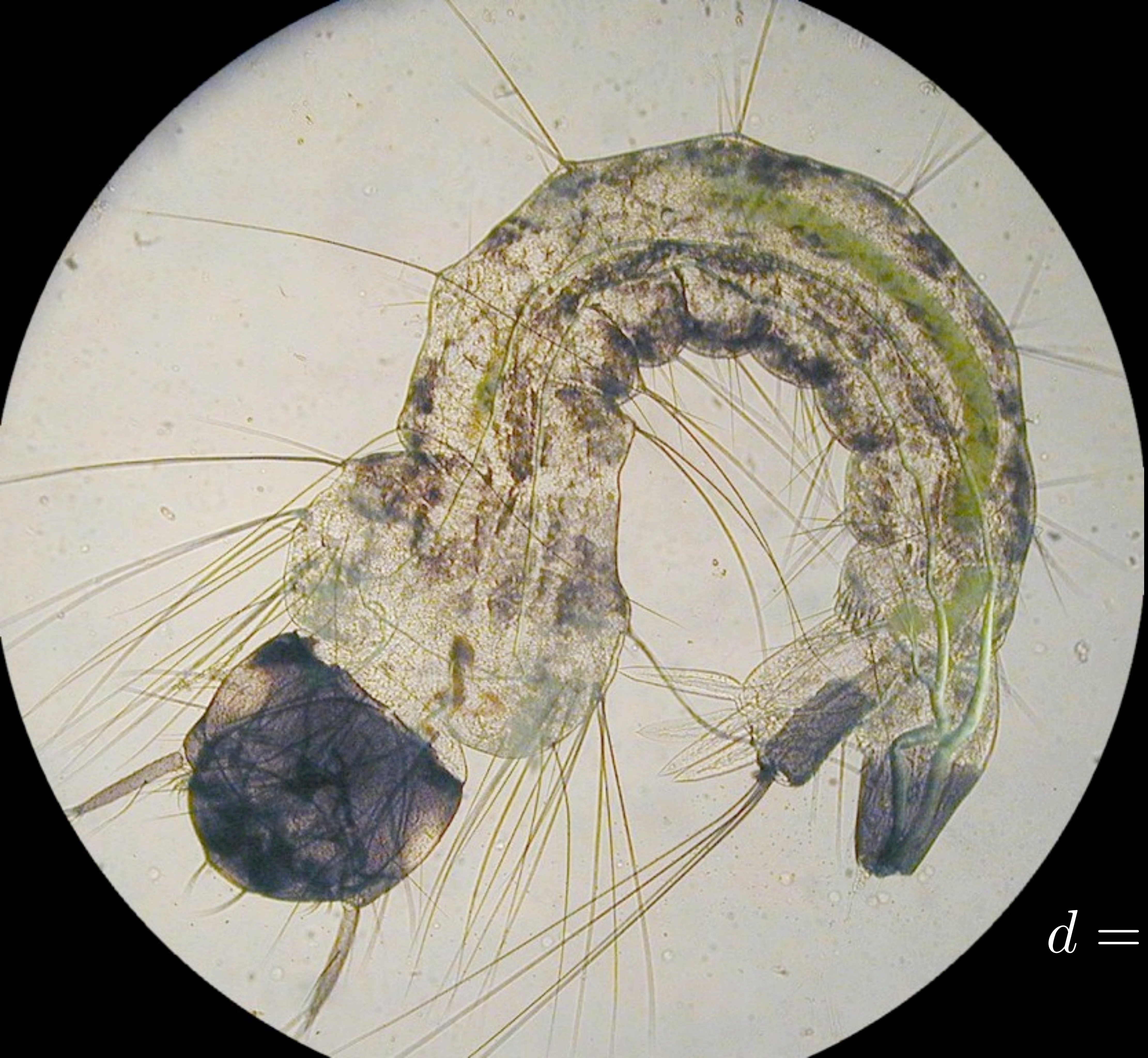
Scanning Electron Microscopy

An Introduction by Lorenz Lechner

Learning Goals

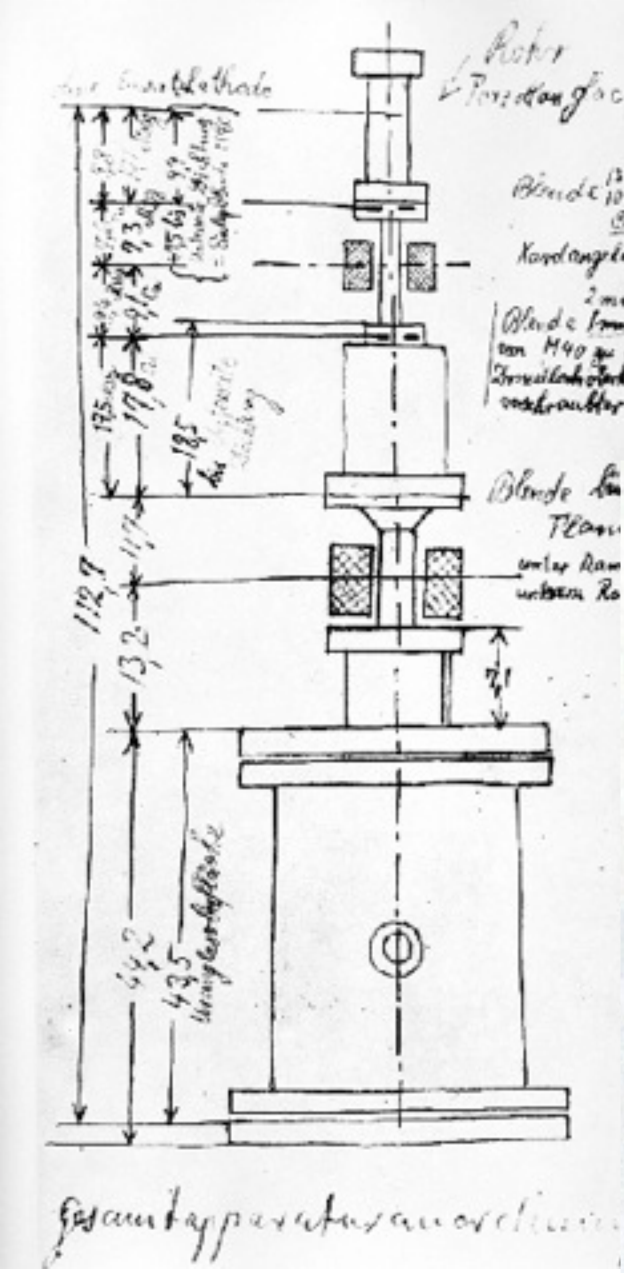
- Basic Operating Principles
- SEM Hardware
- Understand/aquire SEM images
- SEM Applications
- *Focused Ion Beam Microscopy*

Overview



$$d = \frac{\lambda}{2n\sin\alpha}$$

Some history...



Wheeled Building Travels 70 mph

This movable testing stand for airplane engines, developed at Roosevelt Flying Field, will travel seventy miles an hour.

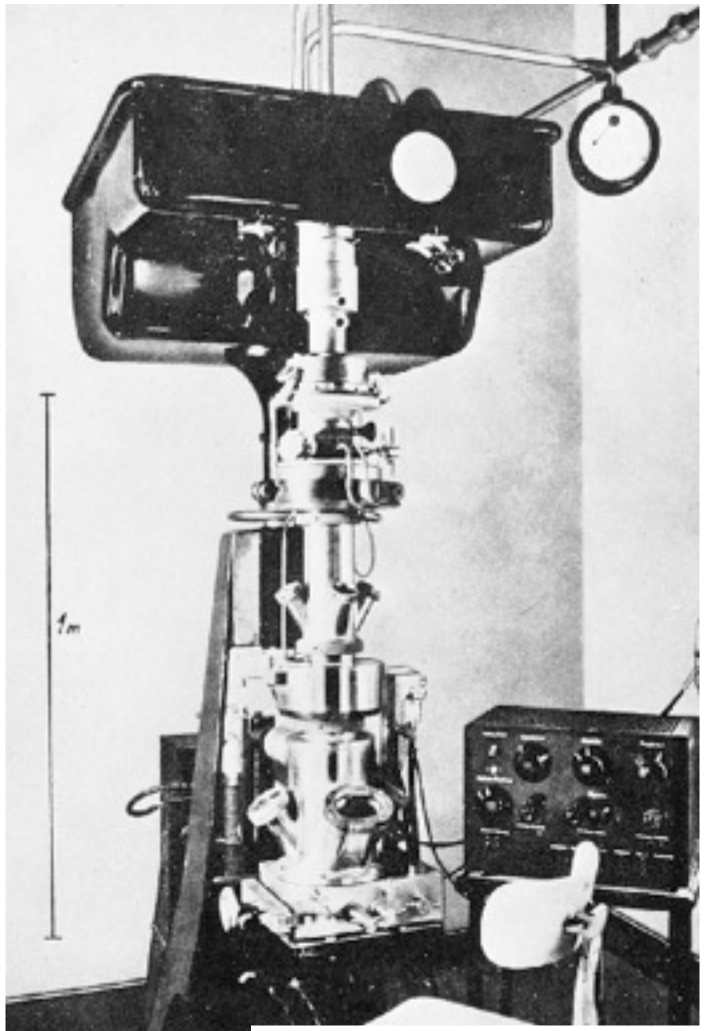
A WHEELED building which travels 70 miles an hour is the result of experiments at Roosevelt Field, Long Island, to develop a testing plant for airplane engines.

A shack-like structure and an engine testing stand were mounted on a chassis which can be propelled under its own power at better than mile-a-minute speed. The advantage of the novel device lies in the fact that engine tests may be conducted at any part of the field, owing to the mobility of the testing stand.

Machine Magnifies 10,000 Times

USING electrons instead of light rays to "see" tiny objects, a German scientist has developed a machine which, by magnification in two stages, enlarges objects about 10,000 times. Maximum enlargement usually possible with optical instruments is 3,500 times. Glass lenses cannot be used in the electron microscope. Electric or magnetic fields take their place, bending the electron streams as lenses bend or focus light rays.

Modern Mechanix (Nov. 1934)



Ernst Ruska
+
Max Knoll

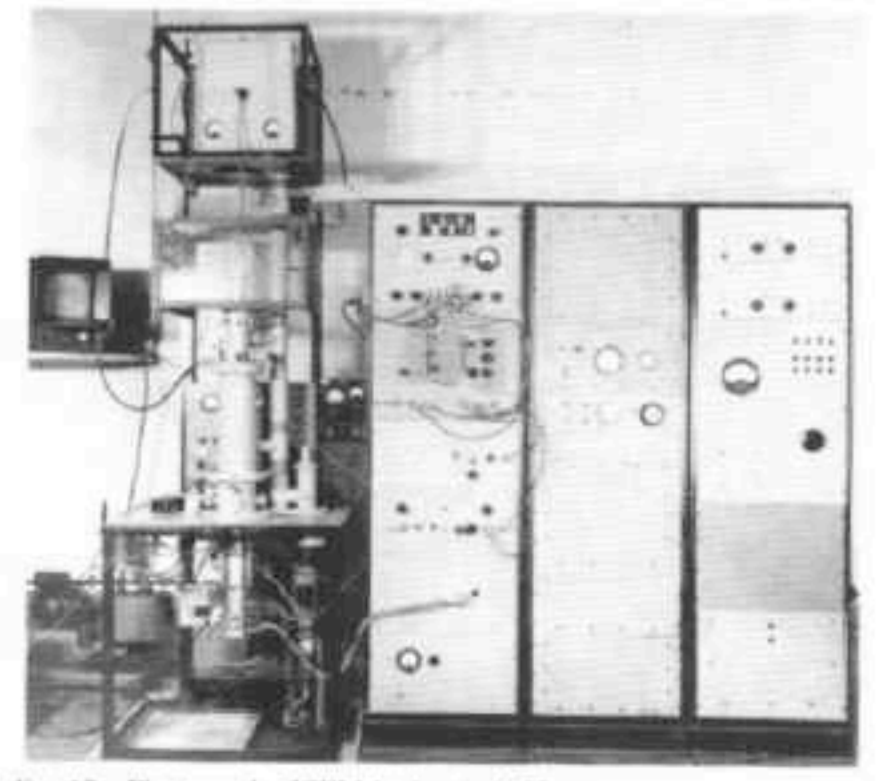


FIG. 12 Photograph of SEM 1 taken in 1953.

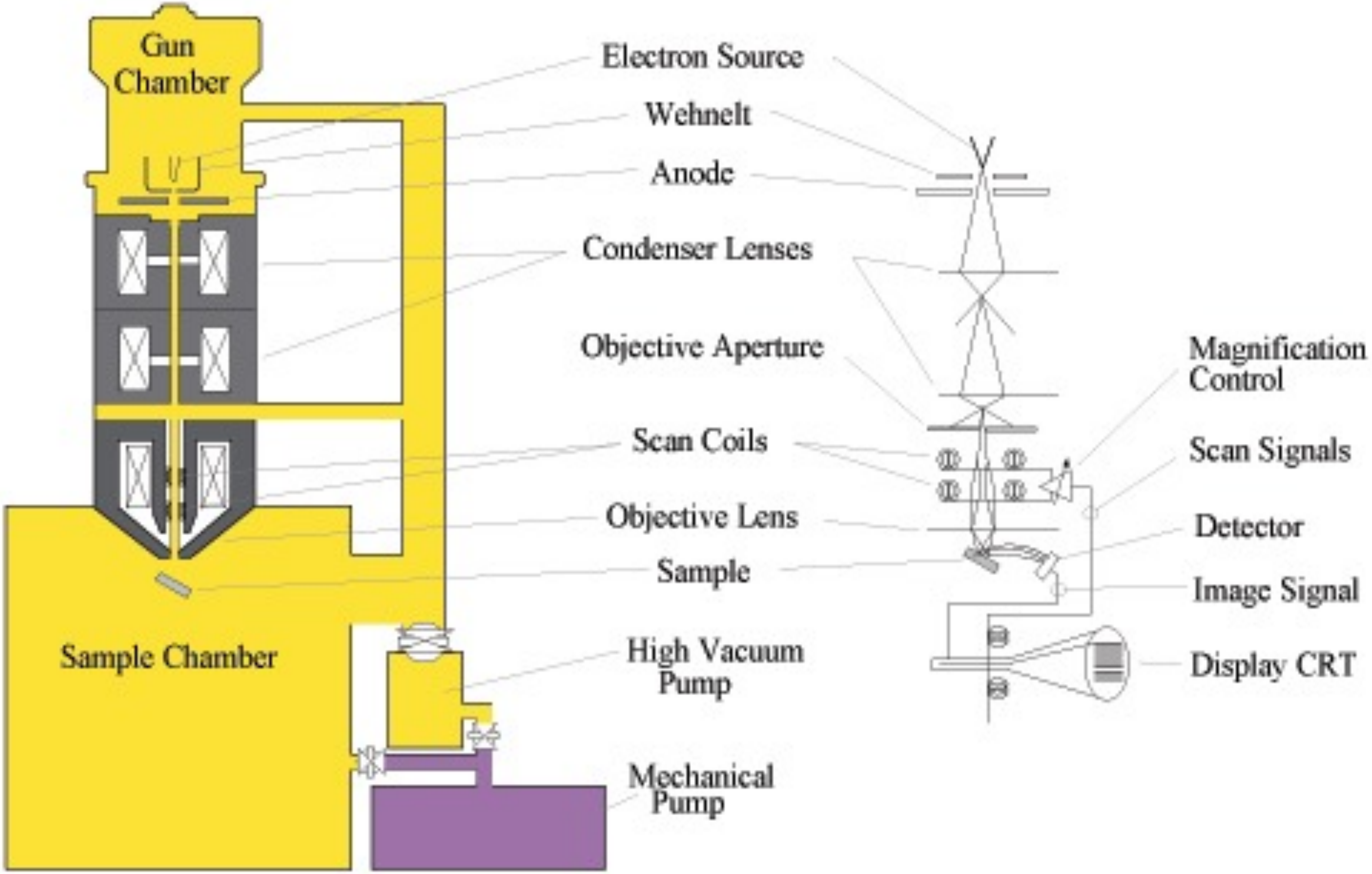
This is not an SEM...

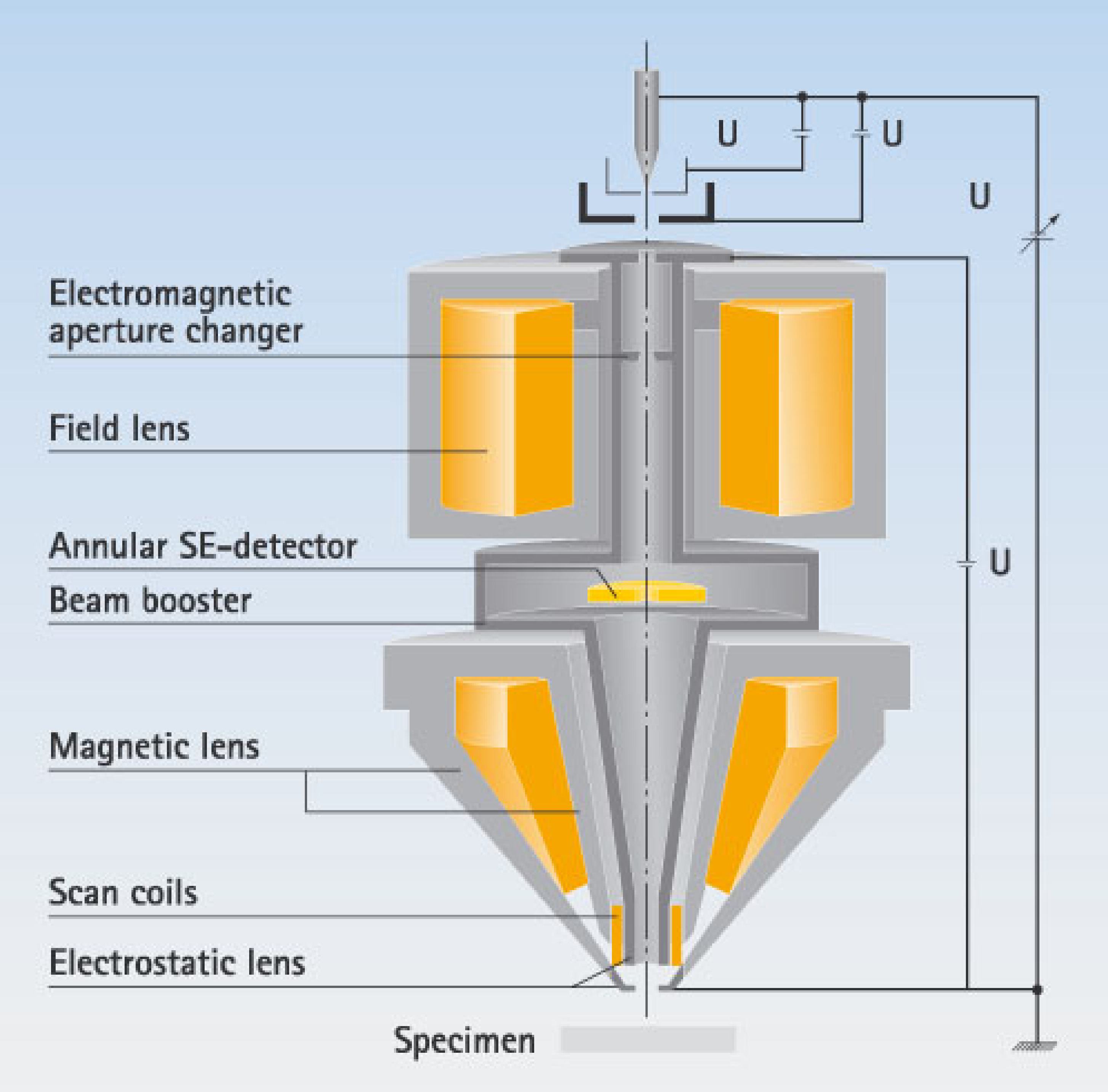
...since transmission electron microscopy is fundamentally different!

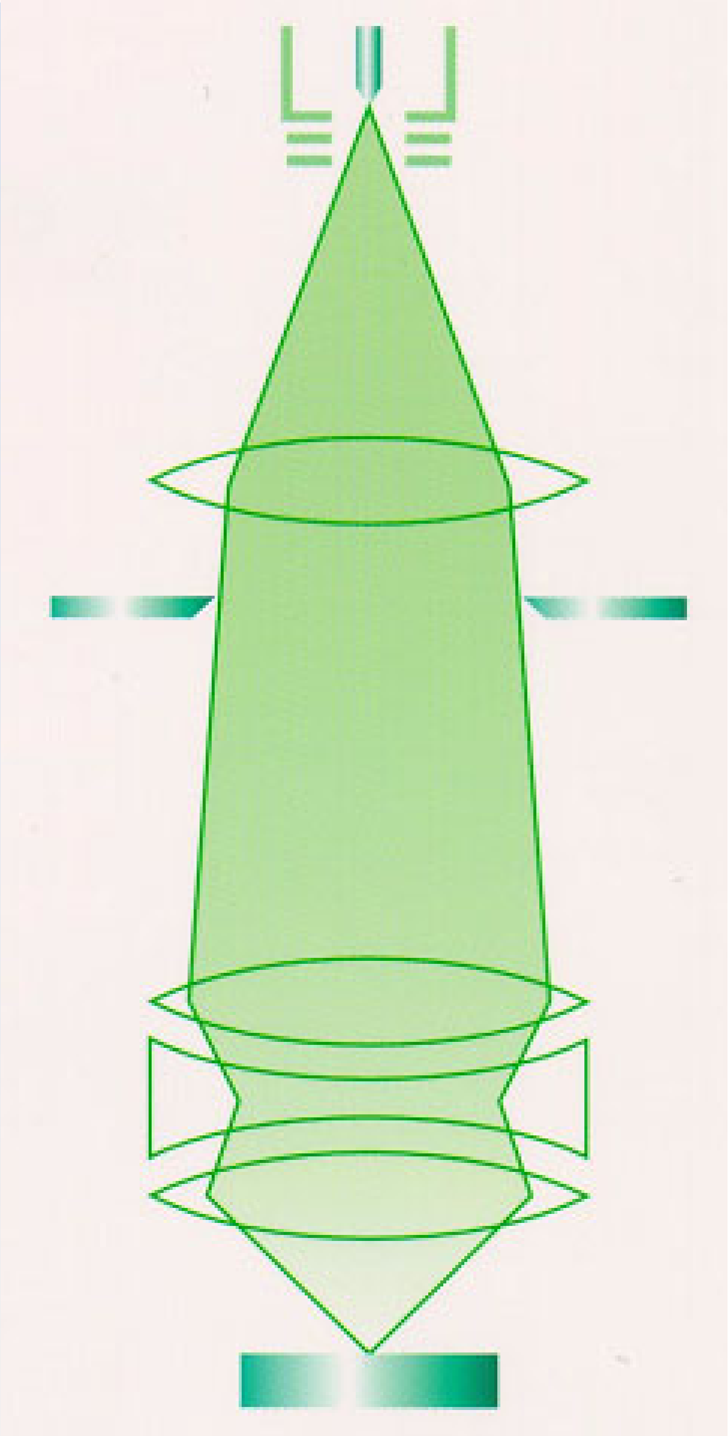
Basic Operating Principle

Hardware


GEMINI
ZEISS
SUPRA 40

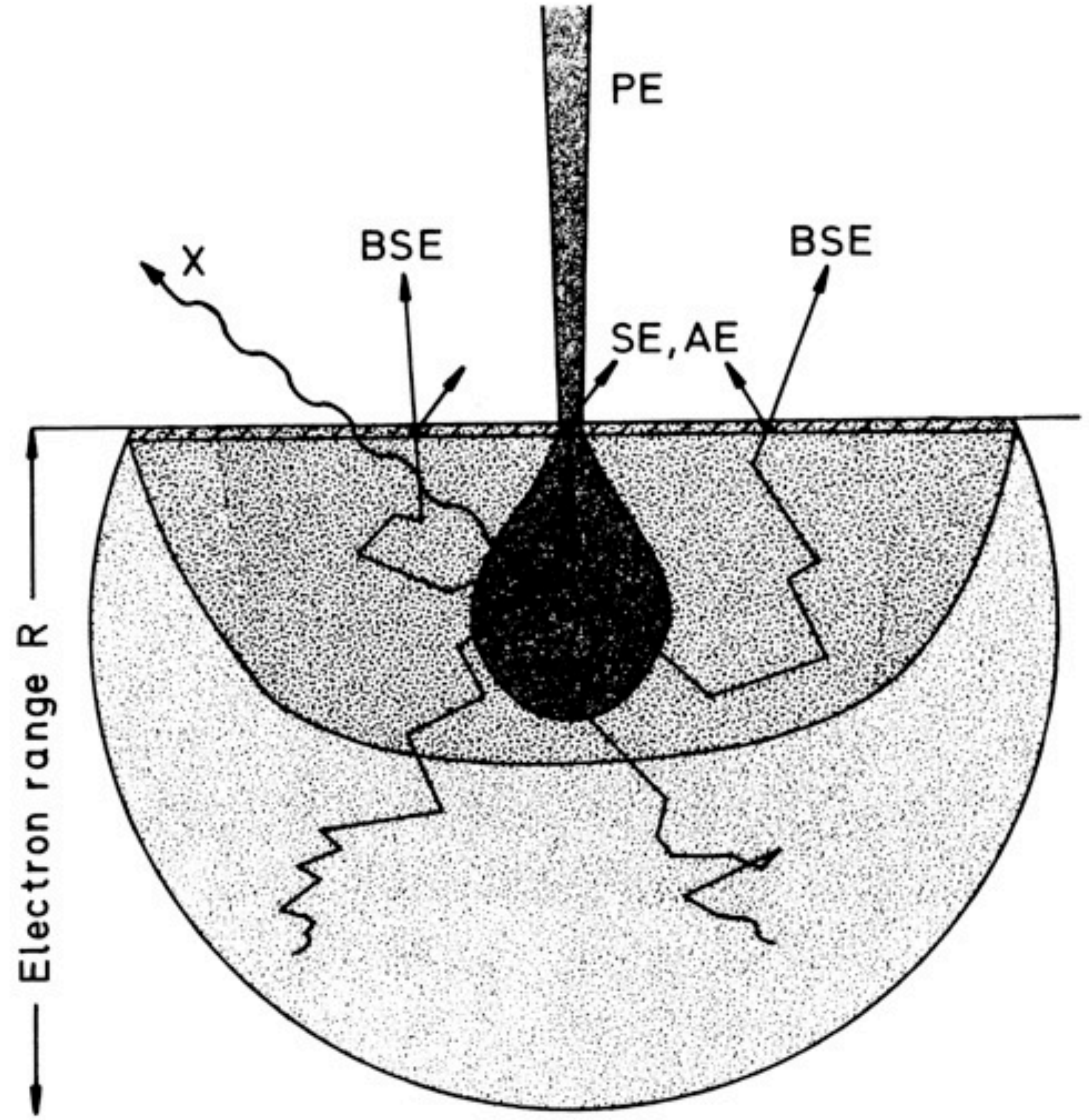

Gun Chamber
Electron Source
Wehnelt
Anode
Condenser Lenses
Objective Aperture
Magnification Control
Scan Coils
Scan Signals
Objective Lens
Detector
Sample
Image Signal
Sample Chamber
High Vacuum Pump
Display CRT
Mechanical Pump



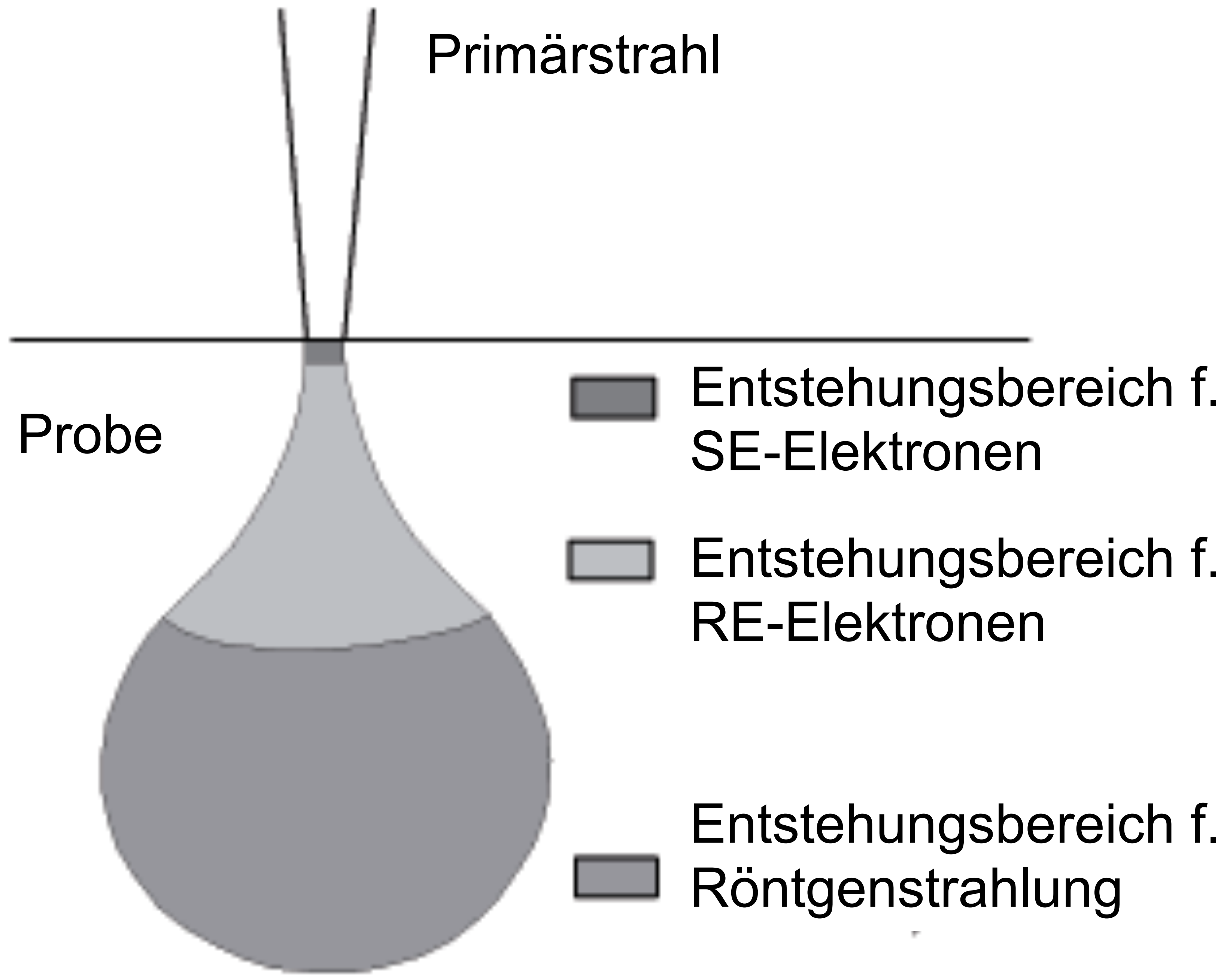


Electron Optics

Electron Interaction



Interaction Volume

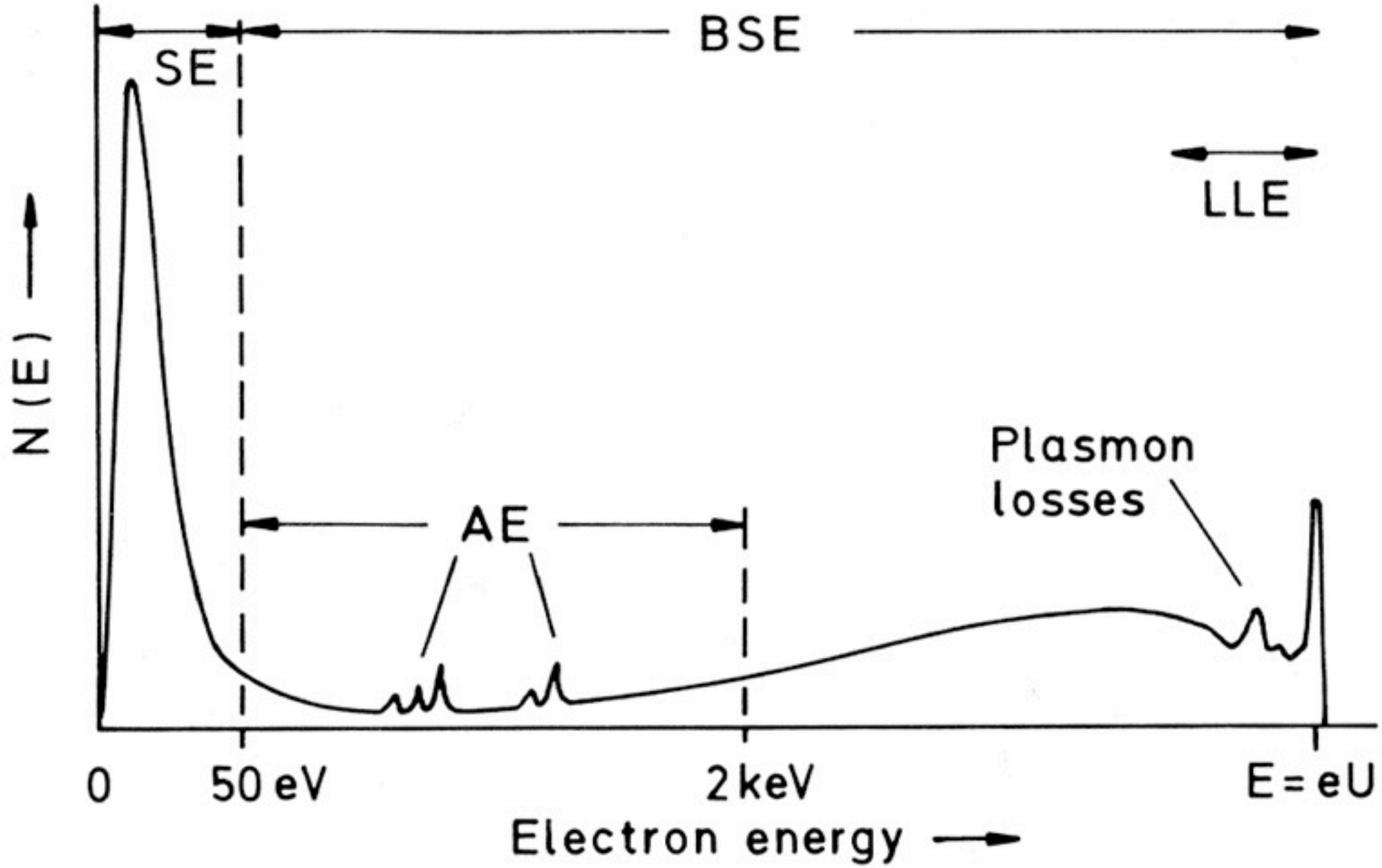


▨ Entstehungsbereich f. SE-Elektronen

▨ Entstehungsbereich f. RE-Elektronen

▨ Entstehungsbereich f. Röntgenstrahlung

Electron Species



Electrons Energy

SEM Imaging

Fundamentals

Scanning

Electron
Microscopy

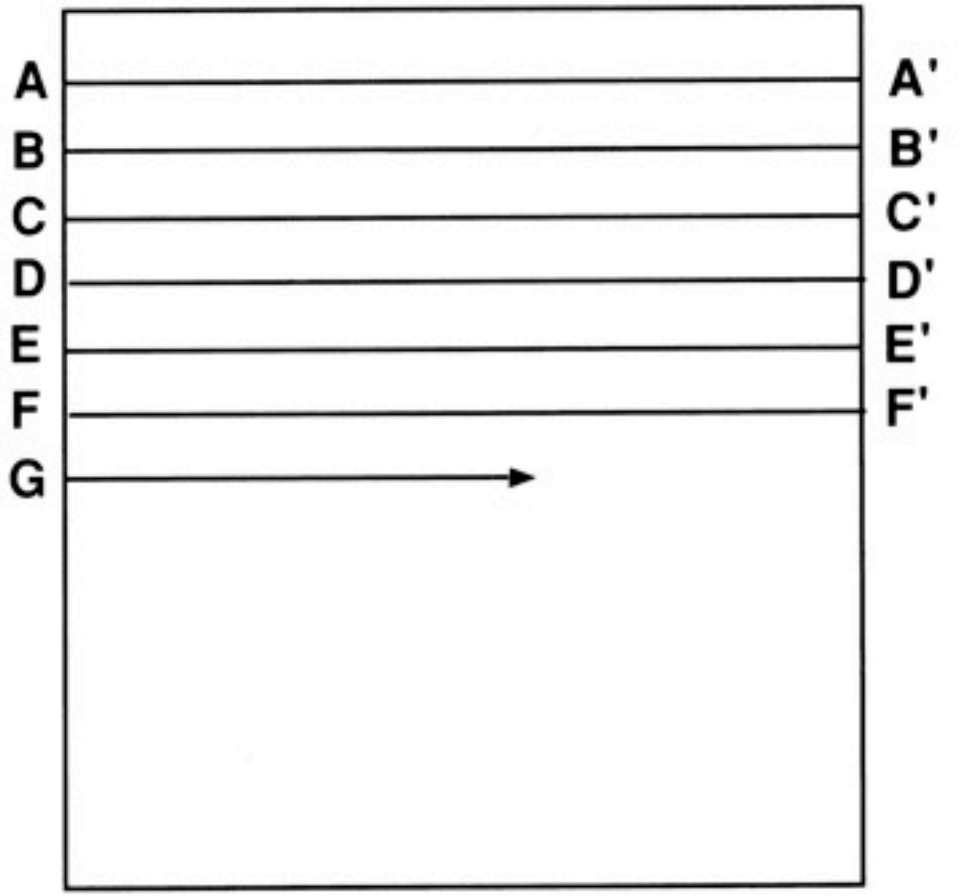
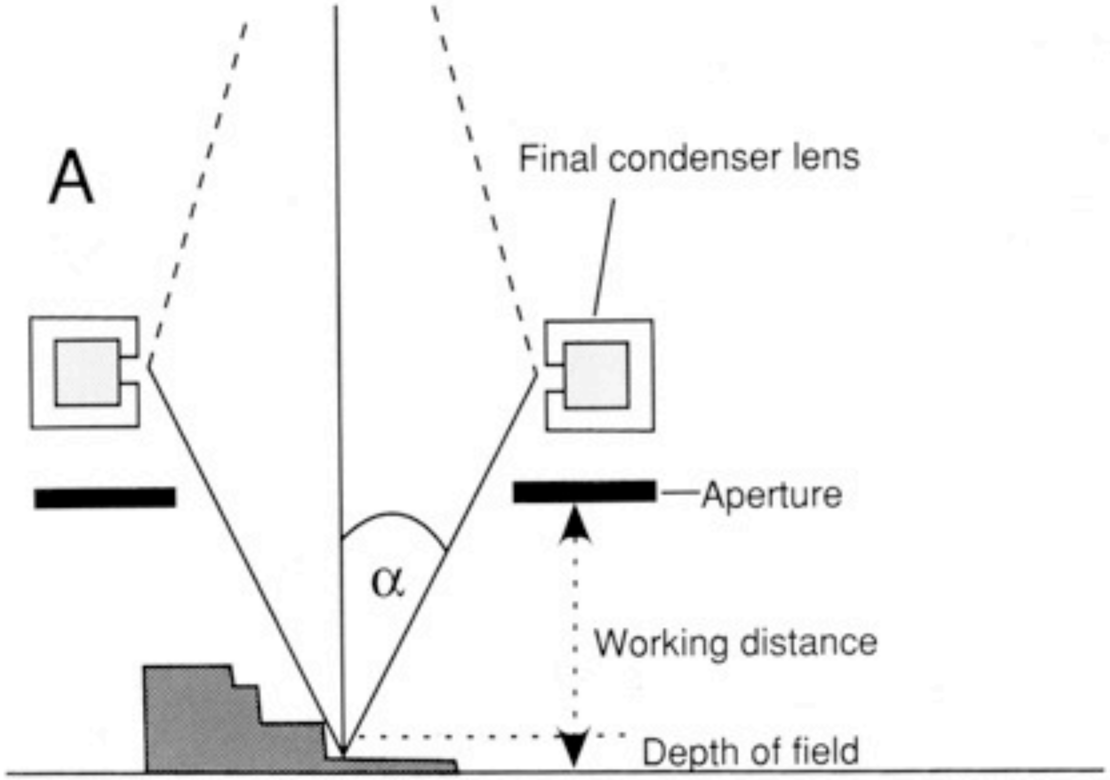
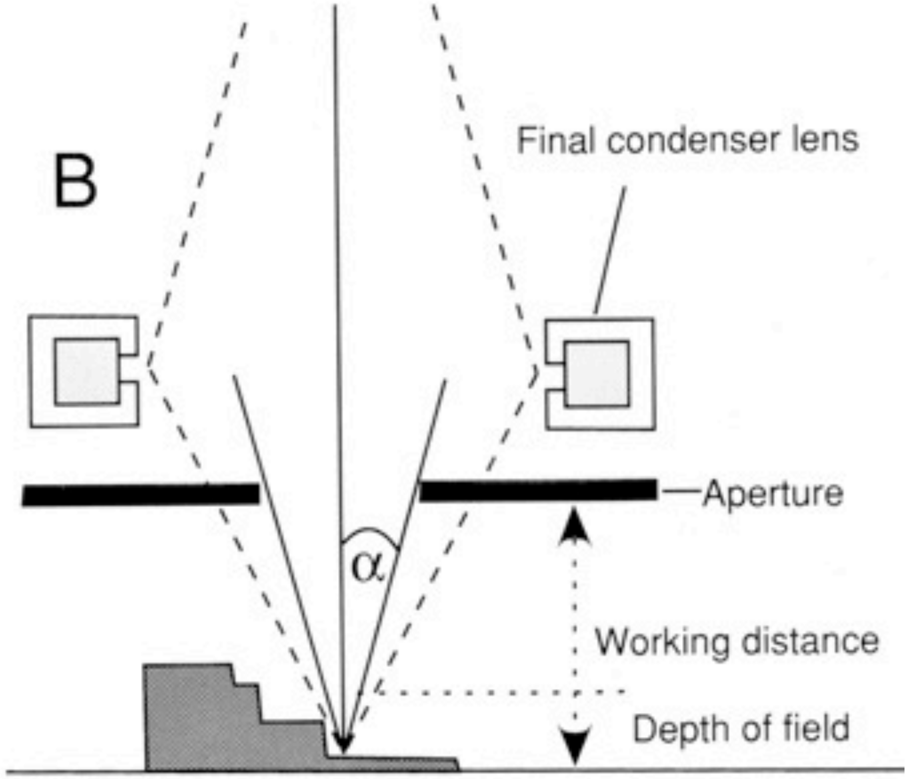
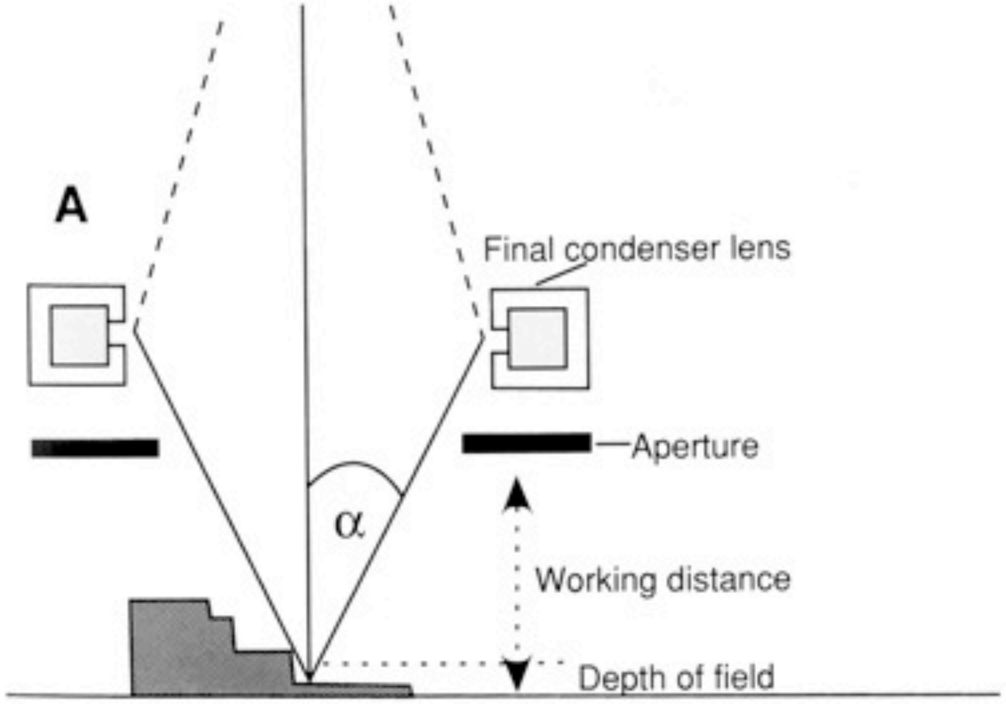


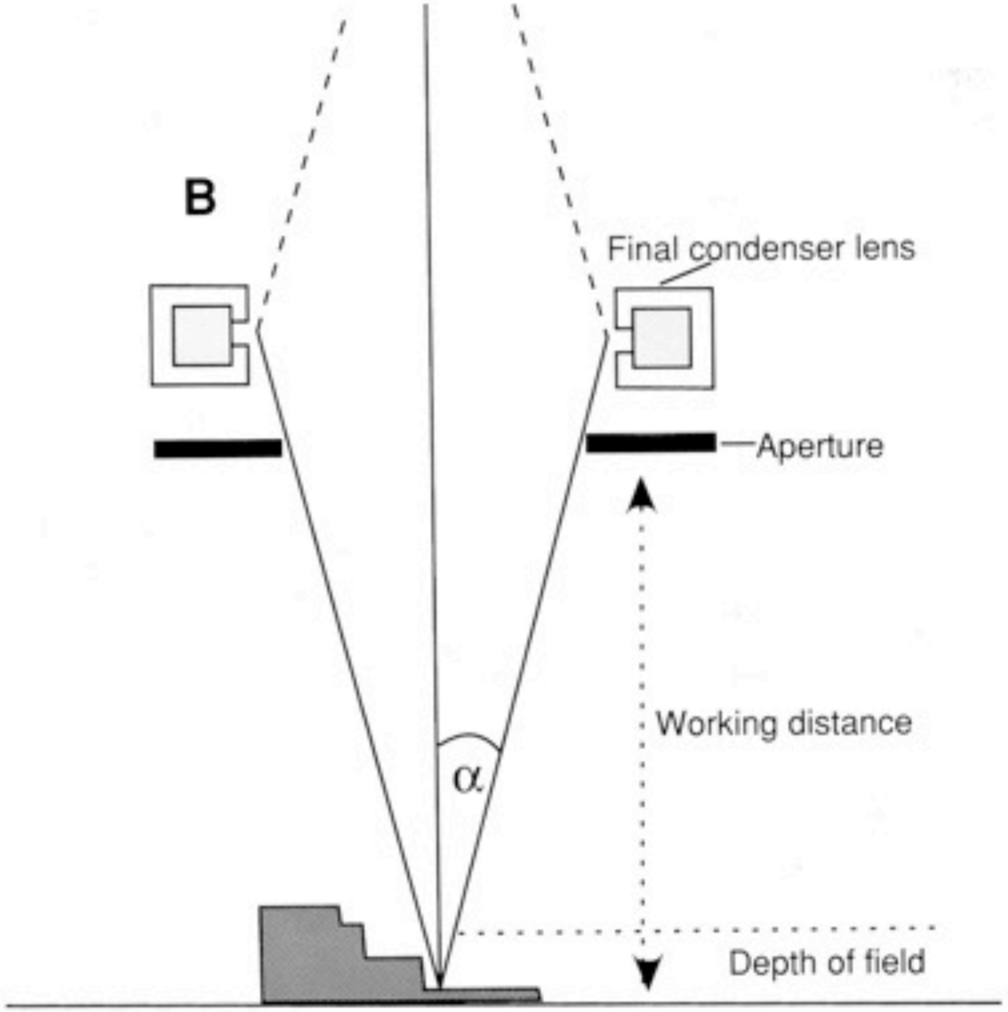
Figure 7-4 The focused beam of electrons is scanned in a raster pattern over the specimen surface. The first scan is from A to A′, with the beam moving down and then scanning line B to B′, etc. (Redrawn from Postek, et al, 1980.)

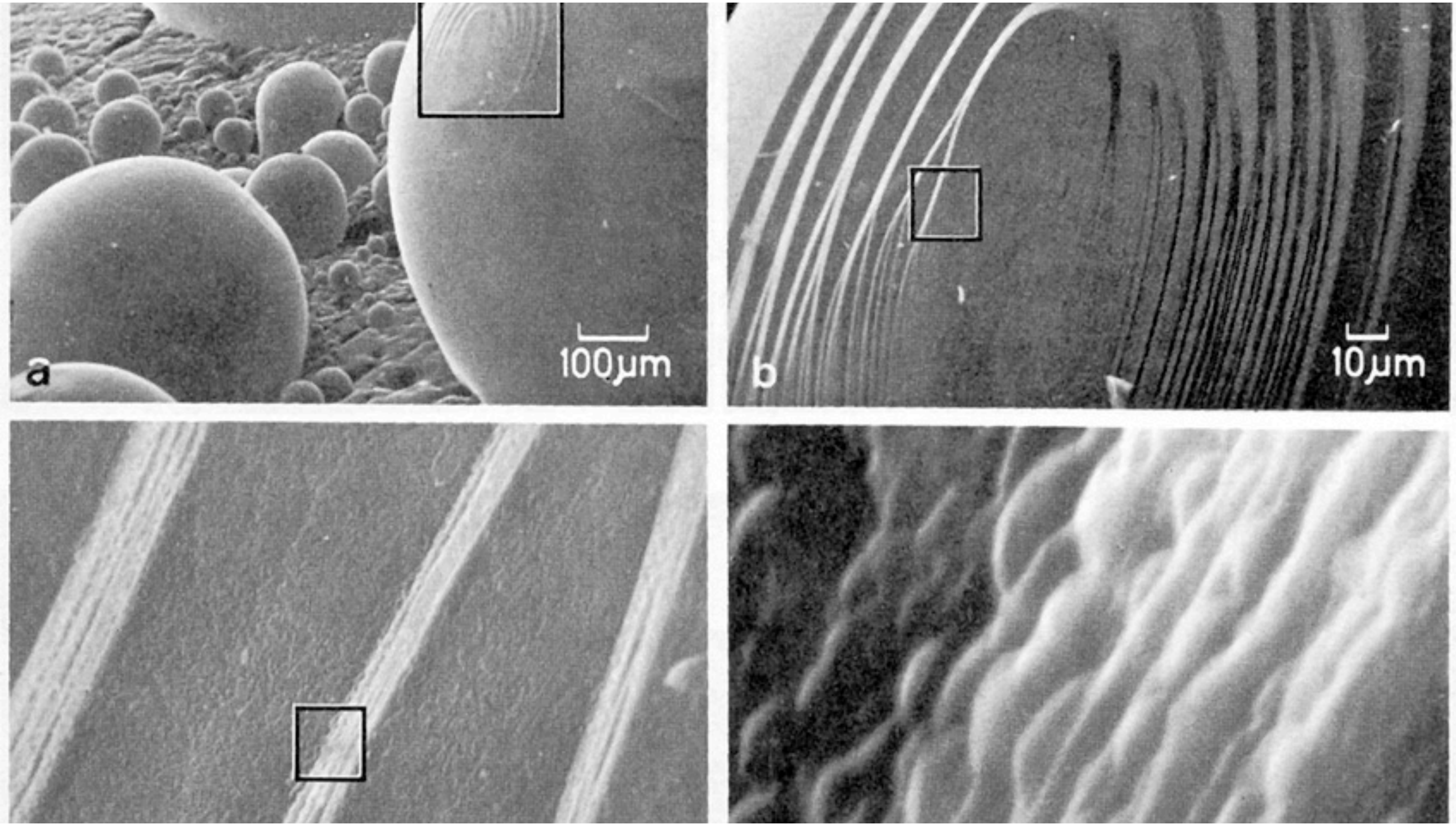
Electron Beam Shape







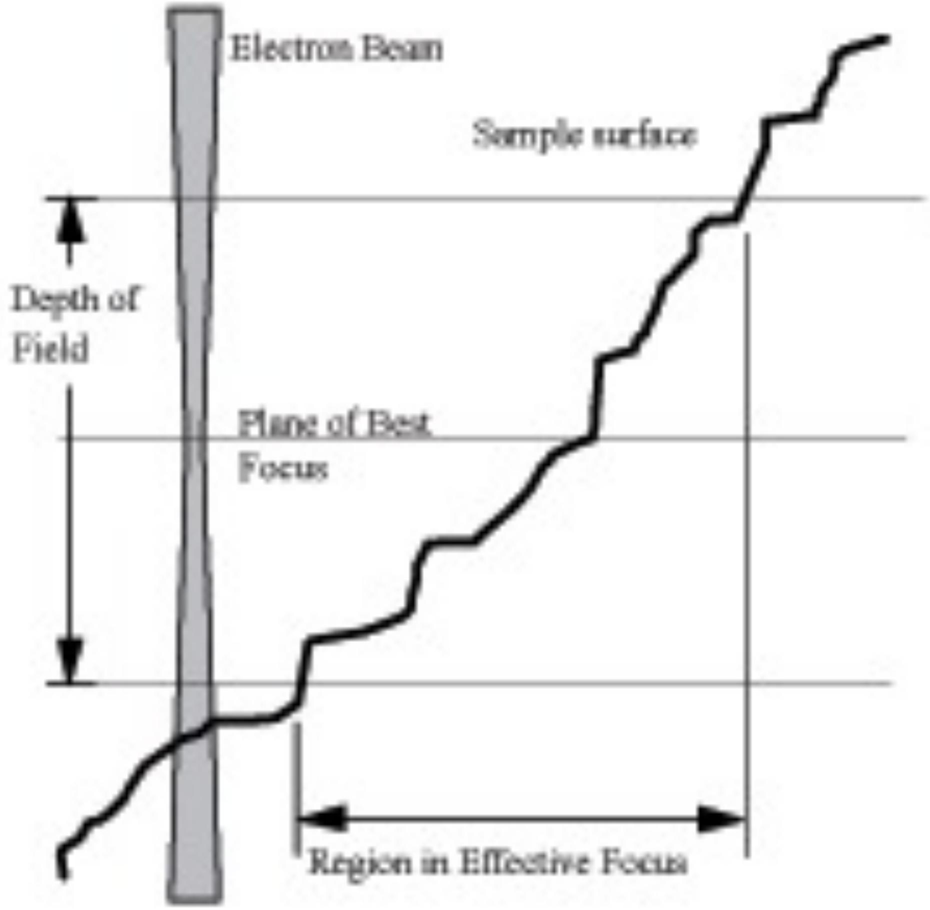




Large Depth of Focus

“Infinite Focus”

For small aperture
And
Large working distance



Contrast Mechanisms

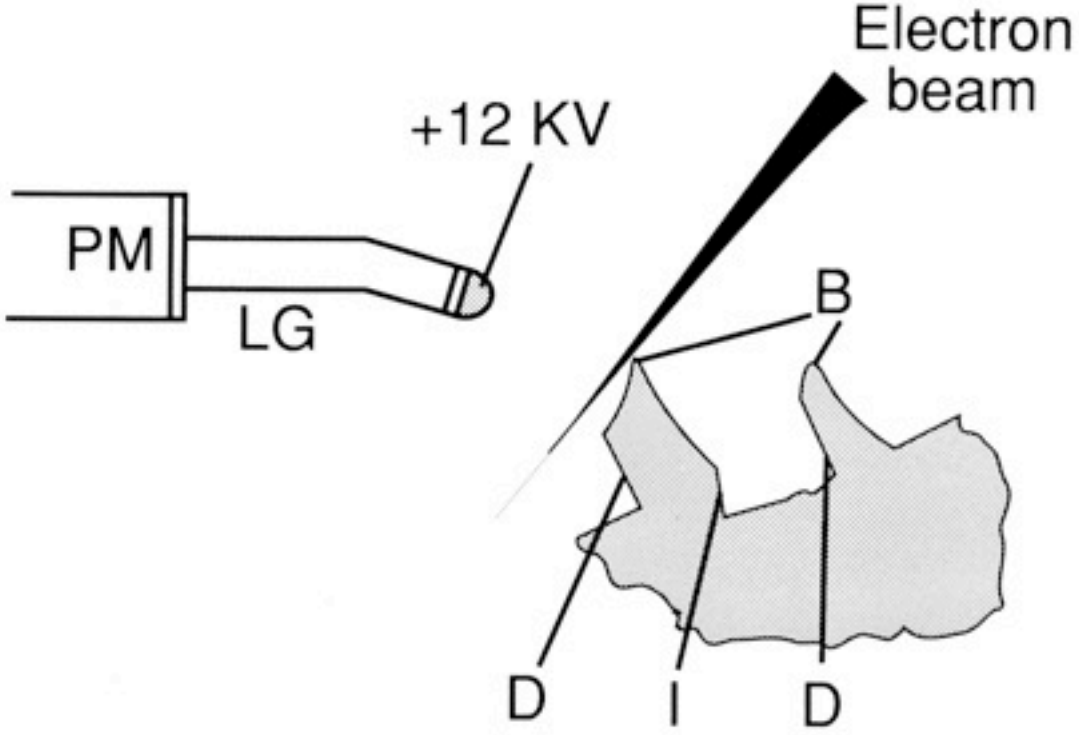


Figure 7-16 Three dimensionality and contrast are due to the yield of secondary electrons from various parts of the specimen. Areas marked B face the beam and are in line of sight with the detector so that they will appear bright, I (intermediate brightness) faces the beam but fewer secondaries reach the detector since it is not in line of sight, D is dark in appearance since the beam does not strike this area and no secondaries are generated.

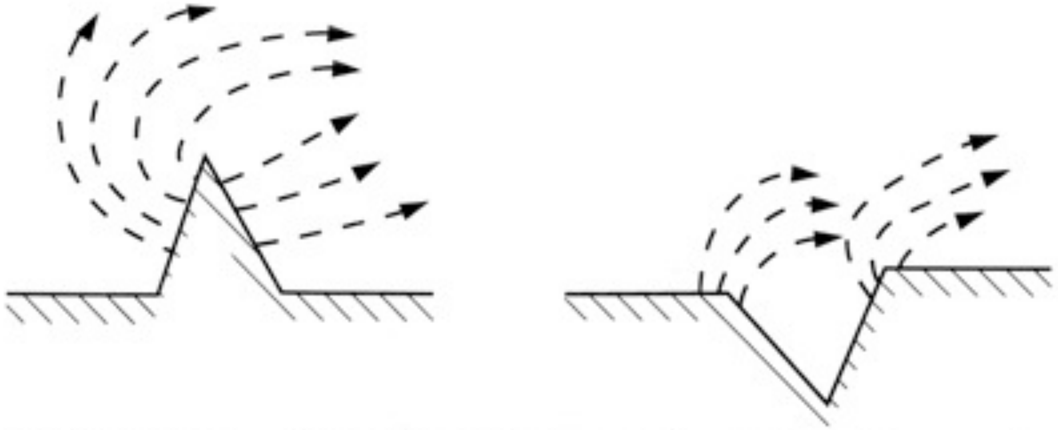


Figure 7-18 The edge effect, or enhanced electron emission, occurs along the edges of thin raised areas since secondary electrons may exit from both sides of the structure.

Secondary Electrons

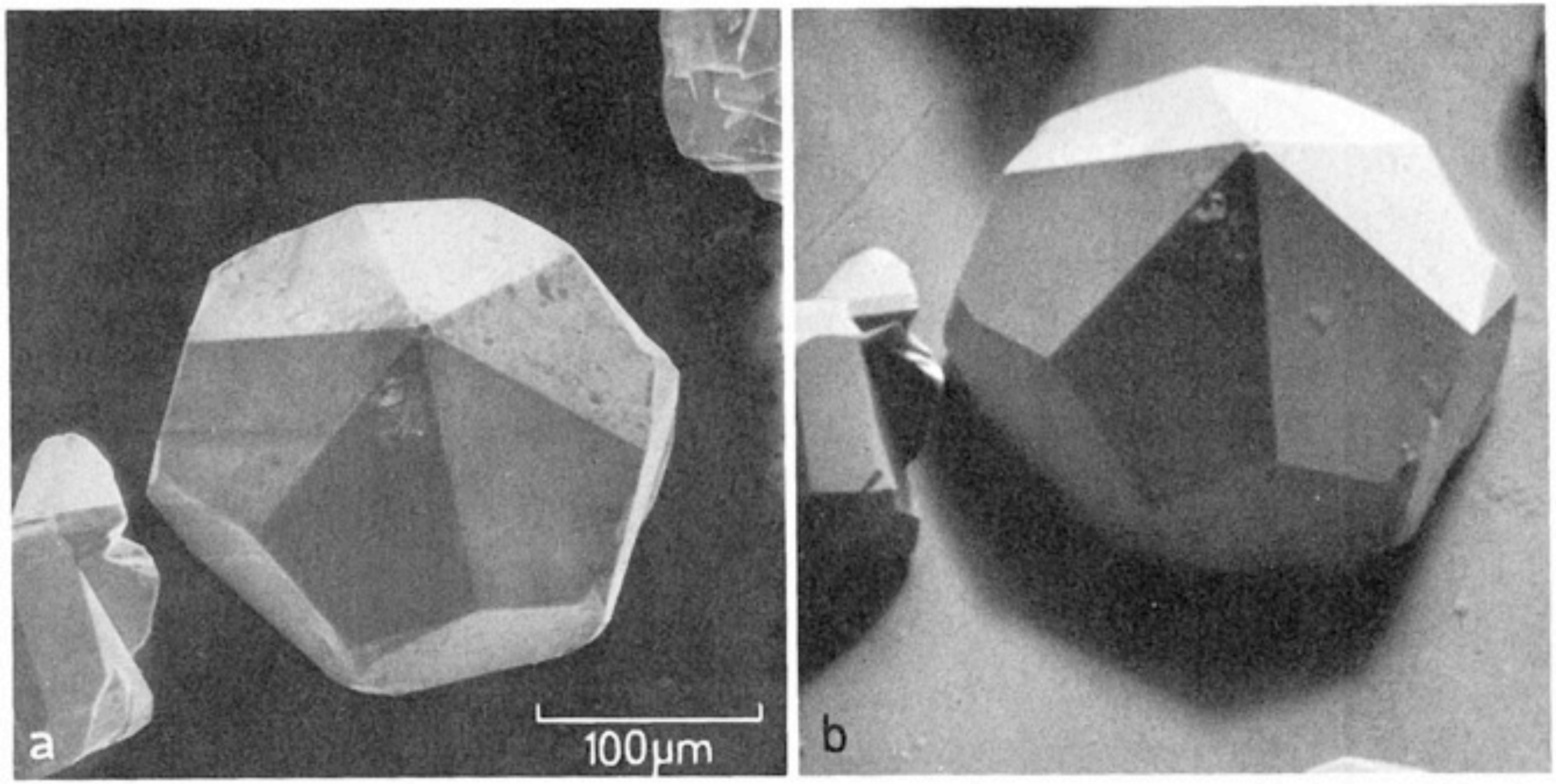


Fig. 6.5a, b

Fig. 6.5a, b. Illustration of the surface tilt and shadow contrast with micrographs of $Ge_{38}P_8I_8$ crystals in the (**a**) SE and (**b**) BSE mode

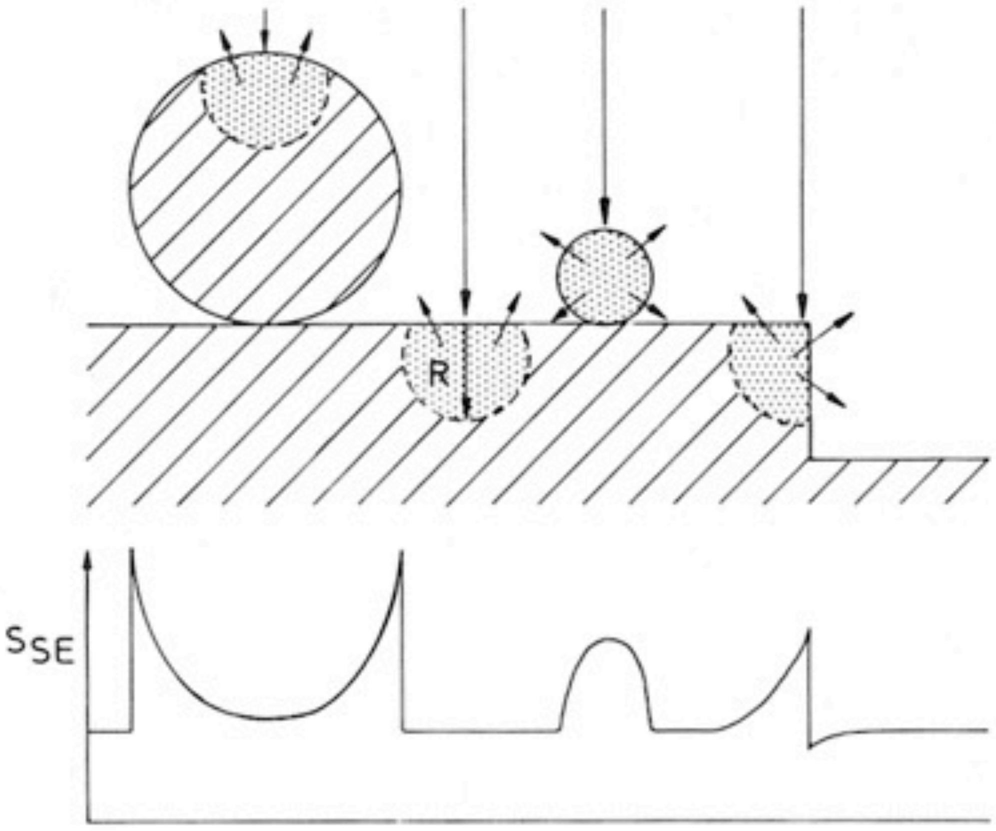
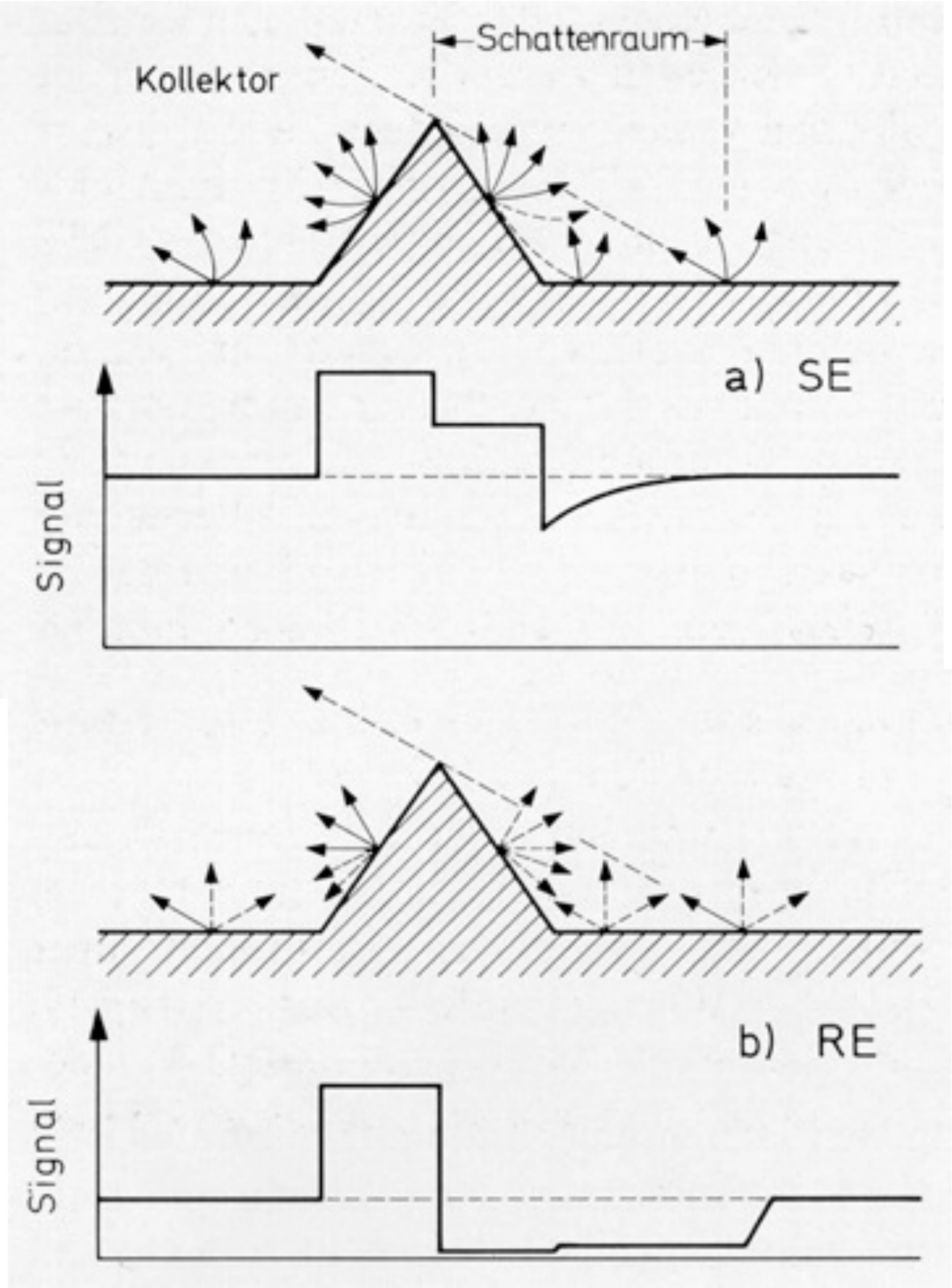
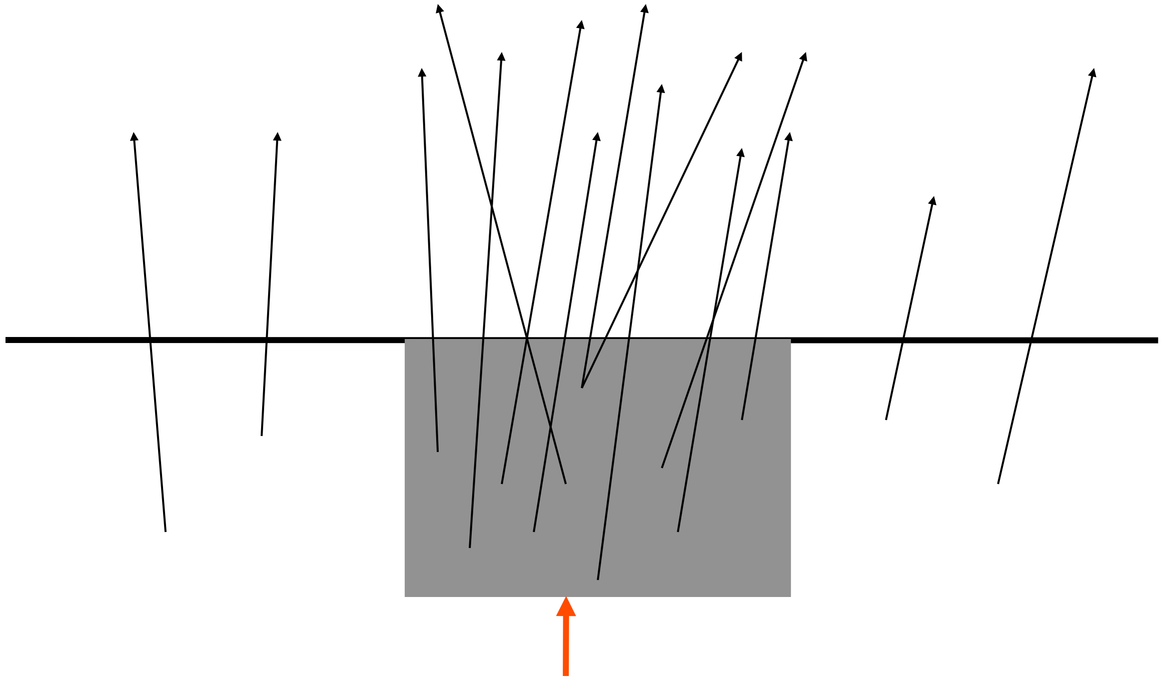


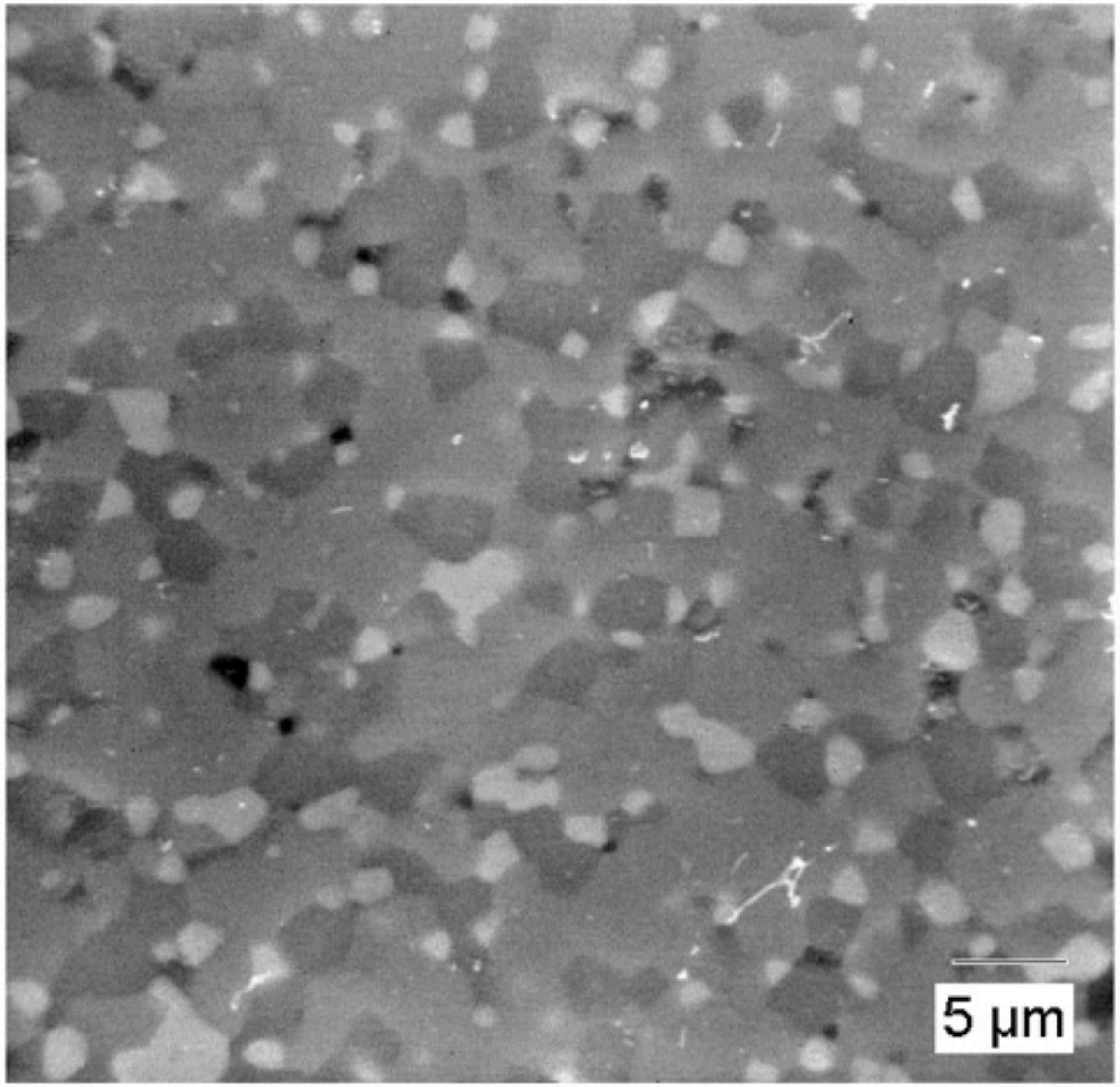
Fig. 6.6. SE signal intensity across spheres with diameters larger and smaller than the electron range *R* and increase of the SE signal at an edge caused by diffusion contrast



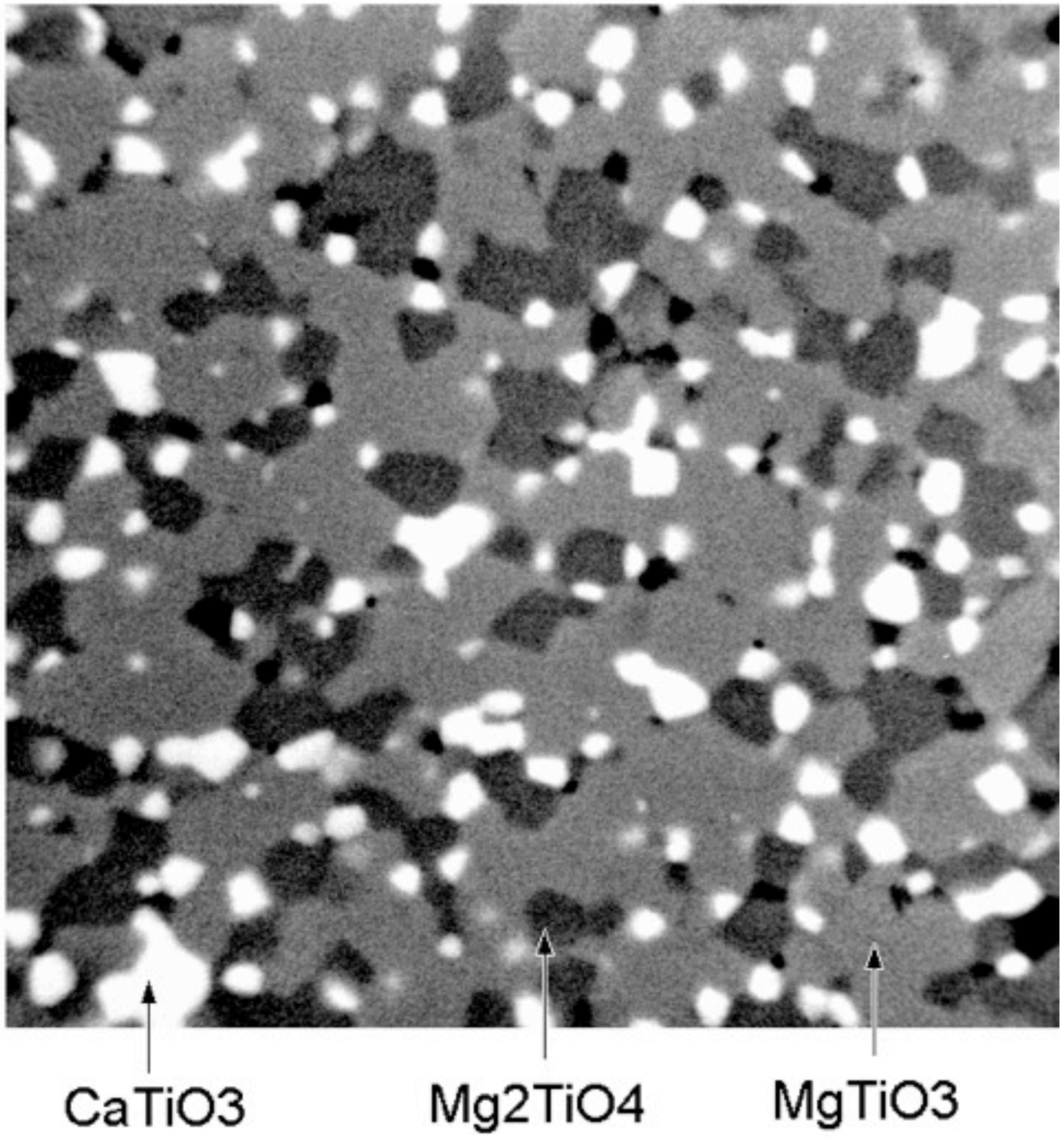


Backscattered Electrons

SE-Bild



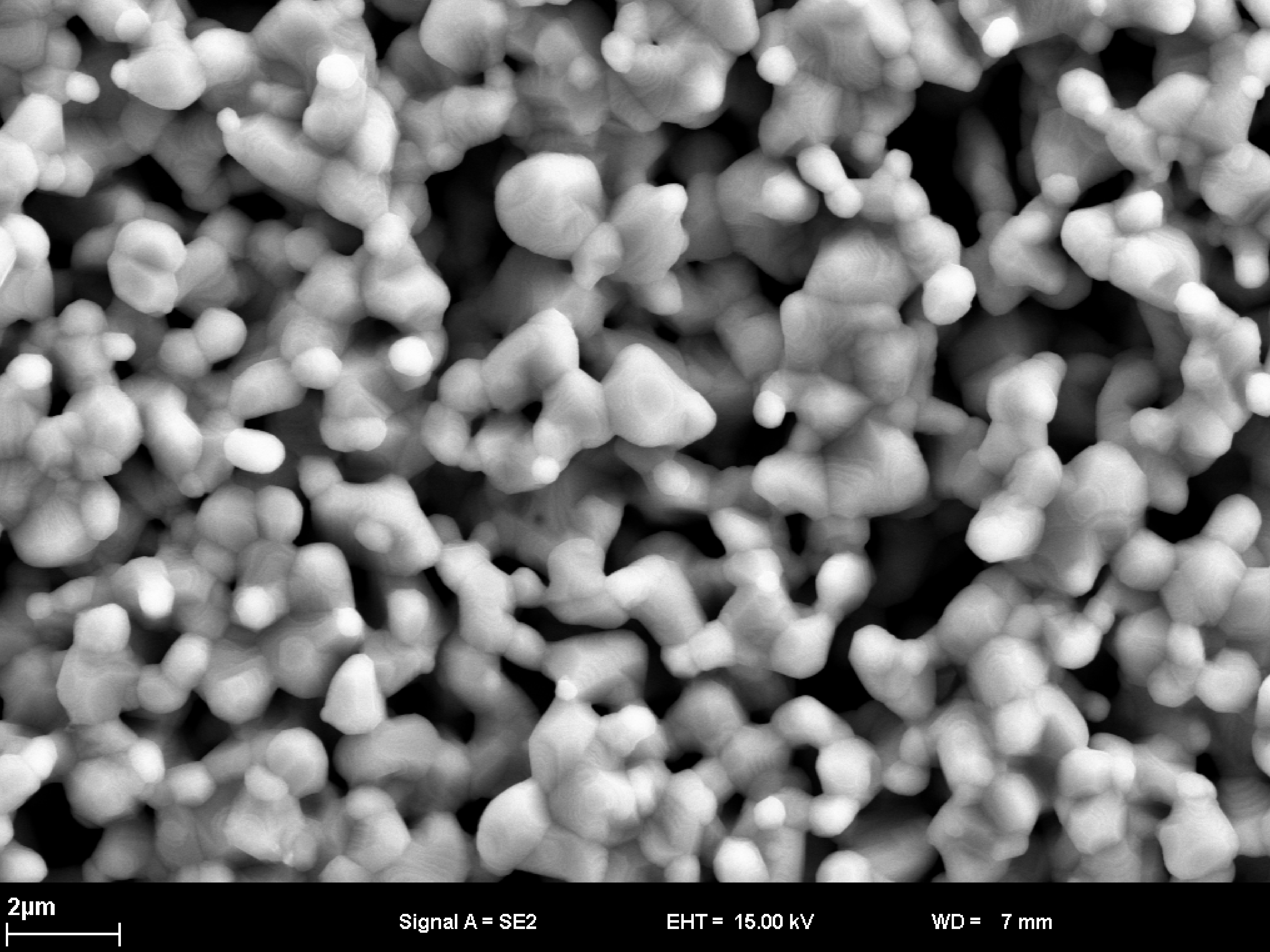
RE-Bild

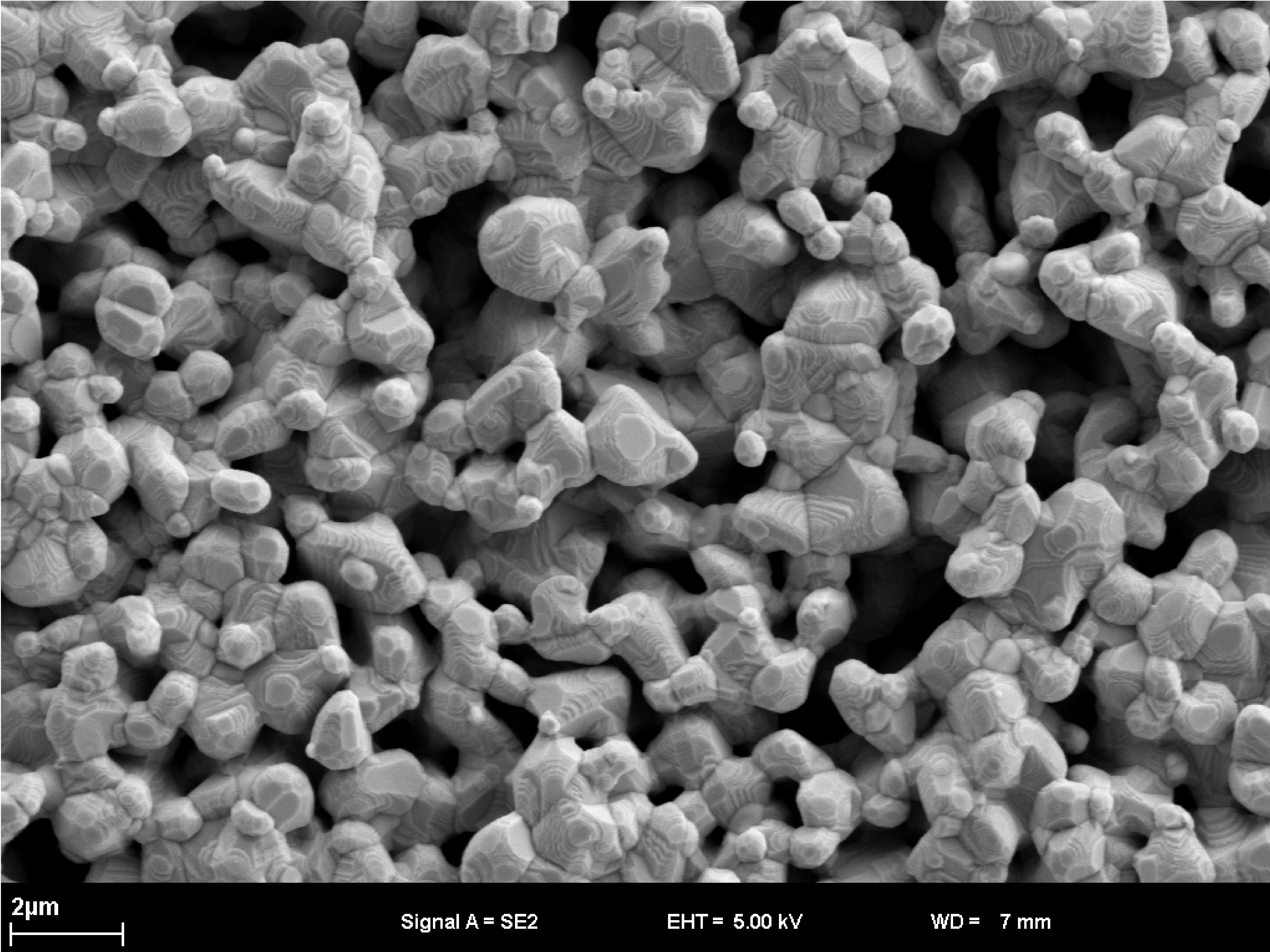


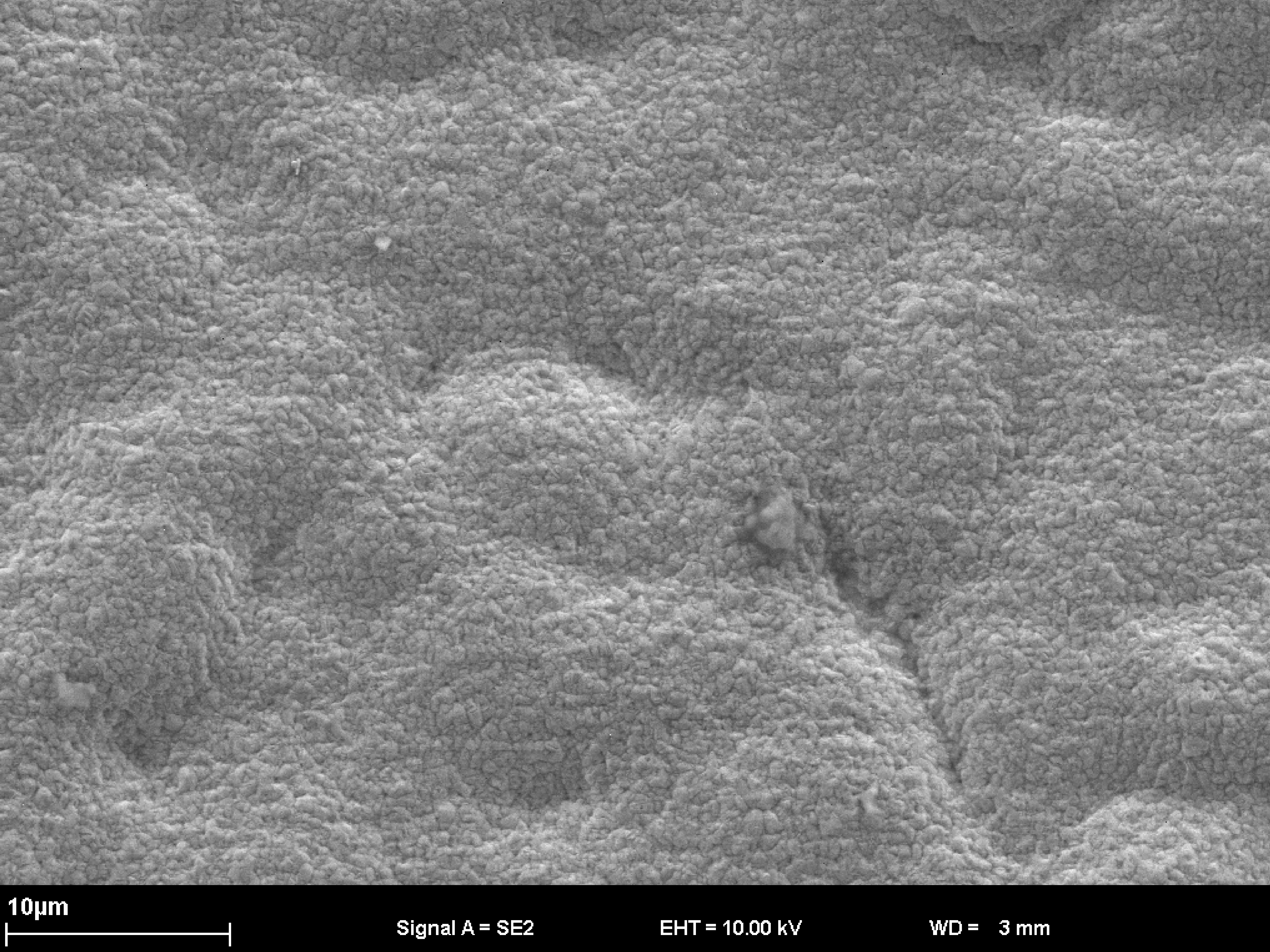
Präparation: Anschliff

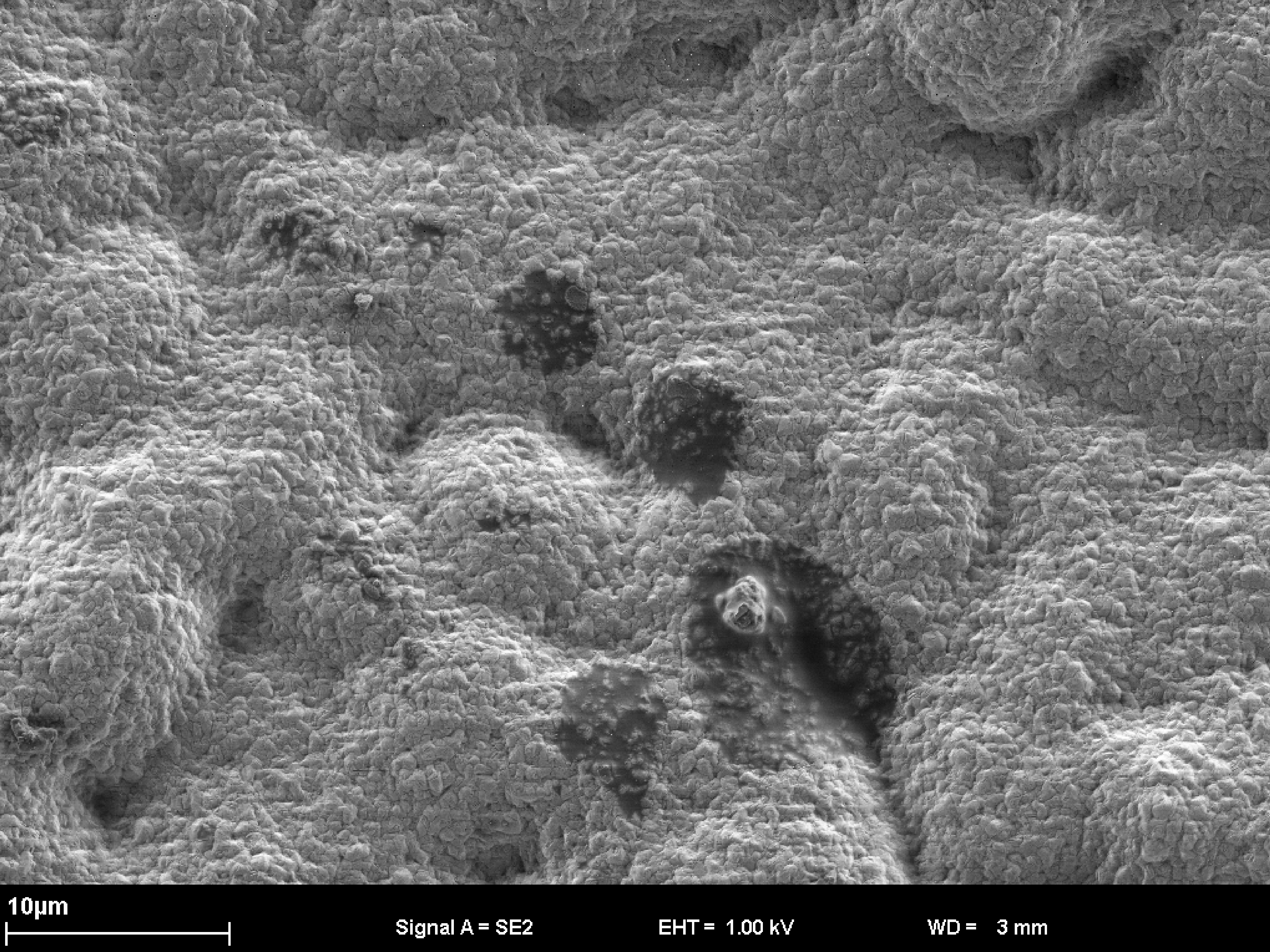
File: MgCaTi-Oxid

Accelerating Voltage

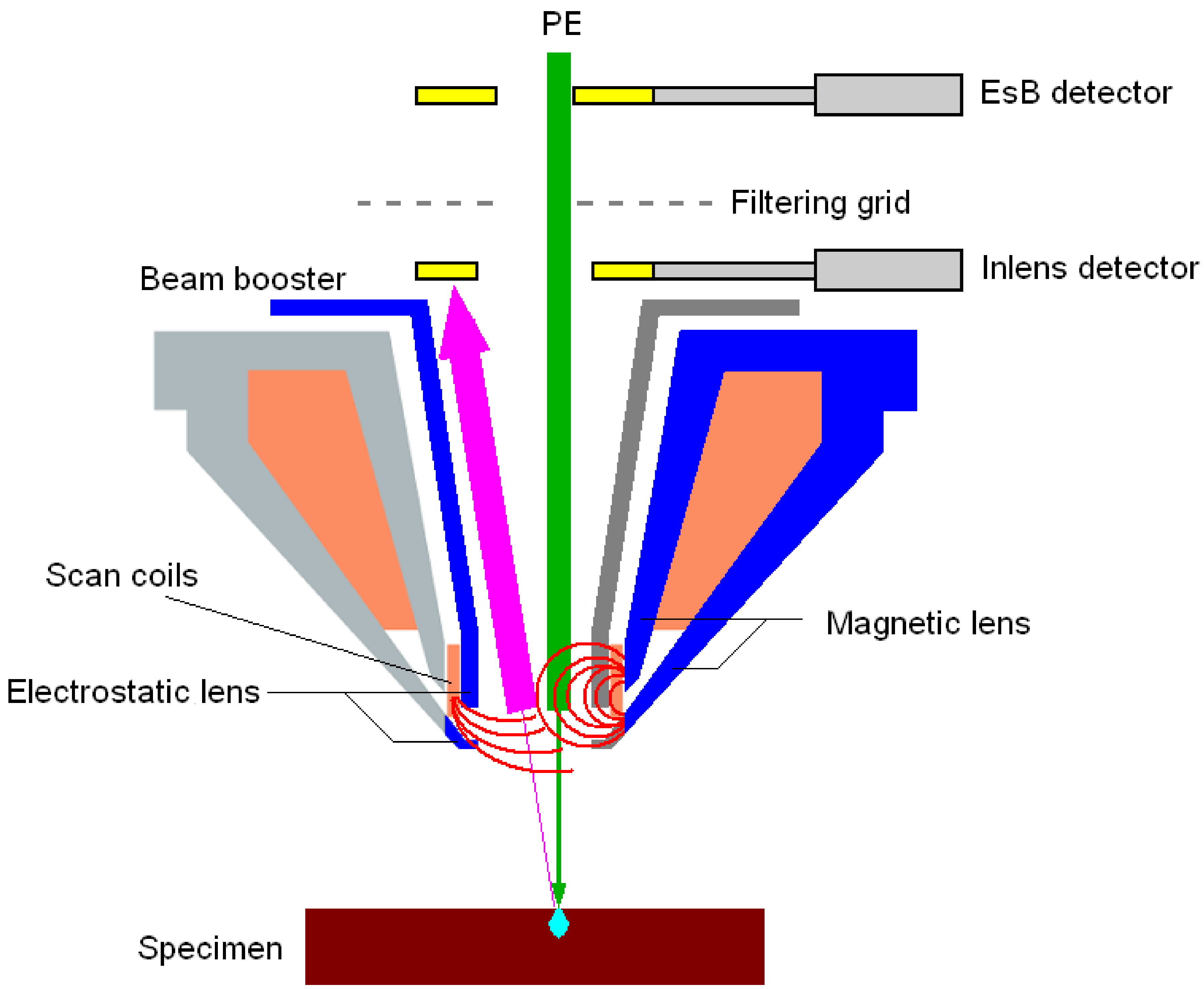

2µm
Signal A = SE2
EHT = 15.00 kV
WD = 7 mm


2µm
Signal A = SE2
EHT = 5.00 kV
WD = 7 mm

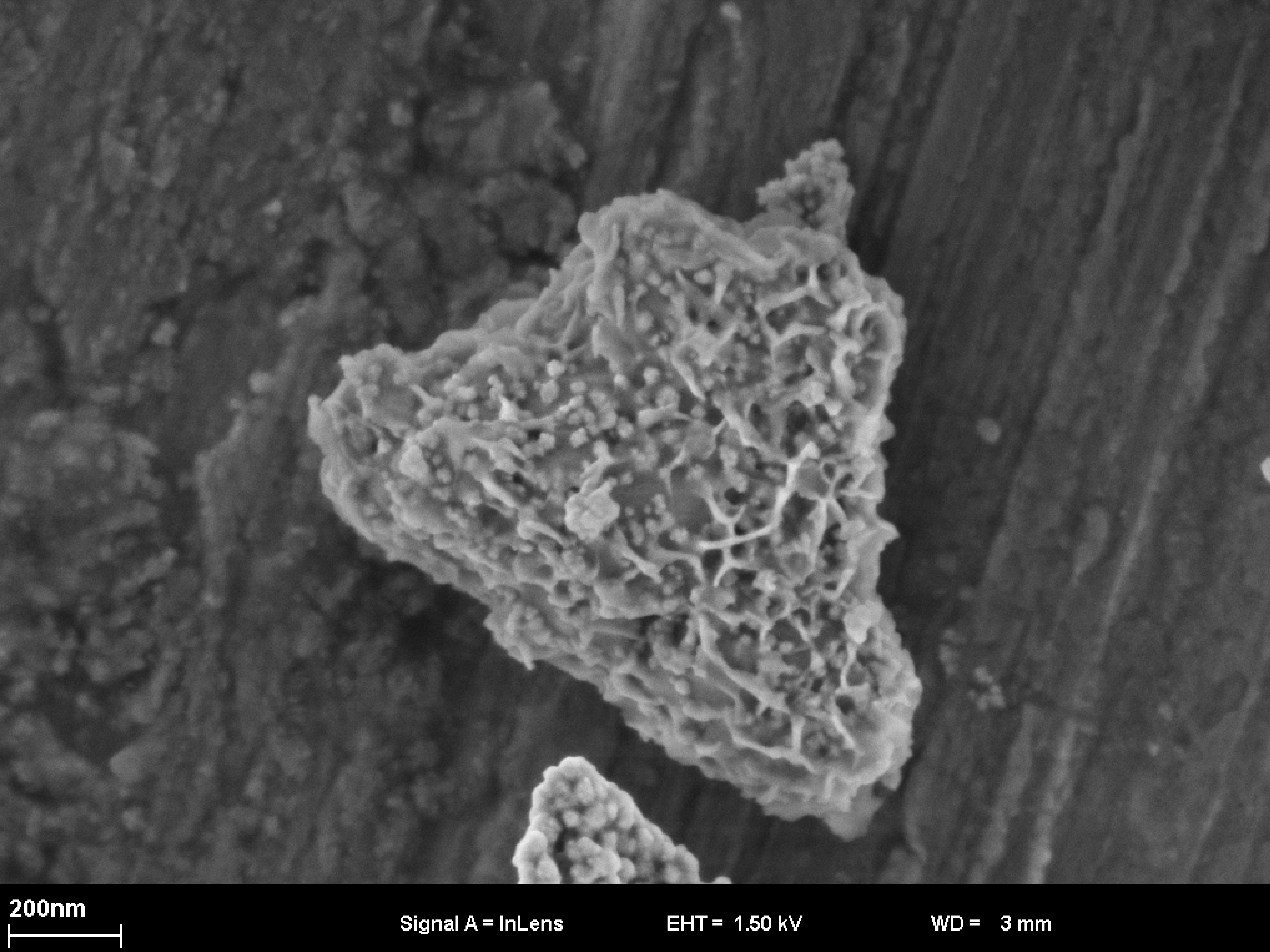

10µm
Signal A = SE2
EHT = 10.00 kV
WD =   3 mm

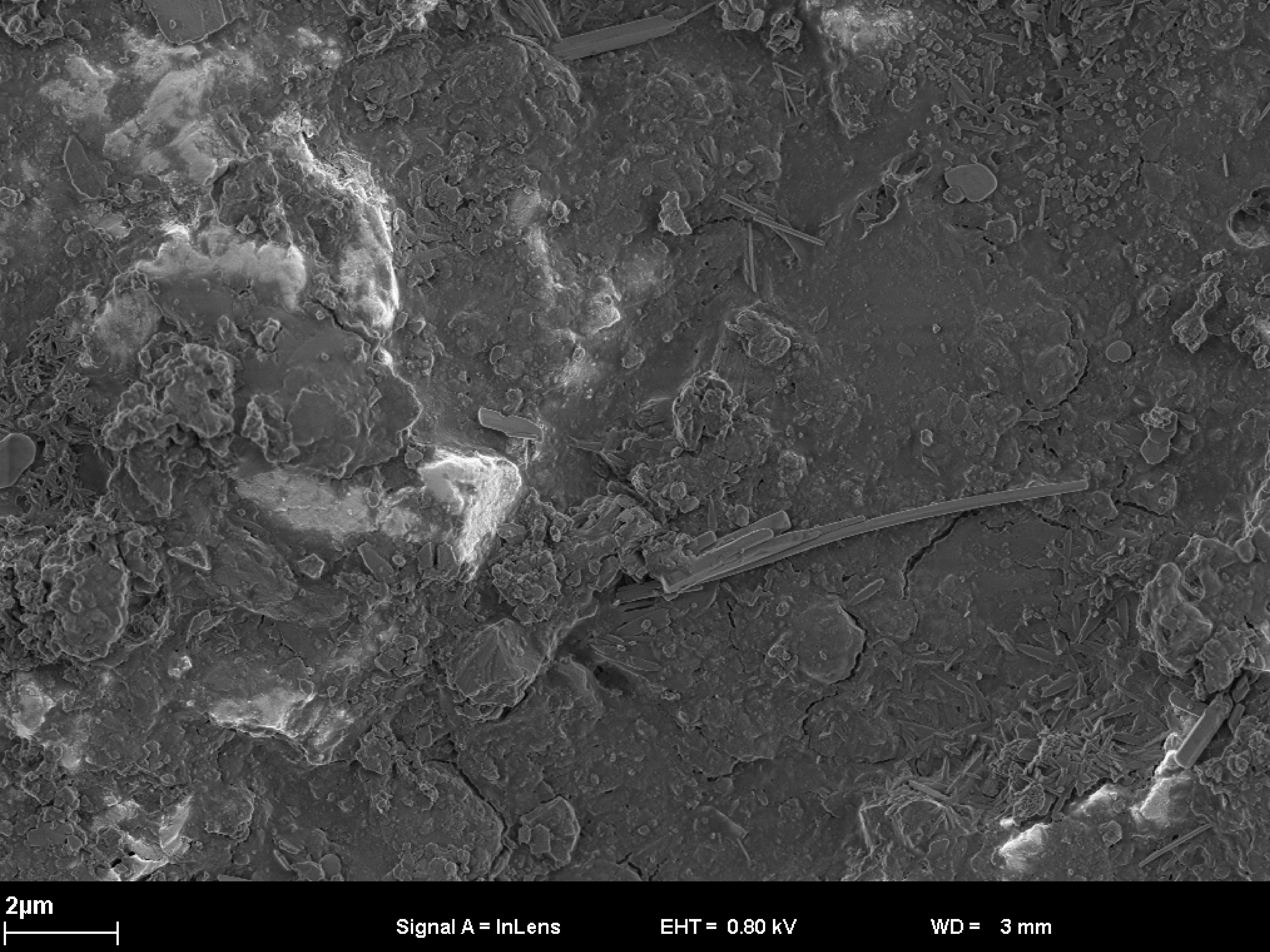

10µm
Signal A = SE2
EHT = 1.00 kV
WD = 3 mm

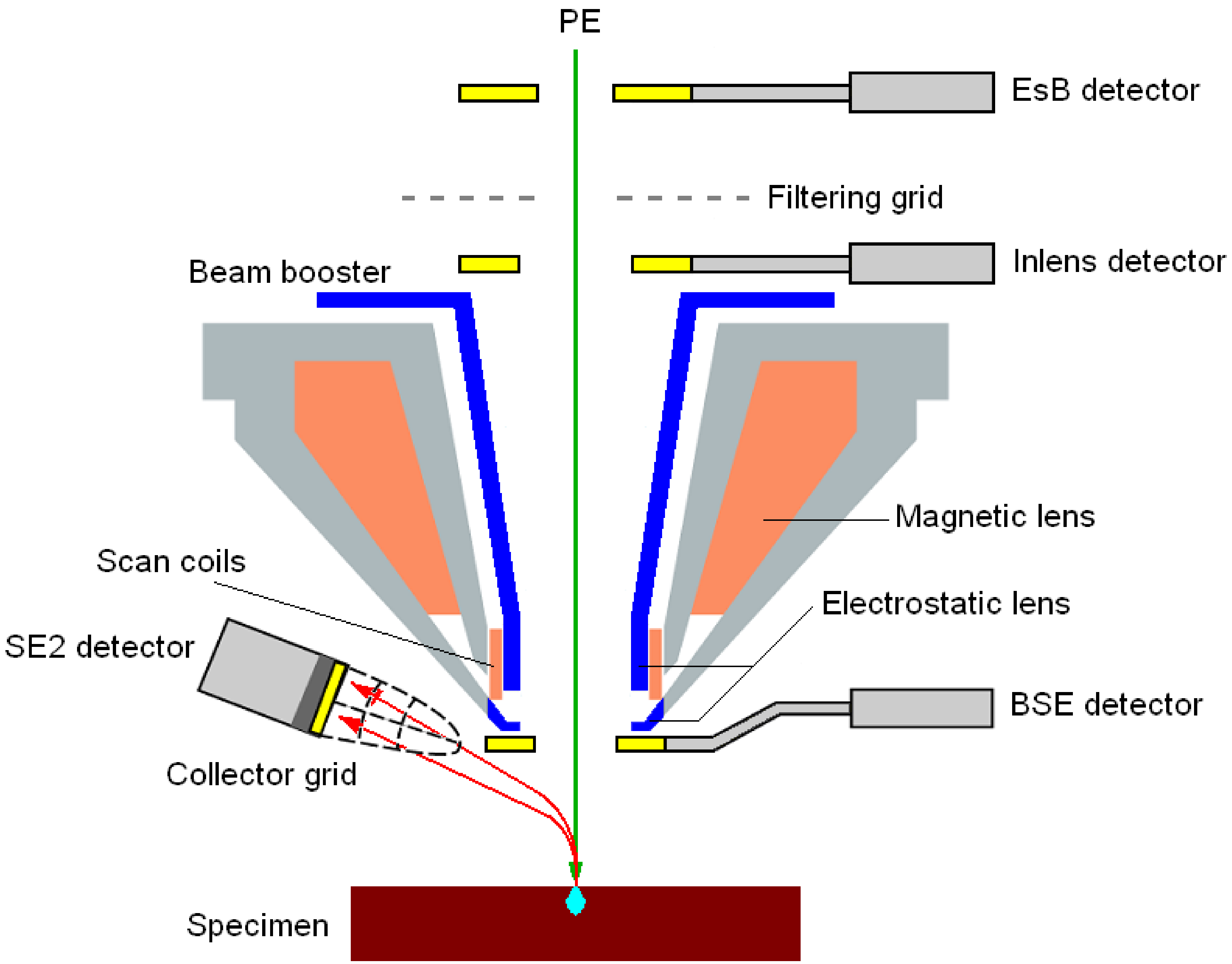
Detectors



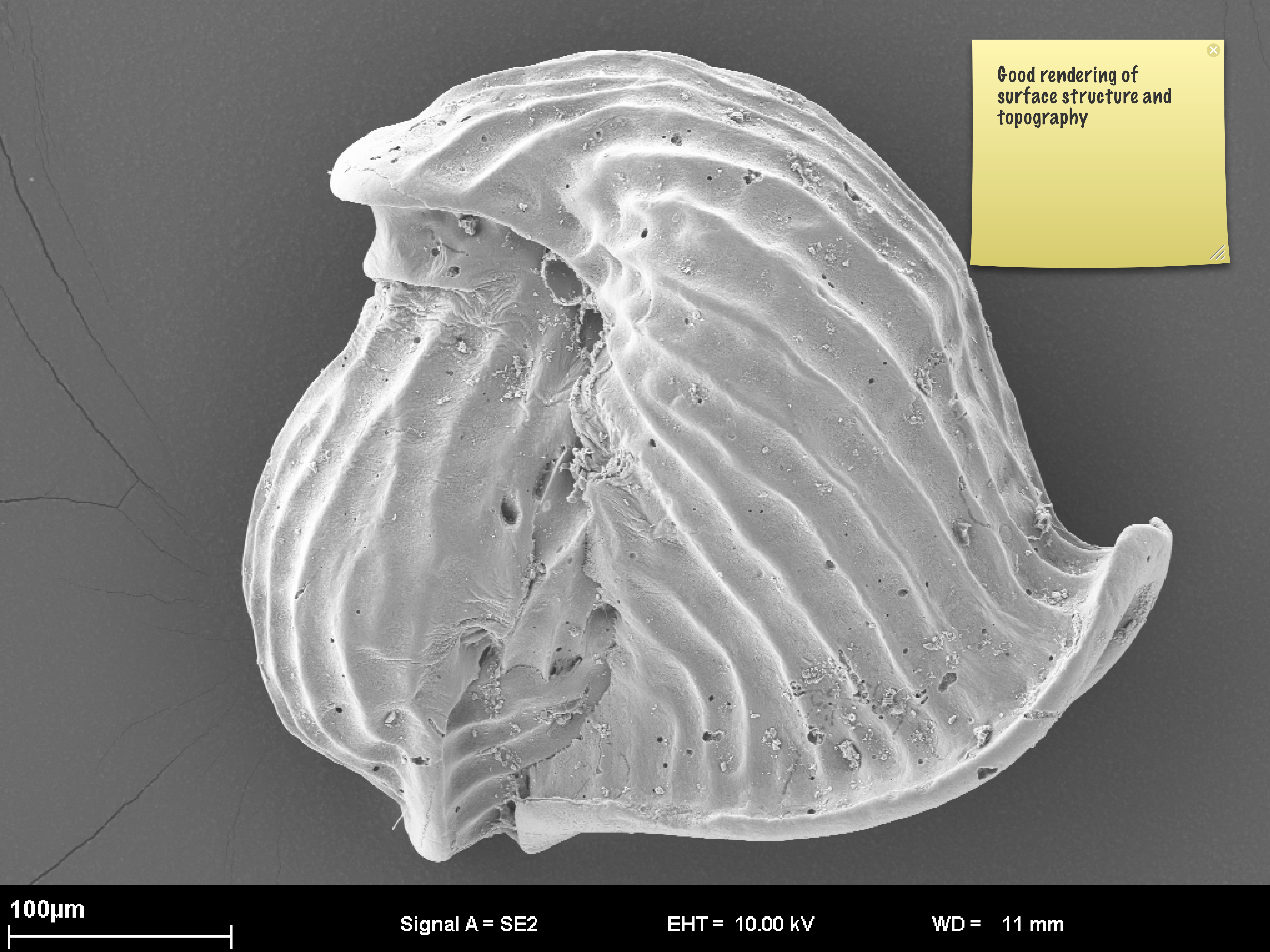
In-lense Detector


200nm
Signal A = InLens
EHT = 1.50 kV
WD = 3 mm

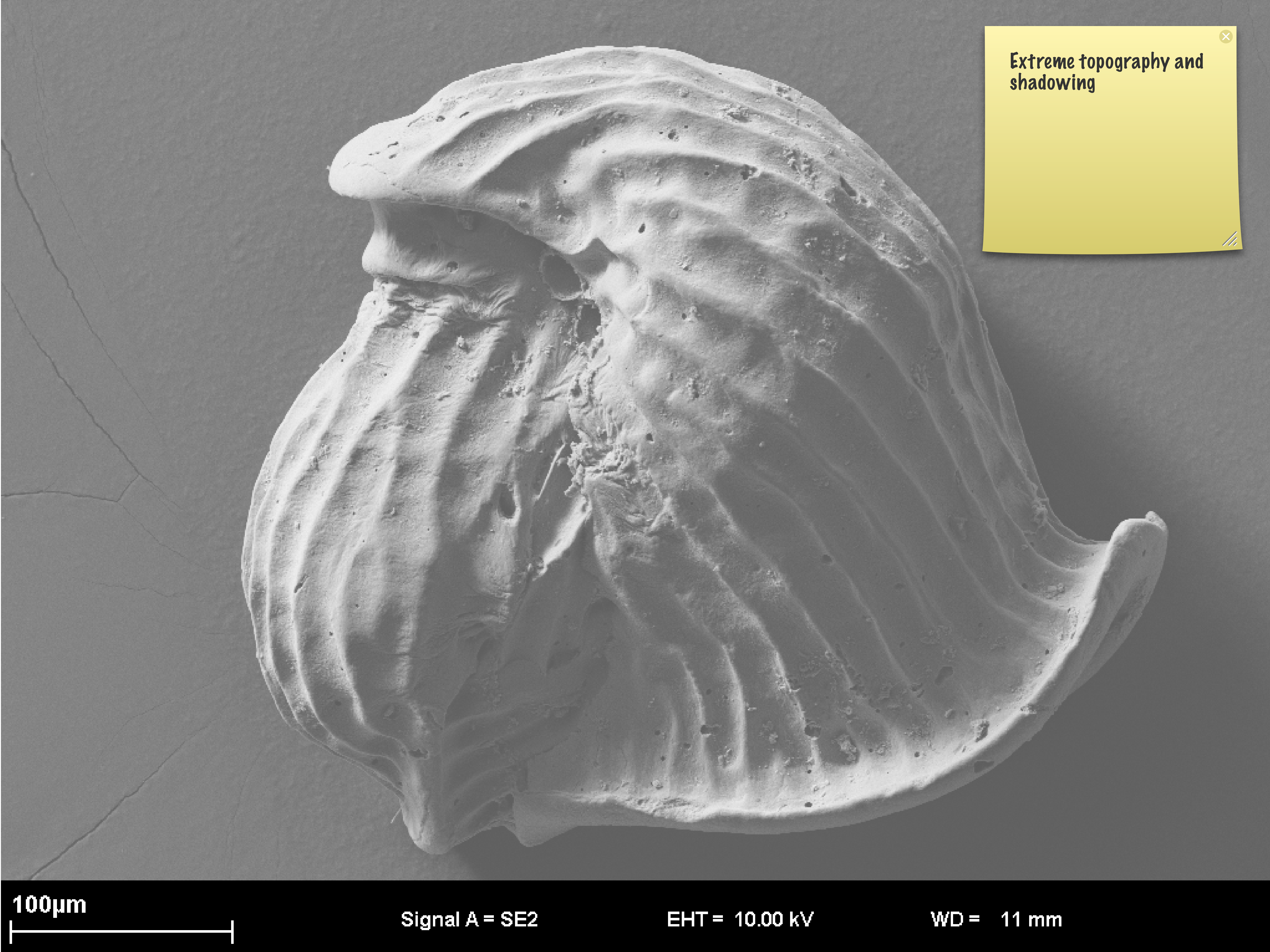

2µm
Signal A = InLens
EHT = 0.80 kV
WD = 3 mm



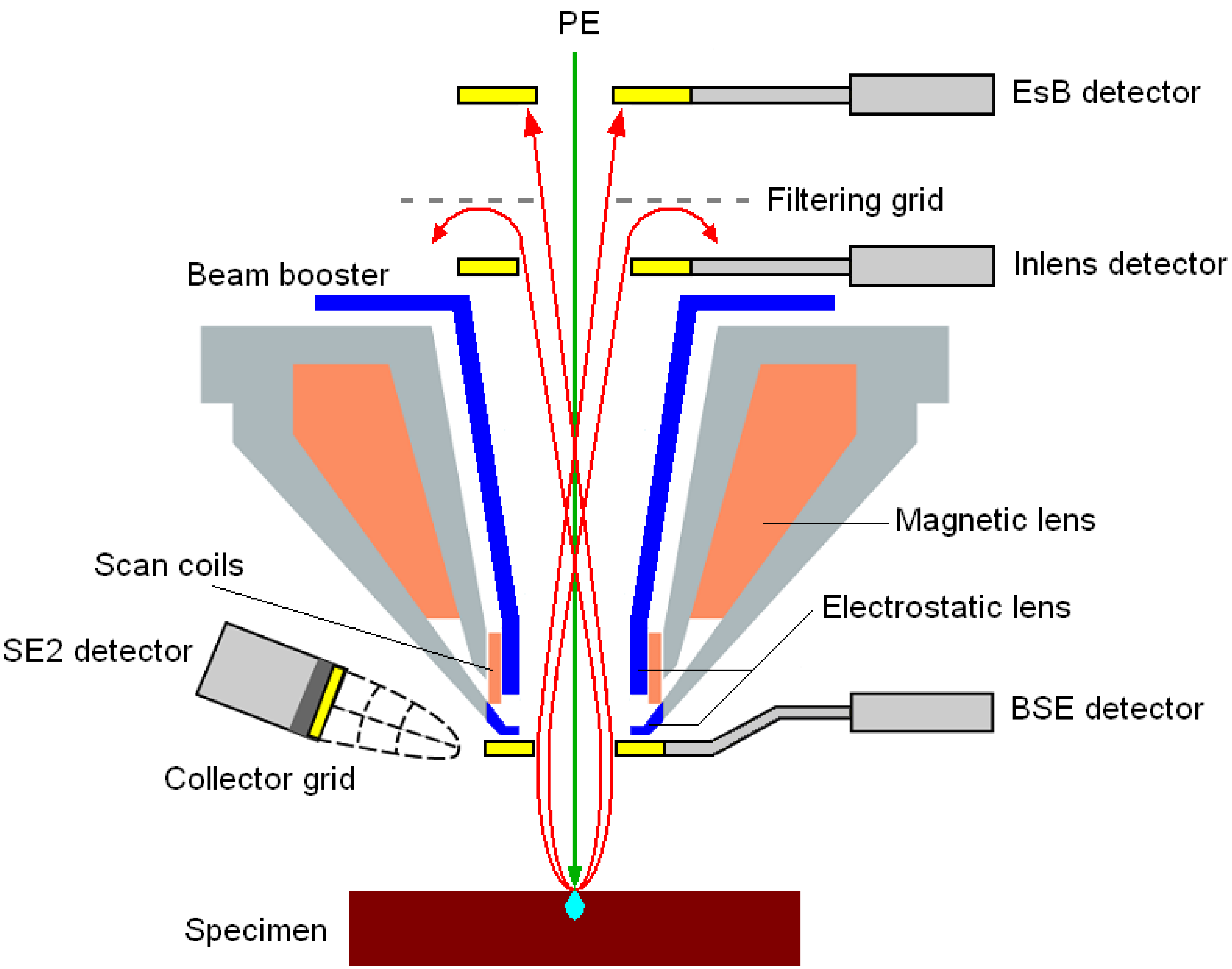
Everhart-Thornley Detector



Good rendering of surface structure and topography

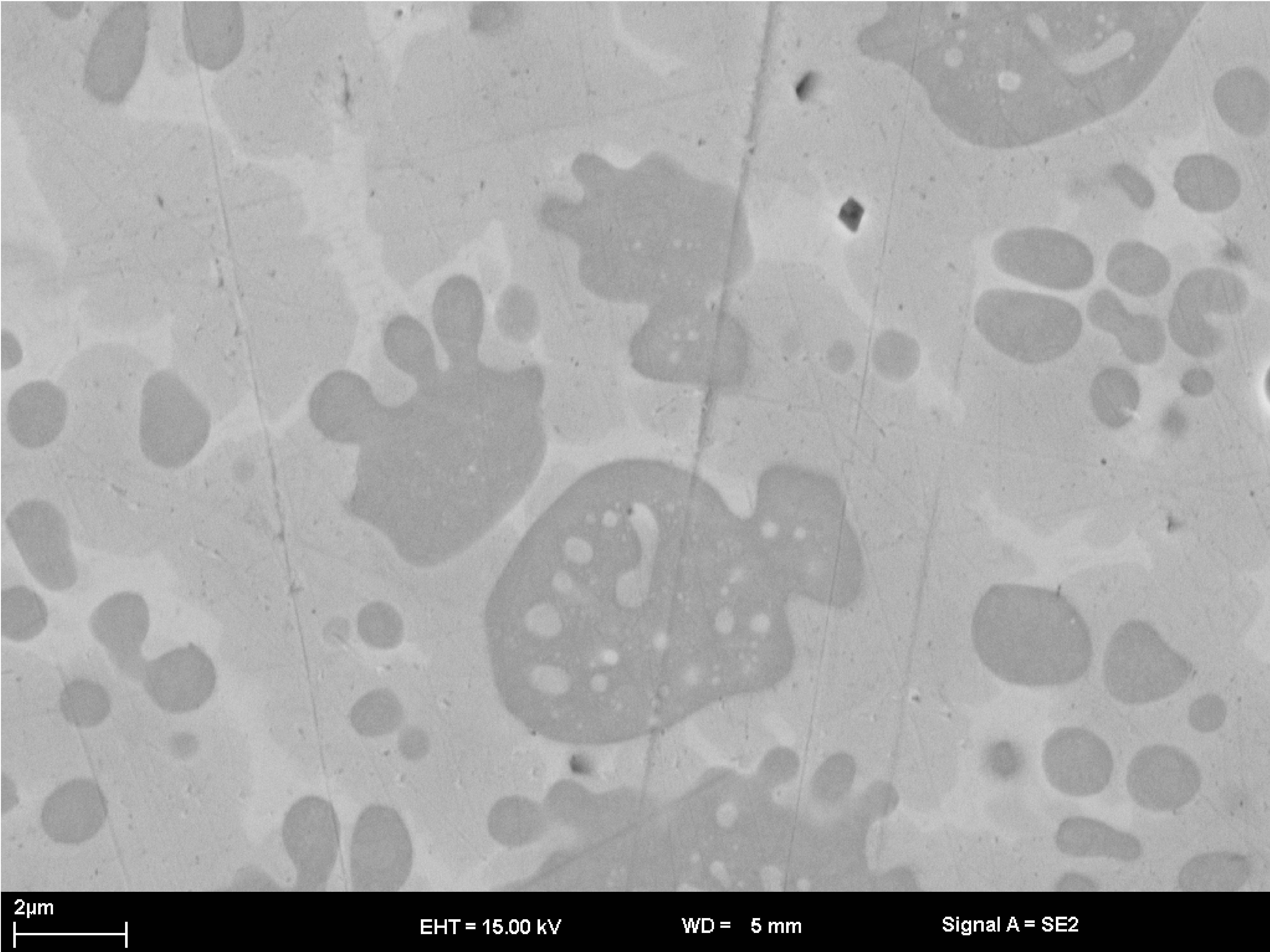


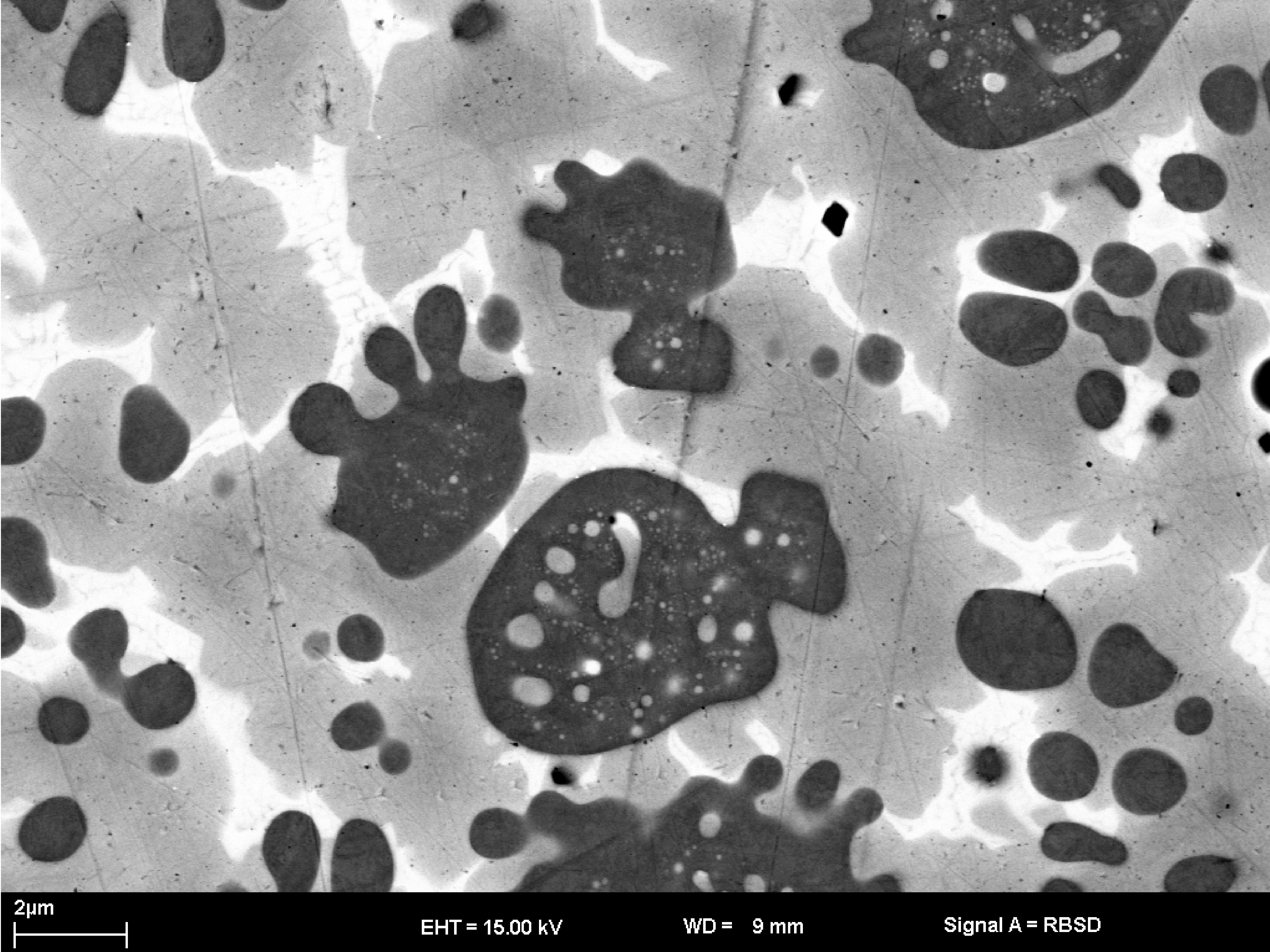
Extreme topography and shadowing

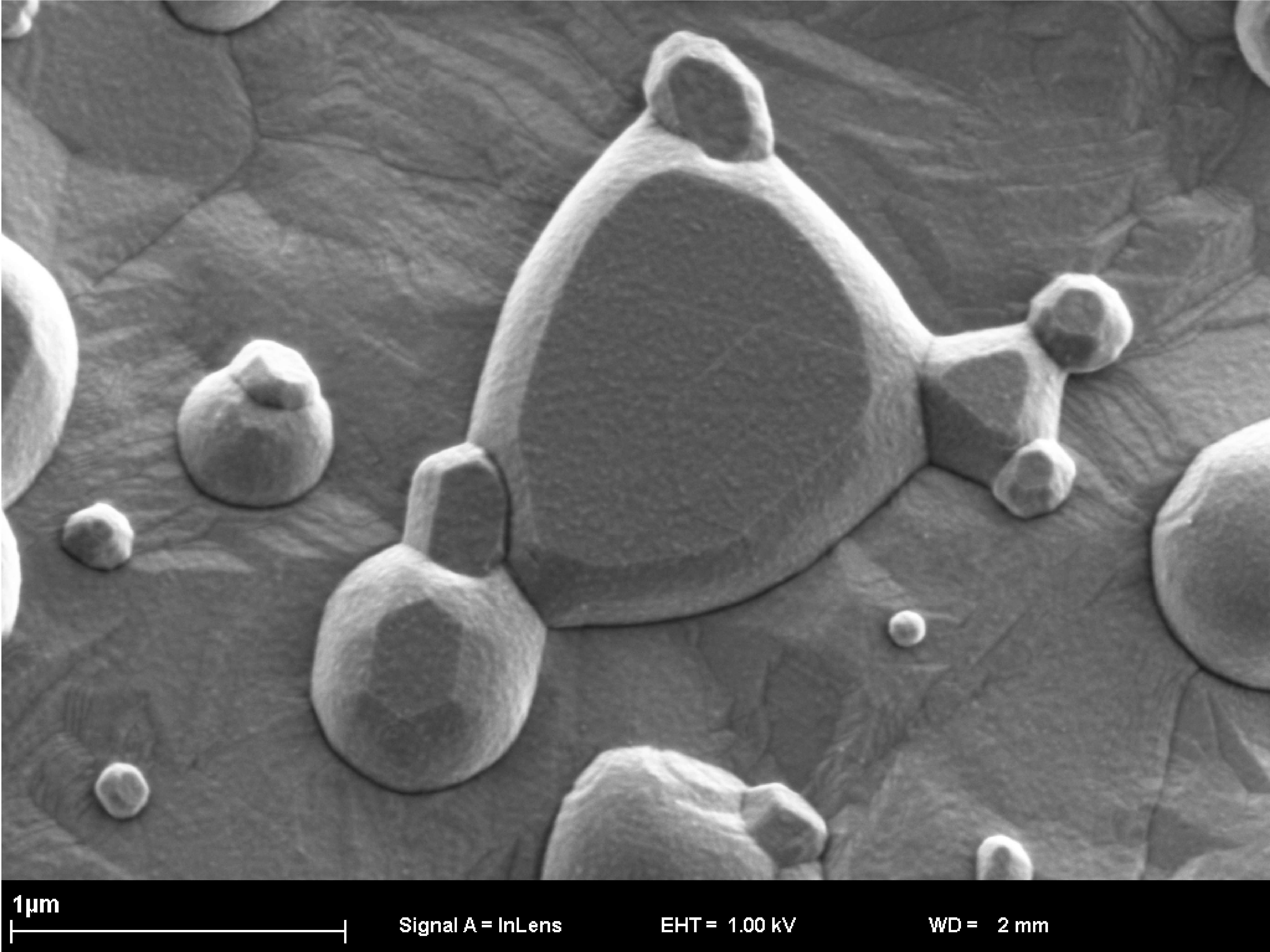


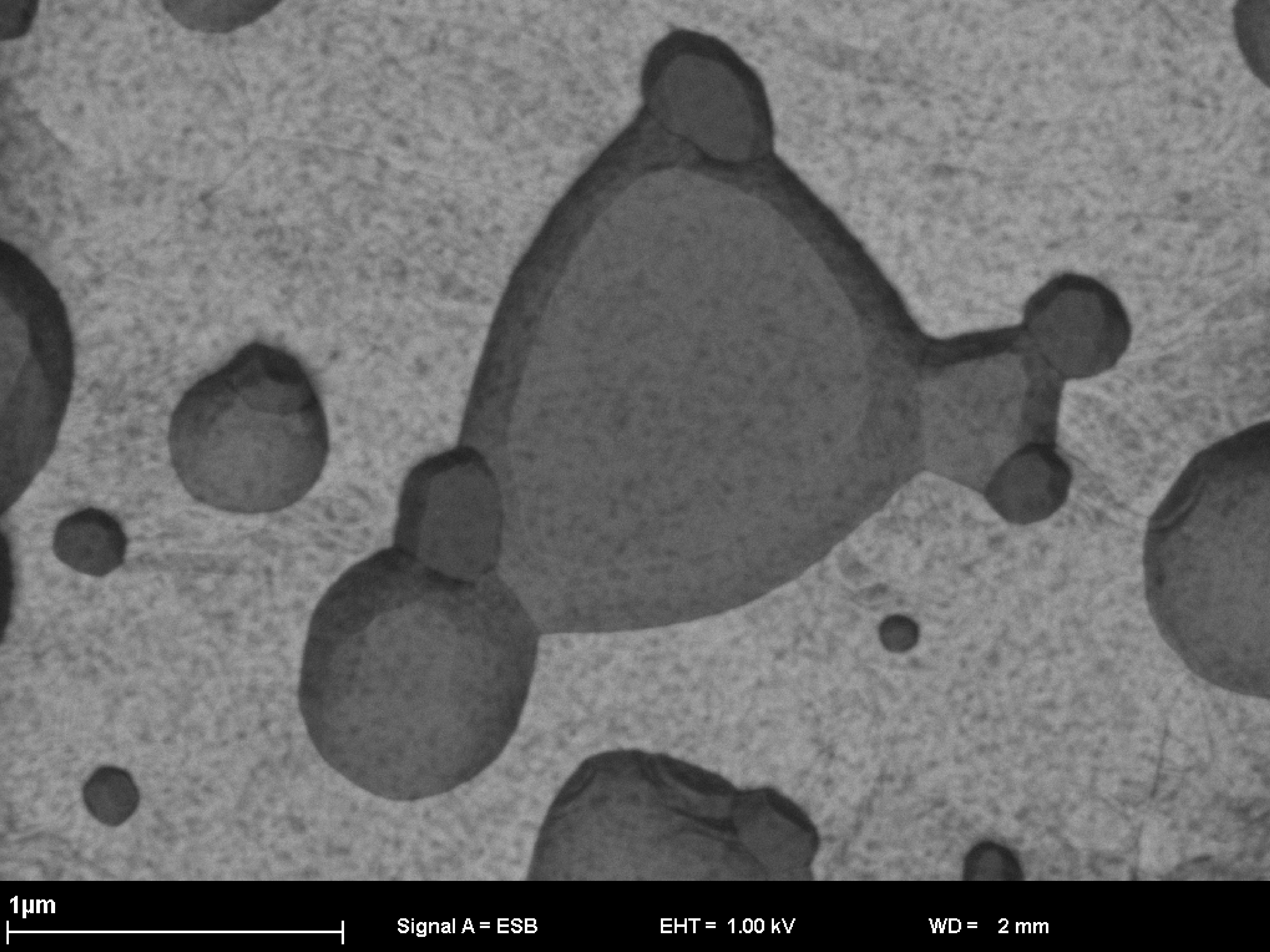
ESB Detector

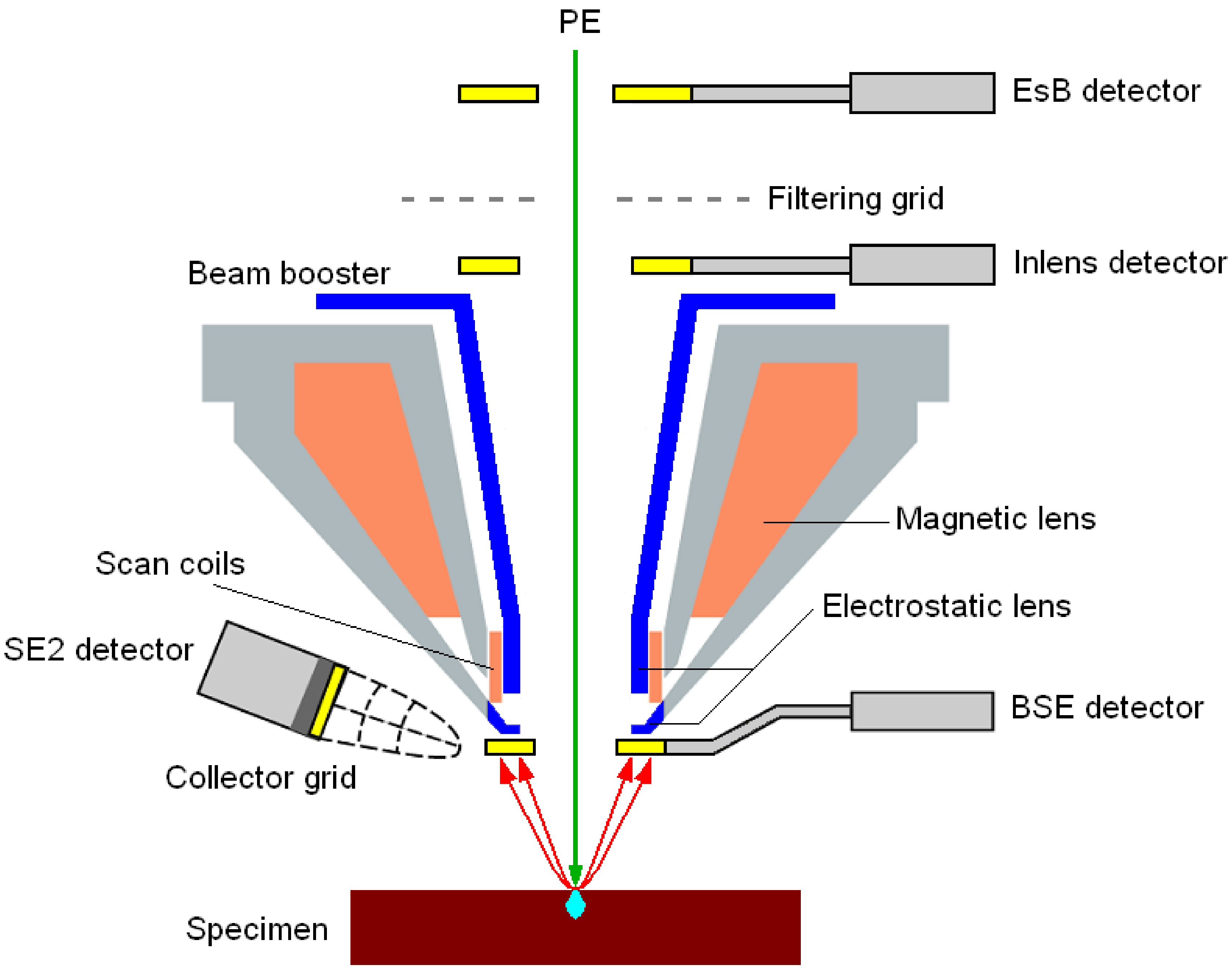
Energy and angle selective BSE


2µm
EHT = 15.00 kV
WD = 5 mm
Signal A = SE2

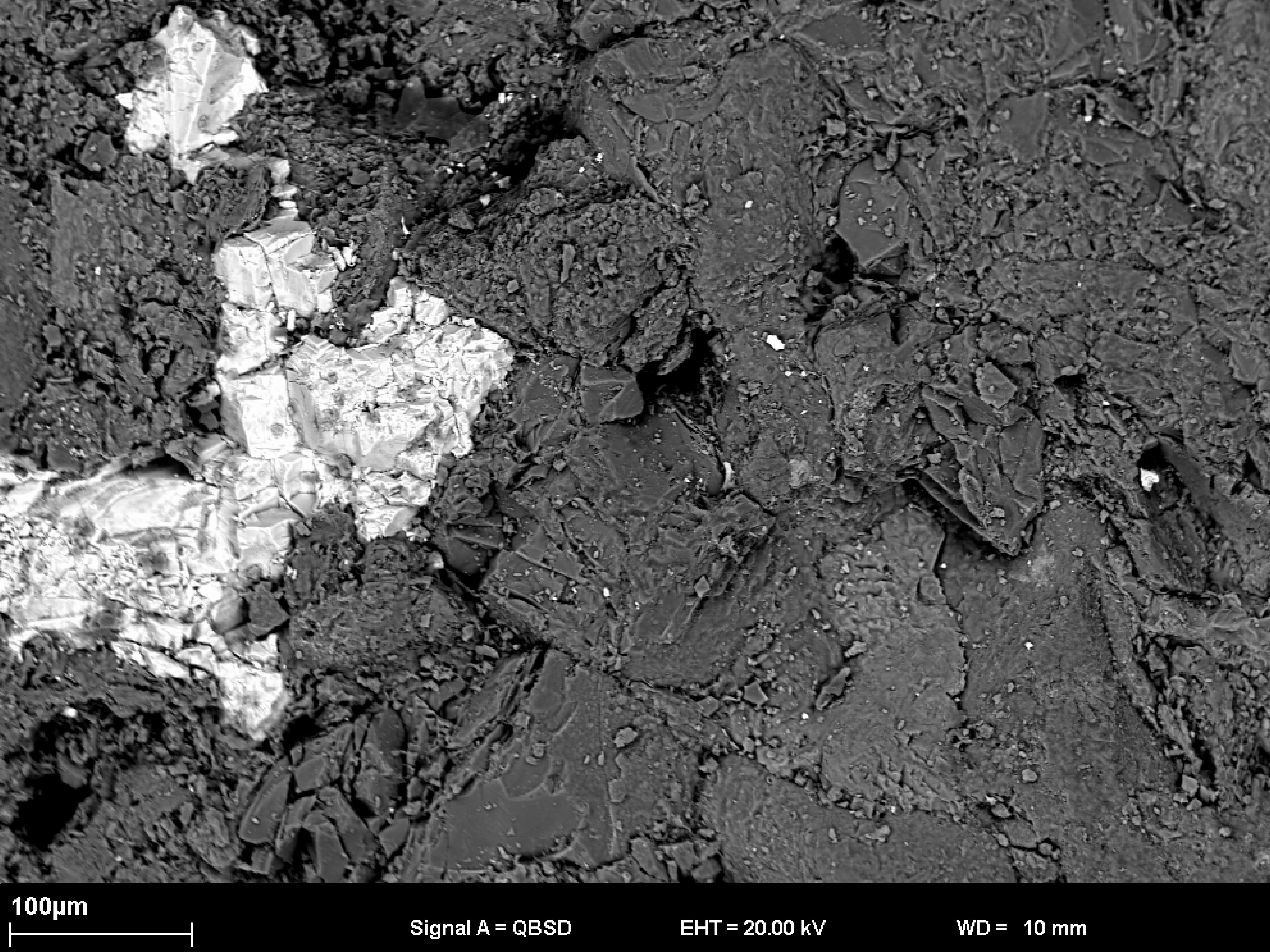

2µm
EHT = 15.00 kV
WD = 9 mm
Signal A = RBSD

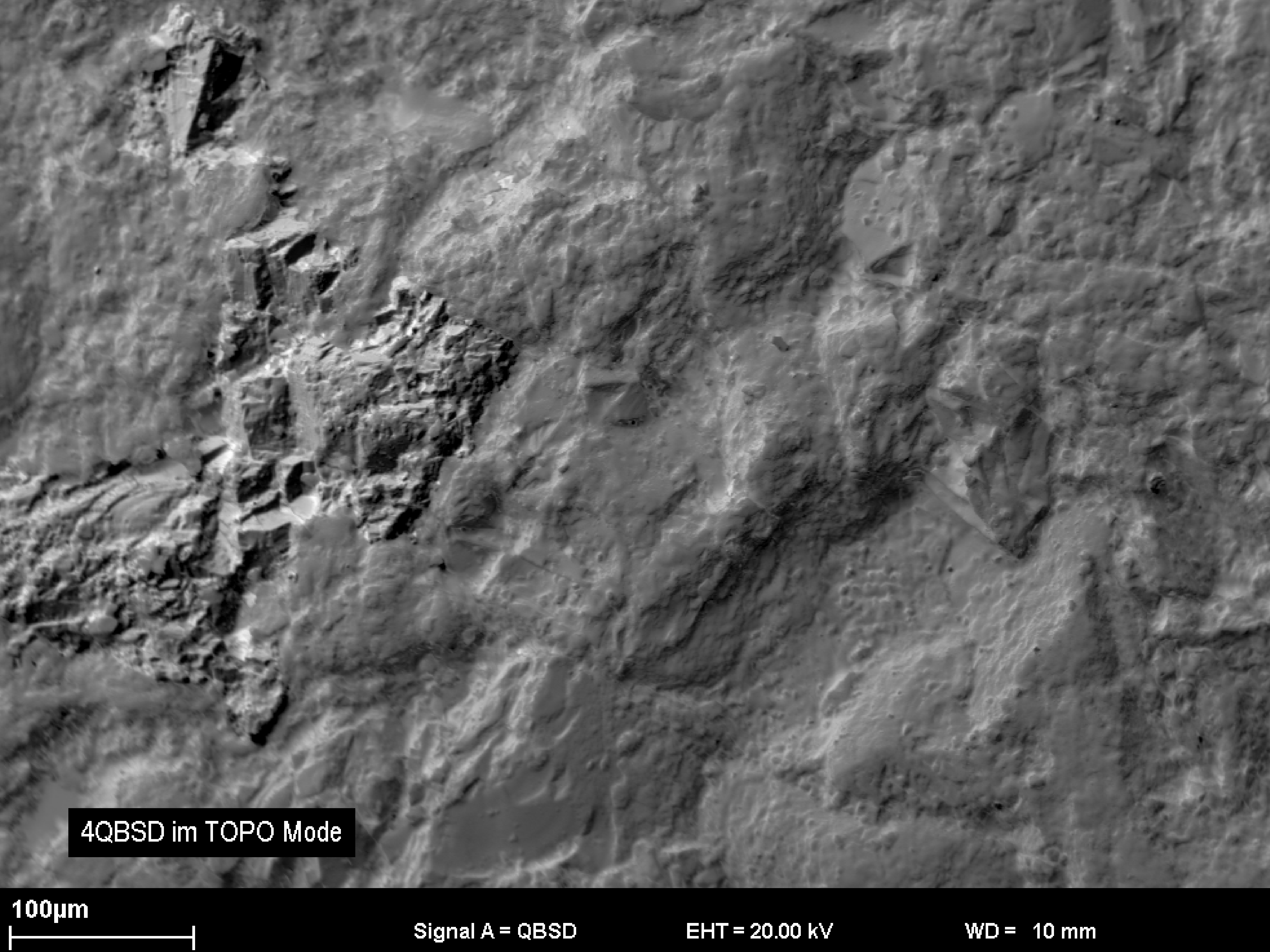

1µm
Signal A = InLens
EHT = 1.00 kV
WD = 2 mm


1µm
Signal A = ESB
EHT = 1.00 kV
WD = 2 mm

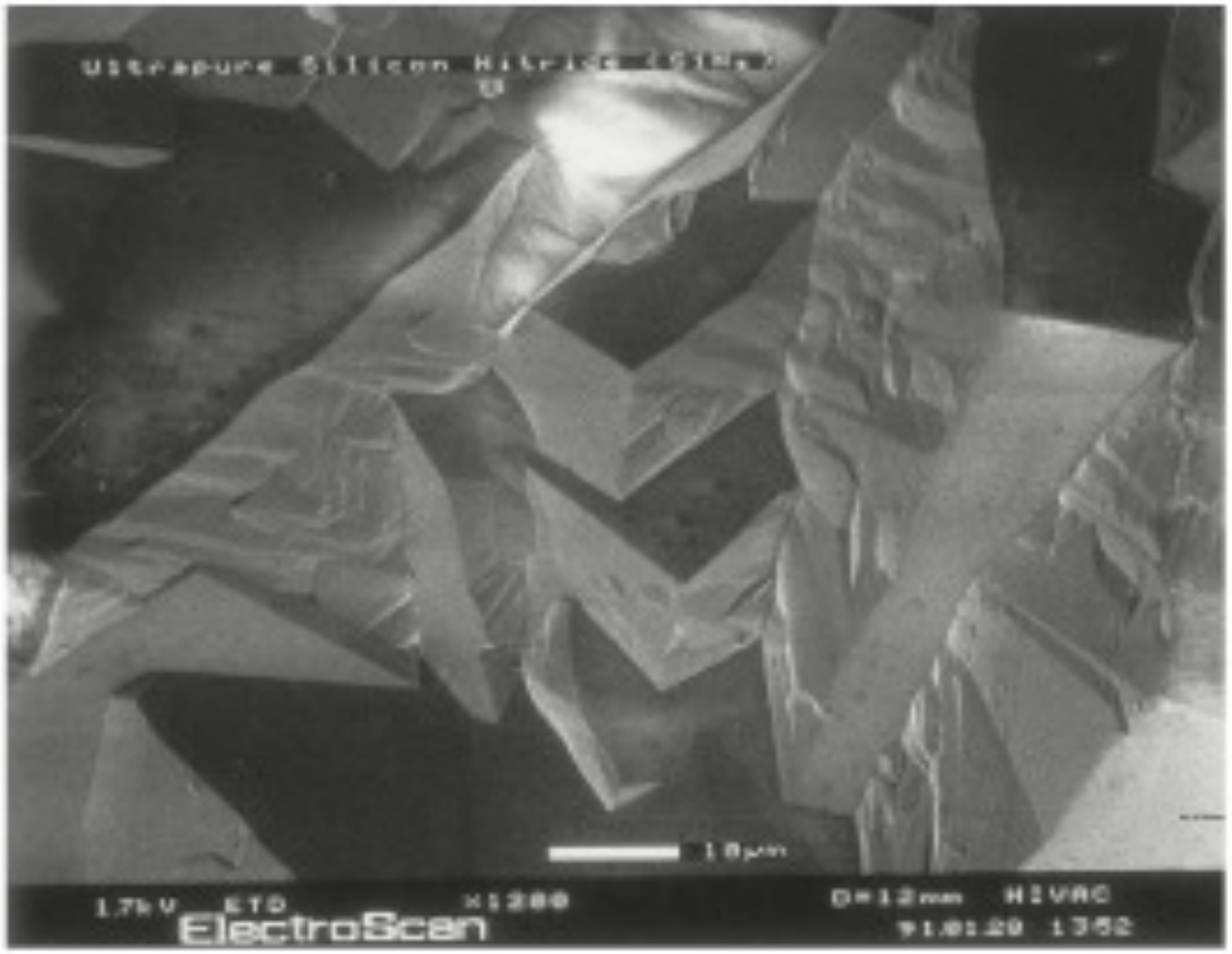


BSE Detector


100µm
Signal A = QBSD
EHT = 20.00 kV
WD = 10 mm


4QBSD im TOPO Mode
100µm
Signal A = QBSD
EHT = 20.00 kV
WD = 10 mm

Suitable Samples

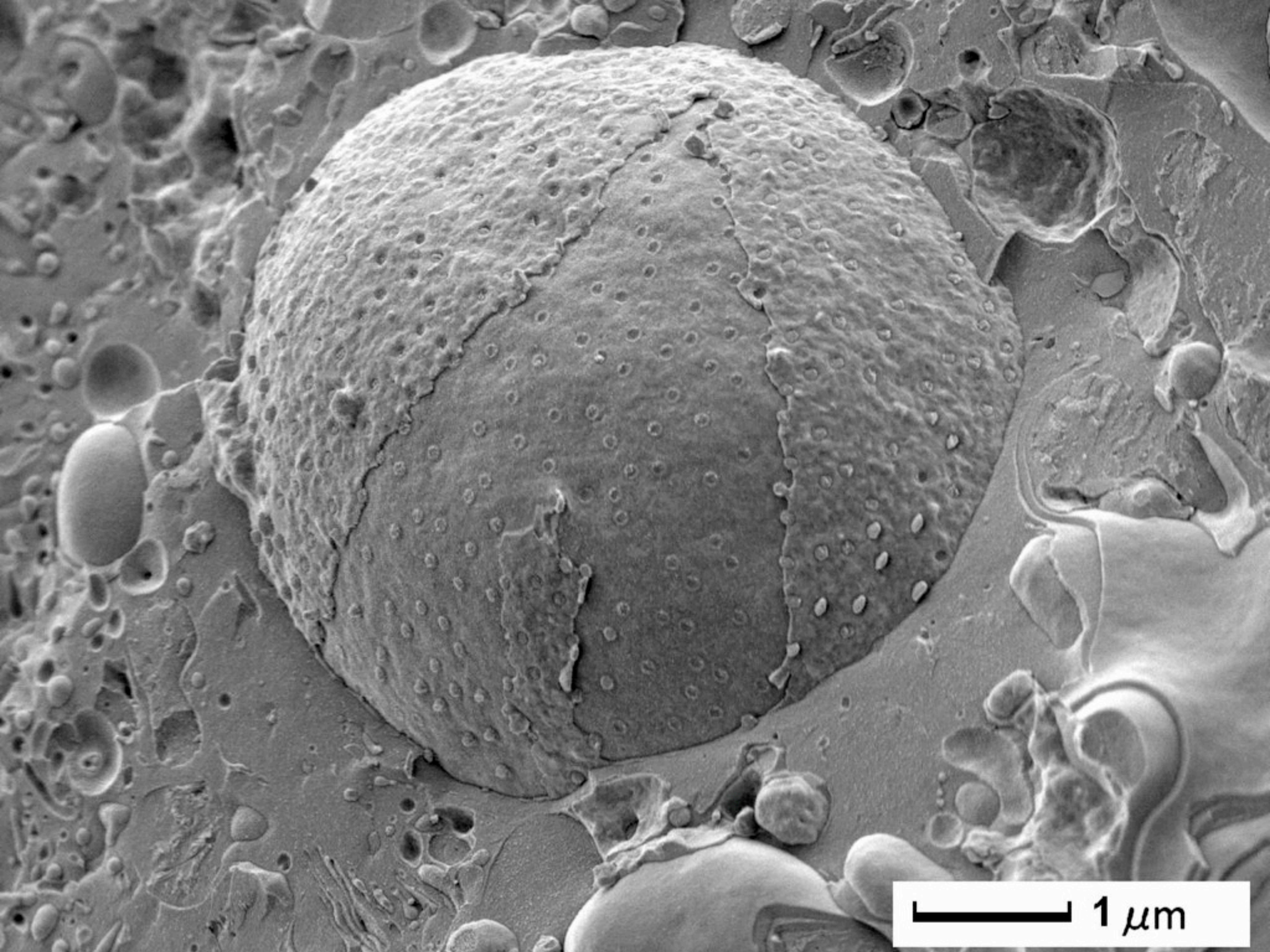


Charging Effects

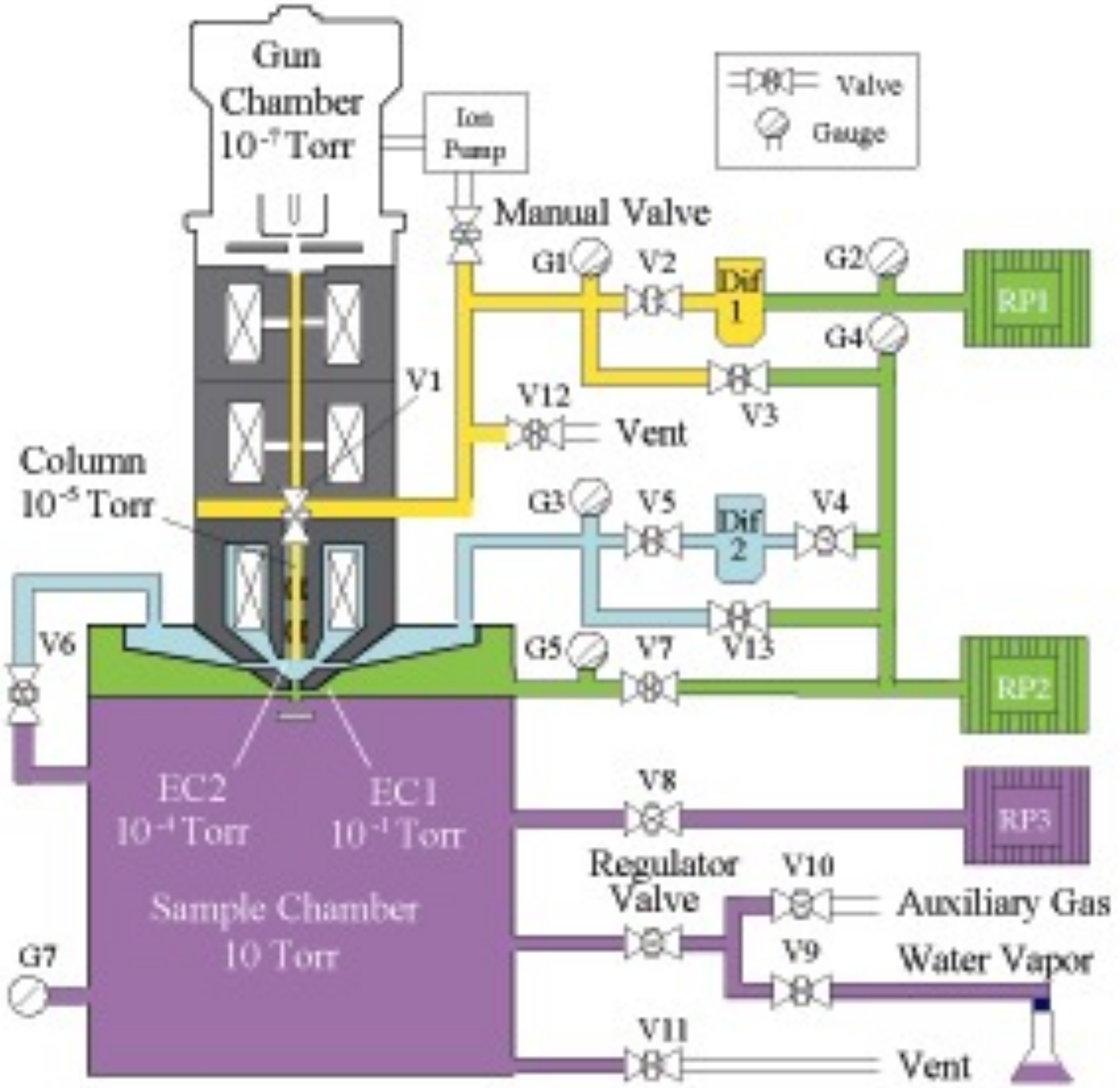

HUMMER VI
SPUTTERING SYSTEM
VACUUM GAUGE
PROCESS SELECT

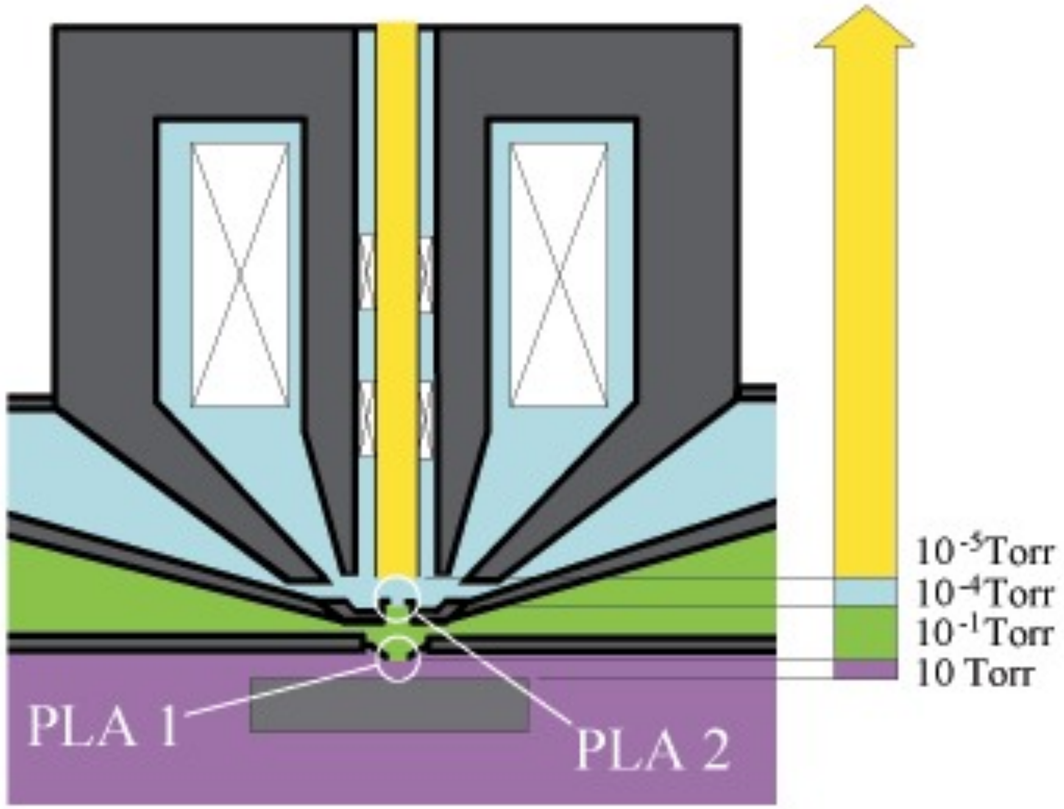
Special SEM

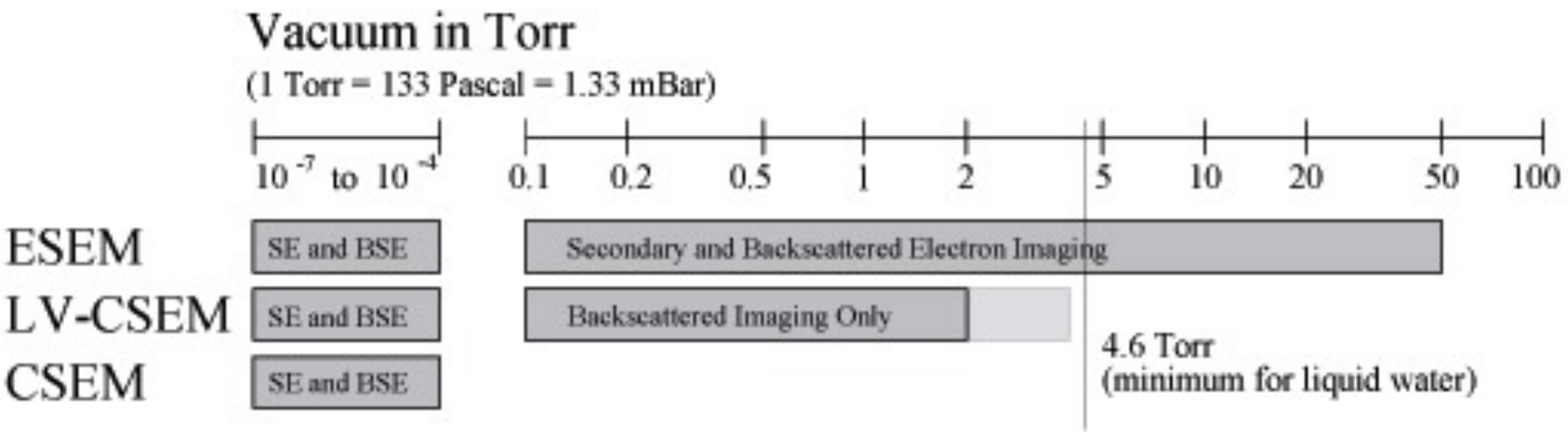
Cryo-SEM

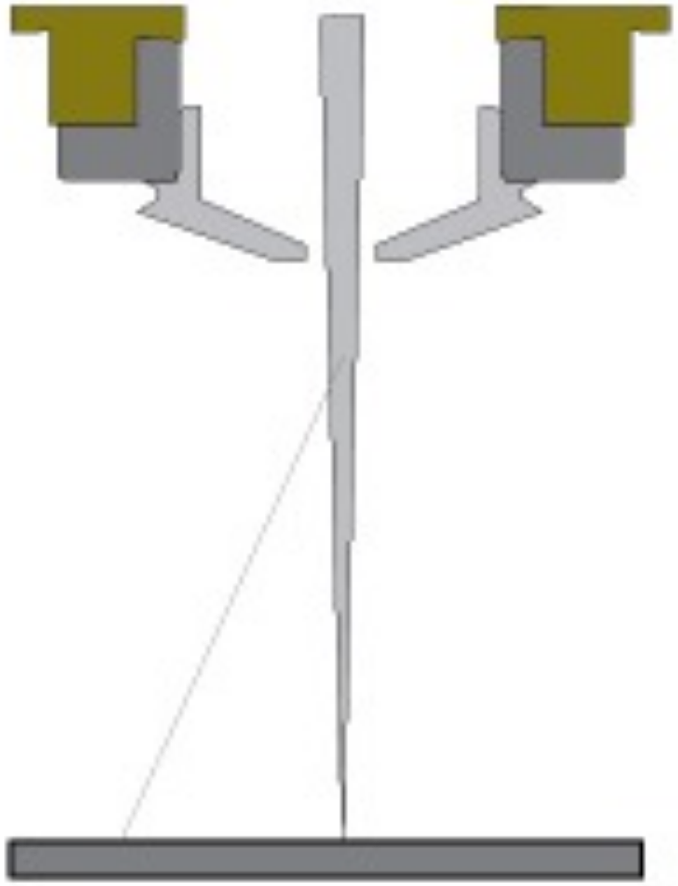

1 μm

Environmental SEM

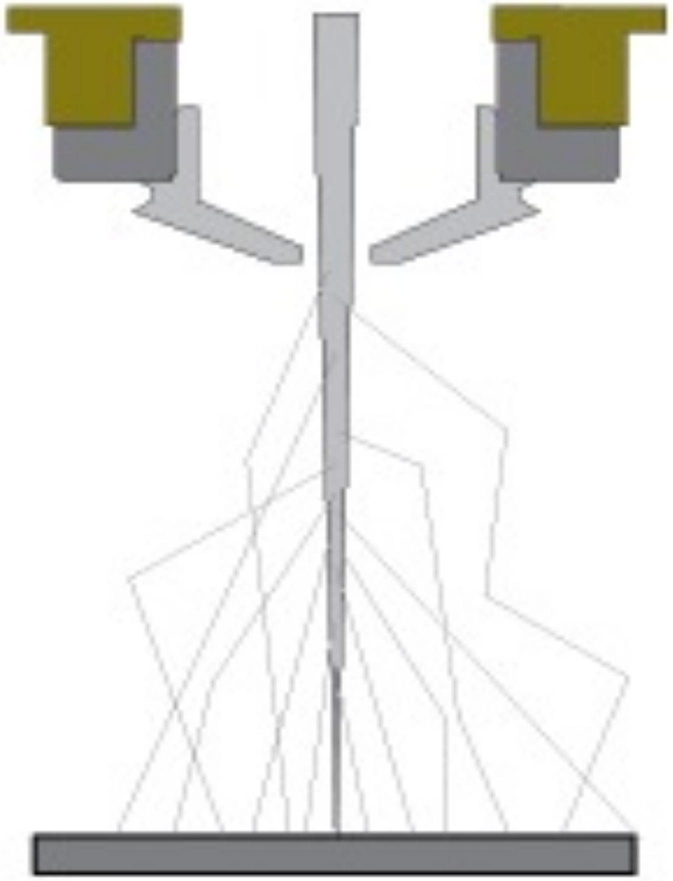

Gun Chamber 10^-7 Torr
Ion Pump
Valve
Gauge
Manual Valve
G1
V2
Dif 1
G2
RP1
G4
V1
V12
Vent
V3
Column 10^-5 Torr
G3
V5
Dif 2
V4
V6
G5
V7
V13
RP2
EC2 10^-4 Torr
EC1 10^-1 Torr
V8
RP3
Regulator Valve
V10
Auxiliary Gas
Sample Chamber 10 Torr
V9
Water Vapor
G7
V11
Vent


10^-5Torr
10^-4Torr
10^-1Torr
10 Torr
PLA 1
PLA 2

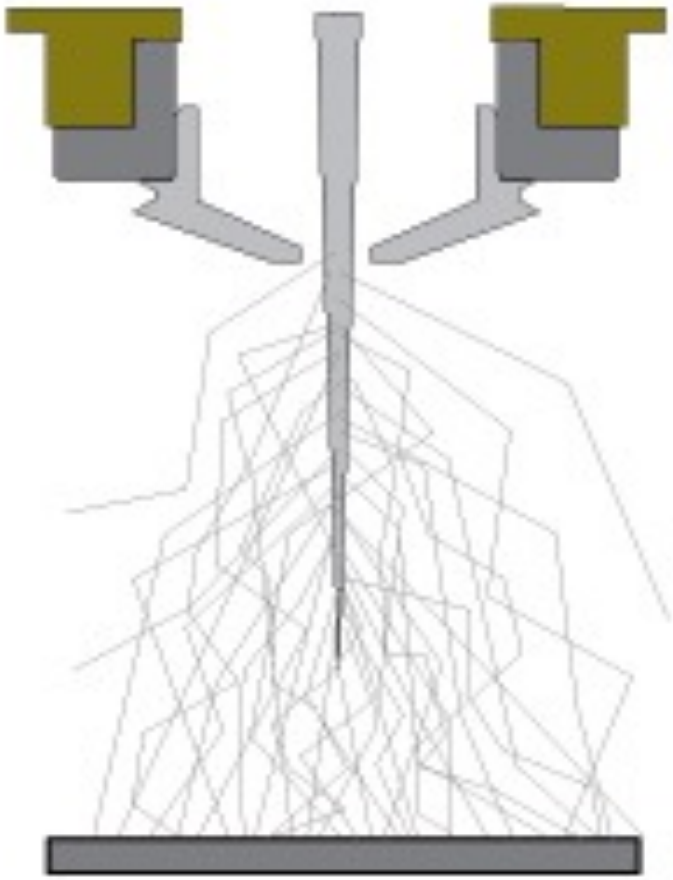

Vacuum in Torr
(1 Torr = 133 Pascal = 1.33 mBar)
10^-7 to 10^-4
0.1
0.2
0.5
1
2
5
10
20
50
100
ESEM
SE and BSE
Secondary and Backscattered Electron Imaging
LV-CSEM
SE and BSE
Backscattered Imaging Only
CSEM
SE and BSE
4.6 Torr
(minimum for liquid water)



Minimal Scattering
Scatter < 5%
$m < 0.05$



Partial Scattering
5% to 95% Scatter
m from = 0.05 to 3.0

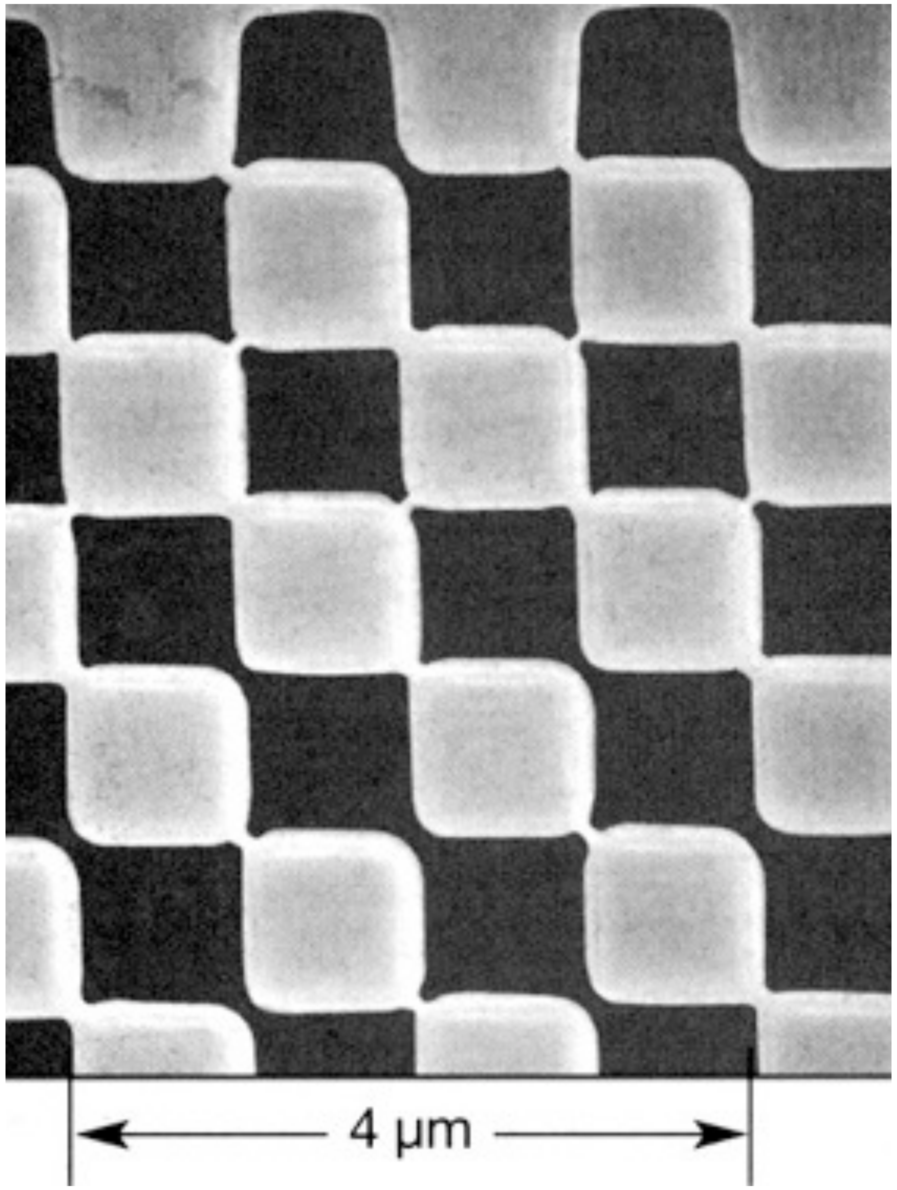


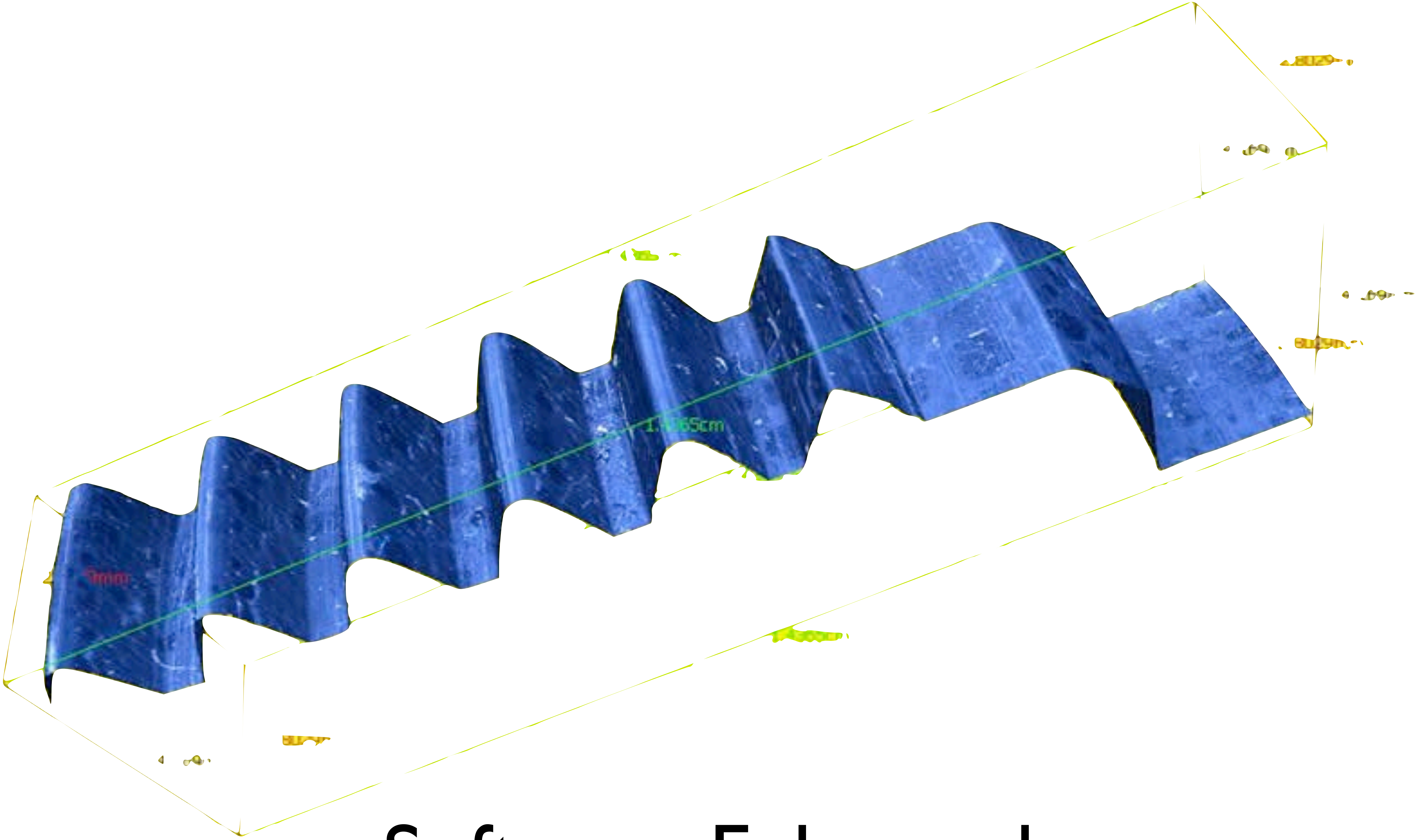
Complete Scattering
Scatter >95%
$m > 3.0$

Analytical Tools

Measuring

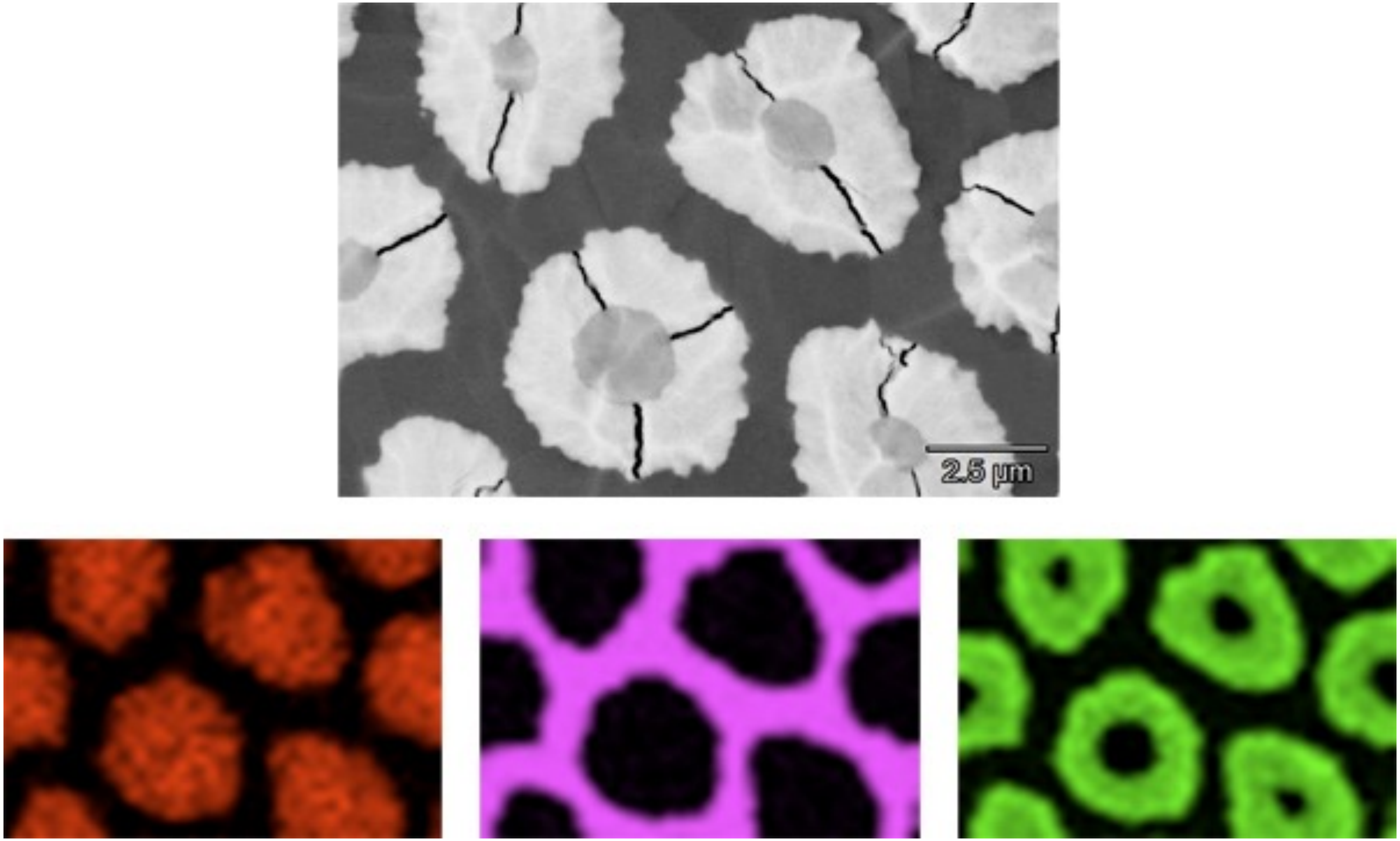
Full 2D
Measurement capabilities
After
Calibration





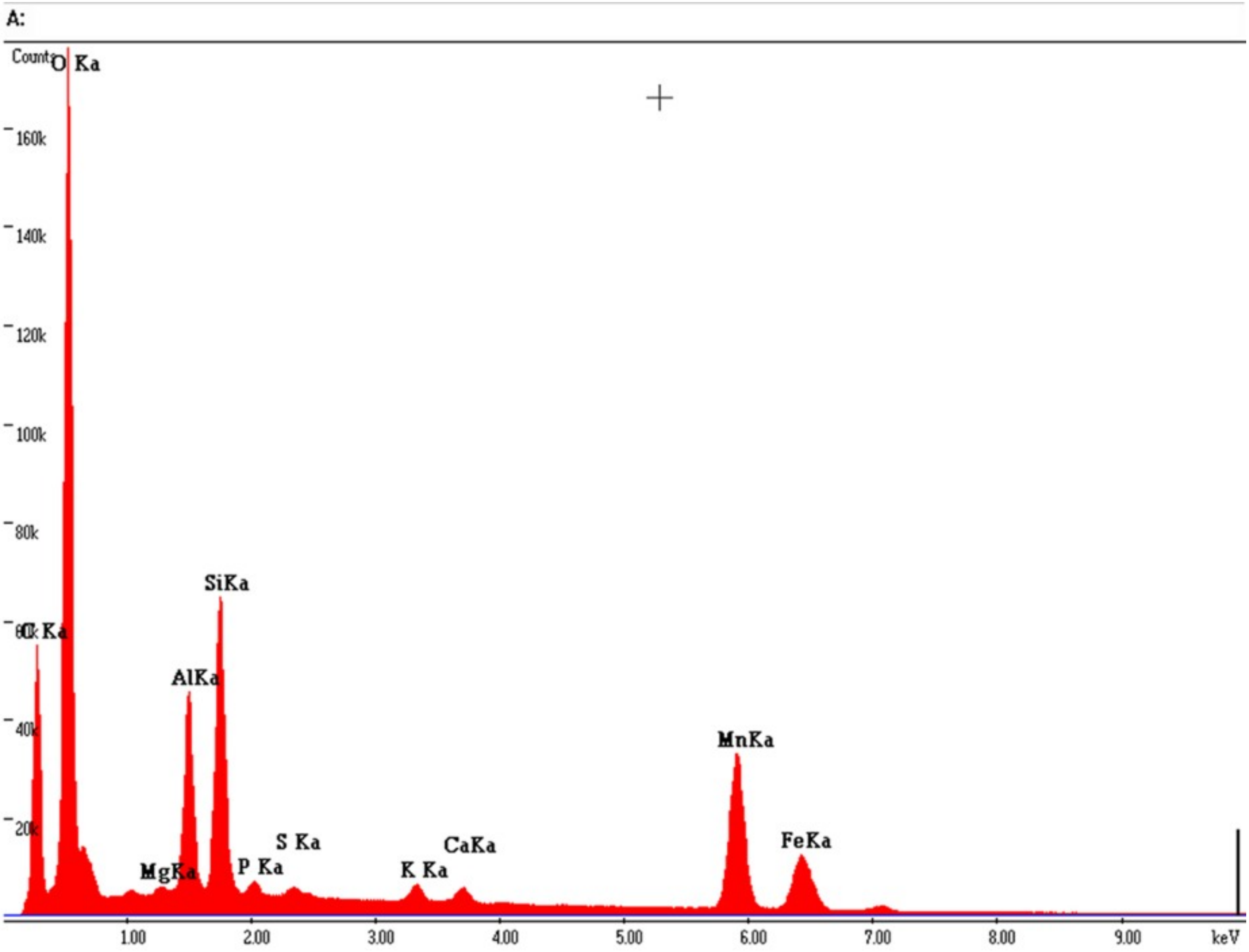
Software Enhanced 3D Measuremnt

Elemental Analysis



EDX

Energy Dispersive X-ray Spectroscopy


A:
Counts
O Ka
C Ka
SiKa
AlKa
MgKa
P Ka
S Ka
K Ka
CaKa
MnKa
FeKa
160k
140k
120k
100k
80k
60k
40k
20k
1.00
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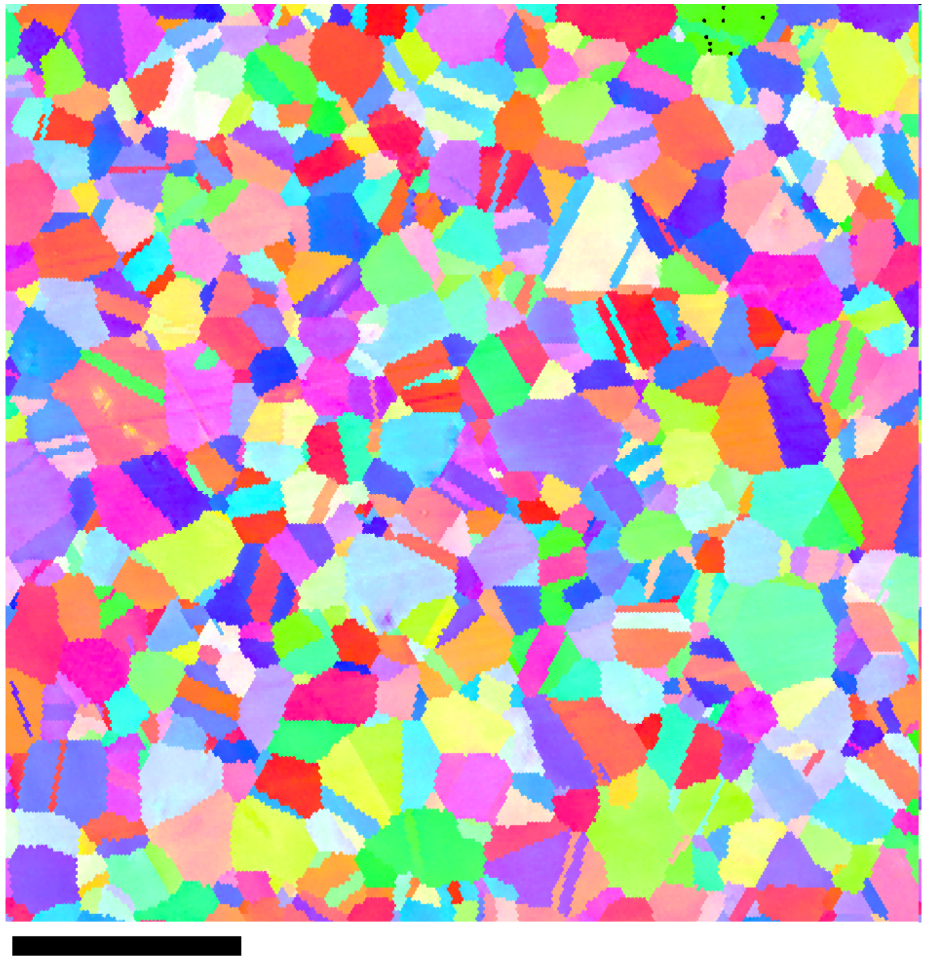
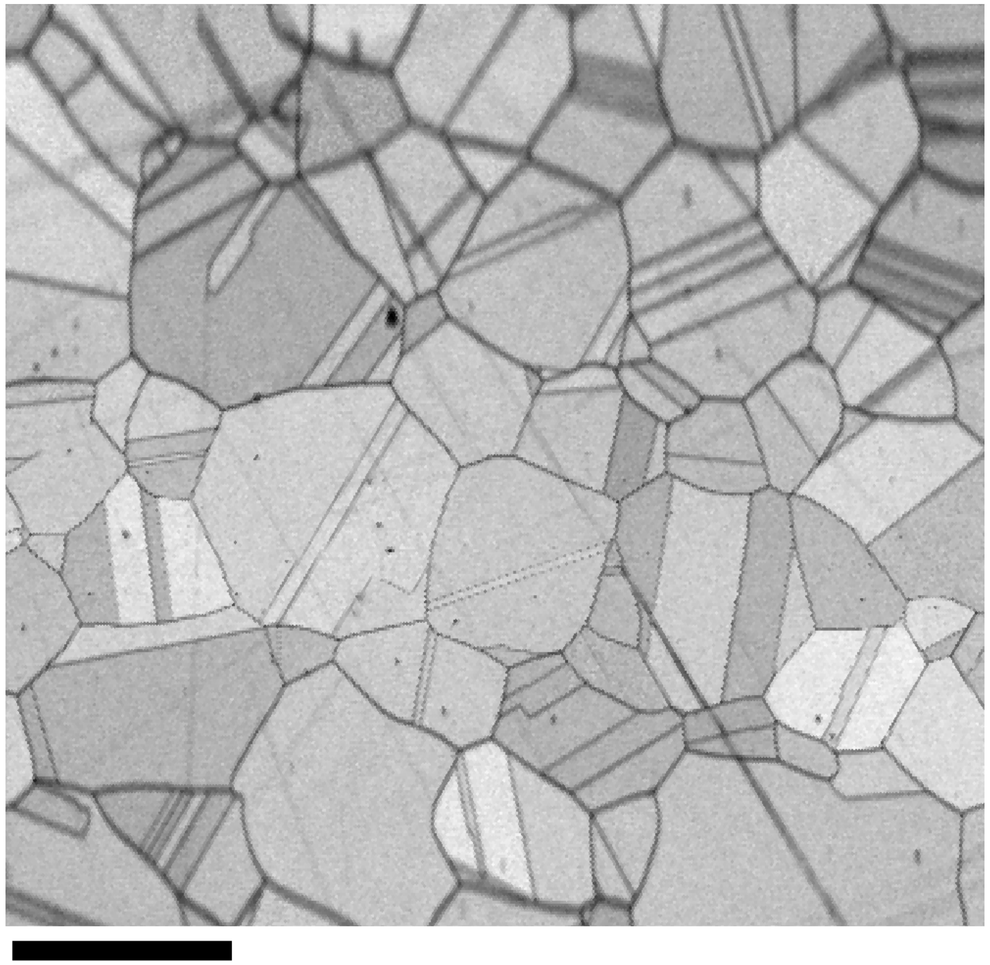
3.00
4.00
5.00
6.00
7.00
8.00
9.00
keV



120.0 µm = 60 steps IPF [001]

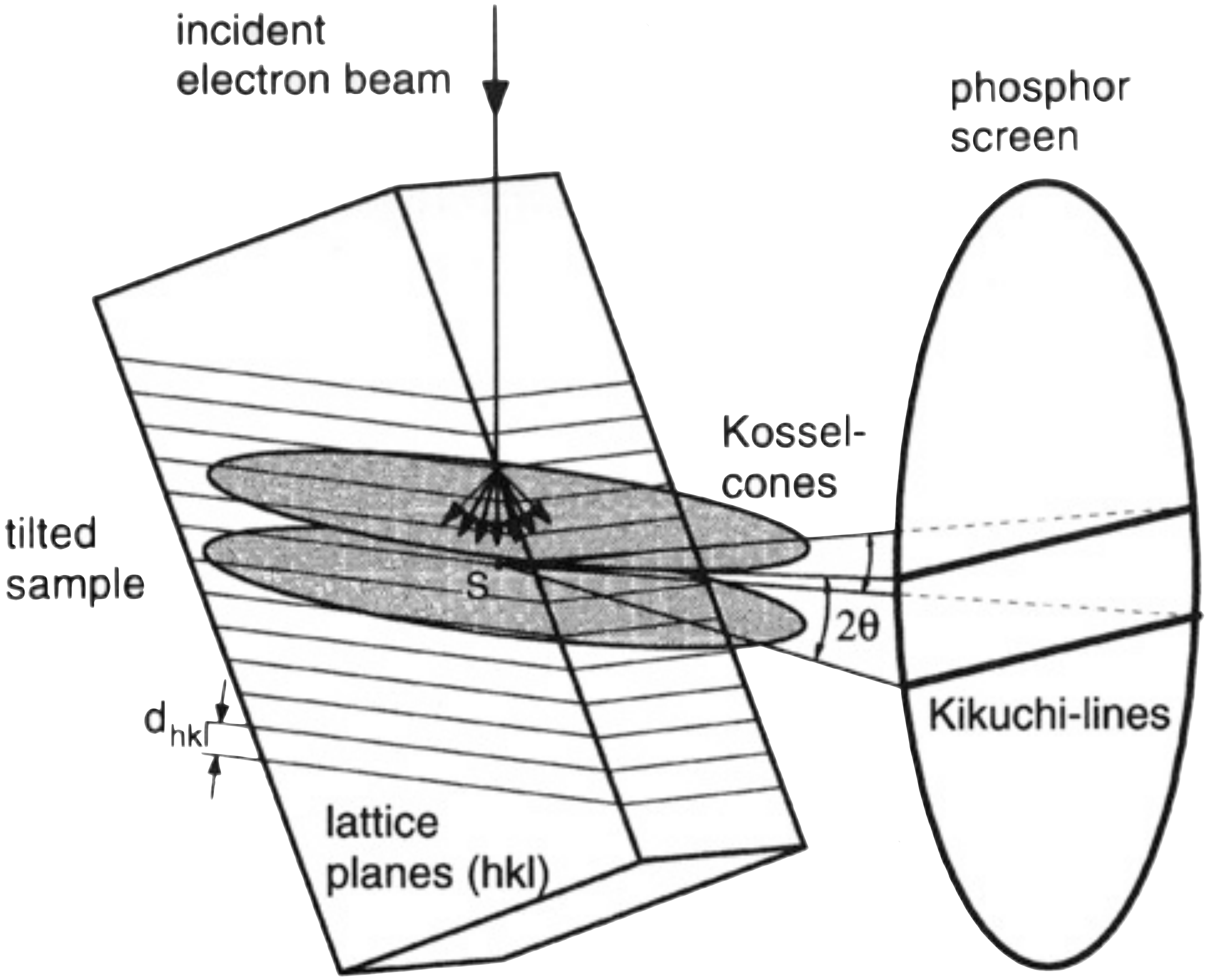
Color Coded Map Type:
Inverse Pole Figure [001]

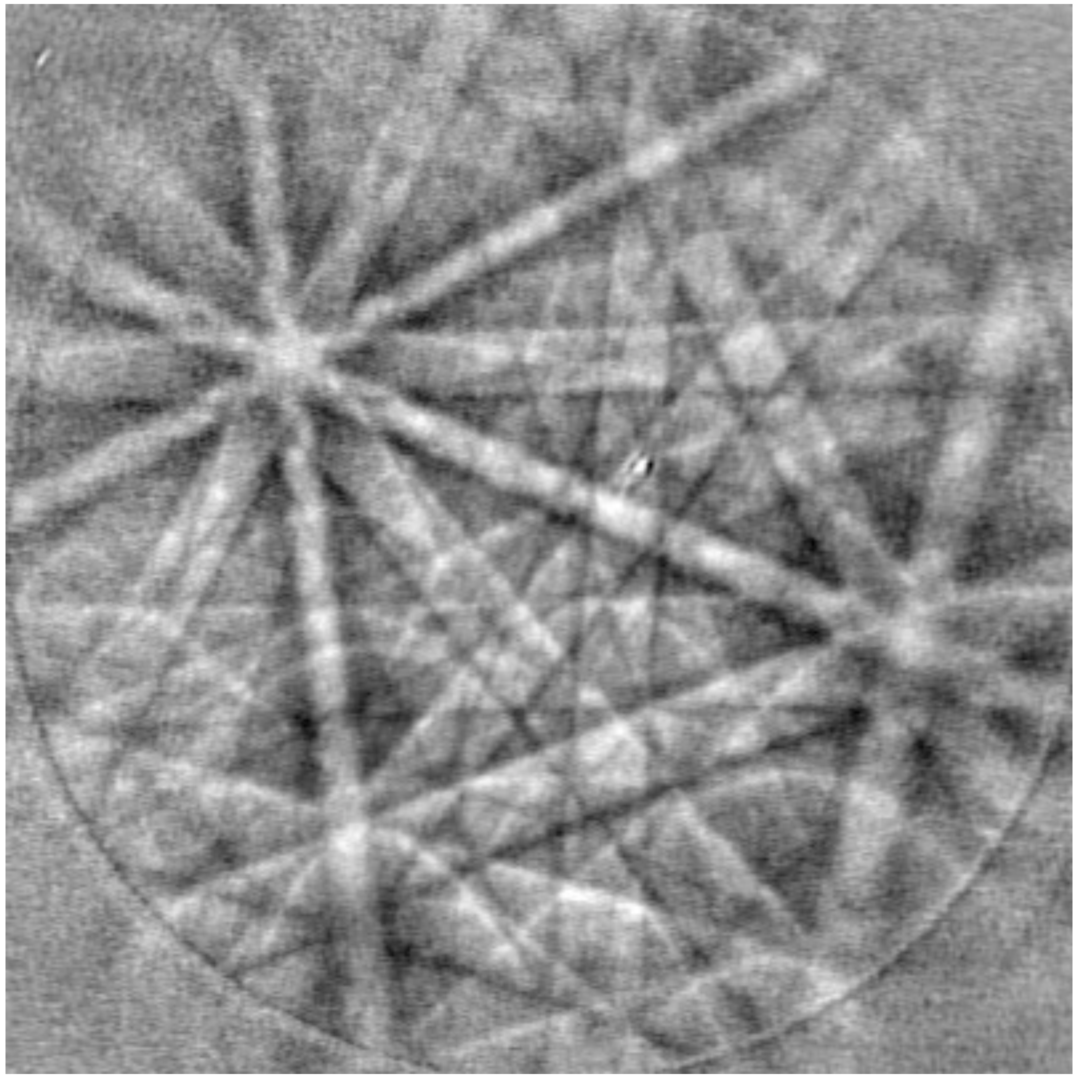


175.0 µm = 70 steps IQ 74.352...385.66

EBSD

Electron Backscatter Diffraction


incident
electron beam
phosphor
screen
Kossel-
cones
tilted
sample
S
2θ
d_{hkl}
Kikuchi-lines
lattice
planes (hkl)



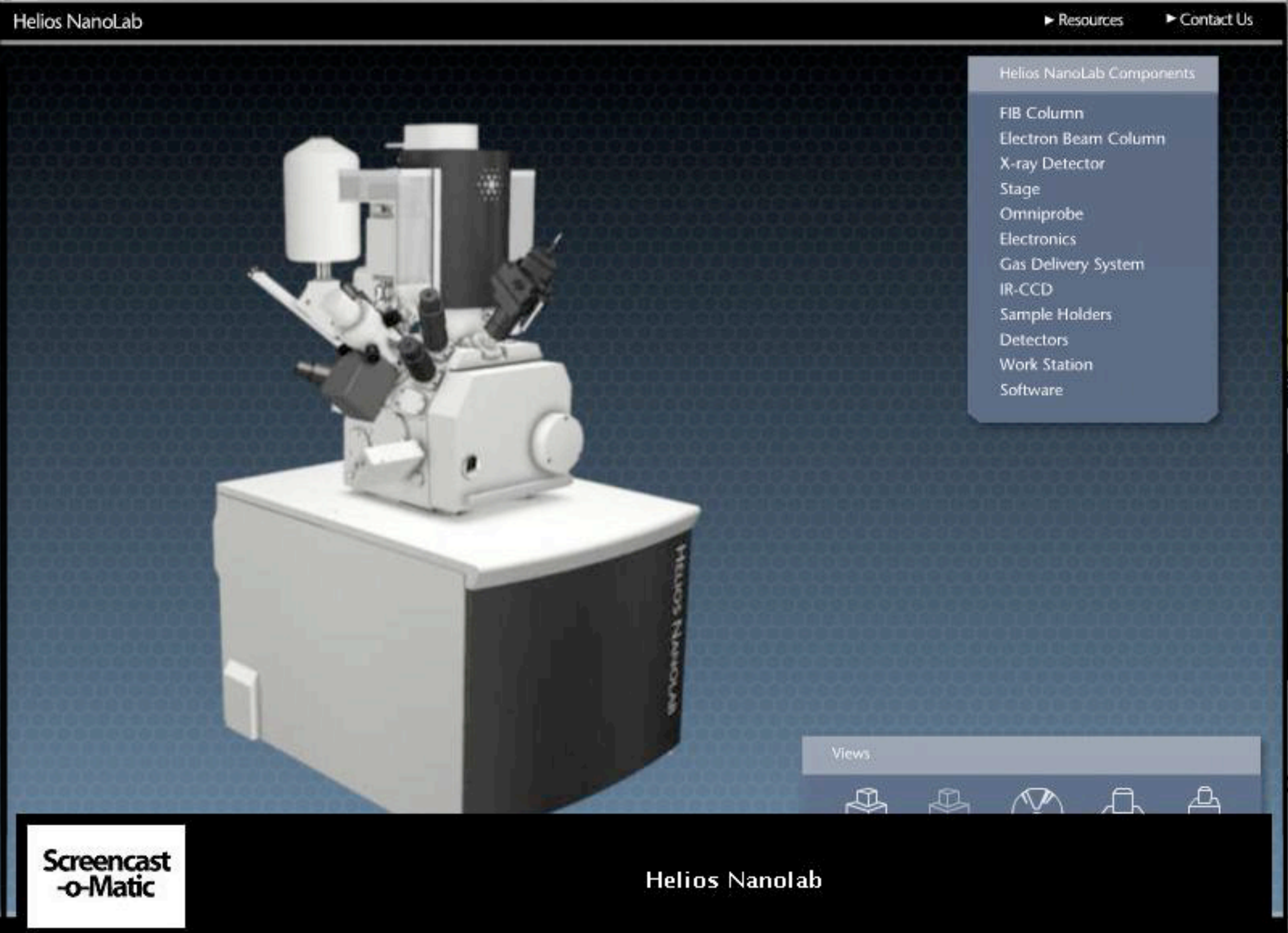
Summary

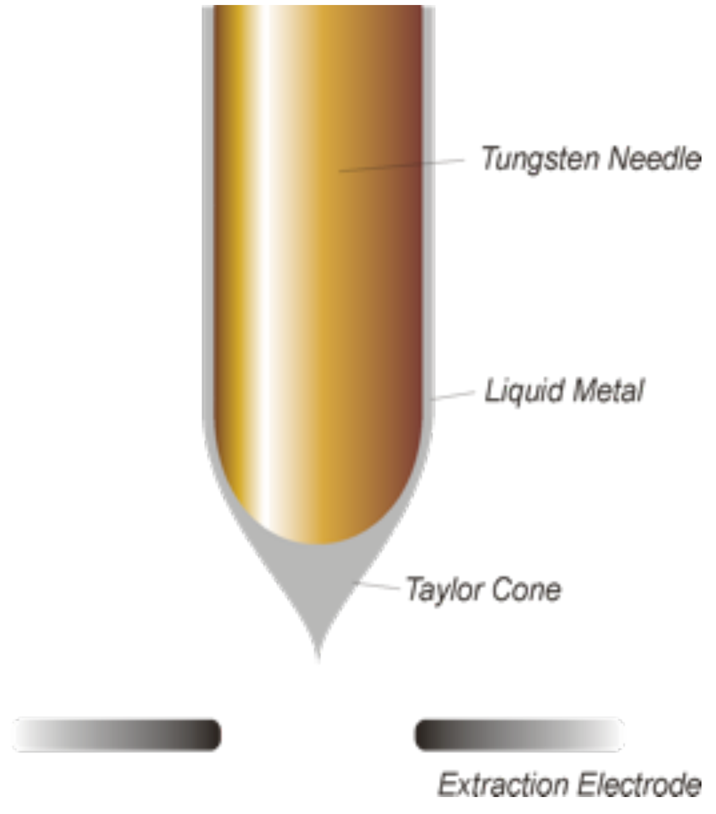
- Basic Operating Principles
- SEM Hardware
- Understand/aquire SEM images
- SEM Applications

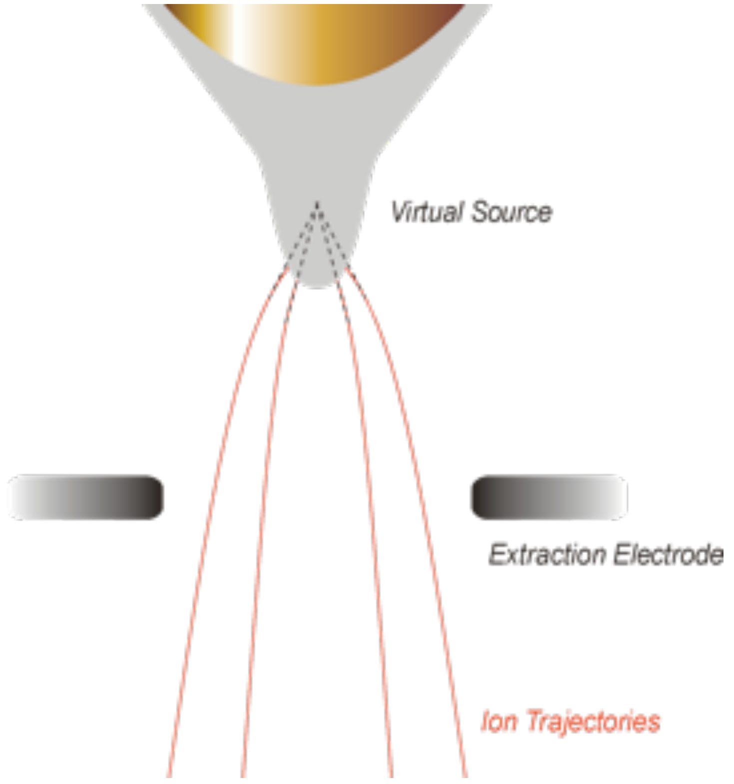
Focused Ion Beam Microscopy

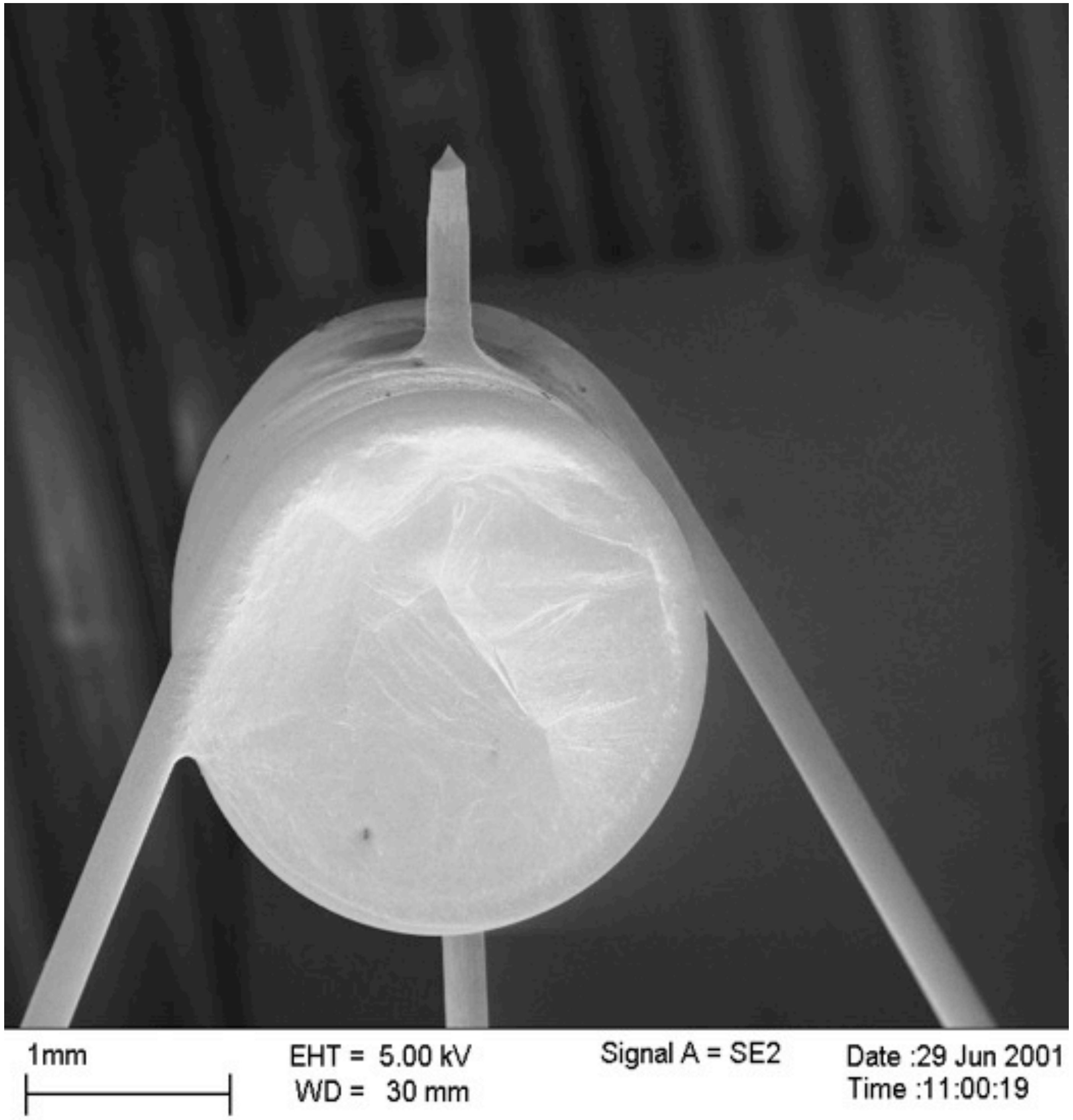
Microscope


GEMINI
NVision 40
ZEISS
SII


Helios NanoLab
► Resources
► Contact Us
Helios NanoLab Components
FIB Column
Electron Beam Column
X-ray Detector
Stage
Omniprobe
Electronics
Gas Delivery System
IR-CCD
Sample Holders
Detectors
Work Station
Software
Views
HELIOS NANOLAB
Screencast-o-Matic
Helios Nanolab

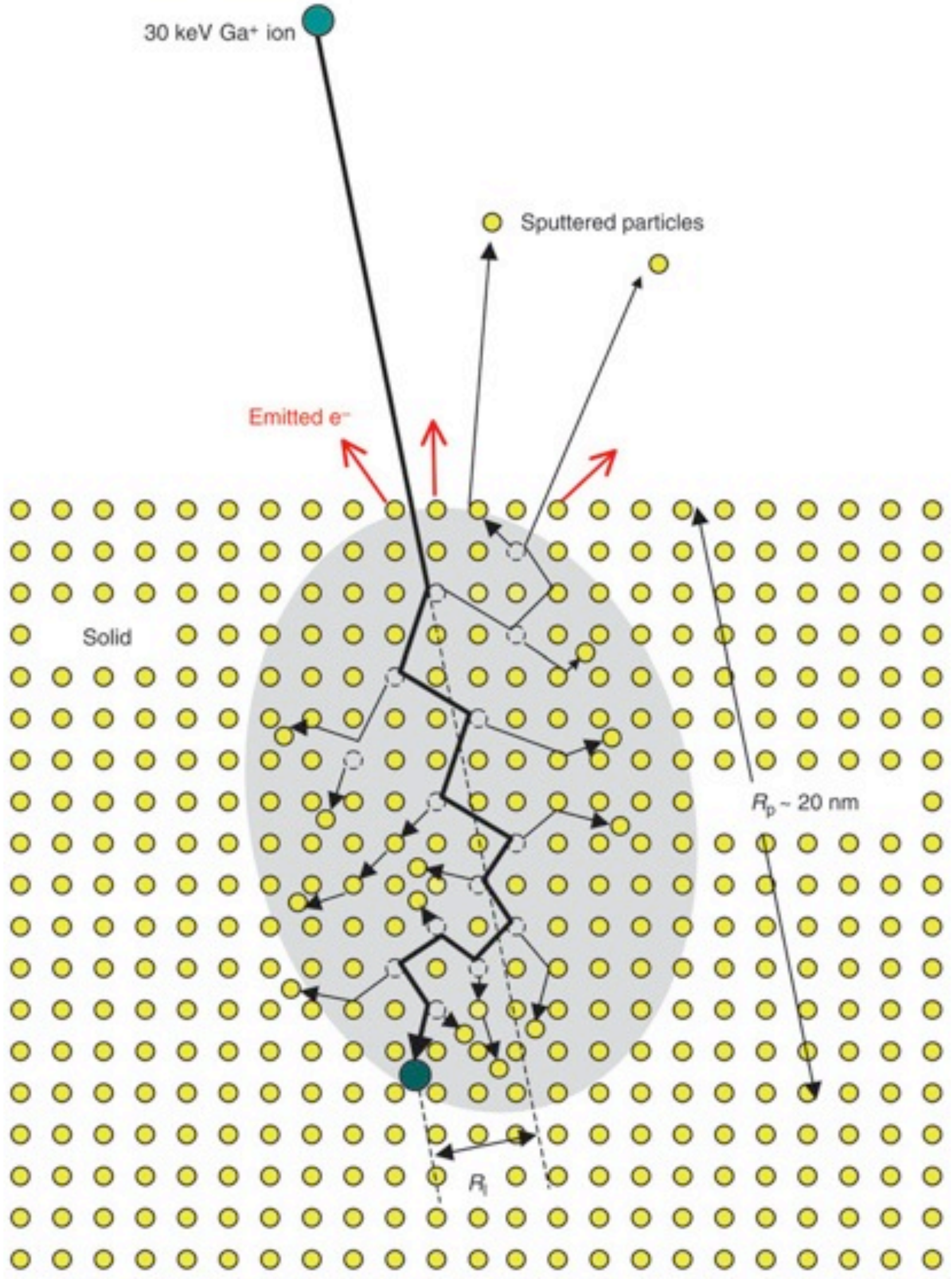

Tungsten Needle
Liquid Metal
Taylor Cone
Extraction Electrode

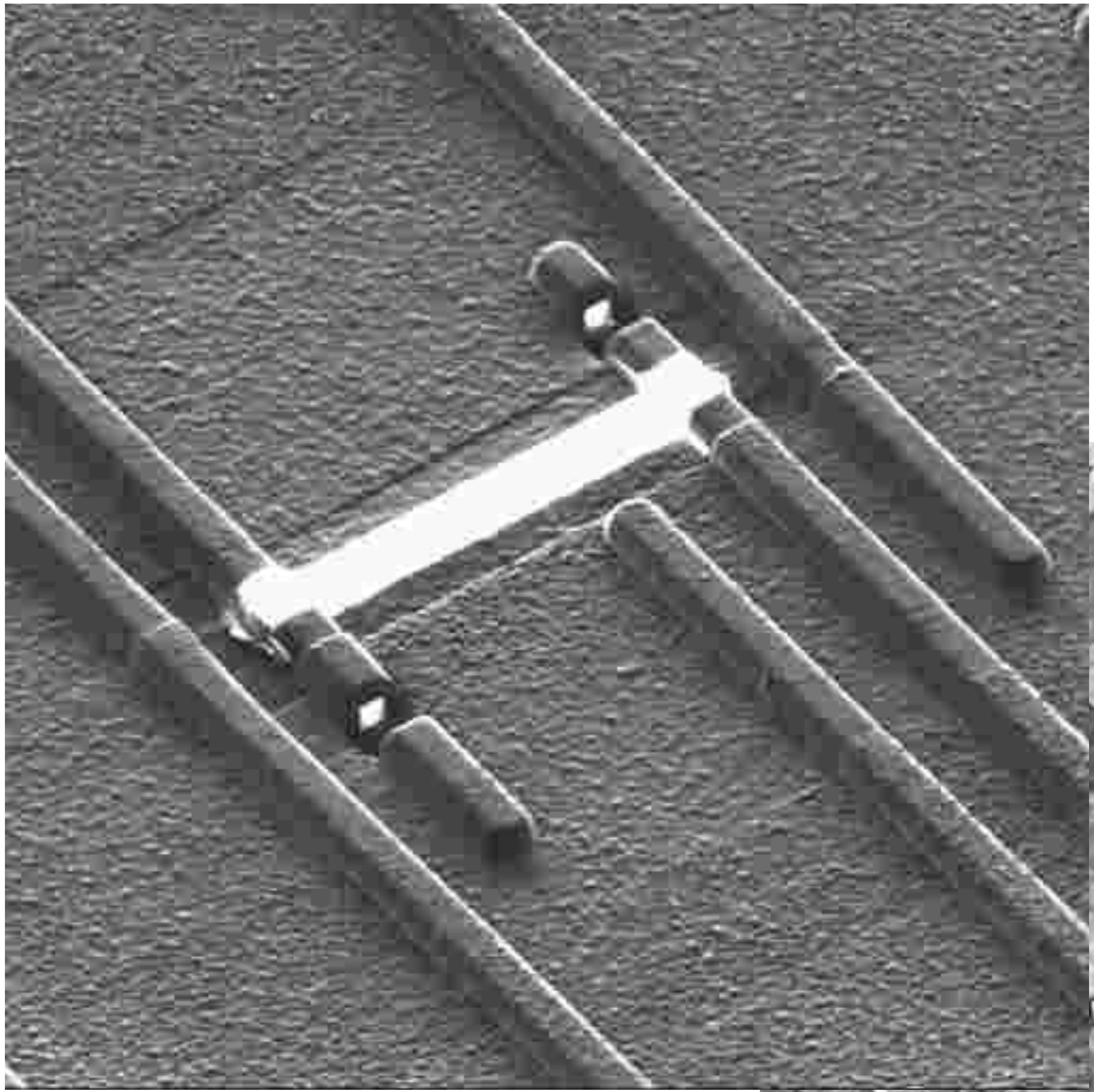

Virtual Source
Extraction Electrode
Ion Trajectories


1mm
EHT = 5.00 kV
WD = 30 mm
Signal A = SE2
Date :29 Jun 2001
Time :11:00:19

Ion Interaction

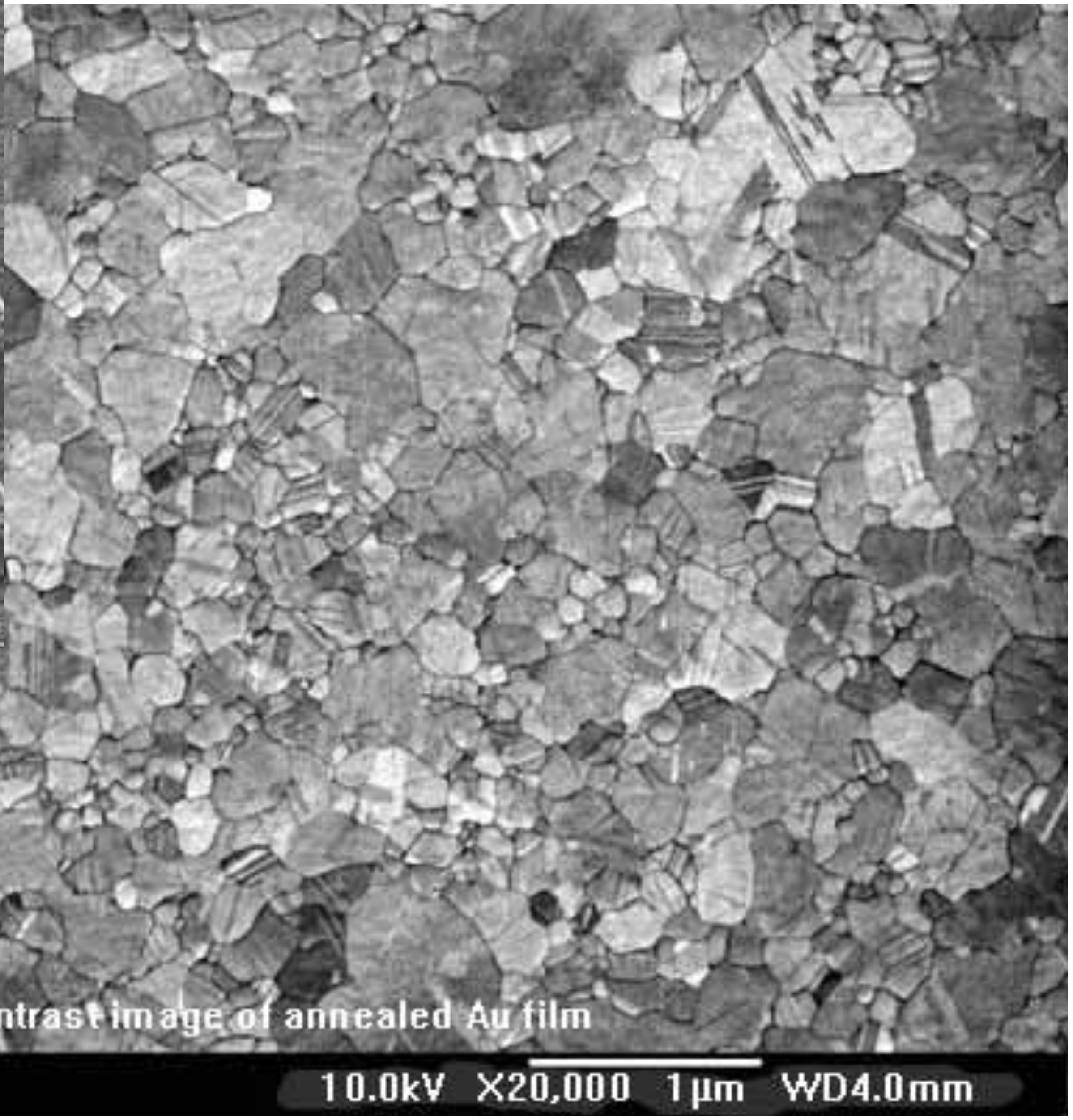
SE, SI, sputtered particles, amorphization, etc.



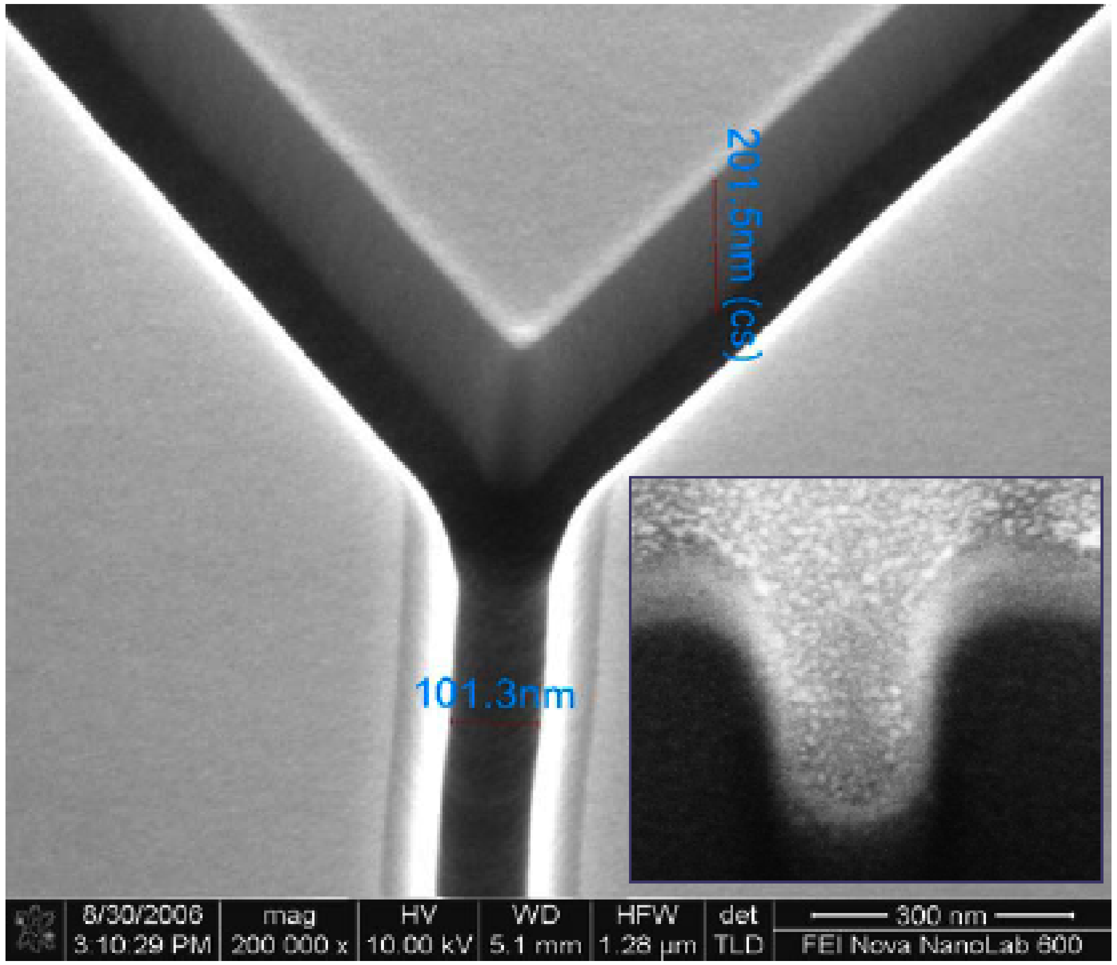


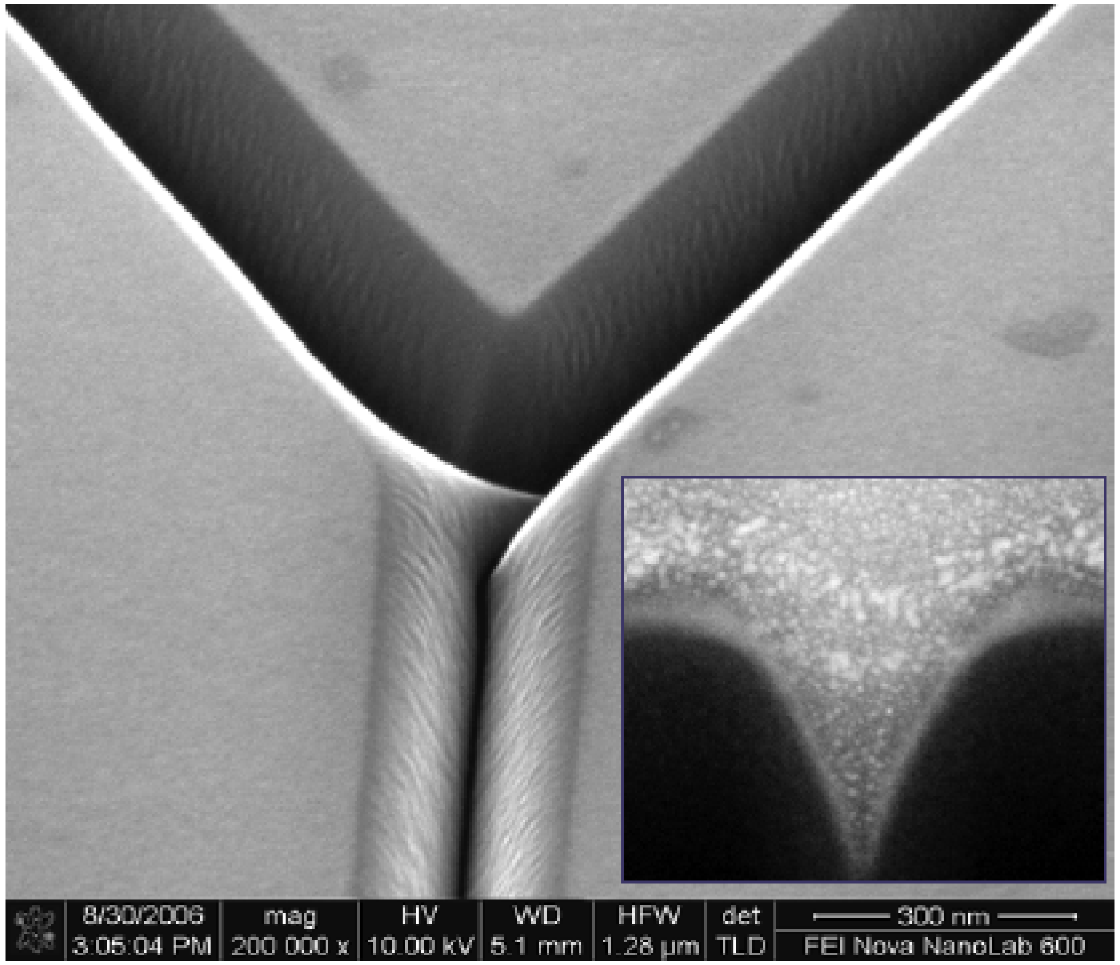
Charge Contrast

Channeling Contrast



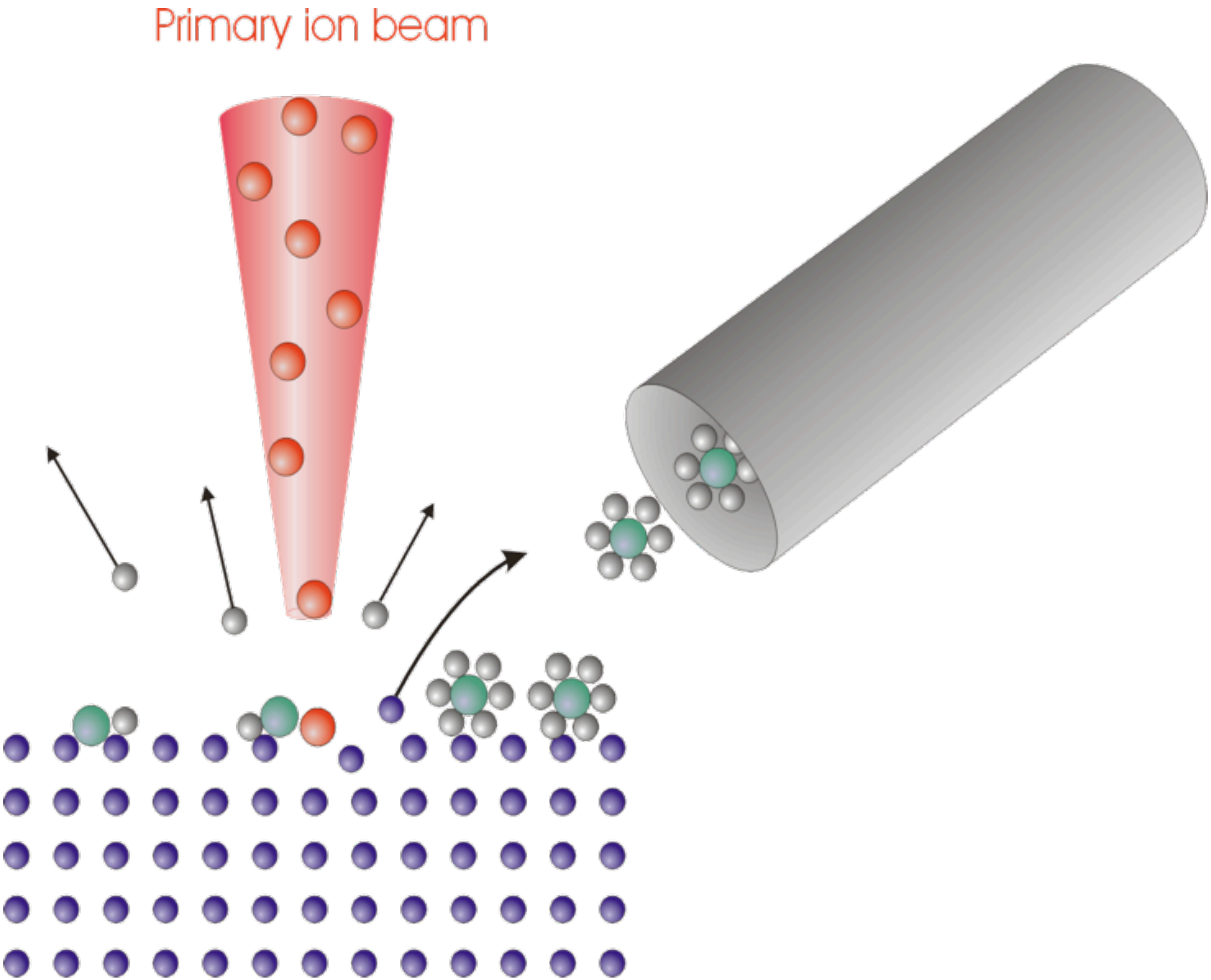
Milling

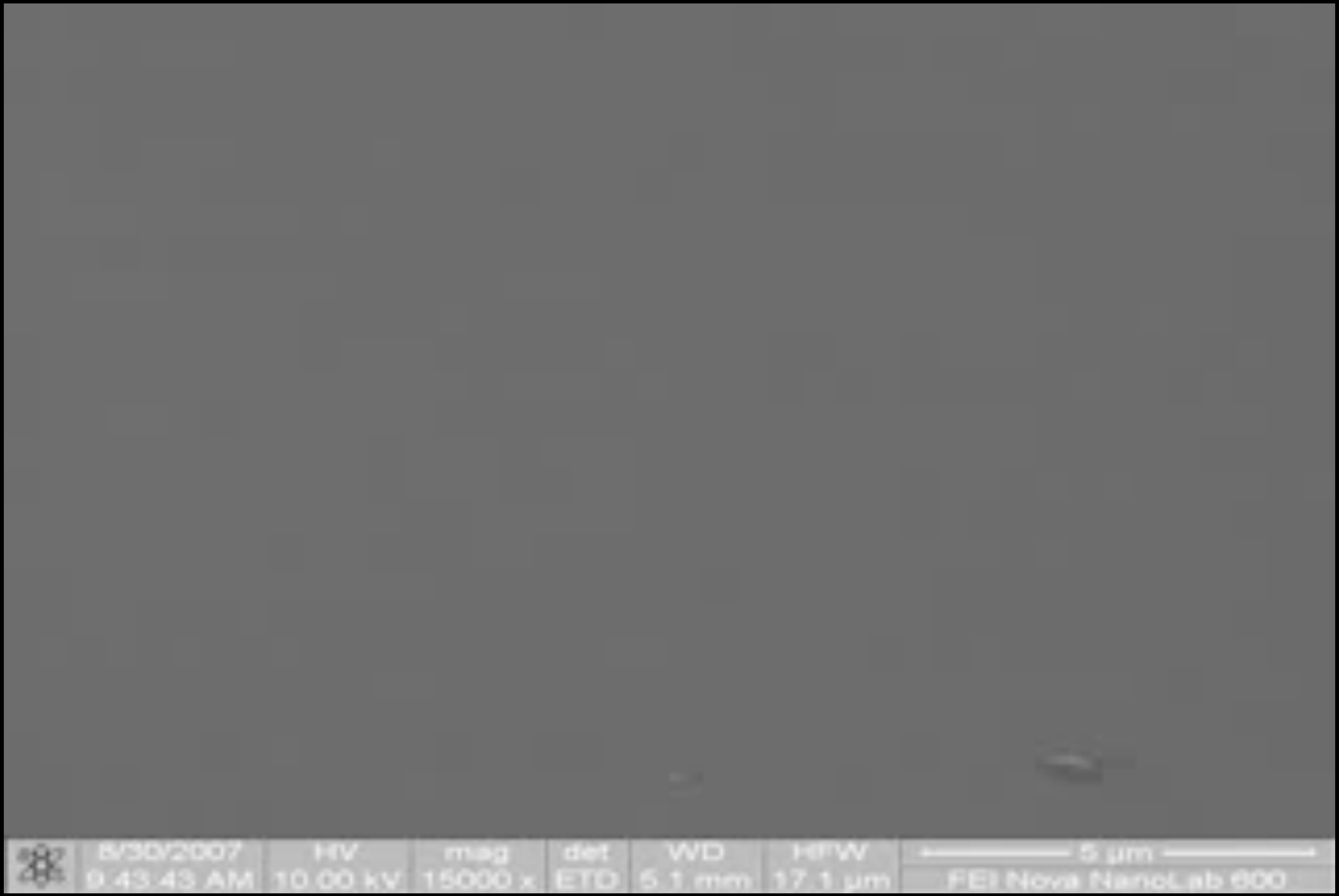

201.5nm (cs)
101.3nm
8/30/2006
3:10:29 PM
mag
200 000 x
HV
10.00 kV
WD
5.1 mm
HFW
1.28 µm
det
TLD
300 nm
FEI Nova NanoLab 600


8/30/2006
3:05:04 PM
mag
200 000 x
HV
10.00 kV
WD
5.1 mm
HFW
1.28 µm
det
TLD
300 nm
FEI Nova NanoLab 600


4/24/2006
1:13:39 PM
HV
10.00 kV
mag
10000 x
det
ETD
WD
5.1 mm
HFW
24.0 µm
5 µm
FEI Nova NanoLab 600

Gas Deposition


Primary ion beam

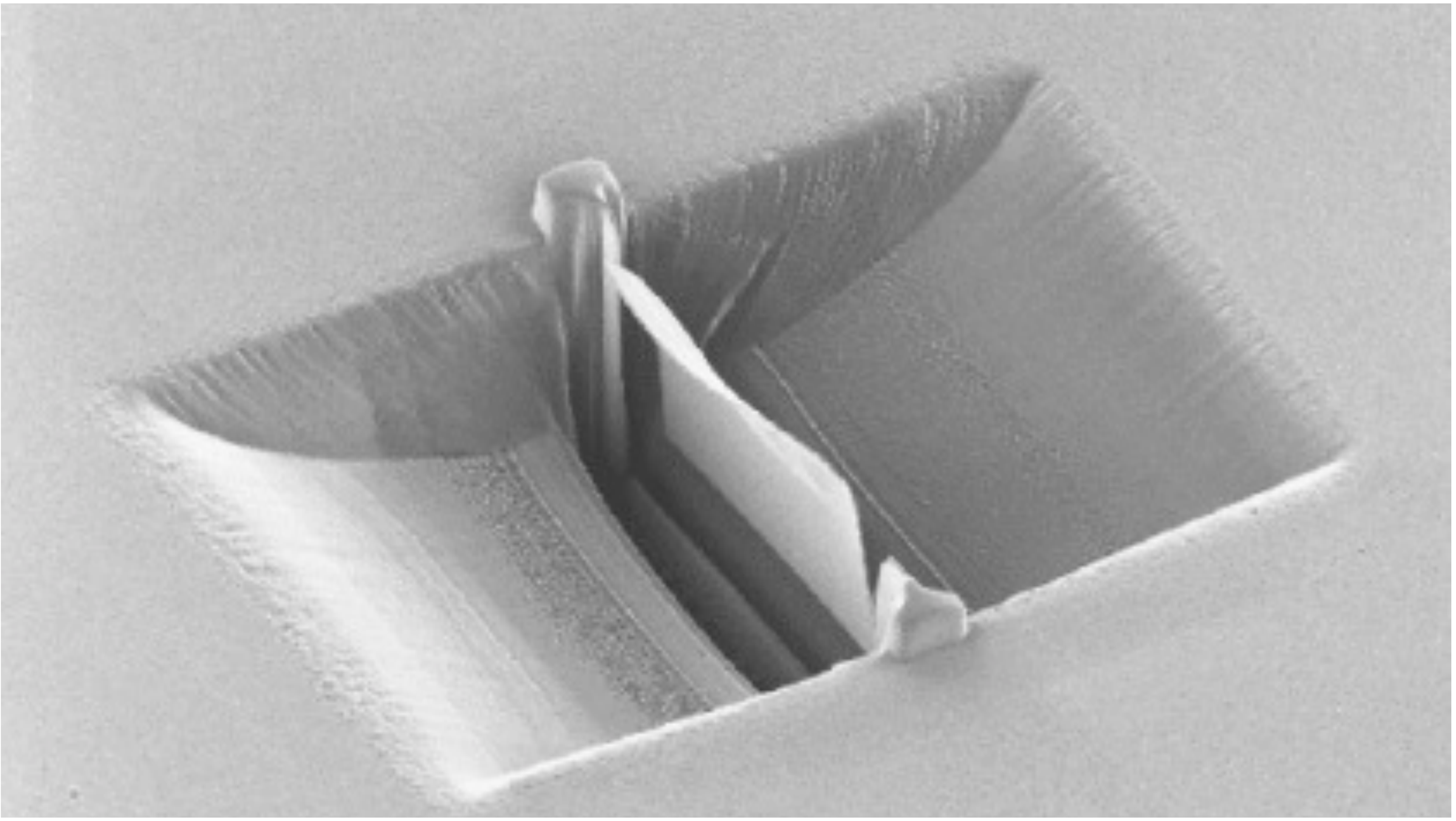

8/30/2007
9:43:43 AM
HV
10.00 kV
mag
15000 x
det
ETD
WD
5.1 mm
HFW
17.1 µm
5 µm
FEI Nova NanoLab 600

EBID

Applications

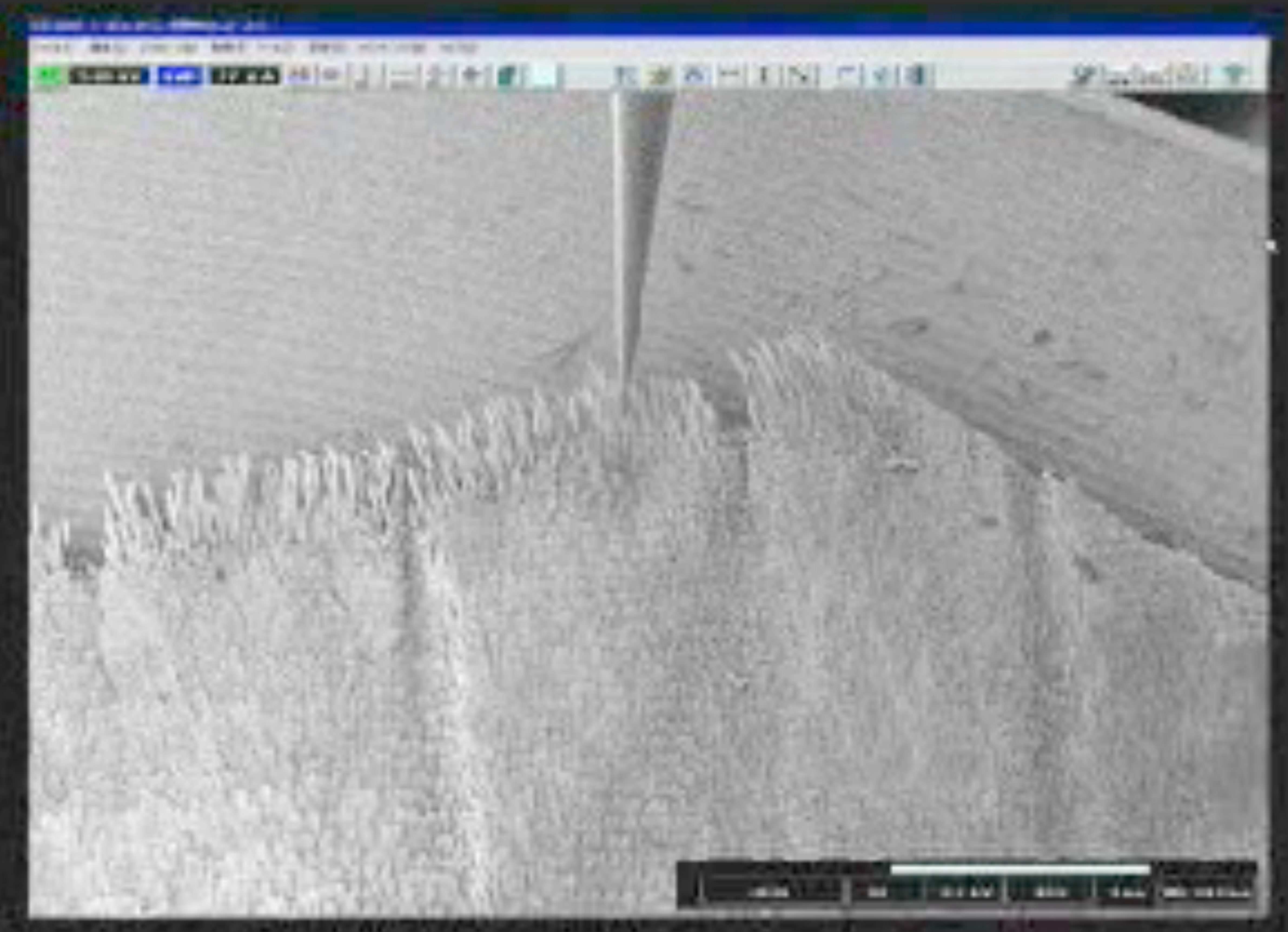
R. Klengel, Fraunhofer IWM

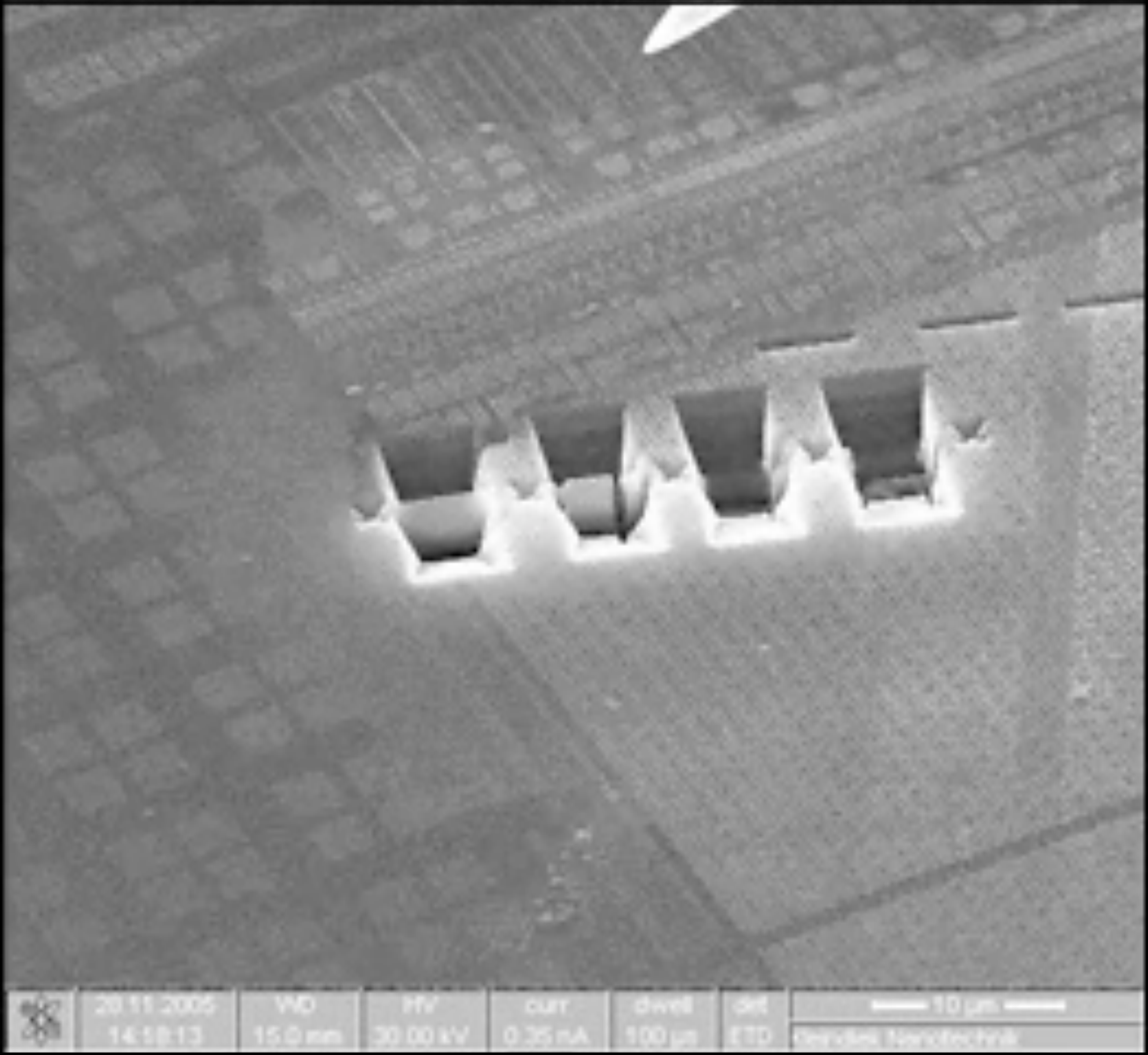
X-sectioning



TEM-Sample Preparation

NanoProbing




20.11.2005
14:18:13
WD
15.0 mm
HV
30.00 kV
curr
0.35 nA
dwell
100 µs
det
ETD
10 µm
Nanotechnik