

5. modern SEM technology and trends

SEM

- Why low voltage SE imaging
- Condition of the surface, coatings, plasma cleaning
- Low voltage BSE imaging
- Polishing for BSE, EDX and EBSD, effect of ion beam etching/polishing

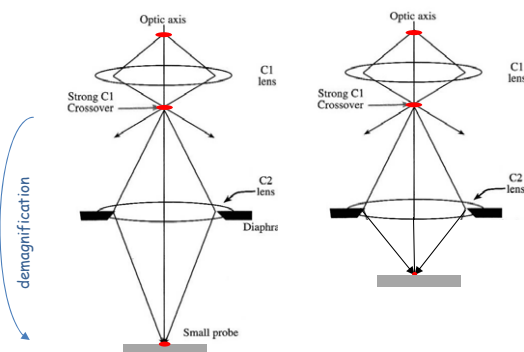
Spherical aberration as limiting factor for small probe sizes

Otto Scherzer:

Spherical aberration arises because the focus depends on the axial distance of the electron path. Physically this is a consequence of the fact, that lens fields have to satisfy the Laplace equation.

The aberration coefficient is substantially of the same order of magnitude as the **focal length**. If the specimen is immersed in the lens field, the minimum value of the aberration coefficient is **half of the focal length**. It diminishes when stronger lenses are used.

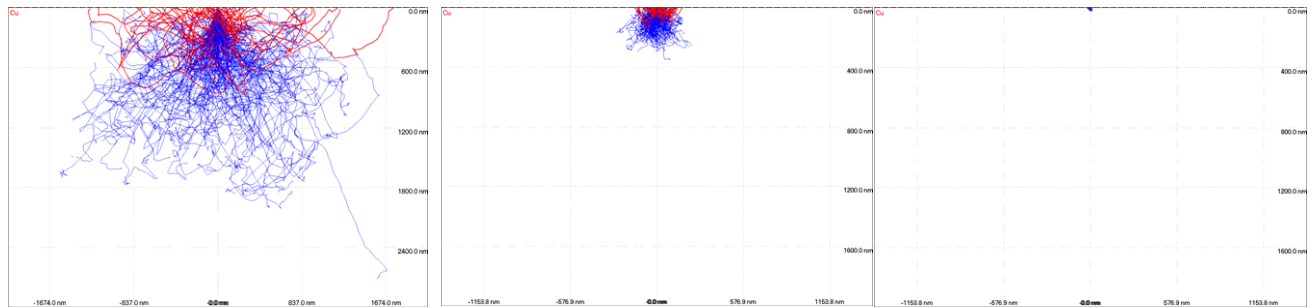
typical «2 condensor» lens system



strong fields, **small working distances**, immersion lenses

interaction of electrons with sample (Cu)

smaller delocalisation of signal creation



30kV

10kV

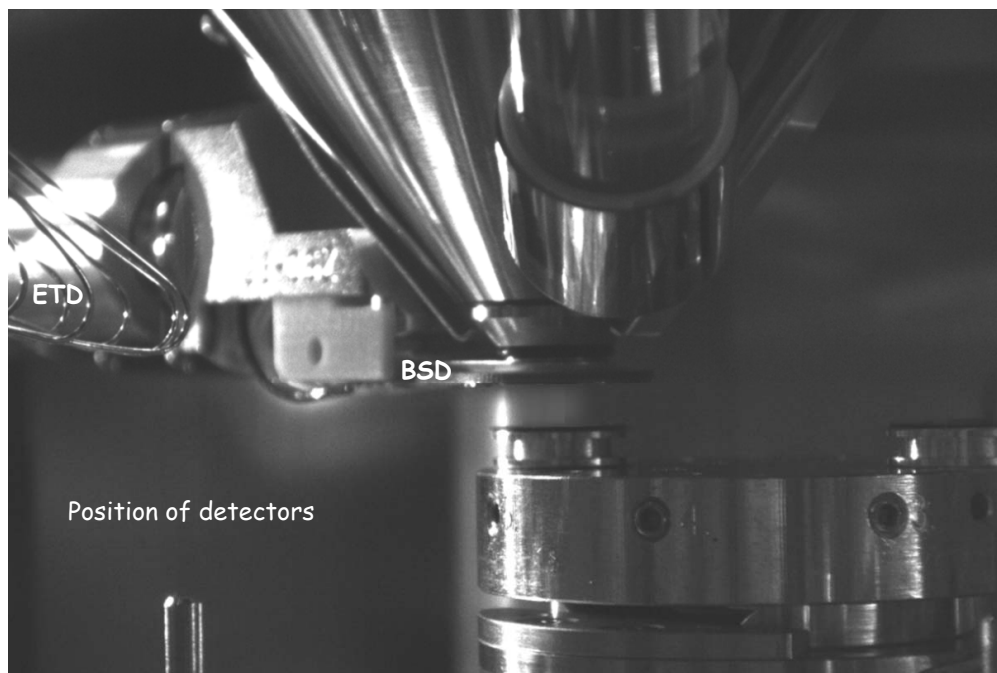
2kV

Low acceleration voltages !

Semestre automne 2024

Microscopie électronique: advanced SEM technology

Marco Cantoni



Mag = 206 X
100 μ m
Semestre aut

EHT = 2.00 kV
WD = 7.1 mm
Image Pixel Size = 1.340 μ m

Signal A = USB TV2
Aperture Size = 30.00 μ m
Stage at T = 0.0 °

Chamber Status = at HV
Chamber = 0.00e+00 Pa
Date : 16 Jan 2018



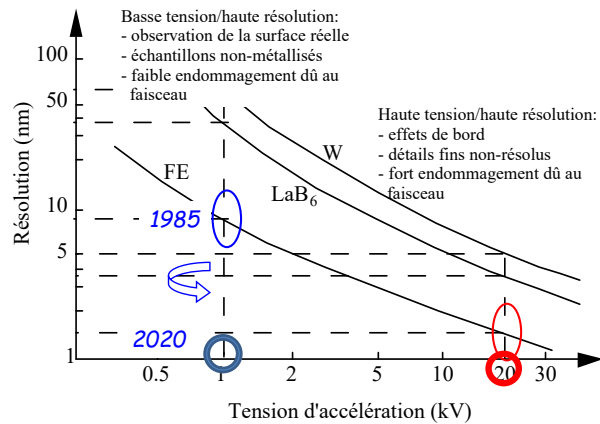
Latest generation of SEM

Electron optics:

Field emission guns, monochromators
beam boosters, beam deceleration,
Lens-design: In-lens, Semi-in-lens,
immersion lens
Short working distance

Detectors:

Everhard-Thornley (SE)
In-column (through the lens, in-lens,
"in-beam") SE detectors
Low Voltage BSE detection,
energy filtering (separation of
materials and topography contrast)



Analytical SEM:
SDD EDX detectors (high throughput, large collection angle)
High-speed EBSD detectors
Beam currents of several 100 nA

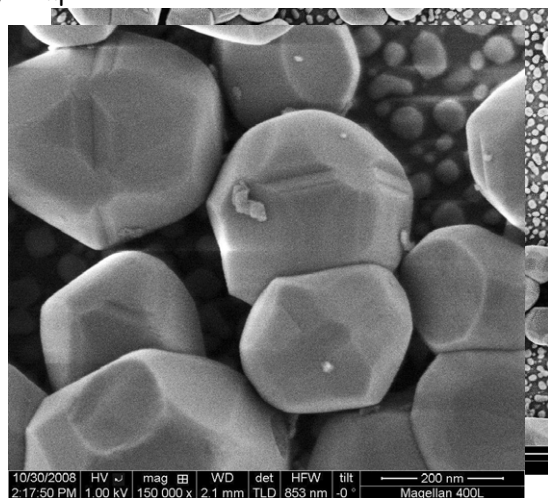
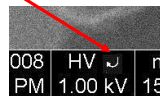
SEM low kV imaging

No specimen preparation needed: low voltage reduces charging effects
Low kV imaging of non-conducting, low density samples

Al₂O₃ Nano-crystals

Technology: stage bias
(beam deceleration between pole piece
and sample)

FEI Magellan
Operator: Ingo Gestmann
Samples: Marco Cantoni

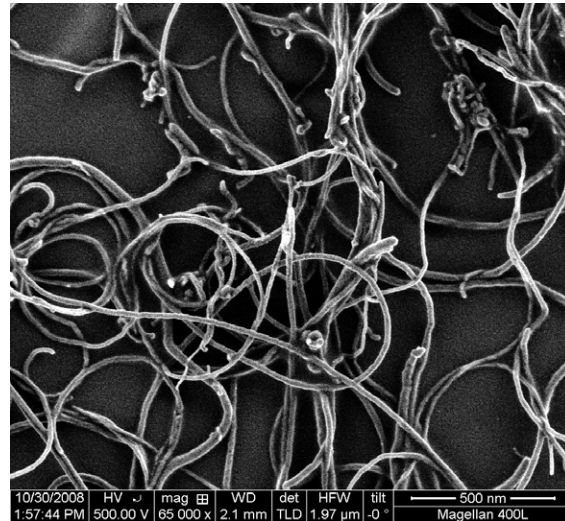


SEM low kV imaging

No specimen preparation needed:
Low kV imaging of low density samples

Carbon nano-tubes
(MWCT)

FEI Magellan
Operator: Ingo Gestmann
Samples: Marco Cantoni



Interaction volume in C



5kV
Electrons are transmitted through nano-tube
almost no interaction, very few SE!
almost invisible

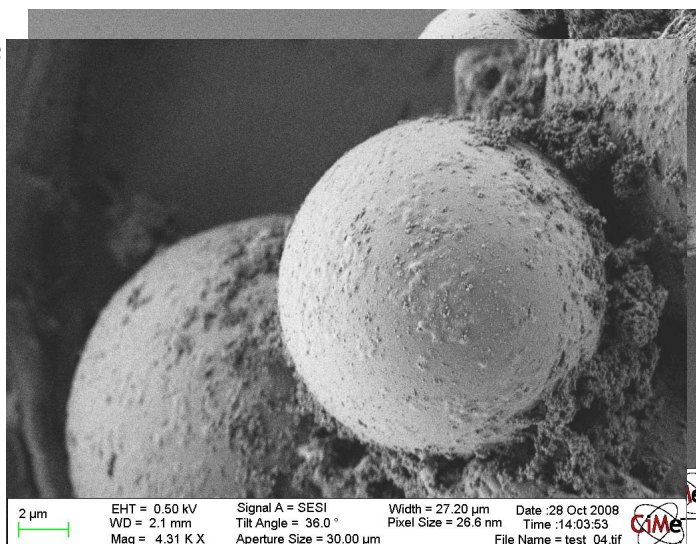
0.5kV
Electrons interact heavily with nano-tube:
Lots of SE

SEM low kV imaging

No specimen preparation needed:
Low kV imaging of non-conducting samples

Liquid filled
organic membranes

Zeiss Nvision 40
Marco Cantoni

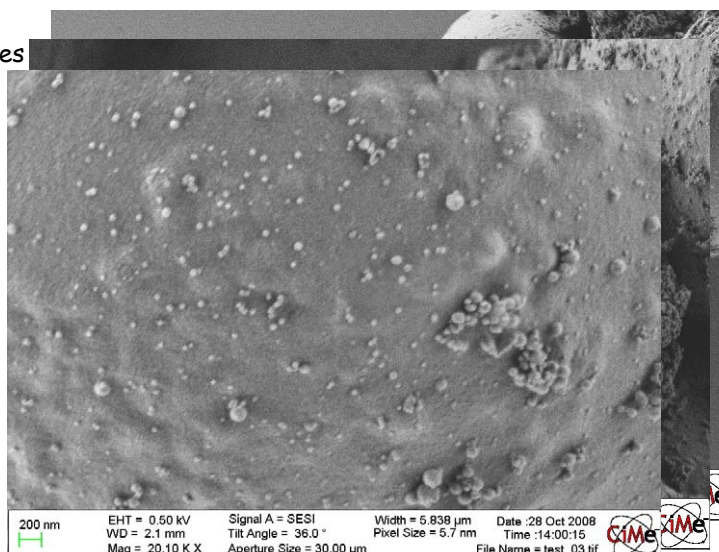


SEM low kV imaging

No specimen preparation needed:
Low kV imaging of non-conducting samples

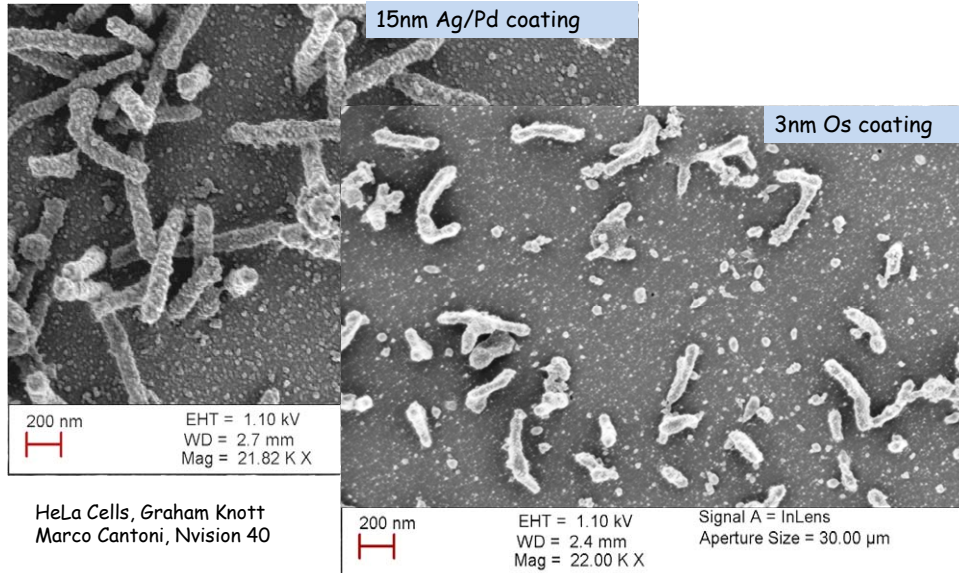
Liquid filled
organic membranes

Zeiss Nvision 40
Marco Cantoni



SEM low kV imaging

Purely organic specimen: non-conductive, low density: biological cells, thin (!) metal coating



MERLIN™ - Analytical power for the sub-nanometer world

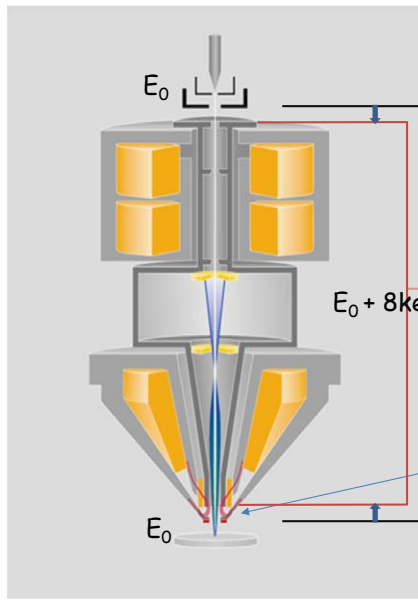


Gemini® II column

Low current configuration (Max. probe current 40 nA):

For high resolution investigations:

- 0.6 nm at 30 kV (STEM mode)
- 0.8 nm at 15 kV at optimal WD
- 1.4 nm at 1 kV at optimal WD
- 2.4 nm at 0.2 kV at optimal WD
- 3.0 nm at 20 kV at 10 nA @ WD = 8,5 mm



Beam "booster" technology

Electron optics operates with high energy beam inside the column

+ 8 keV

$E_0 + 8\text{keV}$

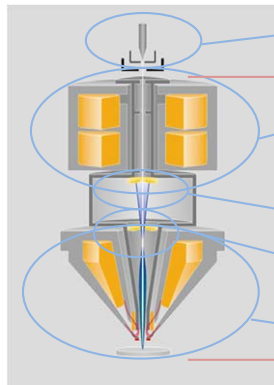
- 8 keV

E_0

- Beam Booster 8keV
- Brightness of the electron probe maintained for low landing energies

▪ GEMINI® II electro-static final lens

MERLIN™ - Analytical power for the sub-nanometer world -



- High stability field emitter cathode
- Maximum probe current 300 nA

- Double condenser lens
- Aperture independent probe current adjustment

- Beam Booster
- Brightness of the electron probe maintained for low landing energies

▪ Energy selective Backscatter detector (EsB)

▪ In-lens Secondary Electron detector

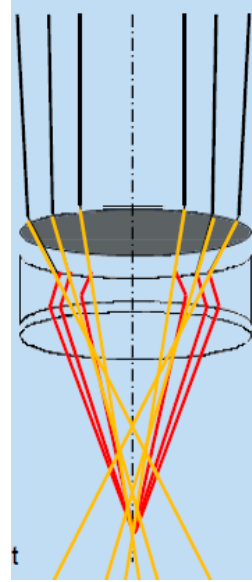
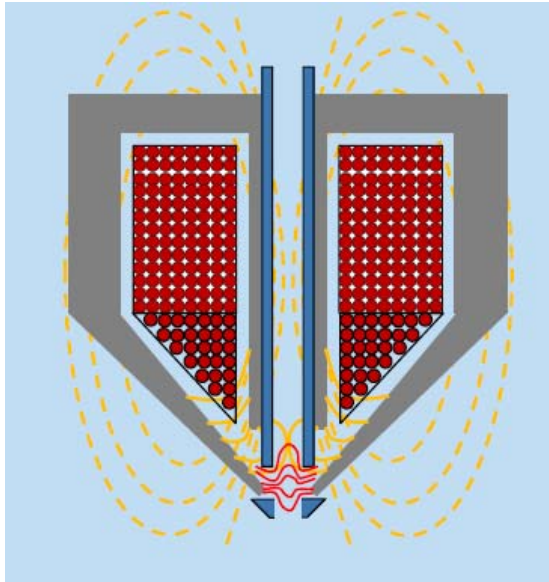
▪ GEMINI® II final lens



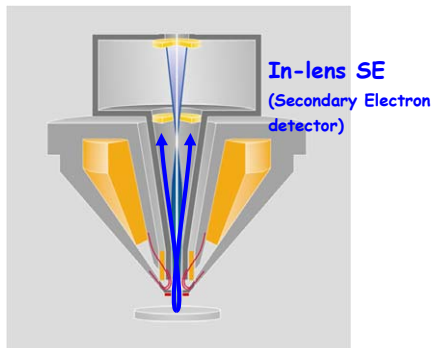
► GEMINI® II design "Complete" detection system

- Proven GEMINI® final lens design
- New double condenser lens for highest probe current possibilities (300 nA)
- Beam booster technology maintains brightness of all electron probes including low landing energies
- True on-axis in-lens SE and BSE detectors

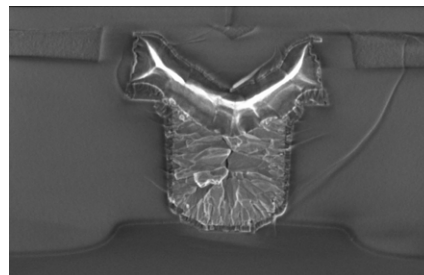
« gemini »-lens:
combination of magnetic (convergent) and electro-static (divergent = neg Cs) lens



MERLIN™
- Analytical power for the sub-nanometer world -



Topographical information
with on-axis in-lens SE detector



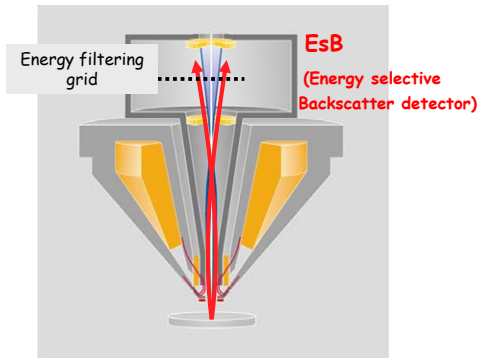
GEMINI® II design
► **Complete detection system**

Complete detection system:

- Unique double in-lens detection
- Acquisition of pure secondary and backscatter electron signals
- Separation of compositional, topographical and crystalline surface information

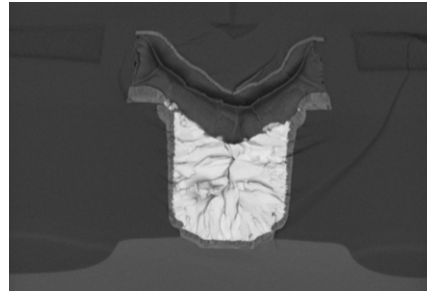
MERLIN™

- Analytical power for the sub-nanometer world -



Compositional contrast

with on-axis in column EsB detector



GEMINI® II design ► Complete detection system

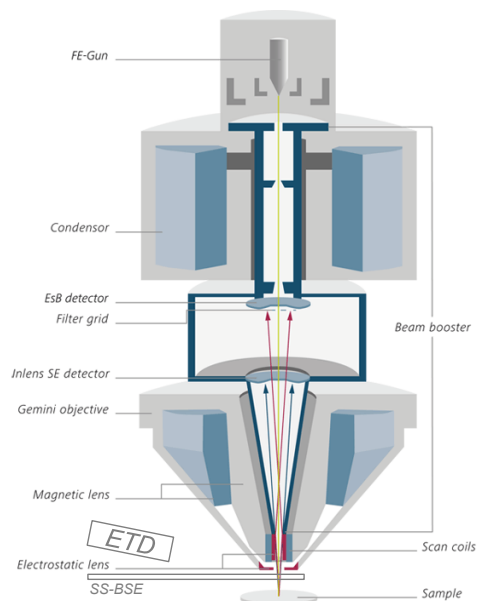
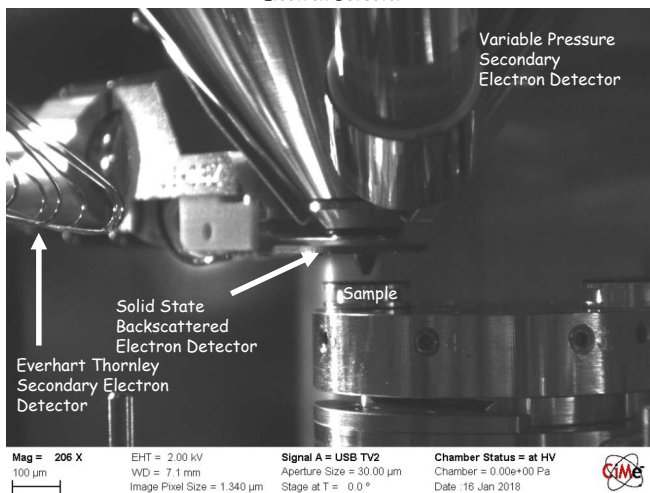
Complete detection system:

- Unique double in-lens detection
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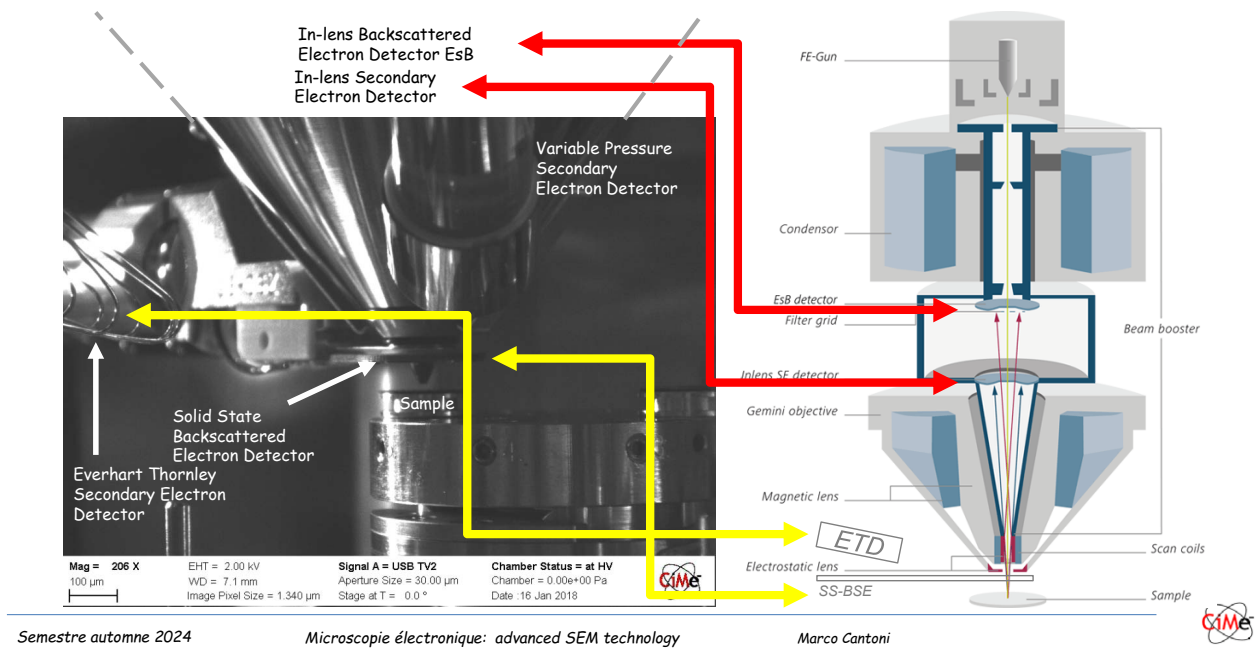
Secondary Electrons and Backscattered Electrons

In-lens Backscattered
Electron Detector EsB

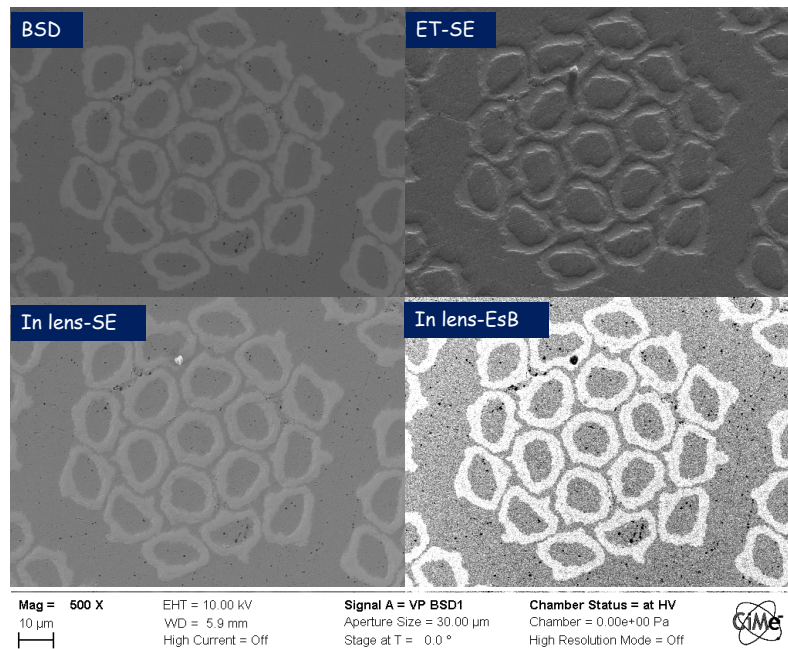
In-lens Secondary
Electron Detector



Secondary Electrons and Backscattered Electrons



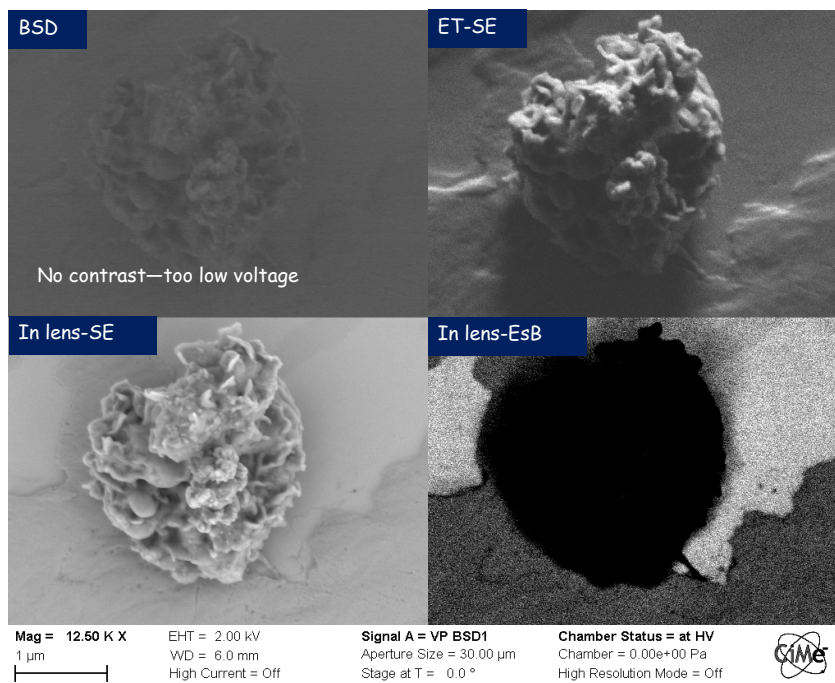
Secondary Electrons (SE) and Backscattered Electrons (BSE) images @10kV



Soild state
BSE detector:
No efficiency

2kV

In-column
SE-detector:
"no illumination"
effect



ETD:
"illumination" effect

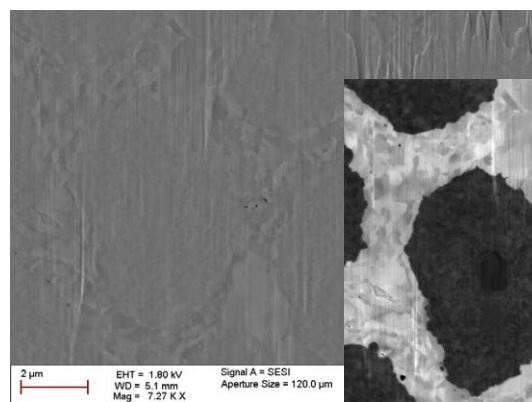
Semestre automne 2024

Microscopie électronique: advanced SEM technology

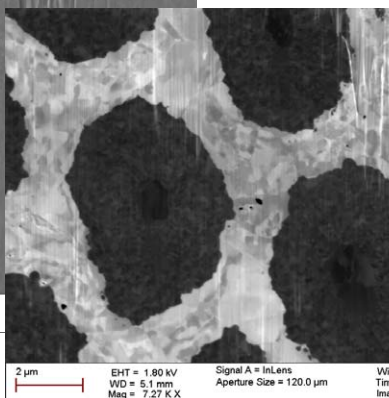
Marco Cantoni



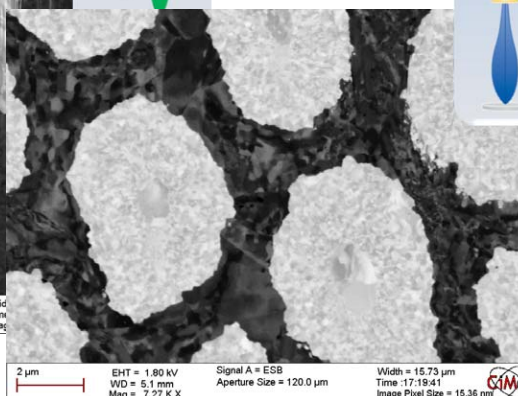
Surface contrast



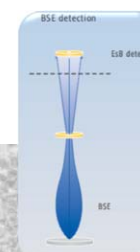
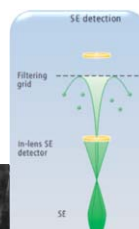
in-chamber SE
ET-detector
topography contrast



in-column
"InLens", SE-detector
"electronic" property contrast



in-column EsB, "energy-selective" BSE-detector
mass-density, "composition" contrast



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Microscopie électronique: advanced SEM technology

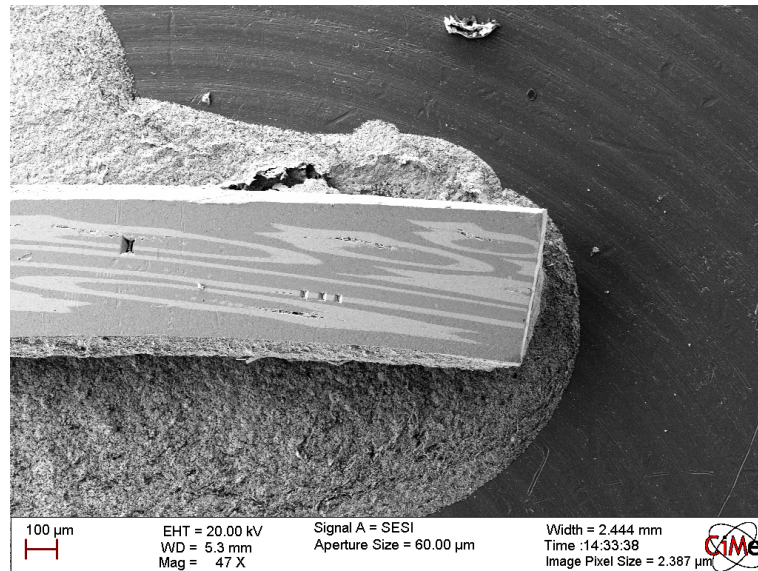
Marco Cantoni



SEM low kV imaging

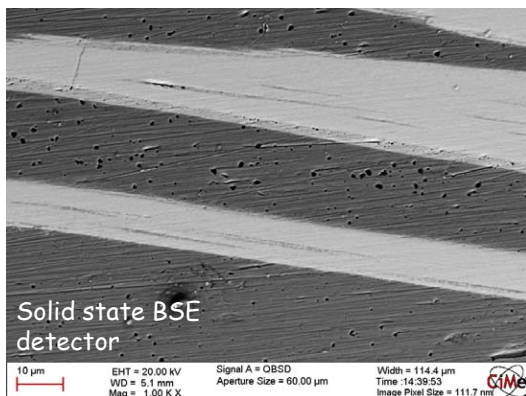
"Easy" sample:

SC wire
 Nb_3Sn in
Cu matrix



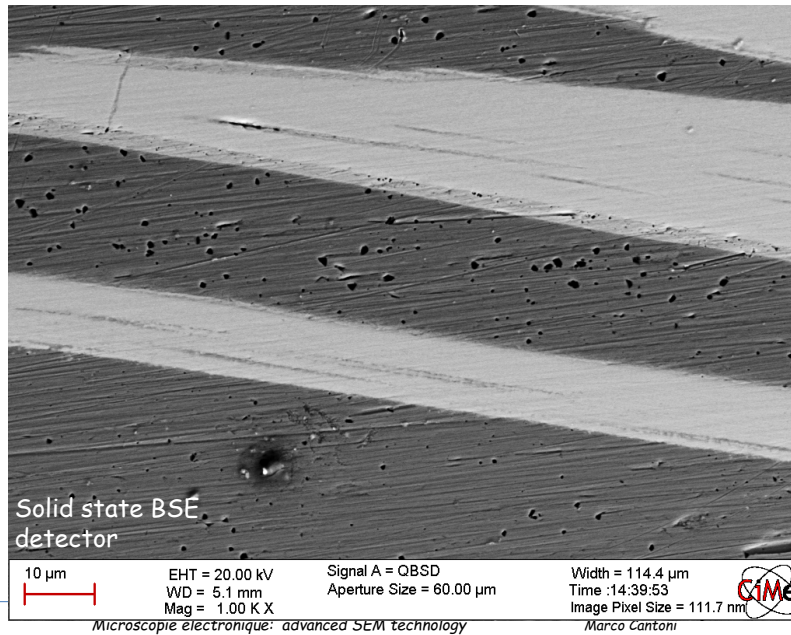
SE imaging

"Easy" samples:

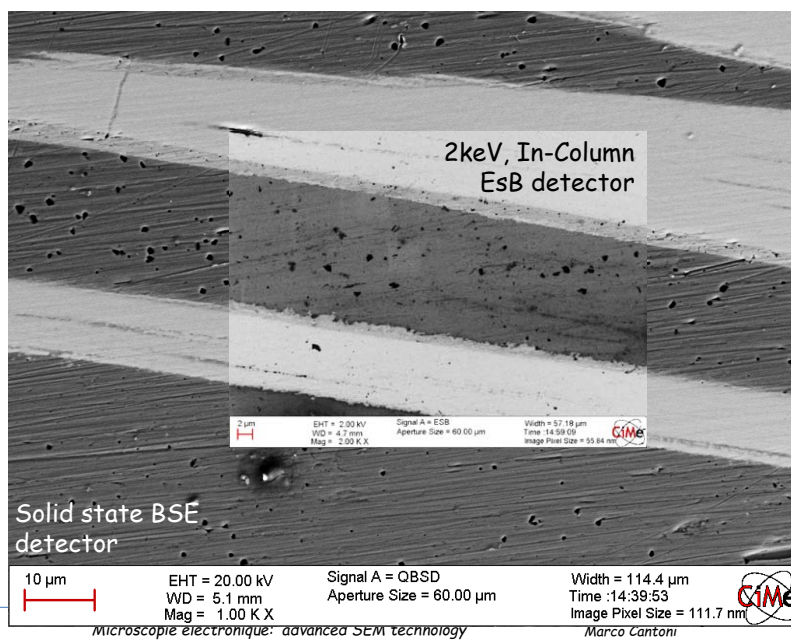


Polished sample: almost no topography !

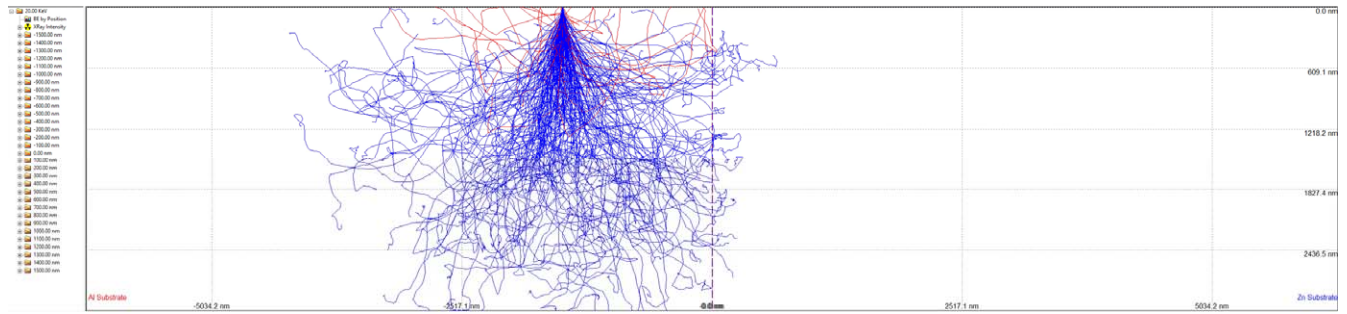
low kV BSE imaging



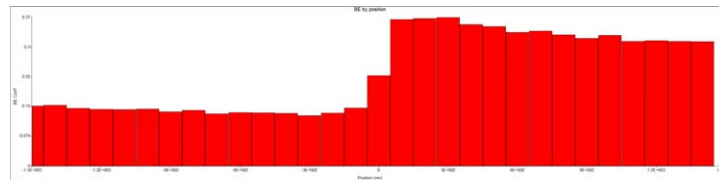
low kV BSE imaging



Simulation of interaction volumes across interface Al (left) and Zn (right) 10 kV



Al Zn

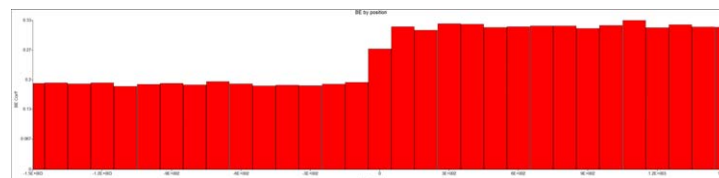


BSE signal

Simulation of interaction volumes across interface Al (left) and Zn (right) 2 kV

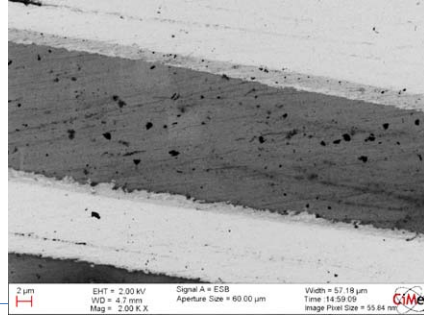
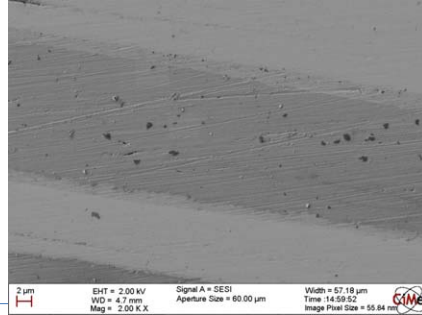
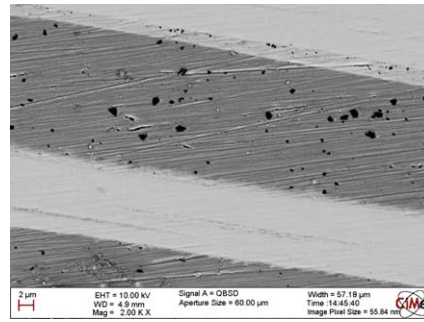
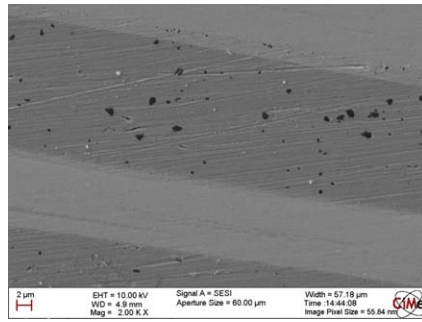


Al Zn



BSE signal

SEM low kV imaging "Easy" samples:



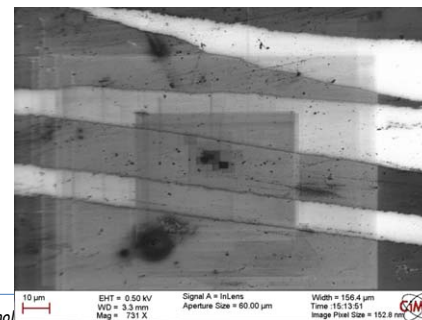
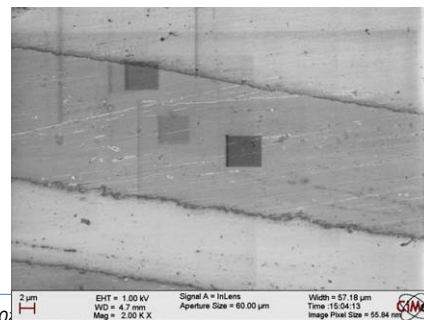
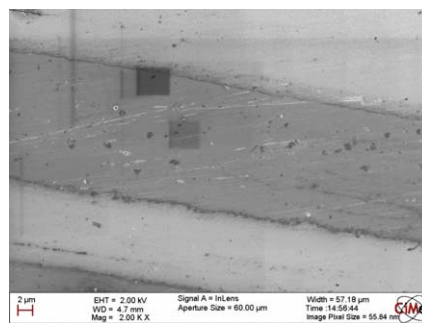
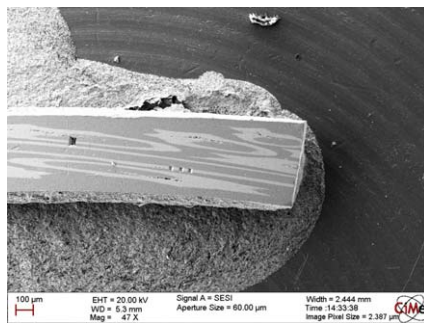
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Microscopie électronique: advanced SEM technology

Marco Cantoni



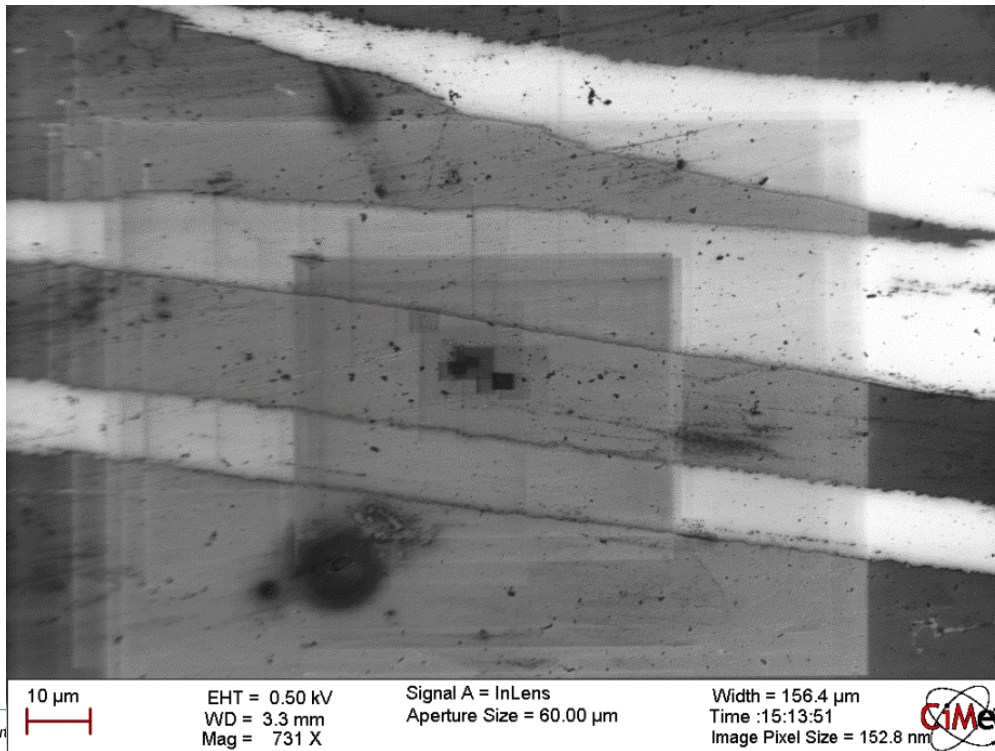
low kV imaging: surface contamination !



Semestre automne 2024

technol





Semestre au



SEM low kV imaging

Contamination by hydro-carbons

- contamination "spoils" imaging at low kV
- How to avoid (at CIME):
 - plasma cleaning of the sample before inserting (oxygen plasma destroys hydro-carbons)
 - Plasma clean the chamber at each insertion (multi-user environment)



first HR-SEM at CIME

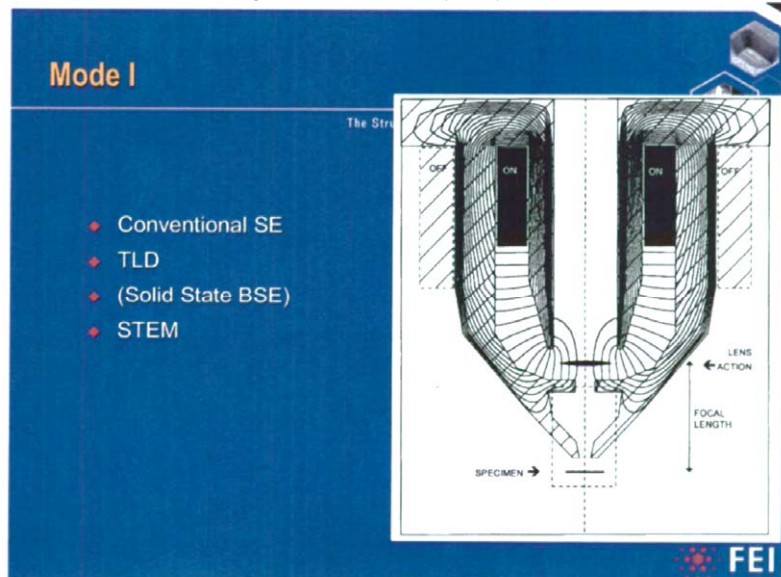


- Starting point: XL-30 SFEG SIRION (since 2001)
- First semi-in-lens HR-SEM:
in-lens (through the lens) detection of SE and BSE

Resolution in UHR mode: 1.5 nm at 10 kV (or higher); 2.5 nm at 1 kV

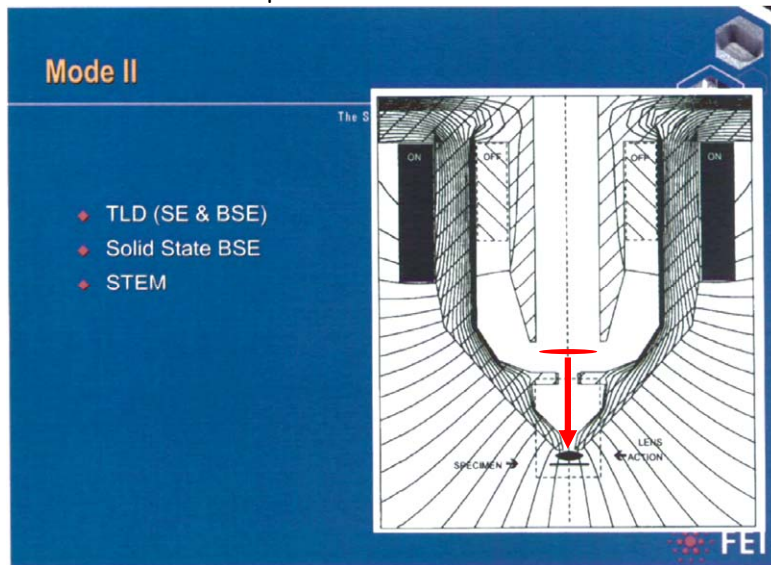
Conventional Mode

magnetic field inside pole-piece



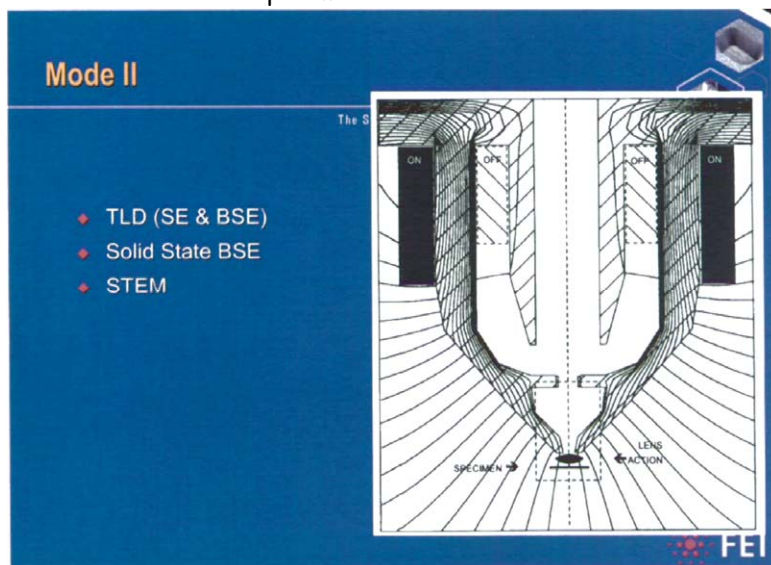
Immersion lens

specimen inside "lens"

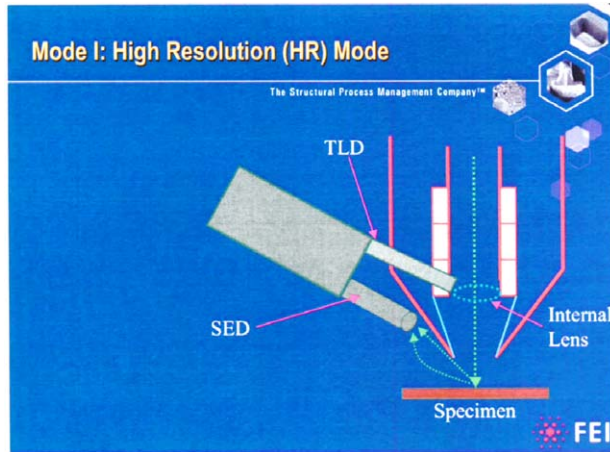


Immersion lens

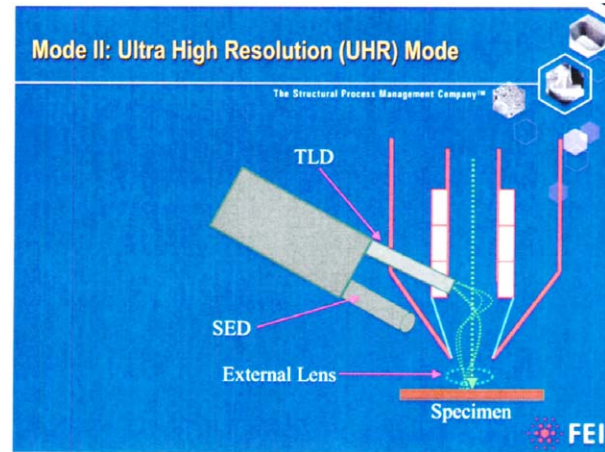
specimen inside "lens"



detection of SE



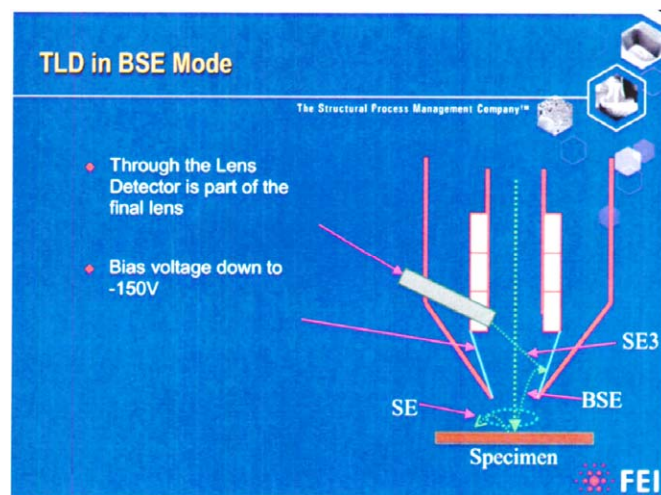
Non-immersion mode



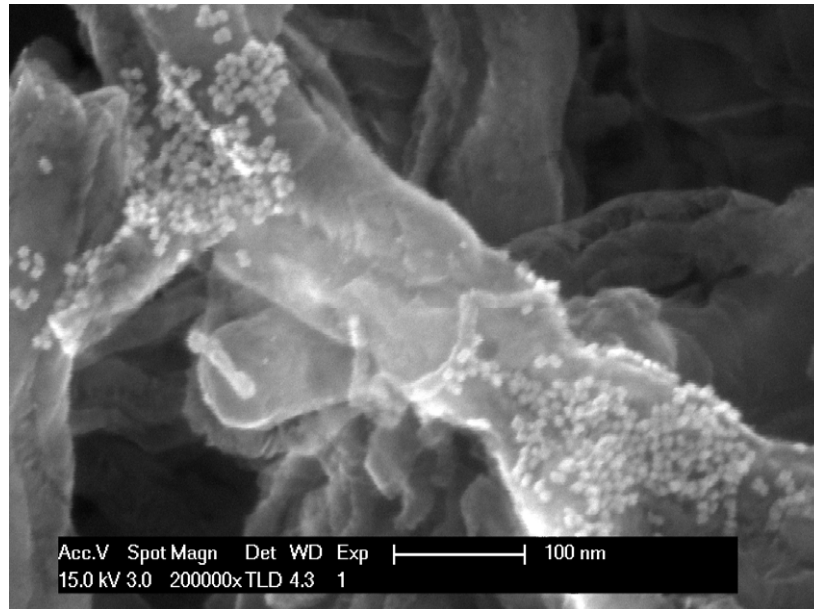
Immersion mode

detection of BSE

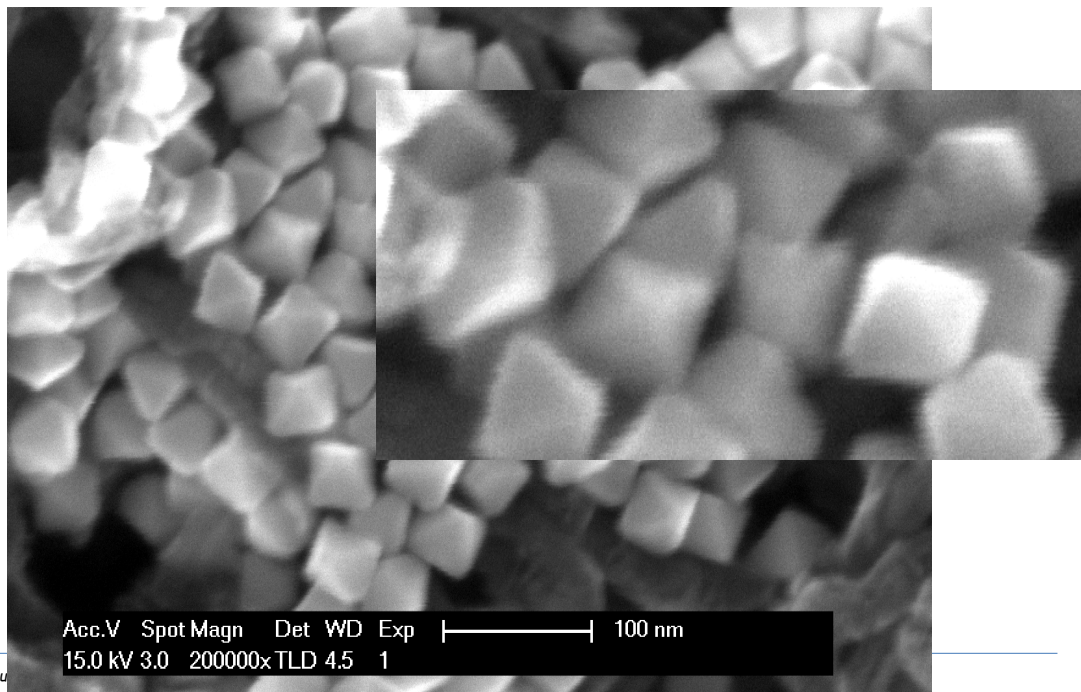
- Bias: repulsion of SE-1 and SE-2 from the sample
- BSE enter the column and hit the inside of the column -> SE-3
- Choice: either SE or BSE mode !!!



Pd catalyst particles on carbon fibres



"flagging", electronic noise at high magnification



Best "SEM" at EPFL: FIB Nvision@CIME, beam booster technology



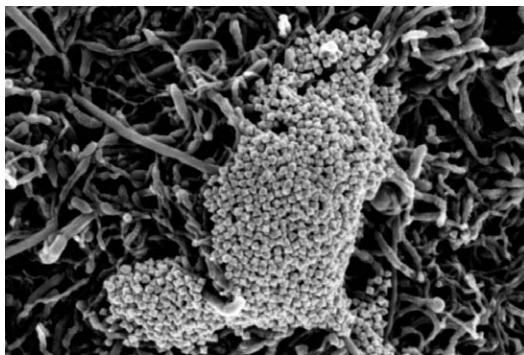
Semestre au

20 nm

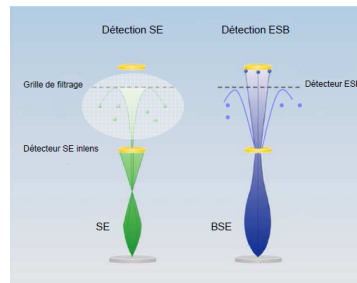
EHT = 1.50 kV
WD = 2.0 mm
Mag = 226.38 K X

Signal A = InLens
Aperture Size = 30.00 μ m

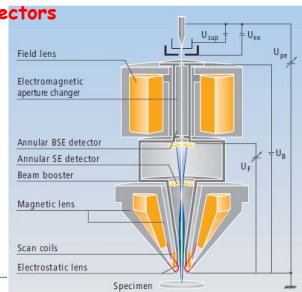
Width = 505.0 nm
Time :10:21:20
Image Pixel Size = 493.2 pm



100 nm EHT = 2.00 kV Signal A = InLens Width = 2.733 μ m
WD = 4.8 mm Aperture Size = 30.00 μ m Time :9:58:54
Mag = 41.83 K X Image Pixel Size = 2.669 nm

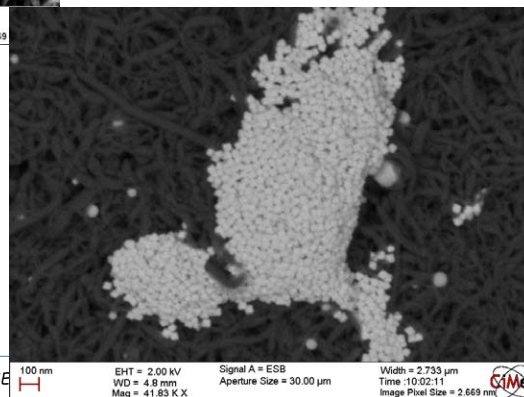


Two different contrasts with one scan: parallel
detectors



Semestre automne 2024

microscopie électronique: advanced SE



100 nm EHT = 2.00 kV Signal A = ESB Width = 2.733 μ m
WD = 4.8 mm Aperture Size = 30.00 μ m Time :10:02:11
Mag = 41.83 K X Image Pixel Size = 2.669 nm





Electron beam resolution

- (site survey required to determine attainable resolution)
- Resolution @ optimum WD
 - 0.8 nm at 15 kV
 - 0.8 nm at 2 kV
 - 0.9 nm at 1 kV
 - 1.5 nm at 200 V
- Resolution @ coincident point
 - 0.8 nm at 15 kV
 - 0.9 nm at 5 kV
 - 1.2 nm at 1 kV

Maximum horizontal field width

- E-beam: 1.5 mm at beam coincident point (WD 4 mm)

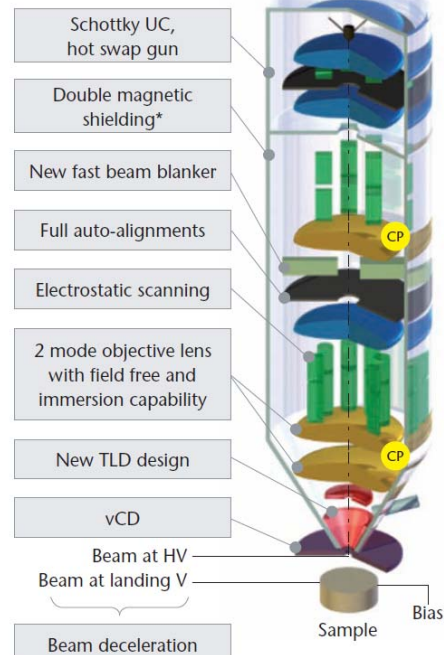
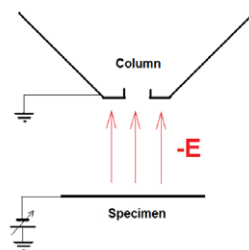
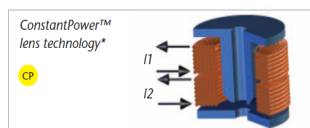
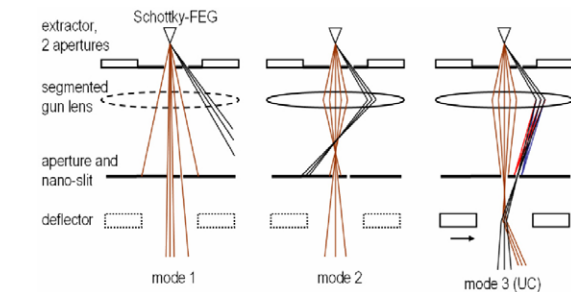
Landing energy range

- 50 V – 30 kV

Probe current

- E-beam: 1 pA to 22 nA

Monochromator (Uni-Colour mode)



2 mode detector
(requires switching conditions)
conversion of BSE into SE (SE-3)

