Scanning Electron Microscopy (SEM)

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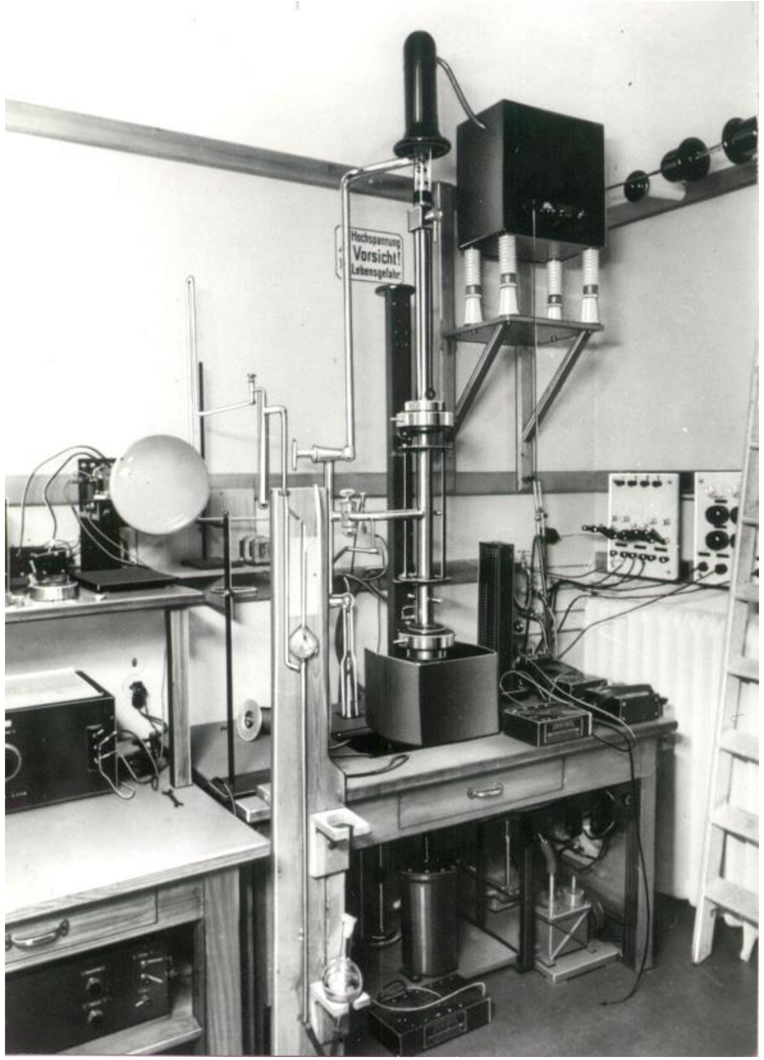
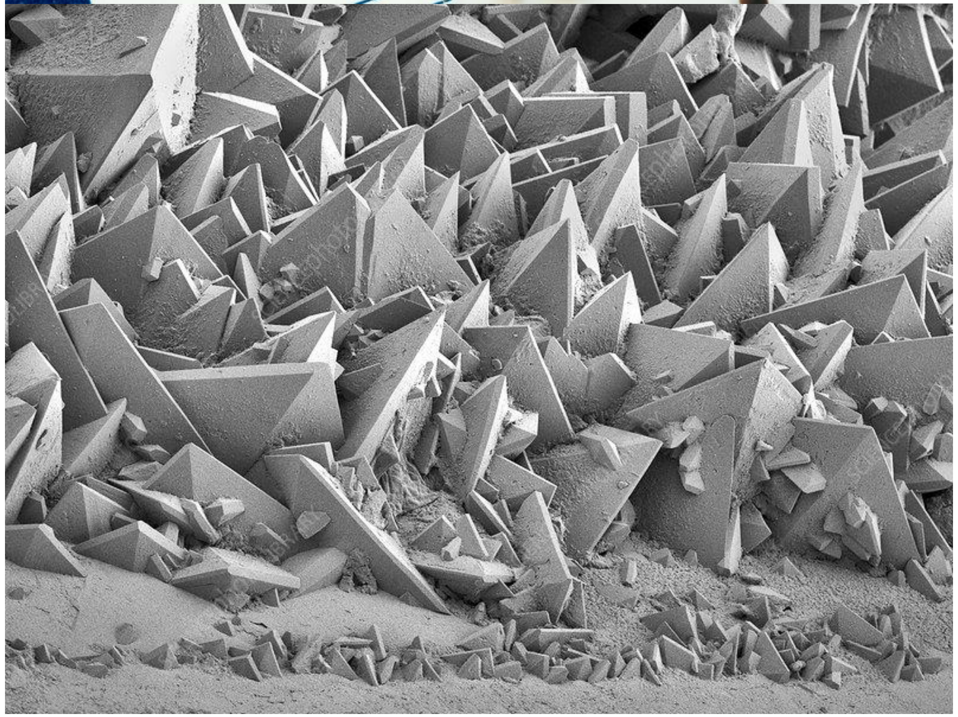
Topics

- Theory of SEM
- What can you see?
- Data interpretation
- Pros & Cons
- Research examples

Picture of a SEM from the nanomicroscopy center

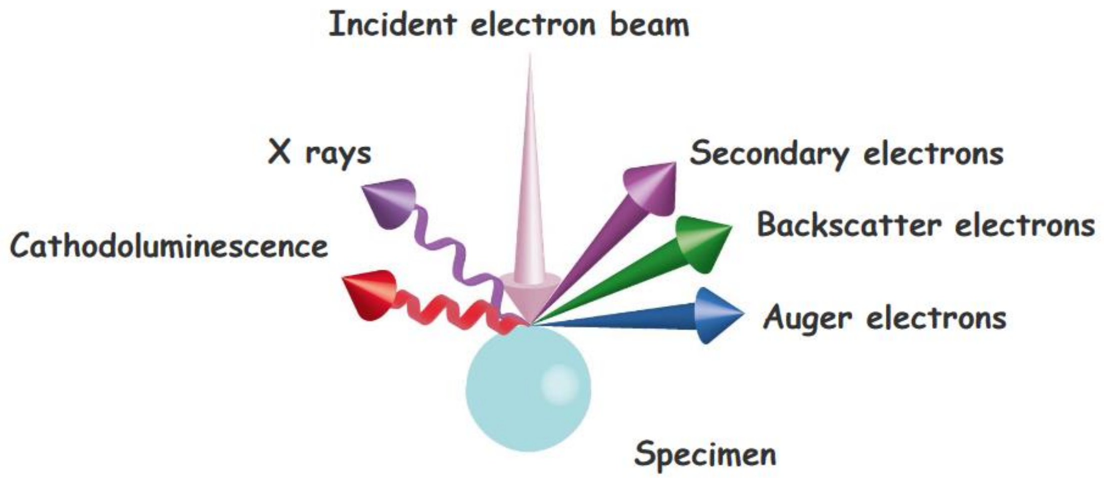


First SEM built in 1937 by Manfred von Ardenne



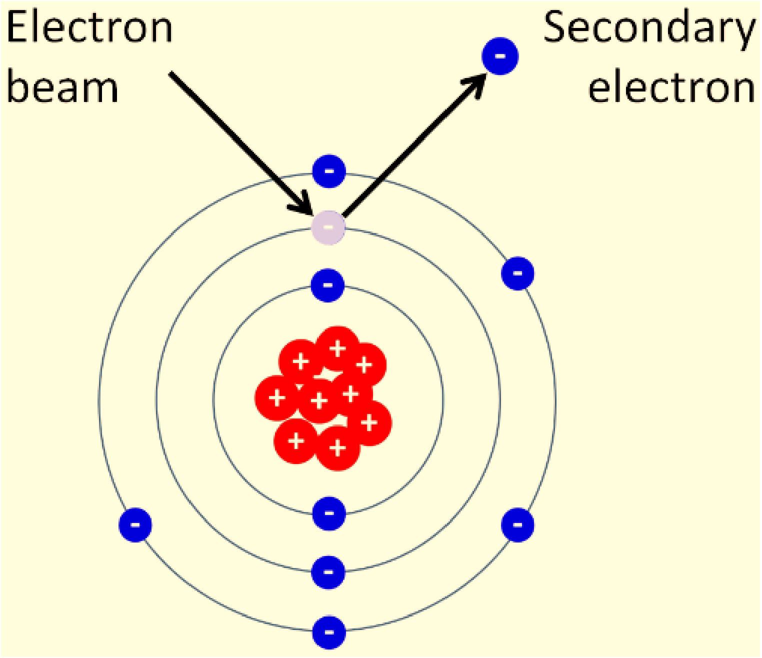
Theory of SEM

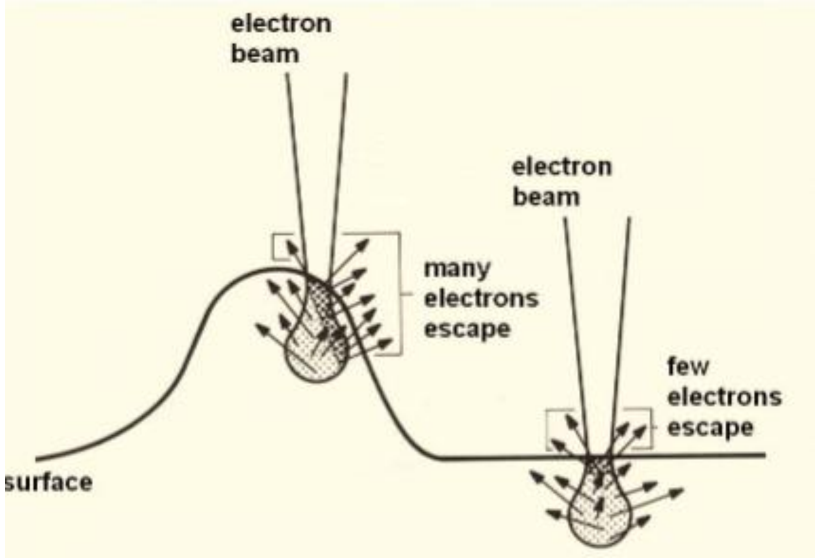
- Uses a focused electron beam to scan the surface of the sample
- Interaction of the beam electrons and the surface atoms cause different kinds of signals that can be then recorded
- Typically samples are in a vacuum, wet conditions possible as well a wide temperature range



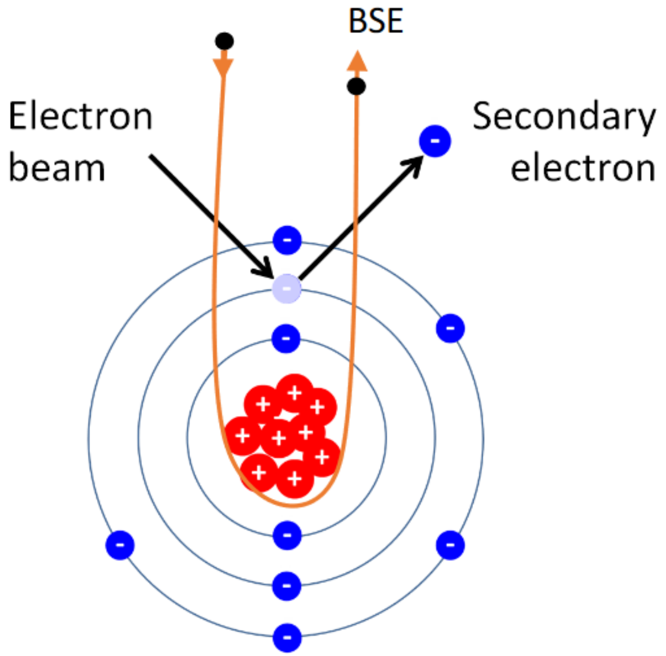
Secondary Electrons (SE)

- Inelastic collision between the incoming electron and valence electrons of the sample which ejects the secondary electron
- SE have low energy (2-50 eV) and it's near the surface which makes high resolution imaging possible
- Surface level depth (5-50 nm)
- Topography contrast/Edge detail

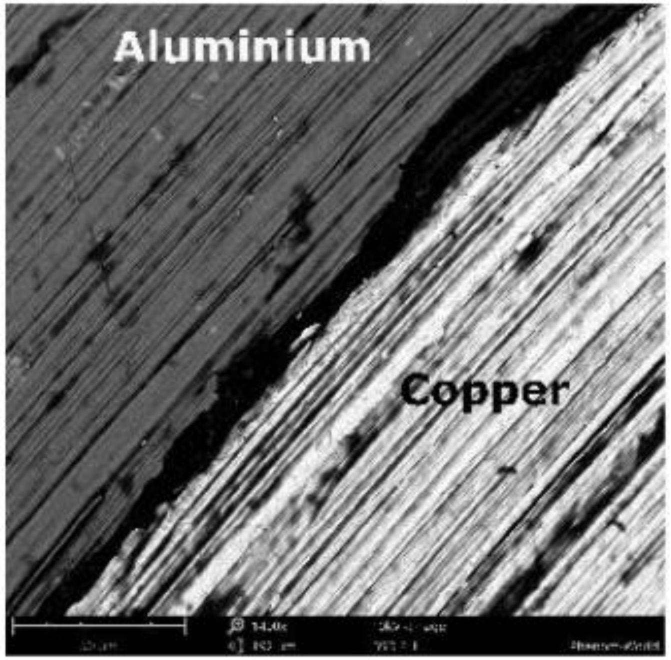


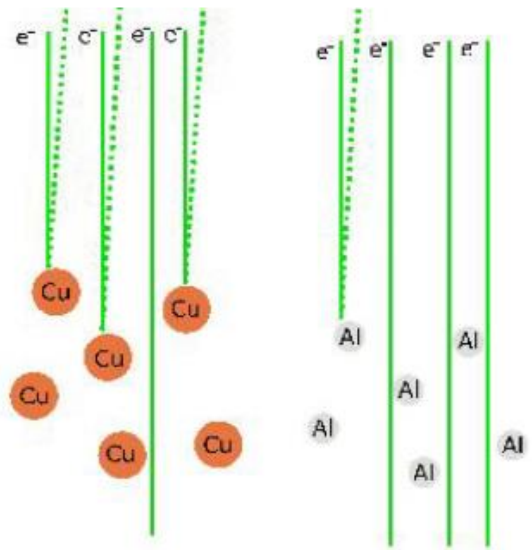


Backscattered Electrons (BSE)



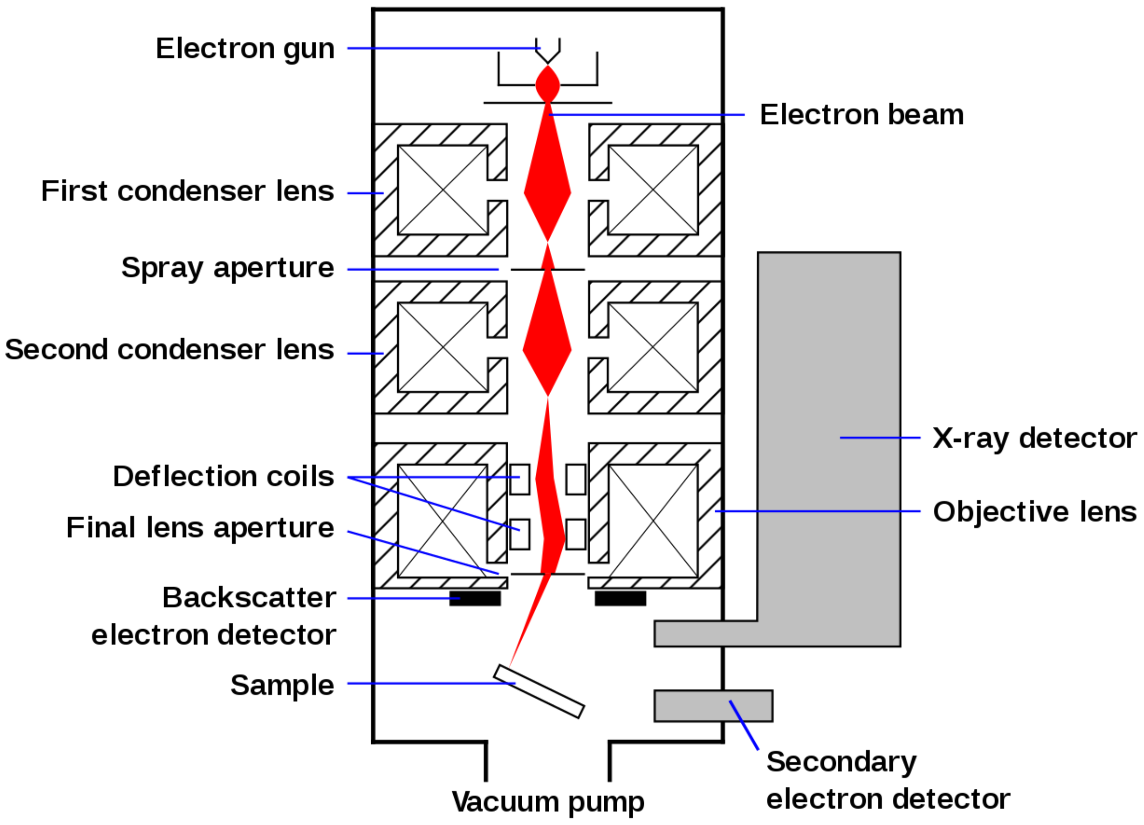
- Incoming electrons get deflected by the nucleus instead
- Higher energy electrons compared to SE
- Deflected from deeper parts (10-100 nm)
- Material contrast which is atomic number dependent



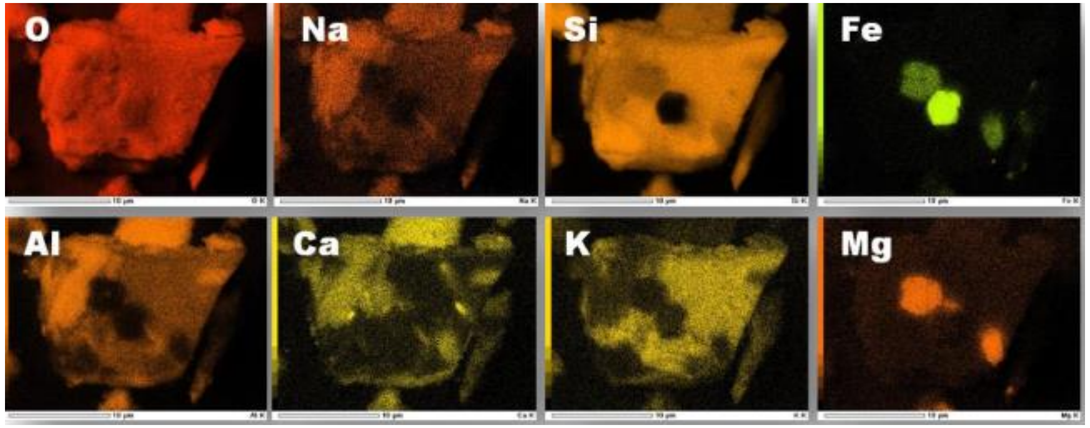


SEM Machine

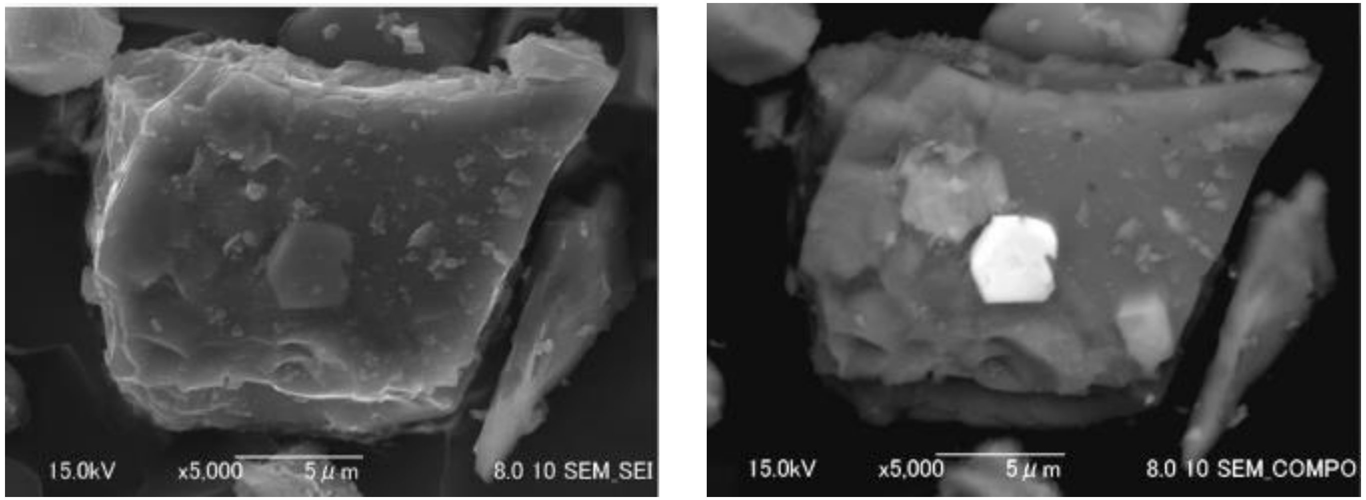
- Electron gun
  - W filament, LaB_6
- Condenser lenses
  - Electromagnetic beam focusers
- Apeture
  - Controls the probe current
- Coils
  - Controls the beam position on the surface
- Magnification range of 10x to 1000000x
- Can go to resolutions under 1 nm



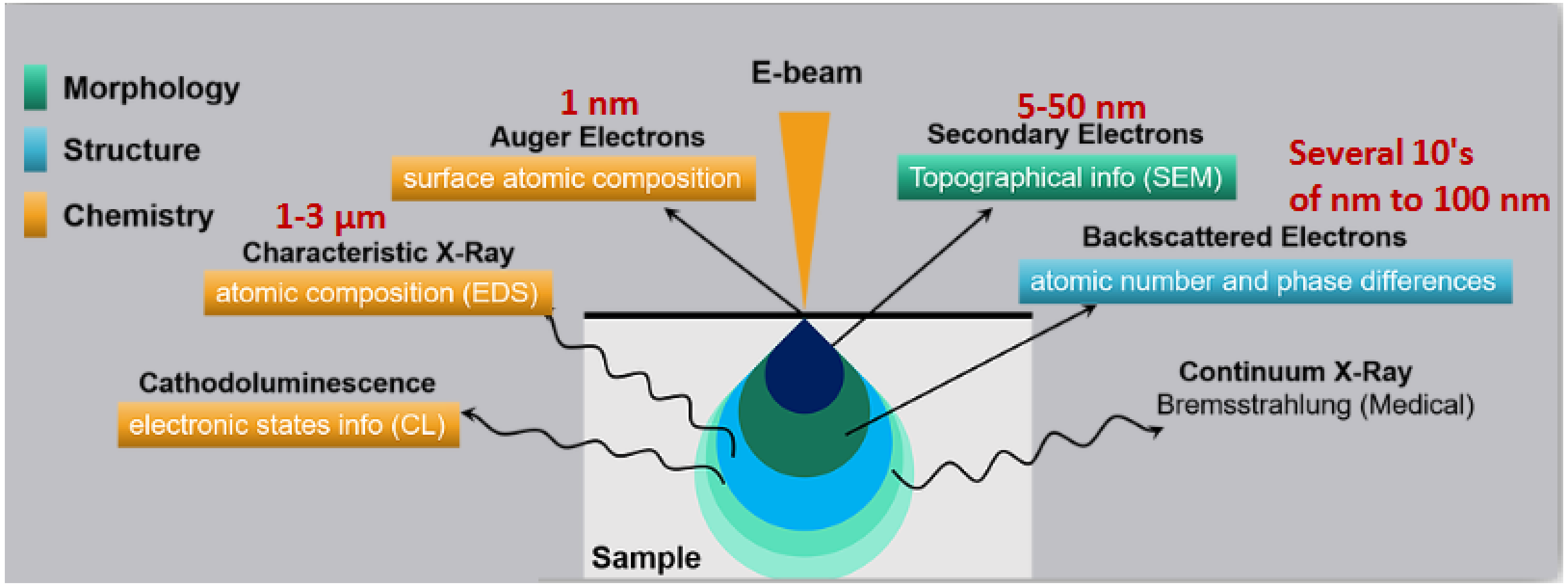
What can you see?



X-Rays

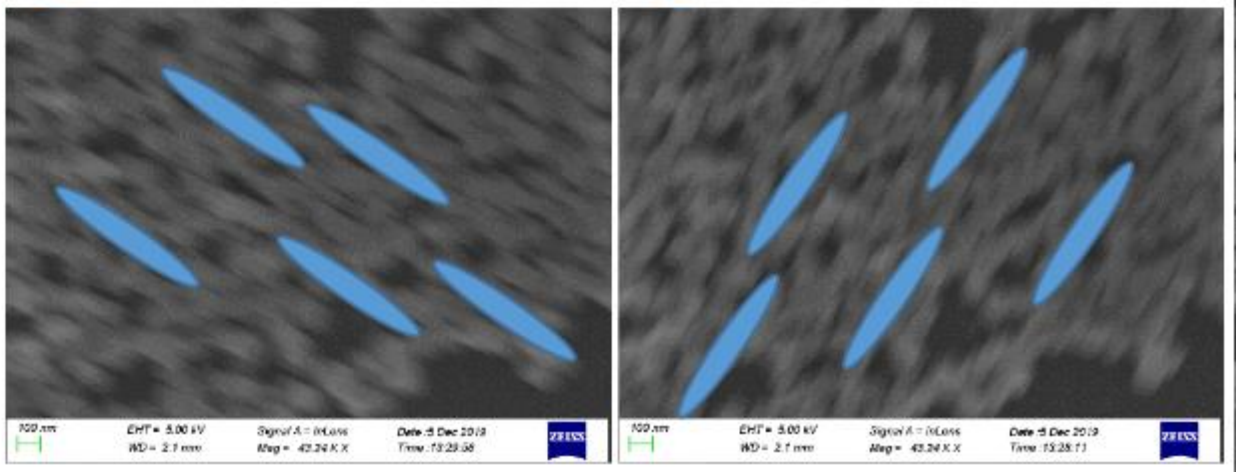


Volcanic ash, SE vs BSE

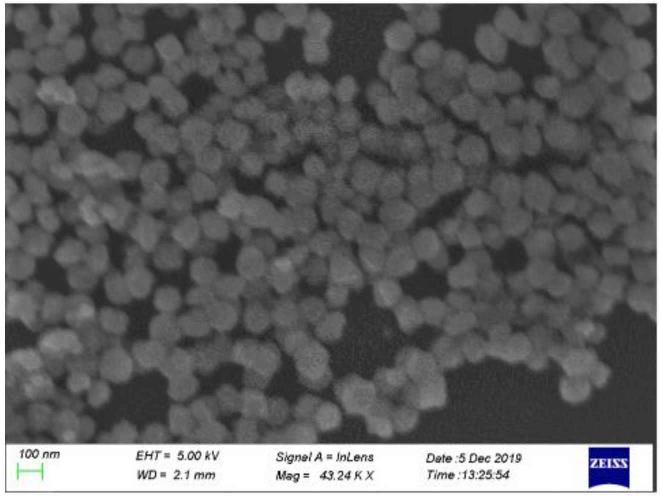


Data interpretation

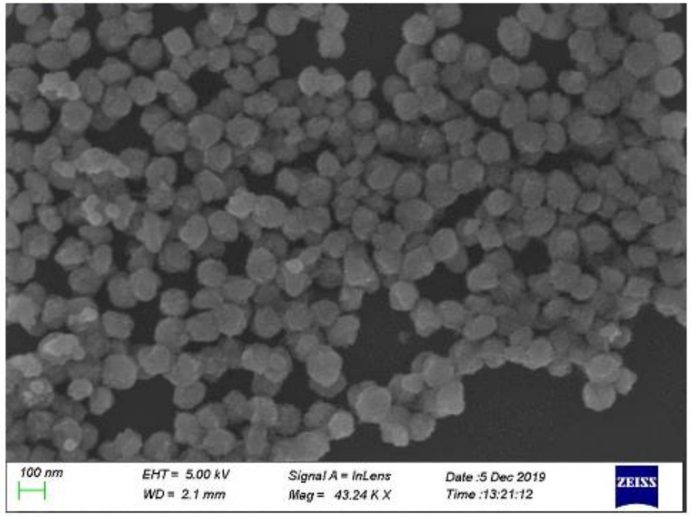
1 Underfocus   2 Overfocus



3 Astigmatism



4 Corrected

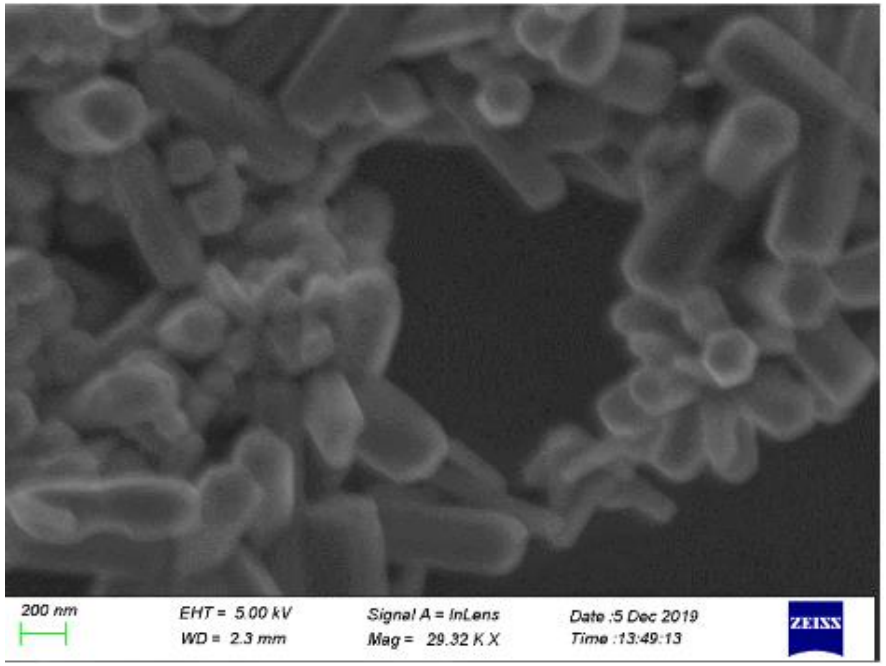


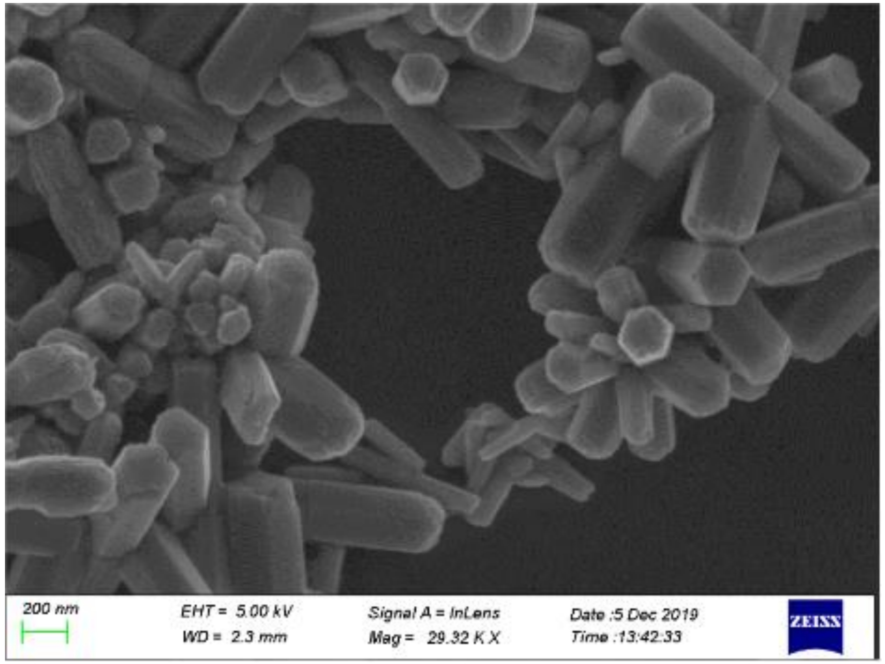
Ways to correct for astigmatism are:

- Higher magnitude
- Focus the image using objective lens control
- Sharpen the image using stigmator coils
    - Stigmator coils create a compensating field opposing the elliptical main beam to make it spherical

Data interpretation

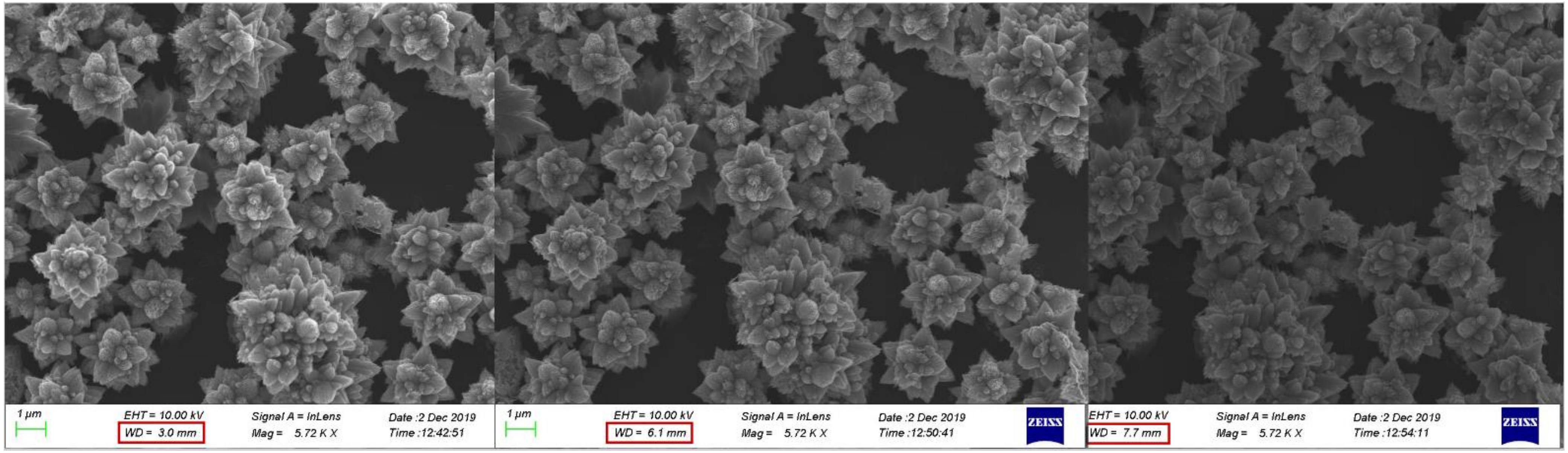
- Wobbling causes the image to move when you try to focus it
- Happens when apeture is not aligned with the electron beam
- Correction happens by switching the current to the objective lens constantly and correcting the apeture to minimize image movement





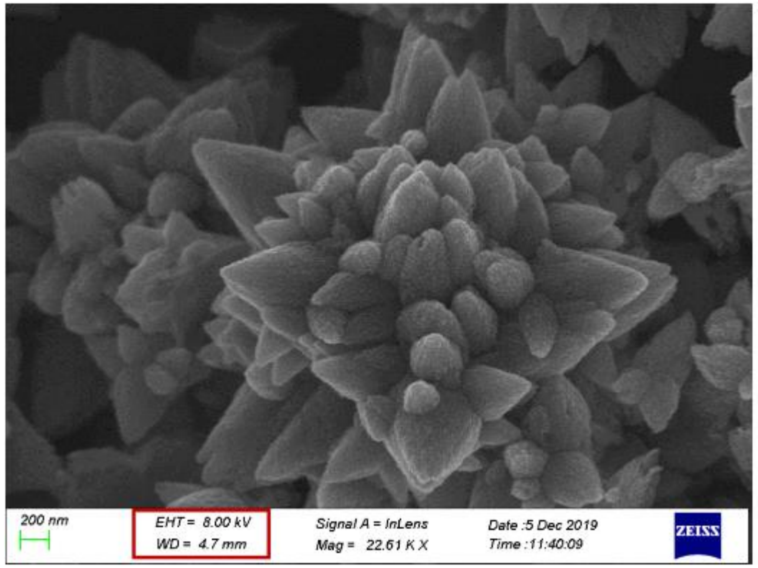
Data interpretation

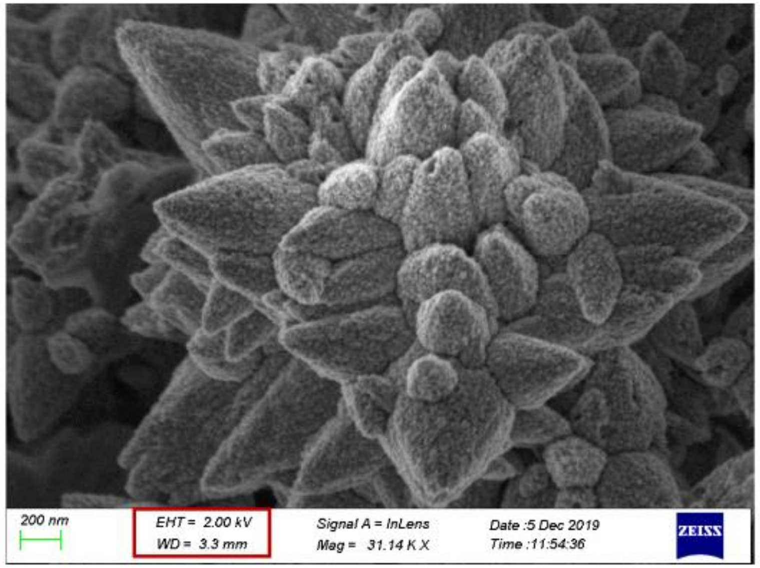
- Working distance affects depth of field, resolution, edge contrast
- Working distance means the physical distance between the beam and the sample

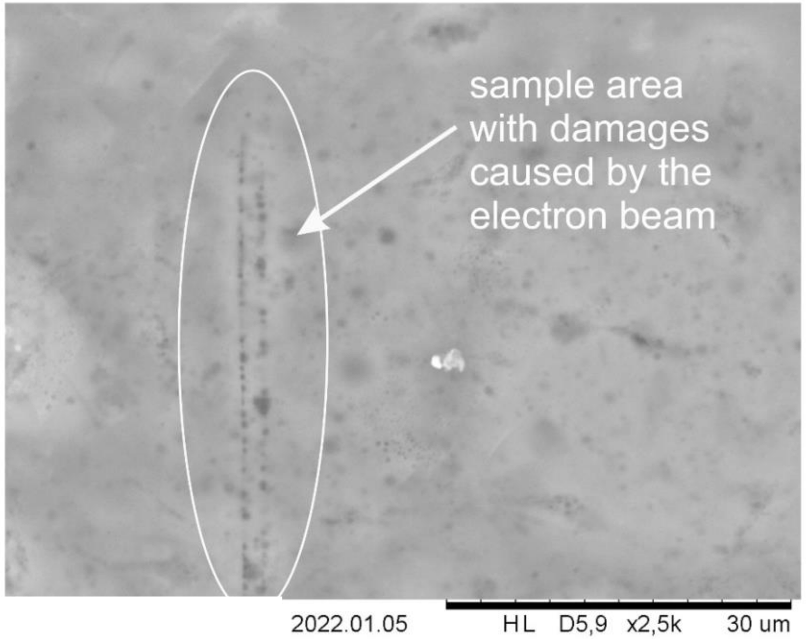


Data interpretation

- Accelerating voltage affects surface details, resolution, edge contrast and sample damage

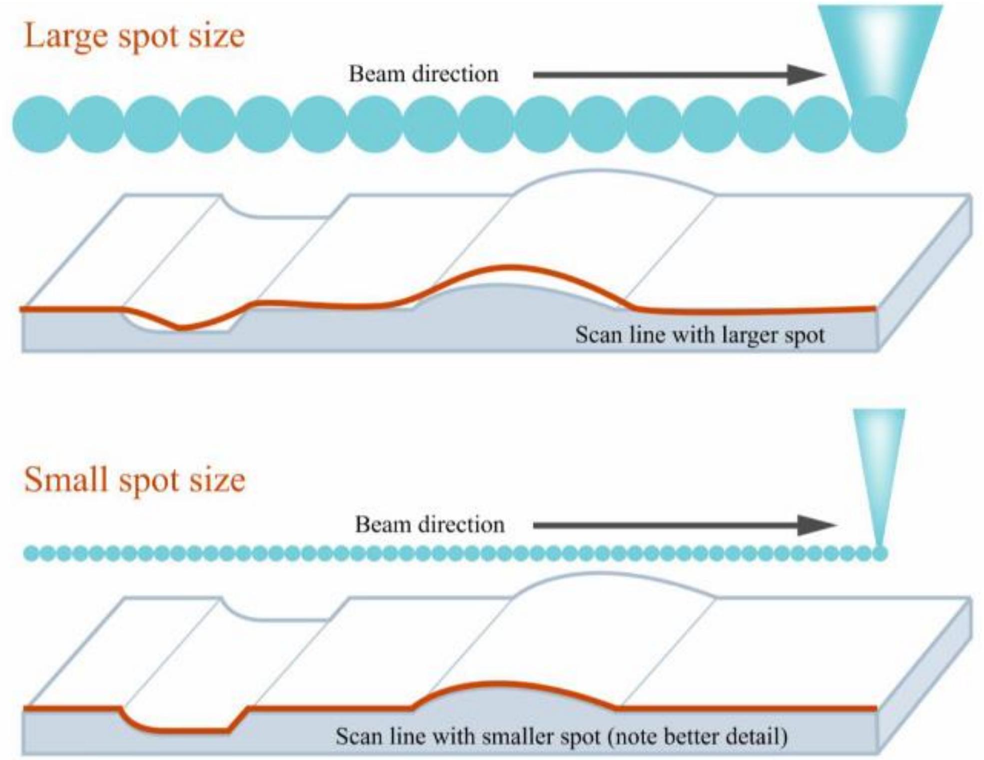


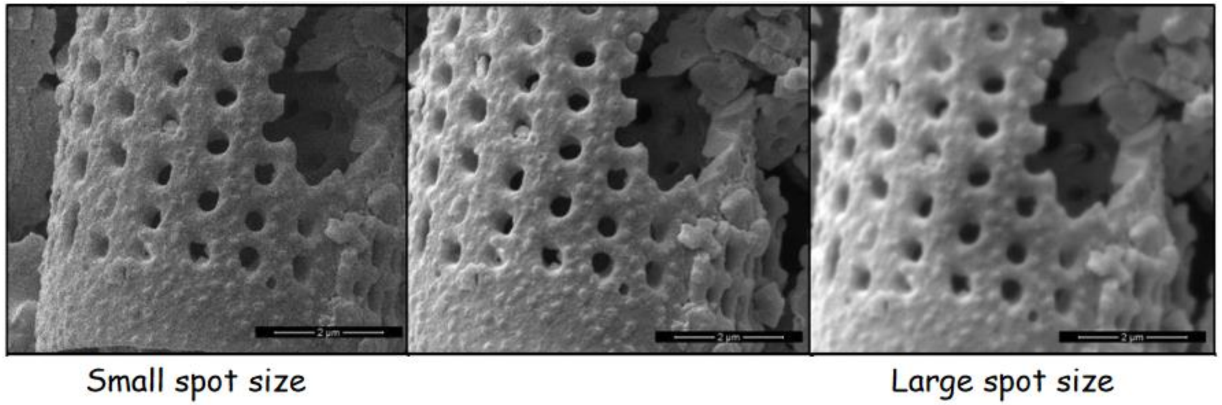




Data interpretation

- Diameter of the final beam affects the resolution and depth of field





Pros & Cons

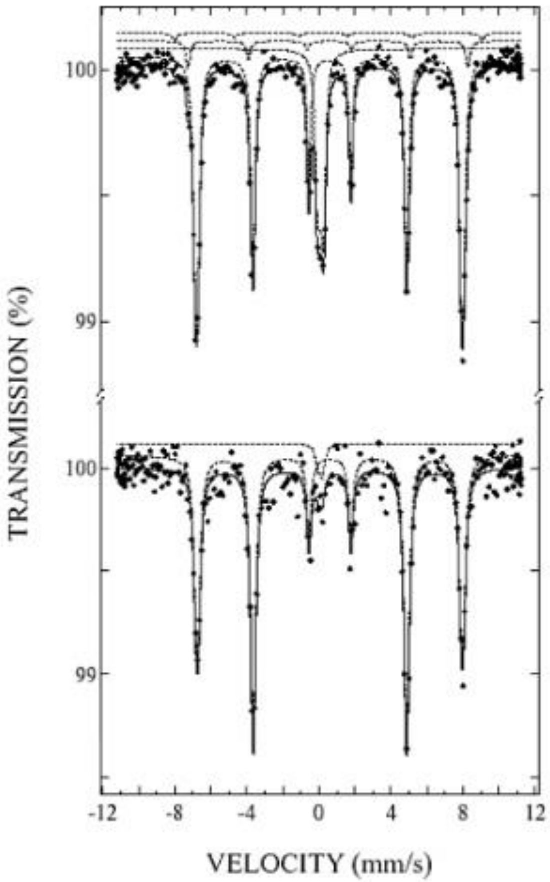
- SEM is good for imaging samples that are too thick for TEM
- Variety of information gained through different signals
- Easy to operate

- Size of SEMs can get large
- Costs can get ridiculously high… (starting from 50k € to over 1 million €)
- Expensive to operate

Research examples – Sr_2FeMoO_6

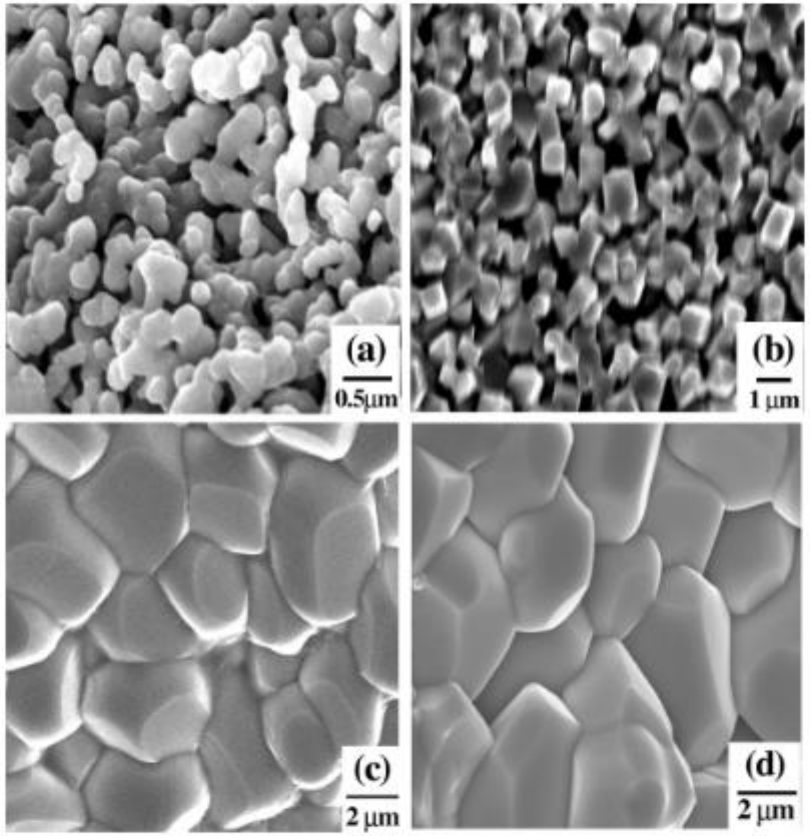
- Tunneling magnetoresistance effect (TMR)
- It suggests that TMR affects the Fe/Mo ordering

- Superparamagnetic (SP) component present in upper graph
- No clear explanation but believed to be by smallest grain fluctuations due to low coercive force and anisotropy energy
- Wet-chemical process for precursor preparation and encapsulation technique combined achieve a high degree of ordering



Sr_2FeMoO_6 - continued

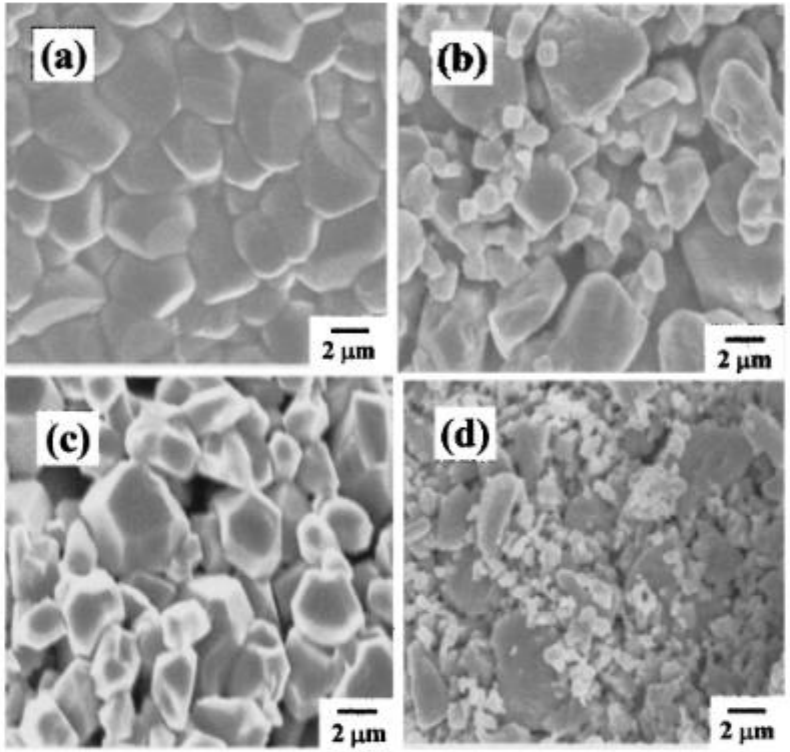
- Picture b) blurry, could be because of wobble, unfocus
- Picture a) big contrast differences



"Simple and Efficient Route to Prepare Homogeneous Samples of Sr_2FeMoO_6 with a High Degree of Fe/Mo Order", Y. H. Huang, J. Lindén, H. Yamauchi, M. Karppinen., *Chem. Mater. 16, 4336-4342 (2004).*

Research examples - Sr_2FeMoO_6 continuation paper

- TMR is explained to be caused by intra-granular two-dimensional defects and grain boundaries/impurity-phase boundaries
- Mix of high degree ordered large grains and lower degree ordered small grains which enhanced the magnetoresistance



”Large low-field magnetoresistance effect in Sr_2FeMoO_6 homocomposites”, Y. H. Huang, J. Lindén, H. Yamauchi, M. Karppinen, *Appl. Phys. Lett.* 86, 072510 (2010).