Introduction to Scanning Electron Microscopy, SEM

A. Danilewsky

- Principle of the Scanning Electron Microscope
- Introduction to qualitative elemental analysis EDX
- Determination of Orientation using "**E**lectron **B**ack **S**catter **D**iffraction, EBSD"

Literature

- L. Reimer, G. Pfefferkorn: "Rasterelektronenmikroskopie" Springer 1977
- **Flegler, Heckmann, Klomparens, Elektronenmikroskopie, Spektrum Akademischer Verlag Berlin und Heidelberg, 1993**
- H. R. Wenk (Ed.): "Electron Microscopy in Mineralogy", Springer Verlag 1976
- L. Reimer: "Scanning Electron Microscopy", Springer 1983
- L. Reimer: "Elektronenmikroskopische Untersuchungs- und Präparationsmethoden", Springer 1967

Literature (continued)

- Joy et al.: "Electron Channeling Pattern in the Scanning Electron Microscope", J. Appl. Phys. Vol 53, No 8 (1982) 439 - 461
- U. Holzhäuser: "Charakterisierung von Einkristallen mittels Electron Channeling Pattern", Diplomarbeit Universität Freiburg 1992
- Humphreys, "Reviw: Grain and subgrain characterisation by electron backscatter diffraction, J. of Mat. Sci. 36 (2001), 3833
- Schmidt, Peter Fritz: "Praxis der Rasterelektronenmikroskopie und Mikrobereichsanalyse ", Fritz Schmidt - Renningen-Malmsheim : Expert-Verlag, 1994 (Kontakt & Studium ; 444 Meßtechnik)

Useful Links

Alexander Fels:

"Grundlagen der Raster-Elektronenmikroskopie"

http://www.reclot.de

Dr Geoff Lloyd:

"SEM Electron Backscattered Diffraction“
der “RMS spring school 2002, Leeds”

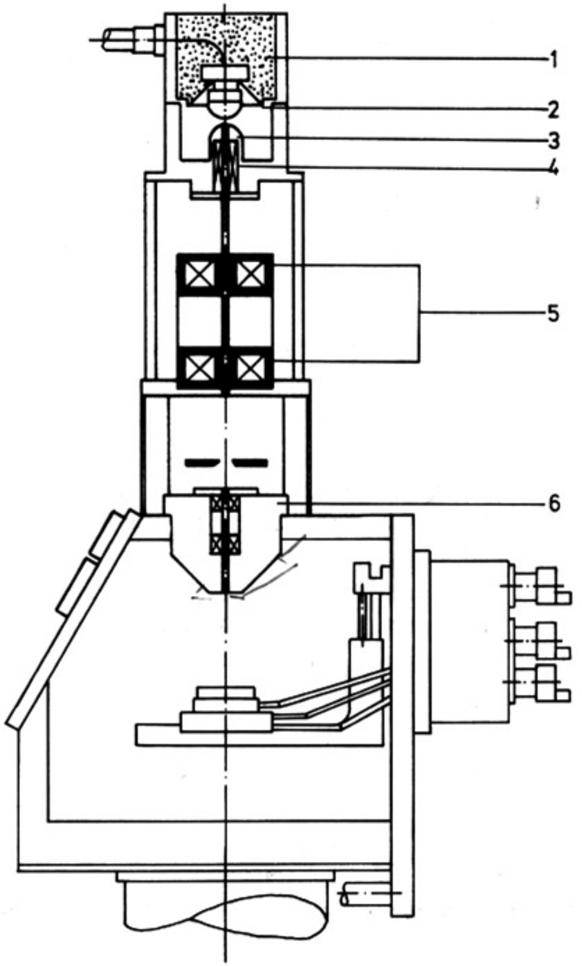
http://www.see.leeds.ac.uk/research/igt/people/lloyd/

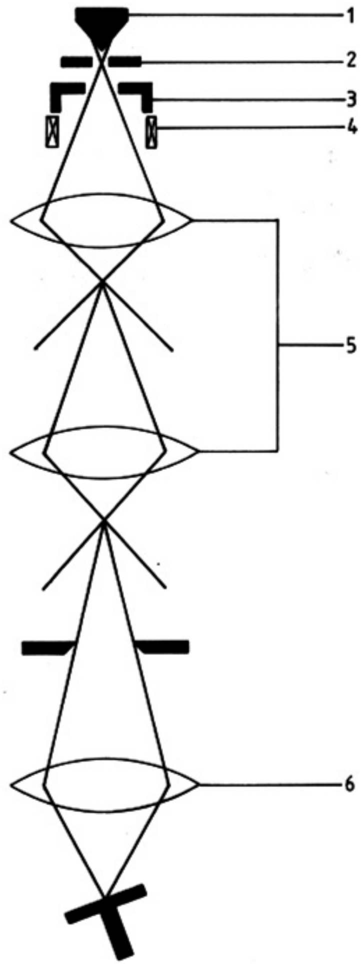
Kurt Helming:

"Crash Kurs Textur"

http://www.texture.de/Multex-Dateien/crash.htm

Configuration of the Scanning Electron Microscope and Path of Rays





(1) Cathode head

(2) Wehnelt cylinder

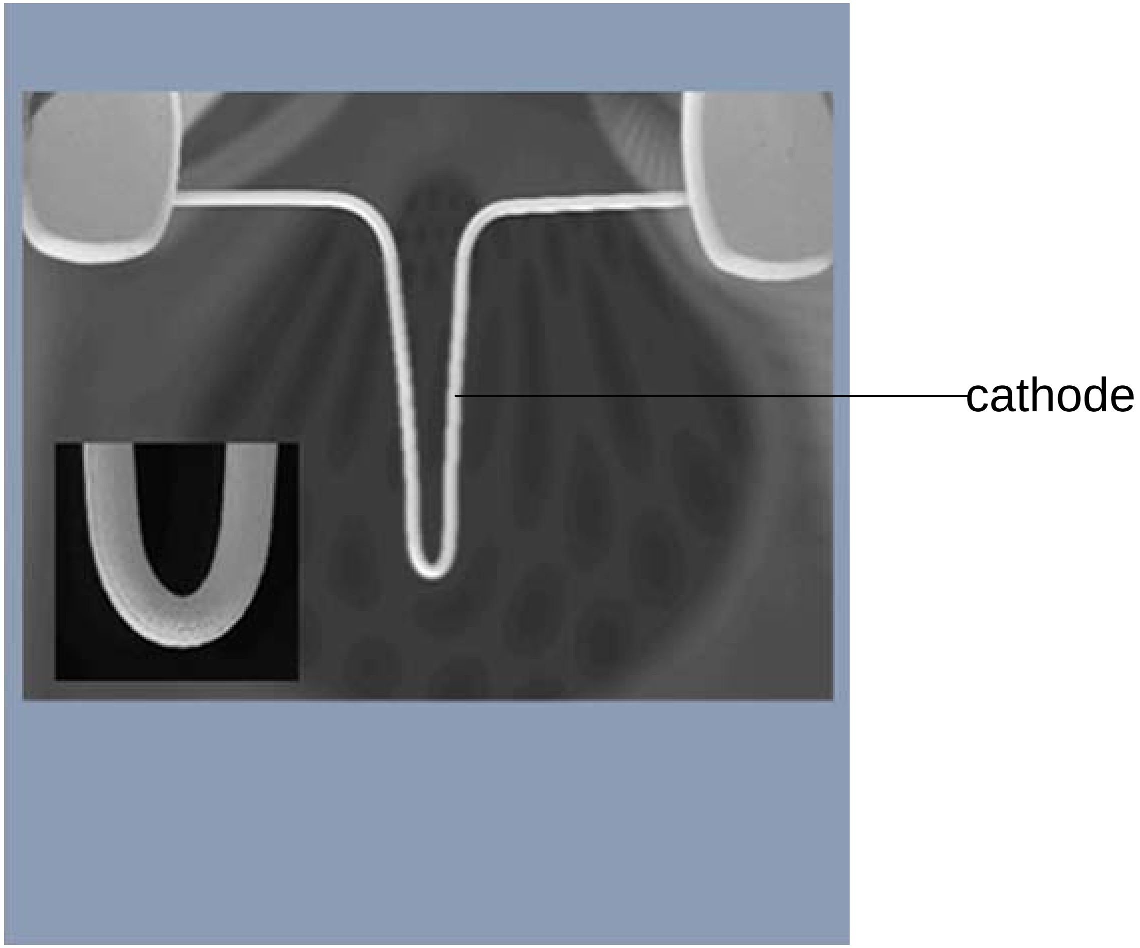
(3) Anode

(4) Beam adjustment by coils

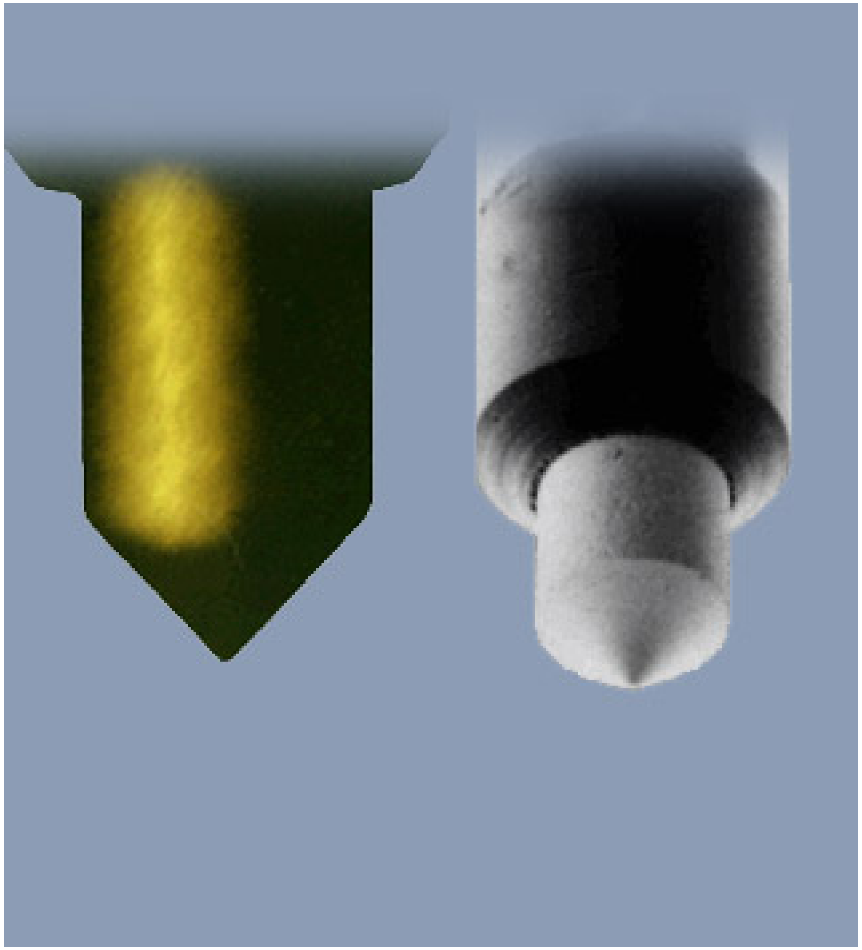
(5) Condenser lenses

(6) Objective lens

Generation of Electrones: Thermionic Electron Gun



Generation of Electrones: LaB_6



High beam current

=> Analysis

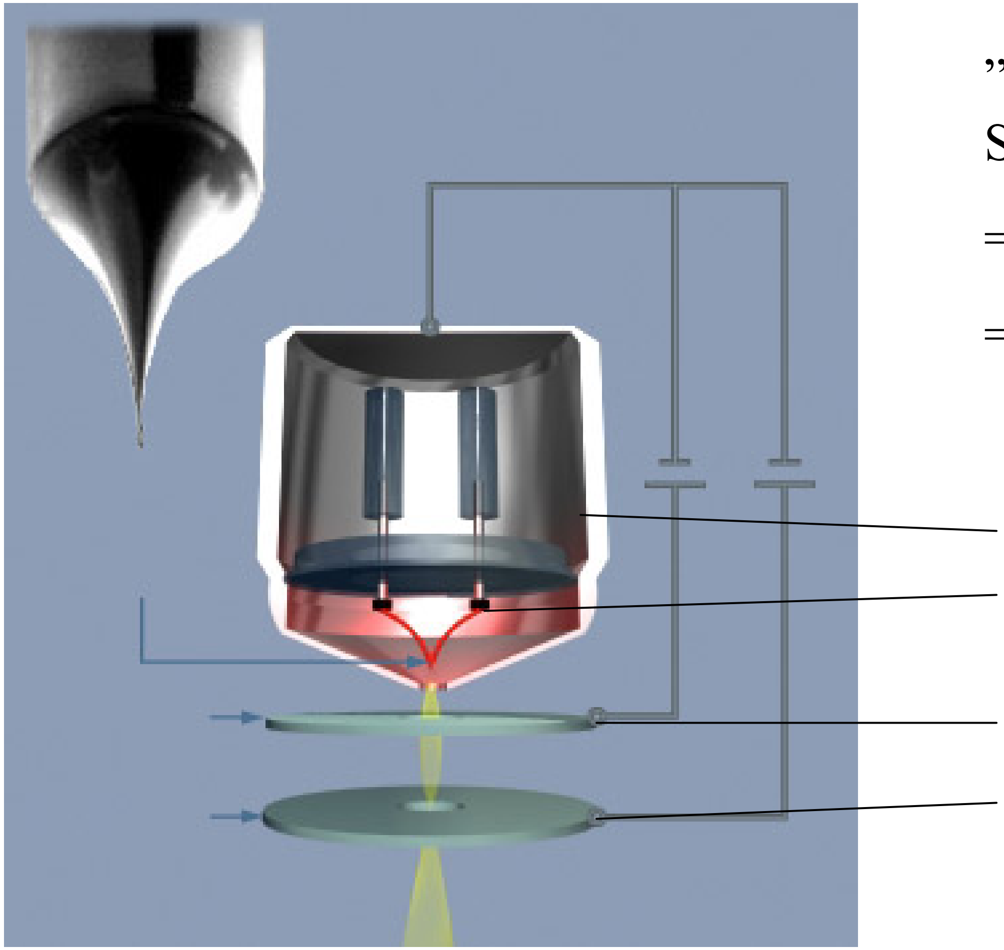
Generation of Electrones: Field Emission

„Hot field emission“,

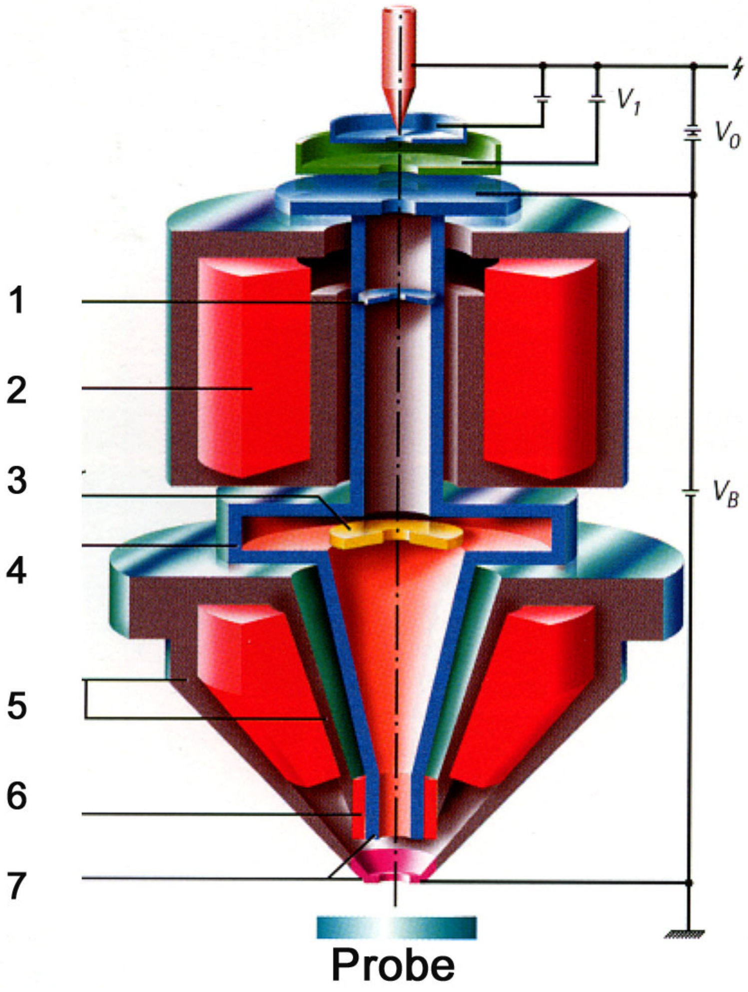
Schottky-cathode

=> High resolution

=> High beam density
"brilliancy "



Field Emission Scanning Electron Microscope



sample

(1) Aperture diaphragm

(2) Field lenses

(3) Inlense SE-detector

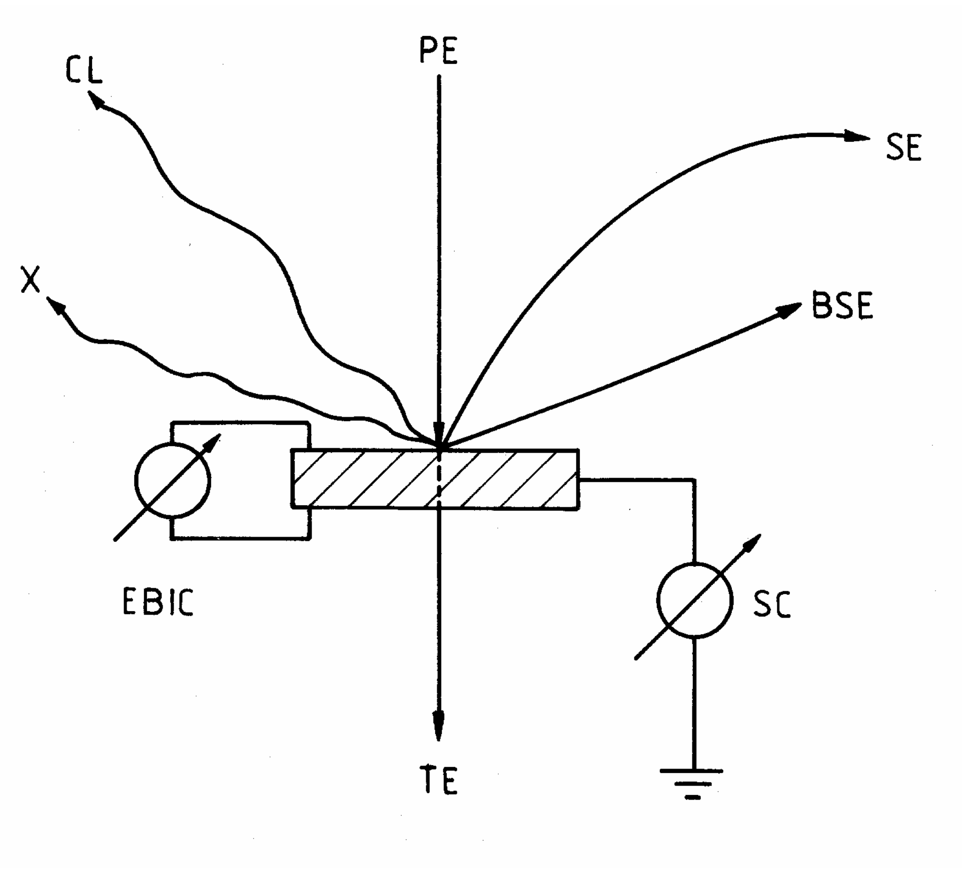
(4) Beam-Booster (blue)

(5) Magnetic lenses

(6) Deflection lenses

(7) Electrostatic lenses

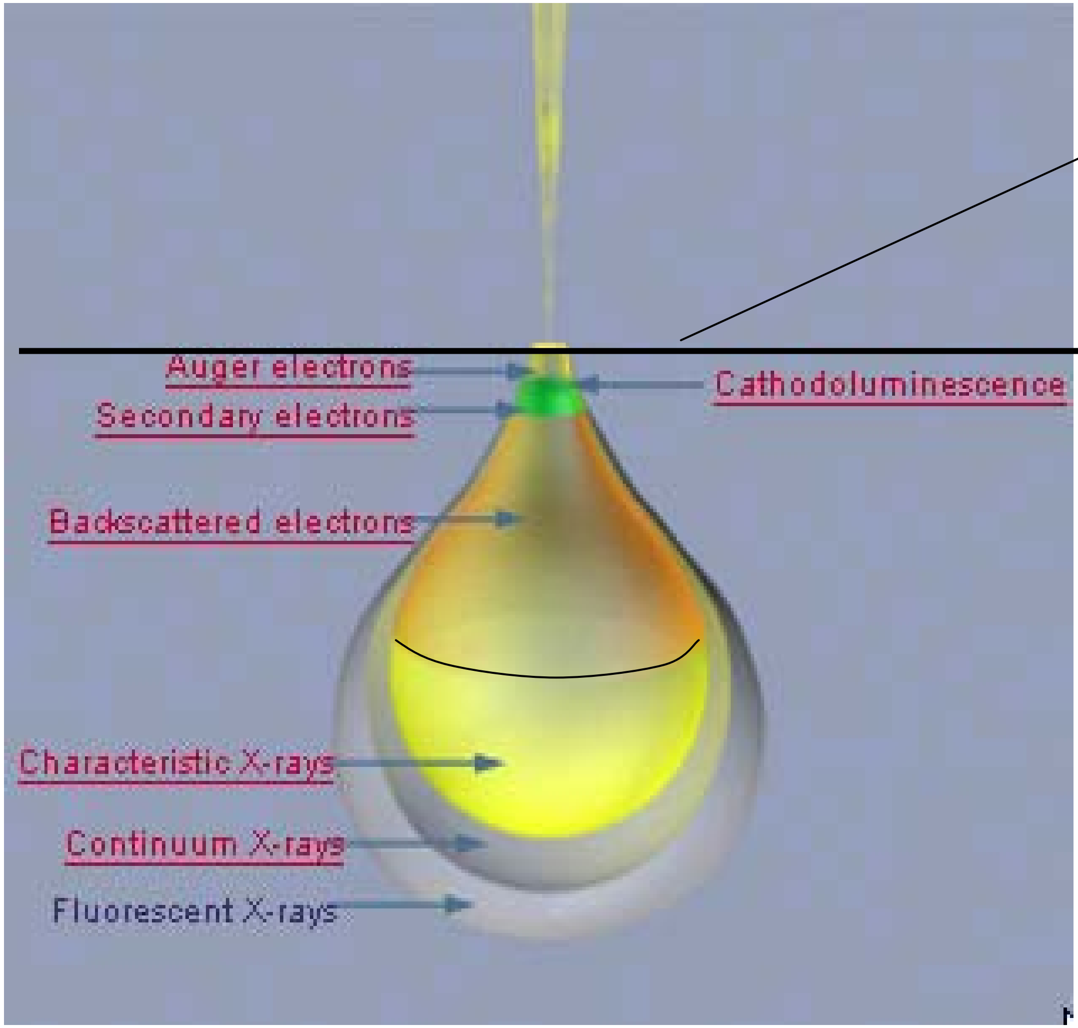
Interaction of Electrons With Matter



SE	Secondary Electrons
BSE	Backscattered Electrons
X	X-Rays
CL	Cathodoluminescence
EBIC	Electron Beam Induced Current
TE	Transmission
SC	Sample Current

\+ Heat !

Different Depths of Signal



Sample Surface

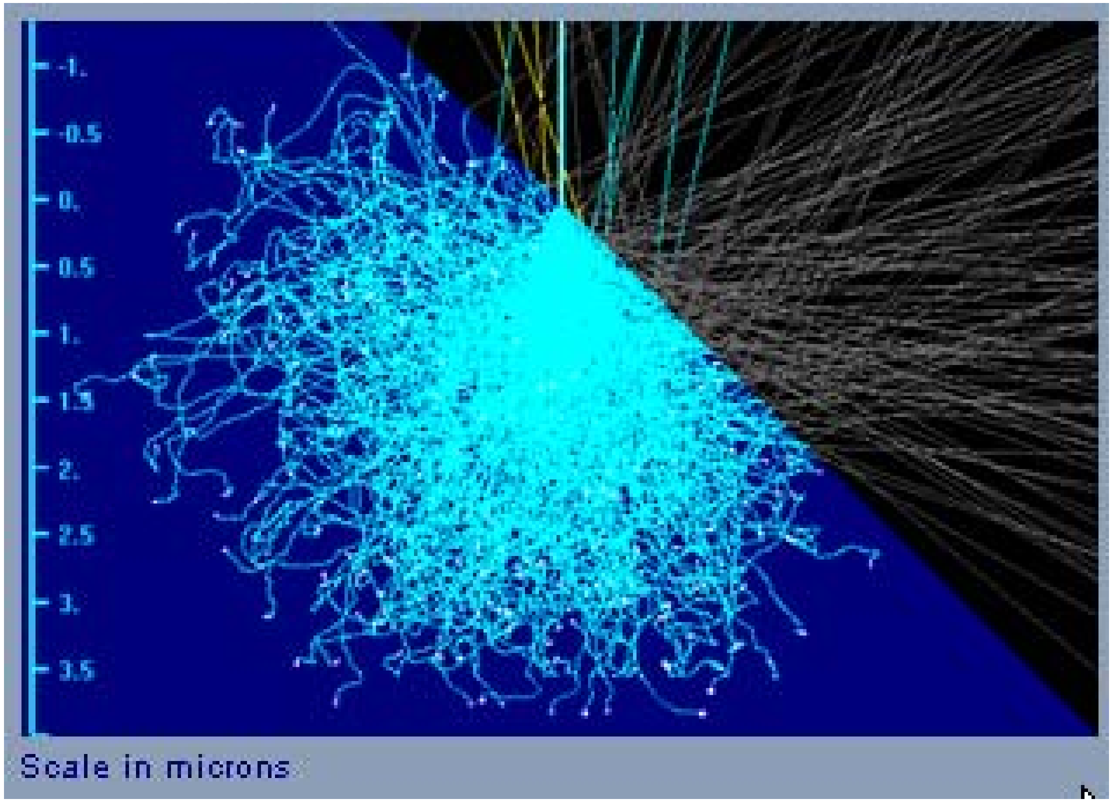
Auger - Electrons

Secondary Electrons

Backscattered Electrons

X-Ray

Interaction Volume: "Expansion Pear"



(1) Si at 5 kV, 0° Tilt

(2) Si at 20 kV, 0° Tilt:

more SE

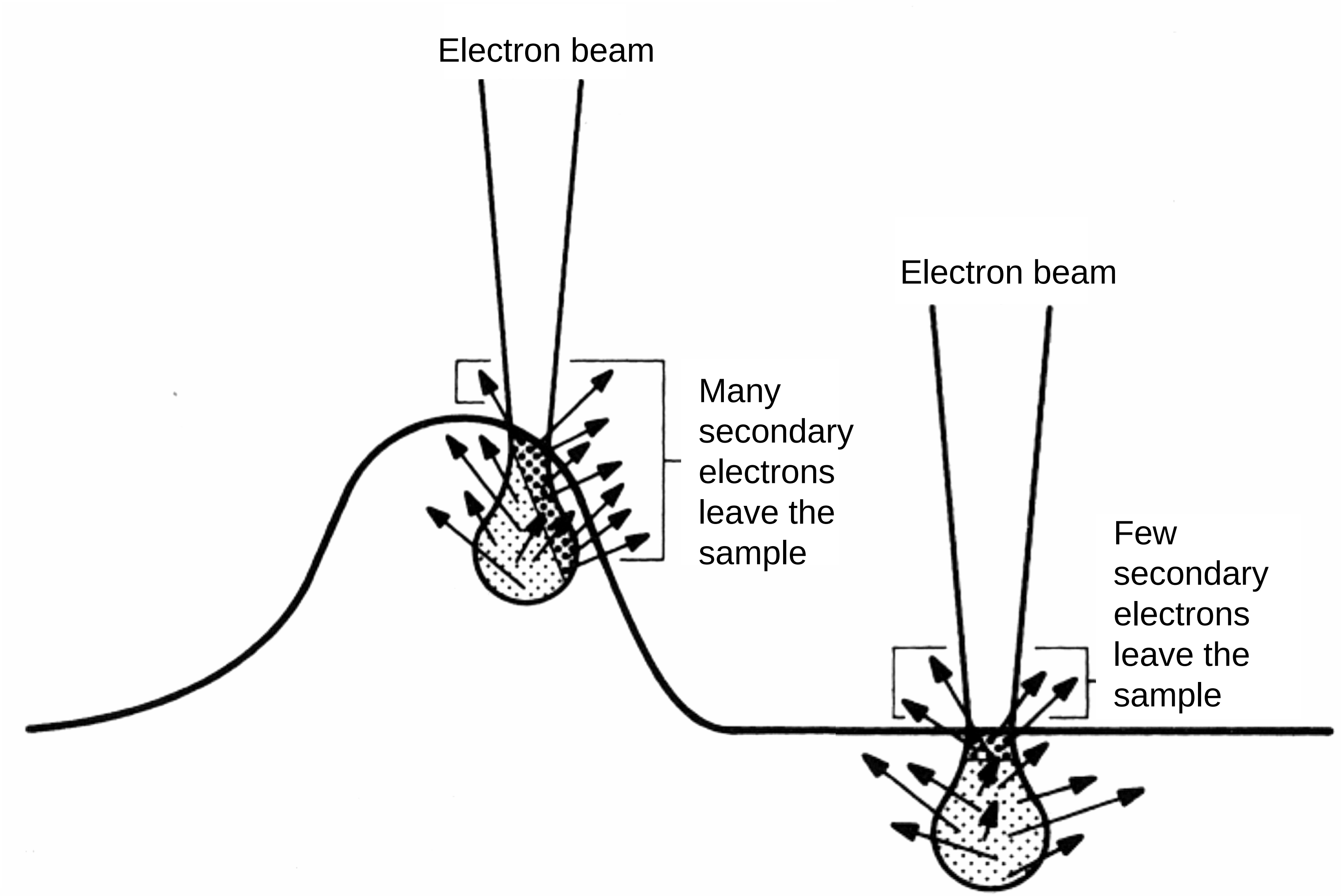
(3) Si at 20 kV, 45° Tilt:

Much more SE

„Suface Tilt Contrast“

„Edge Contrast"

Topographic contrast



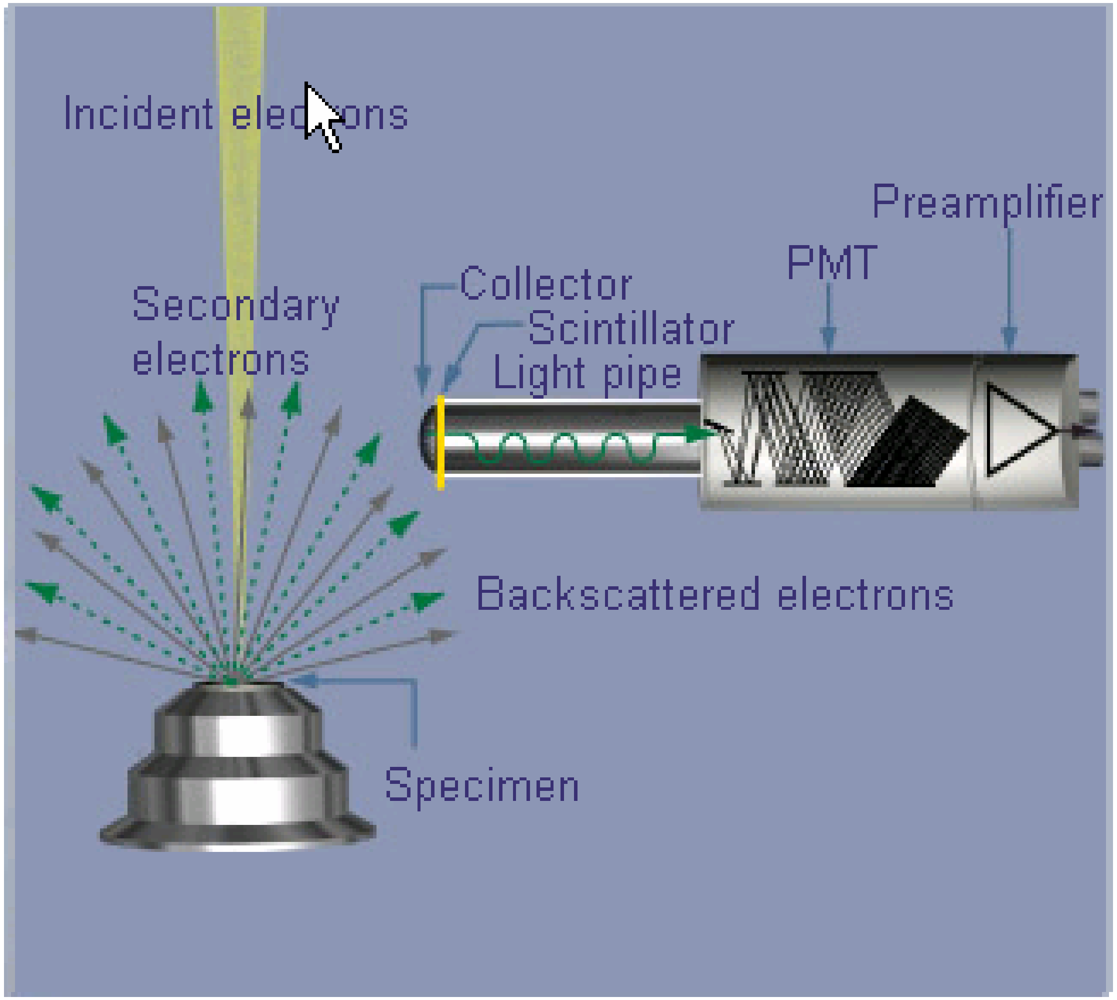
Electron beam

Many secondary electrons leave the sample

Electron beam

Few secondary electrons leave the sample

Secondary Electron, SE - Detection



Secondary Electron Detector

according to

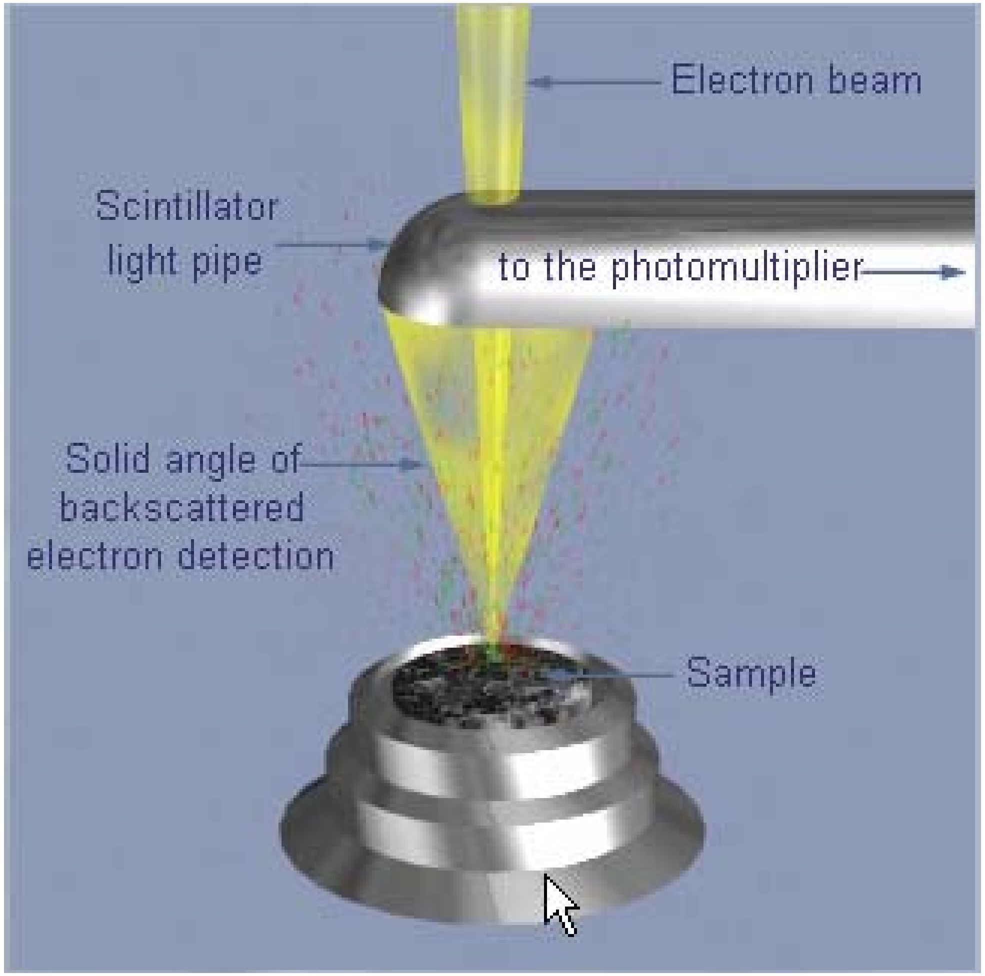
Everhart - Thornley

Negative voltage:

SE are rejected,

Only a few BSE reach the detector

Back Scattered Electrons, BSE - Detection



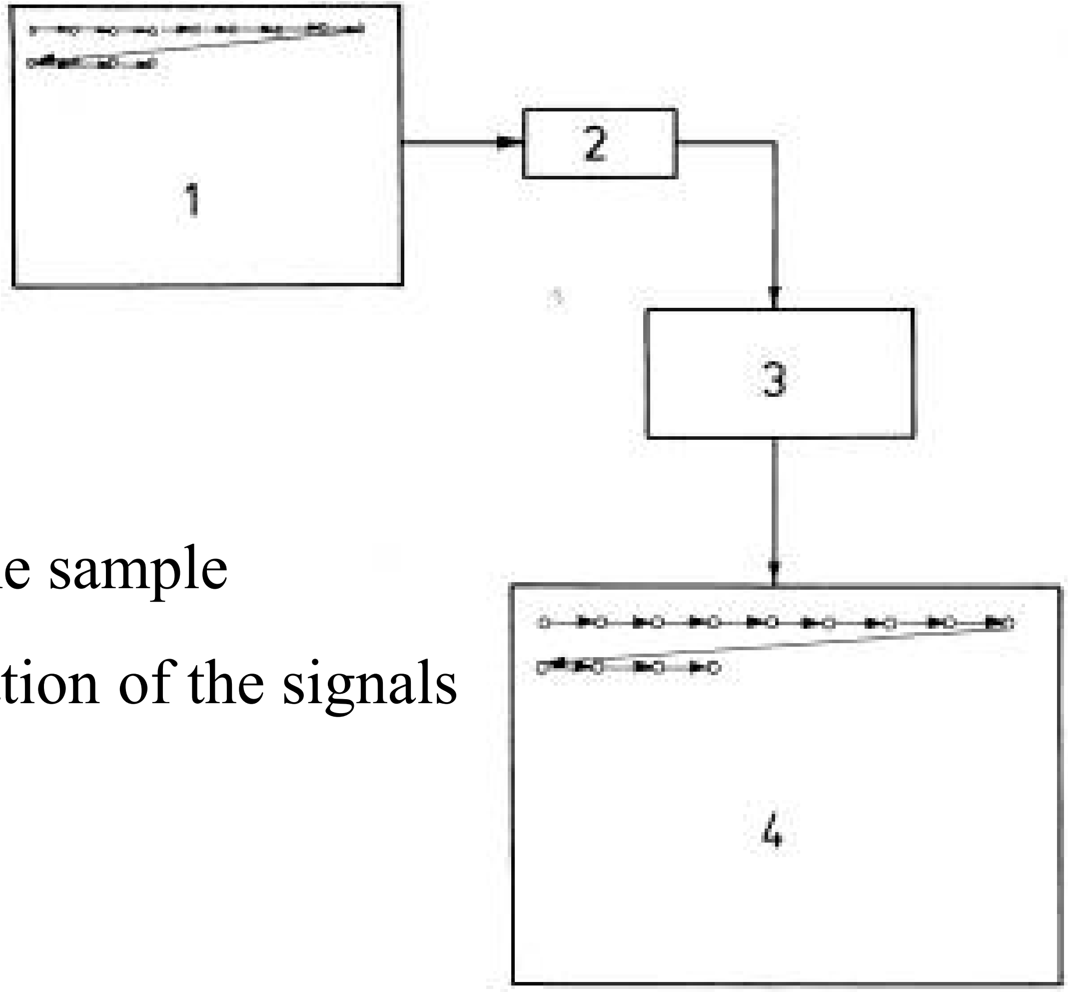
BSE detector:

Mainly plane detector above the sample

Scintillating crystal, e.g.

"YAG"
(Y-Al-Garnet)

Image Generation: Principle



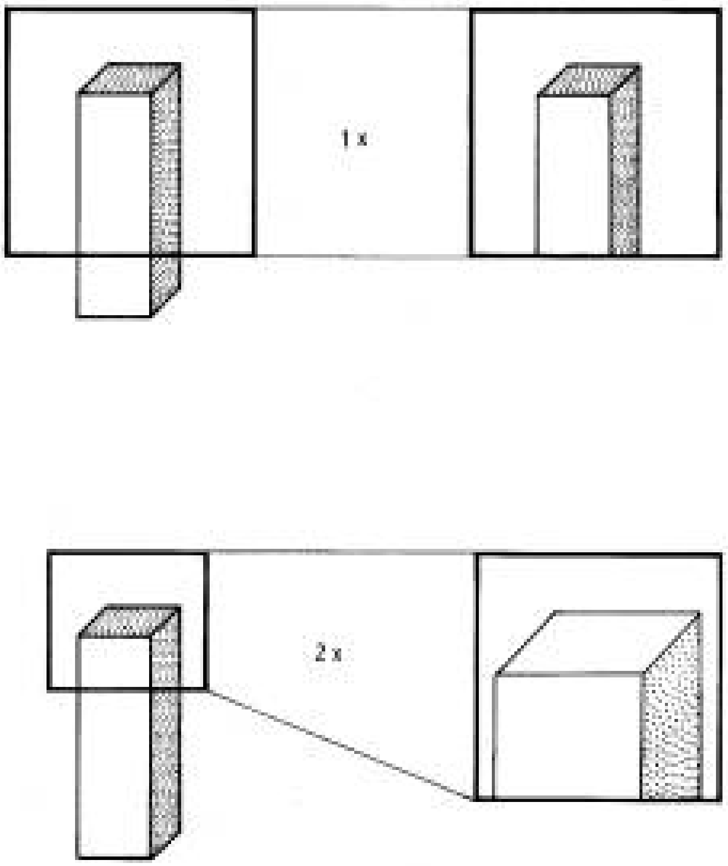
(1) Pointwise scanning of the sample

(2) Detection and magnification of the signals

(3) Digital video processing

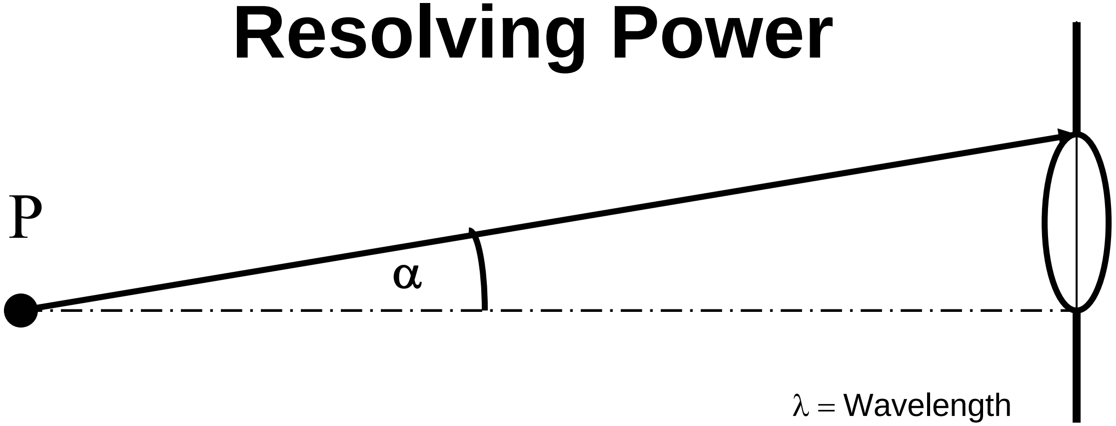
(4) Illustration on monitor

Image Generation: Magnification



- Reduction of the scanned surface while
- the number of measured points **remains constant**
- as well as the monitor size remains constant

Resolving Power



$$s = \frac{\lambda}{n \cdot \sin\alpha} \qquad \lambda = \frac{h \cdot c}{E}$$

λ = Wavelength

n = Refraction index

α = Half angle of aperture (Objective)

n · sin α = A = numerical aperture

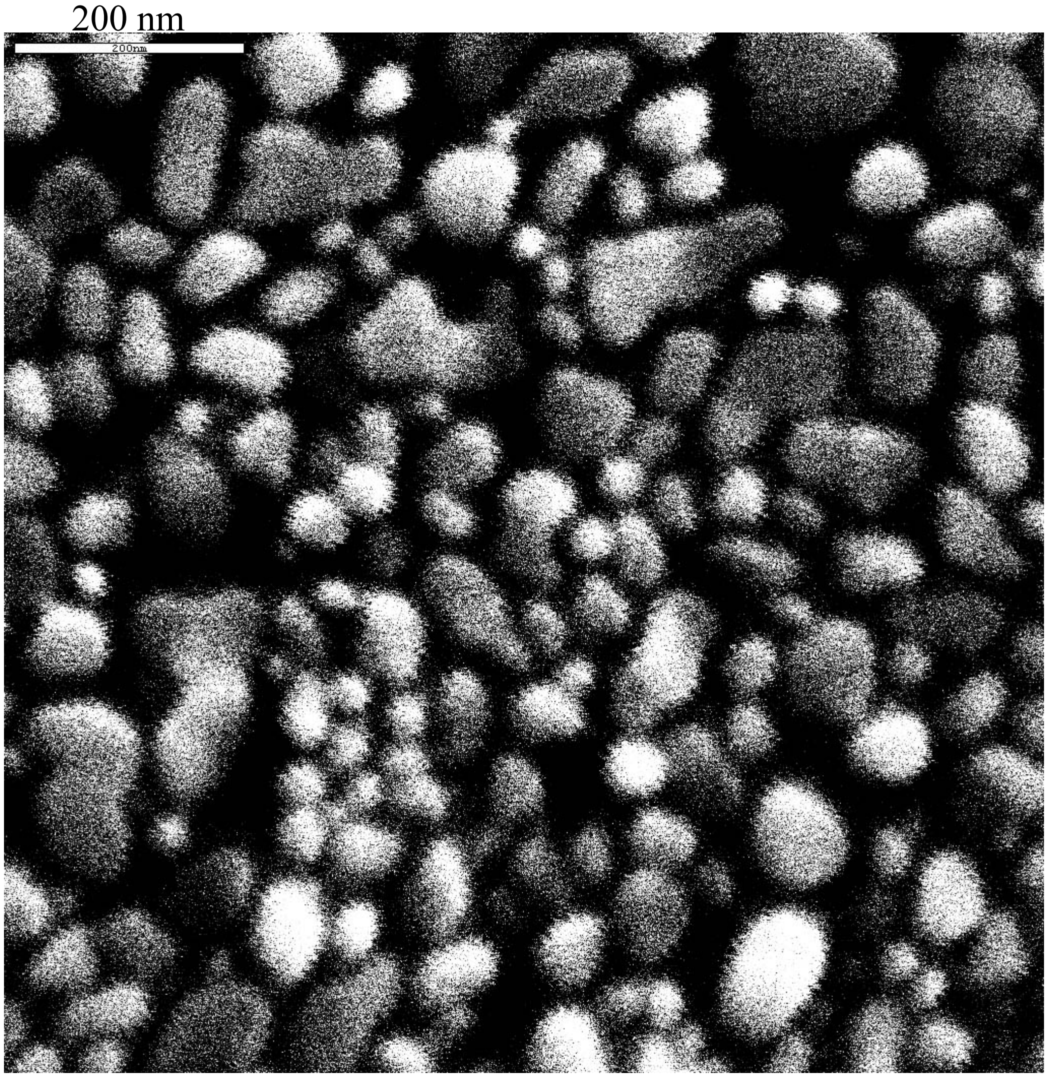
E = Kinetic energy

h = Planck´s quantum of action

c = Speed of light

	Visible light	**Electron beam (30 KeV)**
λ [nm]	500 nm	0,007 nm
A	0,90	0,002
s_{min} [nm]	400 nm	3,5 nm

High - Resolution: Au - Standard



Depth of Sharpness T

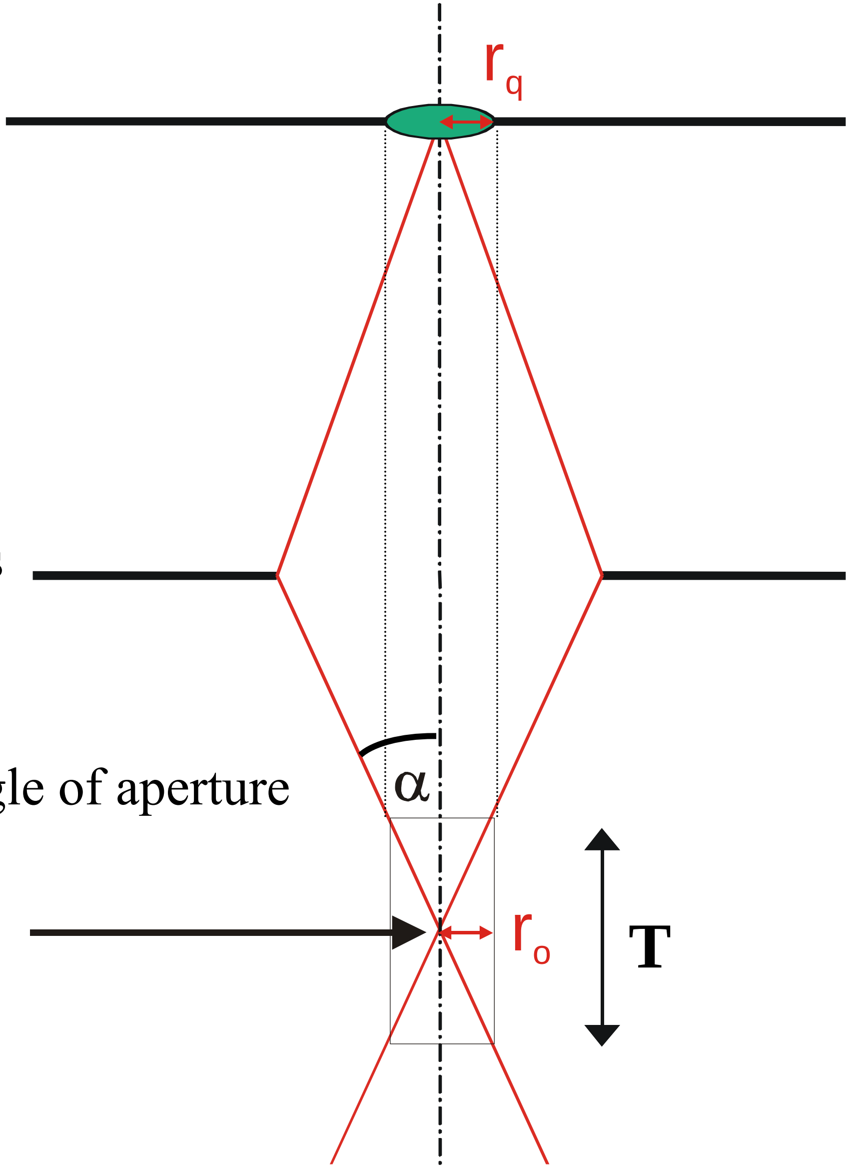


Image Plane

Objective lens

α = half angle of aperture

Focal plane

Sharp image for $r_o < r_q$

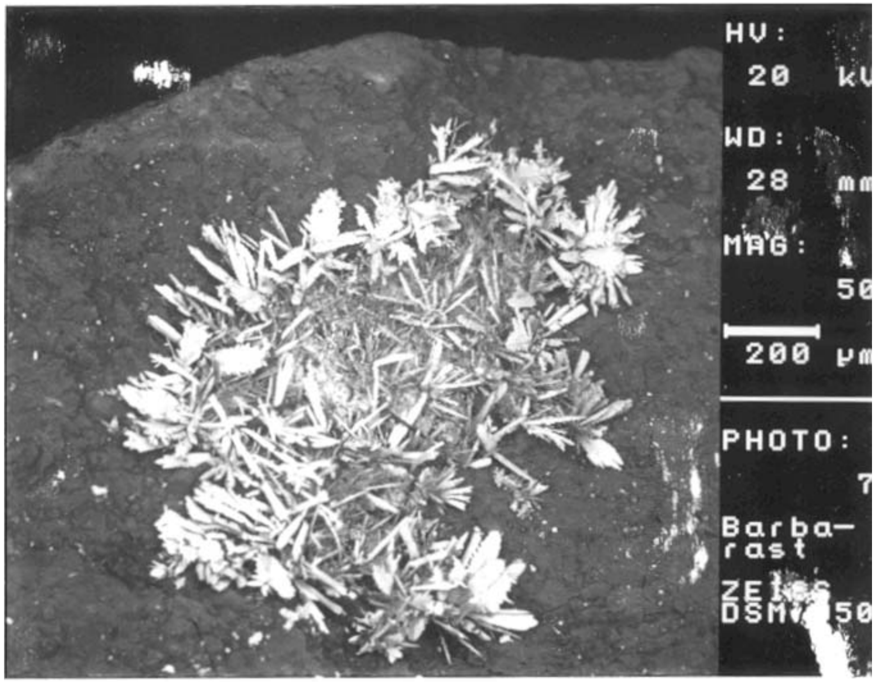
$$T = \frac{2 \cdot r_o}{\alpha}$$

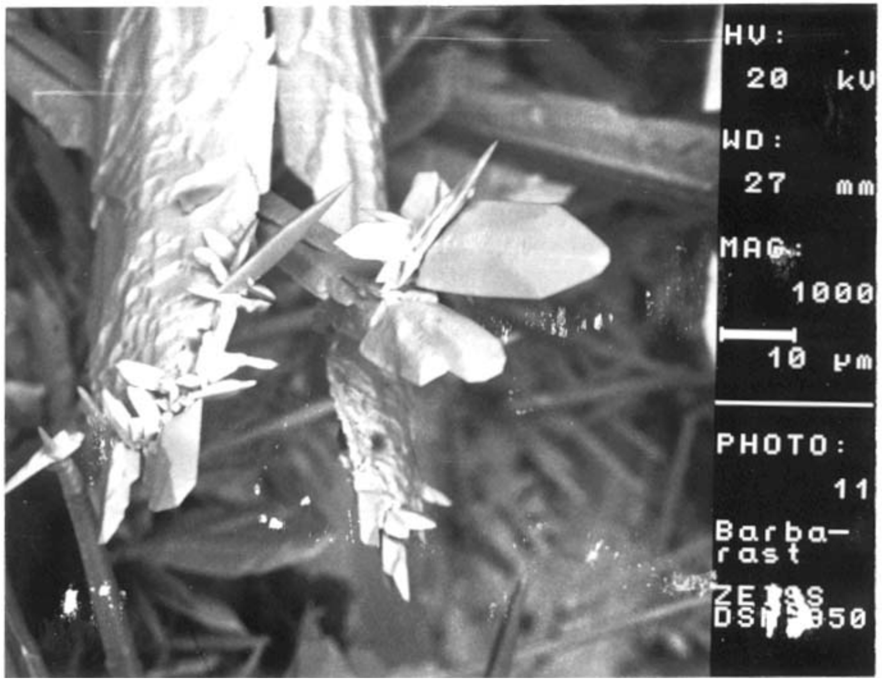
Magnification 1000-fold:

Light microscope: T = 0,8 µm

SEM: T = 50 µm

Example of a SE Image with High Depth of Sharpness
C_{2h} - 2/m , monokline - prismatic
Akanthit, Ag_2S, Barbarast

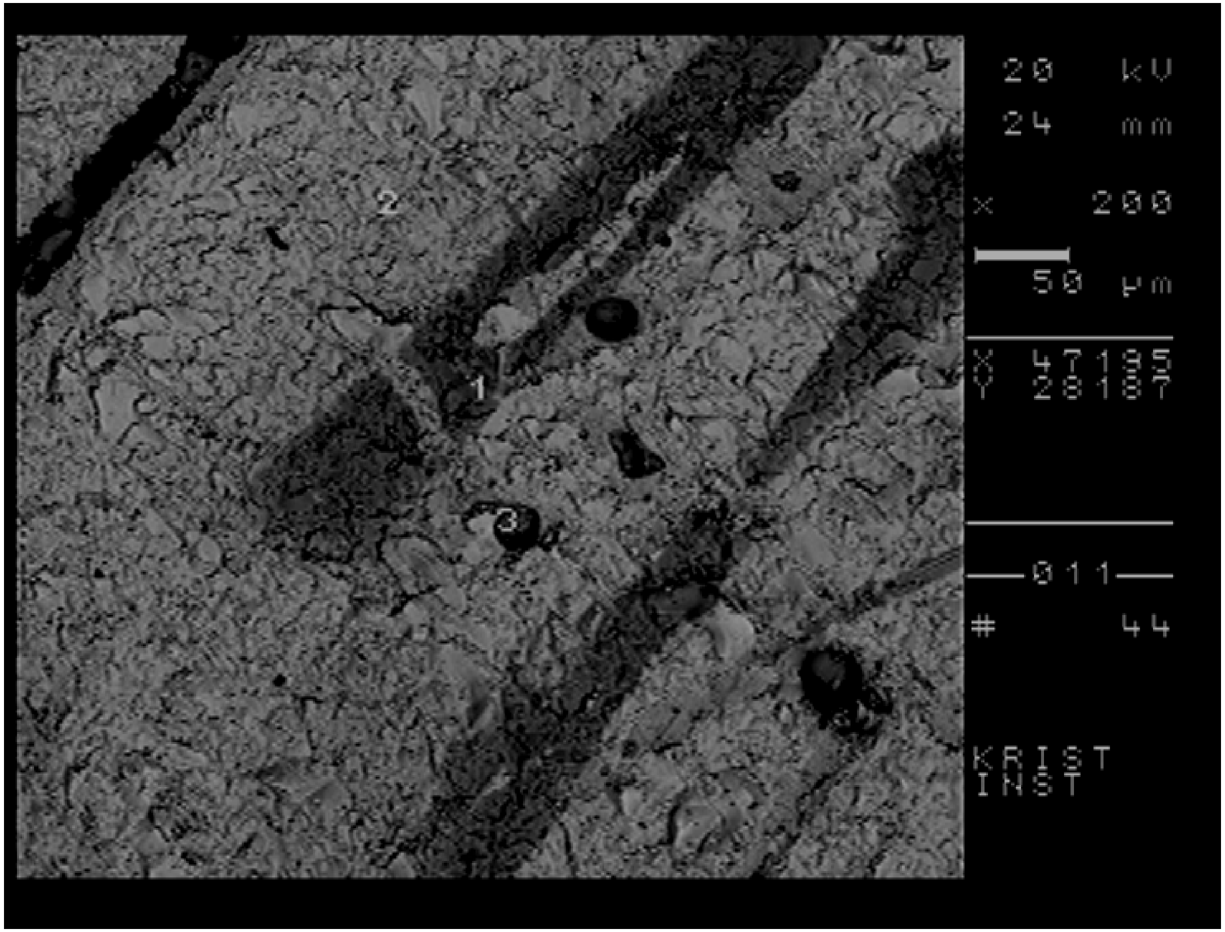




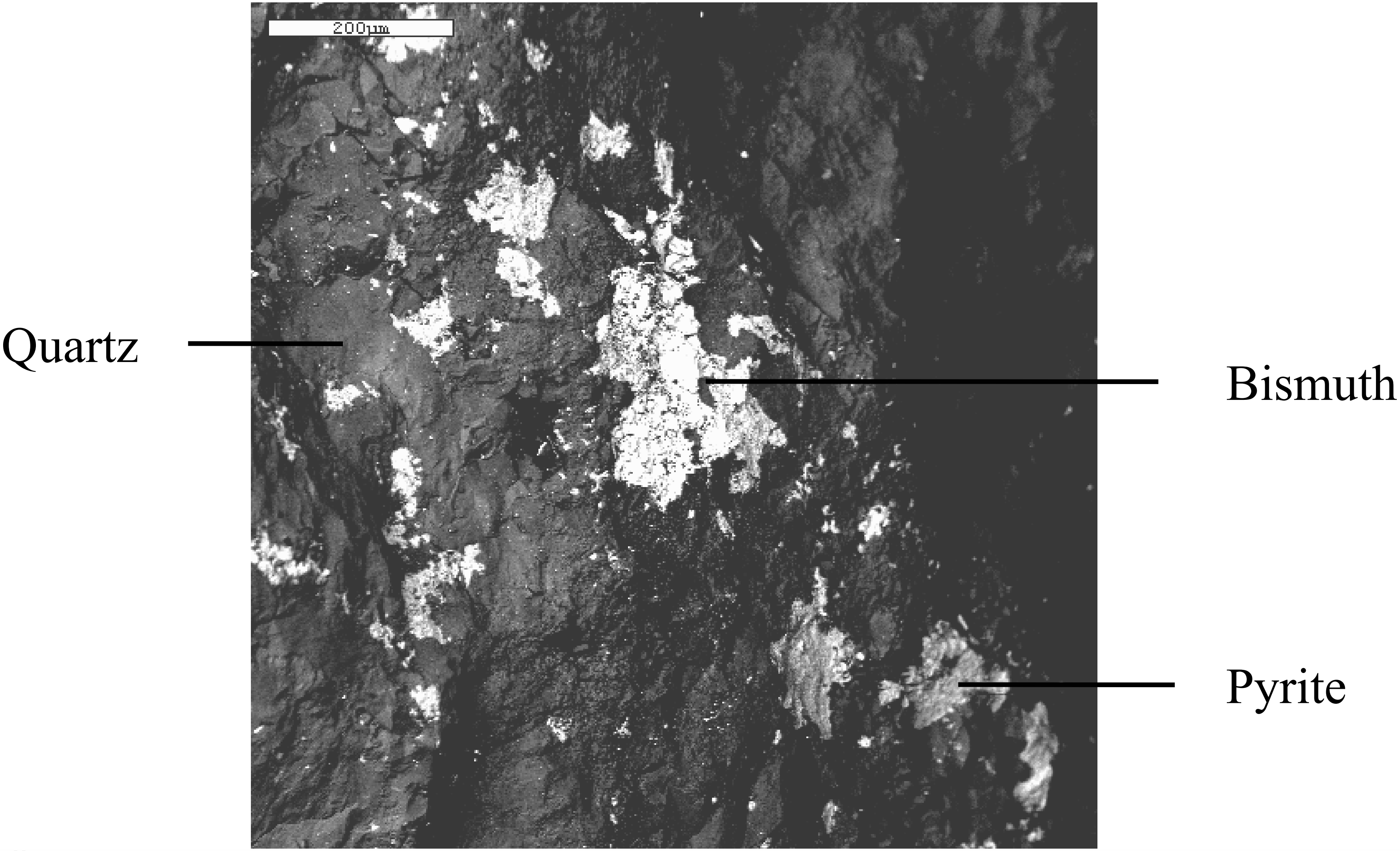
Collection Dany

Low-temperature modification of Ag_2S (<179 °C)

Examplary BSE-Image with Material Contrast
(Al,Ga)Sb - Crystals in (Ga,Al)Sb - Matrix

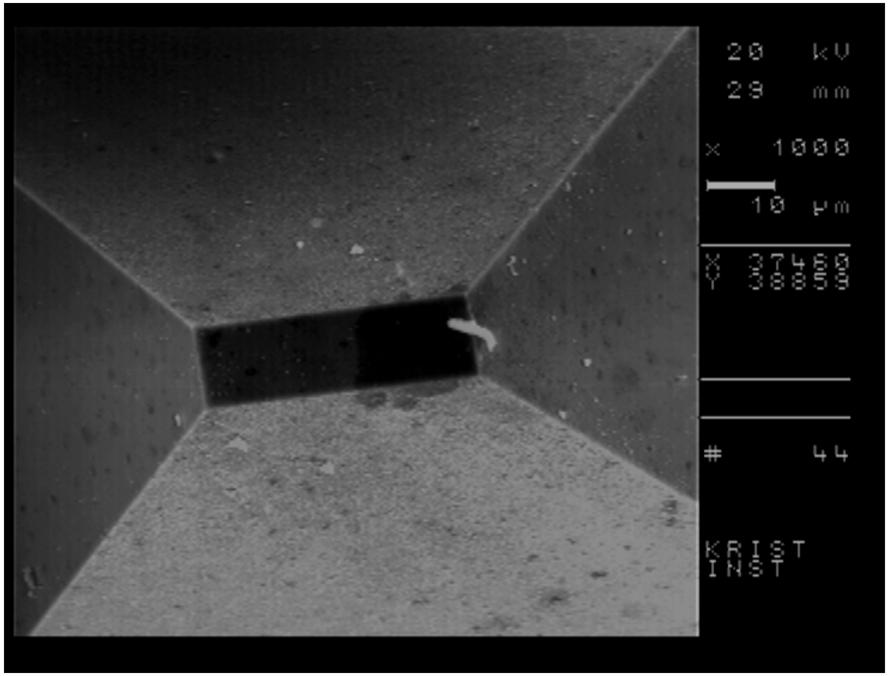


Examplary BSE-Image with Material Contrast
Bismuth and Pyrite in Quartz

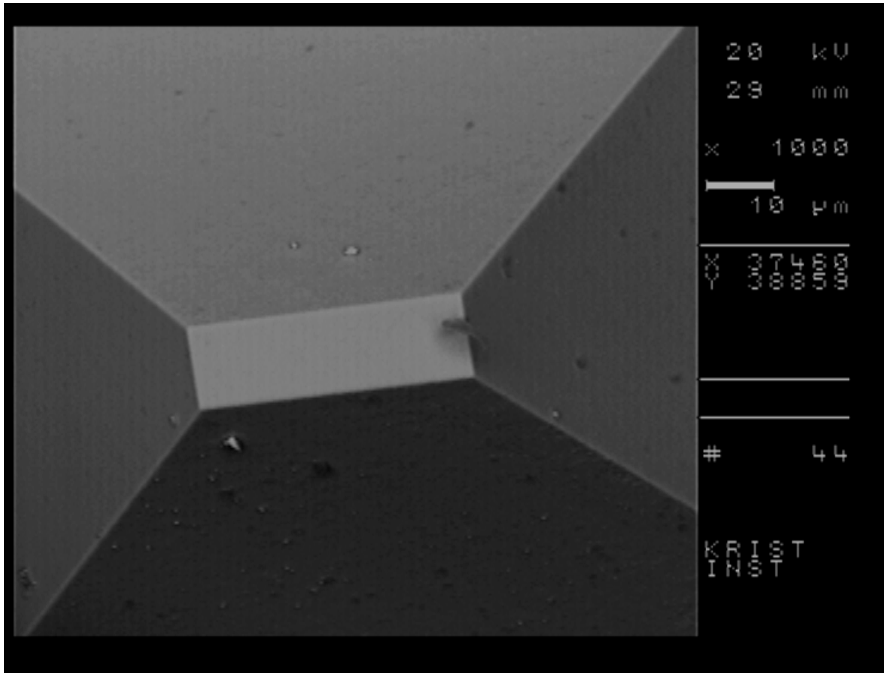


Comparison of SE and BSE Image

SE



BSE



GaAs: cubic, F - $\bar{4}3m$, Sphalerite - Structure,

Combination of (001), {111} and {$\bar{1}\,\bar{1}\,\bar{1}$}