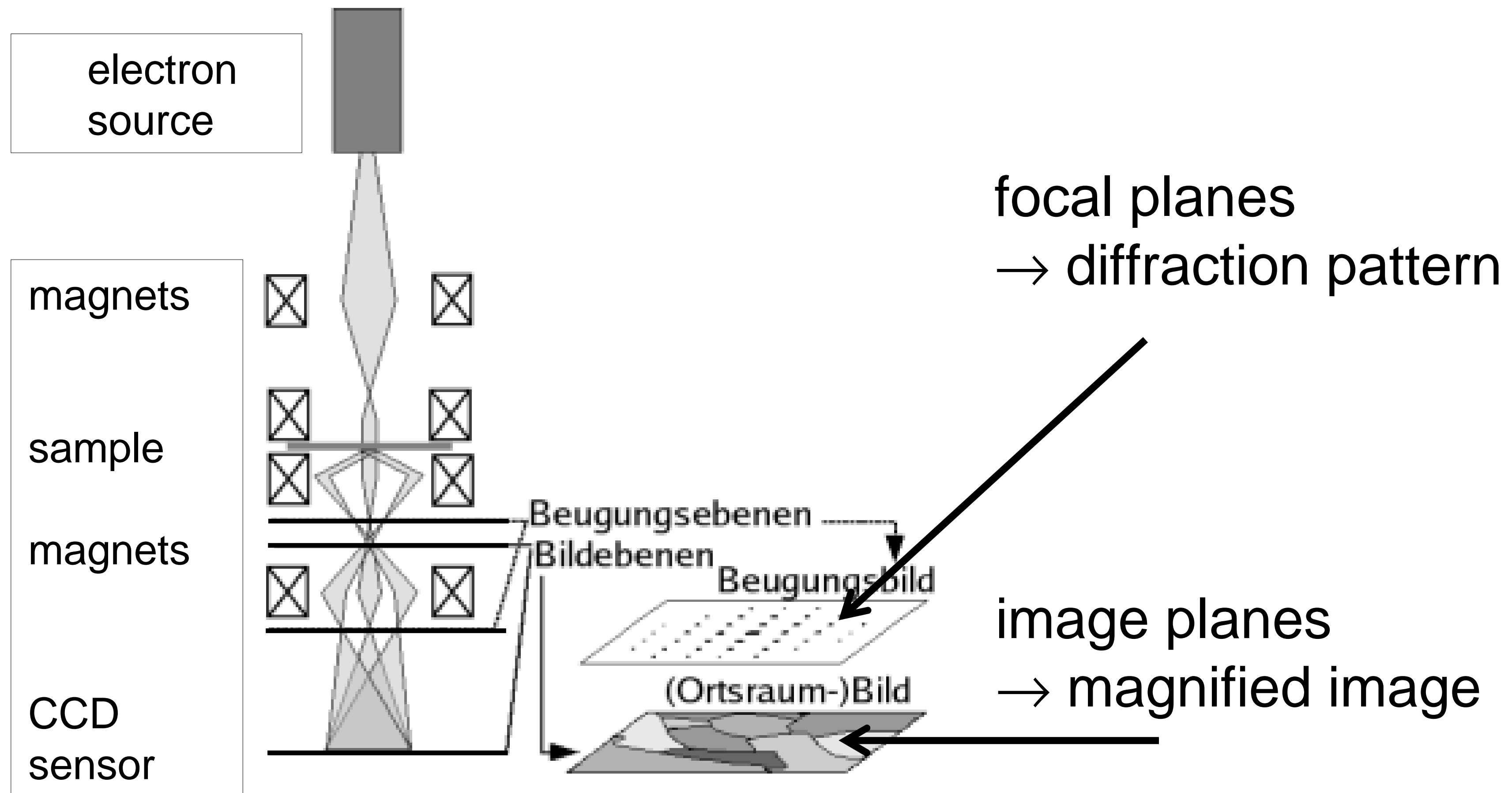
8. Transmission Electron Microscopy TEM



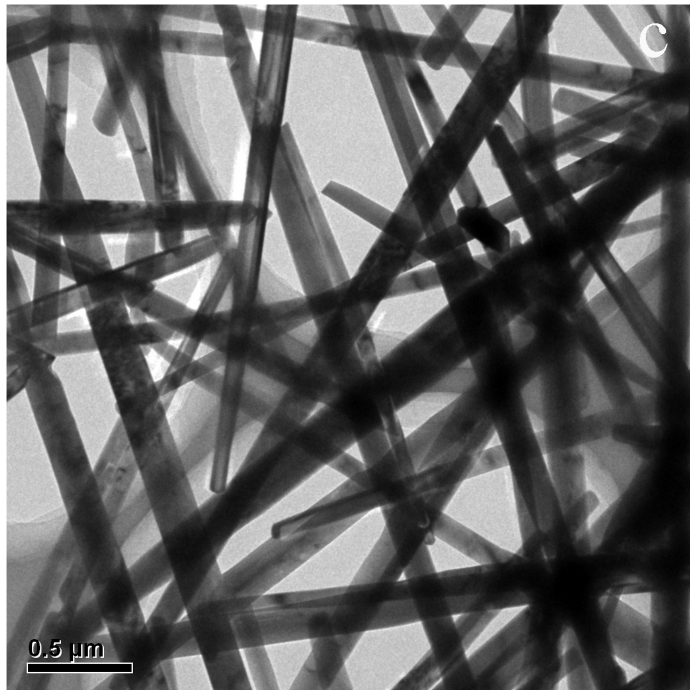
Electron beam passes the sample.
→ very thin sample

Excellent resolution.
→ down to atomic scale

8. Transmission Electron Microscopy TEM

Electron Diffraction ED

(002)
(101)
(110)
d
100 nm



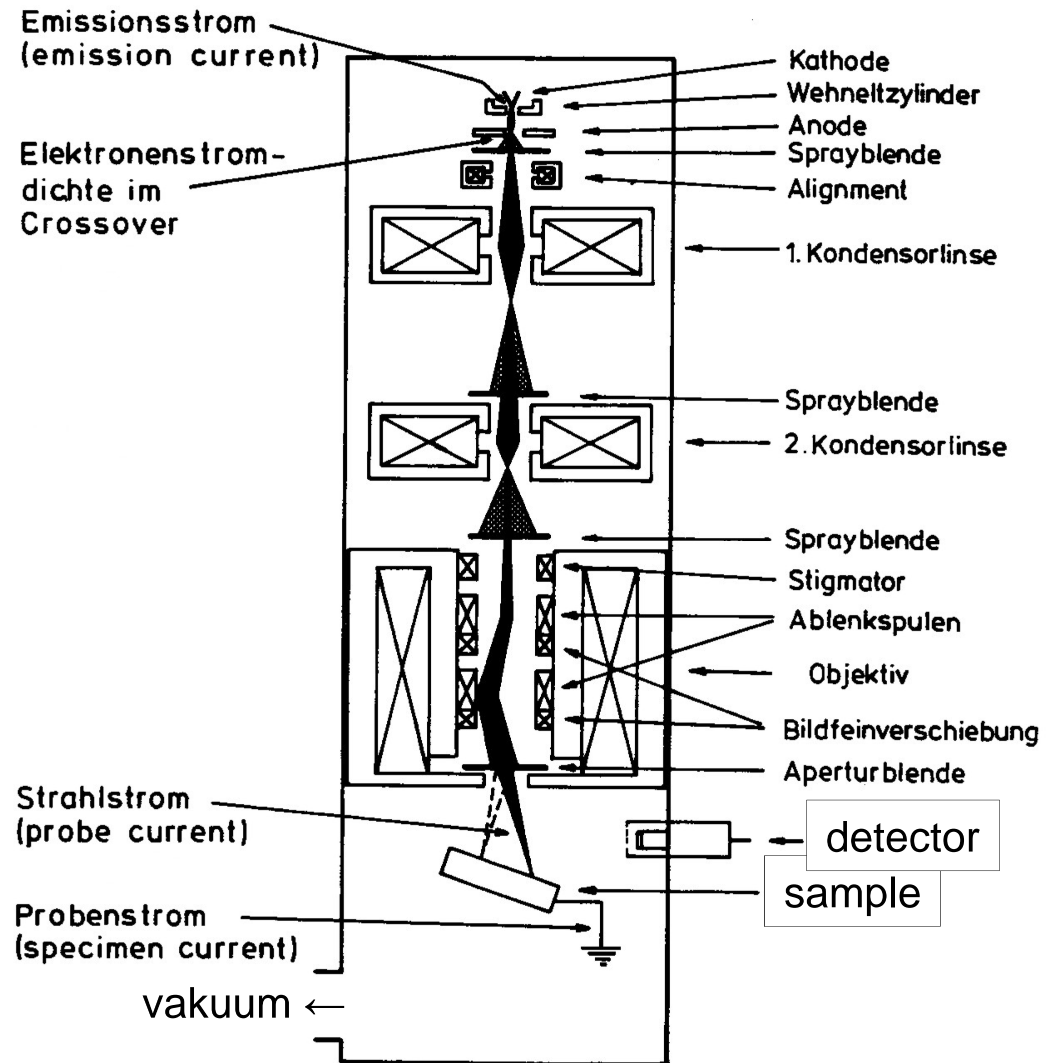
magnified images

9. Scanning Electron Microscopy SEM

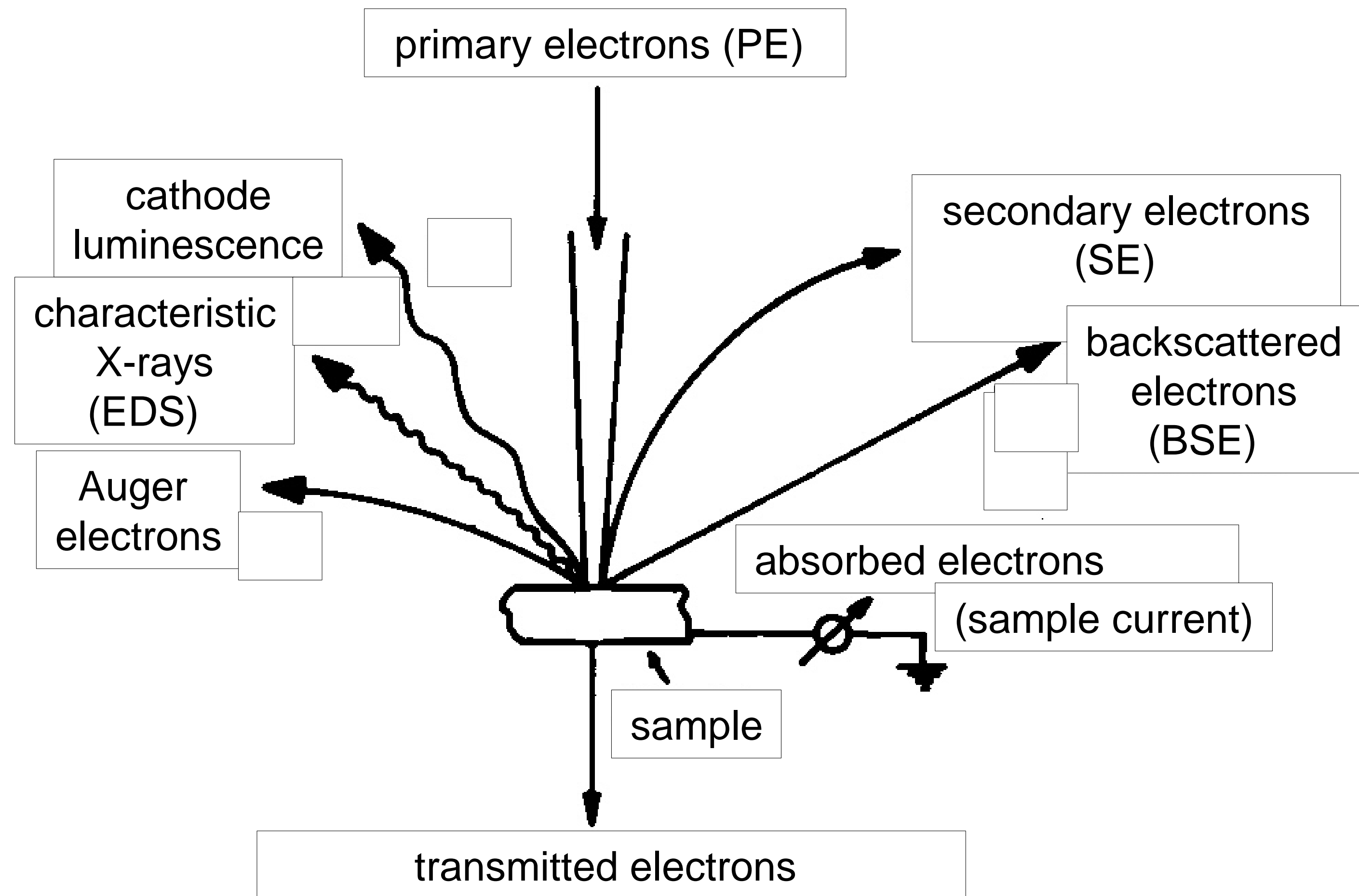
The sample (in vacuum) is scanned by the electron beam.

The electrons emitted from the sample are detected.

- variable sample size
- simple sample preparation
- limited resolution (~ 50 nm)



9. SEM



primary electrons (PE)

backscattered electrons (BSE) elastic scattering $E_{BSE} \approx E_{PE}$

secondary electrons (SE) inelastic scattering $E_{SE} < 50$ eV

characteristic X-rays element analysis (EDS)

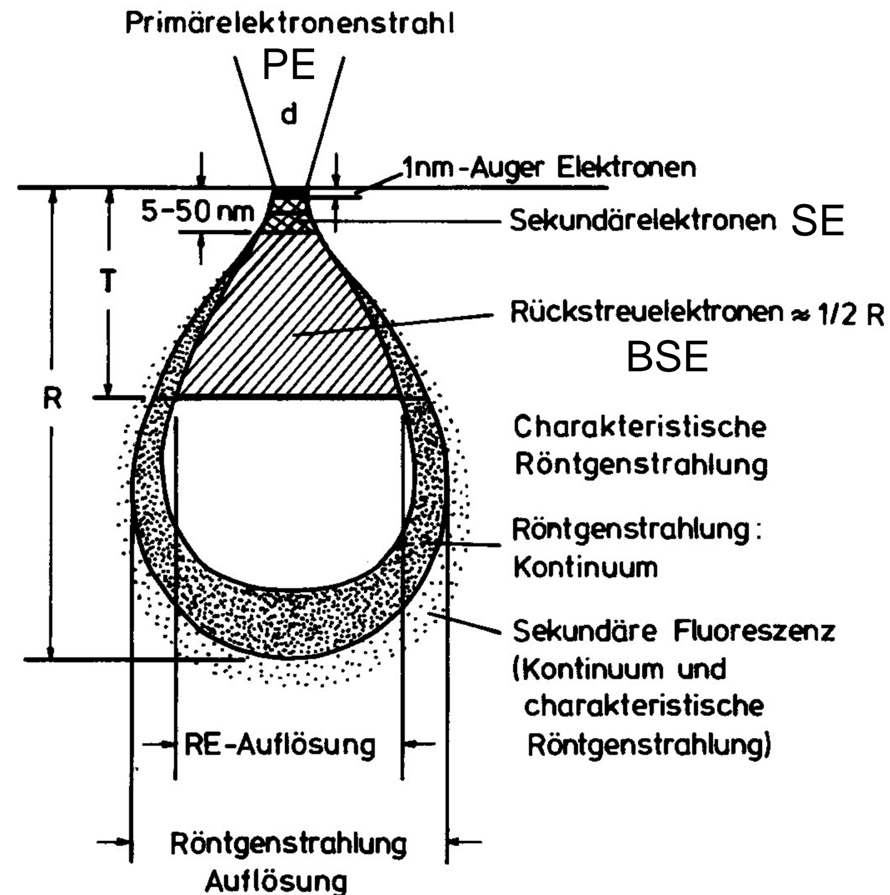
9. SEM

$E_{PE} \sim E_{BSE}$

$E_{Auger} < E_{SE} << E_{BSE}$

PE beam diameter
d ~ 0.005 nm

resolution ——
SE ~ 10 nm
BSE > 50 nm



Reichweite R der PE und Austrittstiefen der verschiedenen Signale im REM
- — R: Reichweite der PE
- — T: Austrittstiefe der RE
- — Auflösungsgrenze der RE ≈ 1/2 R
- — Auflösungsgrenze der Röntgenstrahlung ≈ Wechselwirkungsvolumen
- — Auflösungsgrenze der sekundären Fluoreszenz >> Wechselwirkungsvolumen

9. SEM interaction volume

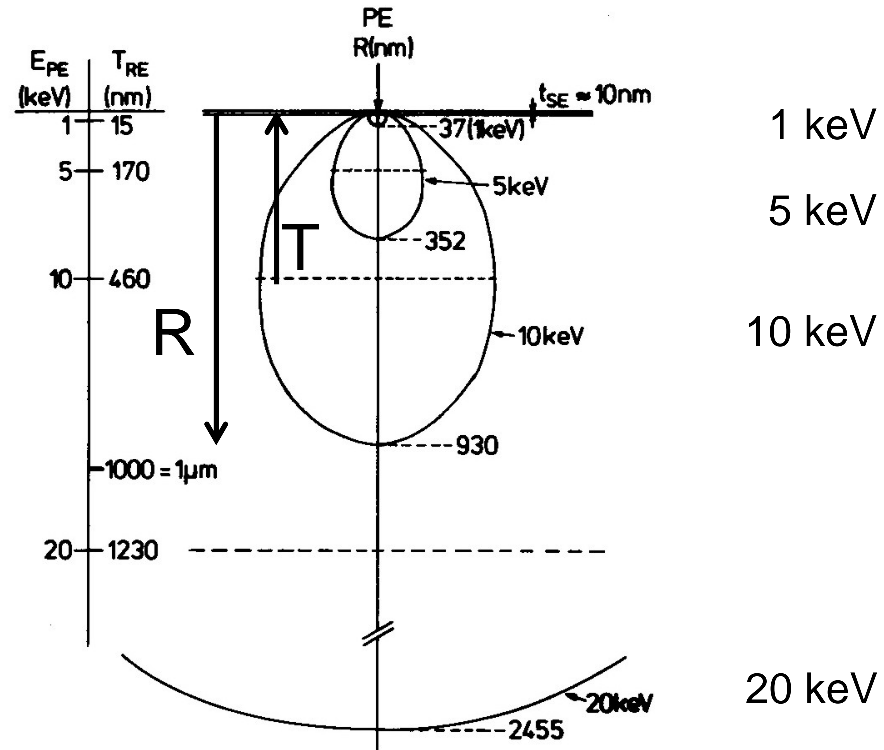
penetration depth (R) of PE

and

escape depth (T) of BSE

T ≈ R / 2

aluminum for various PE energies

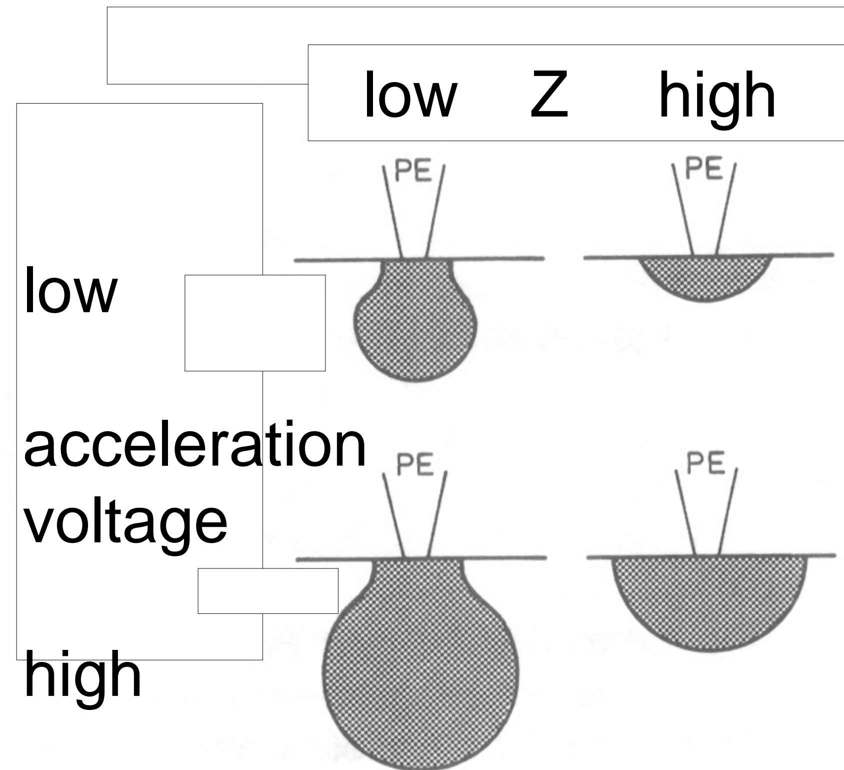


Reichweite R, Wechselwirkungsvolumen und Austrittstiefe T in Al für E_{PE} von 1, 5, 10, 20 keV
——: Reichweite R der PE, ---: Austrittstiefe T der RE

9. SEM interaction volume

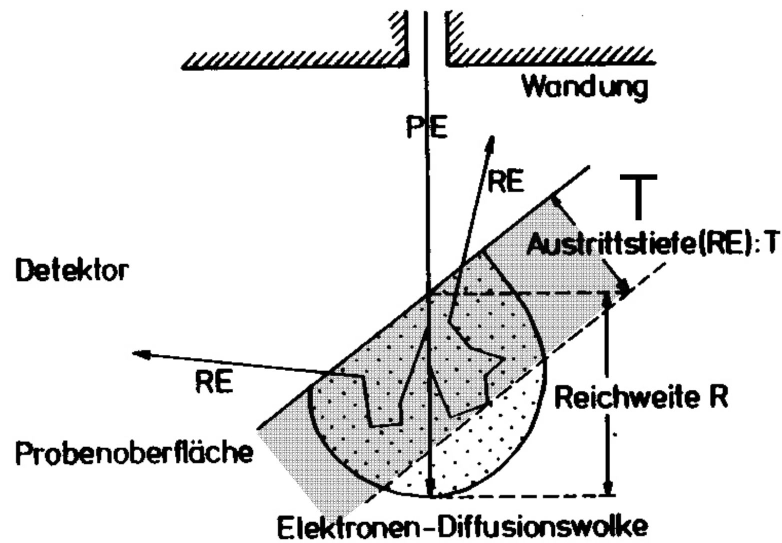
PE energy
- penetration depth
- interaction volume

Electron density of sample
- shape and
- depth of interaction volume

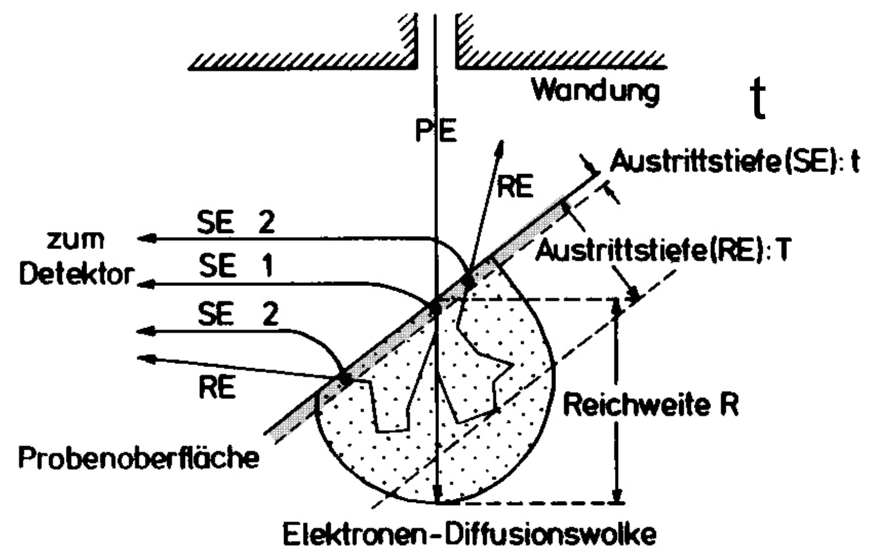


9. SEM interaction volume

BSE



SE



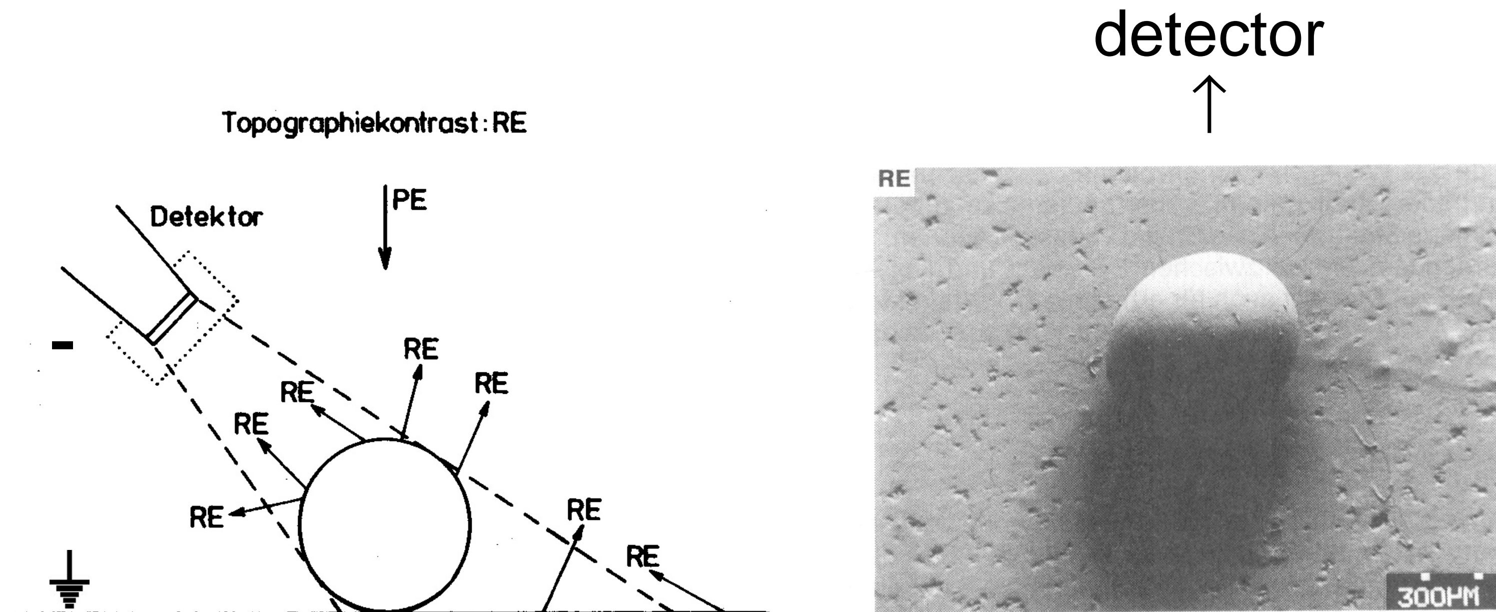
$R \sim E_{PE}$

$T \approx R / 2$
($T \approx$ 1-2 μm)

$t \approx$ 5x free path length of SE

metals: $t \approx$ 5 nm
isolators: $t \approx$ 50 nm

9. SEM topography for BSE



$E_{PE} \approx E_{BSE}$ (typical 10 – 25 keV)

shadow effect

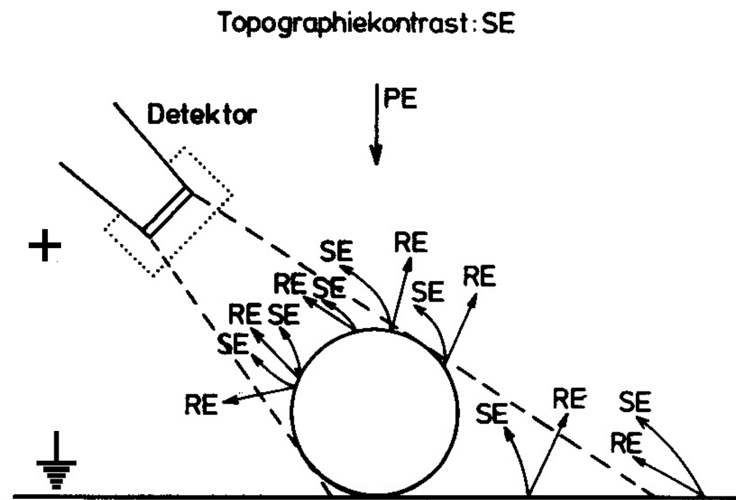
BSE: straight flight path, weak deflection by electric field

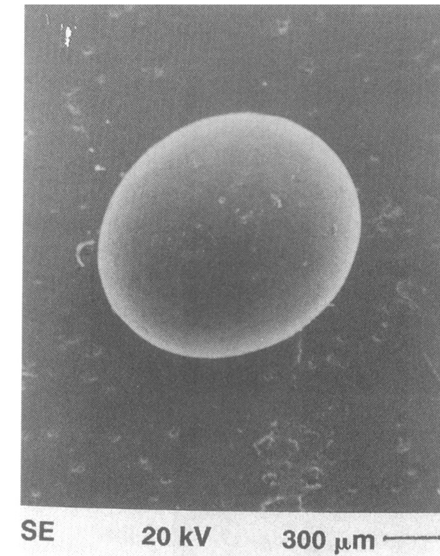
$\rightarrow$ bright surface towards detector

$\rightarrow$ shadow at back side

Negative voltage on detector keeps SE away.

9. SEM topography for SE





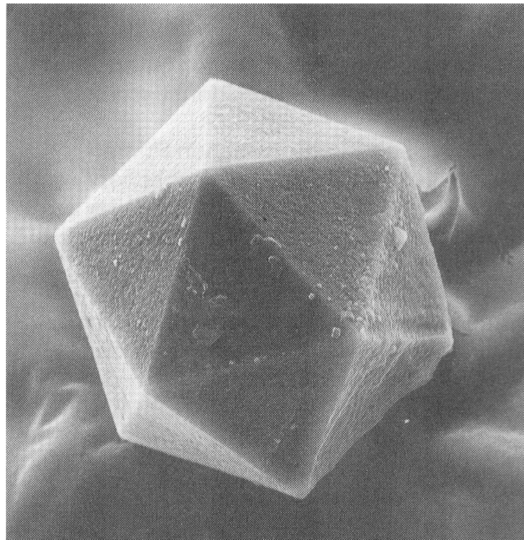
E_{SE} < 50 eV

edge effect

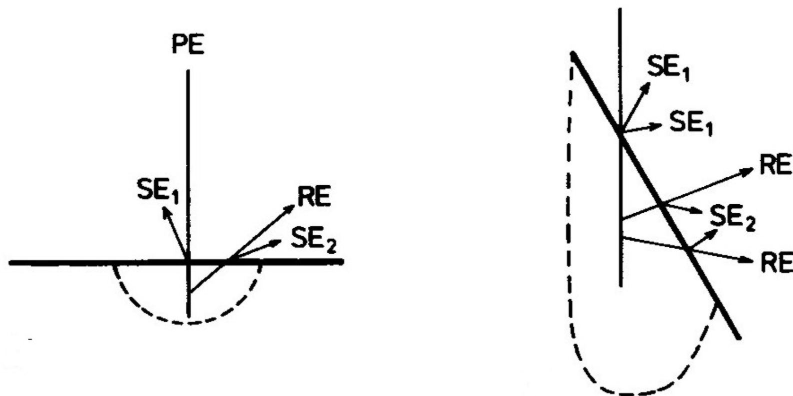
SE: curved flight path, strong deflection by electric field
The surface to volume ratio determines the SE intensity.
$\rightarrow$ bright edge

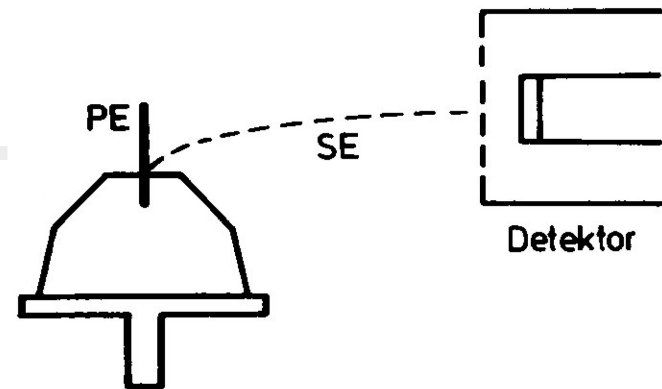
Positive voltage attracts SE towards detector.

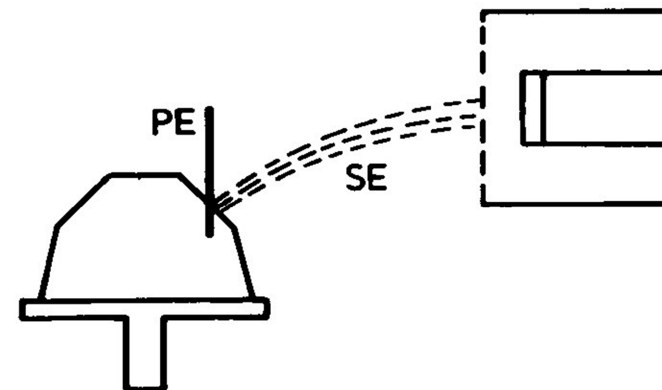
9. SEM topography SE

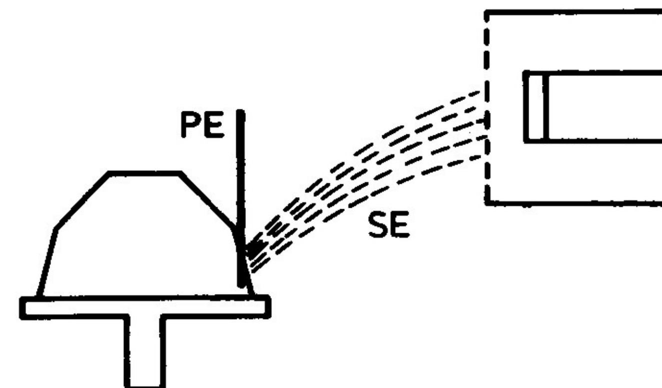


SE signal depends on surface inclination.

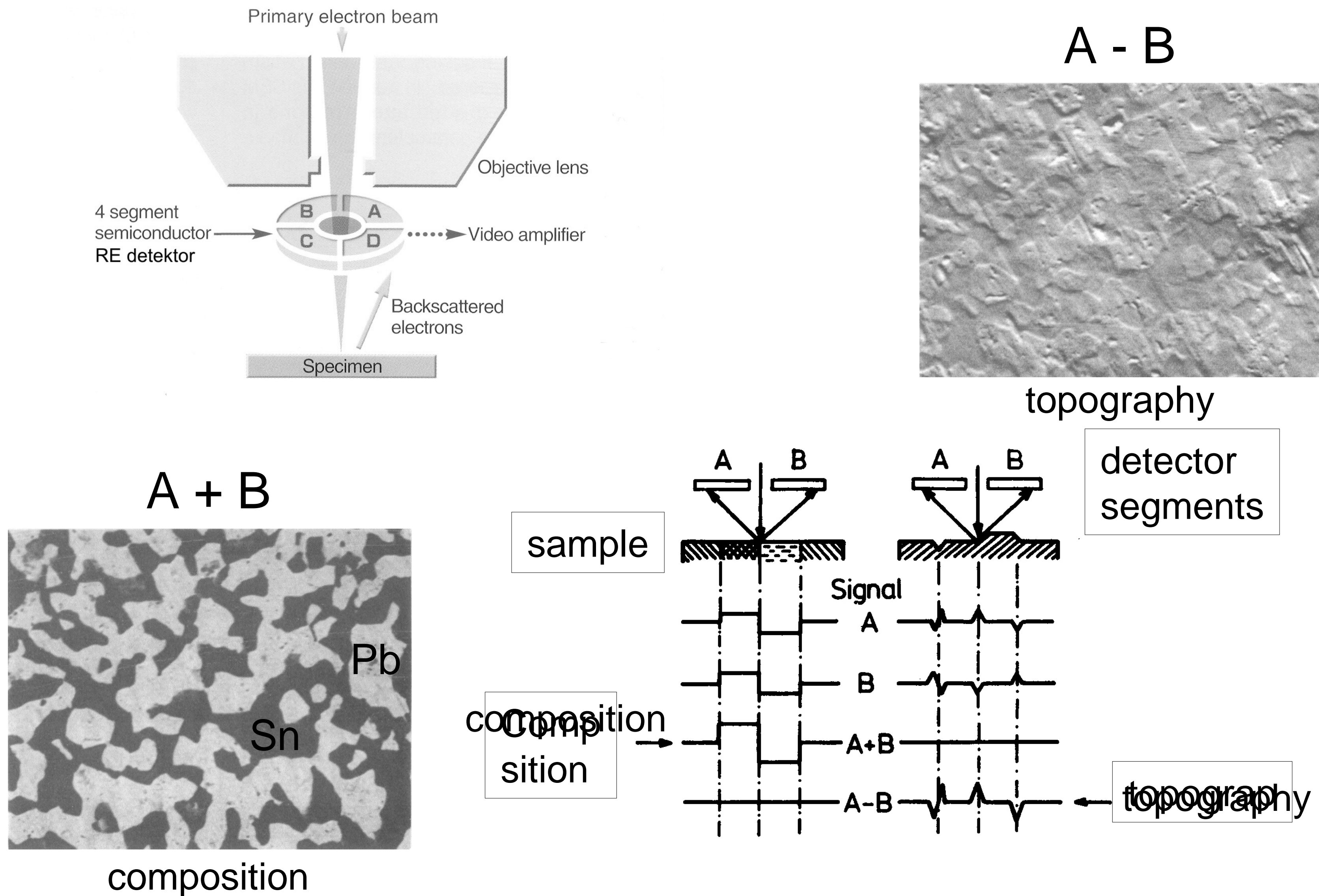




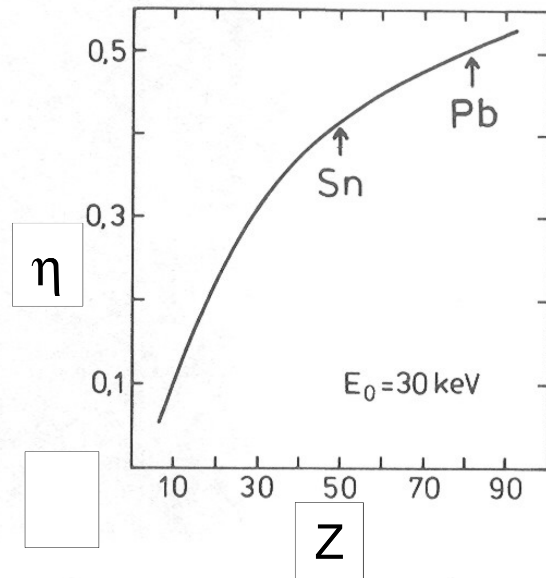




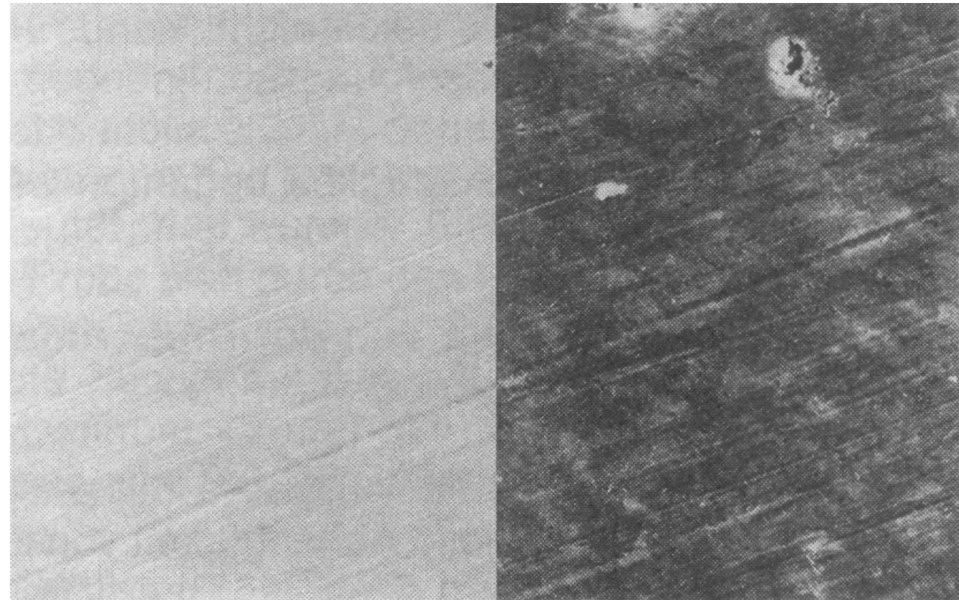
9. BSE enhanced composition or topography contrast



9. Composition contrast



interaction coefficient η
→ electron density

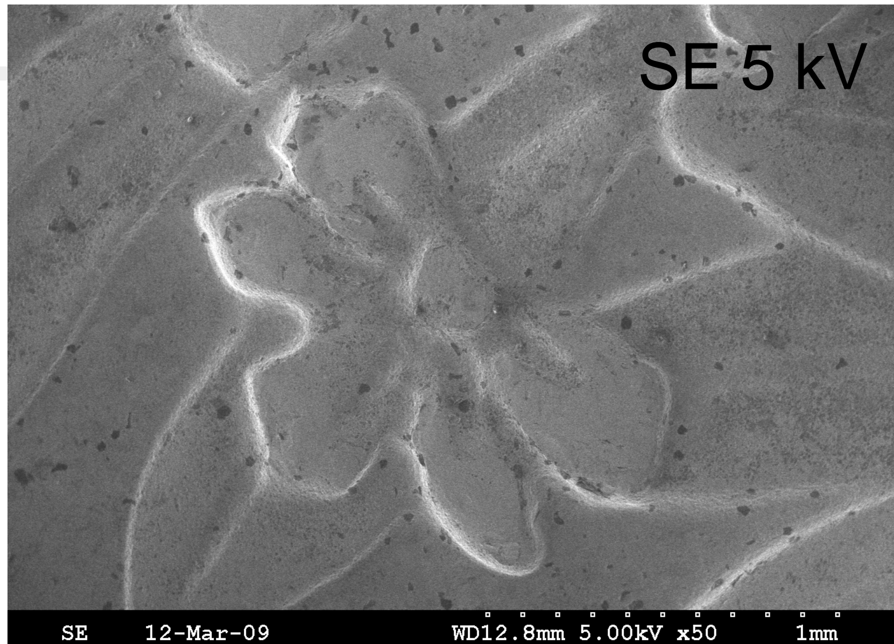


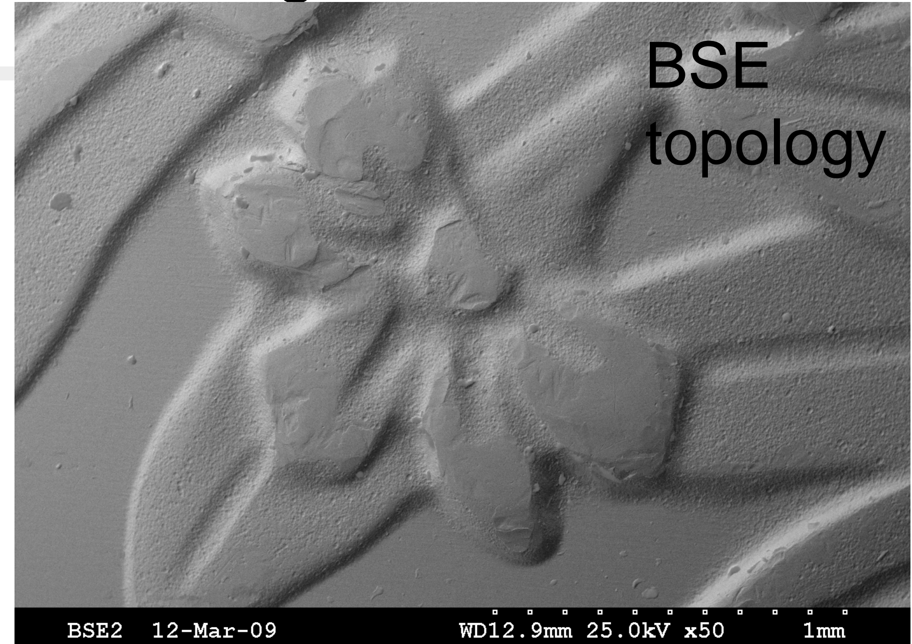
Au sputtered　　C sputtered

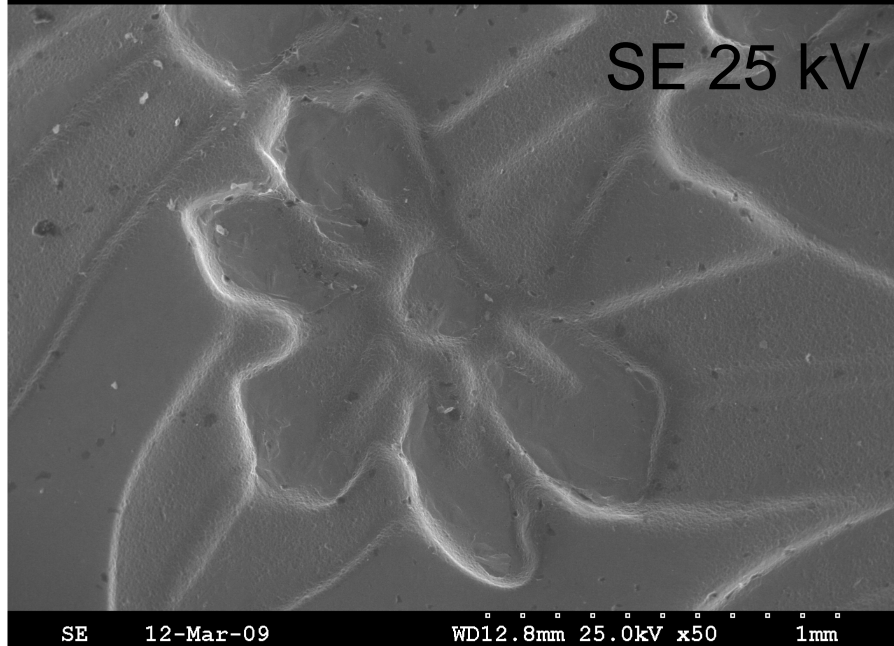
heavy elements → bright

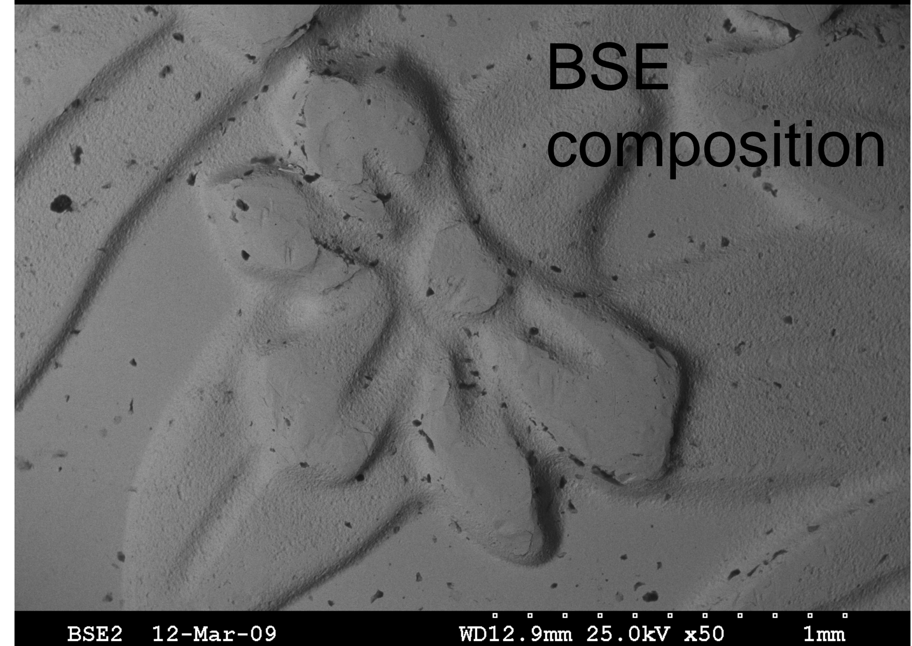
light elements → dark

9. SE versus BSE images









9. Summary EM

TEM images with highest magnification
electron diffraction
demanding sample preparation

SEM SE images (standard)
BSE images - composition
- topography
EDS element analysis
simple sample preparation
(flexible in size and shape)