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Signal Detection

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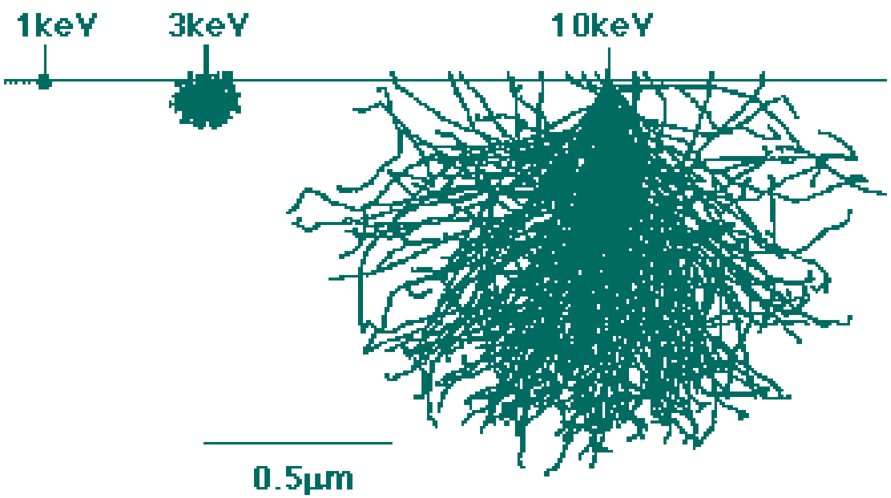
Imaging in the SEM

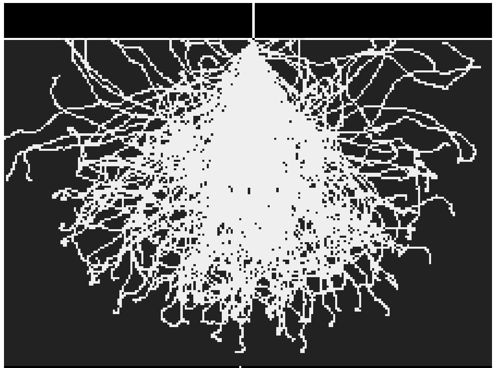
- Images are formed because of the beam interactions that occur
- These interactions do not occur at a point, but all through some volume of the sample
- The size of this volume varies with beam energy…



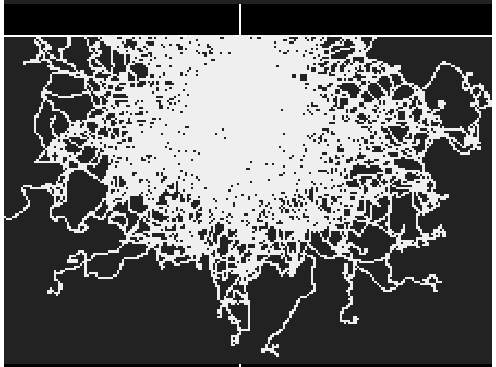
Monte Carlo simulations of electrons in silicon

Shape of interaction volume

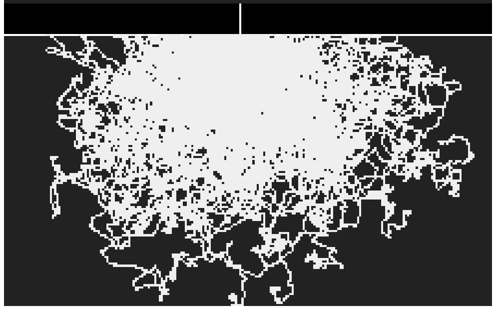
- ....and the shape of the interaction volume depends on the atomic number Z
- High Z elements give more elastic scattering so the electrons are deflected more



Carbon
Z = 6



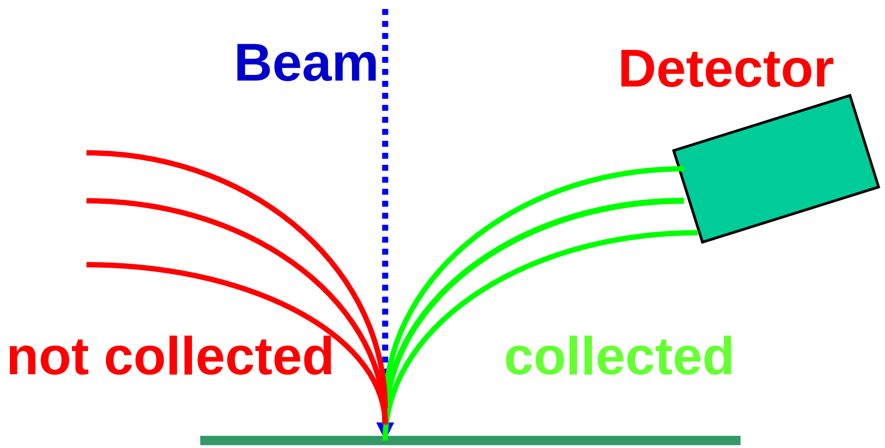
Copper
Z = 29

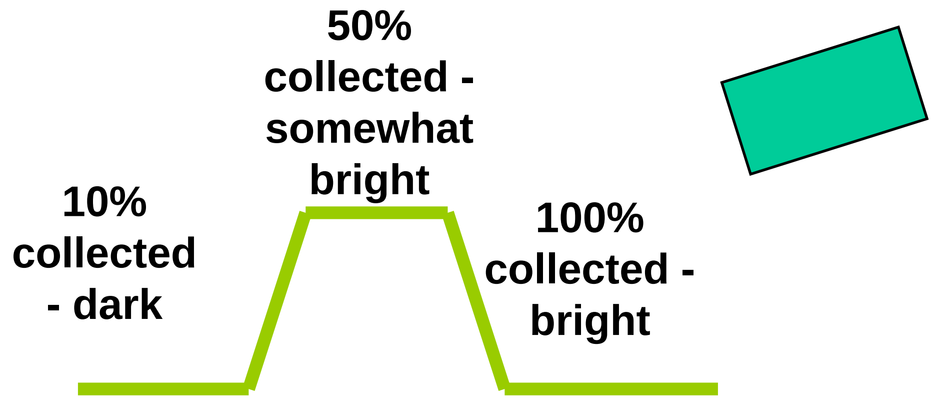


Gold
Z = 79

Detector efficiency contrast

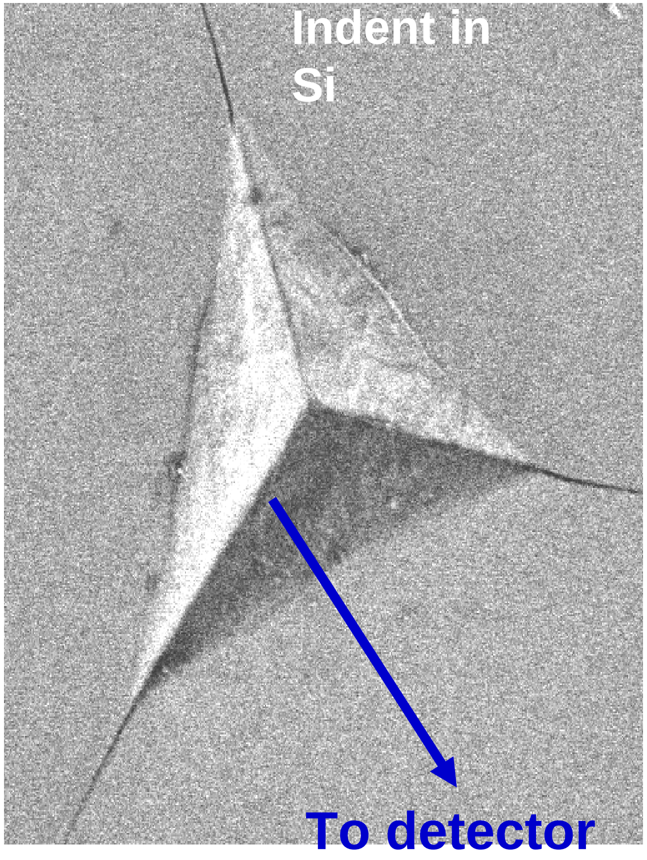
- SE emitted towards the detector are more likely to be collected than those traveling away from the detector since typical SE detectors collect <50%
- The position of a surface relative to the detector will therefore affect how bright it looks in the image.
- This 'detector efficiency contrast' is combined with topographic contrast





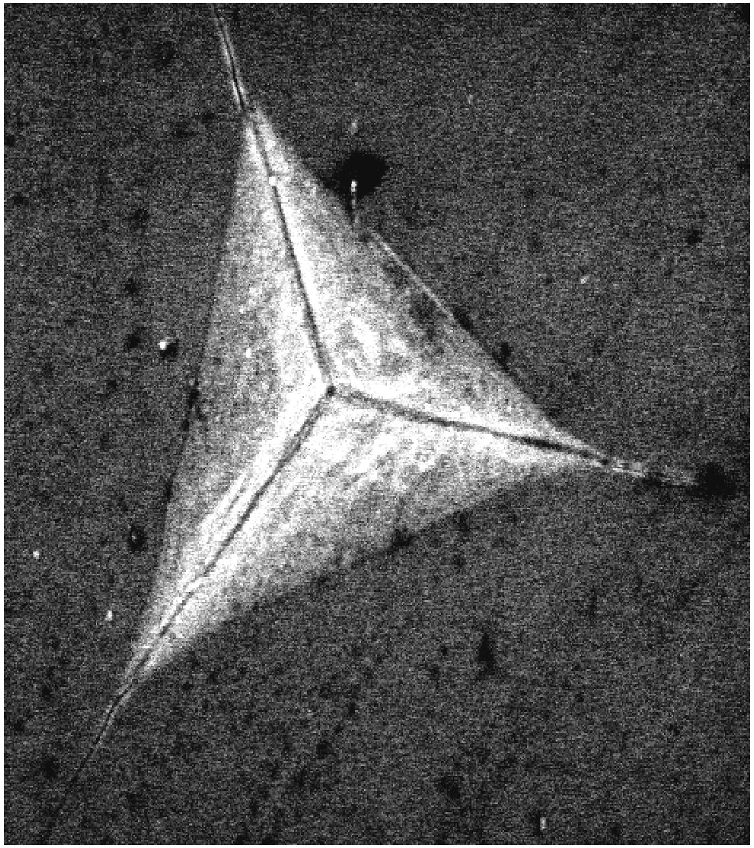
Lower Detector

- The detector position therefore affects the image appearance
- The lower (ET) detector views the sample from one side and so the face looking away from the detector is shadowed



Upper detector

- The upper (through the lens) detector views the sample from above
- The SE collection is now symmetrical and so all faces of the indent are equally visible. They are brighter than the flat surface because of topographic contrast.



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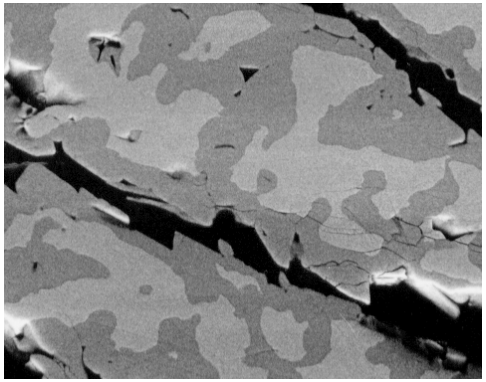
Back Scattered Electrons

- Although secondary electron imaging is the most popular mode in the SEM, back scattered electrons (BSE) are very versatile and offer some unique kinds of information
- Key difference - BSE are incident electrons scattered back out of the sample, SE are electrons which start out in the specimen
- The BSE yield increases with Z and incident angle
- Large, symmetric BSE detector required

Z contrast from Igneous rock



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Imaging performance

- The probe size is determined by the combined effect of the aberrations of the lens
- The magnitude of the aberrations vary with the focal length of the lens - which is about equal to the working distance
- Some lens' designs are more capable than others at combining both high performance and good sample access

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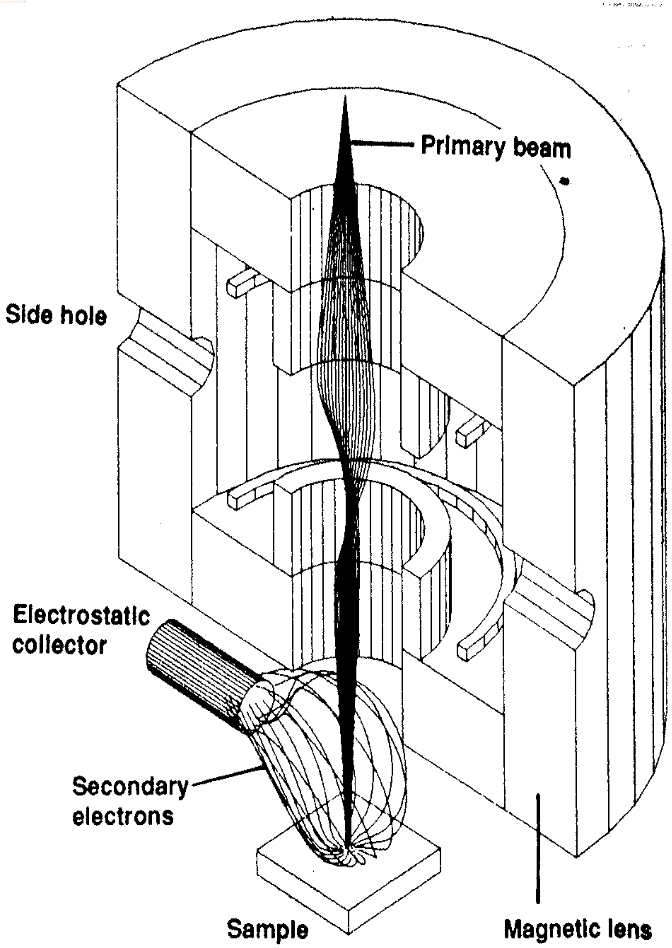
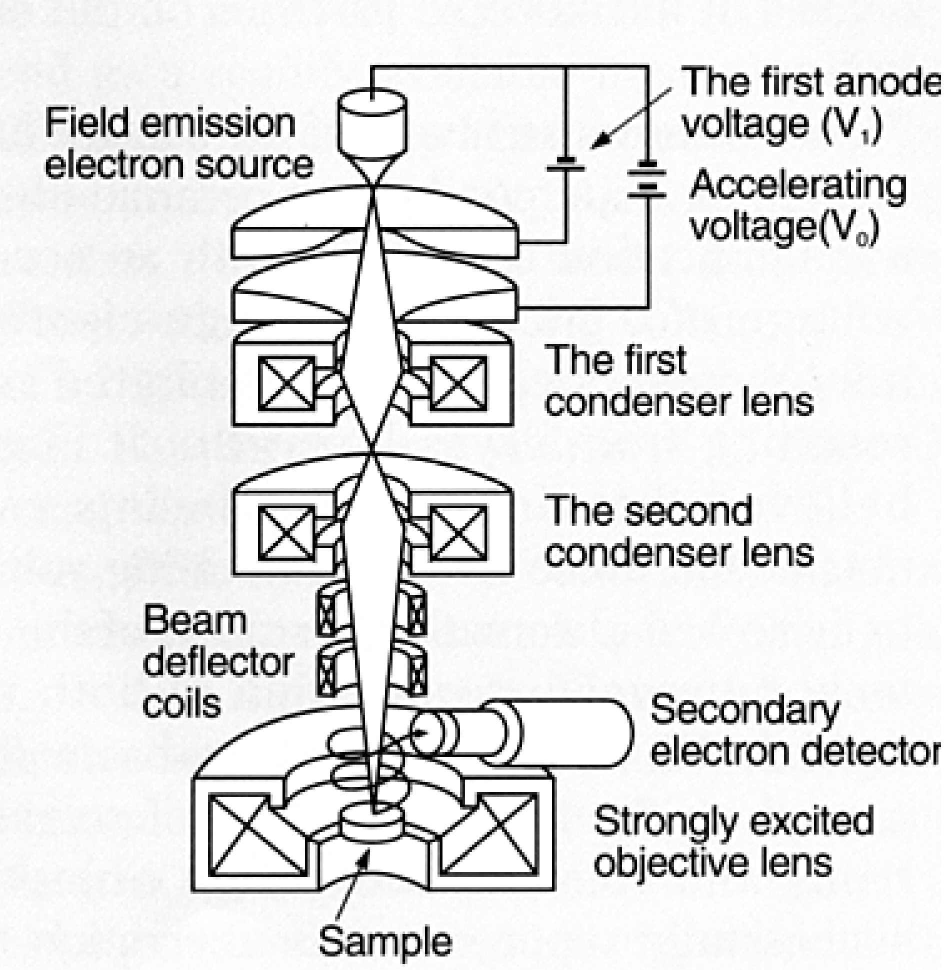
The ‘pinhole’ lens



- The original SEM lens - designed so as to produce no magnetic field in the sample chamber
- Good sample access
- Long working distance (focal length) and so high aberrations
- Poor EM screening
- Asymmetric SE collection due to position of ET

The immersion lens



- Short focal length - so low aberrations
- Good EM screening
- Very stable specimen mounting in lens
- Symmetric SE collection using the ‘through the lens’ (TTL) detector system
- But restricted to small samples (3mm discs)

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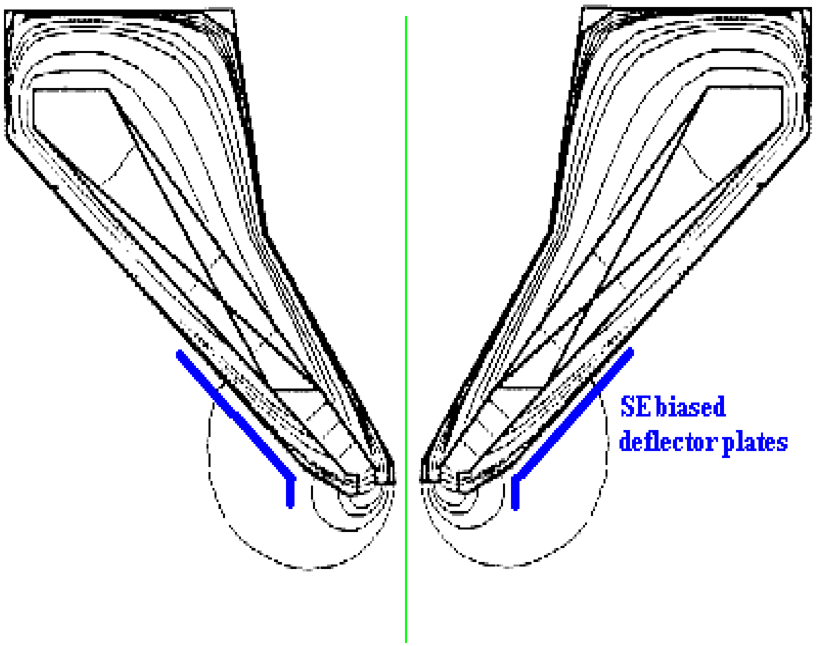
Snorkel (or Single Pole) Lens

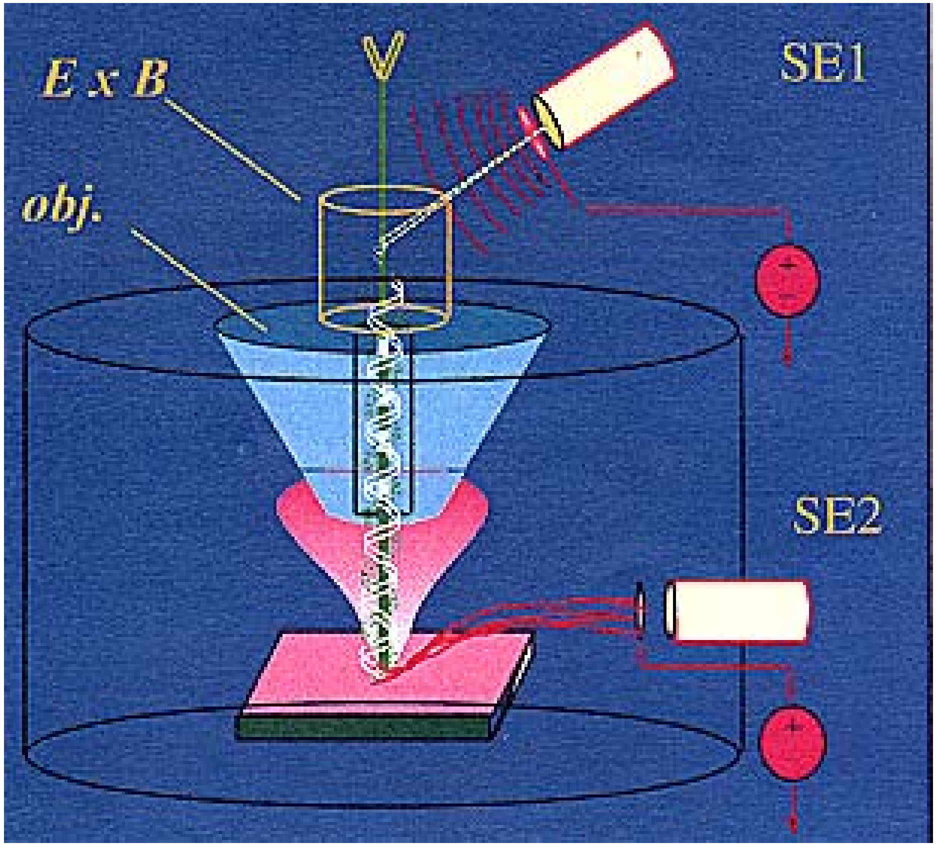
- Based on an original idea by Prof.Tom Mulvey in 1970
- Short focal length - so low aberrations and high performance
- Good EM screening
- The sample is outside the lens so there is no limitation on the size of the specimen
- Can support BSE + two SE detectors for great imaging flexibility ……..



S-4700 lens configuration Excitation - 1000 amp.turns

SE detectors

- Snorkel lens permits multiple detectors to be used
- In-lens (TTL) detector gives a shadow free image with ultra-high topographical resolution. With ExB filter also acts as a BSE detector
- Lower (ET) detector gives SE images with material contrast information and high efficiency at high tilt angles
- These detectors can be used separately or combined



Snorkel lenses allow multiple detectors

Two detectors - different signals

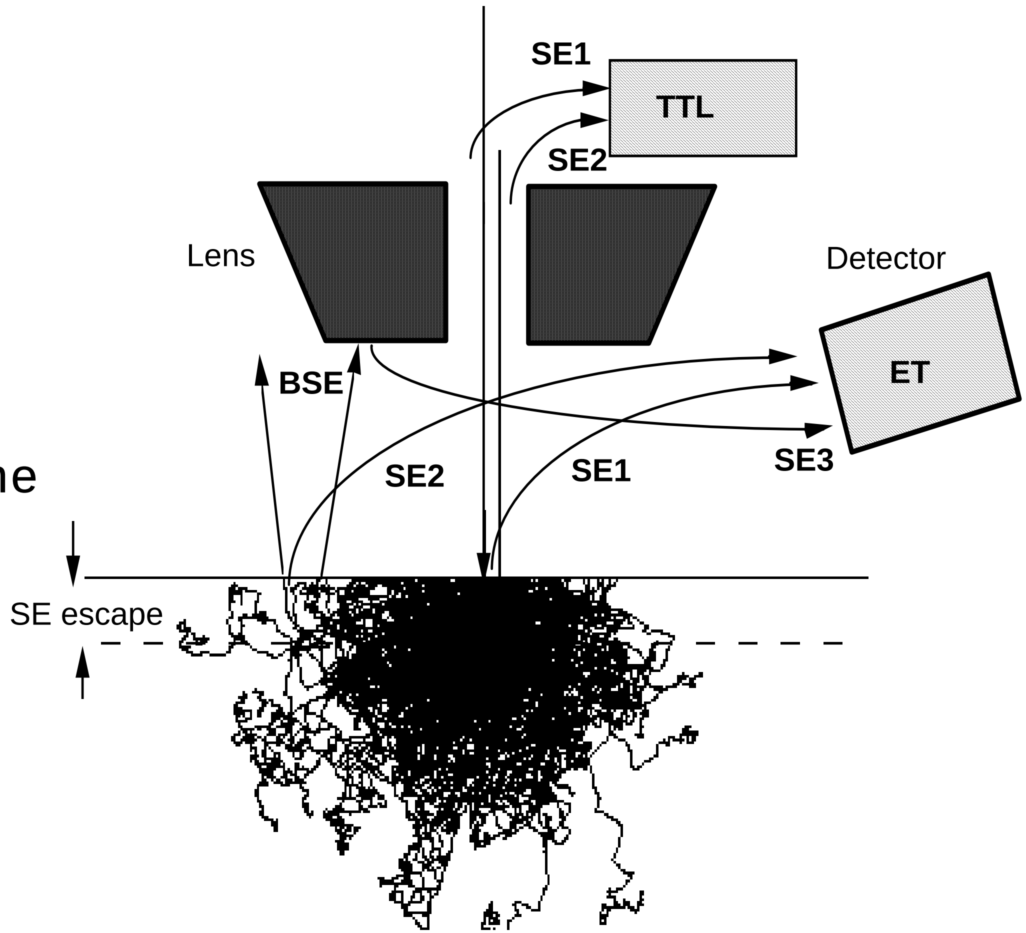
- The upper and lower detectors have a different viewpoint of the specimen and so they 'see' the specimen differently
- In addition these two detectors collect a different mix of the electrons emitted from the sample...

Image Content

» SE1 - produced as the beam enters the sample. These are the ' high resolution' SE

» SE2 - are produced by the BSE as they leave. Low resolution SE

» SE3 - tertiary signal, not from the specimen at all



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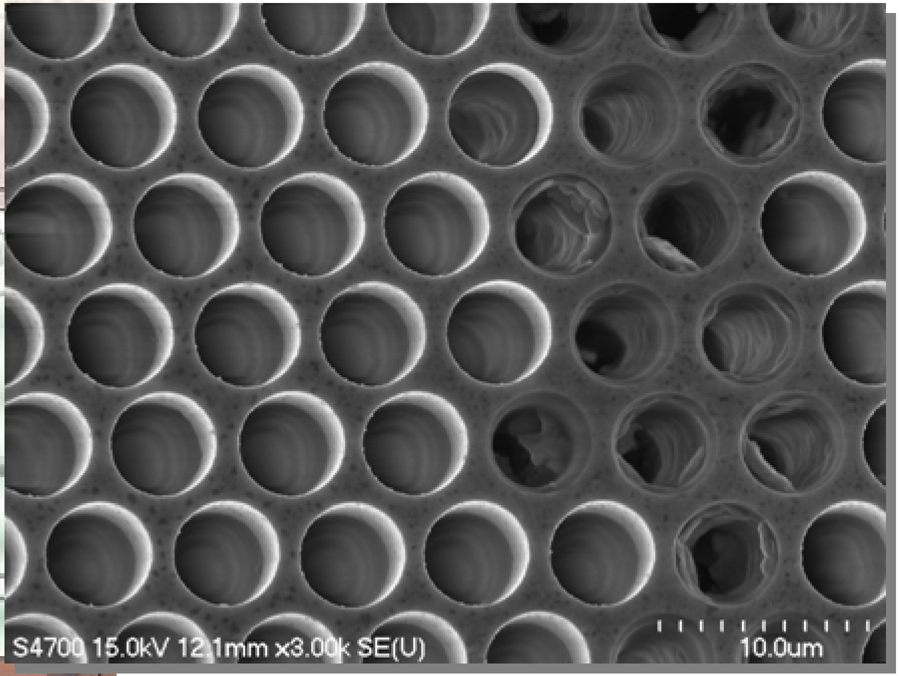
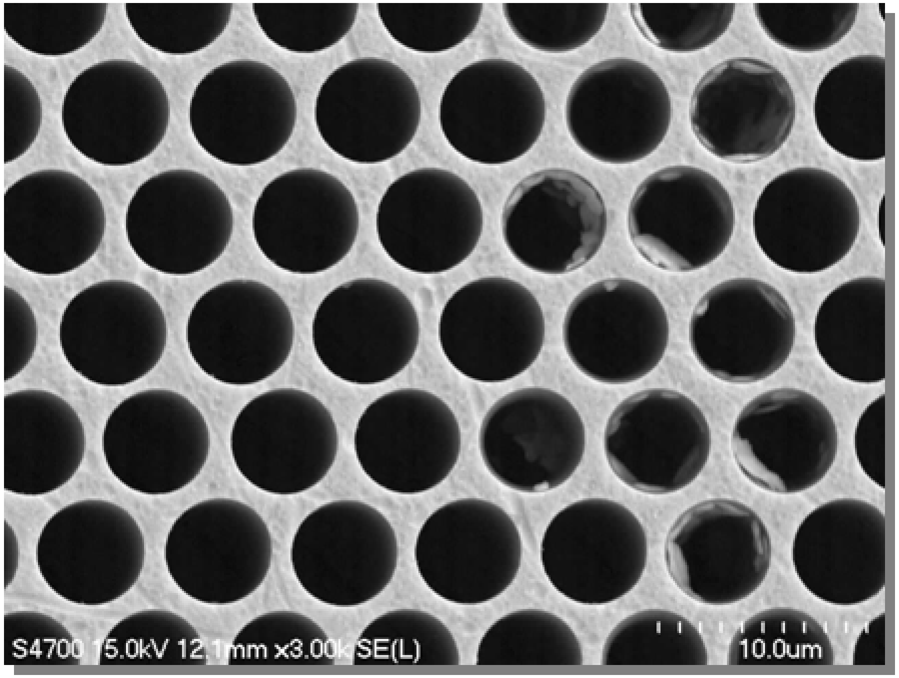
SE Comparison



Upper SE Detector



Lower SE Detector

Vision Goggles- *This sample is a hole-punched silicon wafer with various metals deposited on its surface. The upper detector image shows the metal layer banding on the inside walls of the holes. We are able to see into the holes to gain an understanding of the location of contamination within. The lower detector image emphasizes the surface details and the top portion of the contaminants without the effect of charging in the image.*

The signal mix

- Measurements show that lower detector sees a signal which is typically 40% SE3, 45% SE2, about 15% SE1 and some direct BSE signal
- The upper (TTL) detector sees a signal mix which is about 75% SE2 and 25% SE1
- The upper detector therefore contains a much lower BS component in its signal output and so gives higher contrast images

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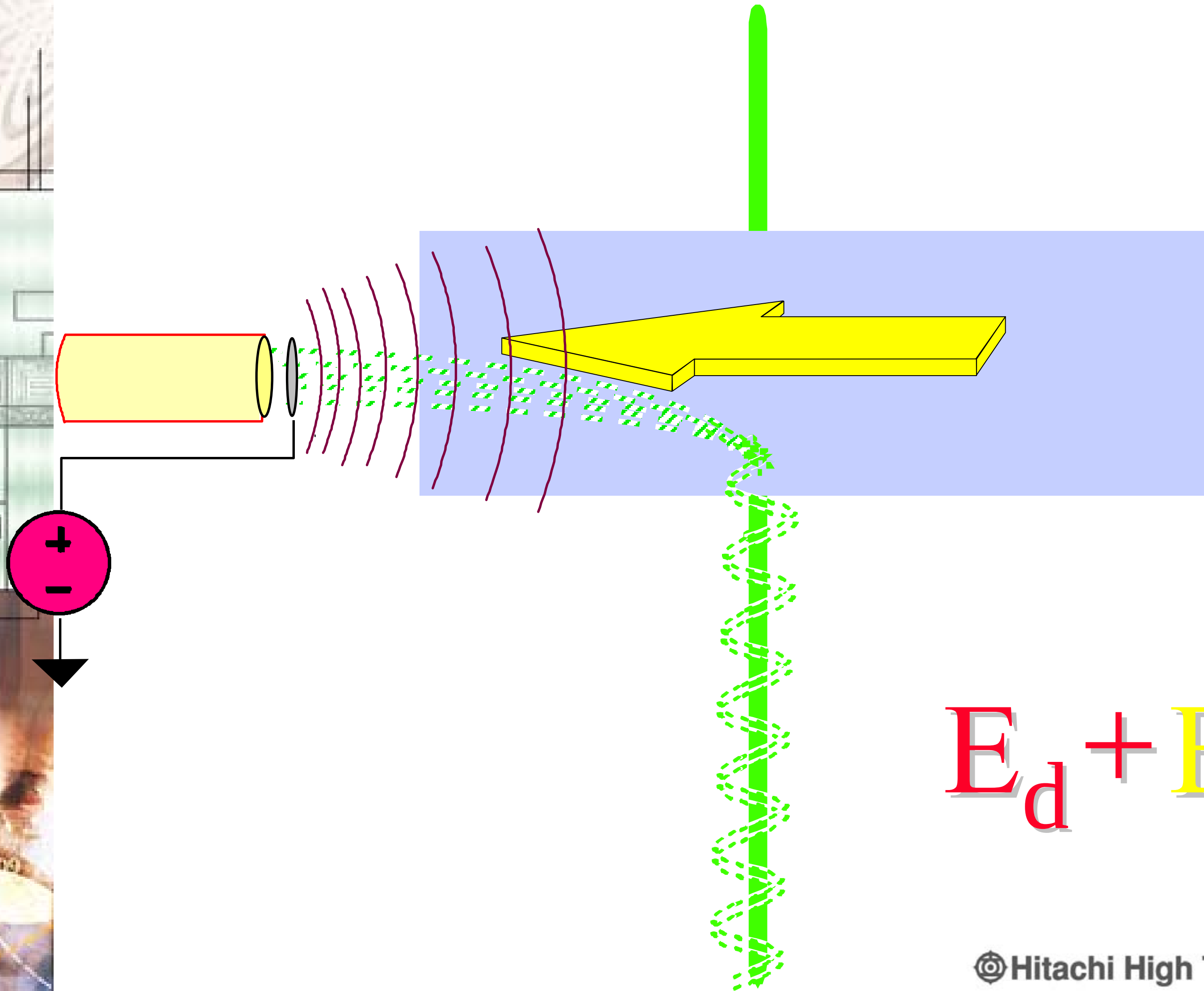
Alignment / Collection Dilemma



$E_d + E_f + B_f$

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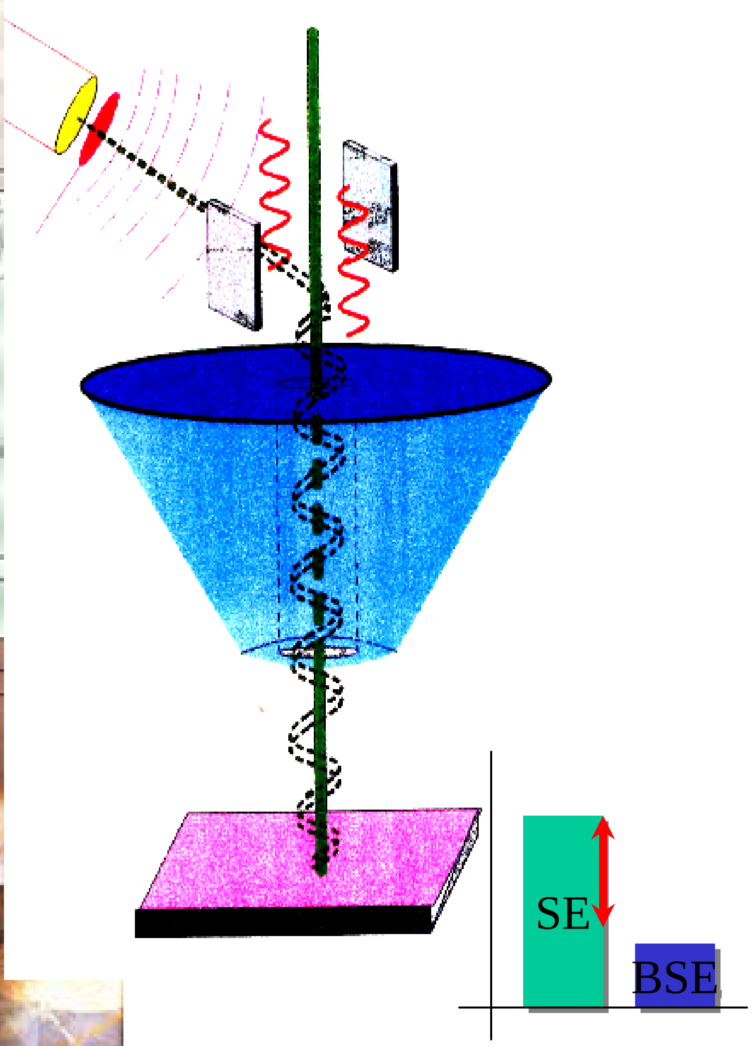
S-4700 Detection System

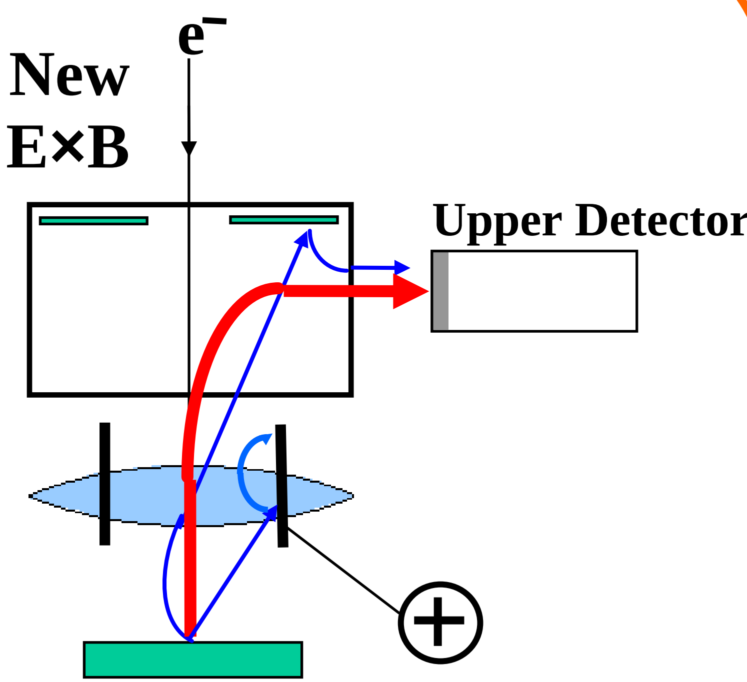


» The ExB filter can now be used to select the mix of electrons reaching the upper detector

» The system can be adjusted to give images consisting of from pure SE to pure BSE, and anywhere in between

» This provides great flexibility in overcoming charging and in optimizing imaging contrast

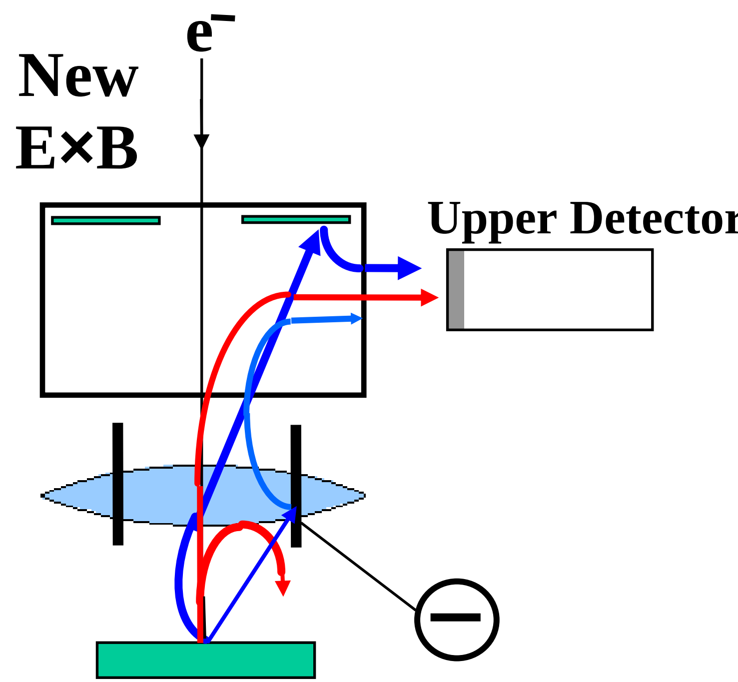
» SE to BSE ratio changes by altering the amount of SEs collected



Topo - SE Mode

SE >> BSE

SE



Compo - BSE Mode

BSE + SE

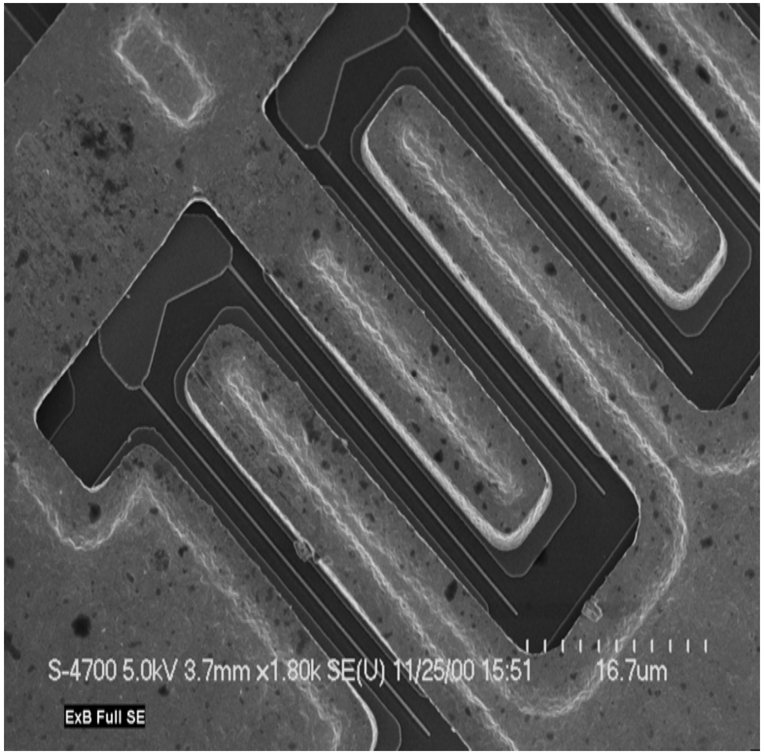
BSE

Positive → *Negative*

100% SE image

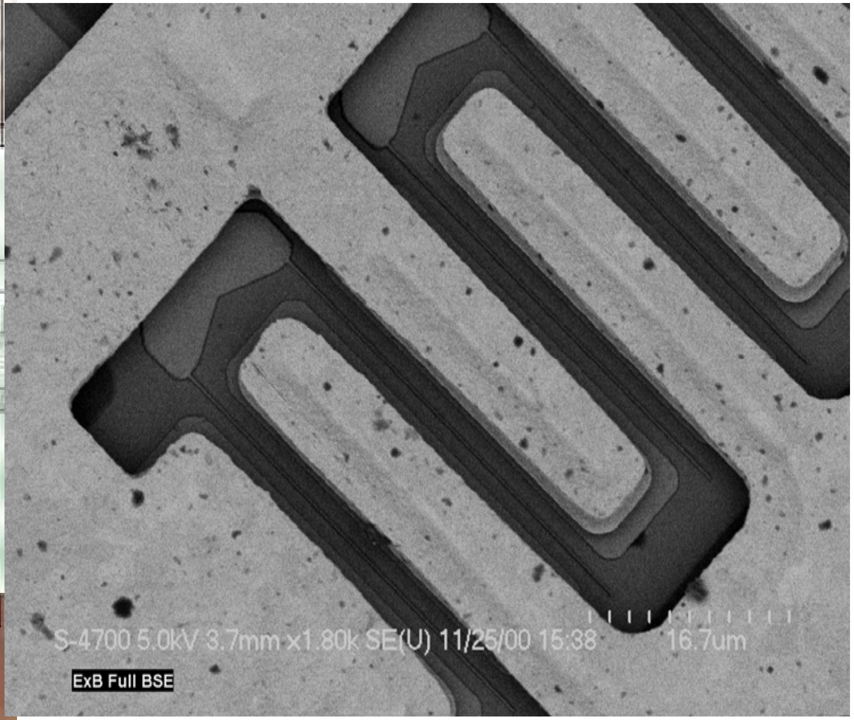
» At one end of the range the TTL detector sees a true SE image

» The energy range of the electrons from which this image is formed can further be tuned by using the stage bias



Device imaged in S-4700 with ExB

100% BSE



100% BSE image
S-4700 with ExB

- At the other end of the control range a true BSE image is available
- Between these two extremes are mixtures which combine the features of both SE and BSE but may be much less prone to charging

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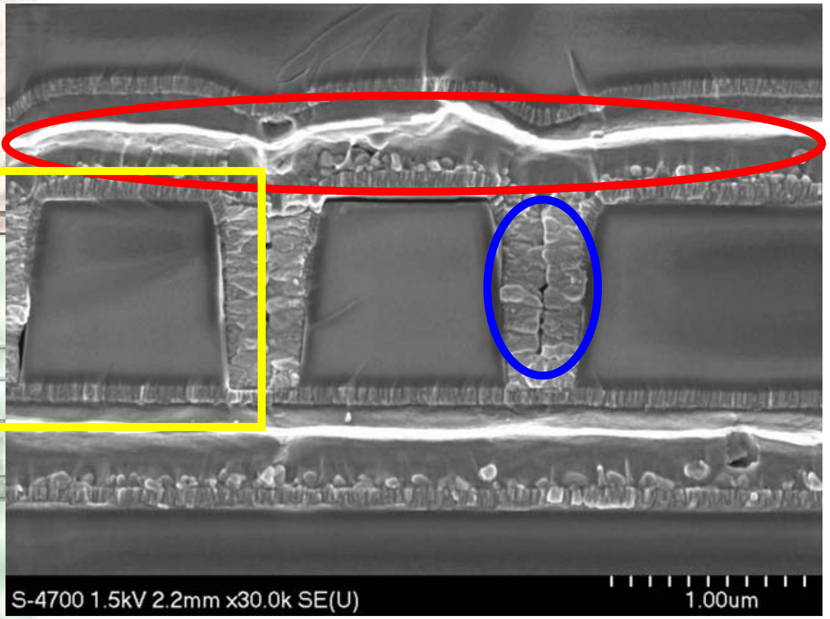
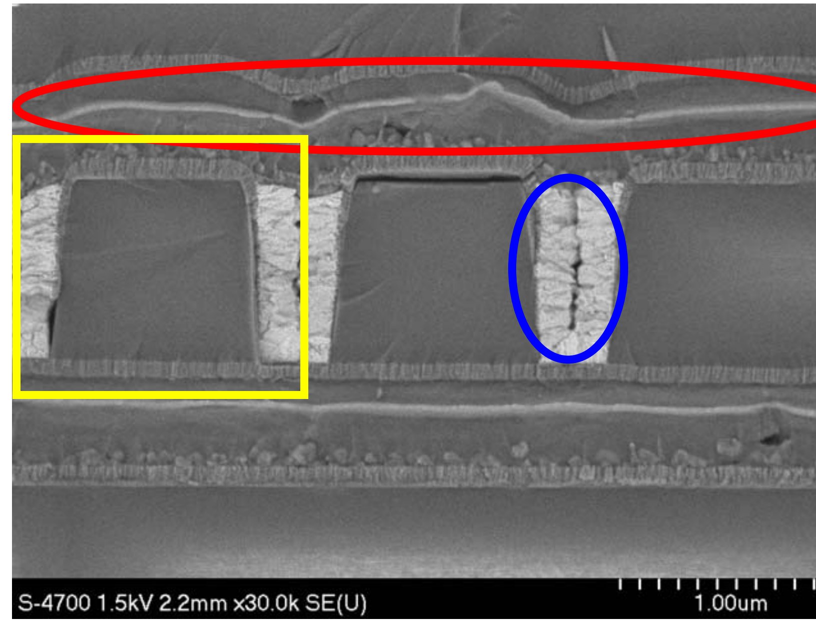
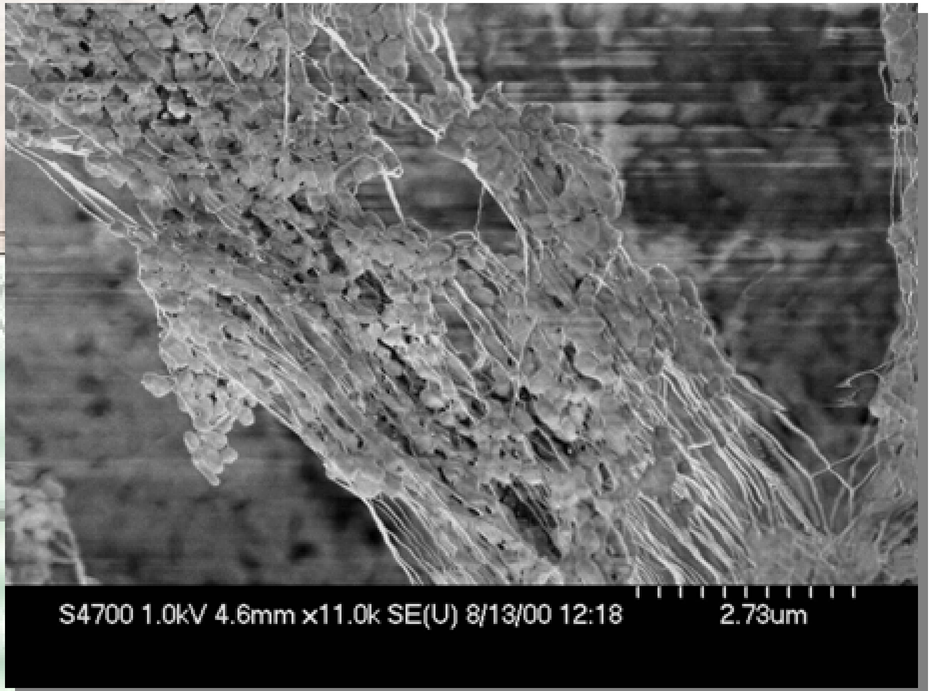
Upper Detector Versatility



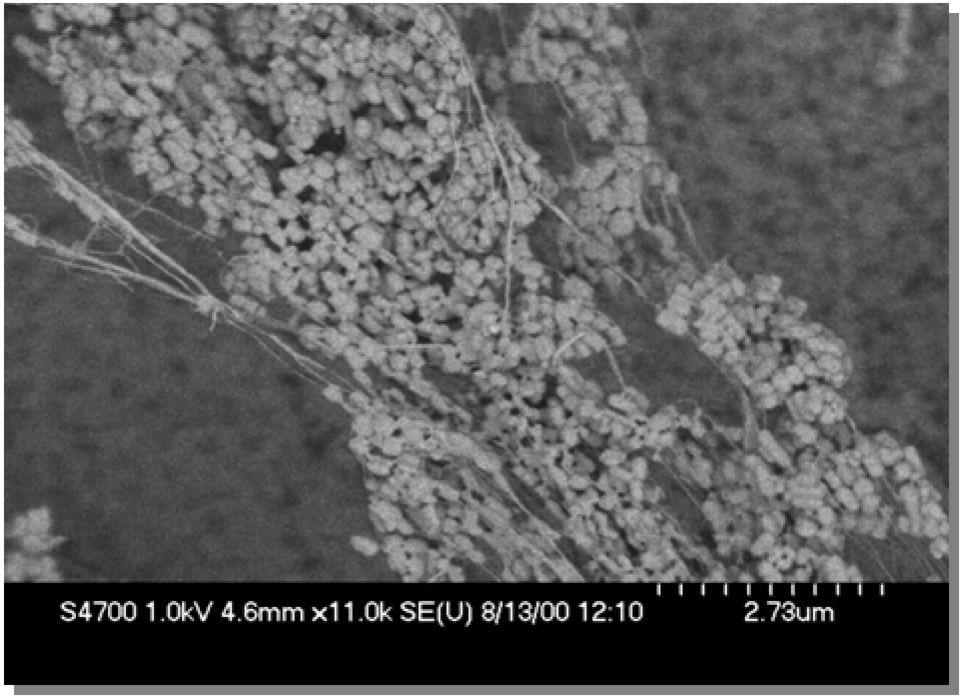


	SE Image	SE/BSE Image
	Edge effect (no detail)	No edge effect, detailed edges
	Topographic information	Composite information
	Charged-up	No charging visible

Minimizes Charge Appearance



Full SE Mode



Full BSE Mode

Teflon Tape- *Notorious for its charging characteristics, this sample is actually charging in both images. However, the right image is made up of electrons (BSEs) that do not represent the top surface where the charge is occurring.*

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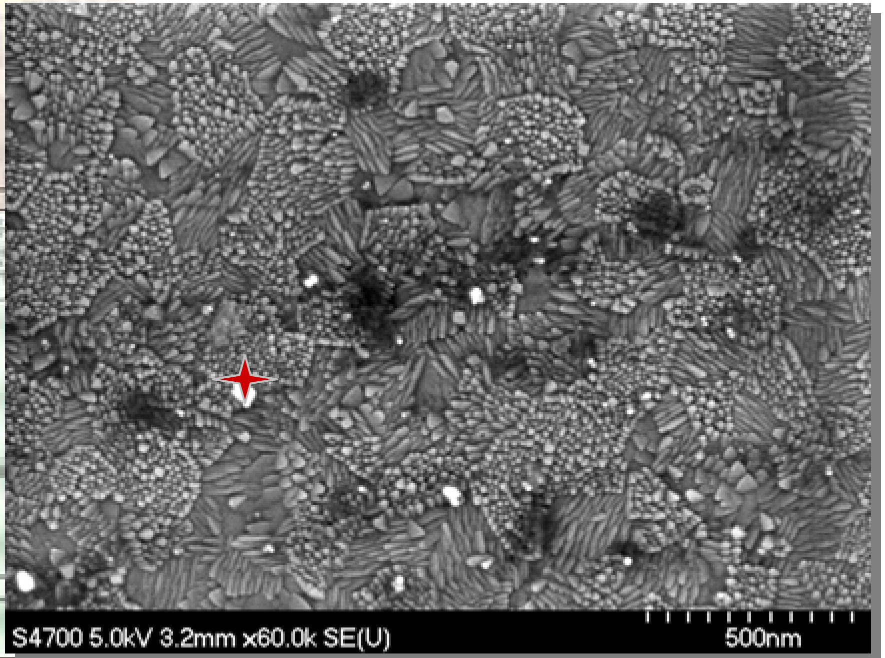
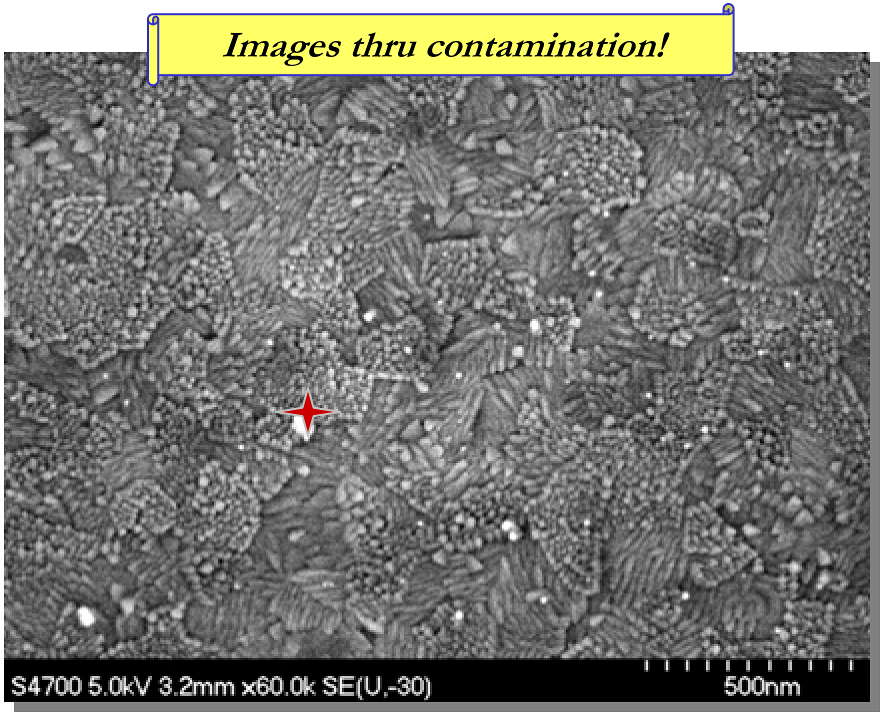
Reduces Contamination Appearance



Full SE Mode

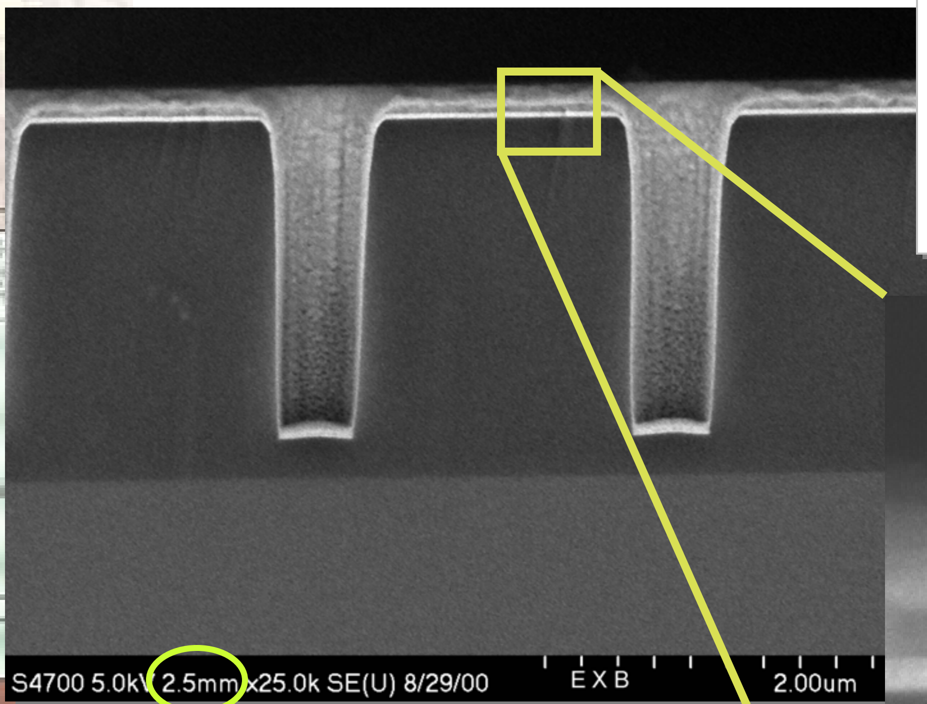


BSE Mix Mode

ITO Film- *Even in the cleanest vacuum systems hydrocarbons on the sample's surface can interfere with low voltage imaging because of its shallow interaction volume. By selecting a moderate setting on the ExB filter, the contamination is removed from the image and the sample details beneath the hydrocarbons can be seen.*

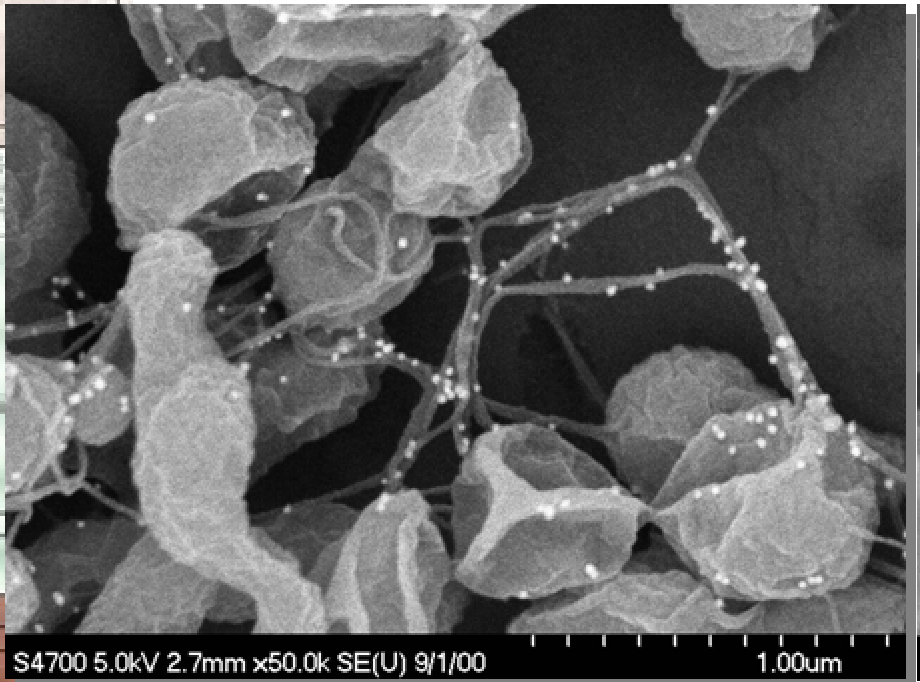
High Resolution BSE Imaging

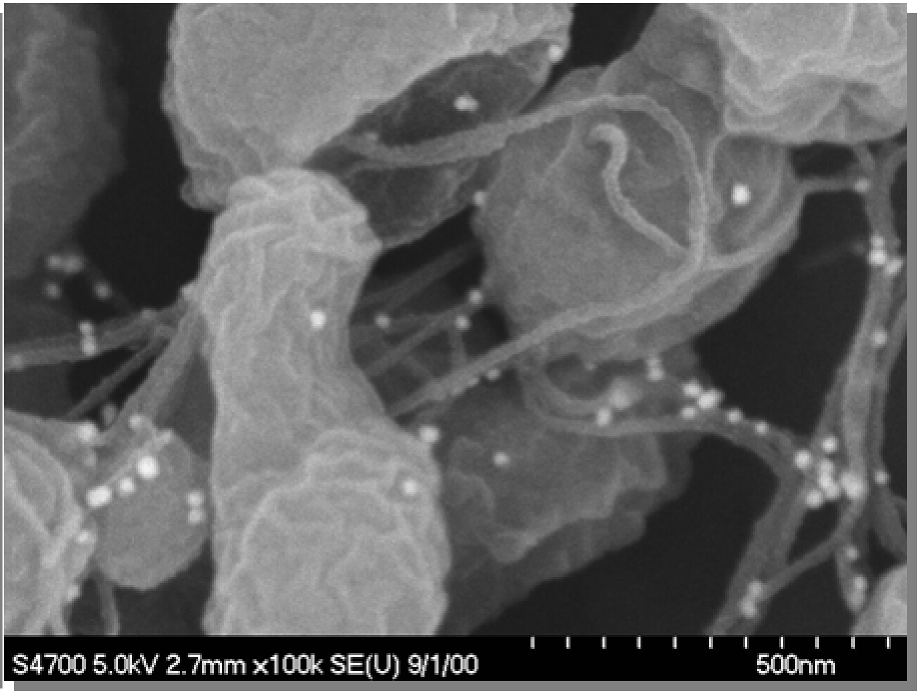
Vias- *Here the backscattered electron signal highlights the tantalum barrier as well as the surface structure within the vias. With the ExB image we can confidently measure the thickness of the tantalum barrier.*



Notice the short WD for high resolution. This is a valuable benefit of the ExB Filter. Other BSE detectors force the WD to 8mm and longer.

Biological Applications





Salmonella Bacteria- *Here the BSE signal highlights the gold label particles on the salmonella bacteria. The gold labels are used to mark various proteins of interest. These high resolution images confirm the theory that the particles are 10nm in diameter and show that most tagged proteins are located on the strands between the bacteria.*

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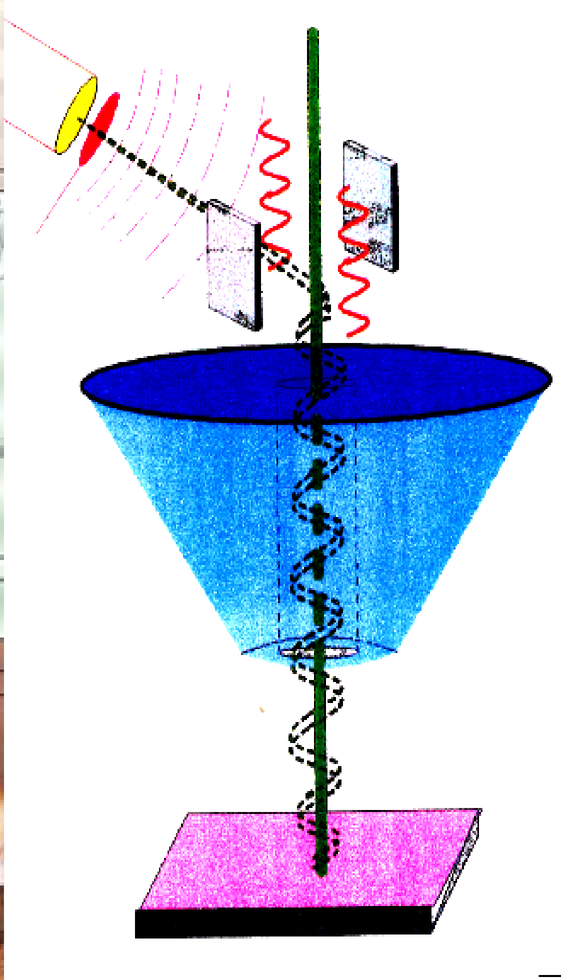
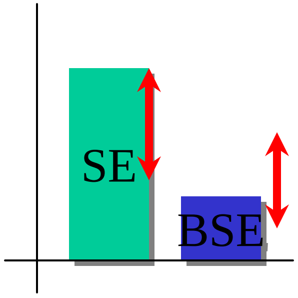
S-4800 Signal Detection





- Same **ExB Filter** as S-4700
- Addition of plates within the objective lens designed to collect and convert BSEs into SEs
- Therefore ratio of SE to BSE changes by adjusting SE **and** BSE signal

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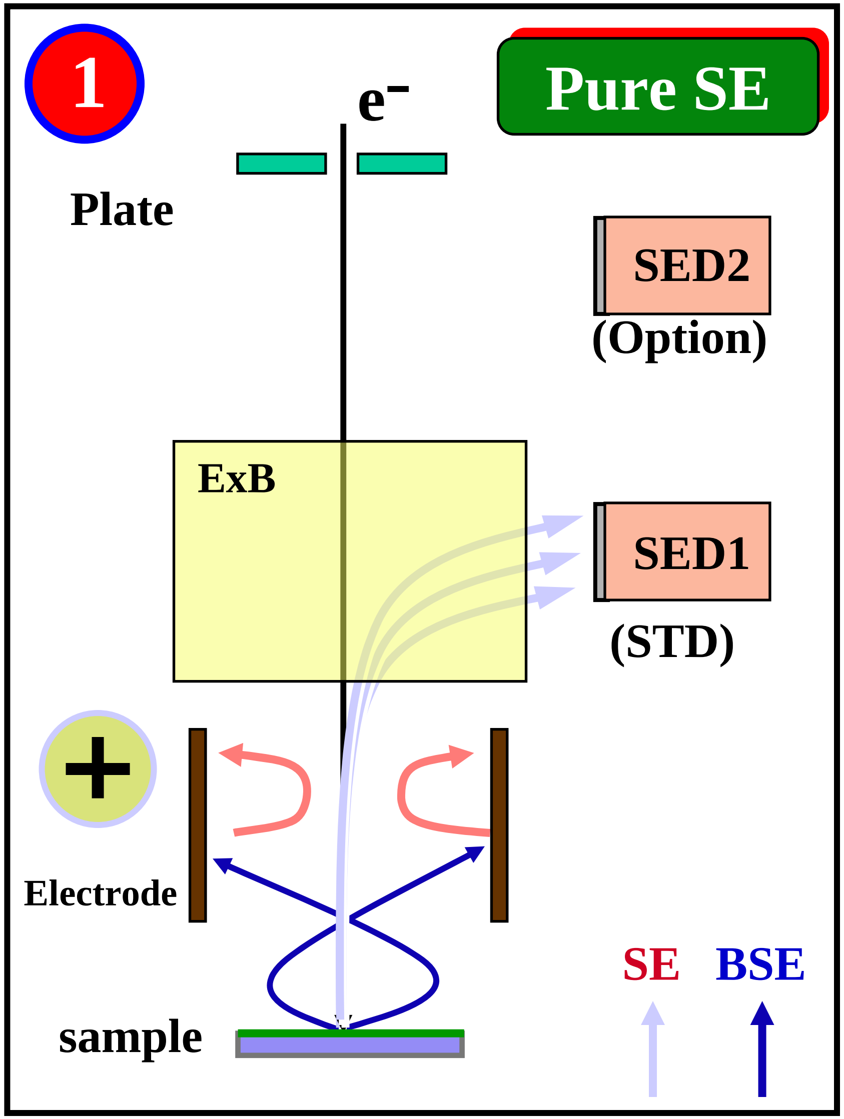
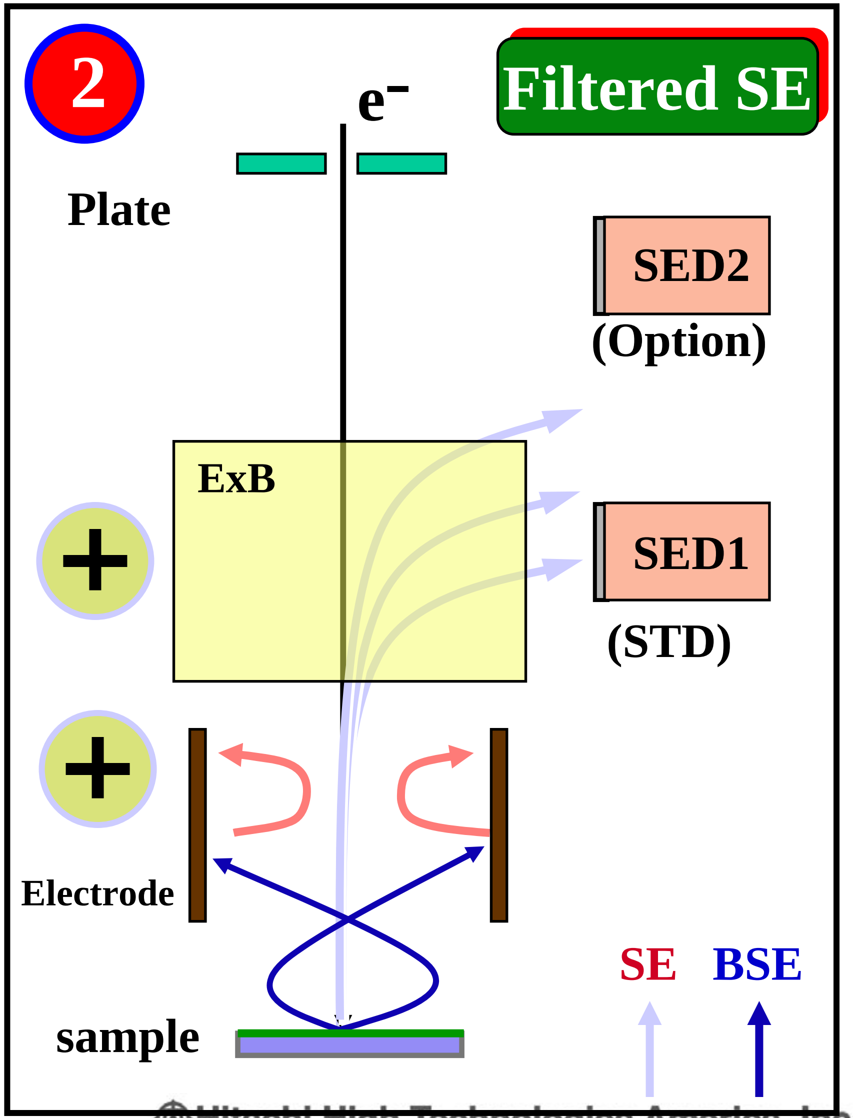
S-5200 ExB Detection Mode





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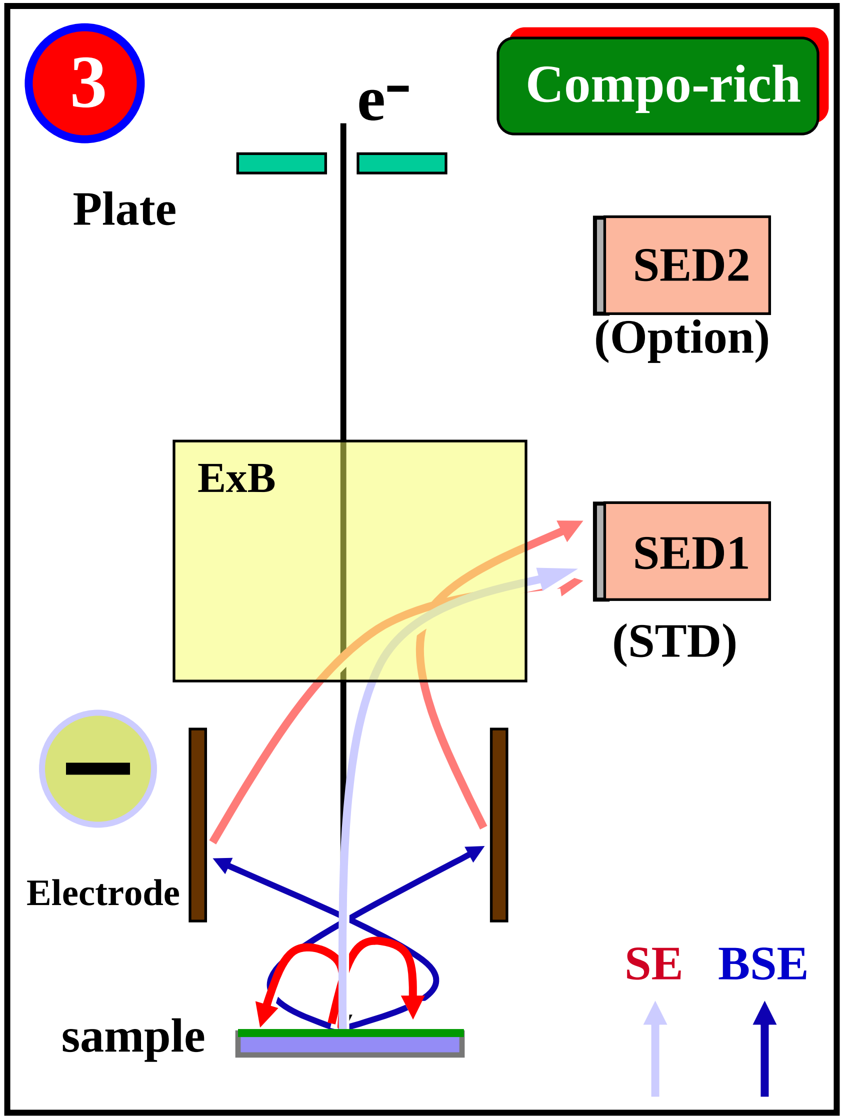
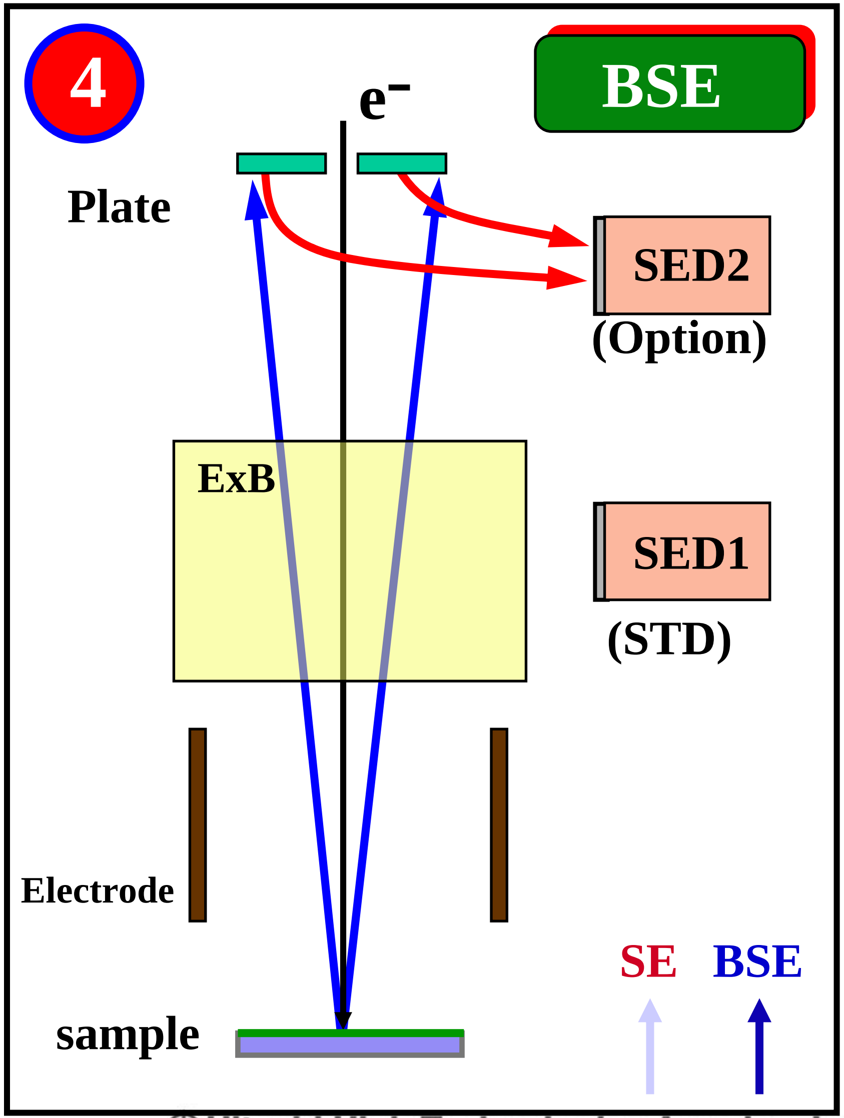
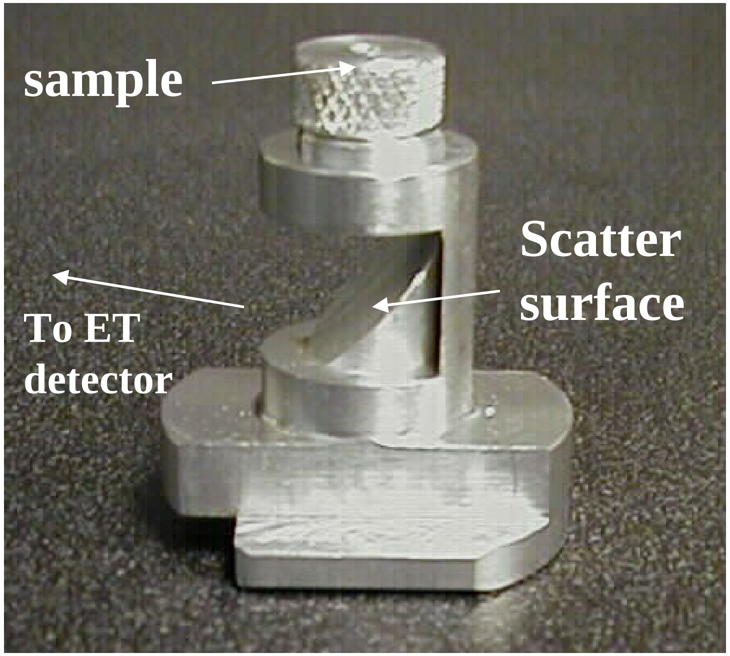
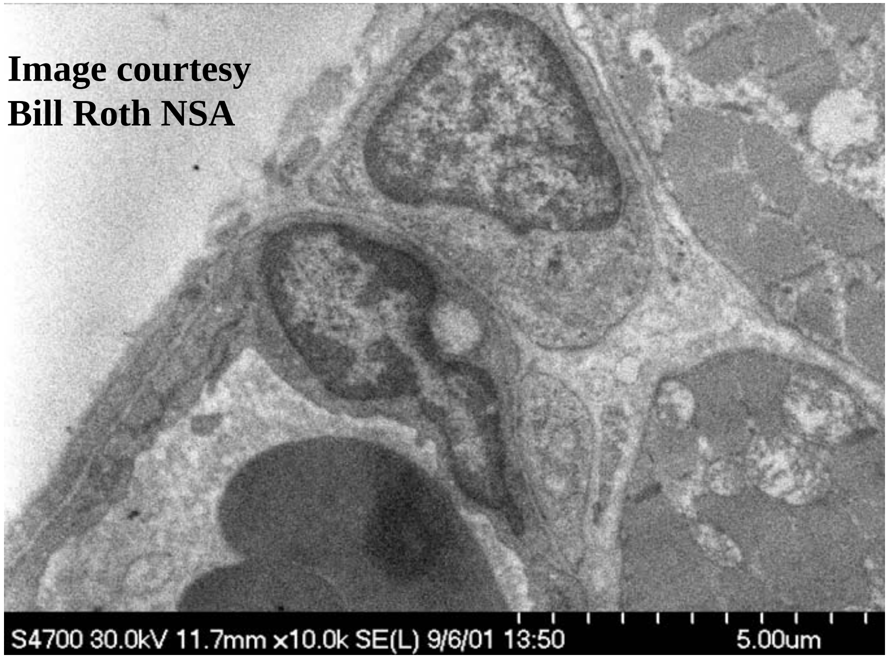
S-5200 ExB Detection Mode





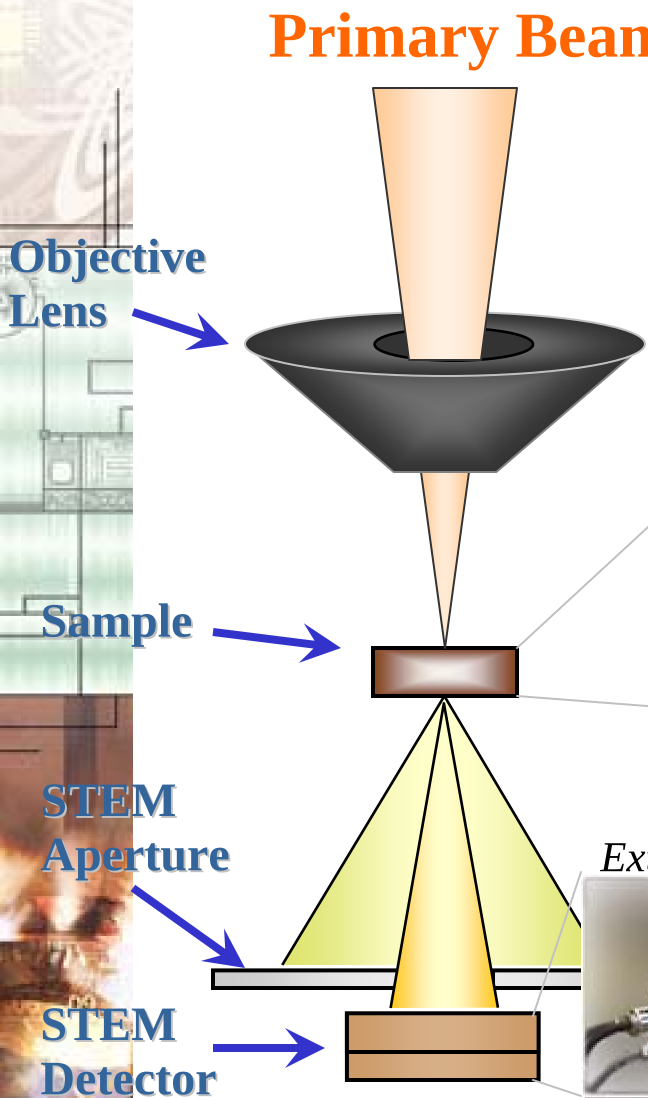
STEM in the SEM





- A FEGSEM also allows excellent STEM operation. A simple adapter permits bright and dark field STEM observation.
- Ideal for biological science - high contrast even from unstained samples.

STEM Imaging



Actual STEM Holder

External View of Detector

Low voltage STEM imaging at 30kV in an SEM can provide high contrast on low atomic number materials. STEM images of various sample types is possible, from semiconductors to powders to biological samples.

The BF-STEM detector is always mounted to the chamber so it is easy to switch between STEM imaging from other imaging modes. The majority of the following examples have both SE and STEM images so that comparisons can be made.

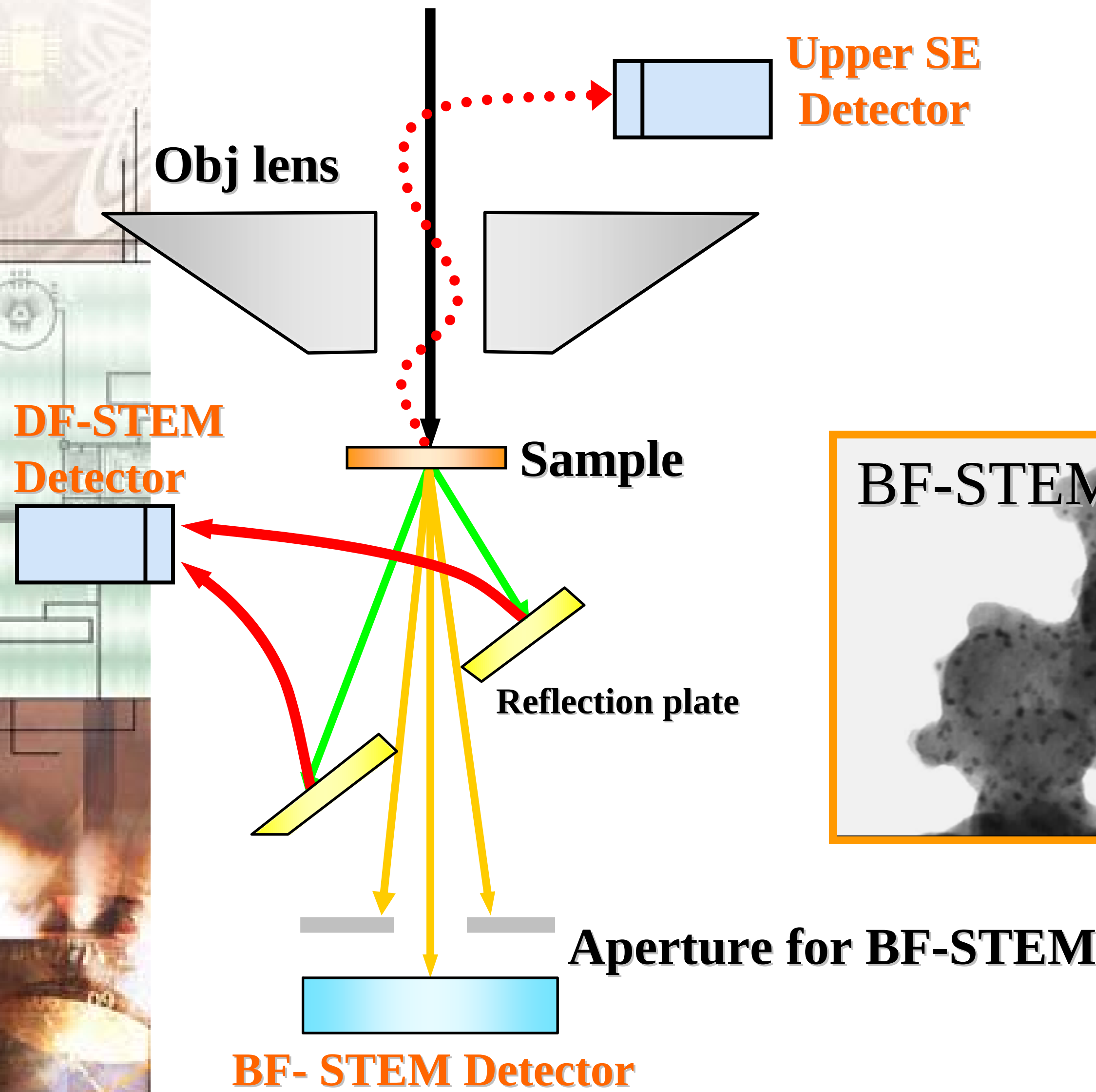
The STEM signal is selectable in the software so that alignment and image focus can be done using the SE image and then compared to STEM information.

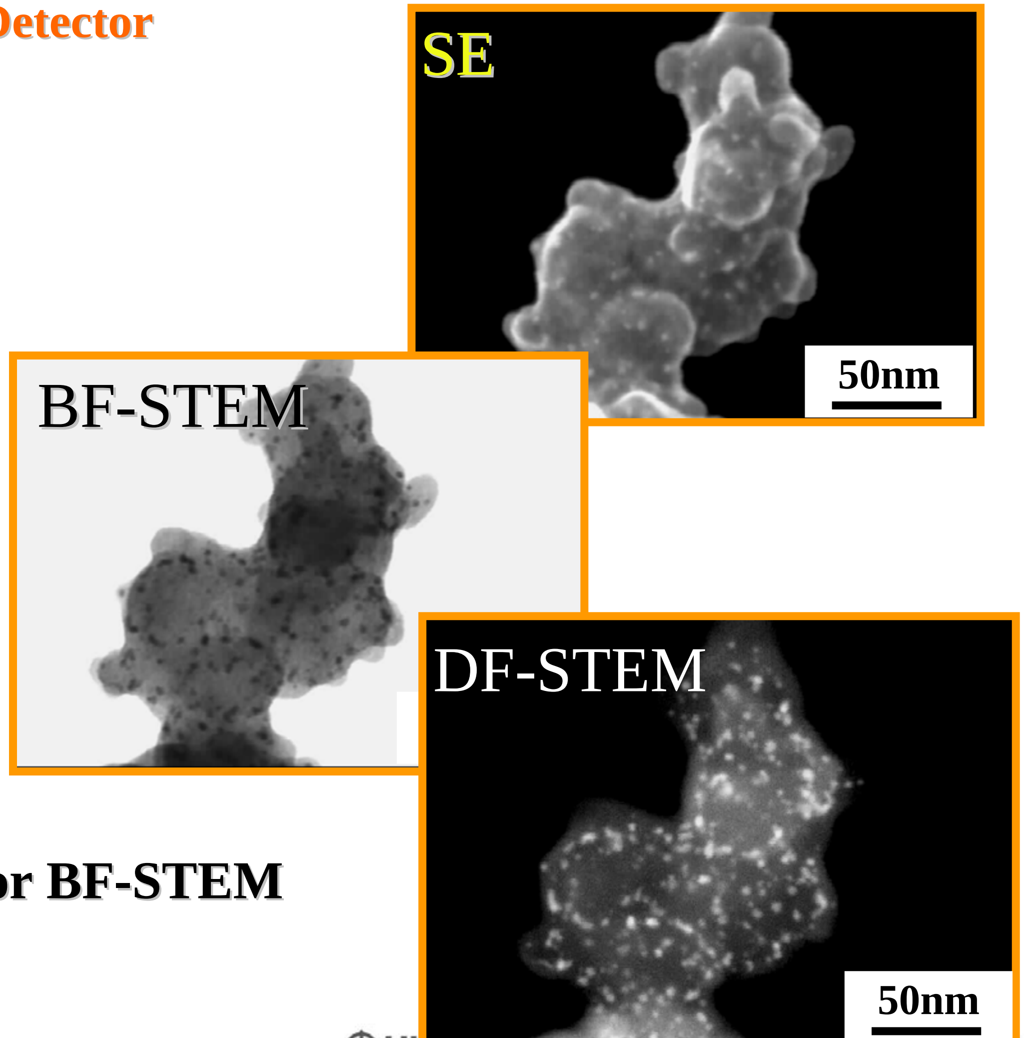
LVSTEM S-5000 Image

- In STEM mode the beam penetration is high.
- Here a metal contact, prepared for 100keV TEM observation is viewed in STEM at 30keV. Note excellent contrast and resolution

Bright field STEM image from S-5000 FEG SEM.

Simultaneous STEM Imaging





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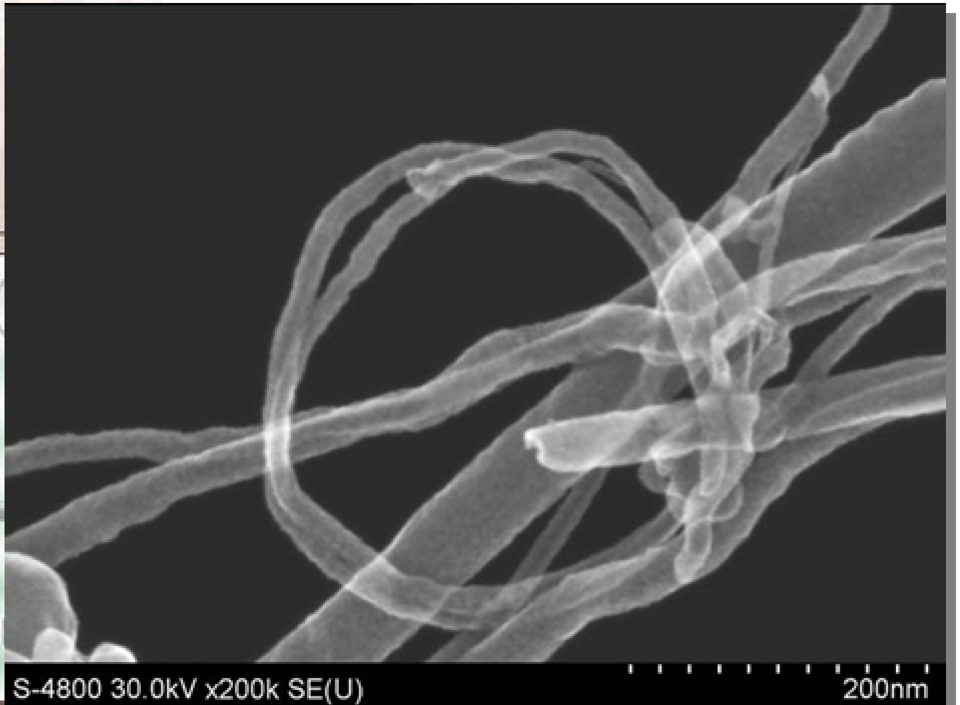
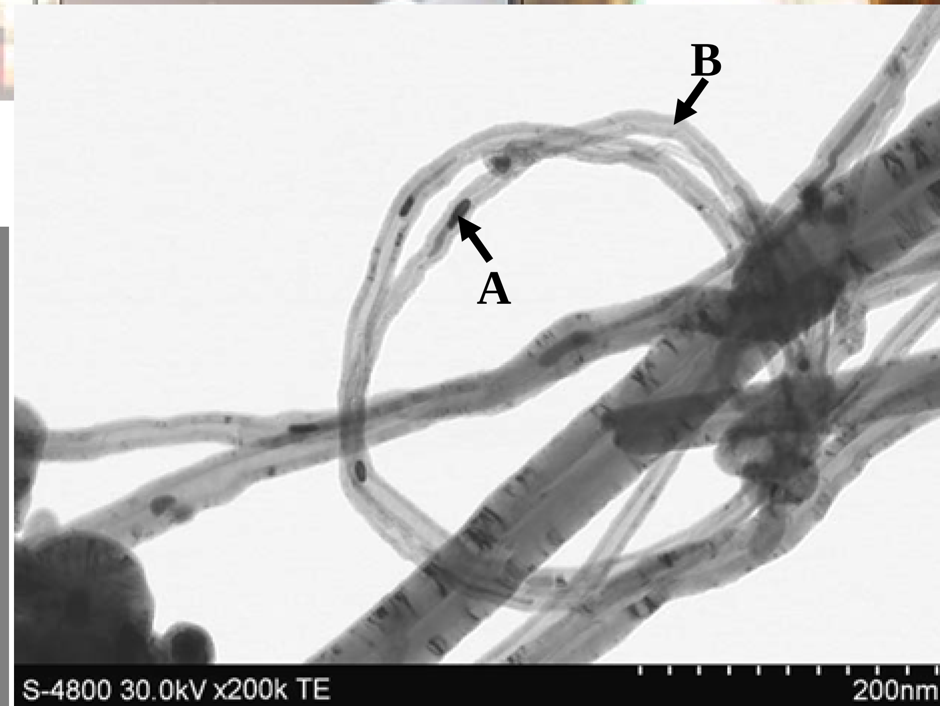
Carbon Nanotubes

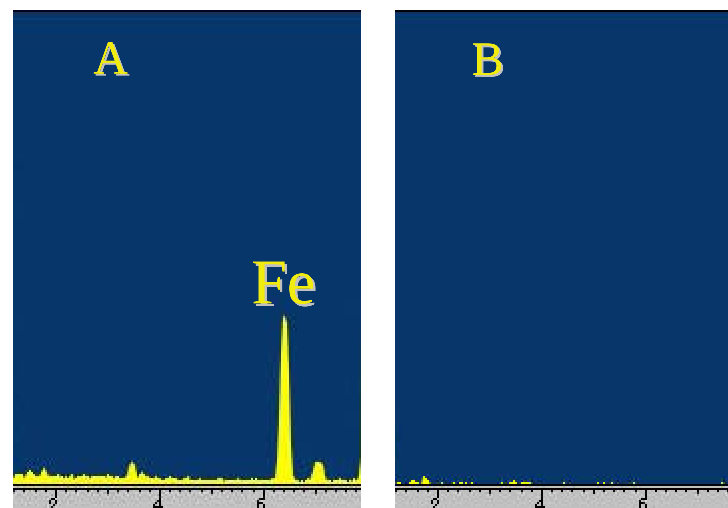


SE



STEM

A step towards their practical use is in the purification of catalytic metals. Using the STEM detector, the inner contents of these nanotubes is visible. In combination with EDS analysis, we can measure 20nm or less of iron that is used in the growing process.



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Carbon Nanotube

The SE image below shows excellent surface structure. The structure is also visible in STEM mode. At 800,000x the internal growth structure of the nanotube and internal tube diameter can be accurately measured.