3. "advanced" SEM technology and trends

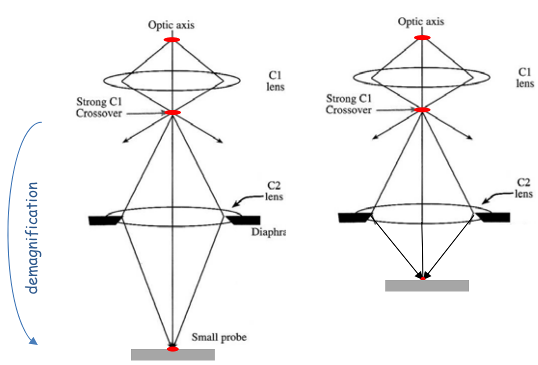
SEM

- Technology for low voltage imaging (electron optics, "in-column" detectors)
- Condition of the surface, coatings, plasma cleaning
- Low voltage BSE imaging ?
- Examples

Spherical aberration as limiting factor for small probe sizes

typical «2 condensor» lens system

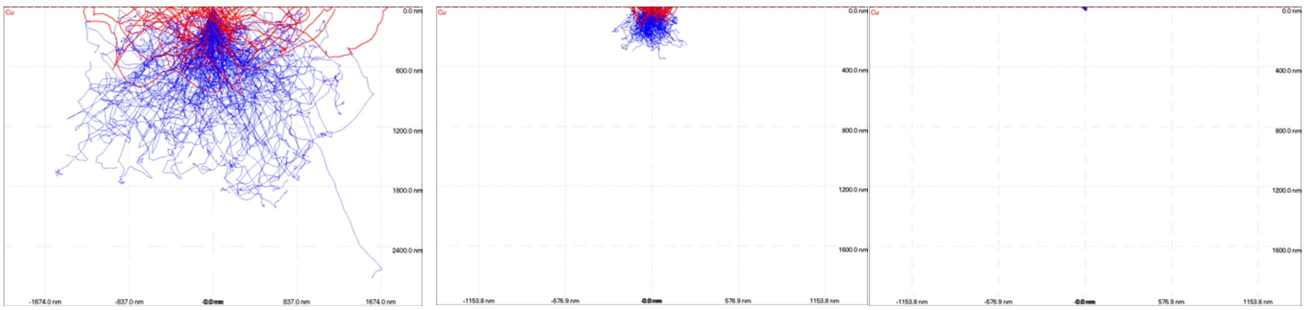
Otto Scherzer:
Spherical aberration arises because the focus depends on the axial distance of the electron path. Physically this is a consequence of the fact, that lens fields have to satisfy the Laplace equation.
The aberration coefficient is substantially of the same order of magnitude as the **focal 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.



strong fields, small working distances, immersion lenses

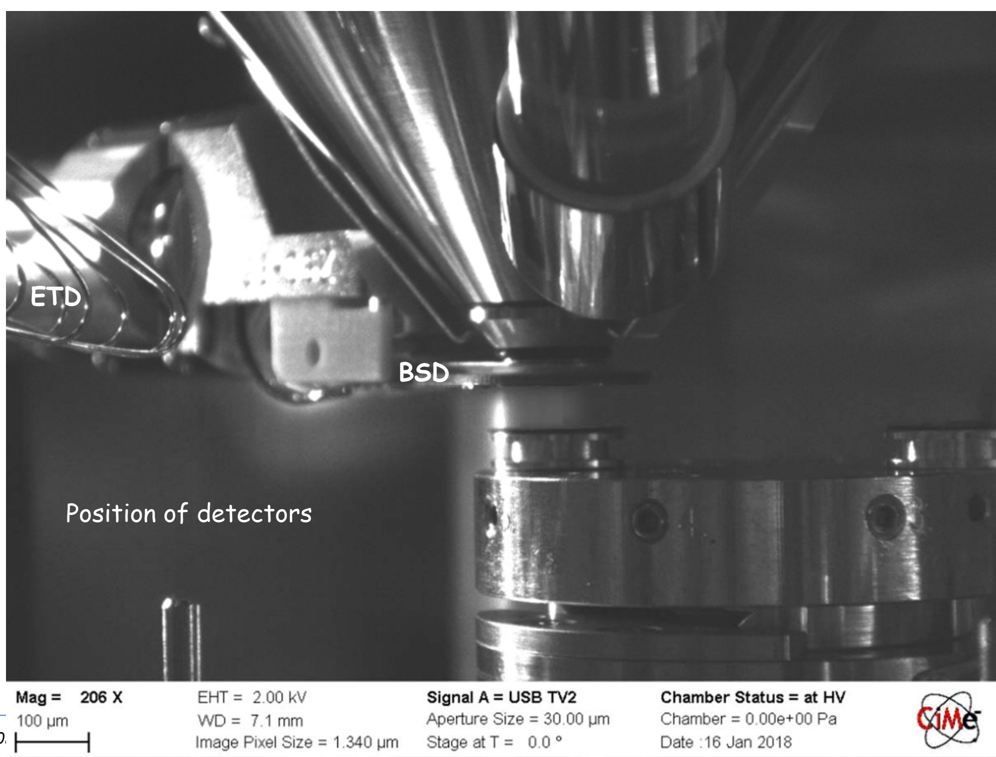
Interaction of electrons with sample (Cu)

smaller delocalisation of signal creation



30kV 10kV 2kV

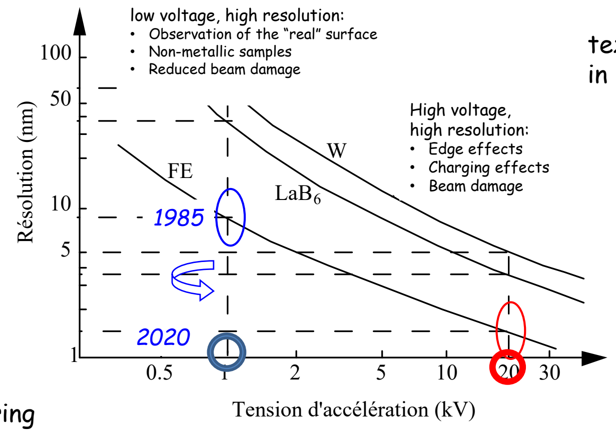
Low acceleration voltages !



Evolution of resolution in SEM

Electron optics
Field emission gun, monochromators
Lens-design:
short working distance
in-lens, semi-in-lens, immersion lens
beam boosters, beam deceleration,

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



text book in 2000

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

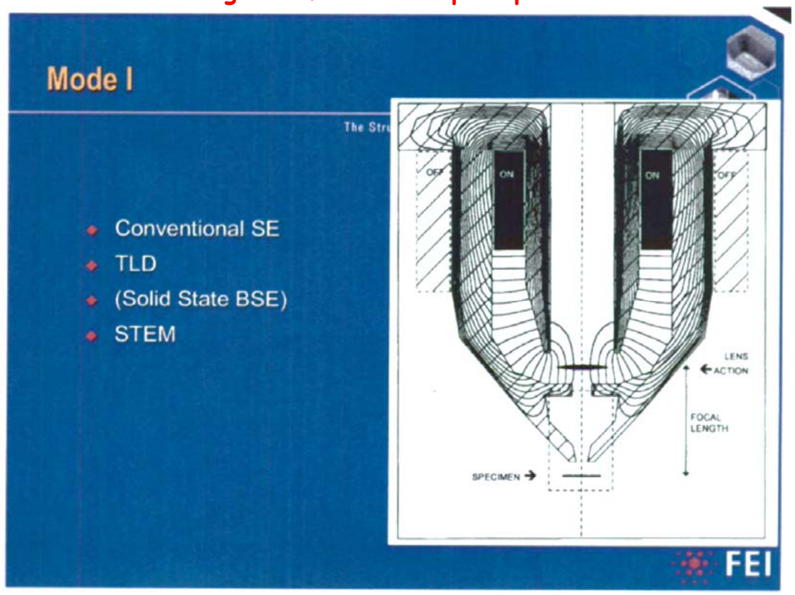
first generation of immersion lens at CIME

- XL-30 SFEG SIRION (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

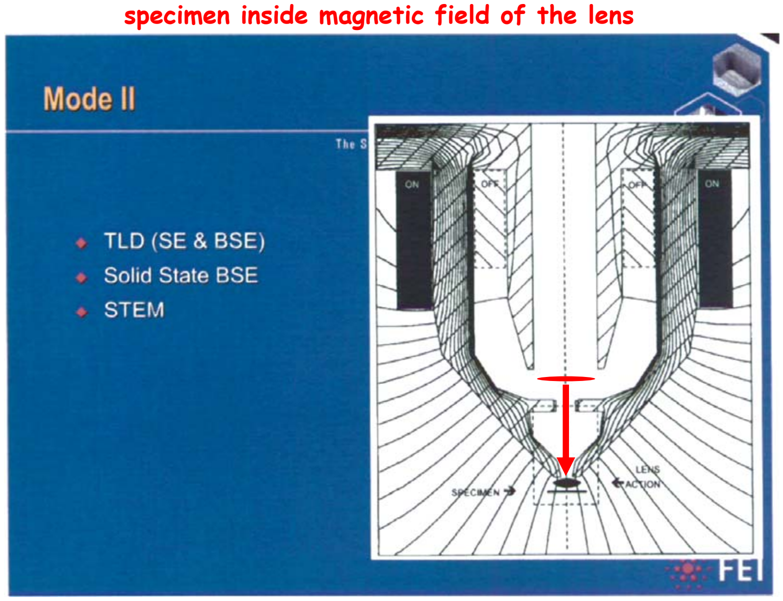
Conventional Mode

magnetic field inside pole-piece



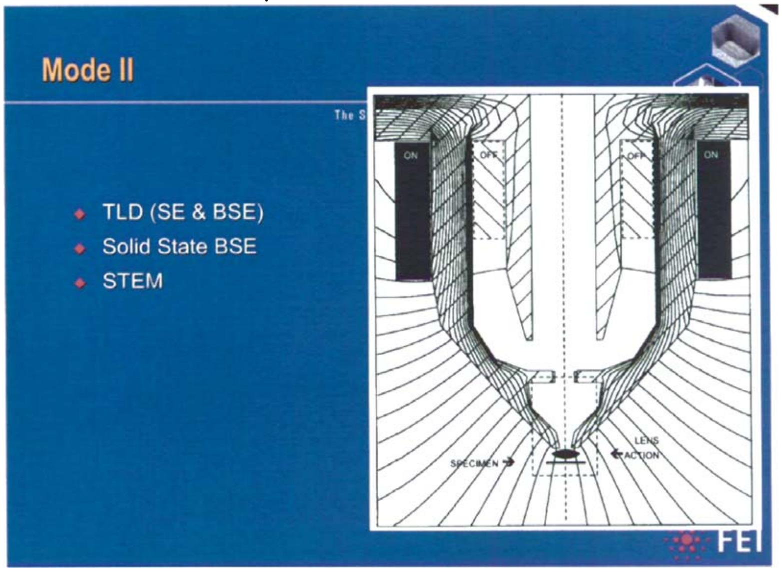
Immersion lens

specimen inside magnetic field of the lens



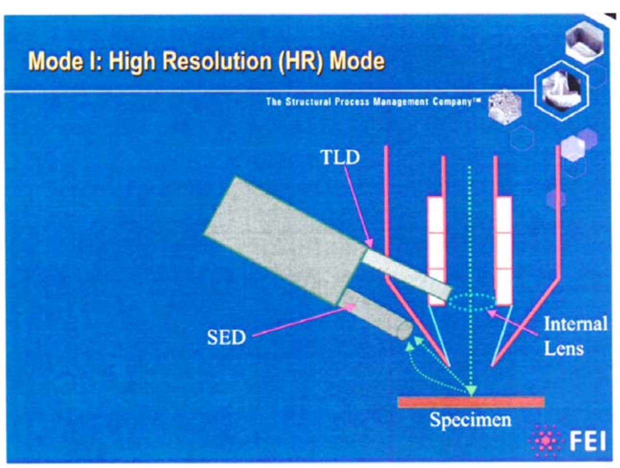
Immersion lens

specimen inside "lens"

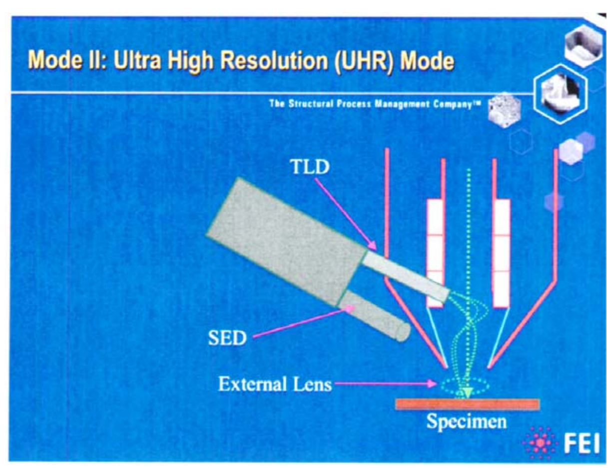


Detection of SE

low energy (secondary) electrons
trapped by magnetic field



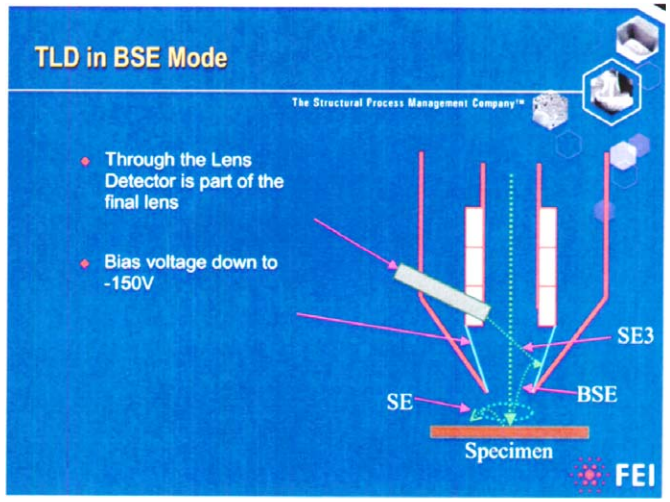
Non-immersion mode

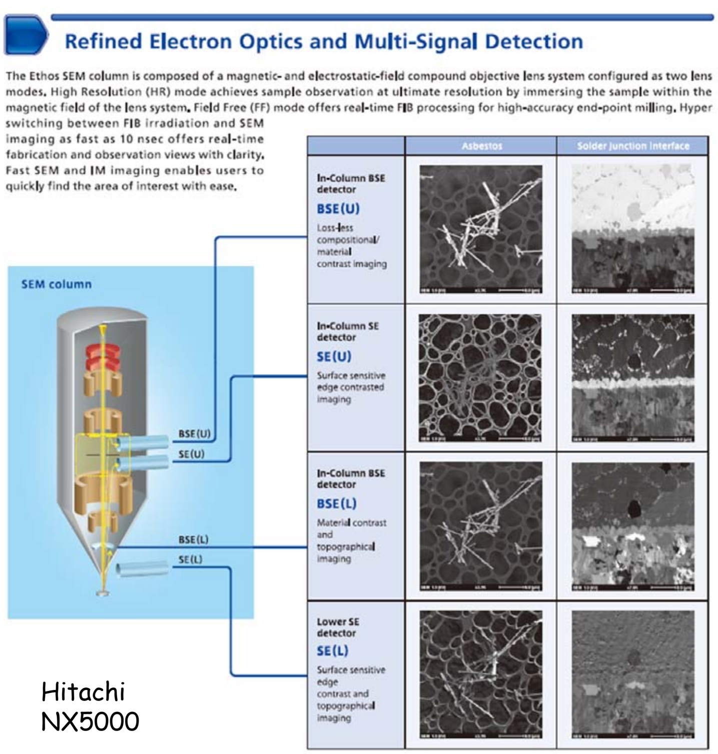


Immersion mode

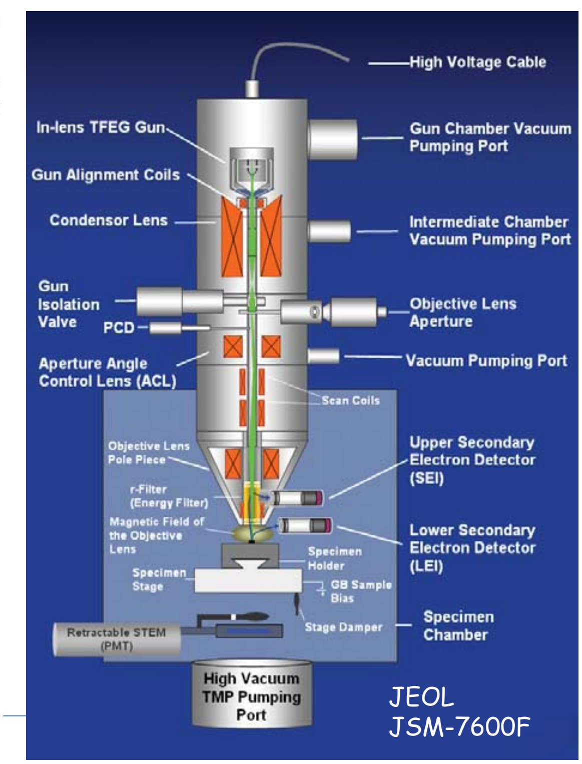
Detection of BSE

- Negative Bias in pole piece: 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 !!!

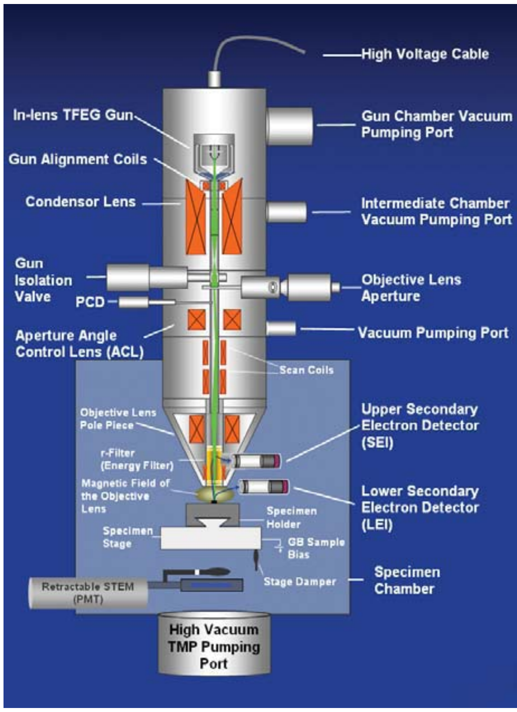


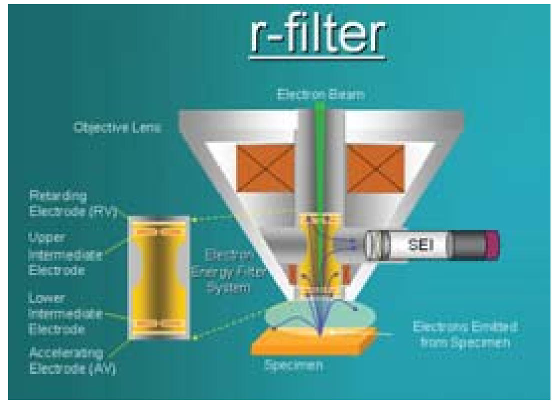


Hitachi NX5000



JEOL JSM-7600F





MERLIN™ – Analytical power for the sub-nanometer world

Gemini® II column

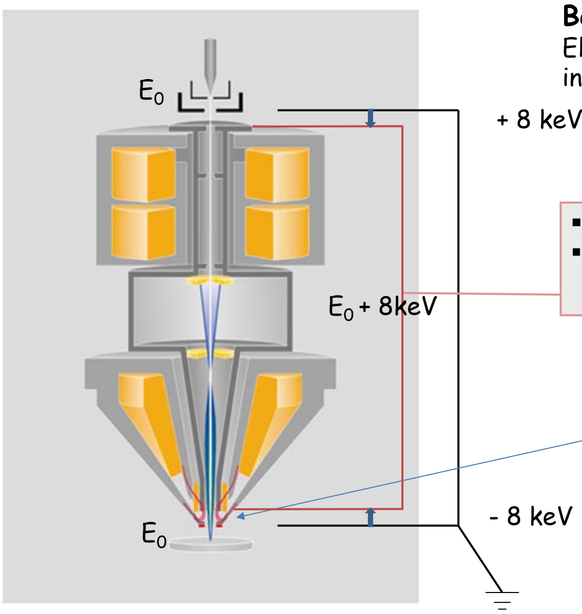
Low current configuration (Max. probe current 40 nA):

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

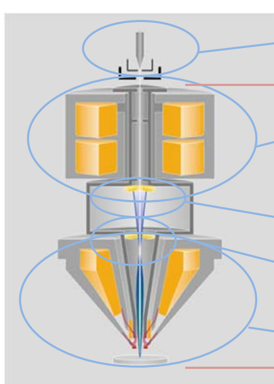
Electron optics operates with high energy beam inside the column



- 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)

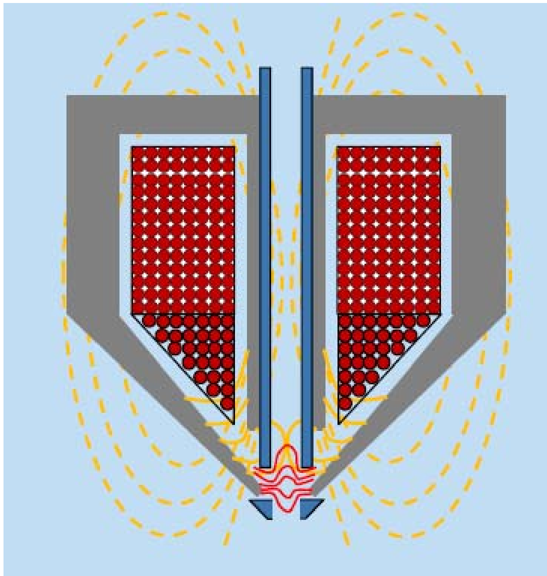
- In-lens Secondary Electron detector

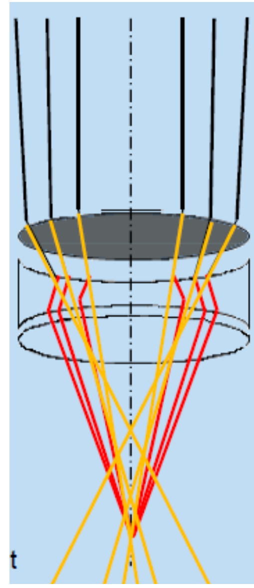
- GEMINI® II final lens

▶ GEMINI® II design
Complete detection
ystem

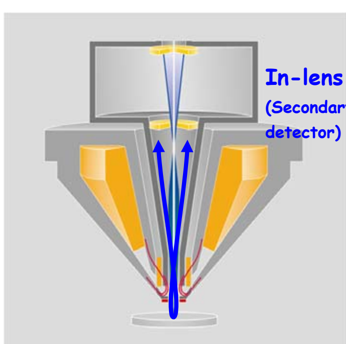
- Proven GEMINI® final lens design
- New double condenser lens for highest probe current possibilities (300 nA)
- Beam booster technology maintains brightness of all electron probes including low landing energies
- True on-axis in-lens SE and BSE detectors

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

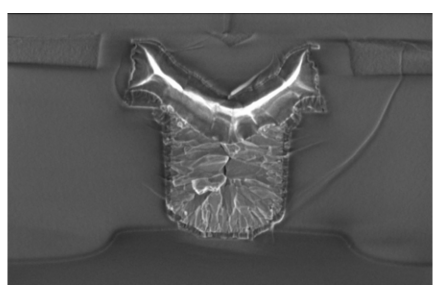




MERLIN™
– Analytical power for the sub-nanometer world –



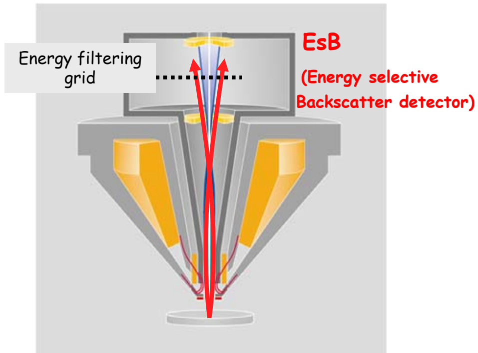
Topographical information
with on-axis in-lens SE detector



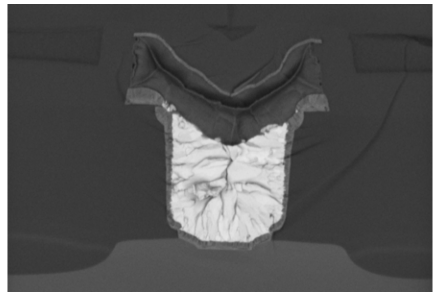
GEMINI® II design
► Complete detection system

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 –



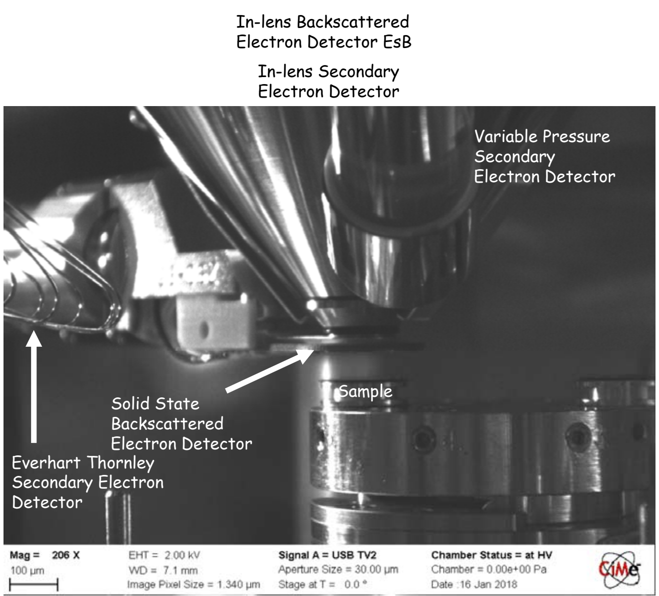
Compositional contrast
with on-axis in column EsB detector

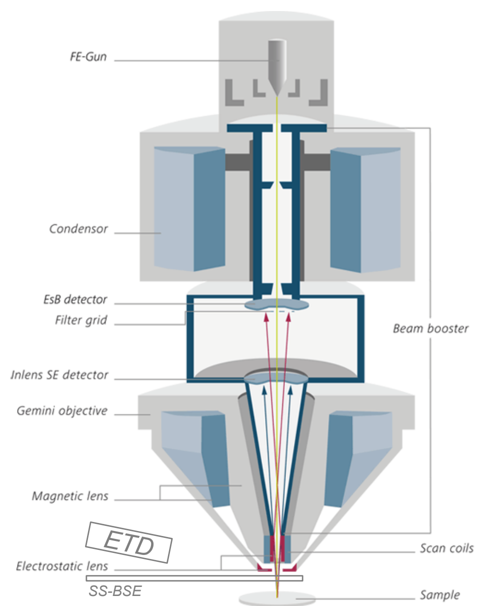


GEMINI® II design
► **Complete detection system**

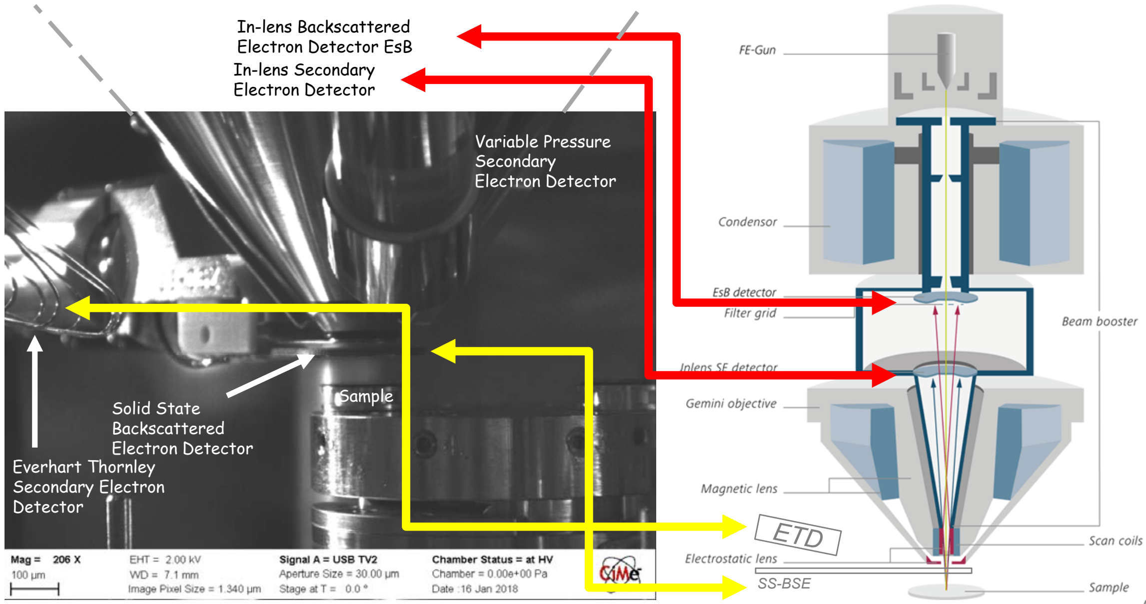
Complete detection system:
- Unique double in-lens detection
- Acquisition of pure secondary and backscatter electron signals
- Separation of compositional, topographical and crystalline surface information

Secondary Electrons and Backscattered Electrons

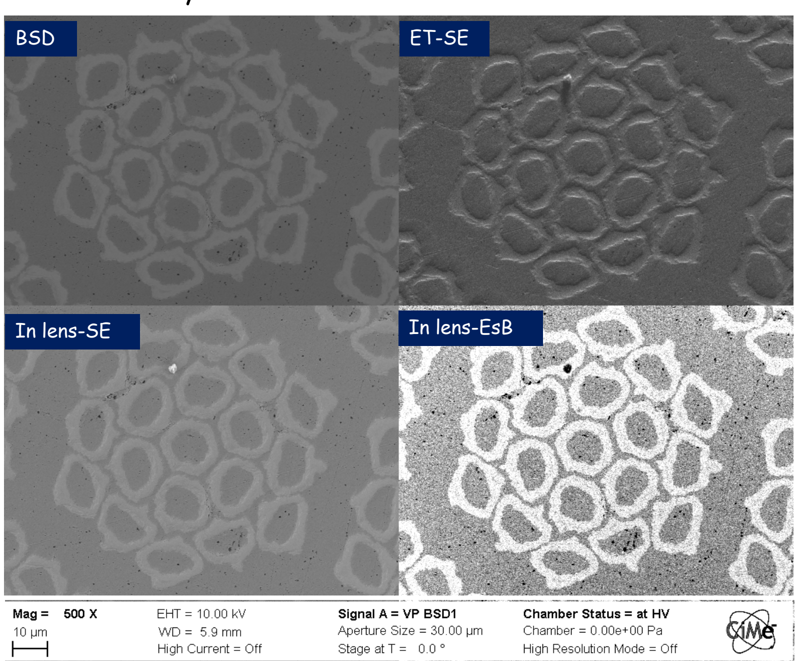




Secondary Electrons and Backscattered Electrons



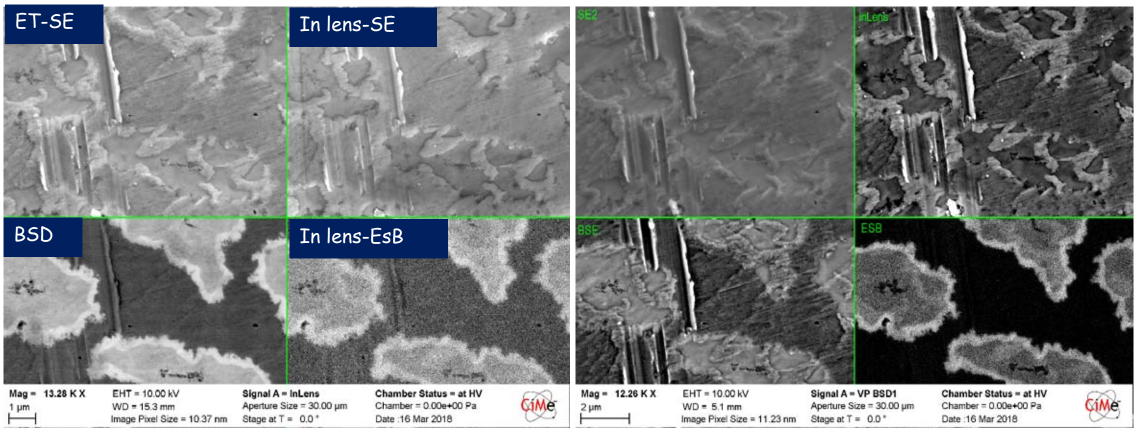
Secondary Electrons and Backscattered Electrons



Secondary Electrons and Backscattered Electrons

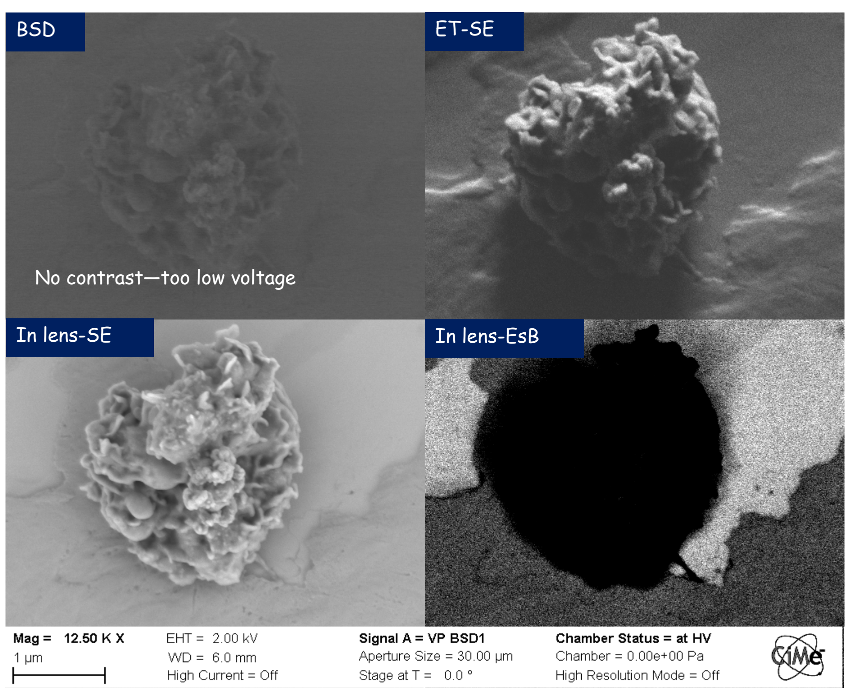
WD of 15.3 mm

WD of 5.1 mm



Shorter work distance improves spatial resolution of fine topographical features (But at lower depth of field!)

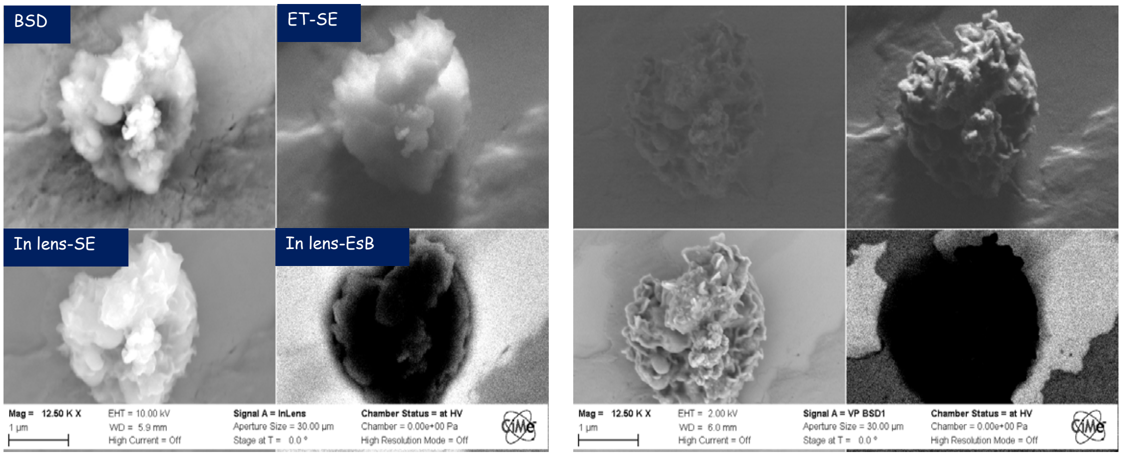
topography shadowing



mass-density

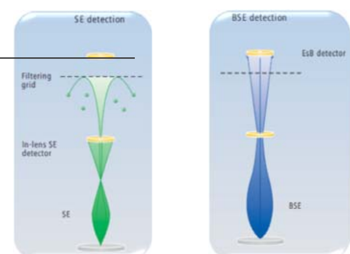
topography

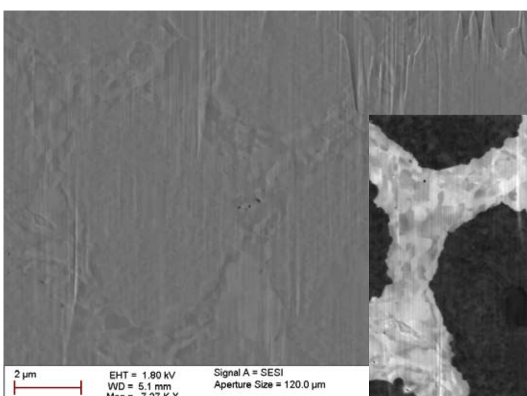
10 kV   2 kV



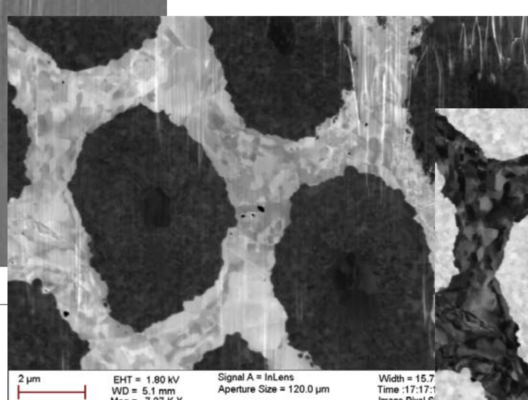
Voltage has 2 important effects on image contrast
1) Size of interaction volume
2) Detector sensitivity/energy selectivity

“different detectors-different contrast”

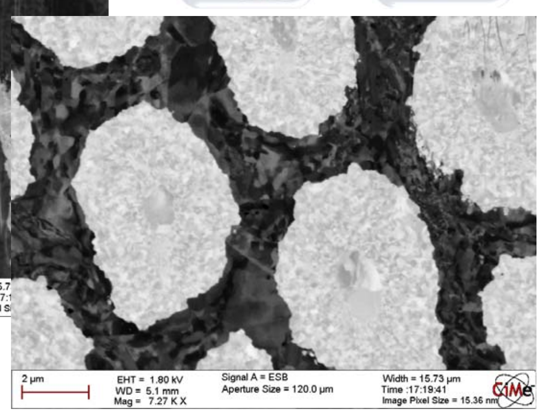




in-chamber, ET-detector (SE)



in-column, “InLens” SE-detector



in-column, “energy-selective” EsB (BSE) detector

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)

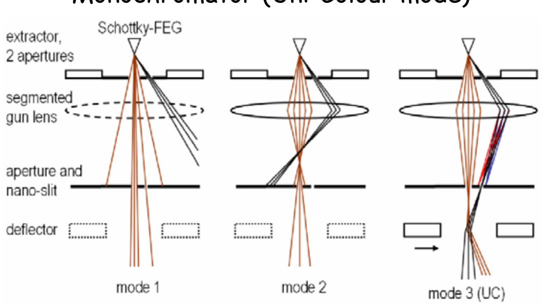
Landing energy range

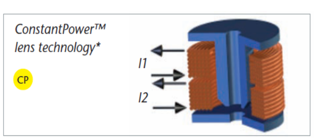
- 50 V – 30 kV

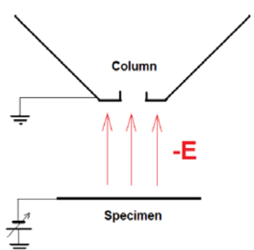
Probe current

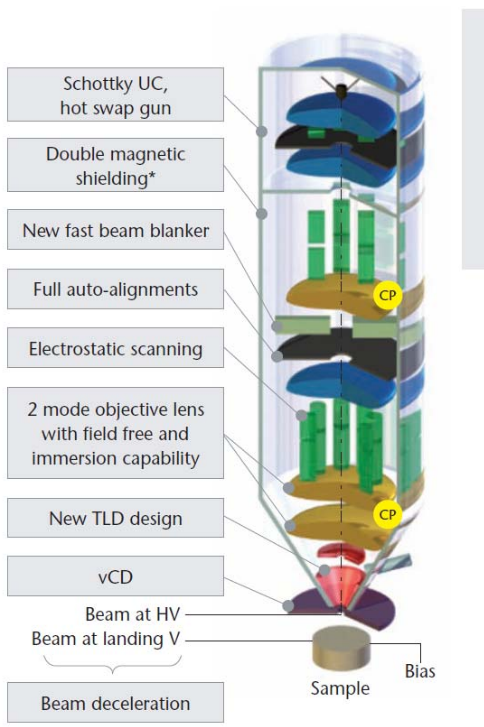
- E-beam: 1 pA to 22 nA

Monochromator (Uni-Colour mode)

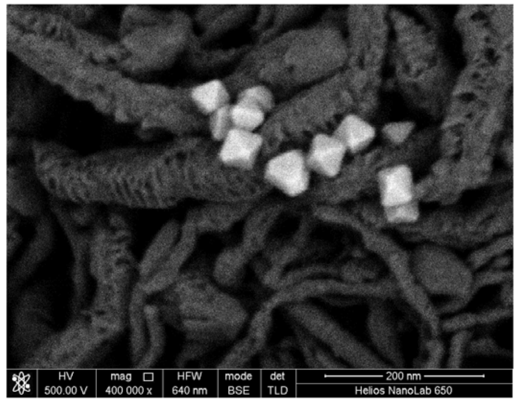


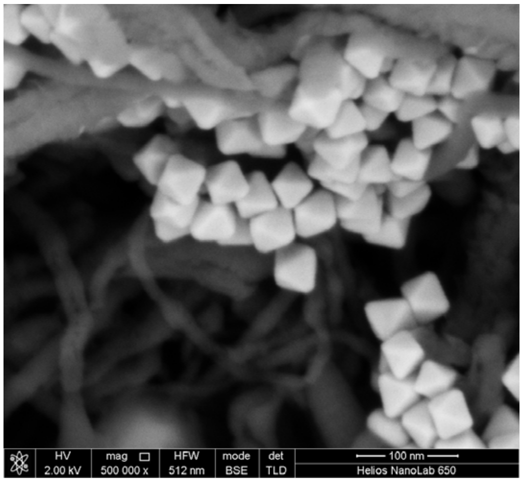


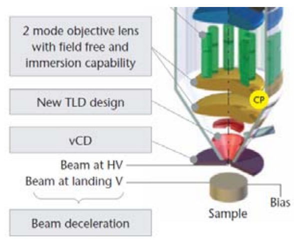




2 mode detector
(requires switching conditions)
conversion of BSE into SE (SE-3)





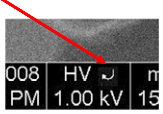


SEM low kV imaging

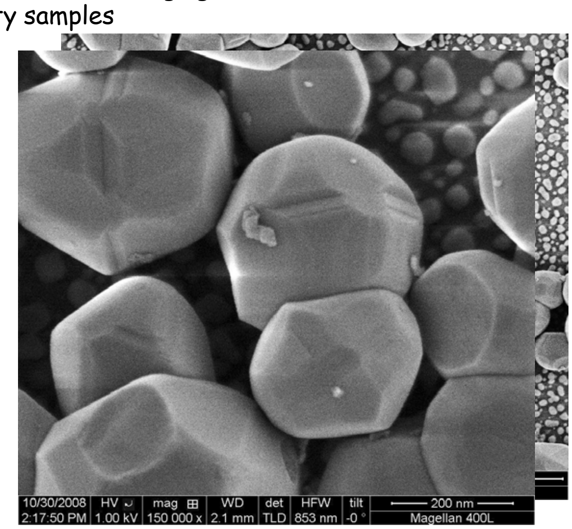
No specimen preparation needed: low voltage reduces charging effects
Low kV imaging of non-conducting, low density samples

Al2O3 Nano-crystals

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



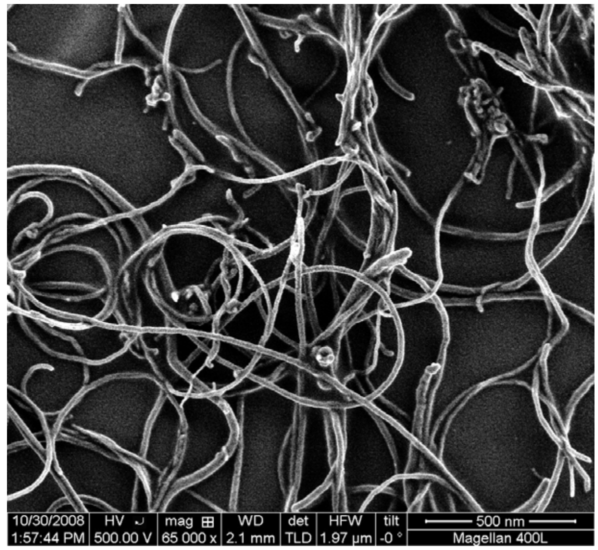
FEI Magellan
Operator: Ingo Gestmann
Samples: Marco Cantoni



SEM low kV imaging

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

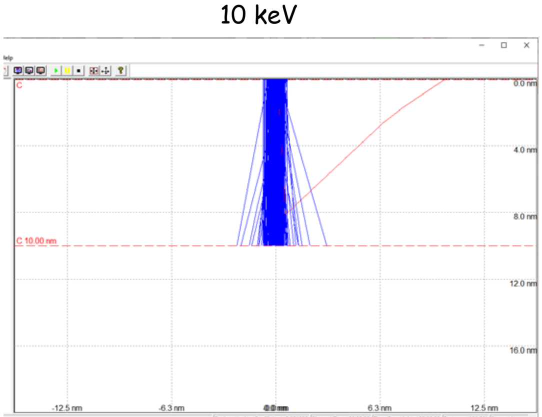
Carbon nano-tubes (MWCT)



FEI Magellan
Operator: Ingo Gestmann
Samples: Marco Cantoni

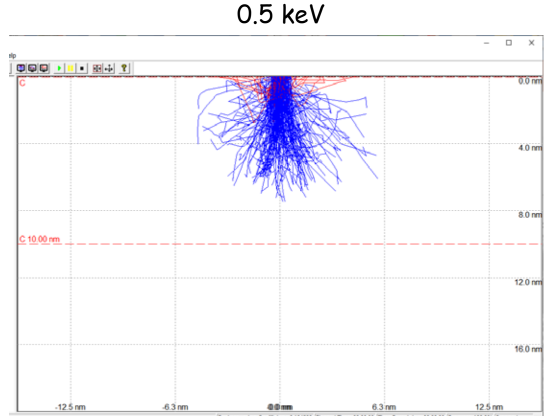
Monte-Carlo Simulation of electron trajectories in C

10 keV



C-NT transparent to electrons
(almost no scattering)

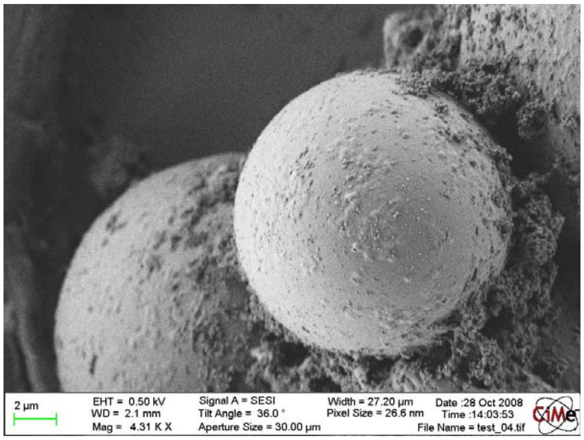
0.5 keV

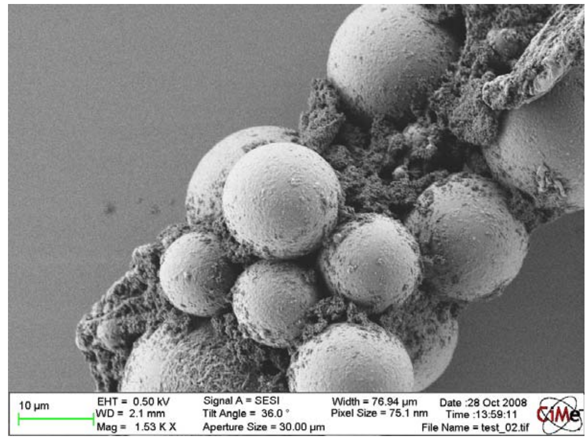


Many interactions (scattering)
contrast generation like for bulk sample

SEM low kV imaging

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





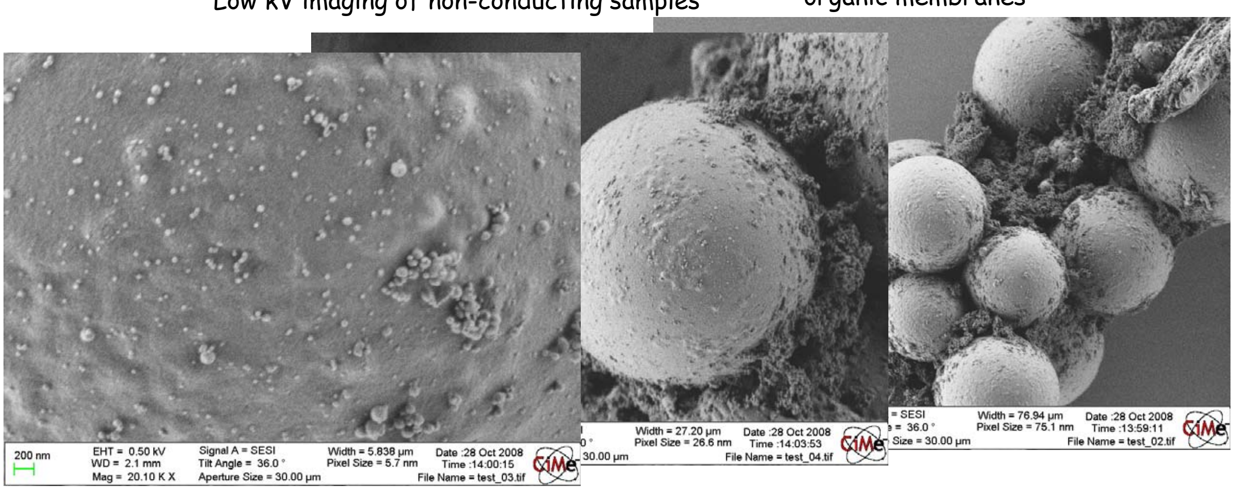
Zeiss Nvision 40
Marco Cantoni

Liquid filled organic membranes

SEM low kV imaging

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

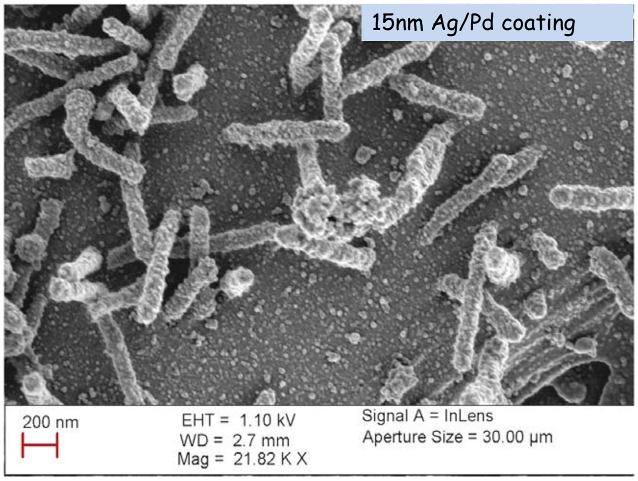
Liquid filled
organic membranes

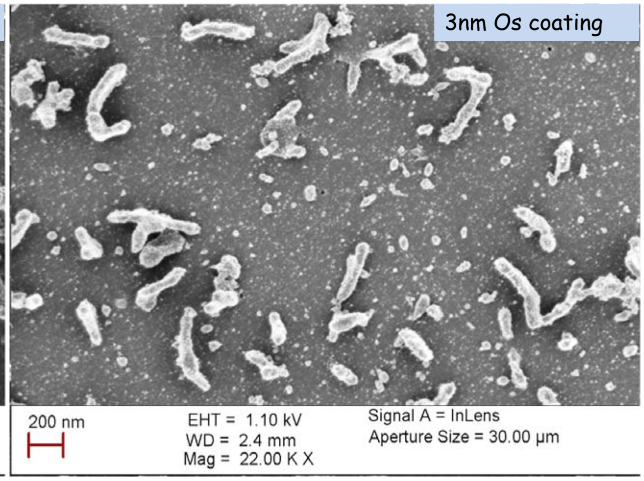


Zeiss Nvision 40
Marco Cantoni

SEM low kV imaging

Purely organic specimen: non-conductive, low density: Metal coating



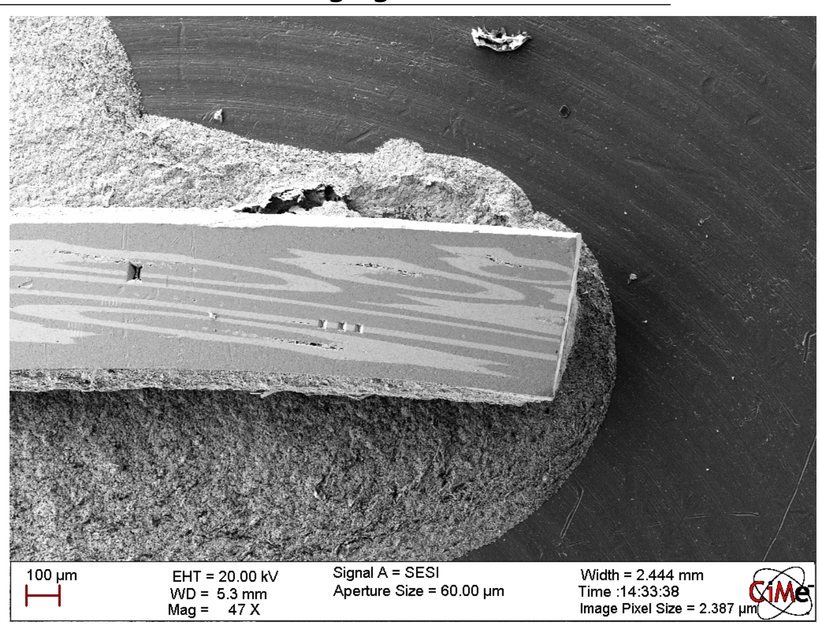


HeLa Cells, Graham Knott
Marco Cantoni, Nvision 40

SEM low kV imaging

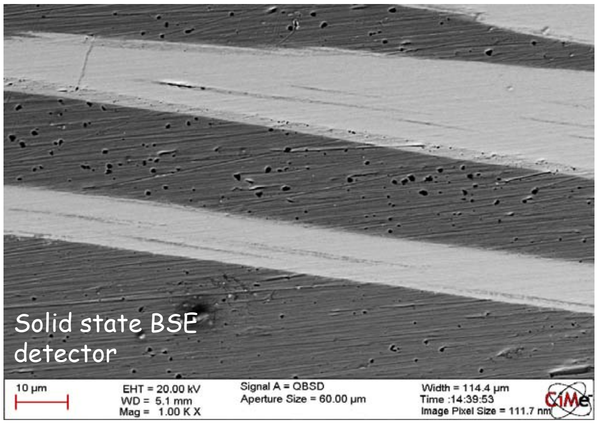
"Easy" sample:

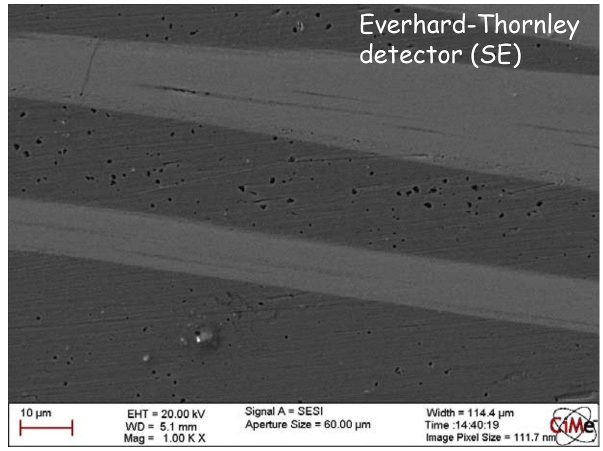
Superconductor wire
Nb_3Sn in Cu matrix



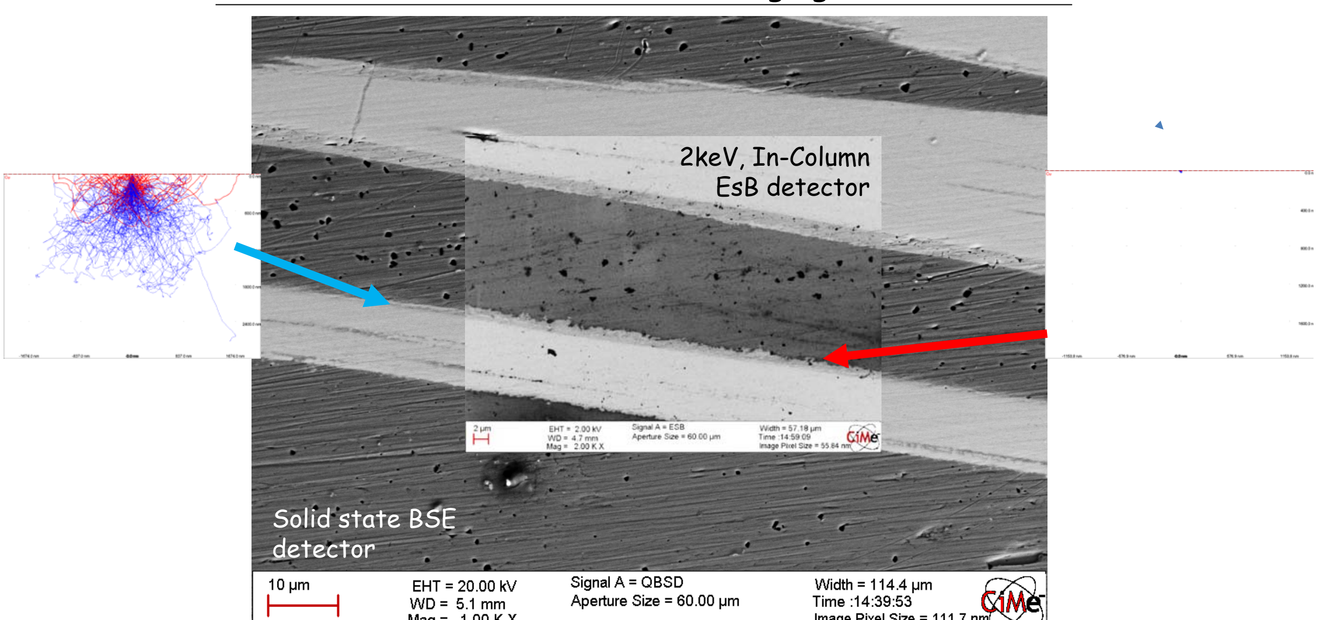
SEM low kV imaging

20 keV classical conditions for metals

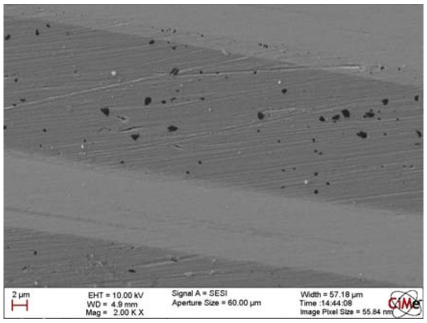


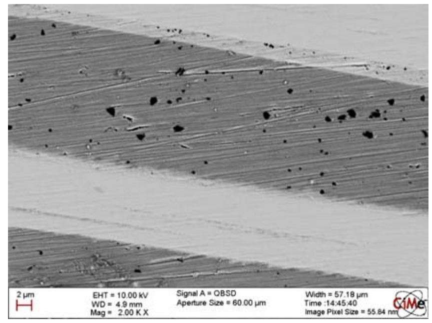


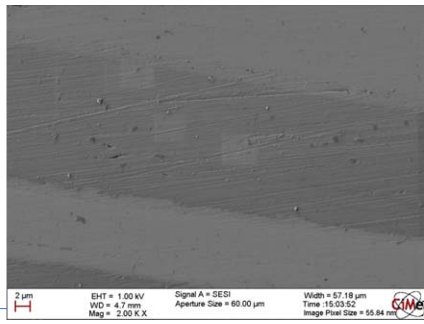
SEM low kV BSE imaging

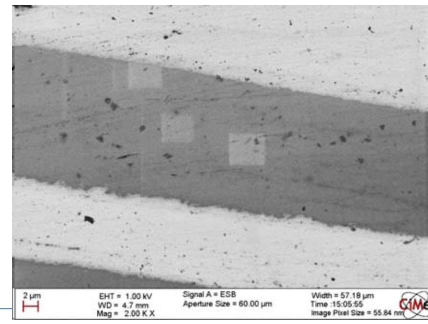


SEM low kV imaging "Easy" samples:

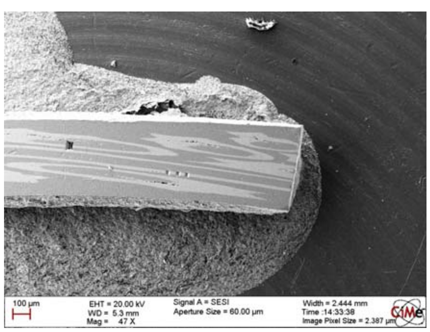


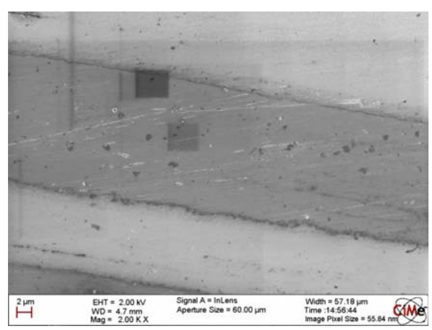


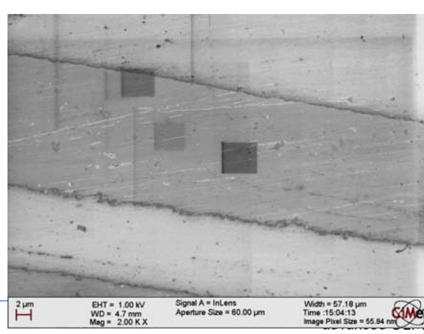


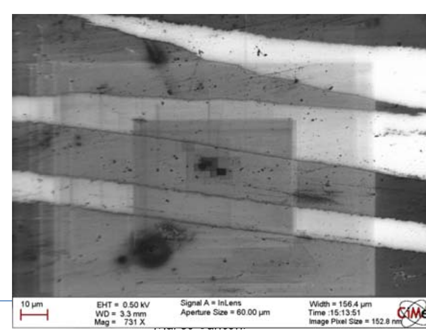


SEM low kV imaging "Easy" samples:

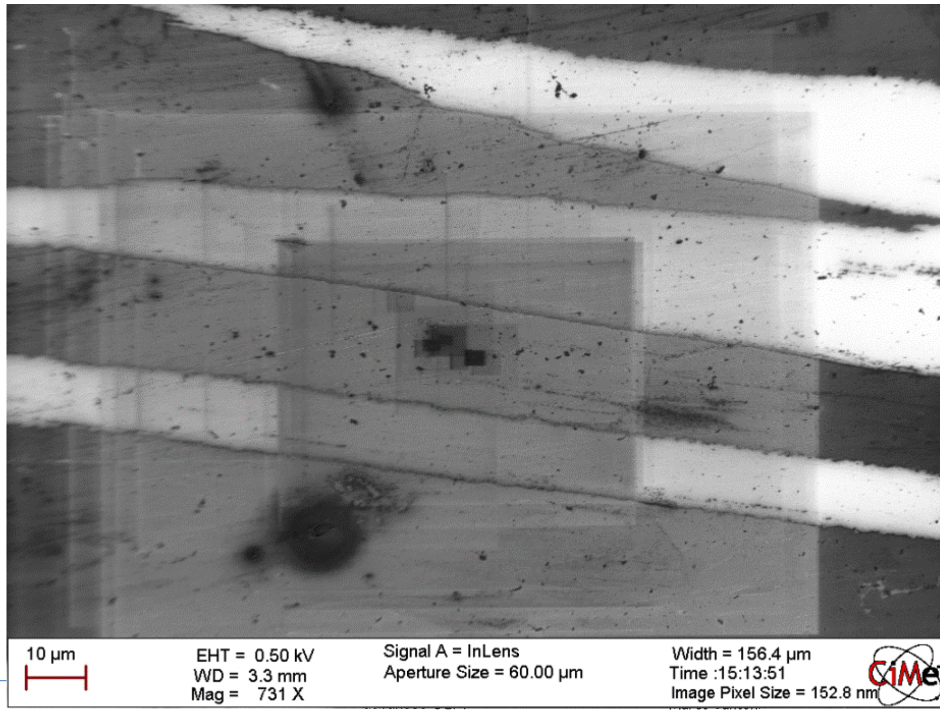








At low kV:
very sensitive to surface layers (contamination)



SEM low kV imaging

Contamination by hydro-carbons
becomes critical at low beam energies

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

examples: contrast reversal at low kV in BSE mode

Contrast reversal in BSE mode at low accelerating voltage

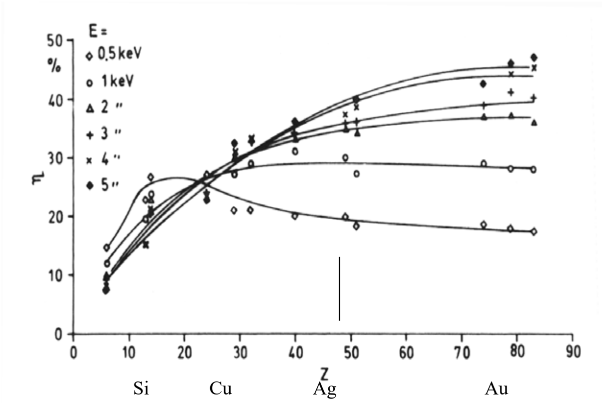
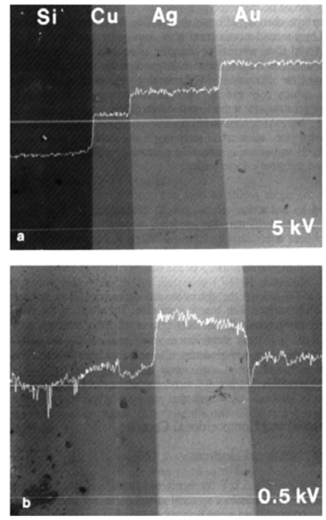


Fig. 4.1. Dependence of the backscattering coefficient η at normal incidence (ϕ=0) on atomic number Z for different electron energies.



from L.Reimer, Image formation in low-voltage SEM