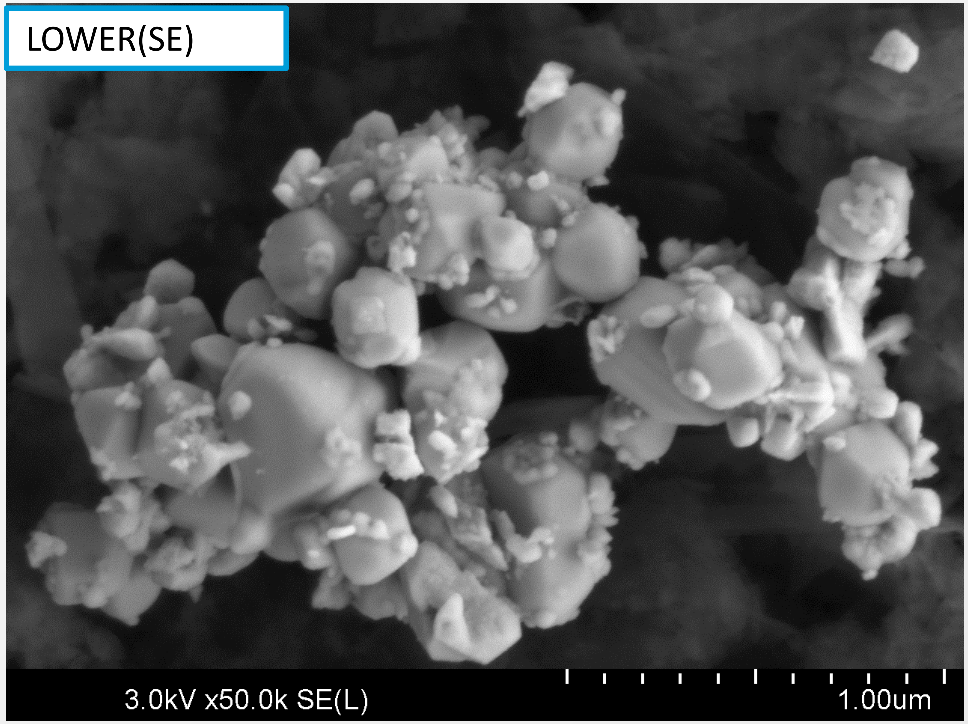
Filtering technology in column
With Hitachi patented ExB Filter

High Angle BSE mode

With New Energy Filter
(High Energy Pass)

What you see depends on the detector !



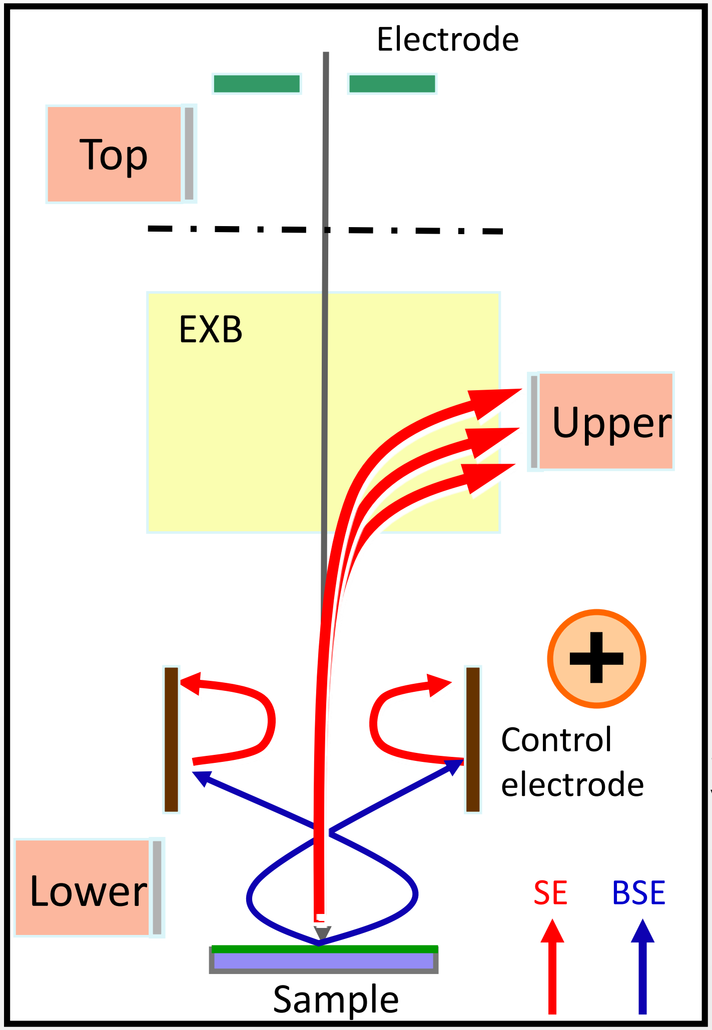


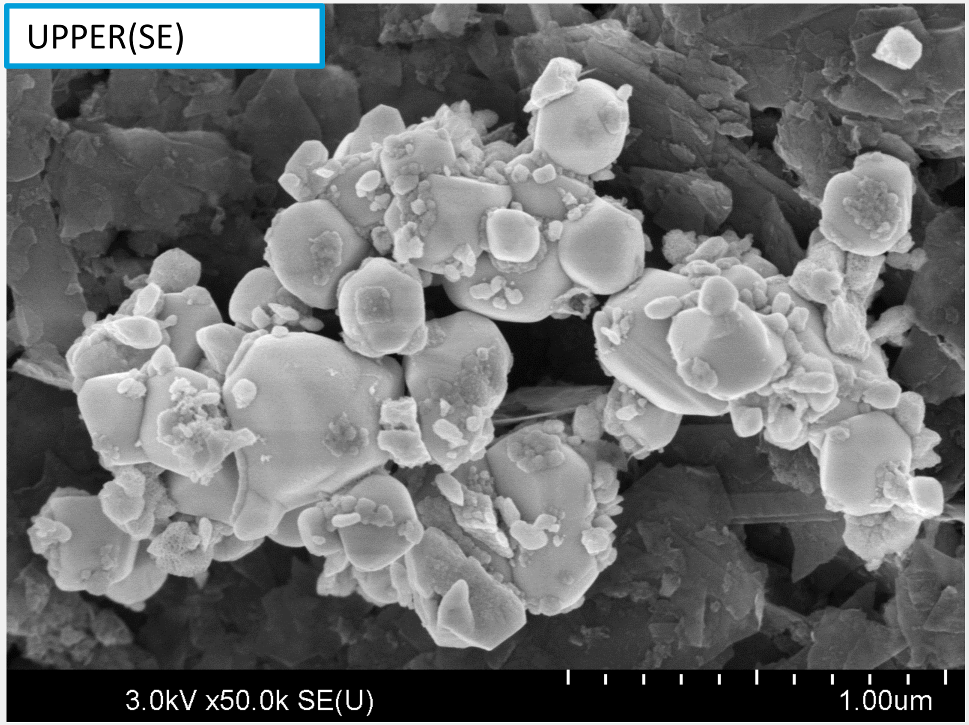
Sample : Photocatalyst
Vacc : 3.0V
Mag. : x 50k

courtesy of : Nagaoka University of Technology, Faculty of Engineering, Dr. Kazunori Sato
Model :SU8020

Topographical image with shadow

What you see depends on the detector !

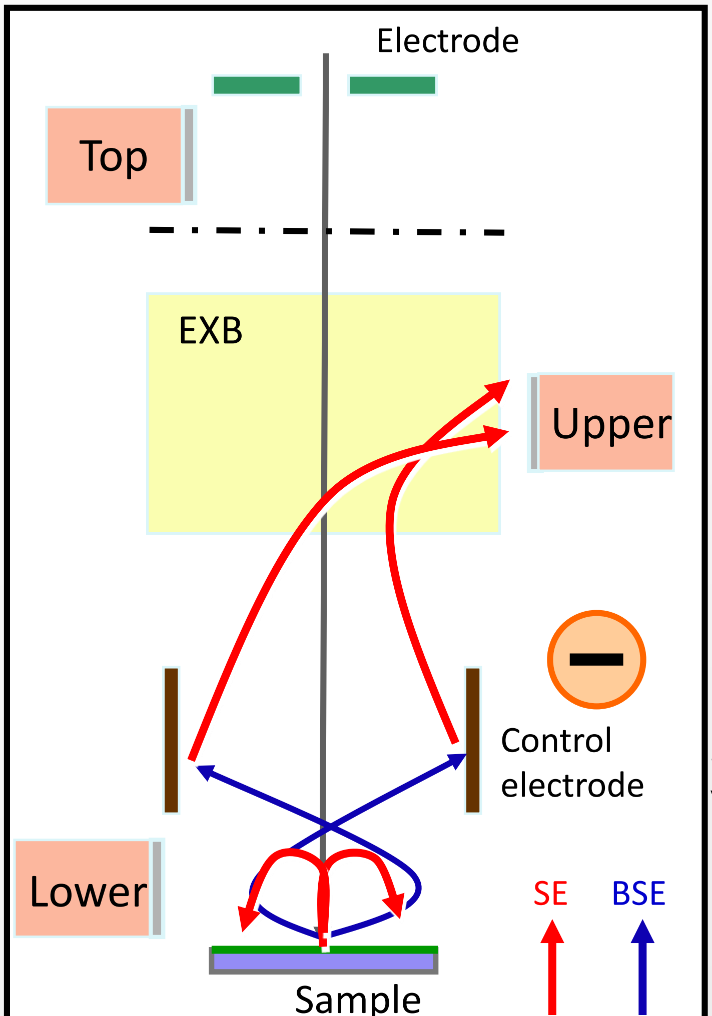


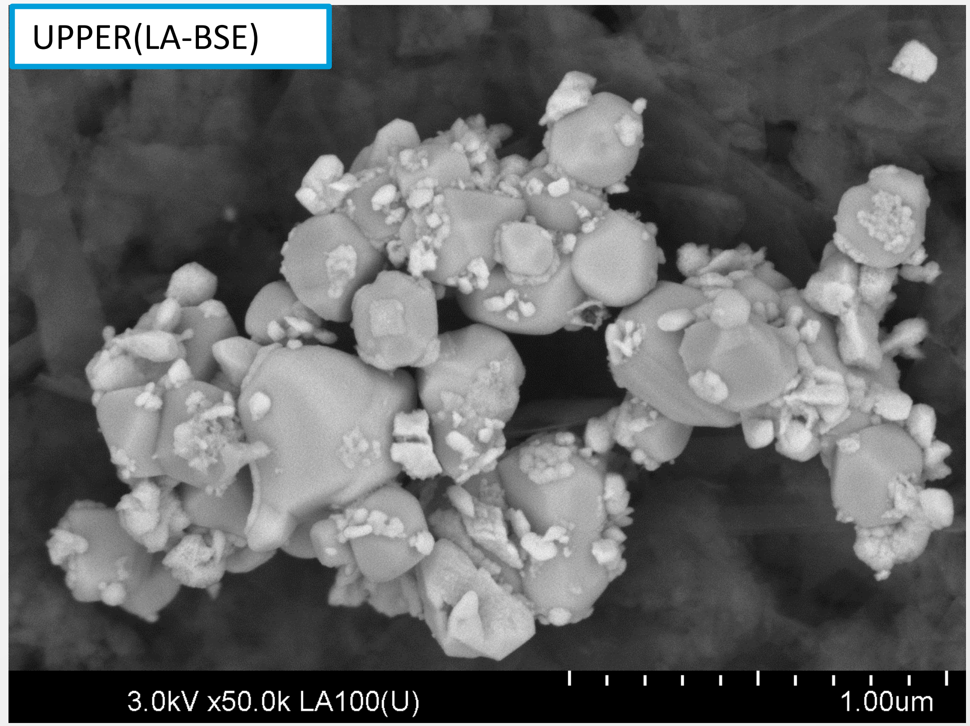


Sample	: Photocatalyst	courtesy of	:Nagaoka University of Technology, Faculty of Engineering, Dr. Kazunori Sato
Vacc	: 3.0V		
Mag.	: x 50k	Model	:SU8020

Surface information
(incl. Voltage contrast)

What you see depends on the detector !



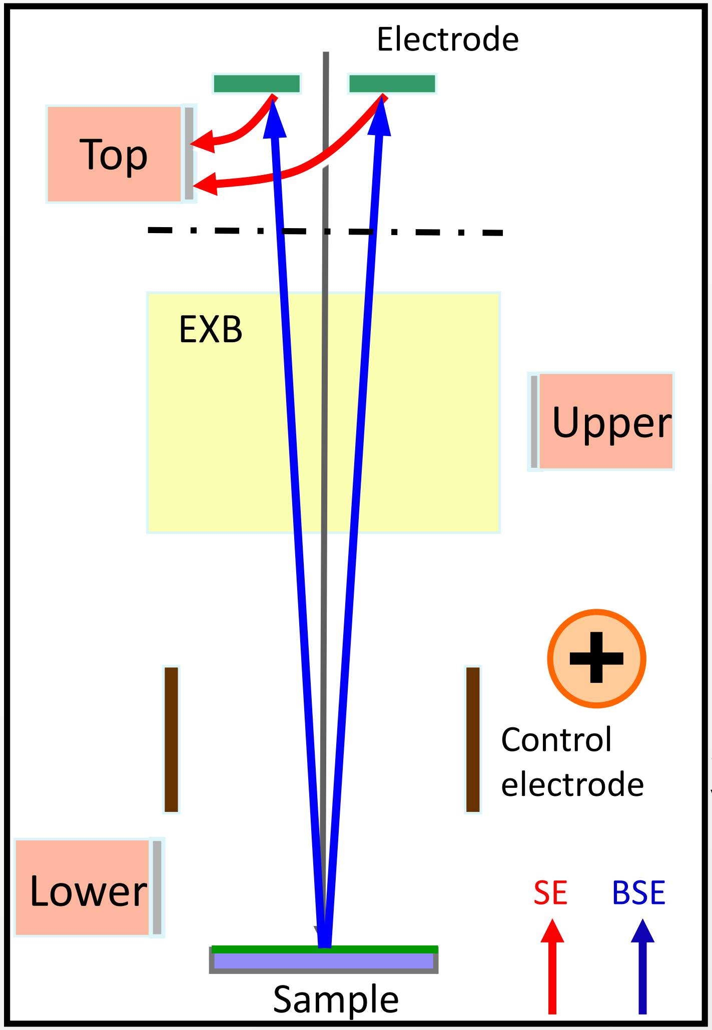


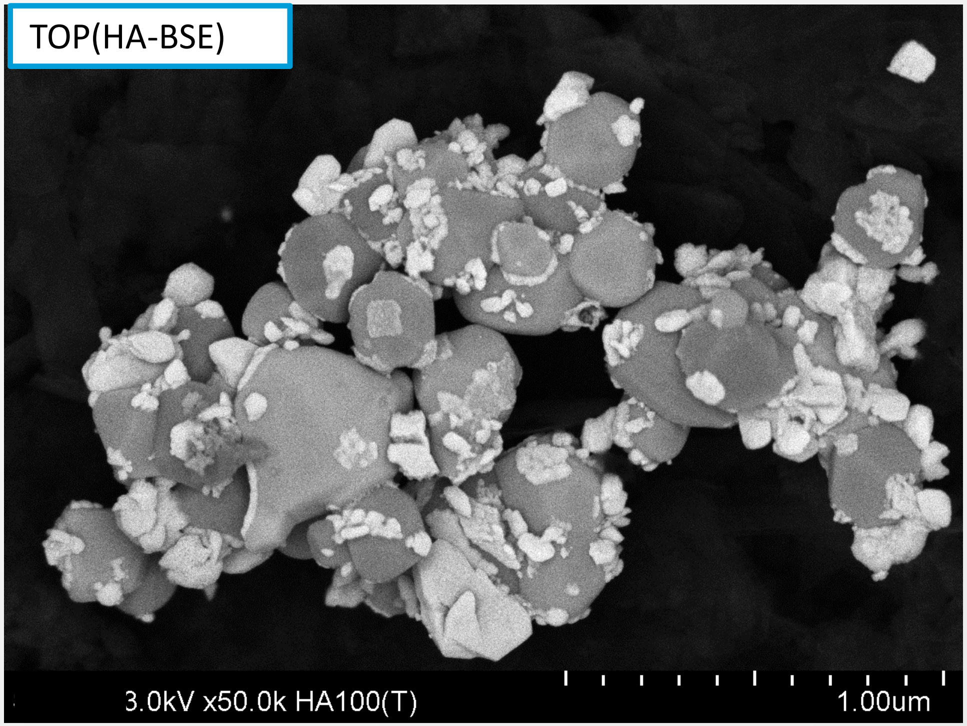
Sample : Photocatalyst
Vacc : 3.0V
Mag. : x 50k

courtesy of : Nagaoka University of Technology, Faculty of Engineering, Dr. Kazunori Sato
Model :SU8020

Topographical + Compositional information

What you see depends on the detector !





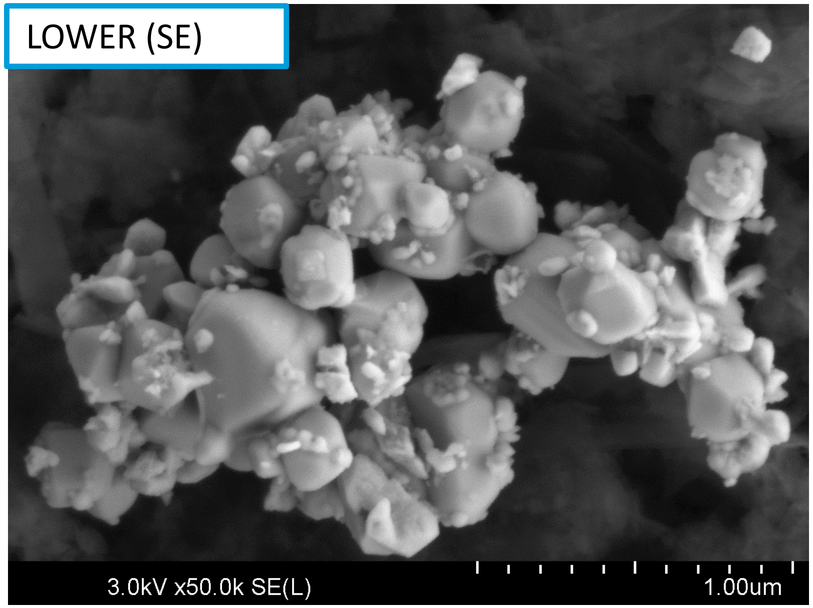
Sample : Photocatalyst
Vacc : 3.0V
Mag. : x 50k

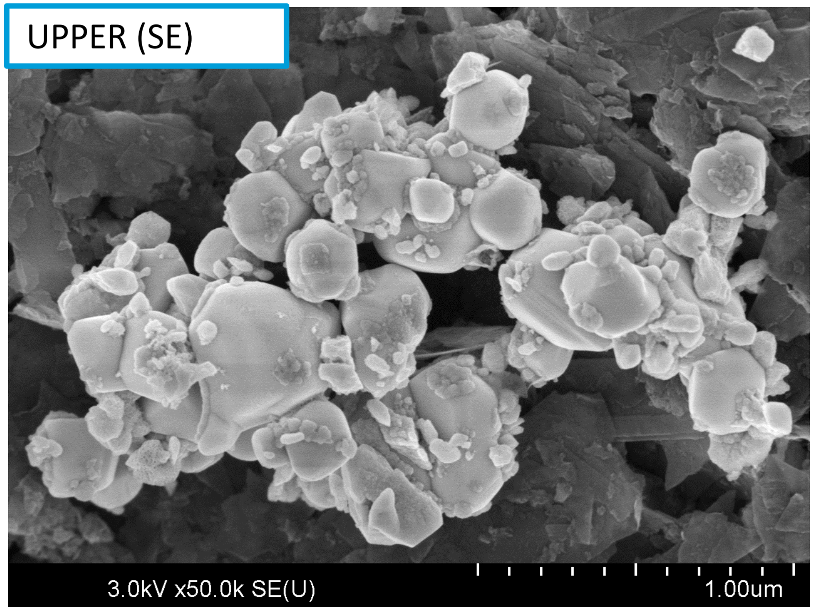
courtesy of : Nagaoka University of Technology, Faculty of Engineering, Dr. Kazunori Sato
Model : SU8020

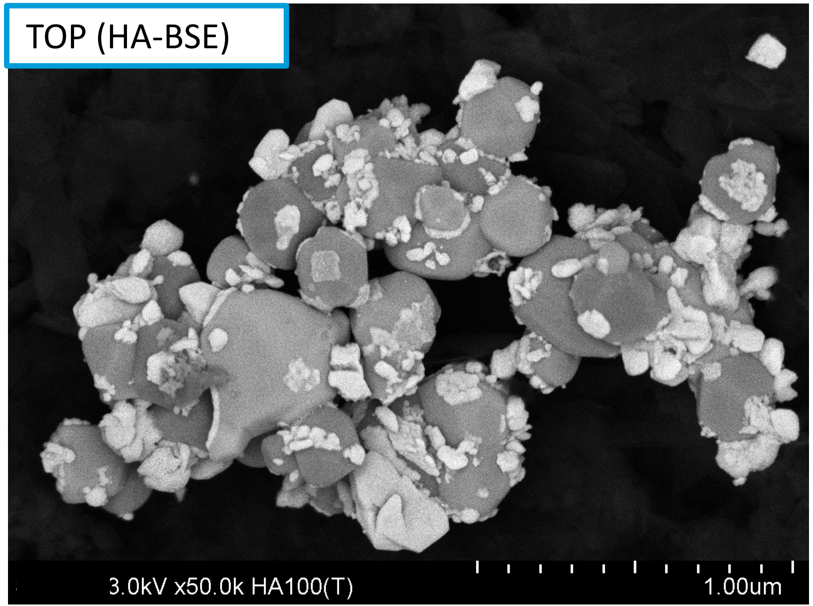
Compositional + Crystal information
(Less topographical information)

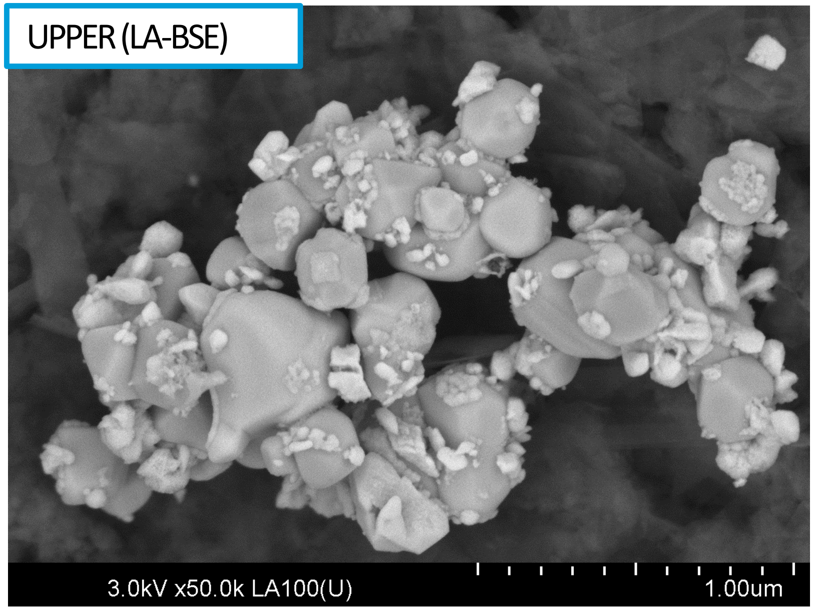
HR - SEM

HR imaging



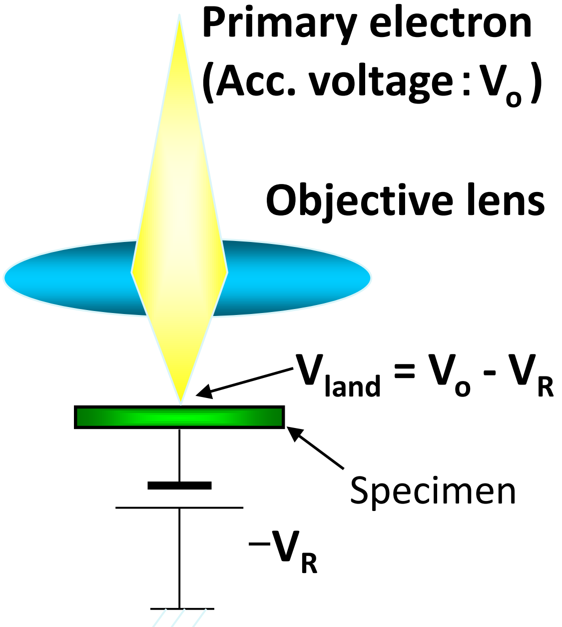






Beam Deceleration Technology

A negative voltage is applied to the specimen to decelerate primary electrons before arriving at the surface.



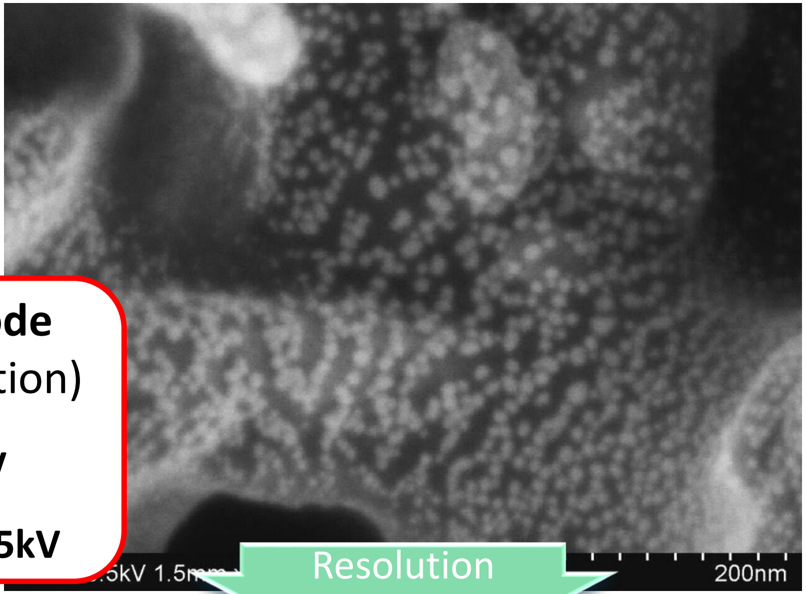
Landing voltage

$-V_R$: Deceleration voltage

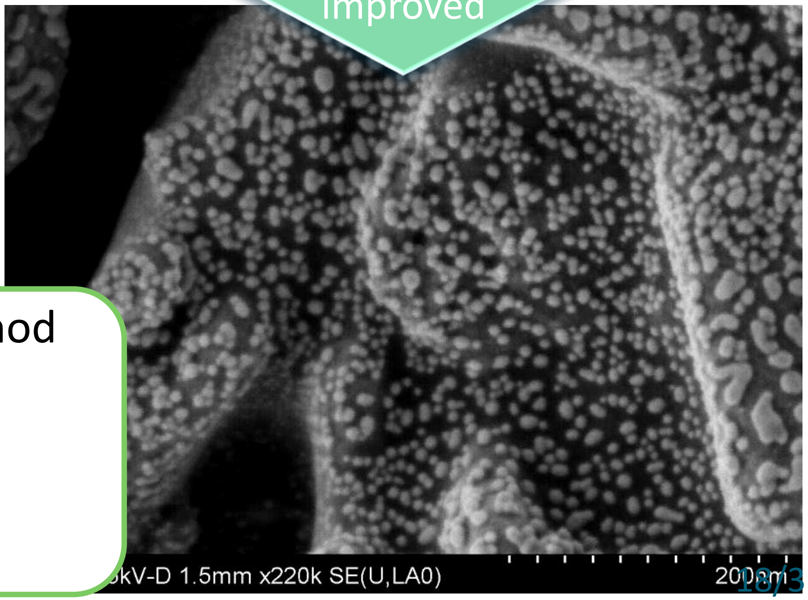
Normal mode
(no deceleration)

$V_R = 0$ V

$V_{acc}=V_{land}=0.5$kV



Resolution improved



Deceleration method

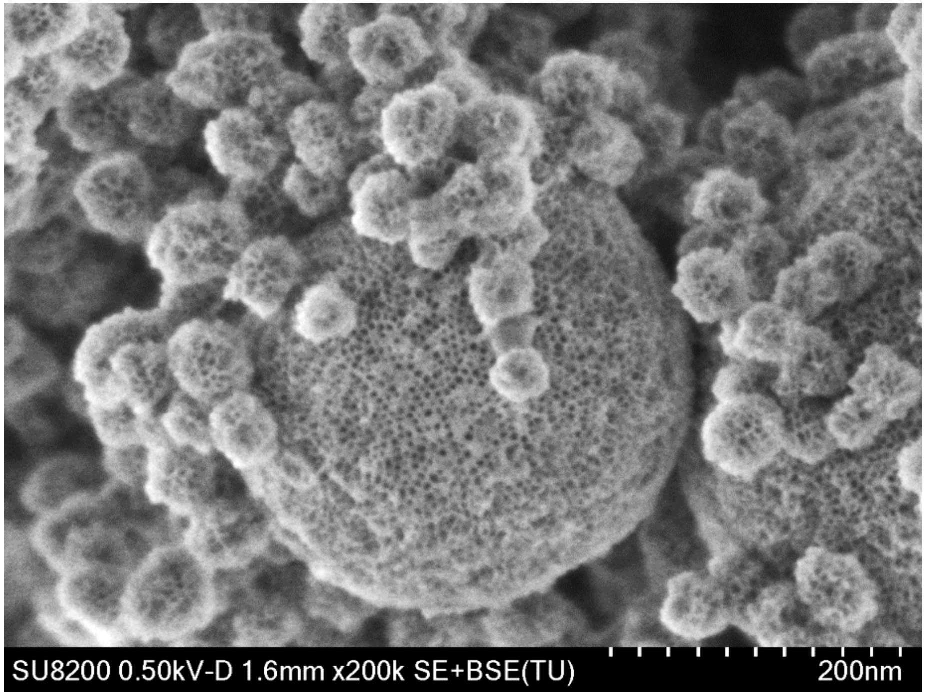
V_{acc} =4kV

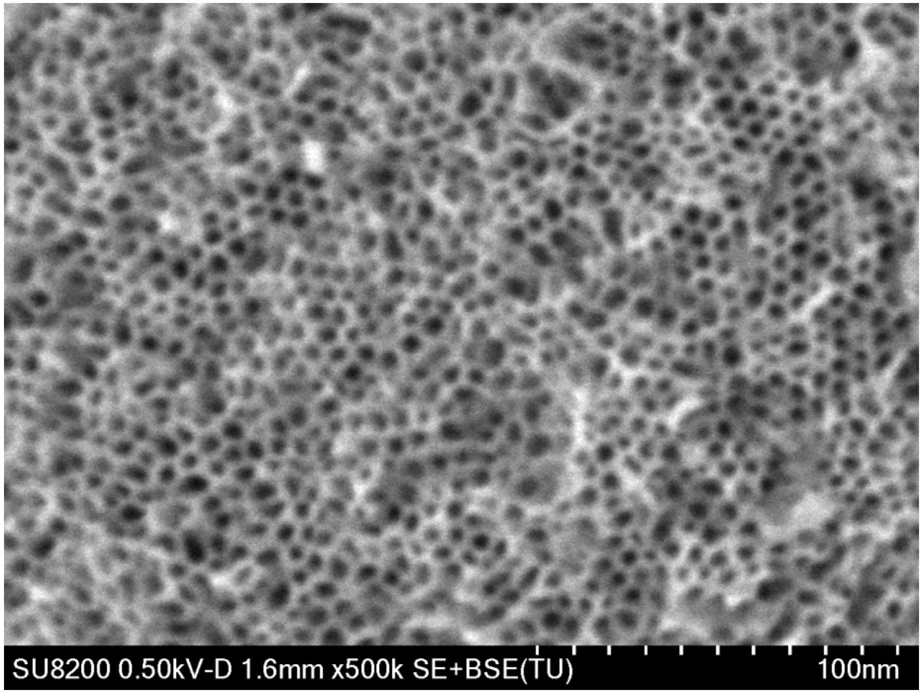
$V_R \leq 3.5$kV

V_{land} = 0.5kV

Beam Deceleration Technology

Low acceleration voltage observation for fine surface structure details





High resolution imaging of :
Mesoporous silica
Landing voltage : 500 V
Deceleration voltage : 3500 V
Mag. : x200k~x500k

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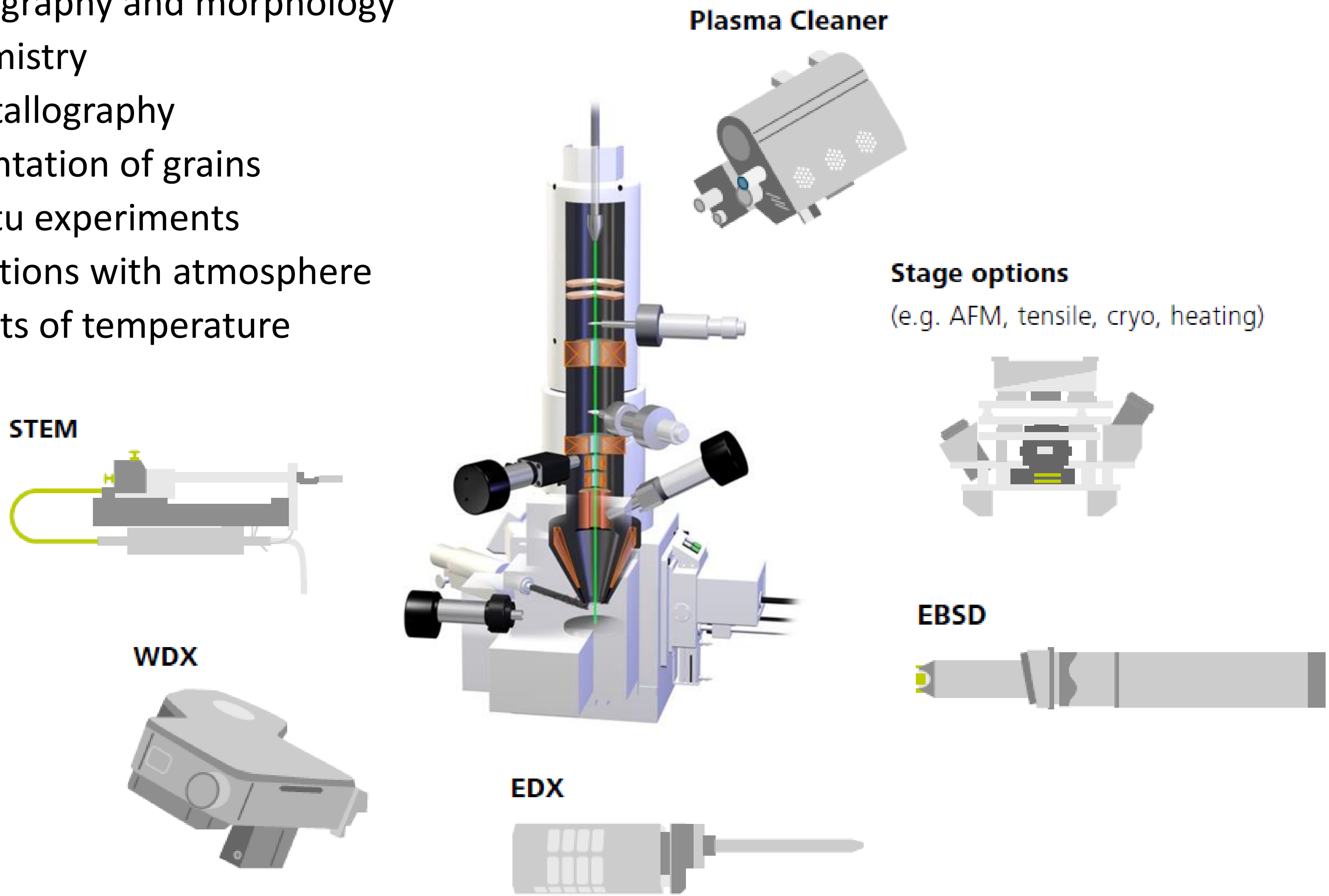
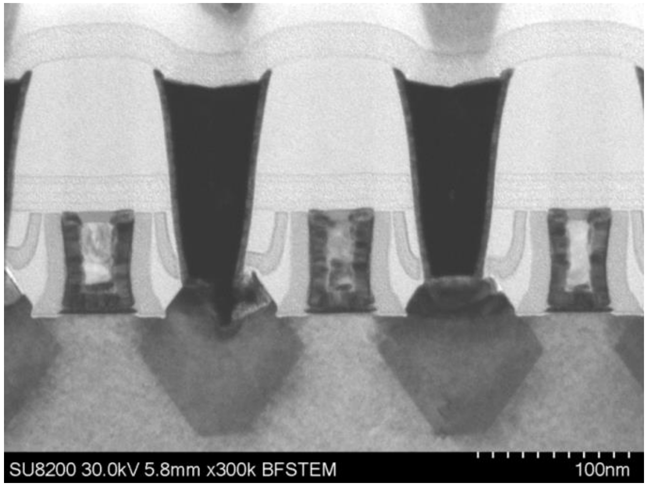
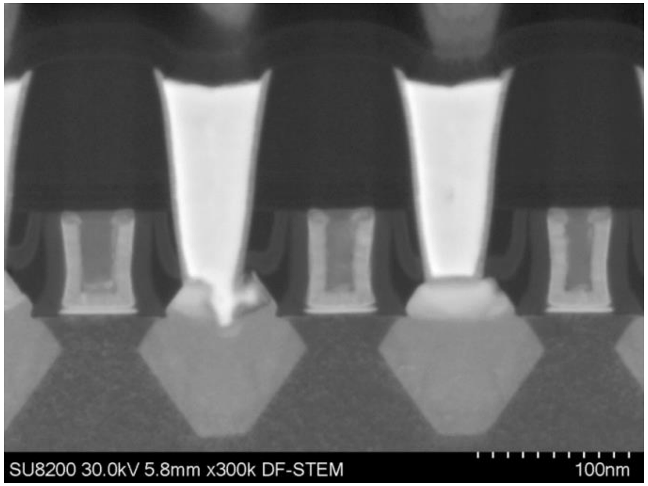
The most versatile instrument for a materials scientist ?

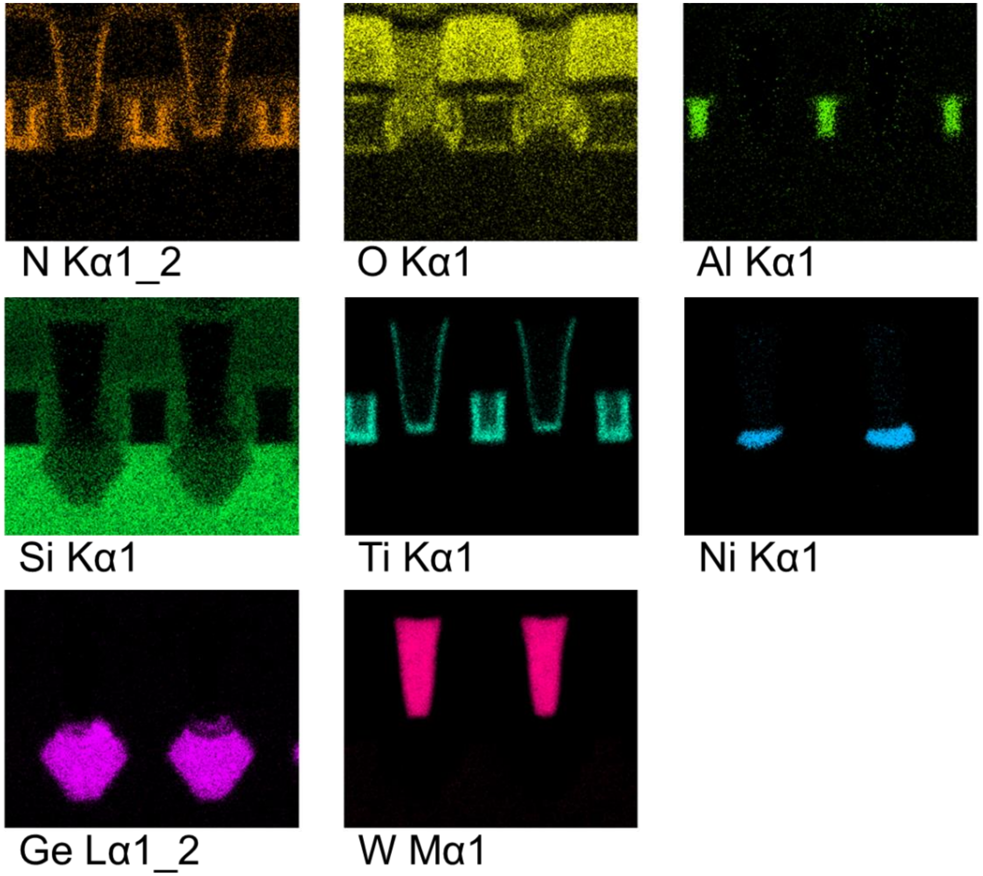
- Topography and morphology
- Chemistry
- Crystallography
- Orientation of grains
- In-situ experiments
- Reactions with atmosphere
- Effects of temperature



Combined multi-imaging and analysis

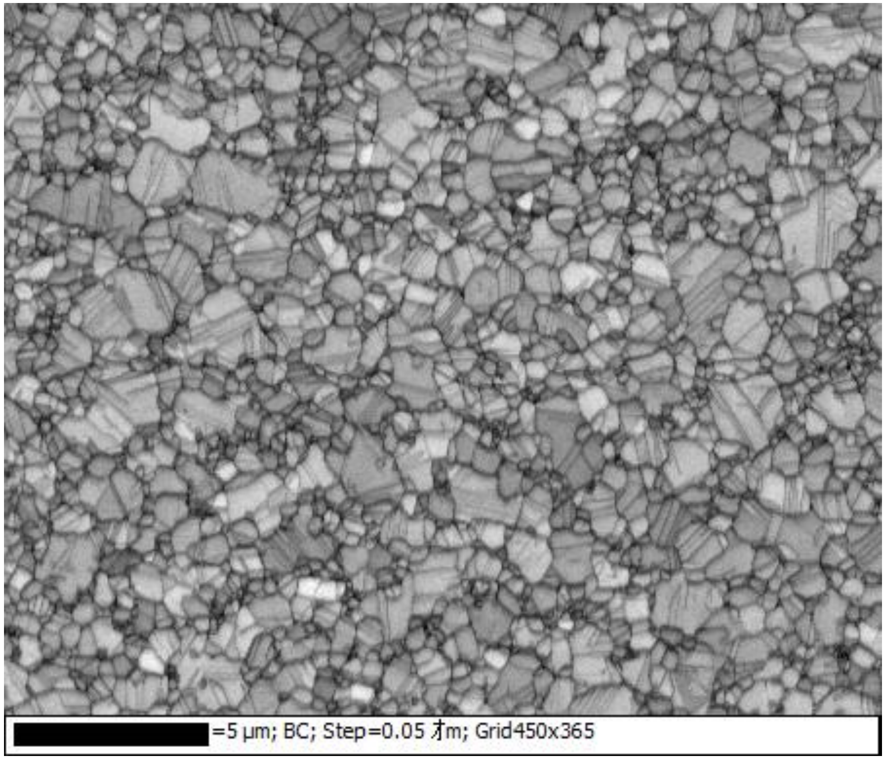




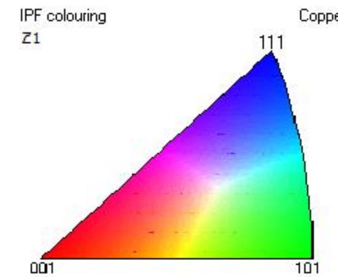


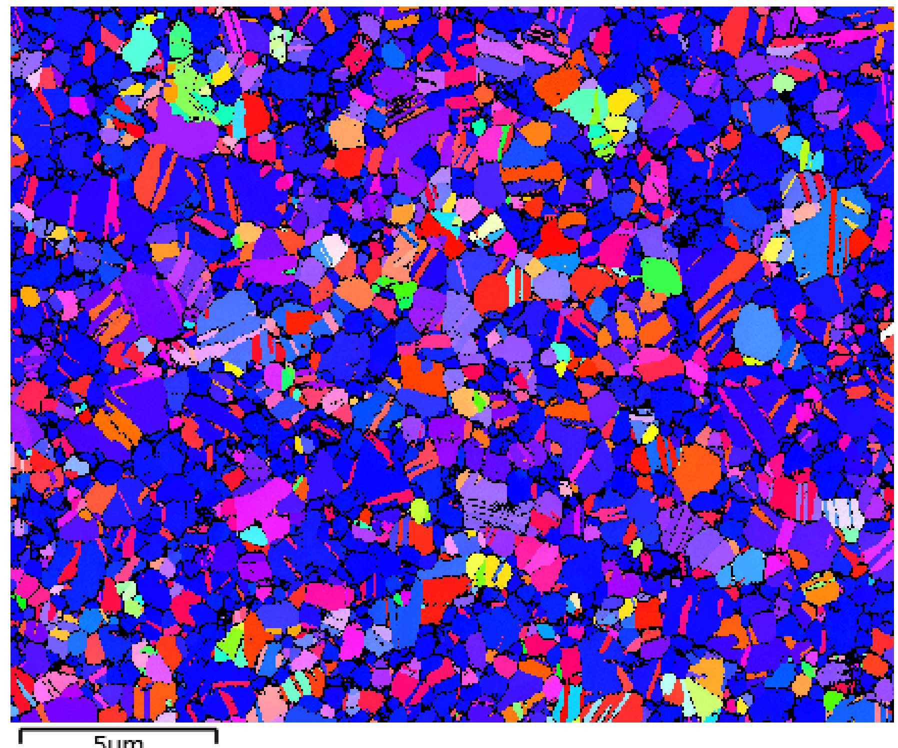
Specimen : PMOS transistor
Vacc. 30 kV
Mag. : x300K

EBSD* mapping



Band contrast map



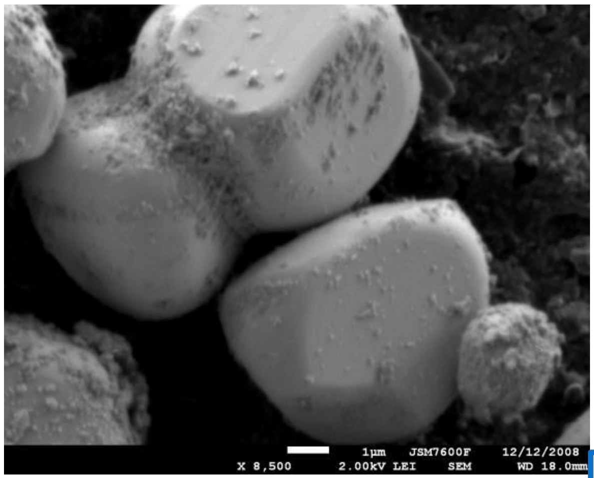


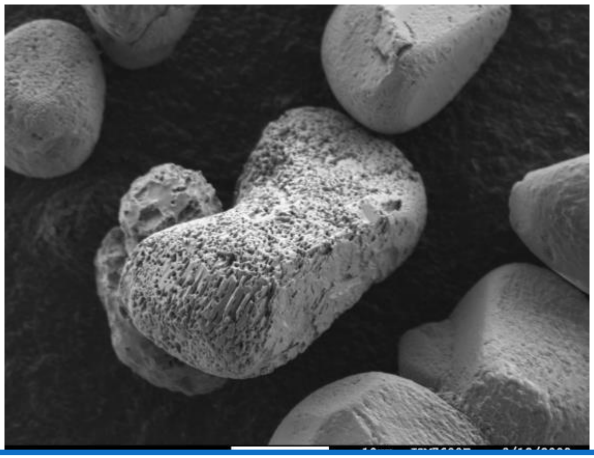
Sample : Cu Line（100µm）
Vacc : 25 kV
Specimen current : 3 nA
Mapping area : 22.5um x 18.3um (50nm step)
Time : 40 min

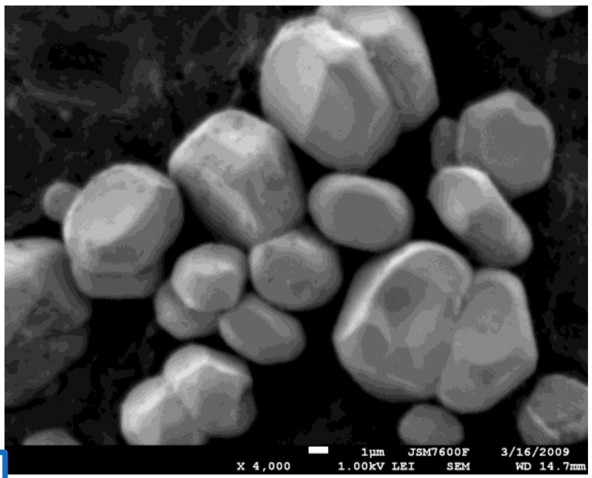
Inverse pole figure map
Z direction

*Electron Backscatter Diffraction

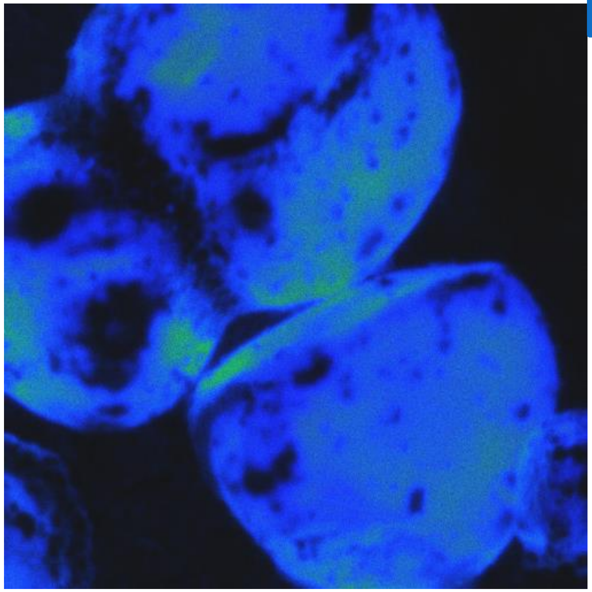
Cathode-luminescence (CL)

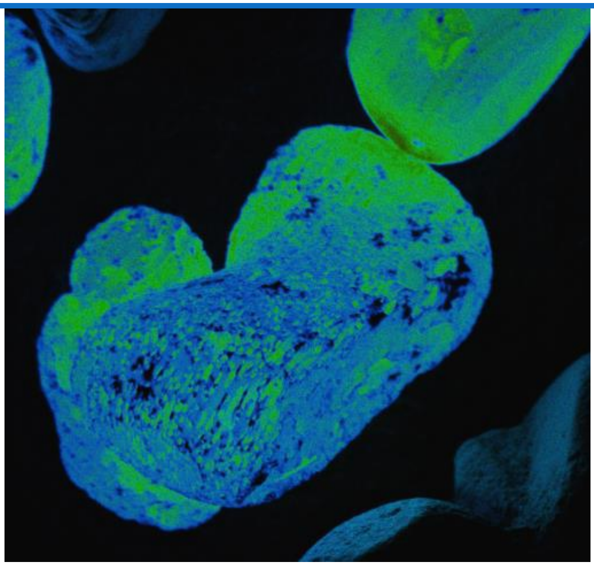


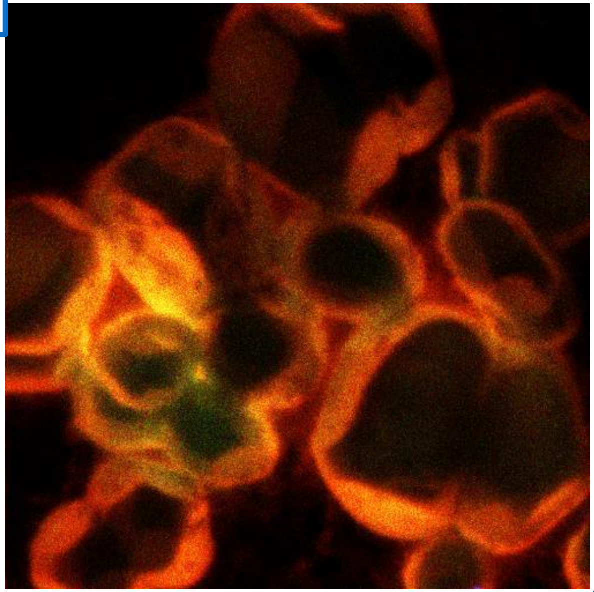




Phosphorus powder @ 2kV







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HR - SEM

CERTeM2020 Investment – Benchmarking

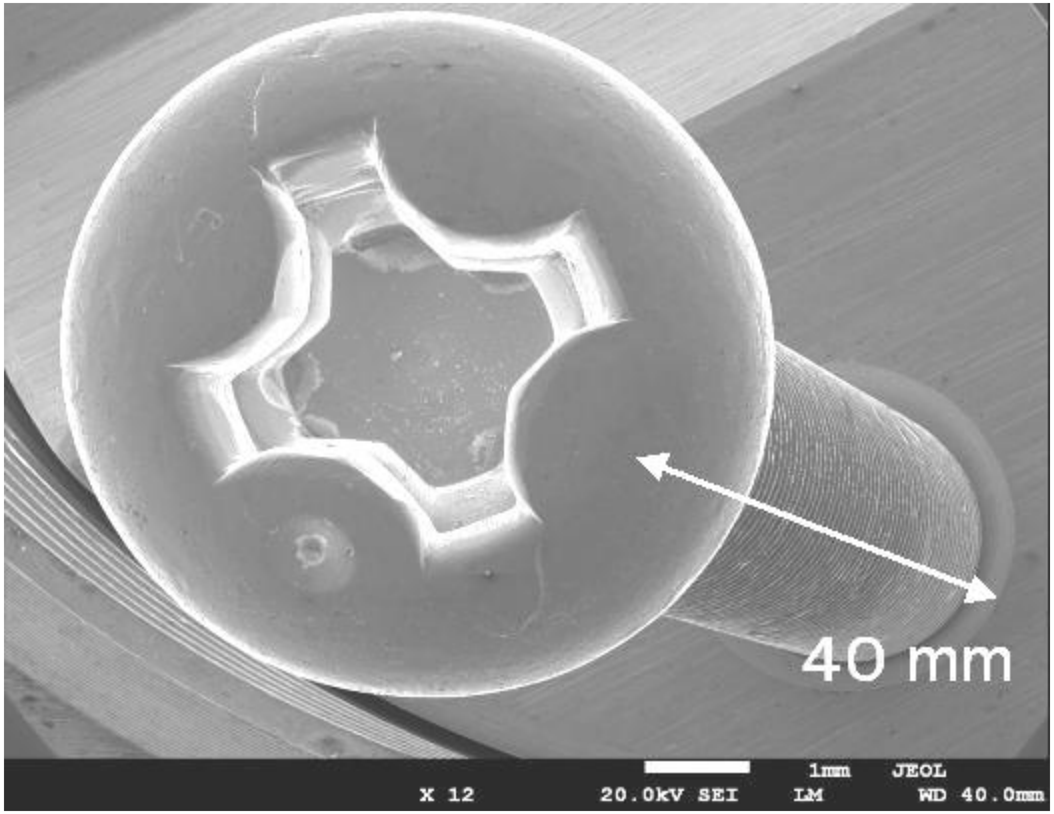
FABRICANT	TESCAN	JEOL	HITACHI	FEI	ZEISS
Modèle	MIRA3	JSM7800F	SU8220	TENEO	SIGMA 500
Source d'électron	Chaude	Chaude	**Froide**	Chaude	Chaude
Résolution	**3.5 nm @ 1 kV**	**1.2 nm @ 1kV**	**1.1 nm @ 1kV**	1.4 nm @ 1 keV	1.6 nm @ 1 kV
Budget MEB (k€)	**338,4**	**398**	**479**	**devis en attente**	**448,3**
Budget EDS (k€)	**50**	**50**	**69,4**	**devis en attente**	**73**
Plasma cleaner (k€)	**inclus**	**27**	**non inclus**	**devis en attente**	**non inclus**
contrat maintenance tout inclus (k€)	**12,7**	**12**	**12,1**	**devis en attente**	**15,6**
Budget total (k€)	**401,1**	**487**	**560,5**	**?**	**536,9**
BASE SAV régionale	PARIS	**CHATELERRAULT**	PARIS	PARIS	PARIS

HR - SEM

CERTeM2020 Investment – Benchmarking

FABRICANT	TESCAN	JEOL	HITACHI	FEI	ZEISS
Avantage	PRIX	RESOLUTION	RESOLUTION (cold FEG)		RESOLUTION
	Faible grossissement x2	Profondeur de champ	Ultra low landing voltage (10 volts)		Colonne Gemini réputée
		Charge Suppression Scan			InLens SE/BSE axial
		Courant de sonde élevée			
		Rapport qualité/prix			
		n°1 national MEB/TEM, proximité du SAV	n°1 MEB semi-cond (SAV connu)		N°2 MEB national
Inconvénient	RESOLUTION	PRIX	PRIX		PRIX
	Position sur le marché				
	SAV ?				

Large depth of focus mode

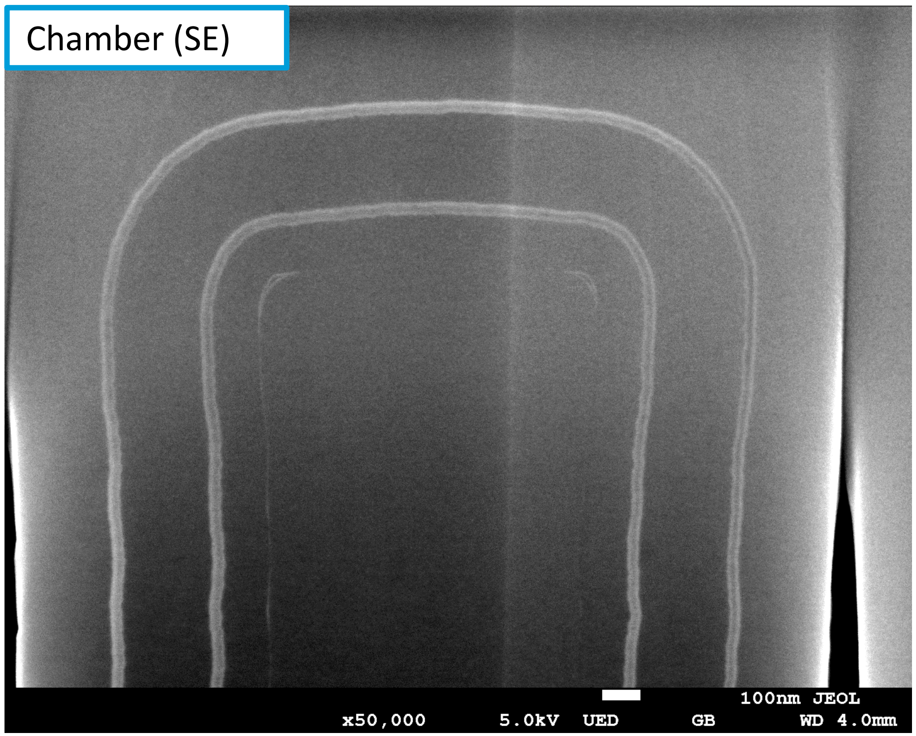


Specimen: screw **Magnification: x 12**

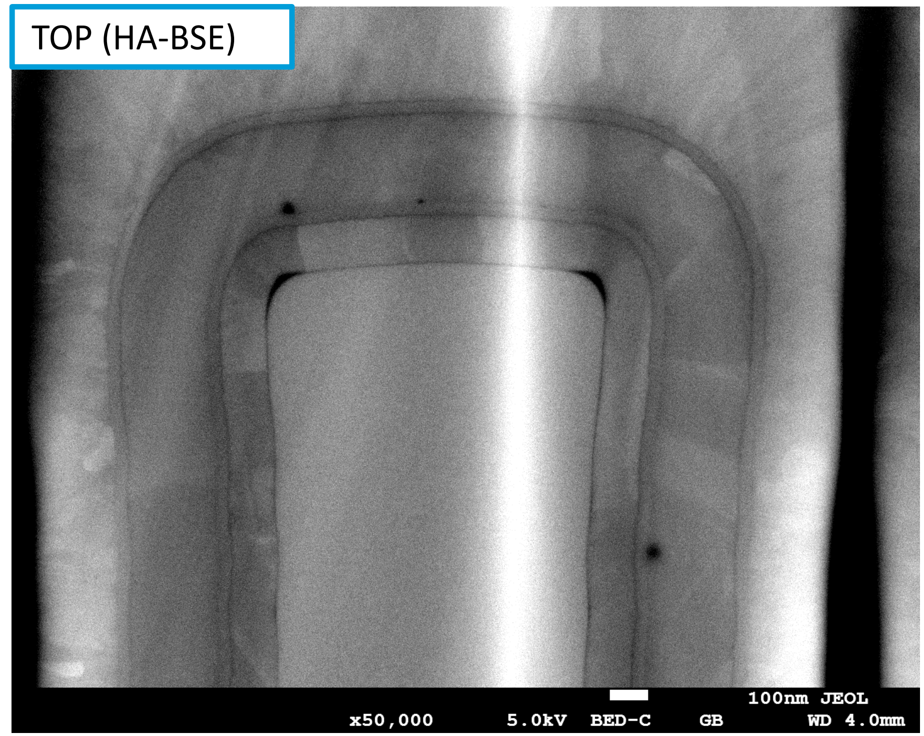
- The LDF mode provides very large depth of focus
- Useful when you observe a large rough specimen

Construction analysis – CP cross section

DEMO JEOL / Hitachi



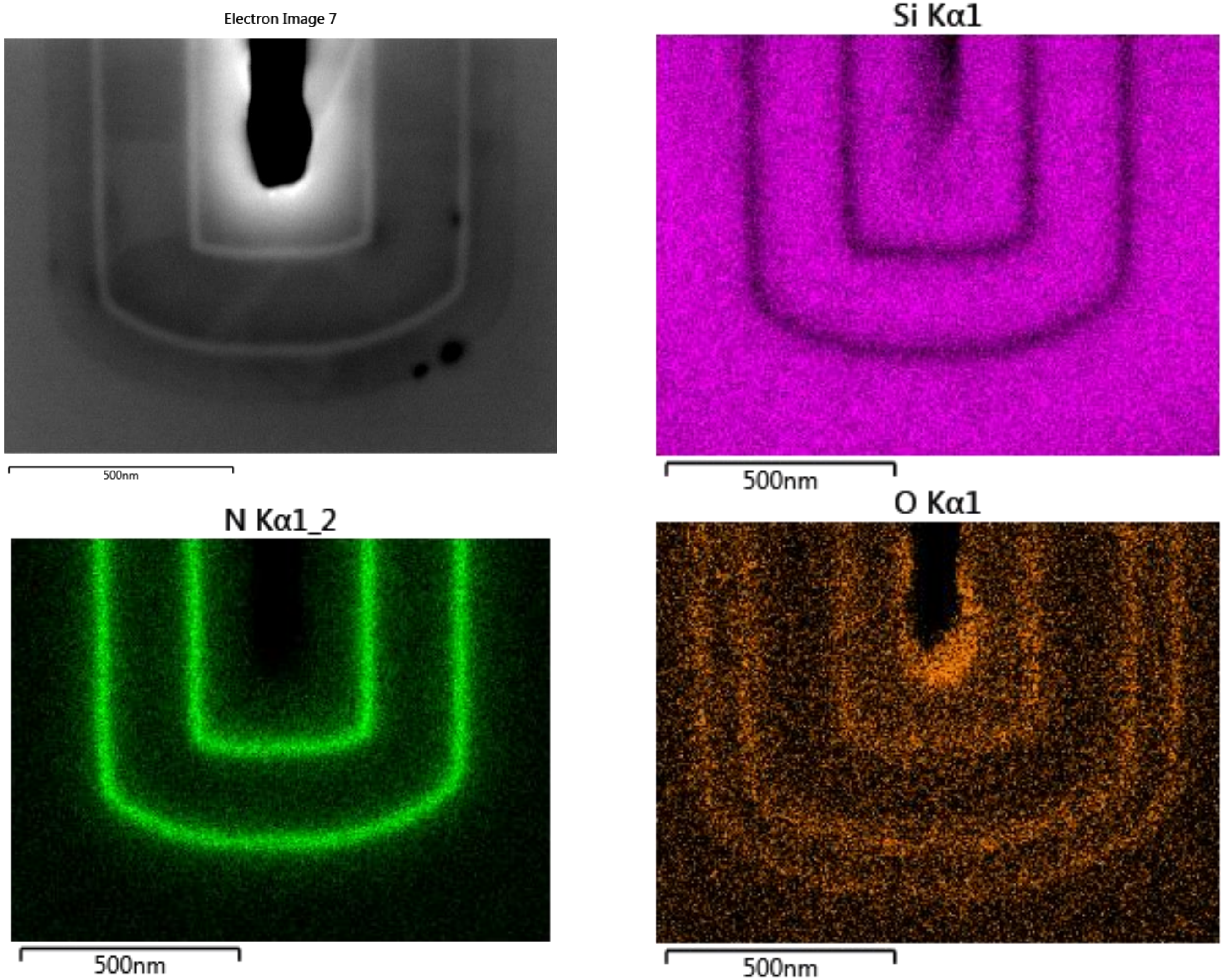
Chamber (SE)



TOP (HA-BSE)

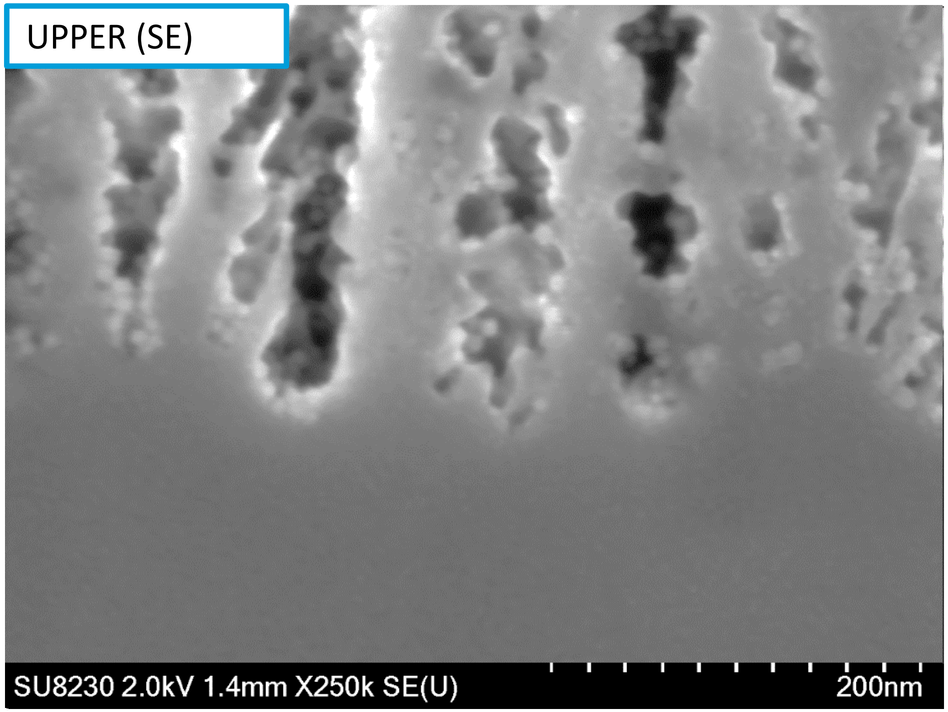
Construction analysis – CP cross section

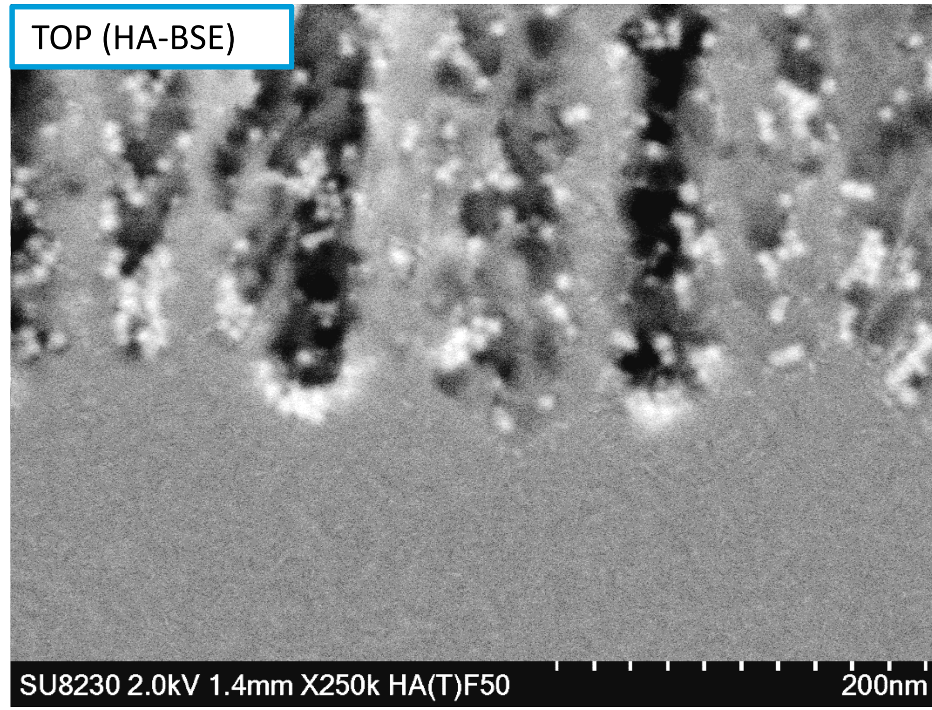
JEOL / Hitachi DEMO



HR imaging – CP cross section

DEMO Hitachi





Porous Silicon with FeCo particles

Sample prepared by B.Bardet, PhD student – TOURS2015

Merci de votre attention !