Webinar Series in TEM:
Transmission Electron Microscopy - Part 2

Scanning, Spectroscopy, and 3D Imaging in TEM

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Customer Success Manager - APAC

Material and Structural Analysis

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Transmission Electron Microscopy Webinar Series

Outline: Part 01

- Basic Theory of TEM
- SEM vs. TEM: What are the differences
- Conventional TEM Imaging
    - Bright-Field Imaging
    - Dark-Field Imaging
- Electron Diffraction
    - Selective Area Electron Diffraction
    - Convergence Beam Electron Diffraction
    - Nano Beam Electron Diffraction
- Advanced TEM Imaging
    - High-resolution TEM
- Special Investigation Cases
    - Magnetic Samples
    - Soft Materials
    - In-situ Investigations
    - Life-Sciences

Transmission Electron Microscopy Webinar Series

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Outline: Part 02

- Scanning Transmission Electron Microscopy (STEM) - Introduction
- TEM and STEM comparisons
- Scanning Transmission Electron Microscopy (STEM) Imaging
- High-resolution Scanning TEM (HRSTEM) Imaging
- Differential Phase Contrast Imaging (DPC)
- Spectroscopy in TEM
  - Energy-Dispersive X-Rays Spectroscopy
  - Electron Energy Loss Spectroscopy
- Tomography in TEM: For 2D to 3D Imaging

Transmission Electron Microscopy Webinar Series

Outline: Part 03

- An Overview of TEM Sample Preparation
- Various Types of TEM Sample Preparations
  - Conventional Techniques
  - Focus Ion Beam Techniques
- Practical Aspects of TEM Sample Preparations

Transmission Electron Microscopy Webinar Series

Outline: Part 04

- An Overview of TEM for Biological Materials Research
- Biological Samples Preparations
- Room Temperature Investigations
- Cryo-EM Workflow

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Scanning Transmission Electron Microscope (STEM)

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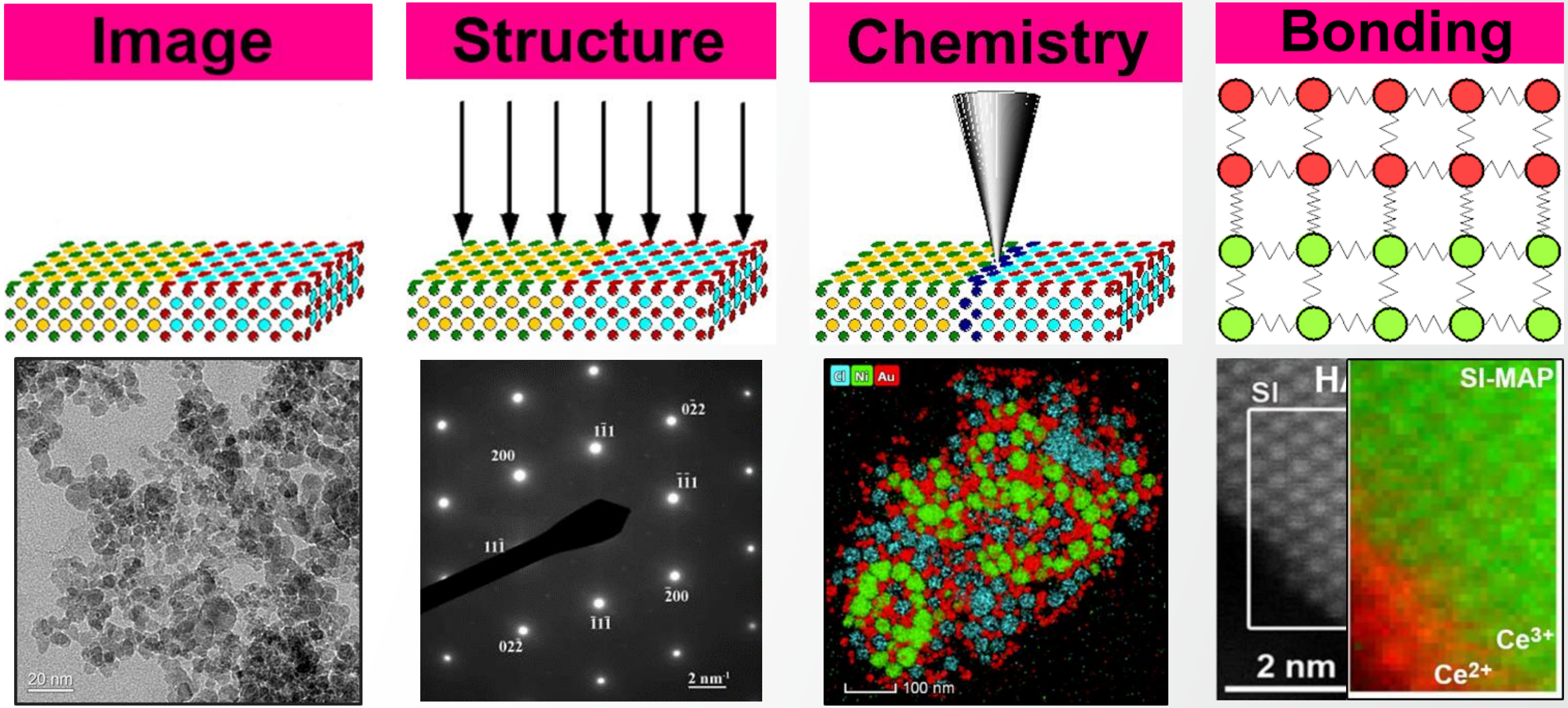
More Than a Conventional TEM



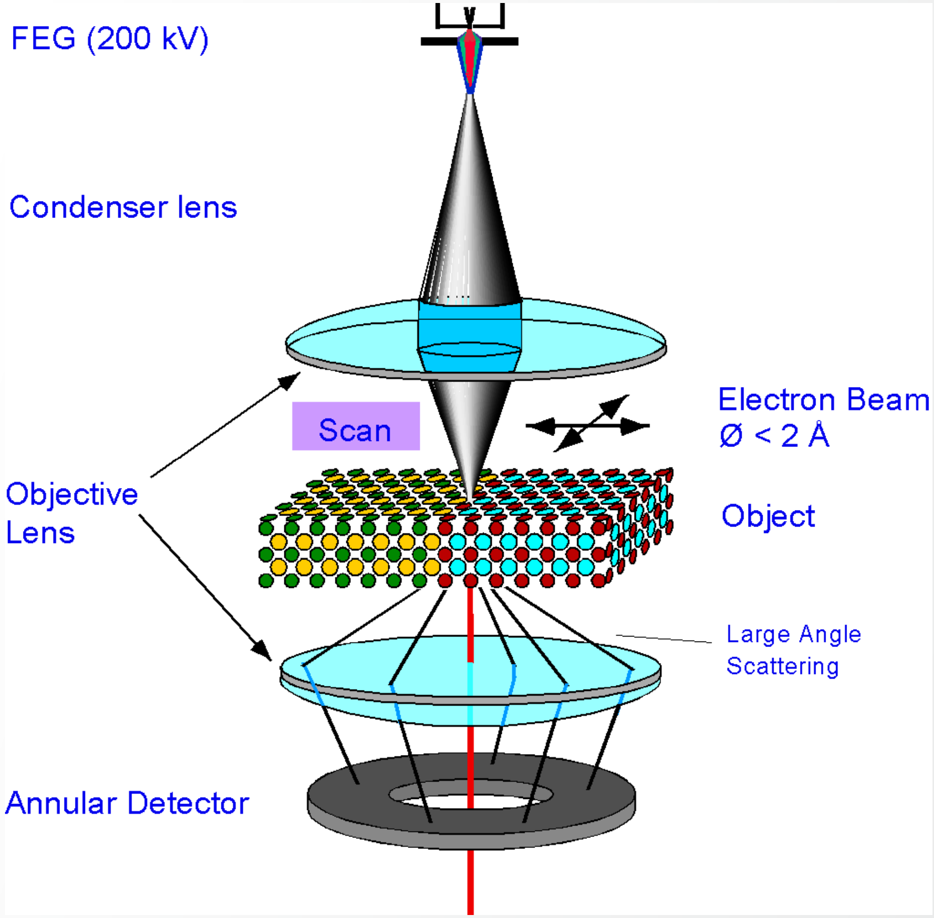
Spectra 300

An Aberration Corrected Microscope

Scanning Transmission Electron Microscope (STEM)

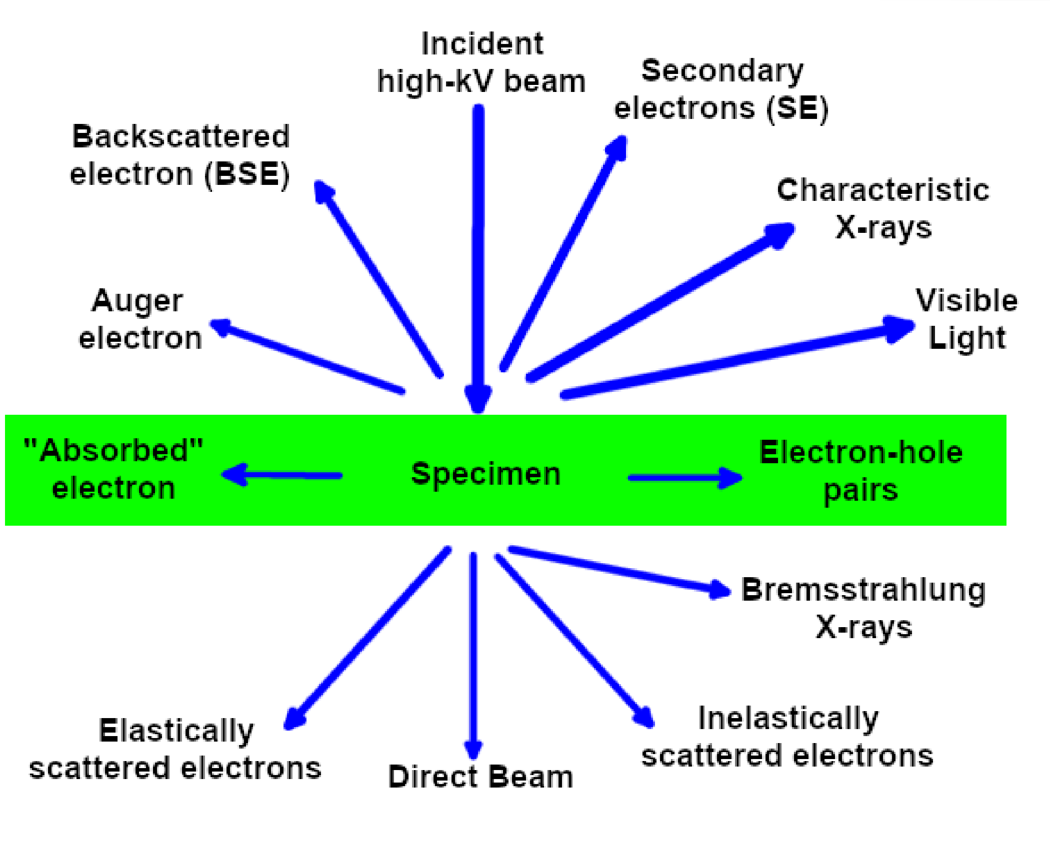
What is STEM

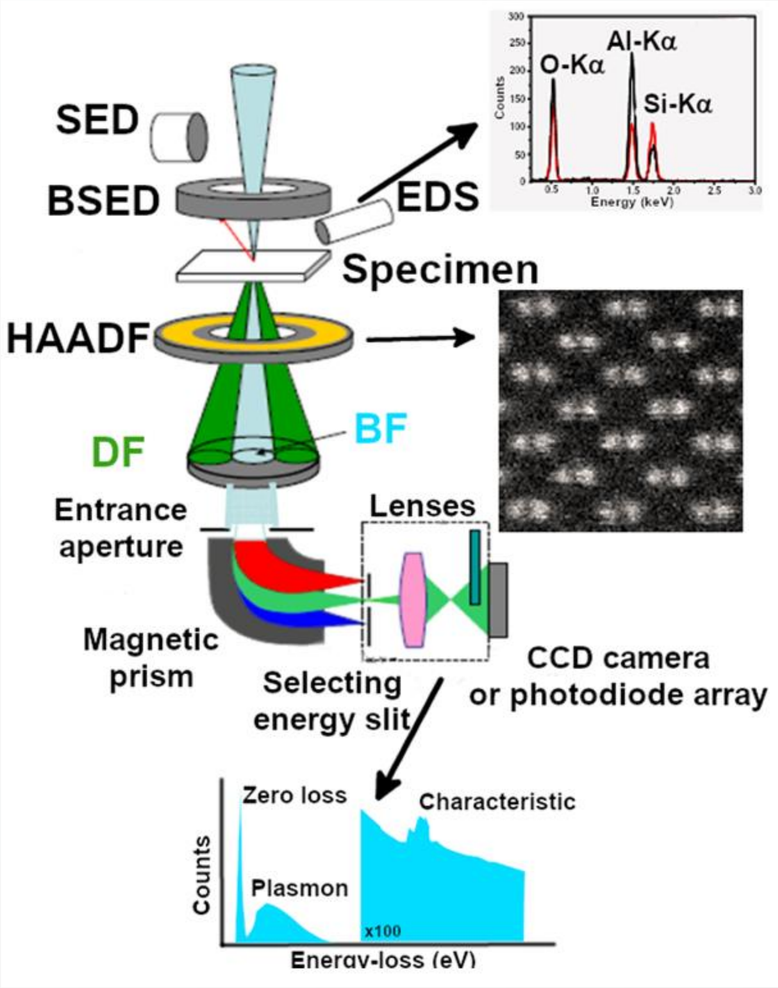
- STEM is a **scanning technique** in TEM
- 'A SEM within a TEM'
- Specimen must be **small** (fitting TEM holder) and **thin** (electron transparent) because the detectors are below



Scanning Transmission Electron Microscope (STEM)

STEM and Spectroscopy: AEM (Analytical (T)EM)





Scanning Transmission Electron Microscope (STEM)

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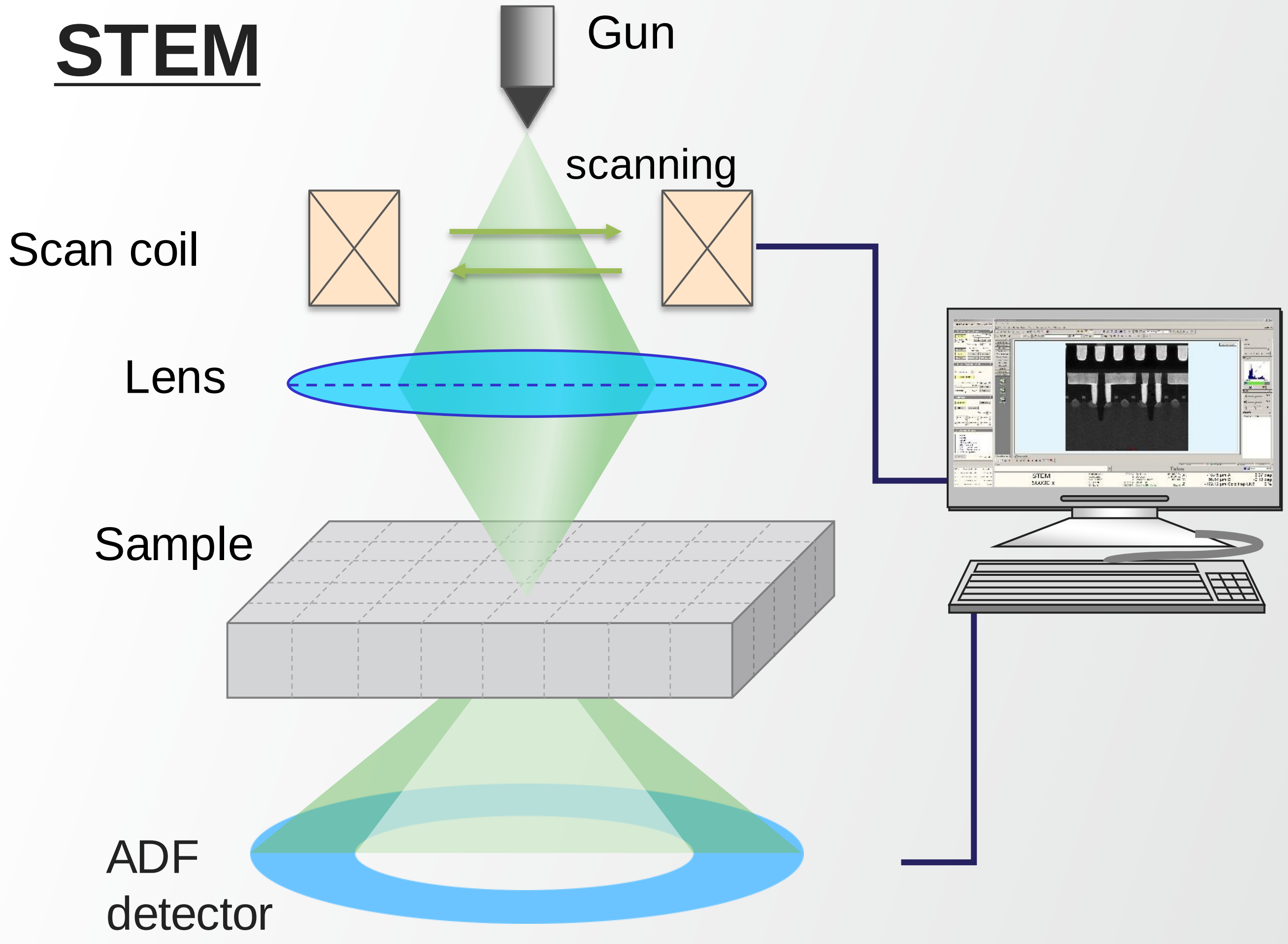
STEM Image Formation

- **STEM works in diffraction mode**, **scanning the small probe over the sample**, one pixel at a time.
- STEM detectors capture diffraction pattern information. Normally they measure the **total signal from all the electrons hitting the STEM detector.**
- Each detector covers a selected region (typically a ring) of the diffraction pattern.
- STEM mode also uses a convergent small probe so the diffraction pattern will typically consist of disks when imaging a crystalline material.



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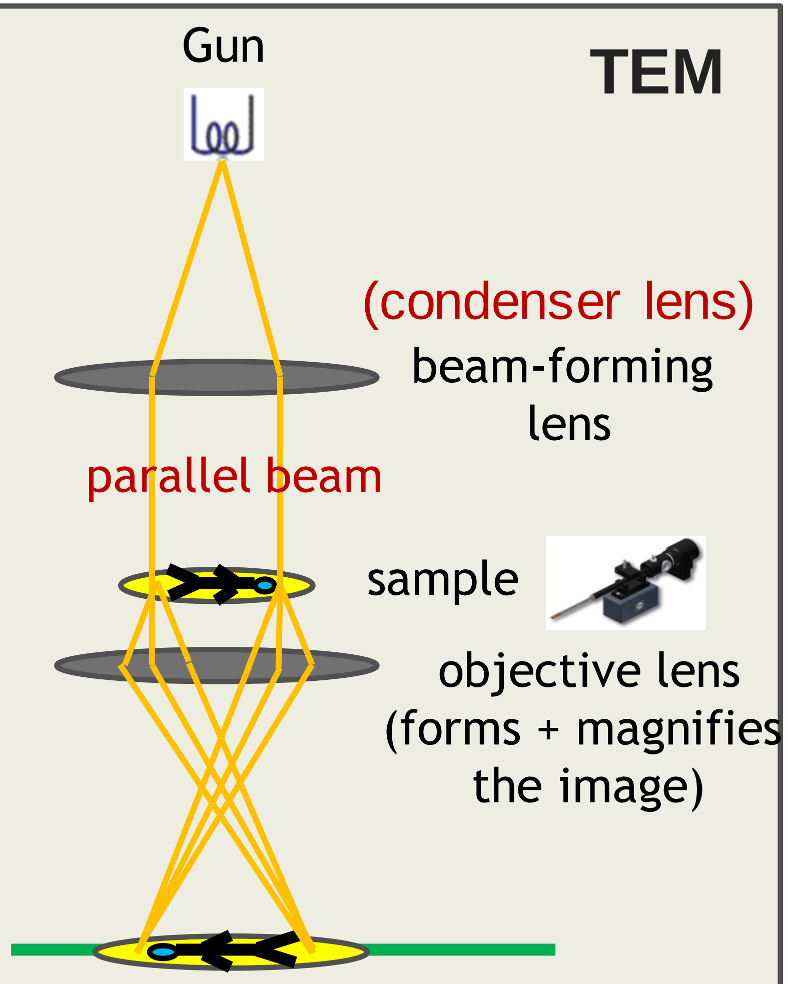
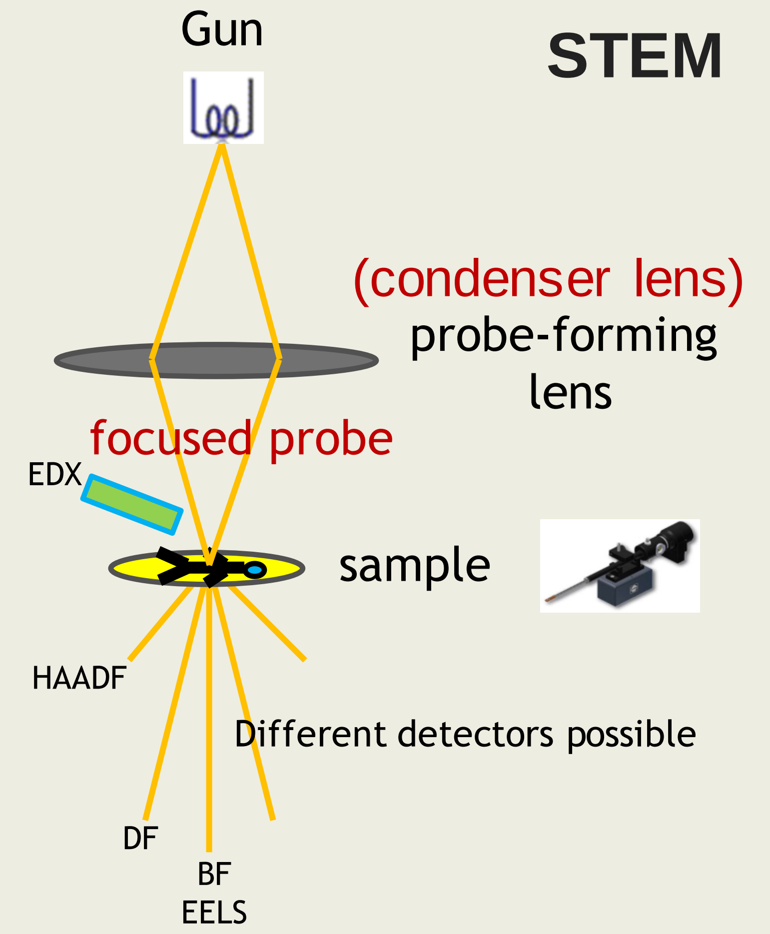
TEM and STEM Comparisons

TEM vs STEM



- Real image formed on screen or camera
- No scanning

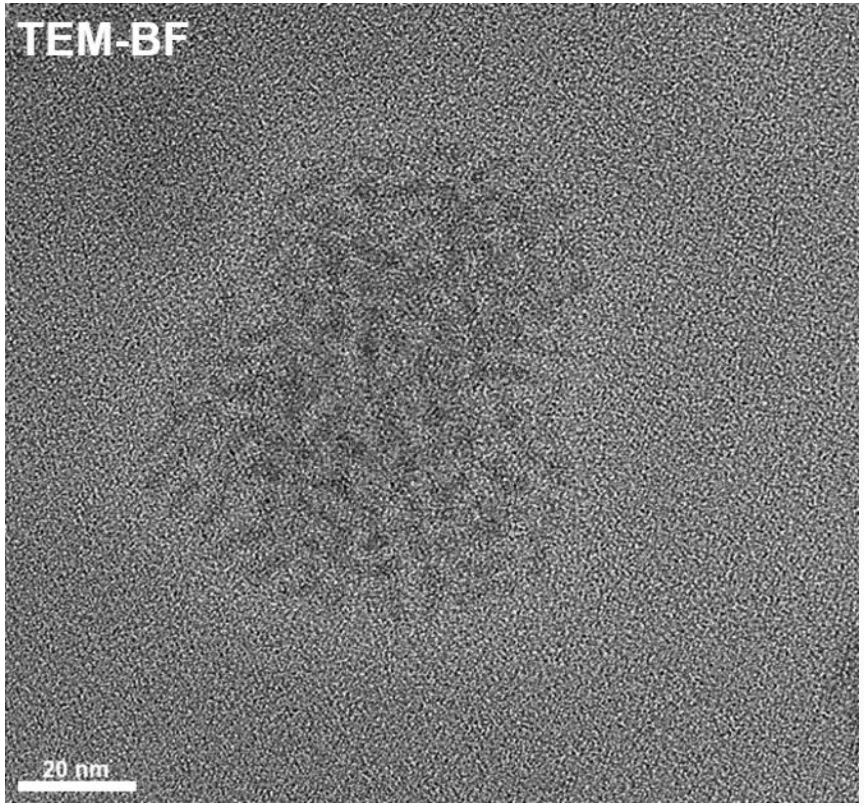


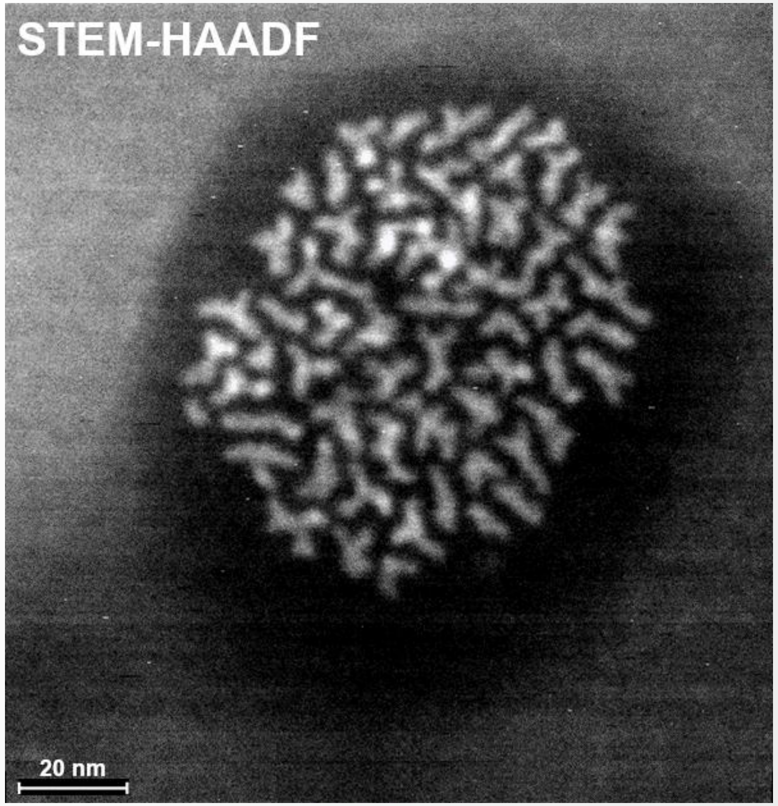
- Scans small probe over sample
- Each pixel measured separately
- Image created using software

TEM and STEM Comparisons

Z-Contrast in STEM Image

- STEM-HAADF image is very sensitive to Z-contrast. Elements with higher Z will show brighter than lower Zelementst.
- CdSe nanoparticles on carbon supporting film.





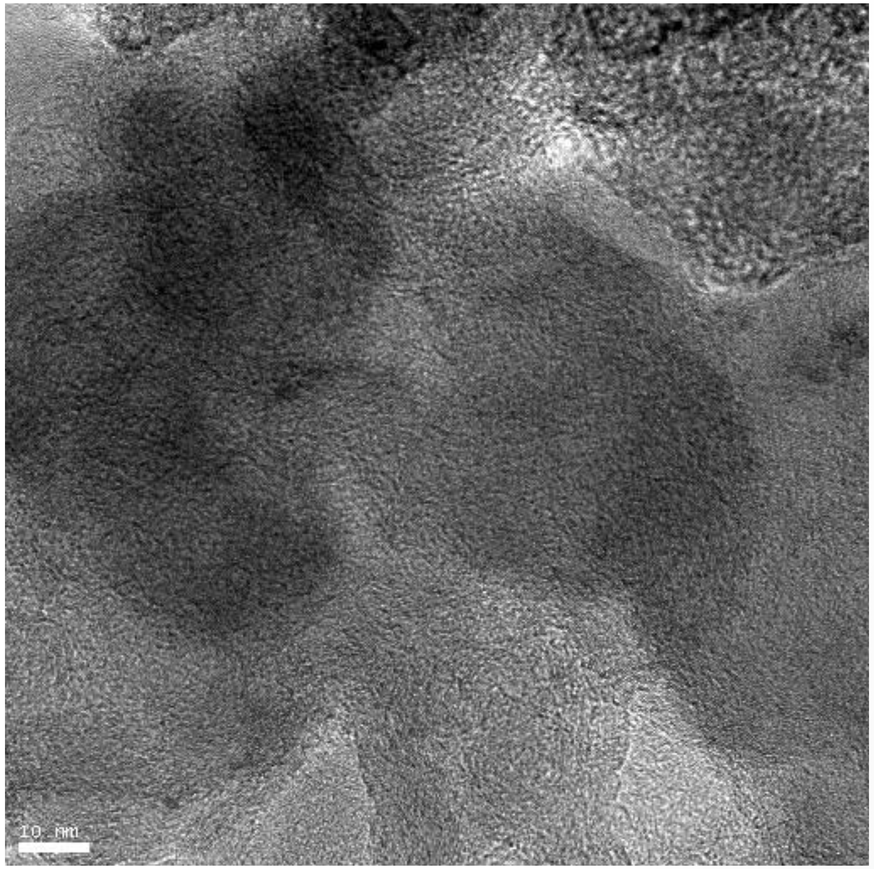
Sample courtesy of Timothy Tan, IBEN, Singapore

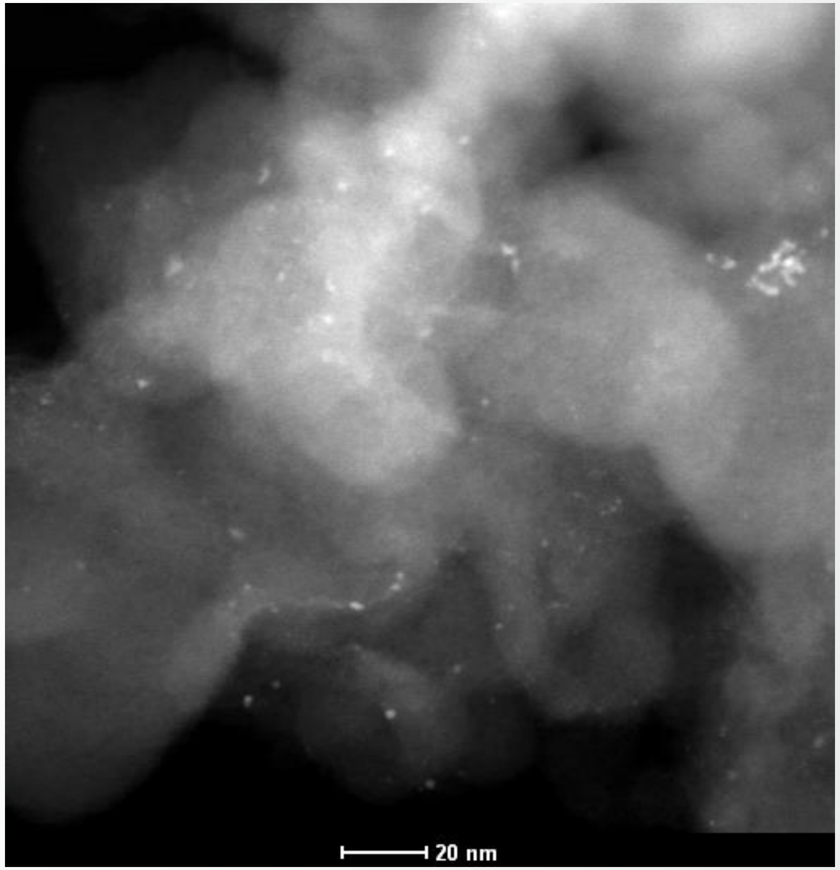
TEM and STEM Comparisons

Combination Z-Contrast and Thick specimen

- RuPt nanoparticles on graphite

TEM





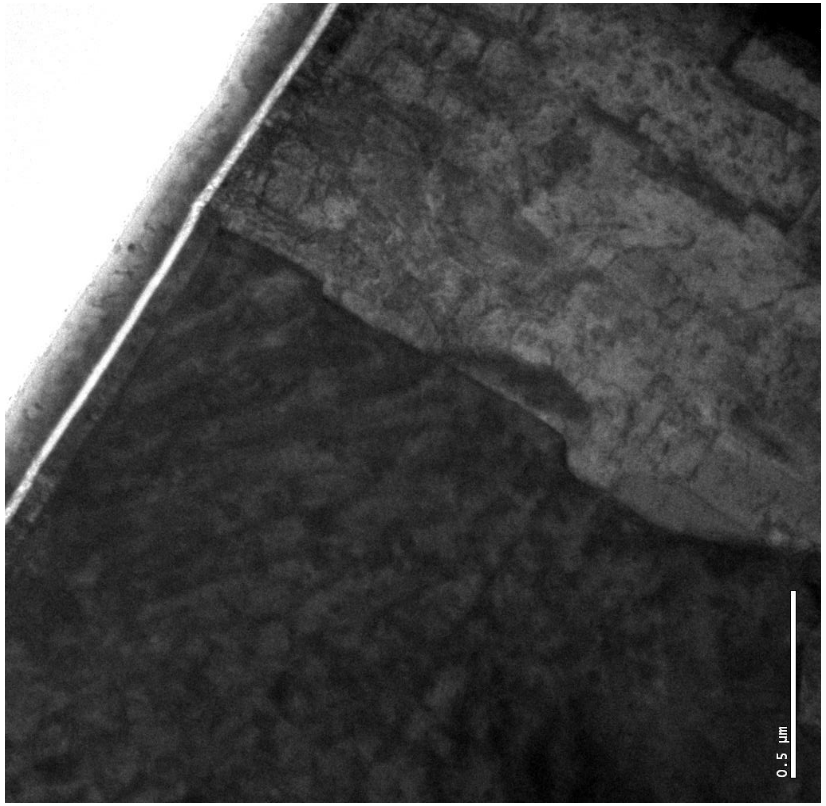
STEM

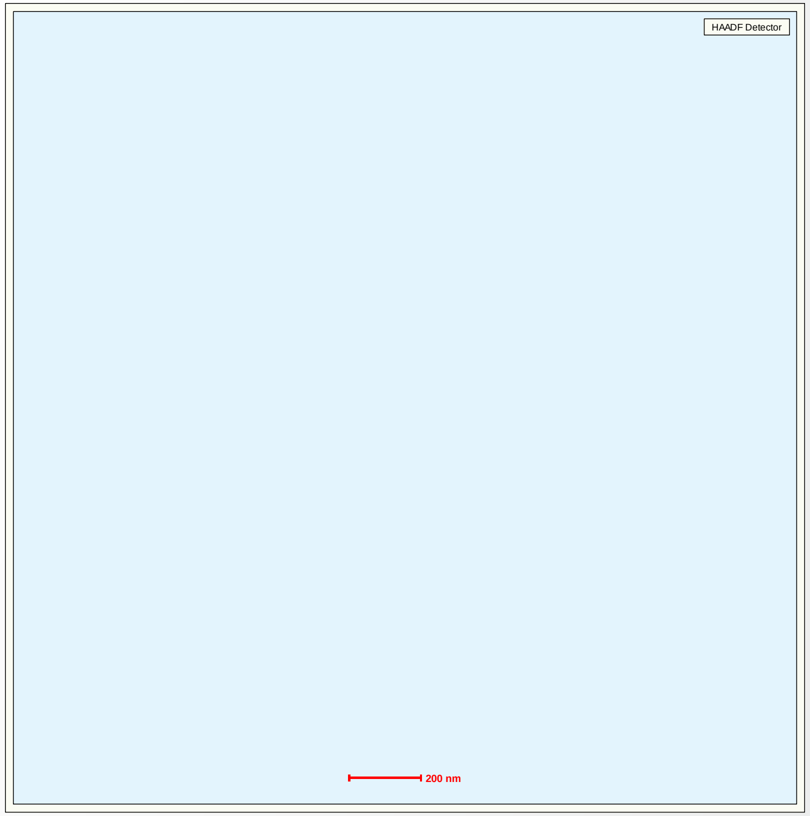
TEM and STEM Comparisons

Thick specimen

- On the same FIB-made thick sample, the TEM image looks not focused due to chromatic aberration, but the STEM image still looks sharp

TEM





STEM

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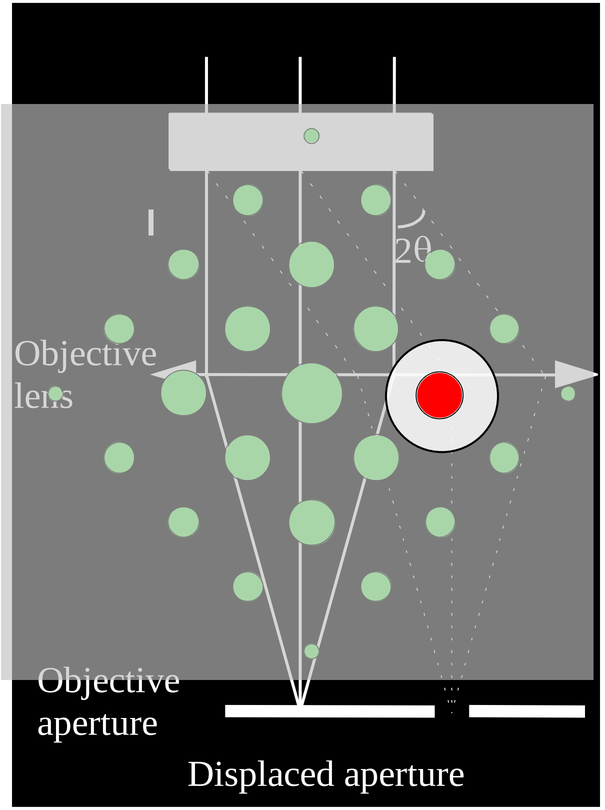
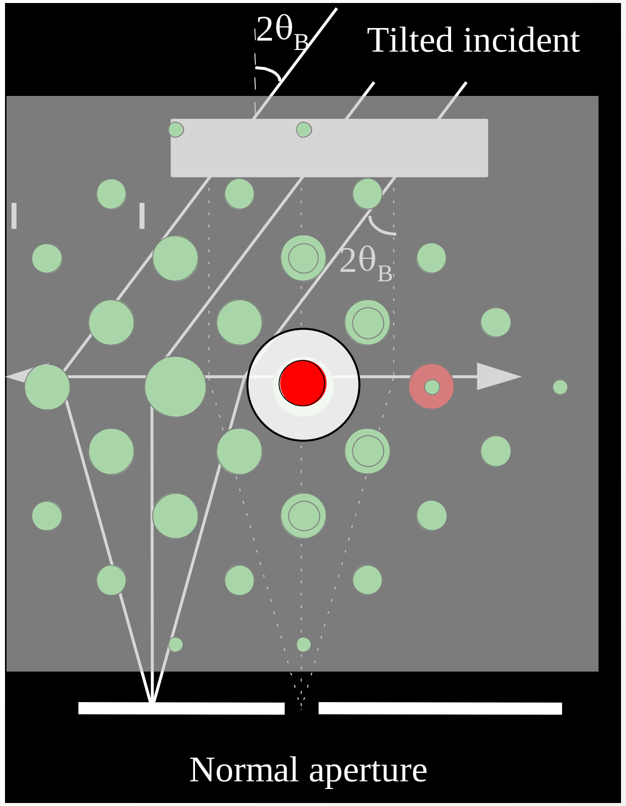
Conventional TEM Imaging: Bright and Dark Field Imaging

Dark Field Imaging

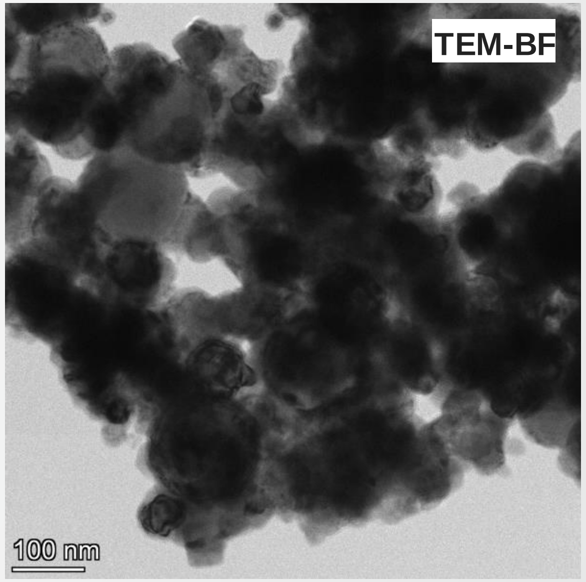
- Standard mode for imaging without the transmitted beam
- Loss of resolution due to higher C_s at off-axis positions
- Two types of DF-Images: Off-axis and On-axis DF

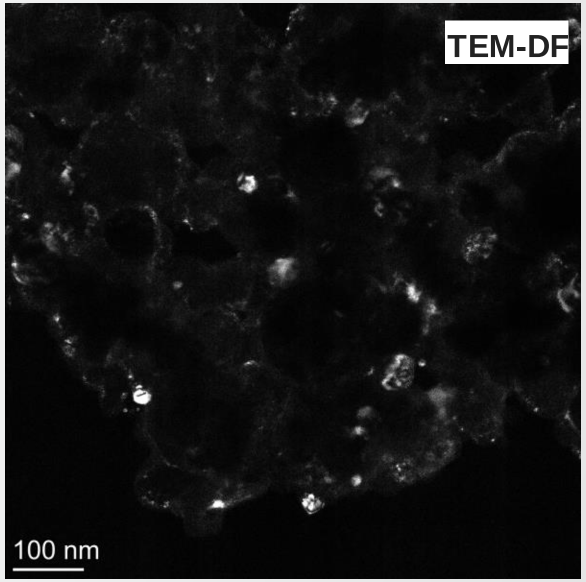


Off-axis DF



On-axis DF

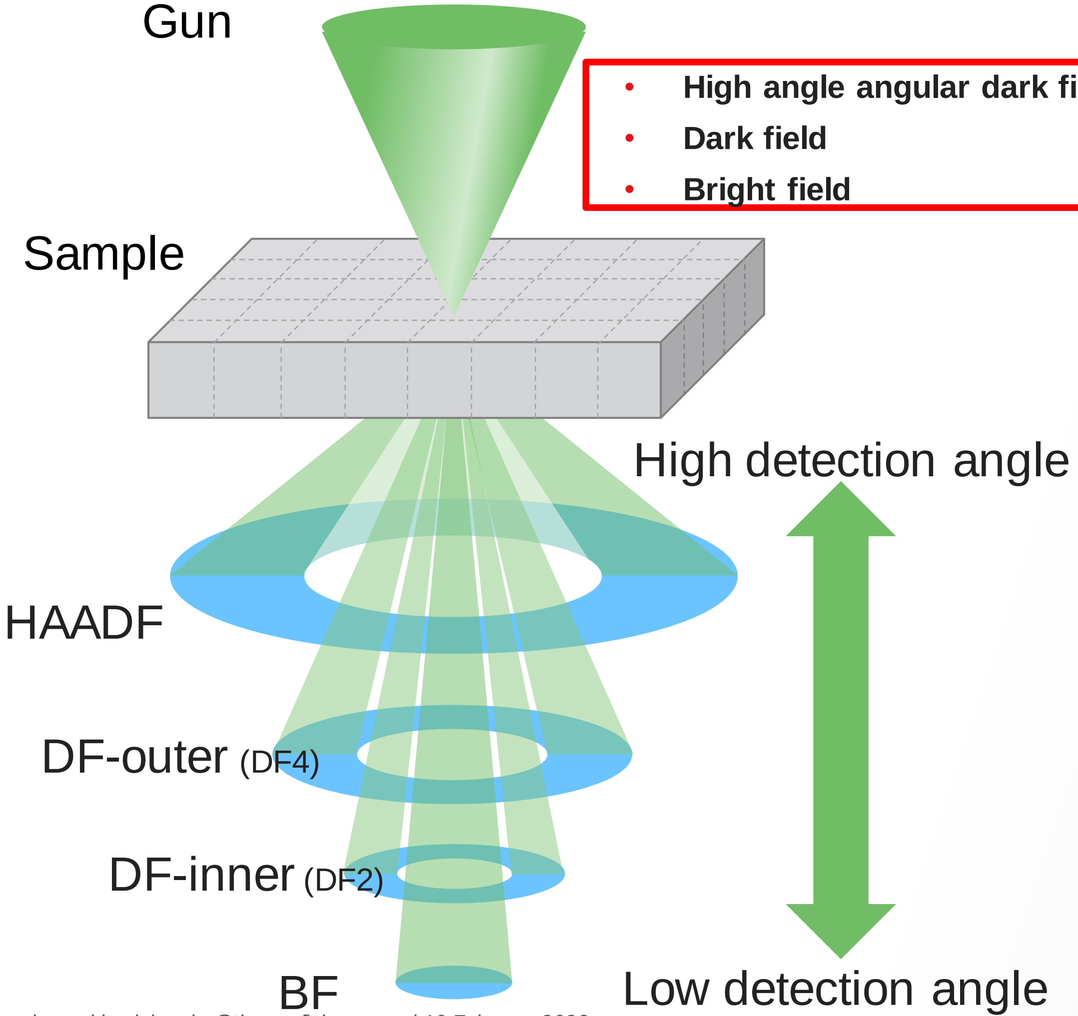




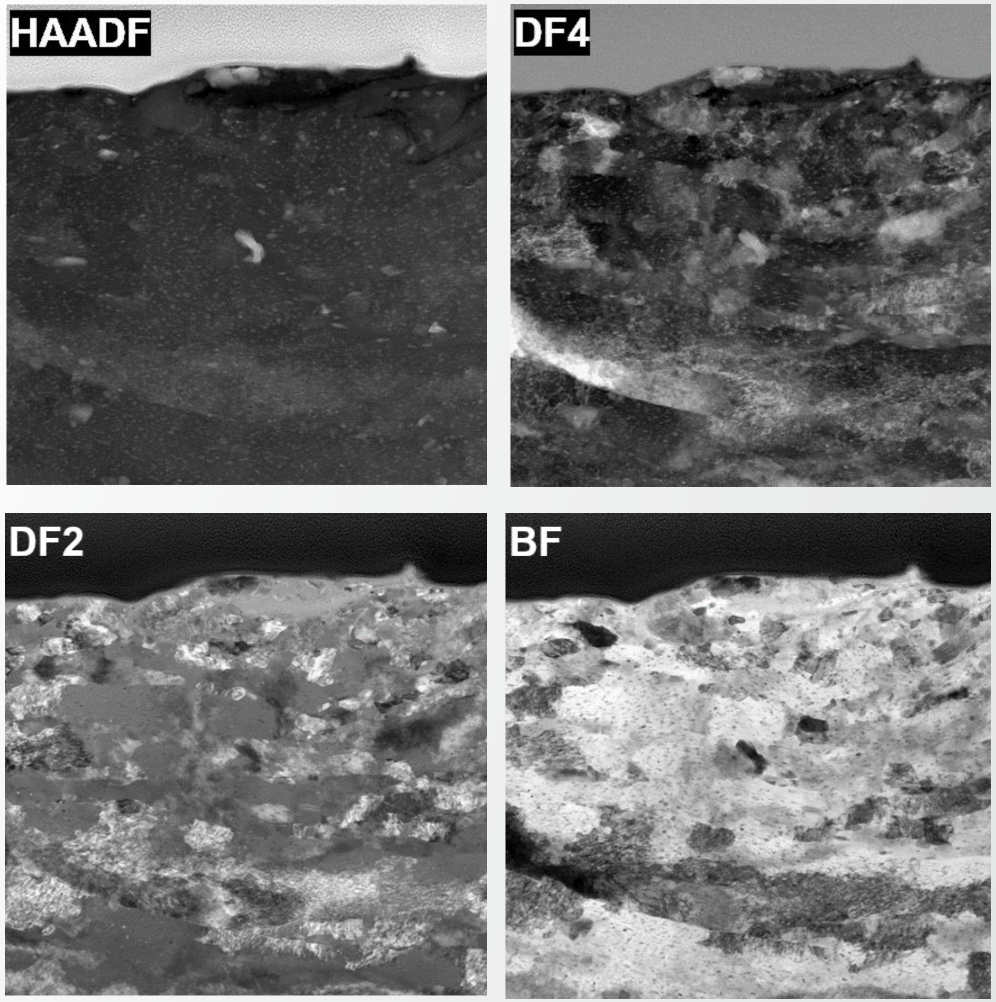
STEM Imaging

Image Detectors in STEM

- A range of different contrast and information is available with different detector geometry
- STEM Detectors- Shot-peened Aluminum alloy 7075

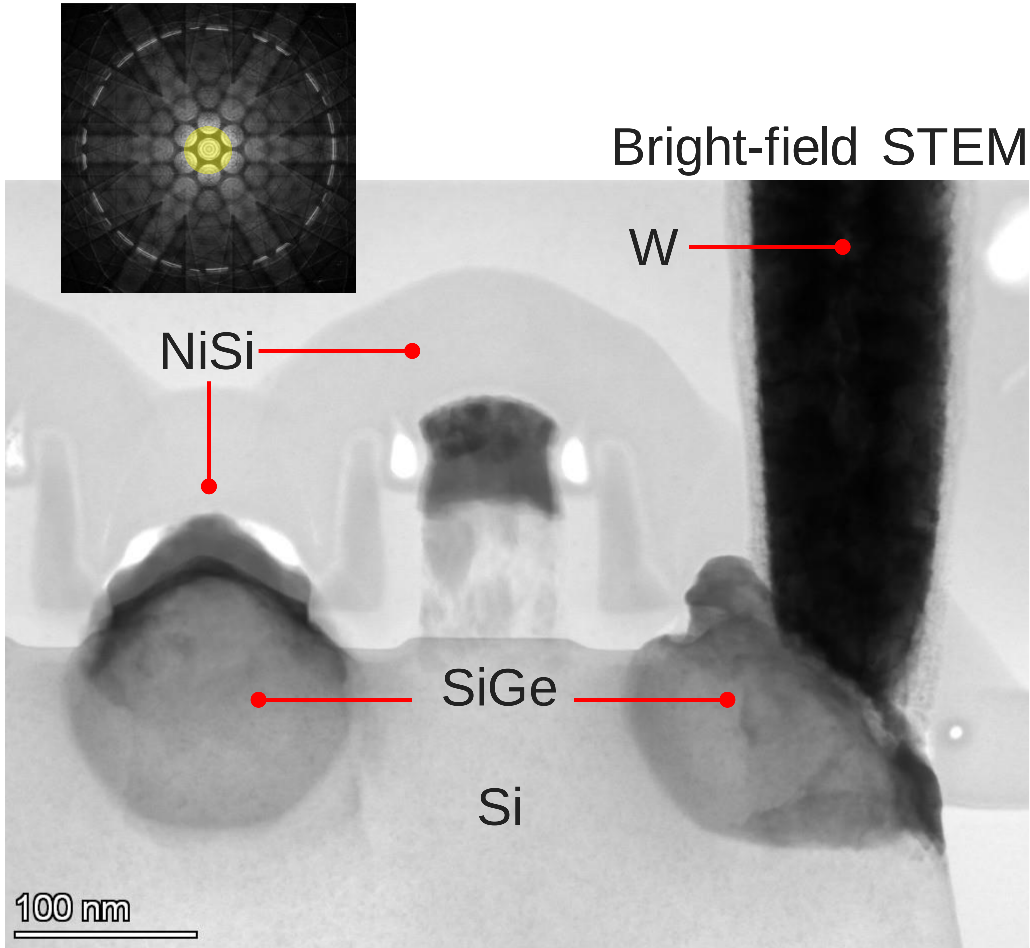


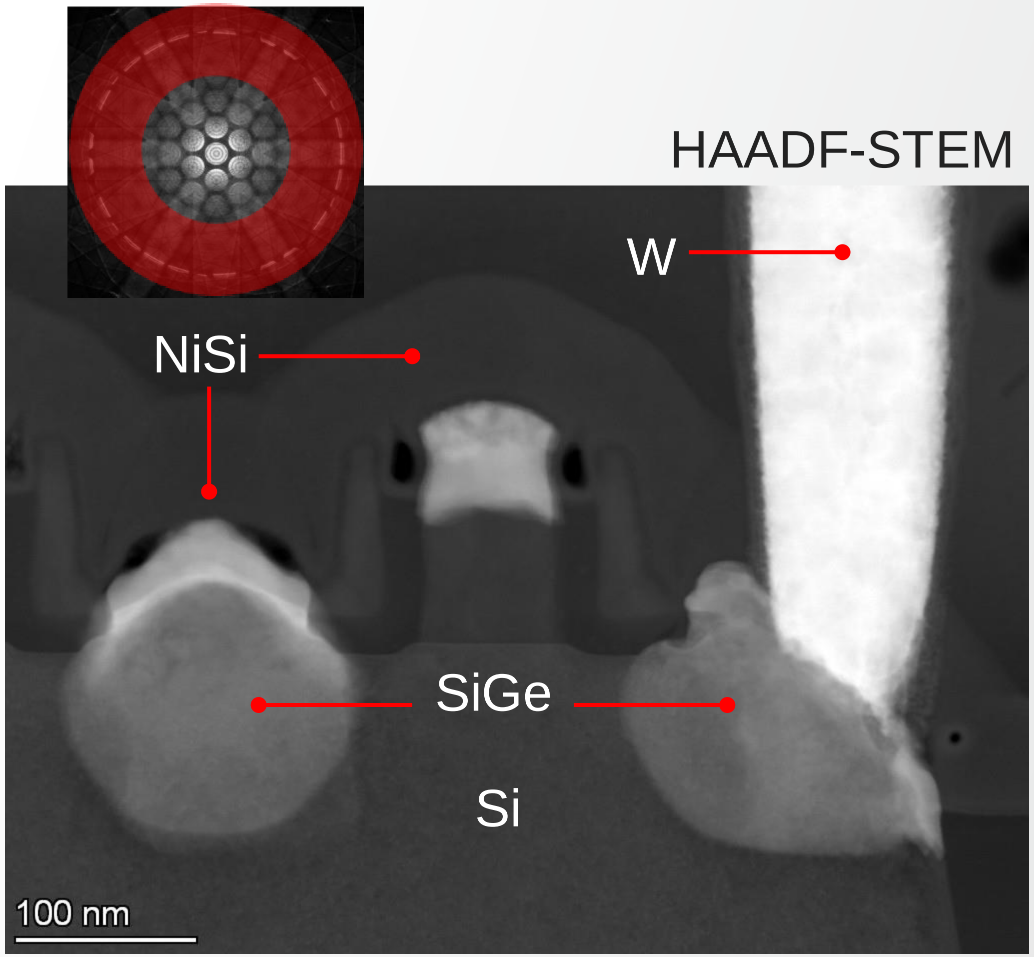
- **High angle angular dark field**
- **Dark field**
- **Bright field**



STEM Imaging

Bright-Field STEM vs (High Angle Angular) Dark-Field Image





Bright-field STEM

Heavy regions are dark, thin and vacuum regions are bright

Dark-field STEM

Heavy regions are bright, thin regions are dark, vacuum is black

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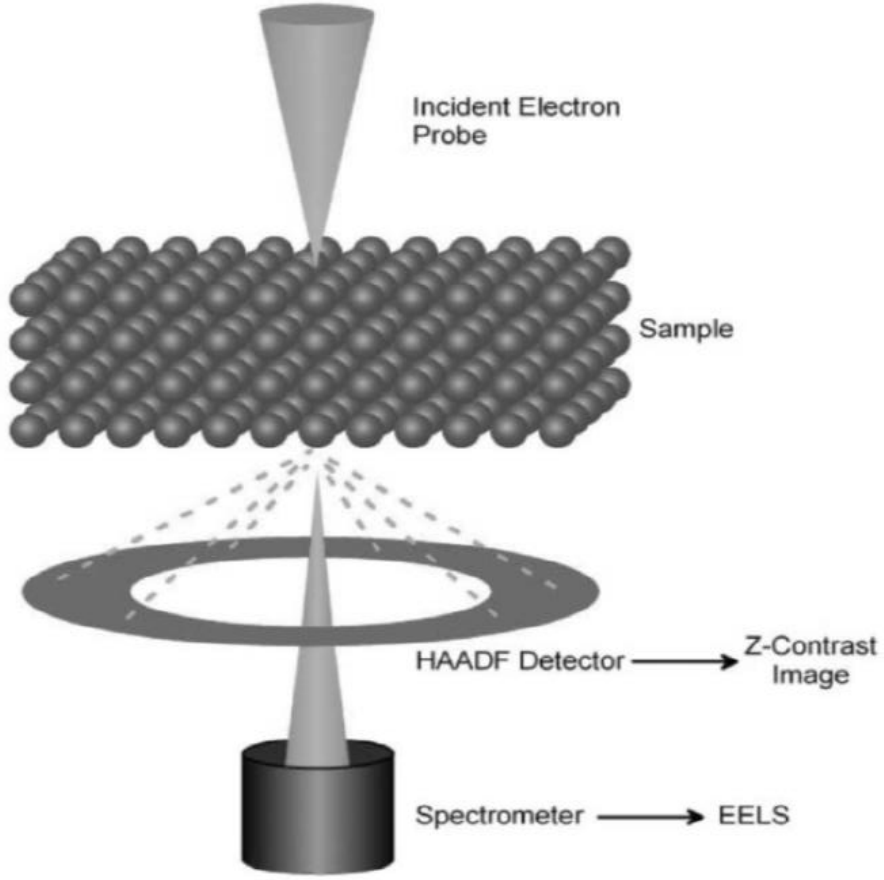
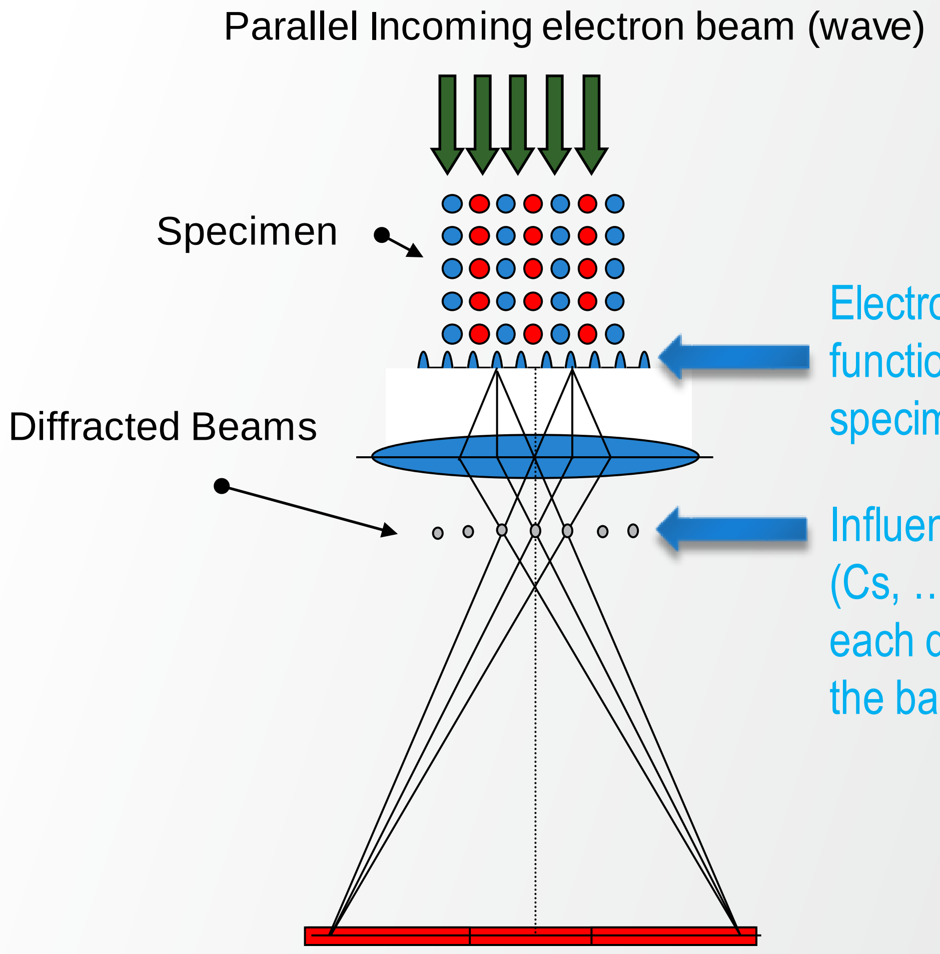
High-resolution Scanning TEM (HRSTEM) Imaging

Small Probe for a Better Spatial Resolution





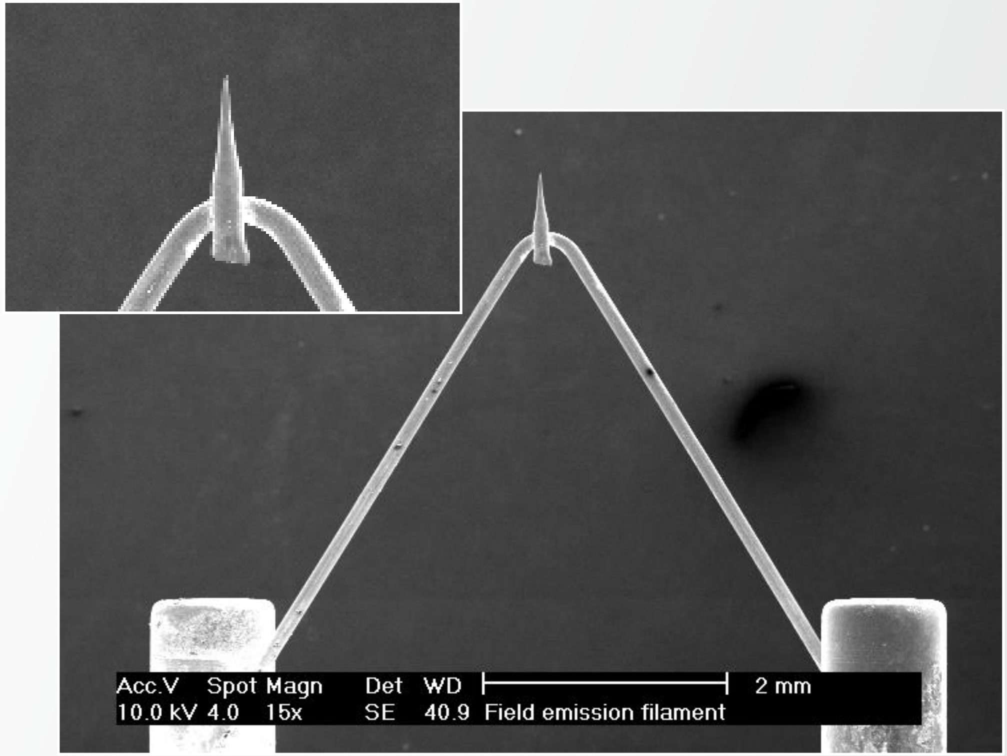
Electron exit wave function is modified by specimen

Influence of the TEM (Cs, …) is multiplied to each diffracted beam in the back focal plane

High-resolution Scanning TEM (HRSTEM) Imaging

Electron Source – Field Emission Gun

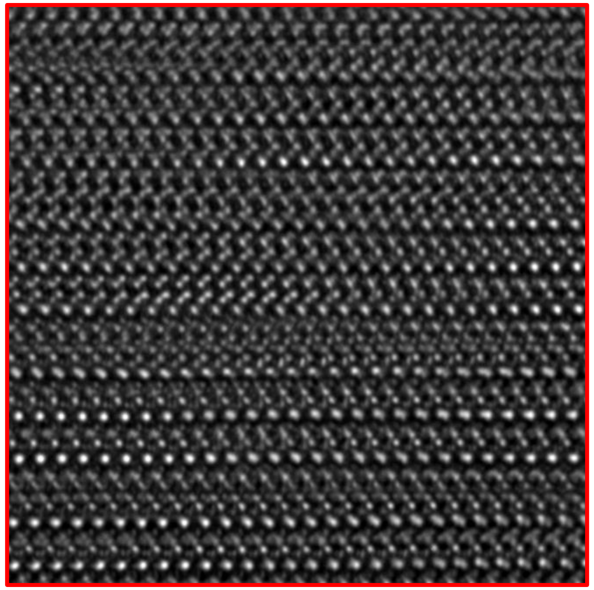
- STEM (HR) needs a bright source of electron:
  - The source must be demagnified to produce a very small focused electron probe; intensity or beam current is lost in the process.
- The only source which can be used is a field emission source:
  - A very sharp tungsten point which only operates in an ultrahigh vacuum environment (10^{-6} -10^{-8} Pa).
  - Very long lifetimes: a couple or more years continuously.



High-resolution Scanning TEM (HRSTEM) Imaging

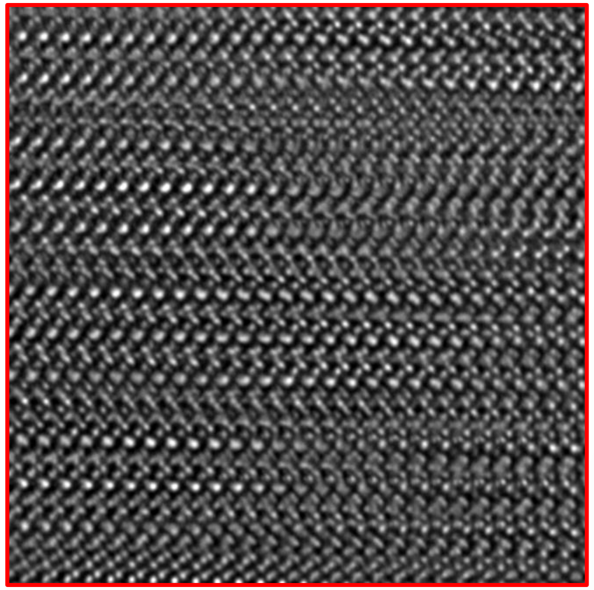
Less Defocus Dependent

Defocus 0 nm

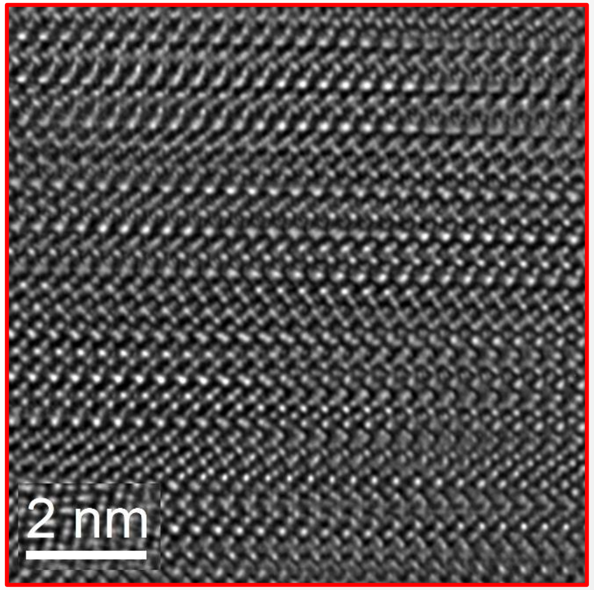


HR-TEM

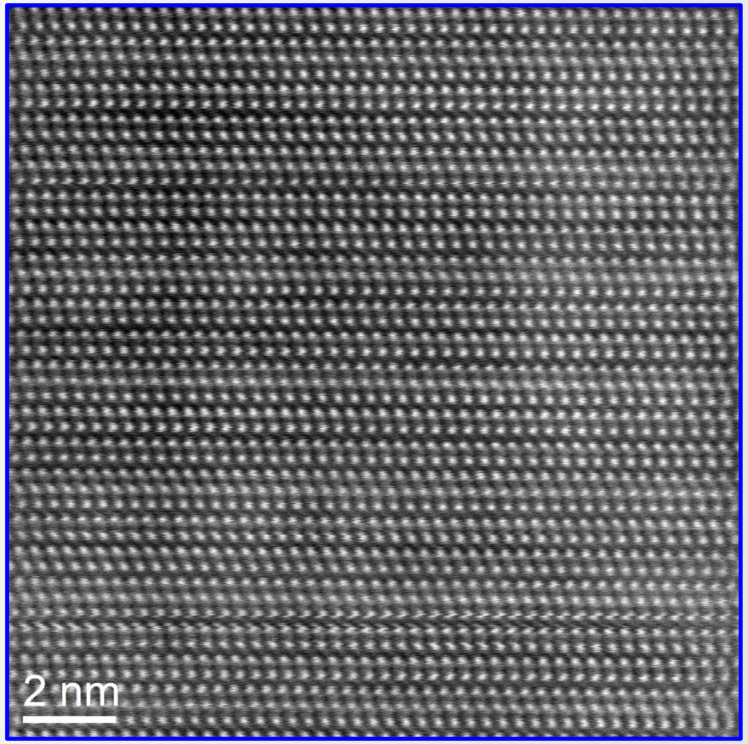
Defocus 1 nm



Defocus 2 nm

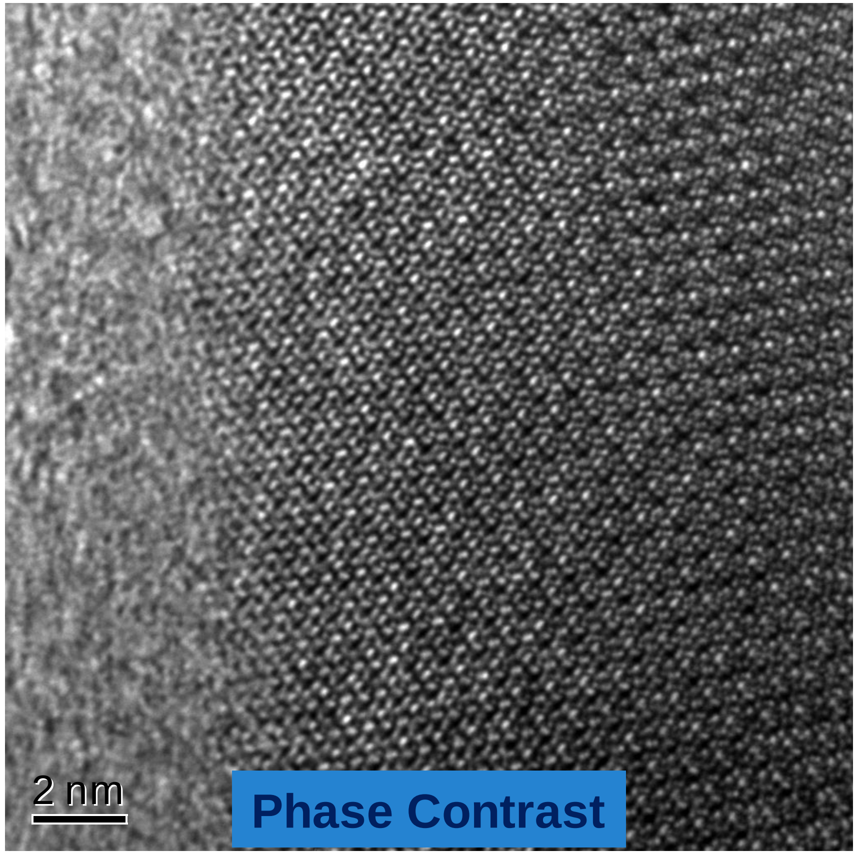


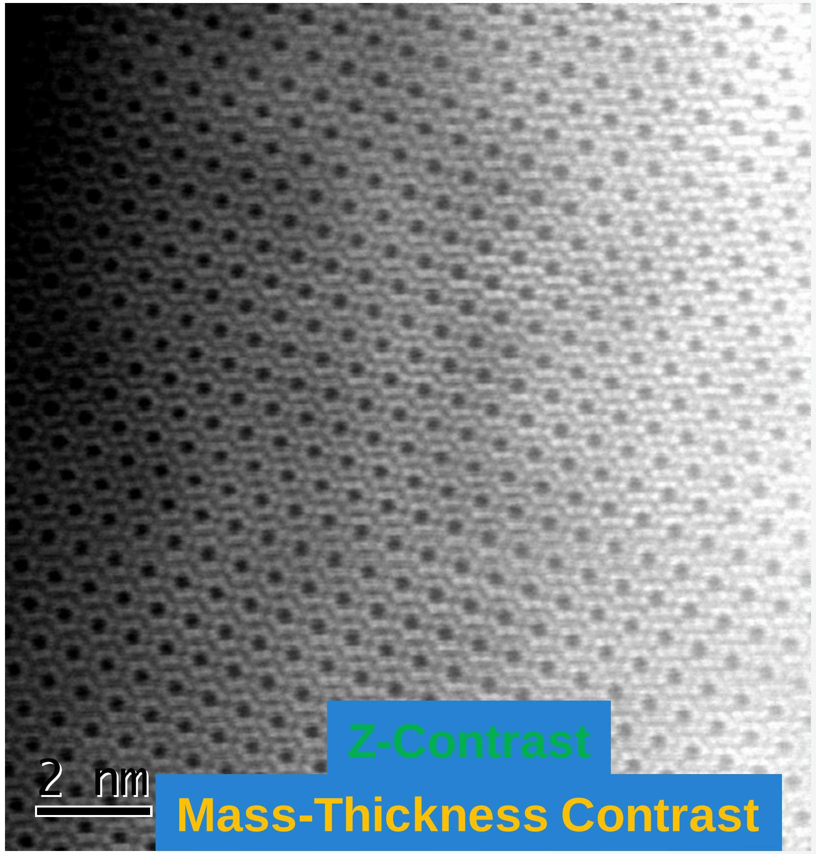
HR-STEM -20 < Defocus < 20 nm

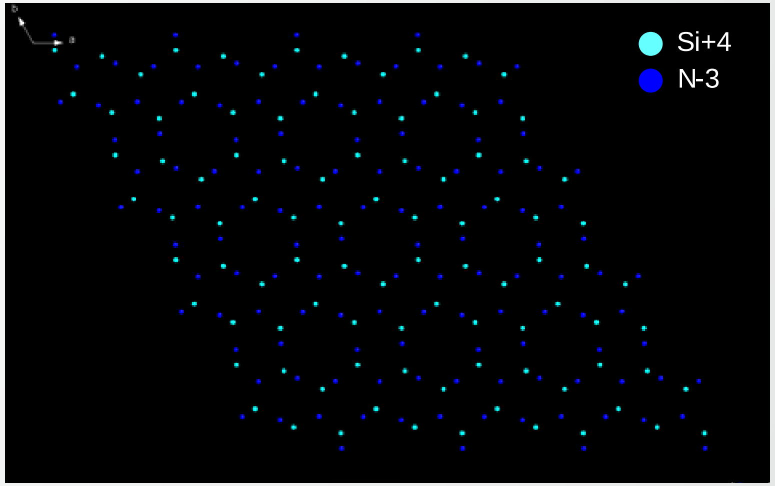


High-resolution Scanning TEM (HRSTEM) Imaging

HRTEM vs HRSTEM Imaging







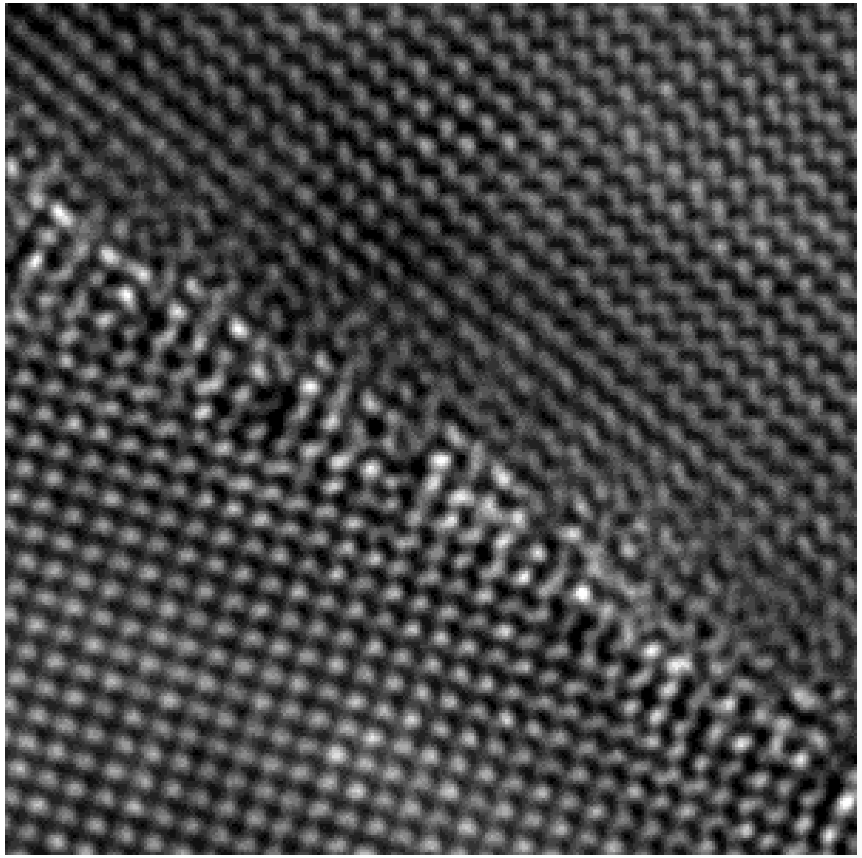
Si_3N_4 structure model

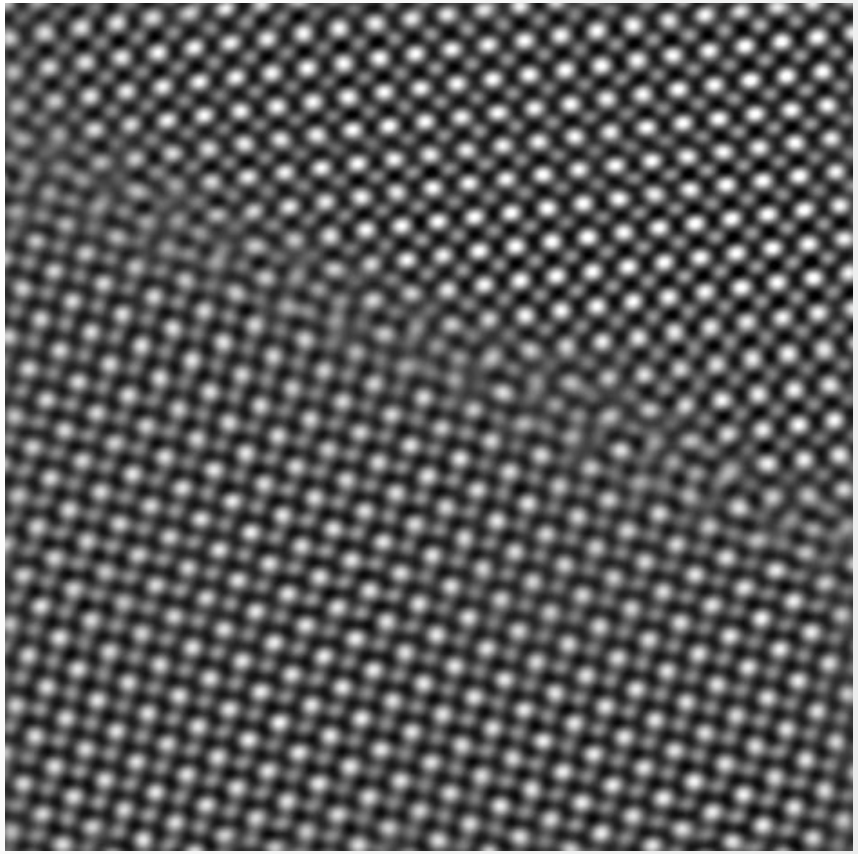
HRTEM and HR-STEM images showing the atomic structure of Si_3Ni_4

High-resolution Scanning TEM (HRSTEM) Imaging

HRTEM and HRSTEM images from the same $SrTiO_3$ bi-crystal boundary

HRTEM





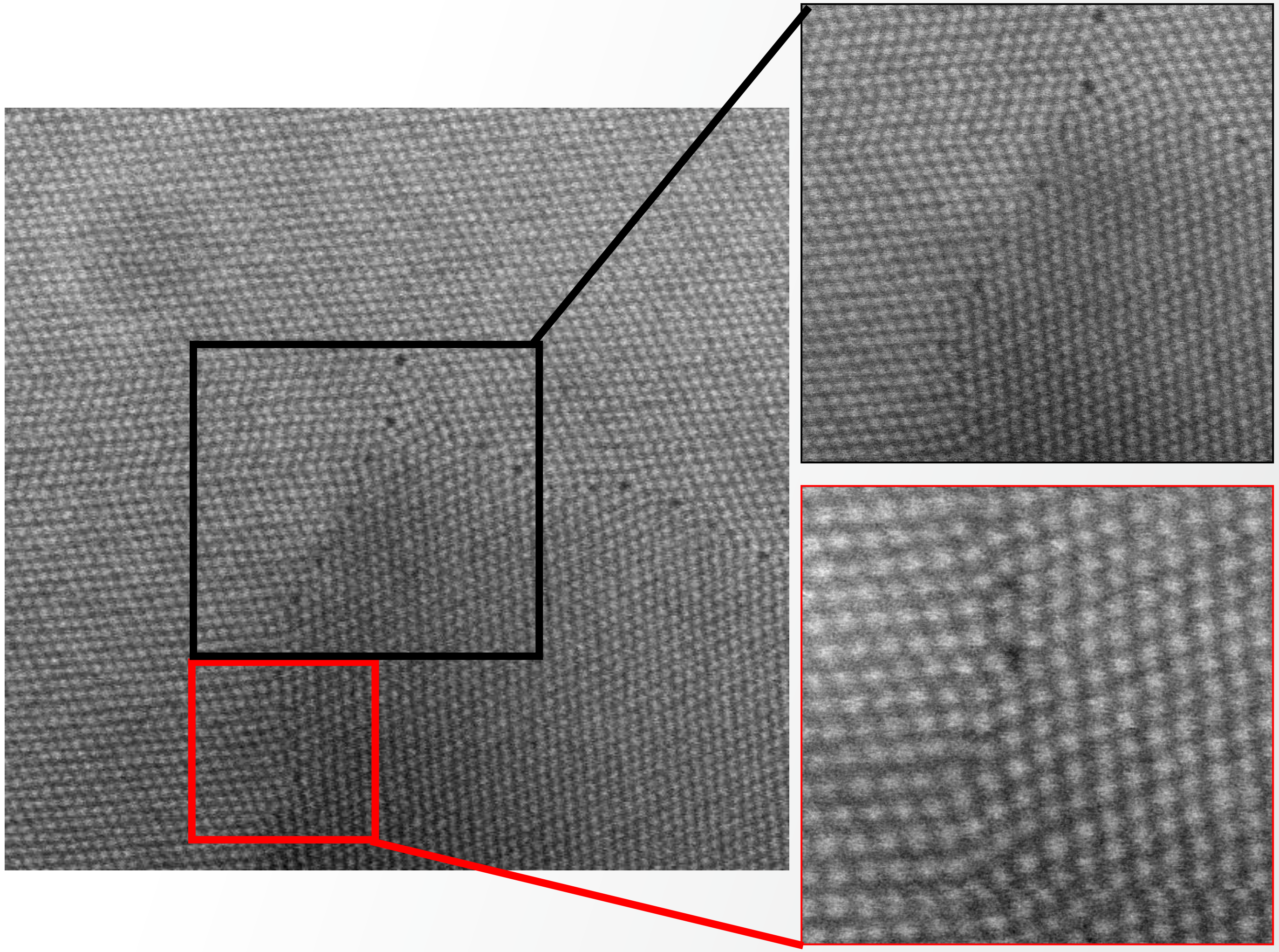
HRSTEM

mohamadriza.iskandar@thermofisher.com

High-resolution Scanning TEM (HRSTEM) Imaging

Point Defects investigation

High Resolution ADF STEM image of a triple-junction in Au poly-crystal. Numerous voids occur at defects at the interface.



Sample courtesy of Dr. T. Radetic, U.Dahmen & C. Kisielowski, NCEM Berkeley, USA

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Differential Phase Contrast Imaging (DPC)

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An Old Non-Standard Imaging Methods in Electron Microscopy

416 OPTIK Vol. 39 (No. 4) 416–436 (1974)

Phase Contrast in Scanning Transmission Electron Microscopy[1]

By *H. Rose*
The Enrico Fermi Institute, The University of Chicago[2]

Received 17 July 1973, in final form 23 July 1973

Abstract

A new phase contrast technique is proposed for the scanning transmission electron microscope (STEM) which significantly lowers the radiation damage in the case of very high resolution. The number of incident electrons per object element (dose) which is required to keep the quantum noise of the phase contrast image below a certain level is at most four times higher for the STEM than for the conventional electron microscope (CEM). The phase contrast images recorded by the STEM show fewer artifacts than those produced by a CEM using parallel illumination. Due to the conical illumination in the STEM only atoms lying in a thin layer of the specimen will show up with significant contrast. Therefore, the STEM is especially appropriate for the detection of single atoms in relatively thick molecules. To get the same images in a CEM, hollow beam illumination must be applied which requires a dose equivalent to that of the STEM.

J. Phys. D: Appl. Phys., 17 (1984) 623–647. Printed in Great Britain

REVIEW ARTICLE

The investigation of magnetic domain structures in thin foils by electron microscopy

J N Chapman
Department of Natural Philosophy, University of Glasgow, Glasgow G12 8QQ UK

Received 23 September 1983

Abstract. Magnetic domain structures in thin foils may be revealed in a number of ways in the transmission electron microscope. The most commonly used modes (Fresnel, Foucault, holographic, differential phase contrast and low angle diffraction) are described and inter-compared. The Fresnel and Foucault modes are simple to implement but provide a mainly qualitative description of the spatial variation of induction throughout the foil. Quantitative information may be obtained from the other two imaging modes but they require more sophisticated equipment. Electron diffraction is particularly useful for studying periodic magnetic structures. Examples of the use of these, and further specialised techniques, are presented by reference to some applications of current interest within magnetism.

452 OPTIK Vol. 41 (No. 4) 452–456 (1974)

Short Note

Differential Phase Contrast in a STEM

By *N. H. Dekkers* and *H. de Lang*
Philips Research Laboratories Eindhoven-The Netherlands

Received 10 September 1974

Abstract

A detection method providing differential phase contrast in a STEM is introduced. The modulation transfer function is discussed together with the influence of the spatial coherence of the illumination.

Ultramicroscopy 2 (1977) 251–267
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NONSTANDARD IMAGING METHODS IN ELECTRON MICROSCOPY *

H. ROSE
Division of Laboratories and Research, New York State Department of Health, Albany, NY 12201, U.S.A.

Received 7 January 1977

A rigorous treatment of image formation, taking into account inelastic scattering and partially coherent illumination, is given for the CTEM. The results also hold for a STEM if the momentum vectors of the incident and outgoing waves are interchanged and the flight direction of the electrons is reversed. A generalized optical theorem is found which connects the anti-Friedel part of the elastic scattering amplitude with the squares of the elastic *and* inelastic scattering amplitudes. This theorem has important consequences for all approximation methods. For example, it shows that inelastic scattering influences the elastic scattering amplitude.

It is further shown that the observed wings in optical diffractograms, obtained from micrographs of amorphous material taken using tilted beam illumination, can only be explained if double scattering (elastic and inelastic) is assumed.

Hollow-cone illumination strongly suppresses the structural noise in the phase contrast image. The corresponding phase contrast transfer function (PCTF) is calculated for two different cone angles, assuming that no beam-limiting aperture is present. In addition, the PCTFs of a corrected microscope are calculated for two different illumination modes, one yielding negative and the other positive phase contrast. Finally, the contrast transfer has been investigated for a STEM operating with a split detector.

Differential Phase Contrast Imaging (DPC)

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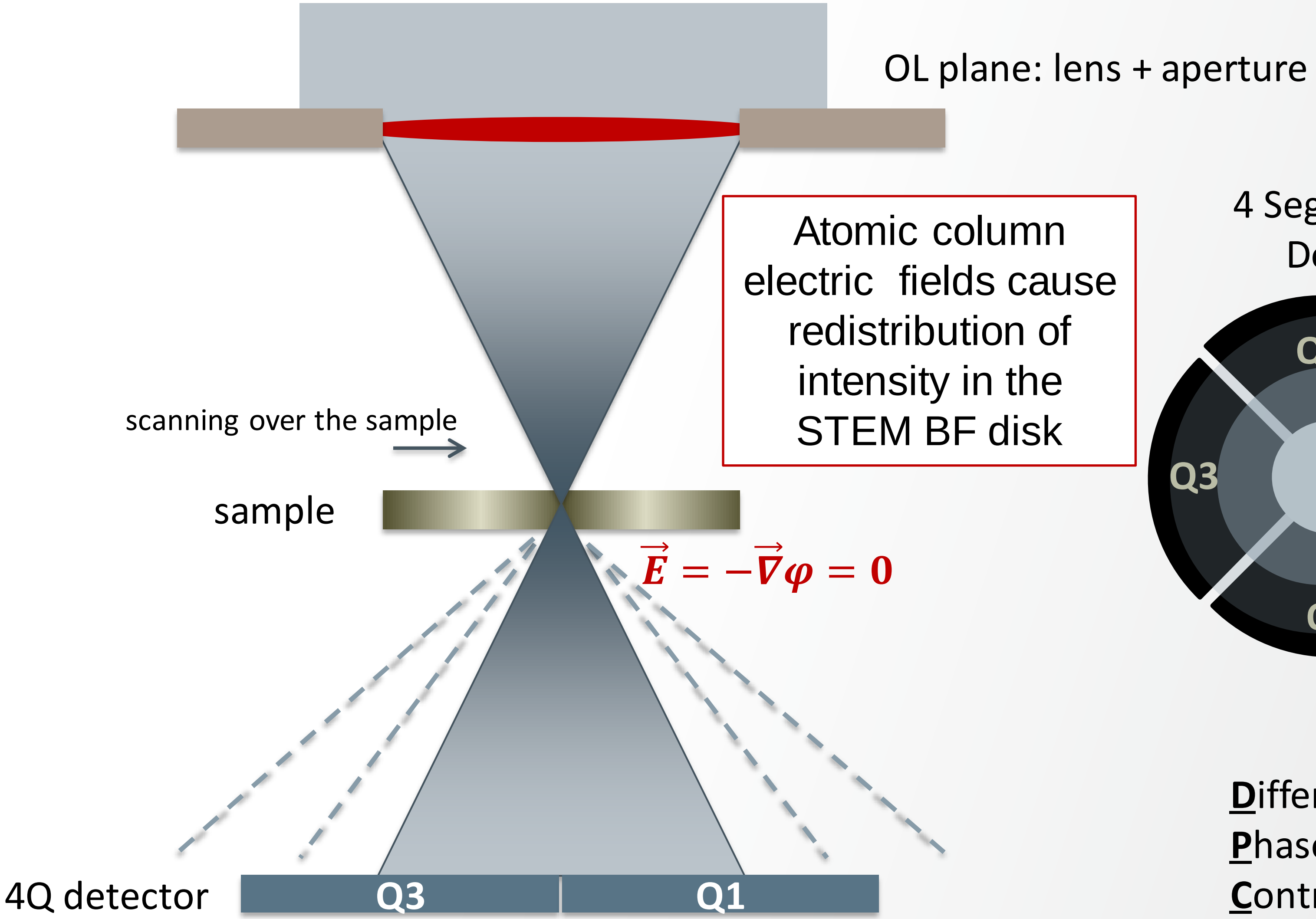
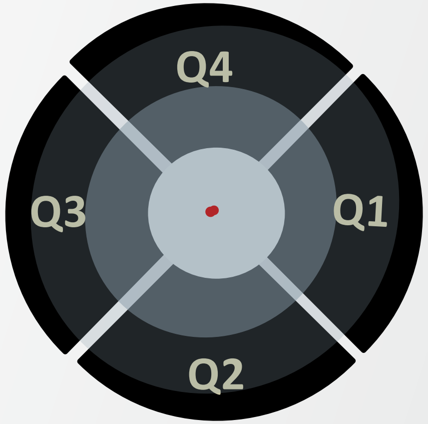
DPC Detector Configuration



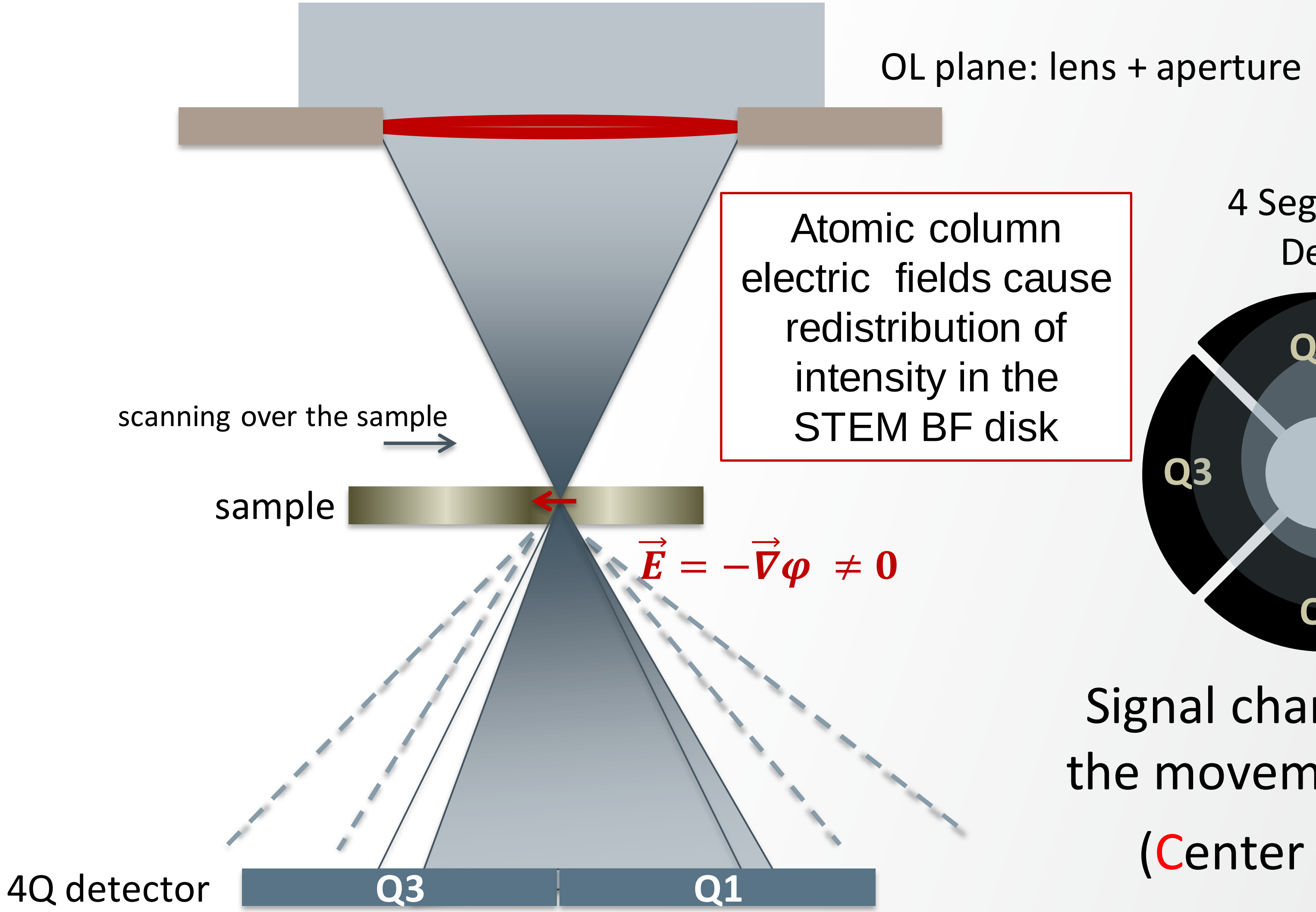
4 Segment DF4 Detector



Differential
Phase
Contrast

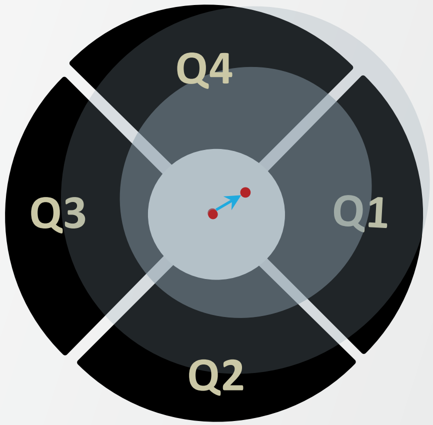
Differential Phase Contrast Imaging (DPC)

DPC Detector Configuration



Atomic column electric fields cause redistribution of intensity in the STEM BF disk

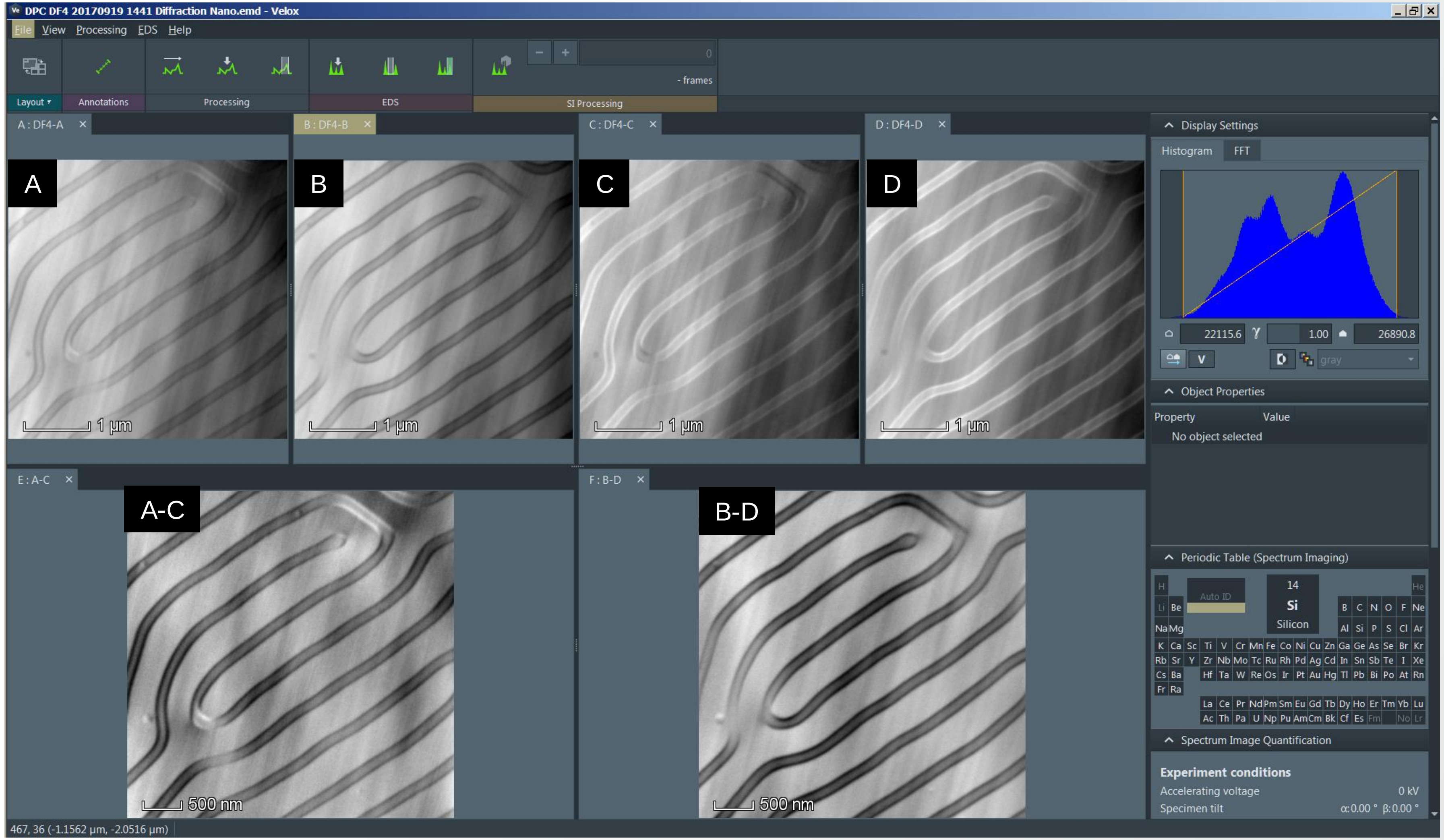
4 Segment DF4 Detector



Signal changes due to the movement of CBED (Center Of Mass)

Differential Phase Contrast Imaging (DPC)

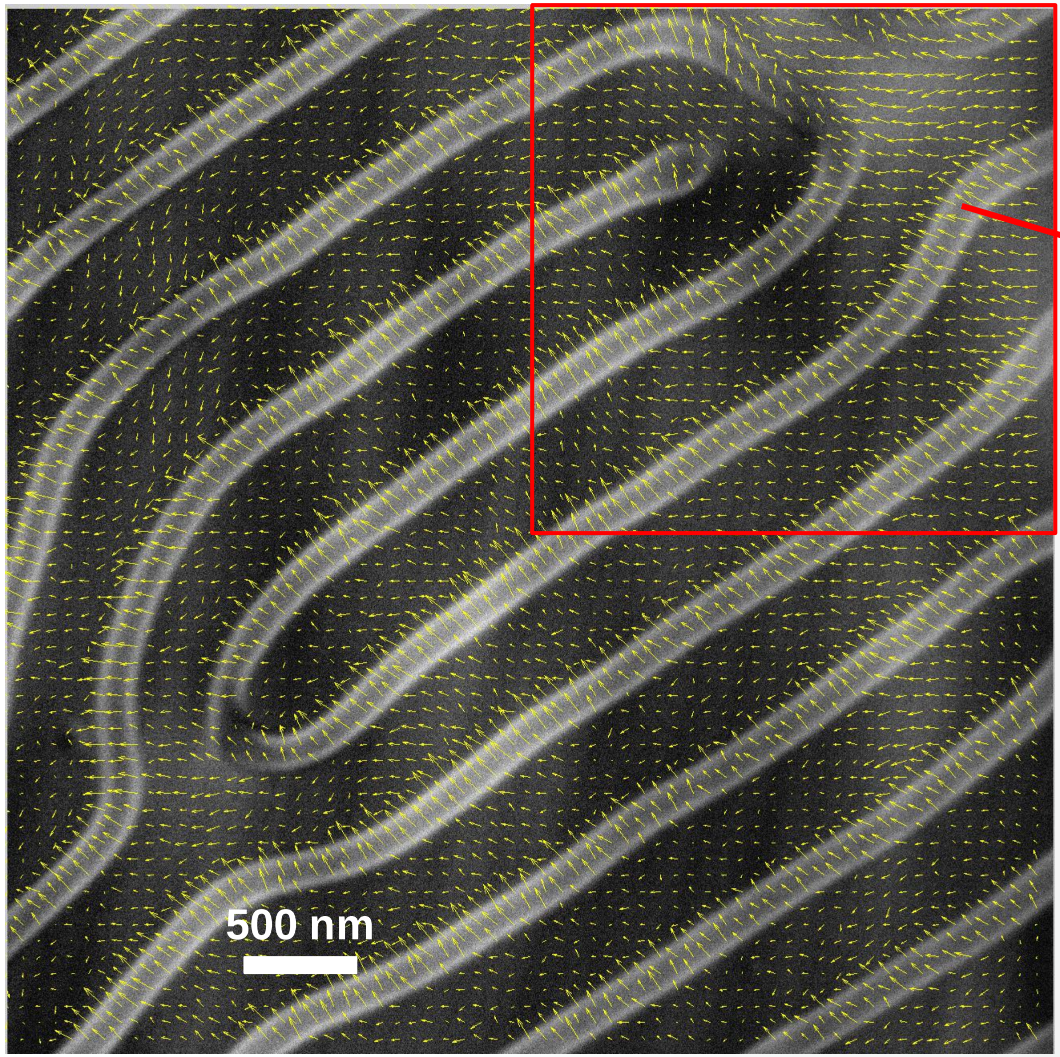
DPC Imaging of Ferrite

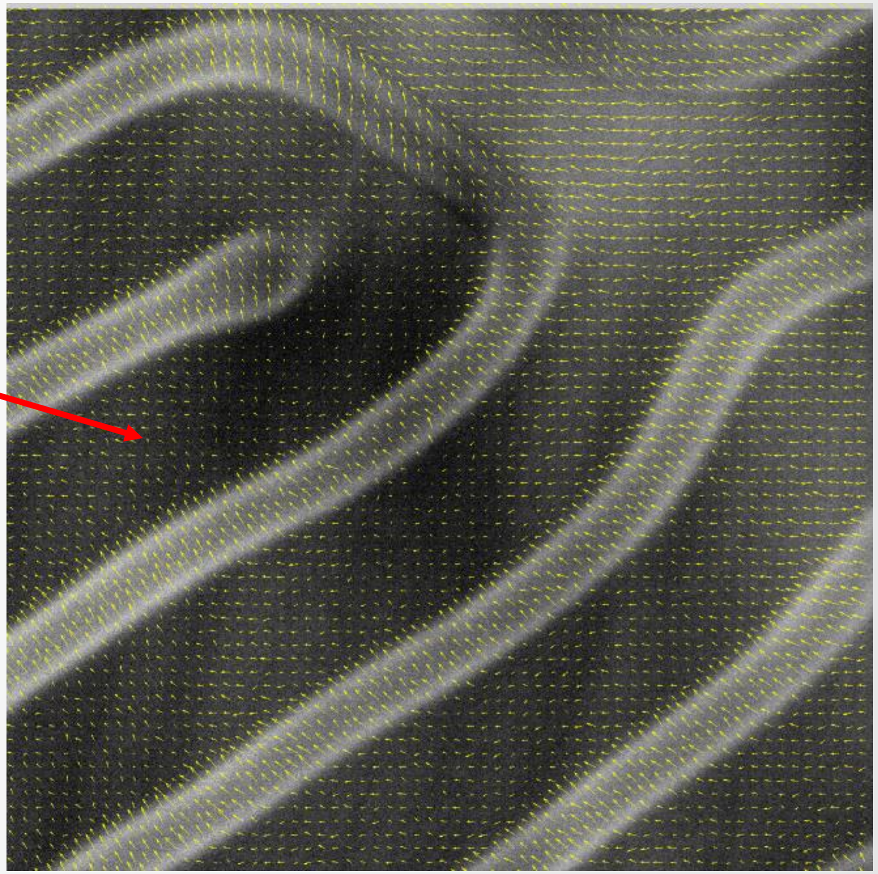


Sample Courtesy: H. Nakajima and S. Mori, Osaka Prefecture University

Differential Phase Contrast Imaging (DPC)

DPC of Ferrite Magnetic Field

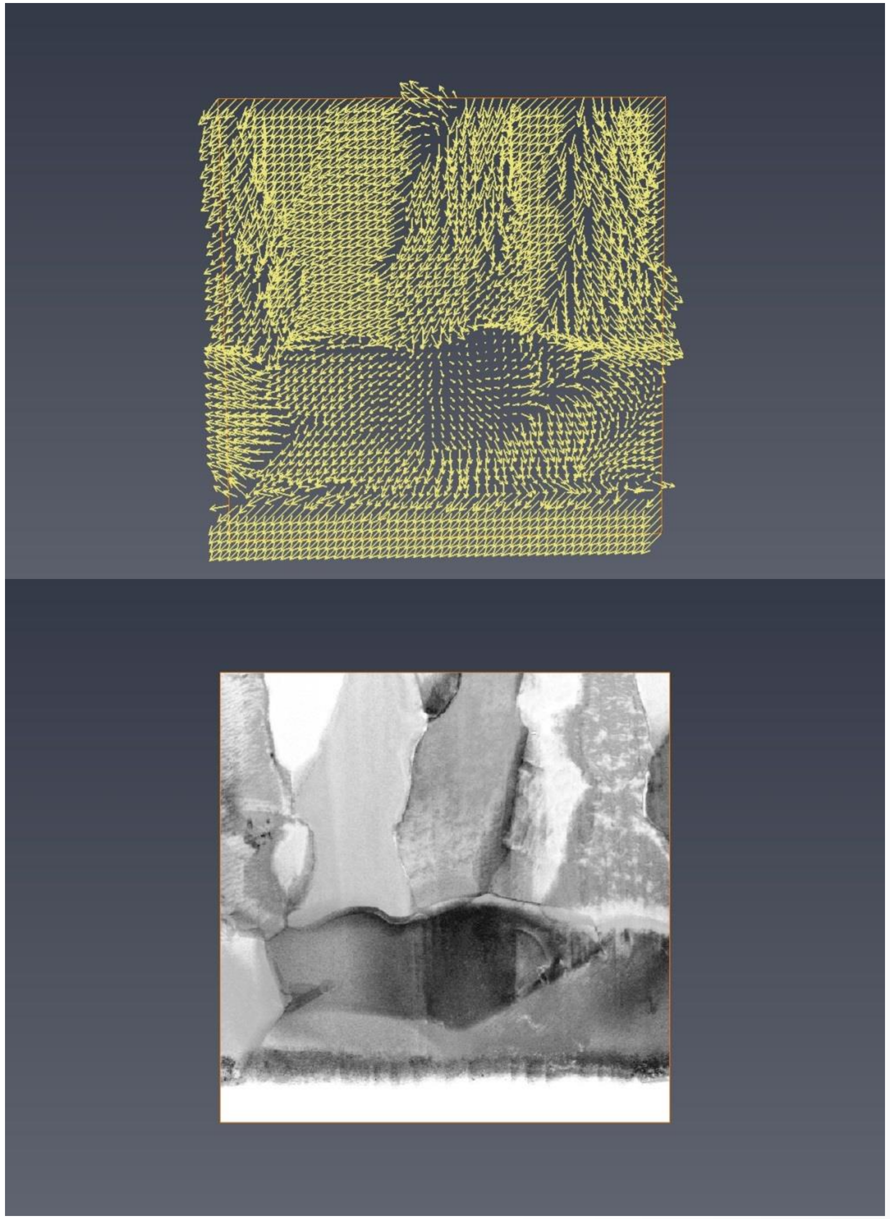




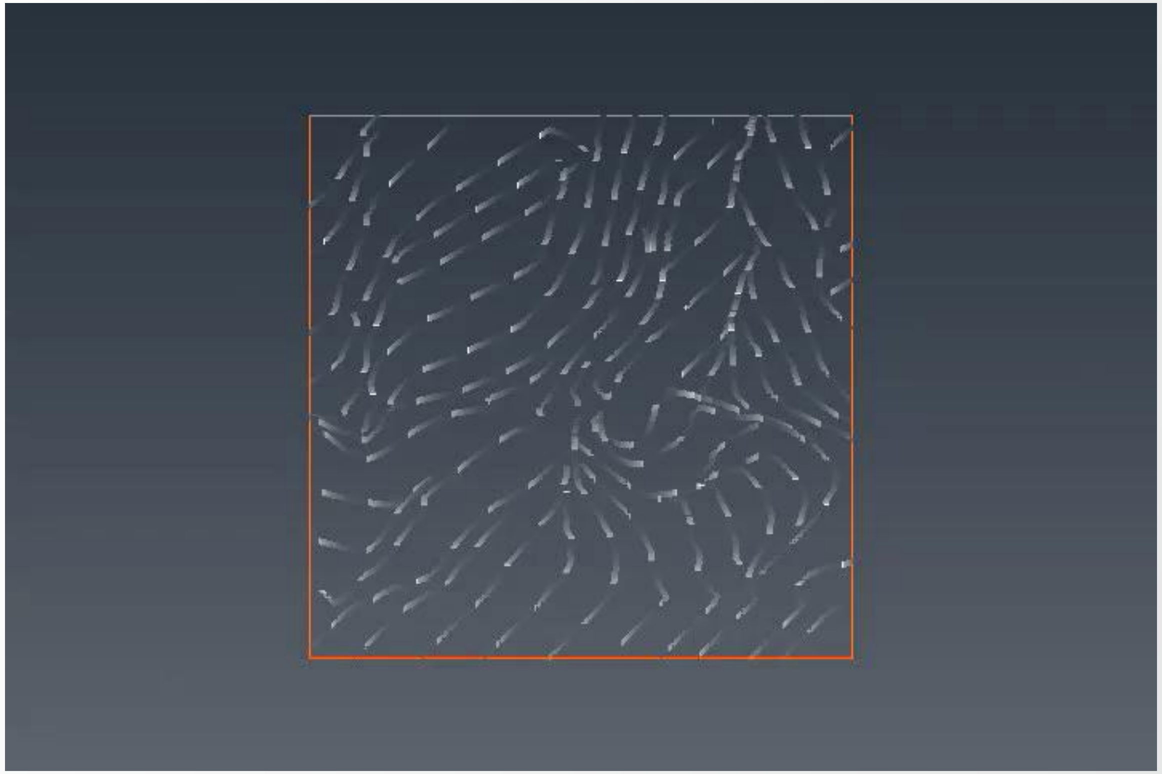
4 Segment DF4 Detector

Sample Courtesy: H. Nakajima and S. Mori, Osaka Prefecture University

Differential Phase Contrast Imaging (DPC)

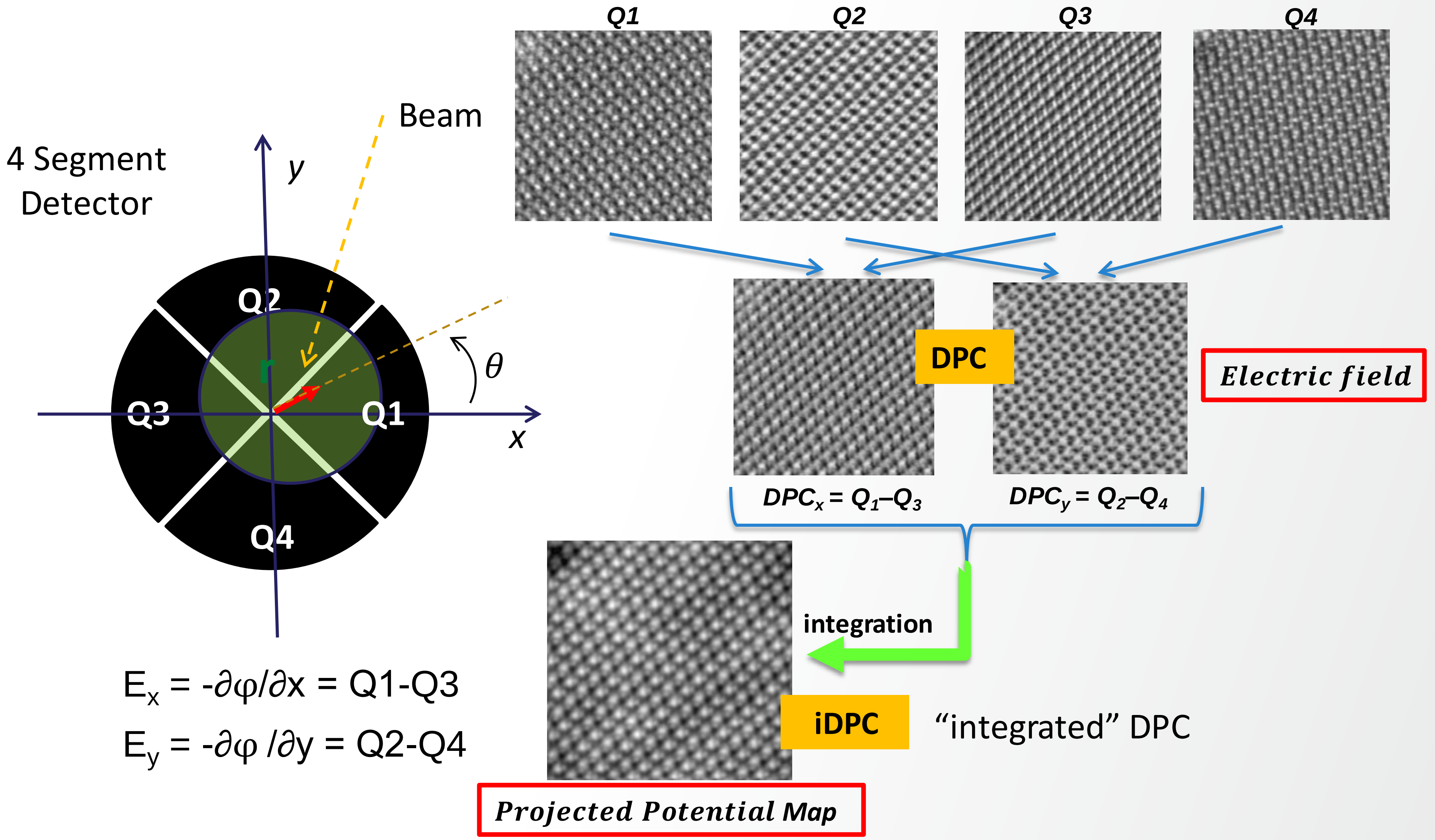


Magnetic Field of Fe_2O_3 Thin Film



Integrated Differential Phase Contrast Imaging (iDPC)

GaN 11$\bar{2}$0 Experimental DPC and iDPC images – Light Element Imaging with iDPC STEM



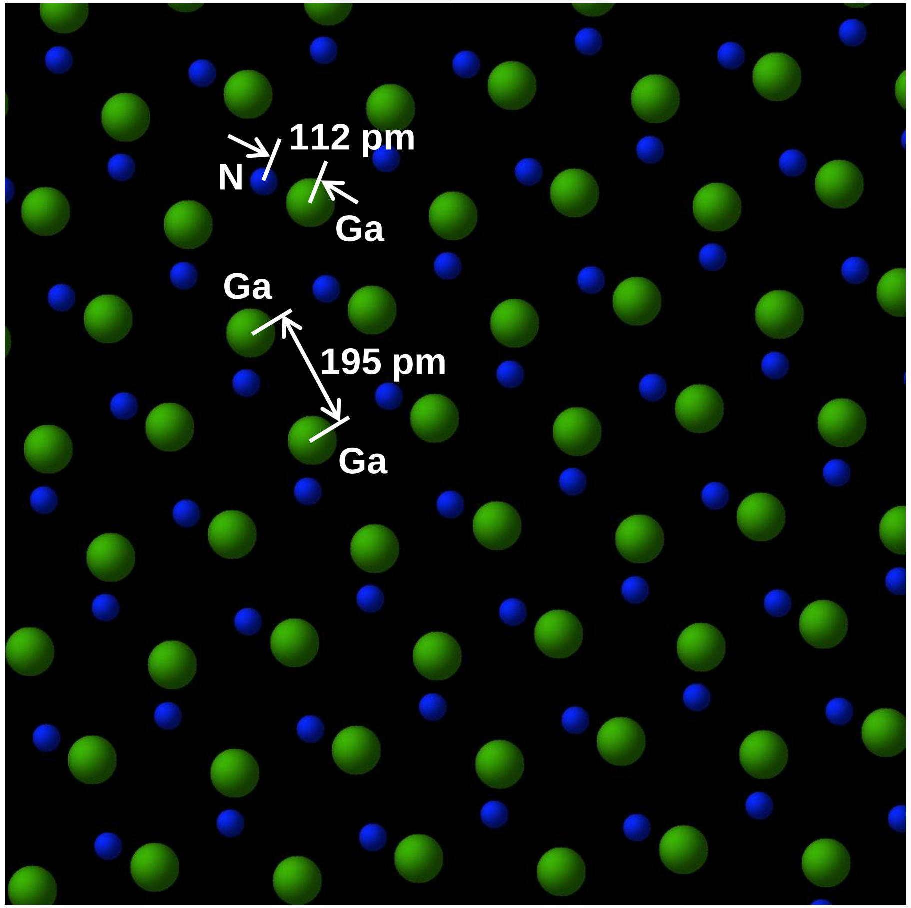
$E_x = -\partial\varphi/\partial x = Q1-Q3$

$E_y = -\partial\varphi/\partial y = Q2-Q4$

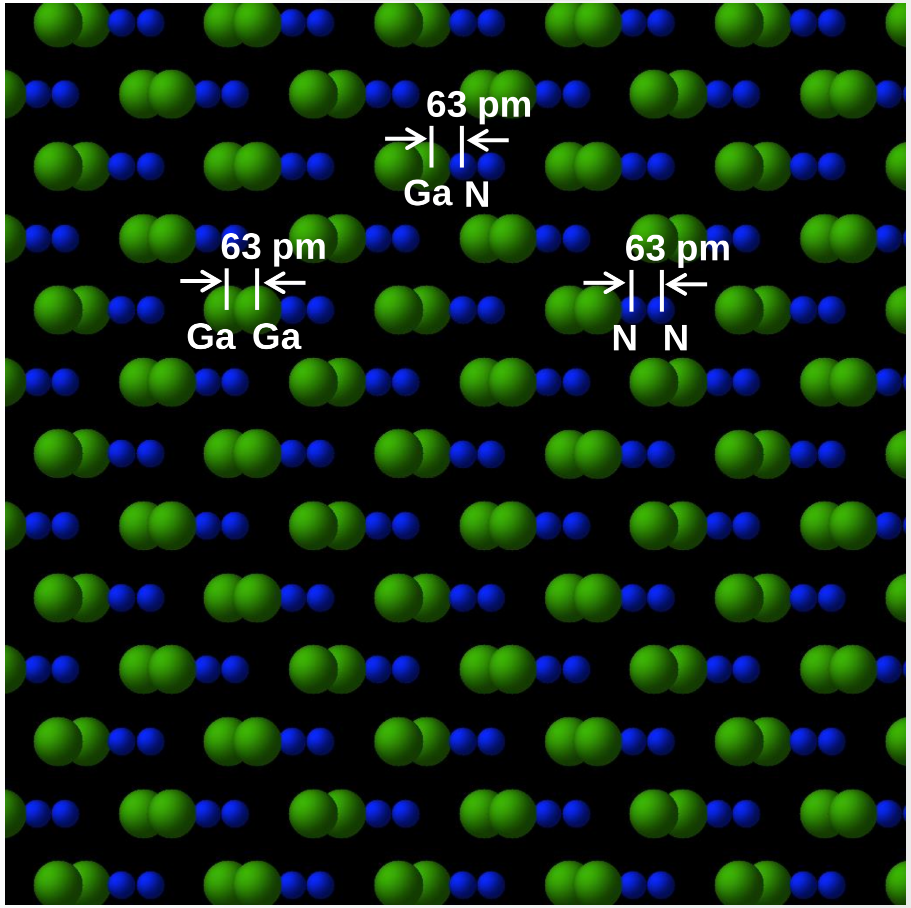
Integrated Differential Phase Contrast Imaging (iDPC)

GaN iDPC – Imaging

GaN [110]



GaN [211]



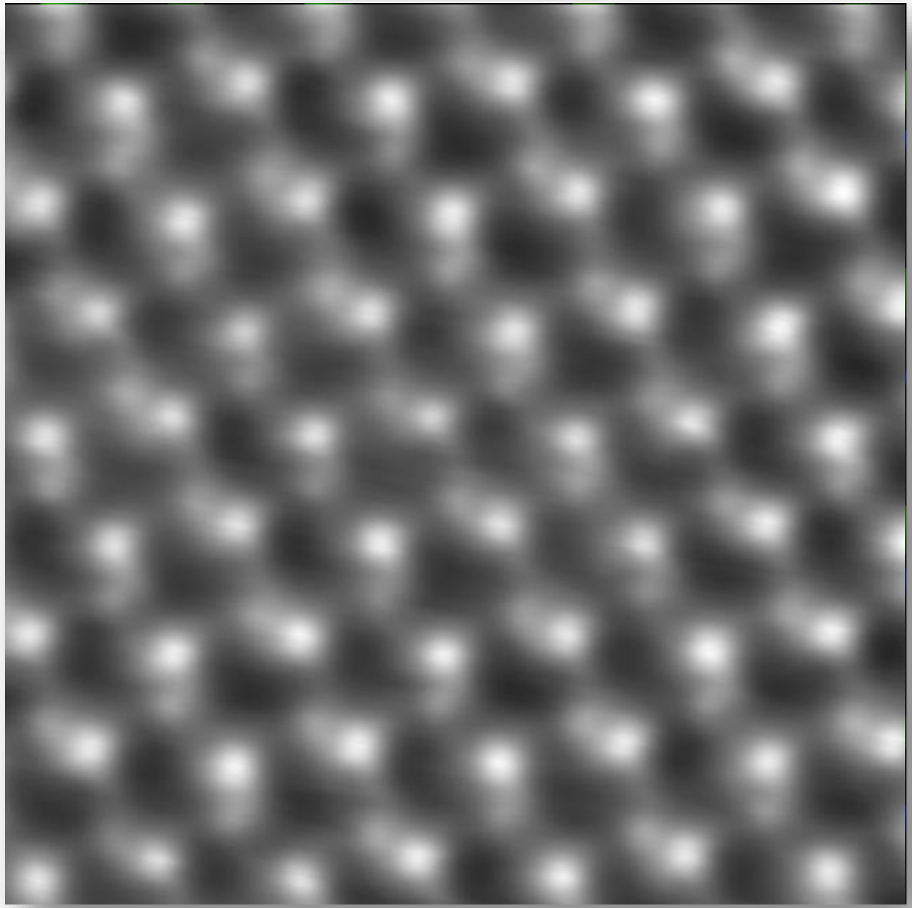
Images and Simulation: Emrah Yücelen

Integrated Differential Phase Contrast Imaging (iDPC)

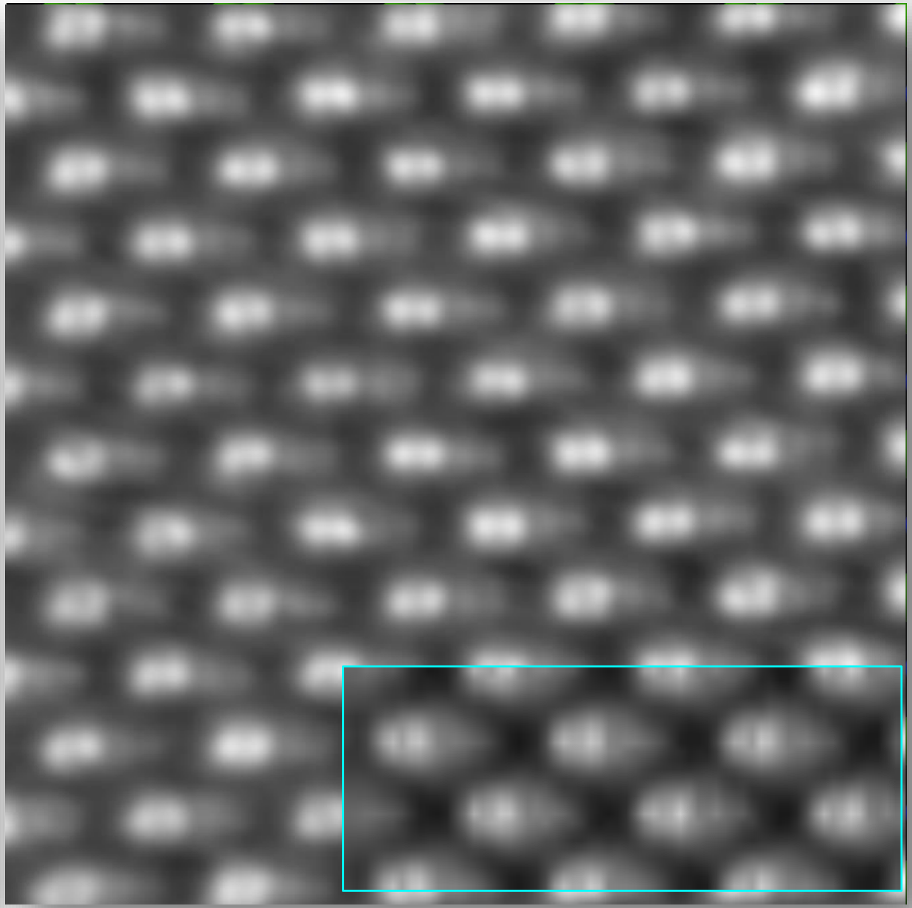
Thermo Fisher SCIENTIFIC

GaN iDPC – Imaging

GaN [110]



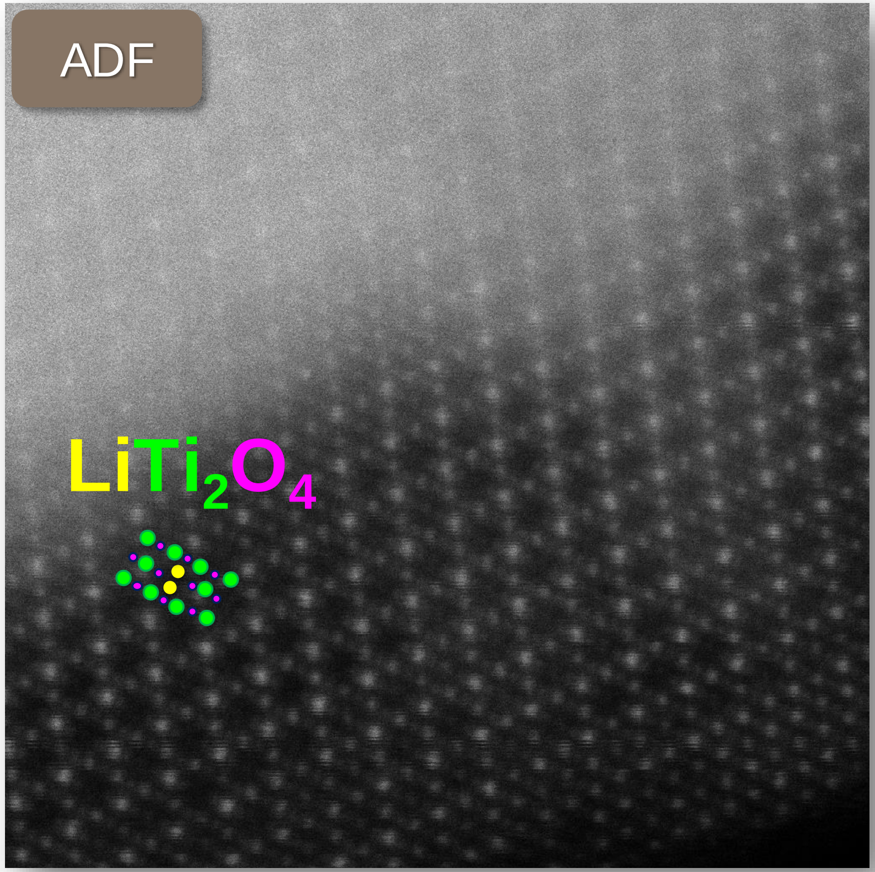
GaN [211]

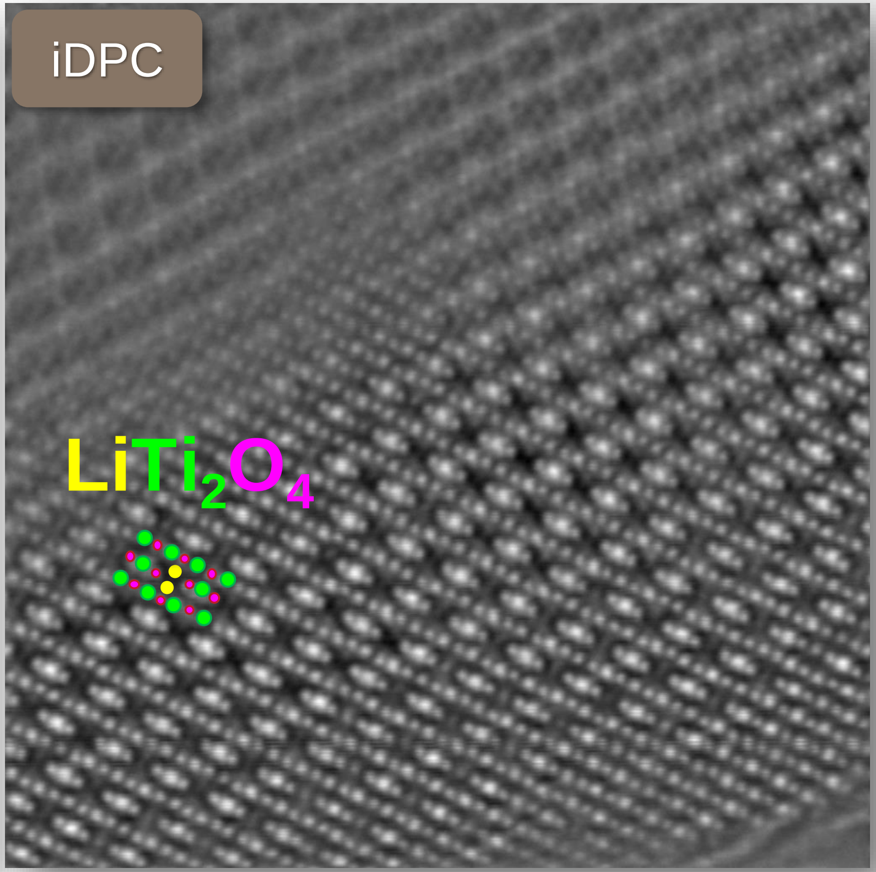


Images and Simulation: Emrah Yücelen

Integrated Differential Phase Contrast Imaging (iDPC)

iDPC for Light Element Imaging



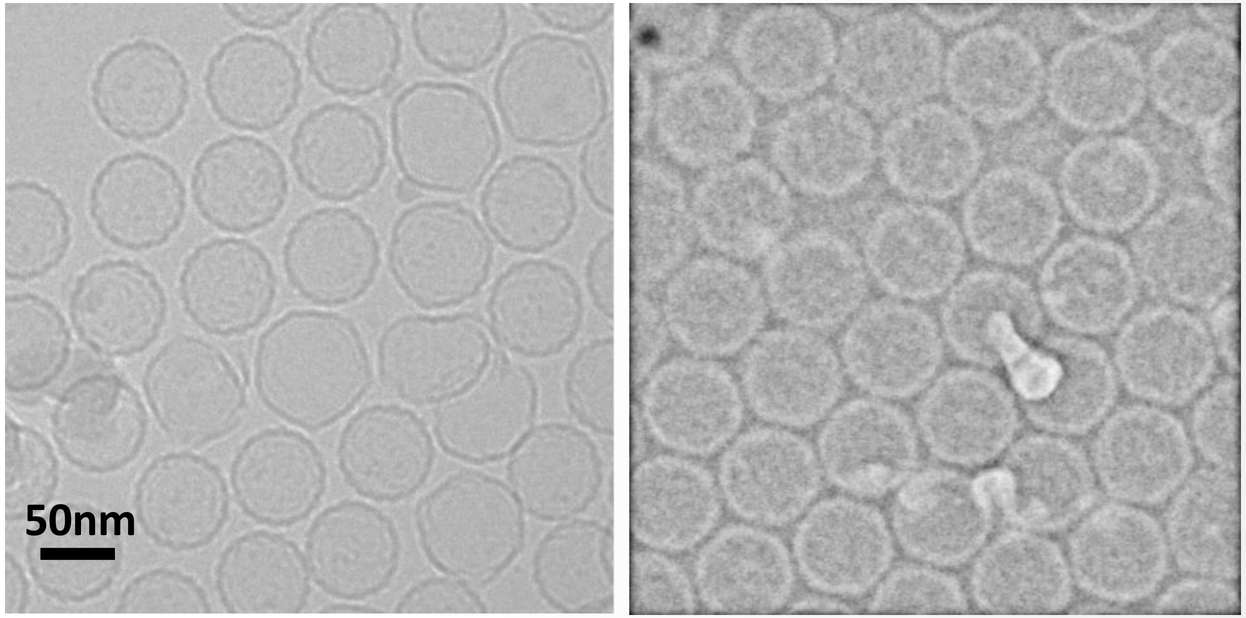


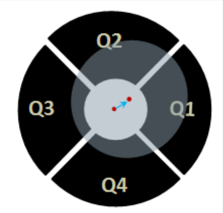
Images: Emrah Yücelen

Integrated Differential Phase Contrast Imaging (iDPC)

Low-Dose Cryo Imaging with iDPC – Virus Imaging on TEM and iDPC-STEM

TEM **iDPC-STEM**





Both images with dose ~ 100 e/Å^2

Courtesy: K. Sader, B. Buijsse
Phase Contrast STEM for thin samples: Integrated differential Phase Contrast
Ivan Lazic, Eric Bosh, and Sorin Lazar, Ultramicroscopy 160 (216) 265-280

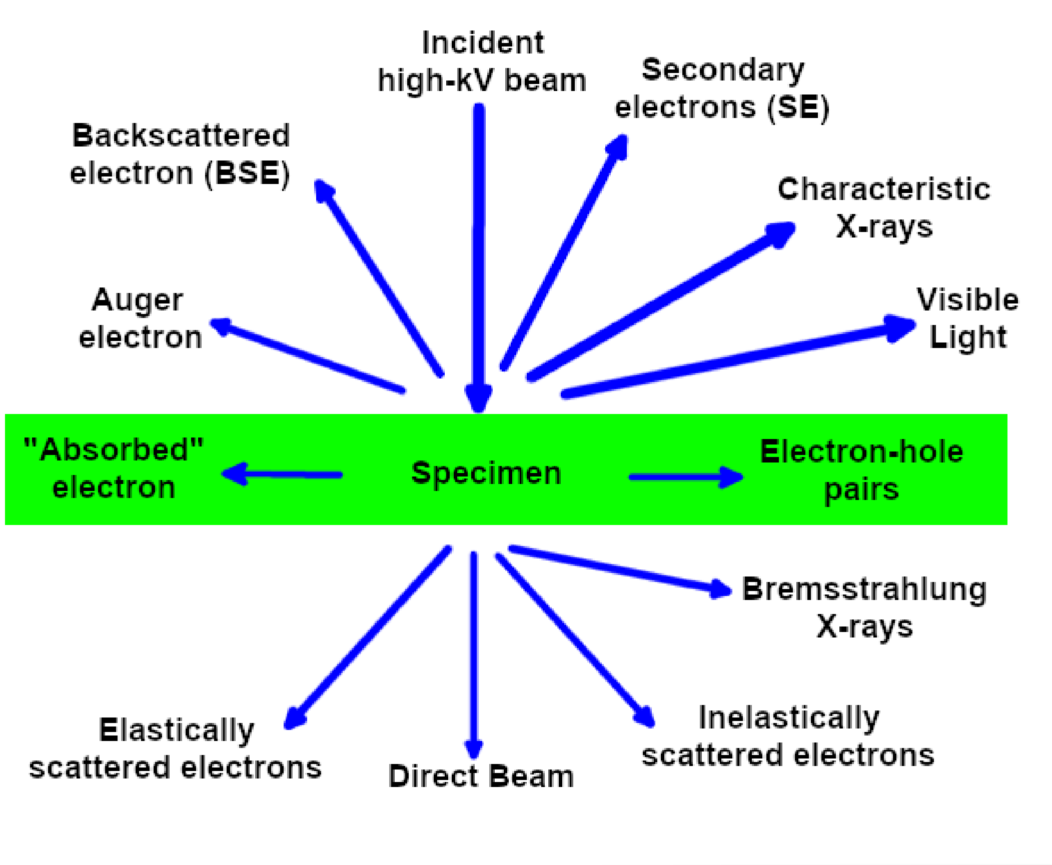
Transmission Electron Microscopy Webinar Series

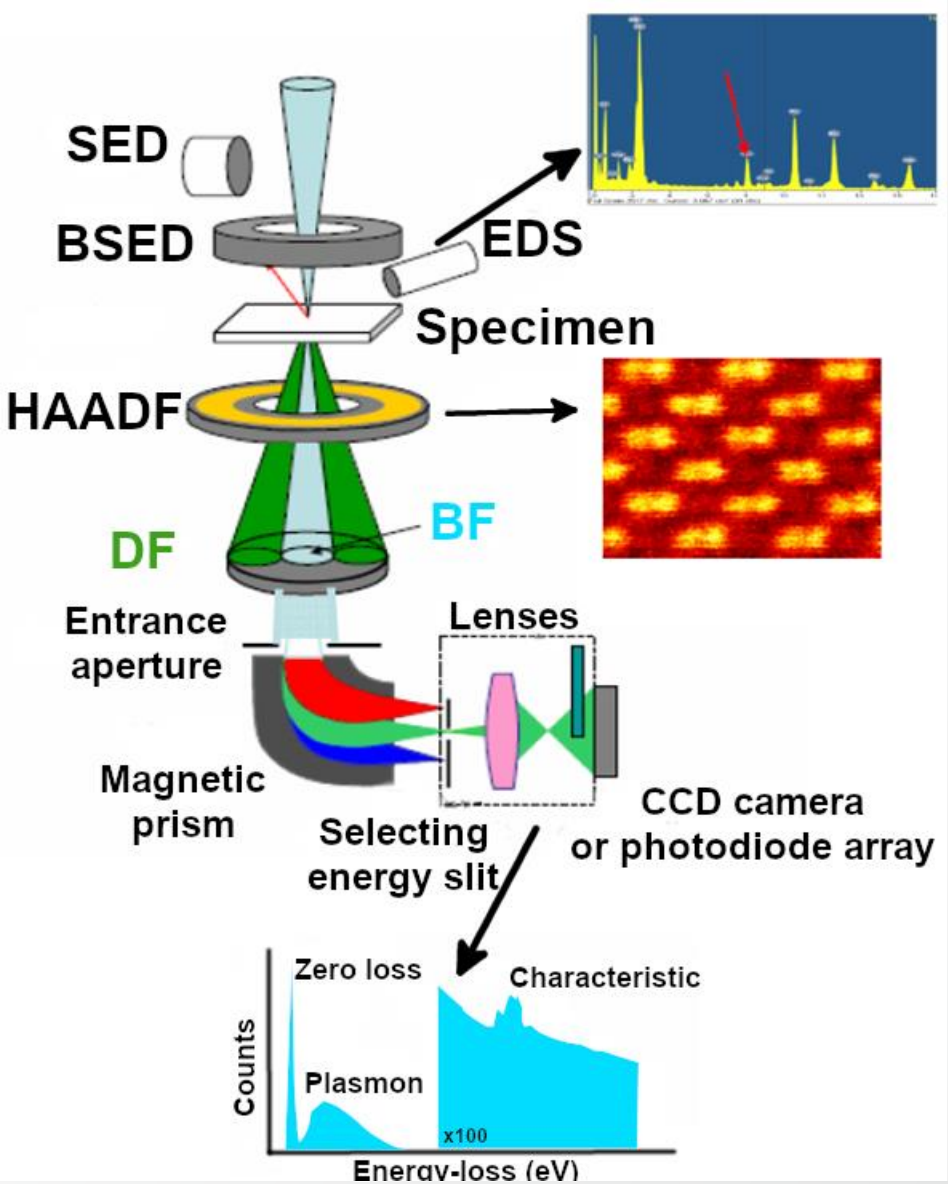
Outline: Part 02

- Scanning Transmission Electron Microscopy (STEM) - Introduction
- TEM and STEM comparisons
- Scanning Transmission Electron Microscopy (STEM) Imaging
- High-resolution Scanning TEM (HRSTEM) Imaging
- Differential Phase Contrast Imaging (DPC)
- Spectroscopy in TEM
  - Energy-Dispersive X-Rays Spectroscopy
  - Electron Energy Loss Spectroscopy
- Tomography in TEM: For 2D to 3D Imaging

Spectroscopy in TEM

Signal Produced during Electron – Sample Interactions

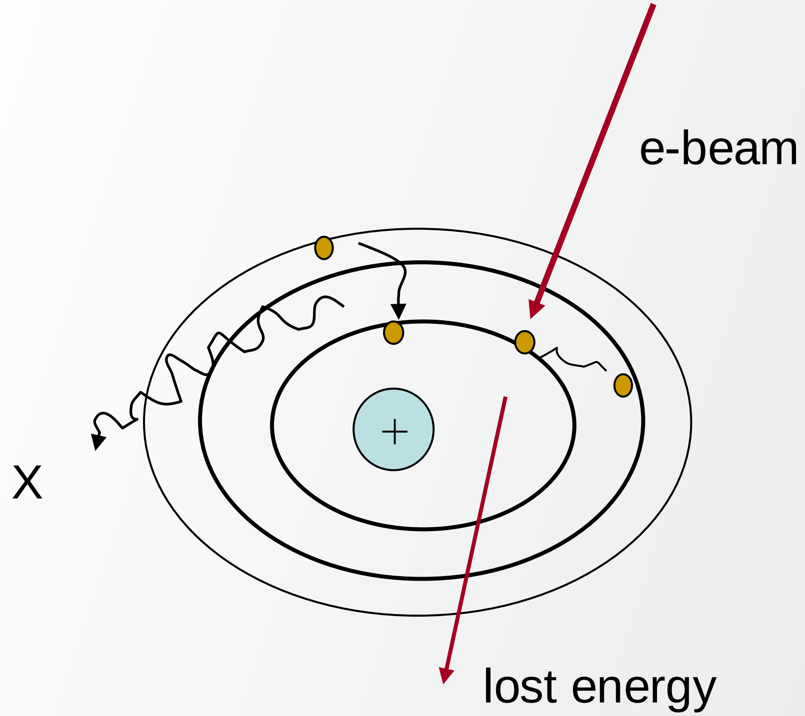




Spectroscopy in TEM

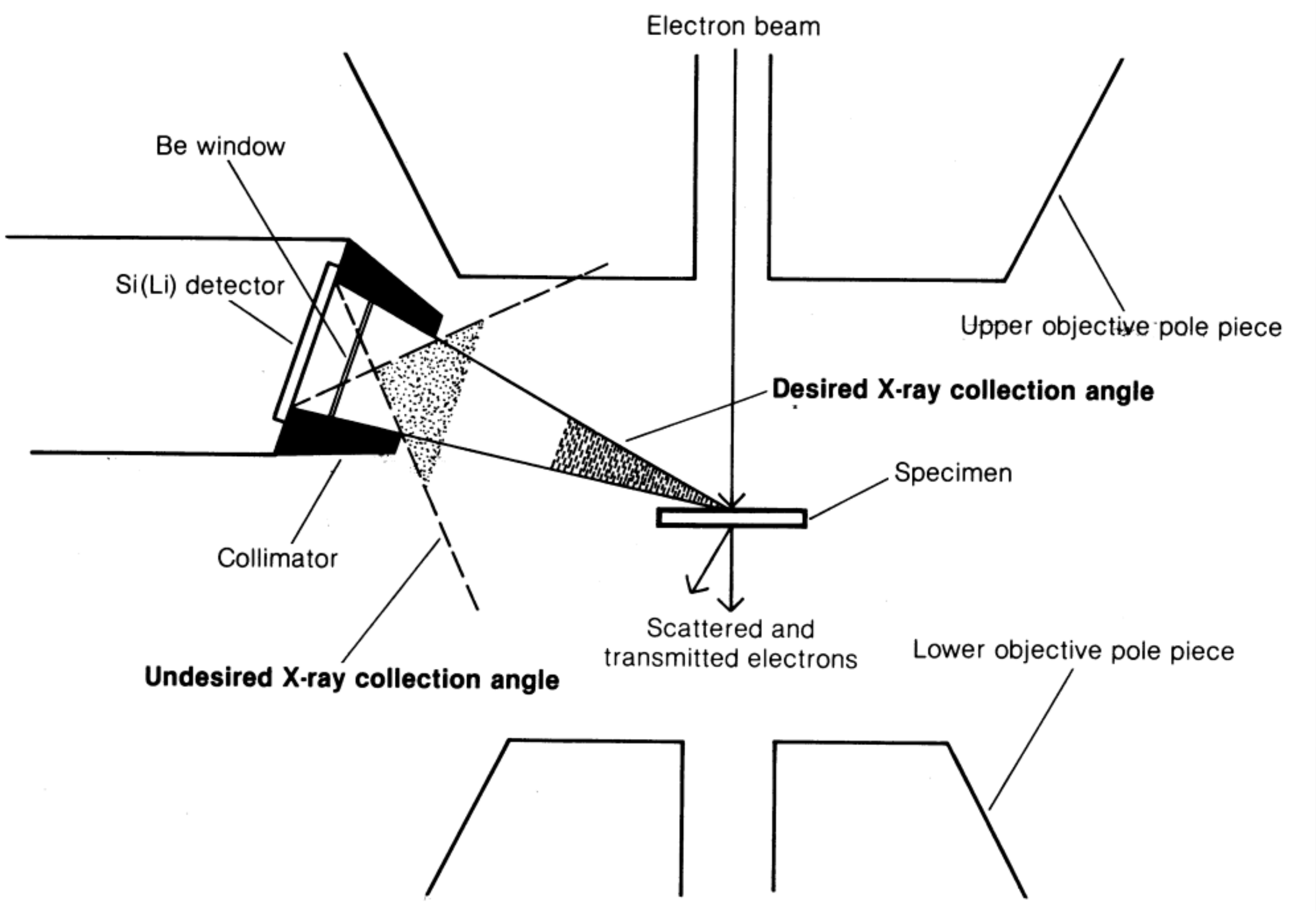
Spectroscopy: Inelastic Effects

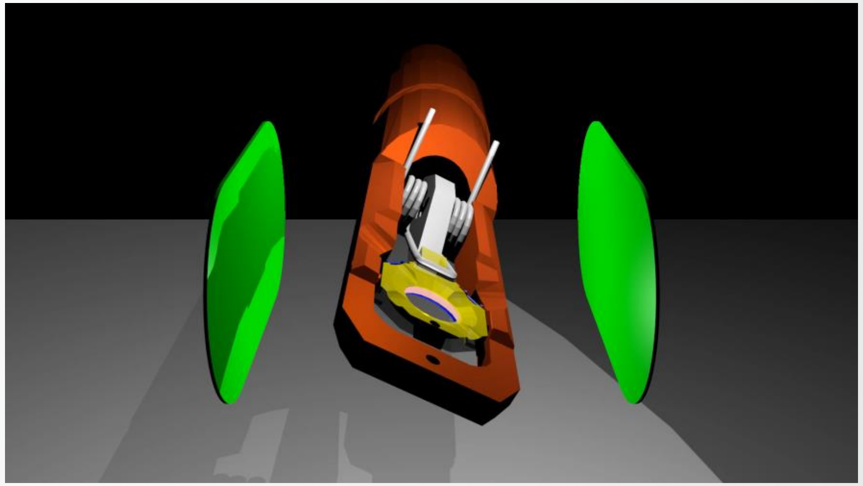
- Energy Dispersive X-ray Analysis (EDS)
  - Detecting X-rays from excited atoms
    - Chemical Information
    - Heavy Elements
    - 120 eV resolution, 0-2 keV range
- Electron Energy Loss Spectroscopy (EELS)
  - Measuring Energy Loss of Primary Electrons
    - Chemical Information
    - Electronic Information
    - Light Elements
    - 1 eV resolution, 0 – 2 keV range

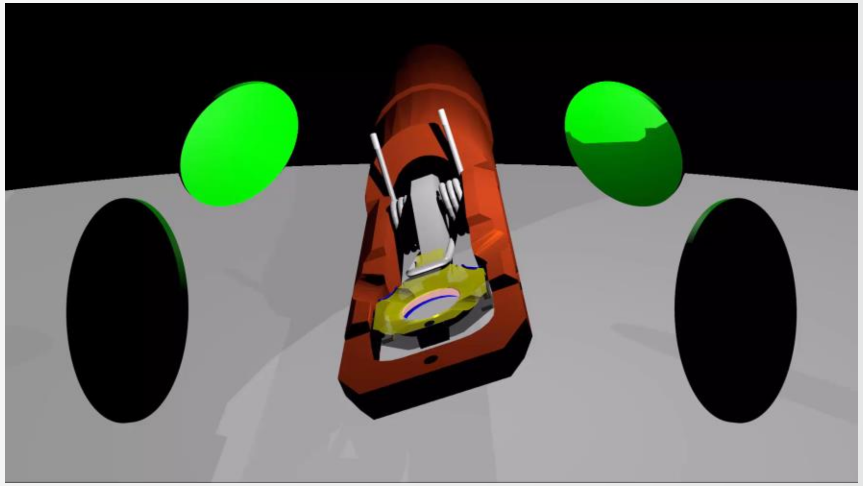


Spectroscopy in TEM - EDS

Energy Dispersive X-Rays Spectroscopy in TEM: EDS Setup

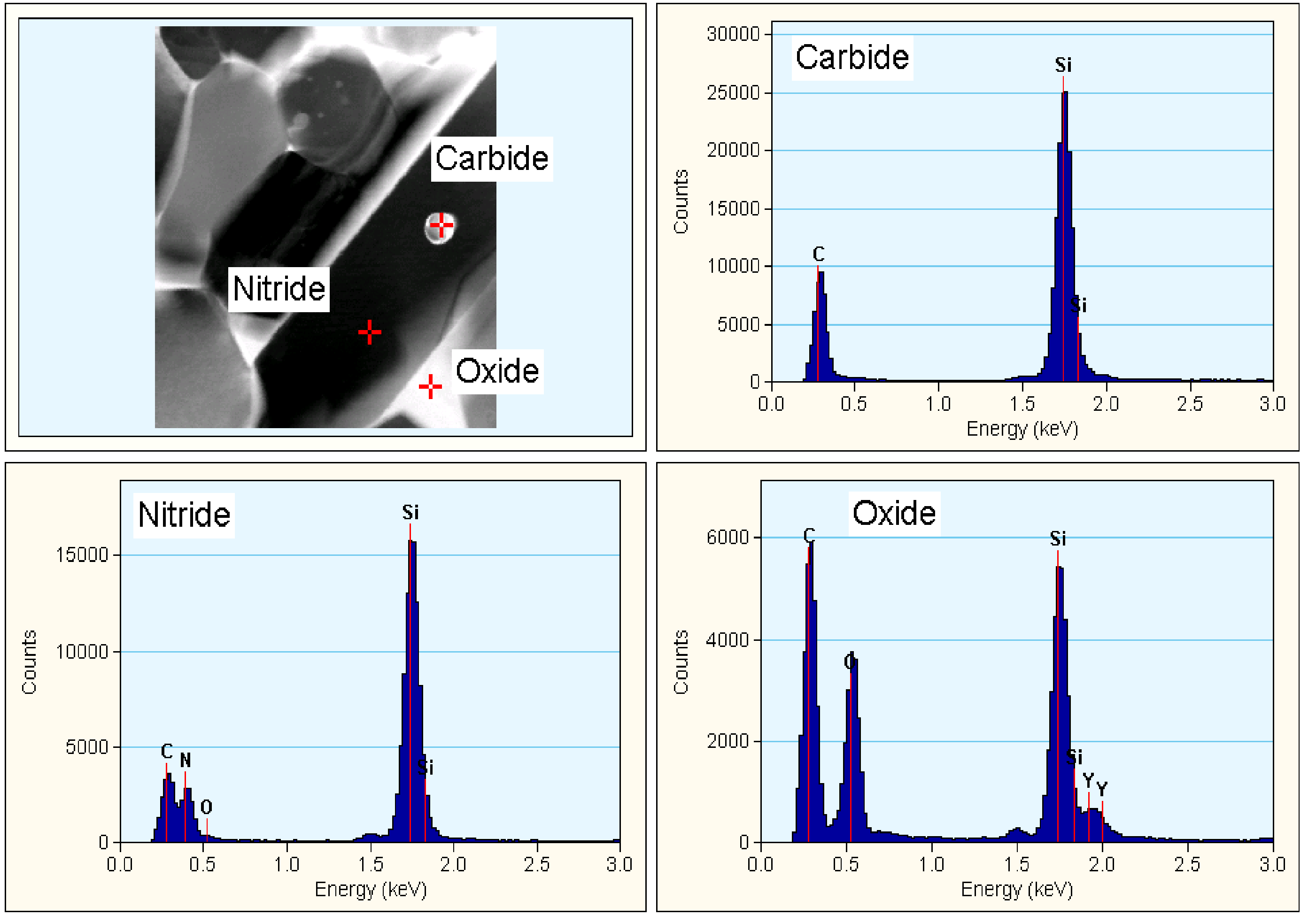






Spectroscopy in TEM - EDS

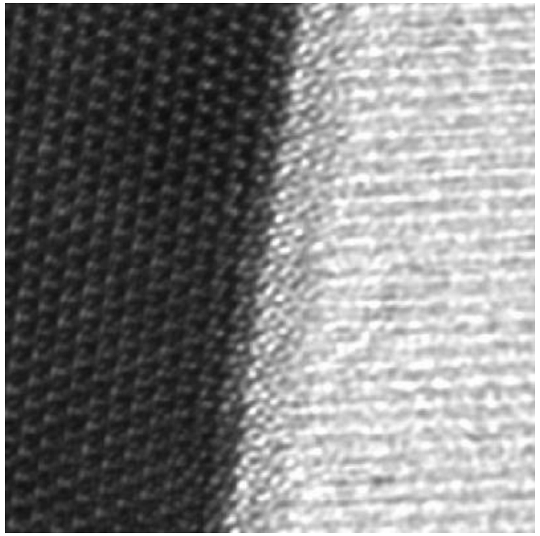
STEM and EDS Analysis: Spot Analysis

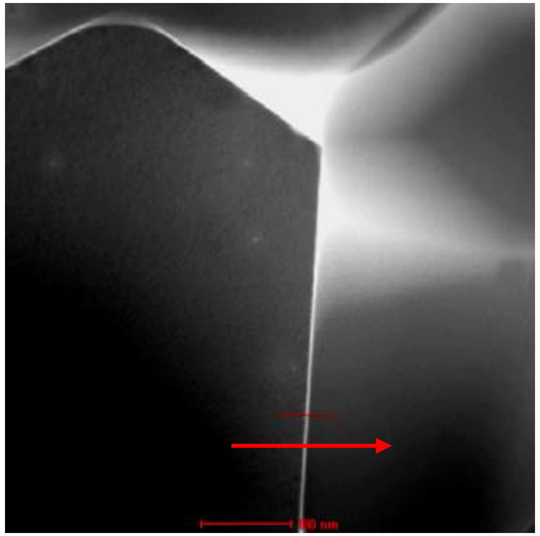


Spectroscopy in TEM - EDS

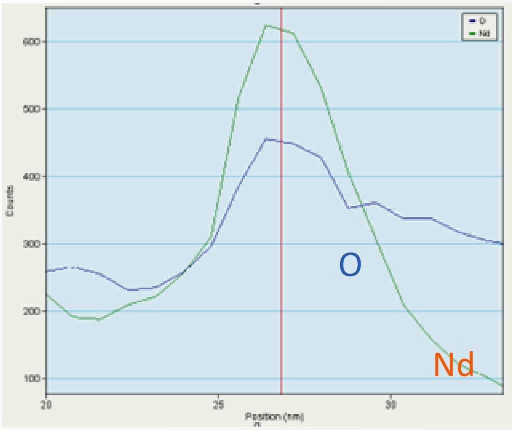
STEM and EDS Analysis: Spectrum Profiling (Line Scan)

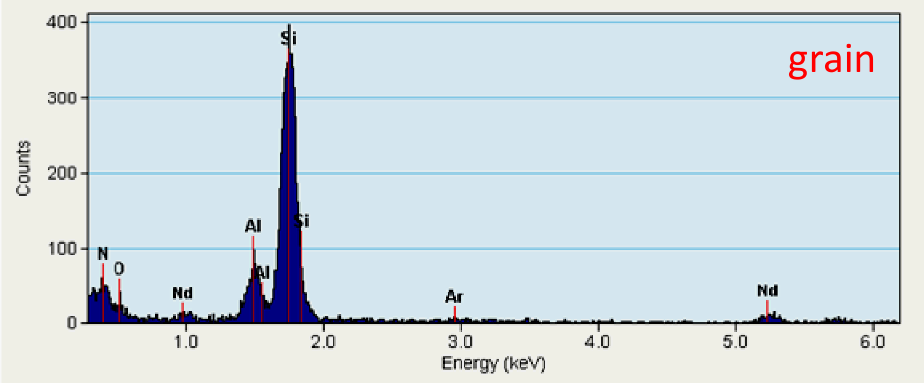
Spectrum profile across a grain boundary in a SiAlON ceramic.
The Nd bearing amorphous grain boundary is about 2 nm wide.

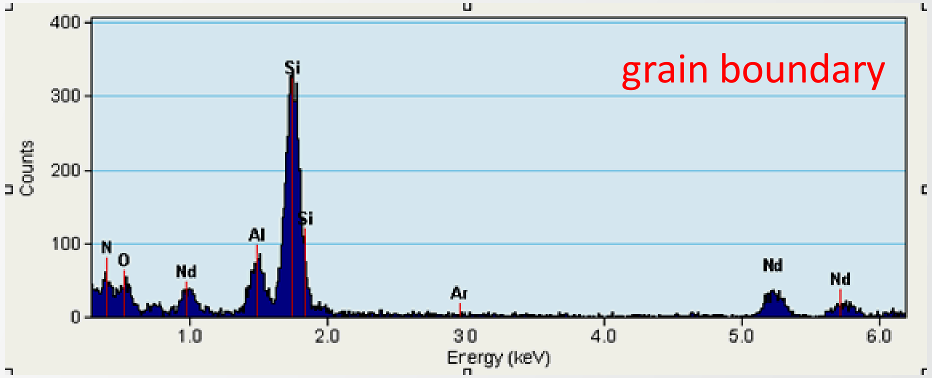




Tecnai F20 S-TWIN



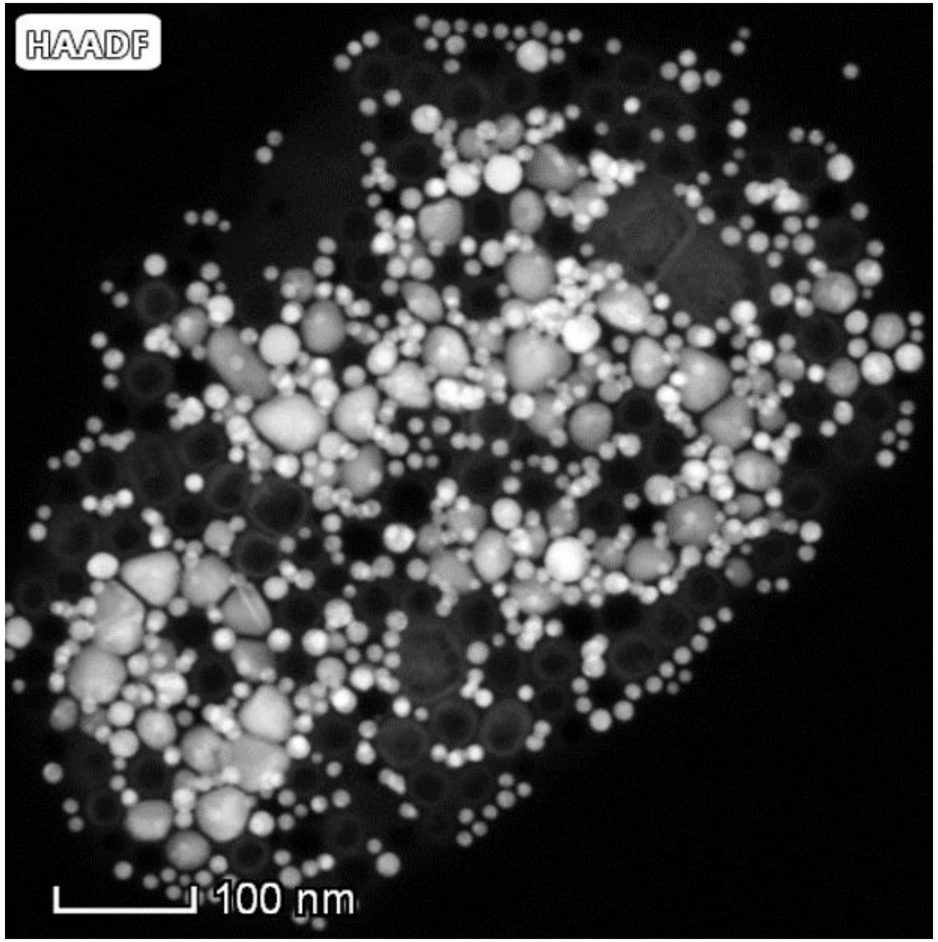


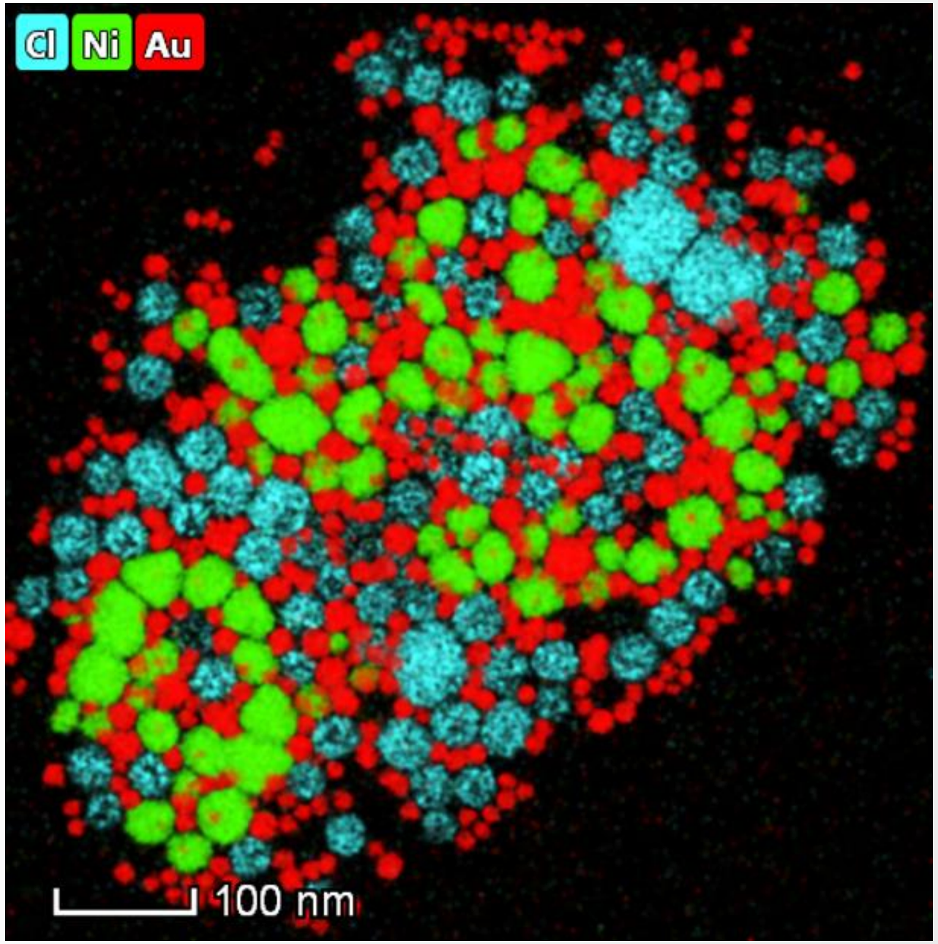


Sample: Prof. Lewis, University of Warwick, UK

Spectroscopy in TEM - EDS

STEM and EDS Analysis: Spectrum Imaging (EDS Mapping)

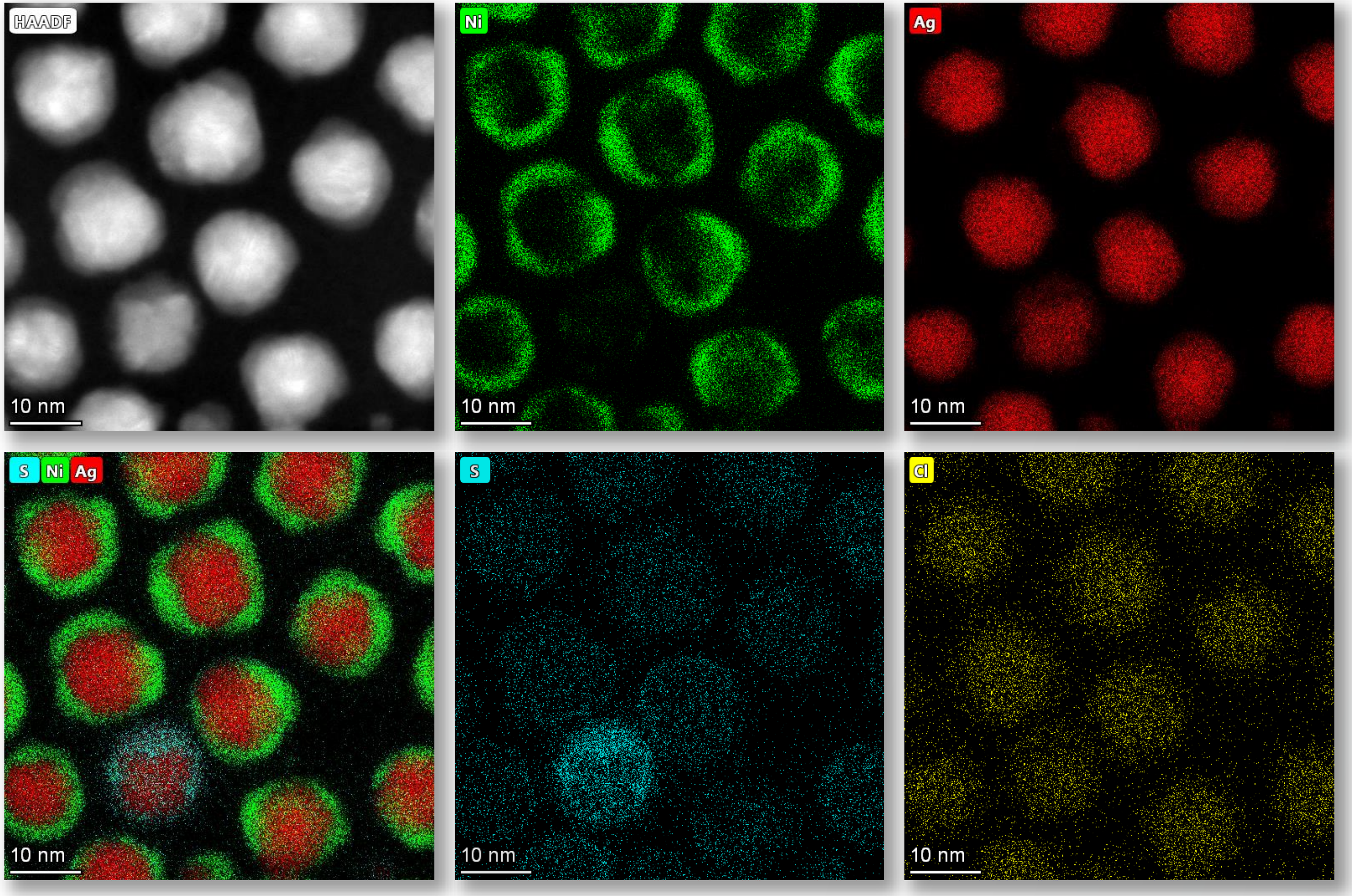




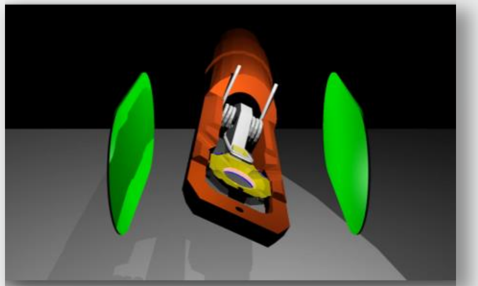
Sample courtesy: J. Bursik, Institute of Physics of Materials, Brno

Spectroscopy in TEM - EDS

AgNi Core-Shell Nanoparticles: Dual-X EDS



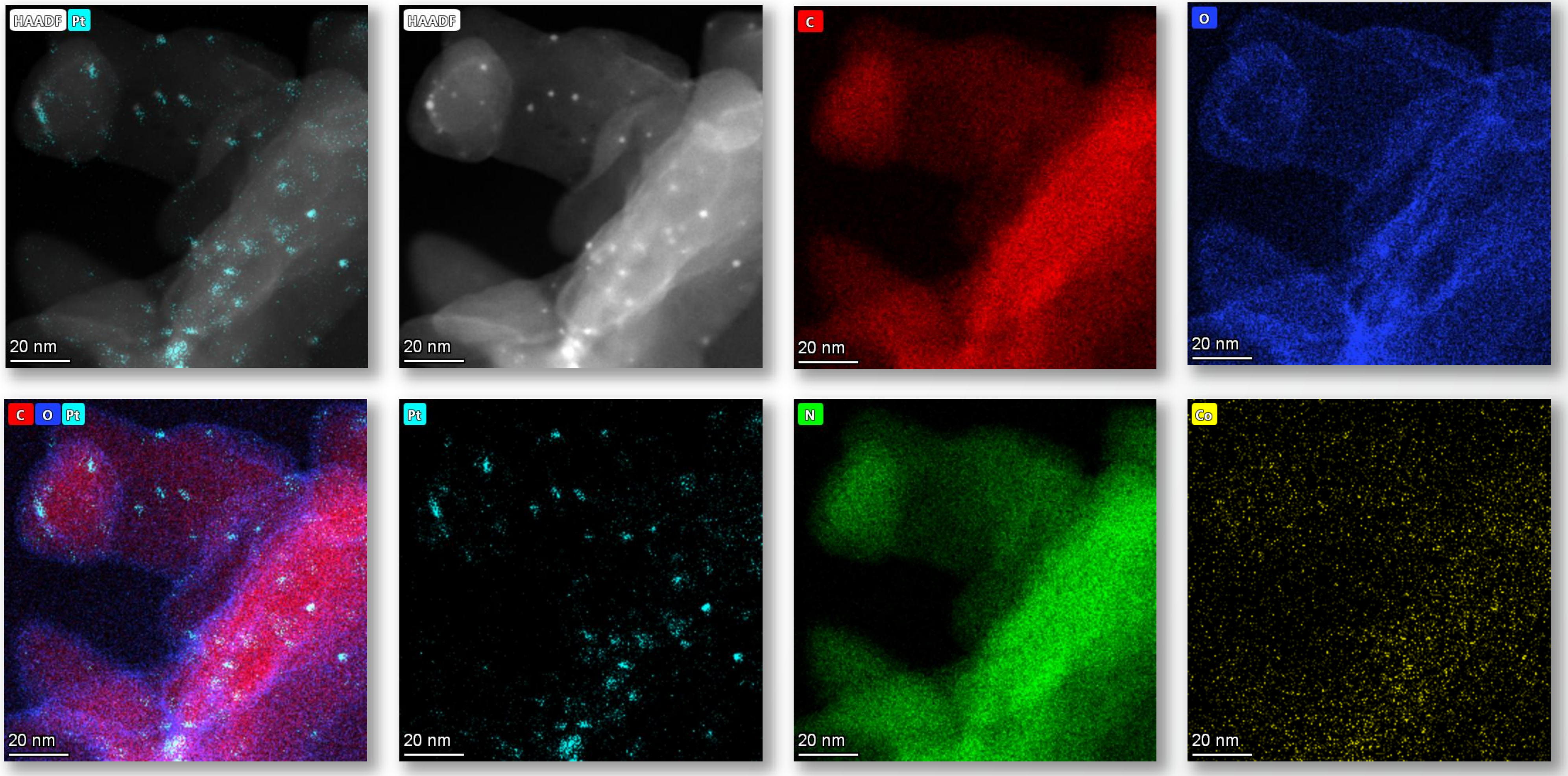
AgNi NPs may be effectively used as catalysts for reducing nitro compounds and degrading organic dyes. System $Ag_{0.6}Ni_{0.4}$ showed the highest catalytic activity for the reduction and degradation reaction of nitro compounds and organic dyes. AgNi NPs were also studied as catalysts for hydrogen generation, and the hydrogen generation rate of AgNi NPs was found to be much higher than Ag and Ni NPs of similar size. Sulfur is unwanted.



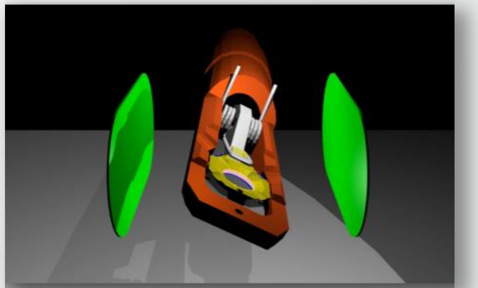
Sample courtesy: J. Bursik, Institute of Physics of Materials, Brno

Spectroscopy in TEM - EDS

C_3N_4(Co)-Pt Beam Sensitive and Thick Dirty Matrix: Dual-X EDS



Photocatalytic hydrogen evolution. The small nanoparticles (Pt) acted as active sites for the improved photocatalytic reaction. Pt on the surface. Co atomically dispersed or located with a diameter less than 1 nm.

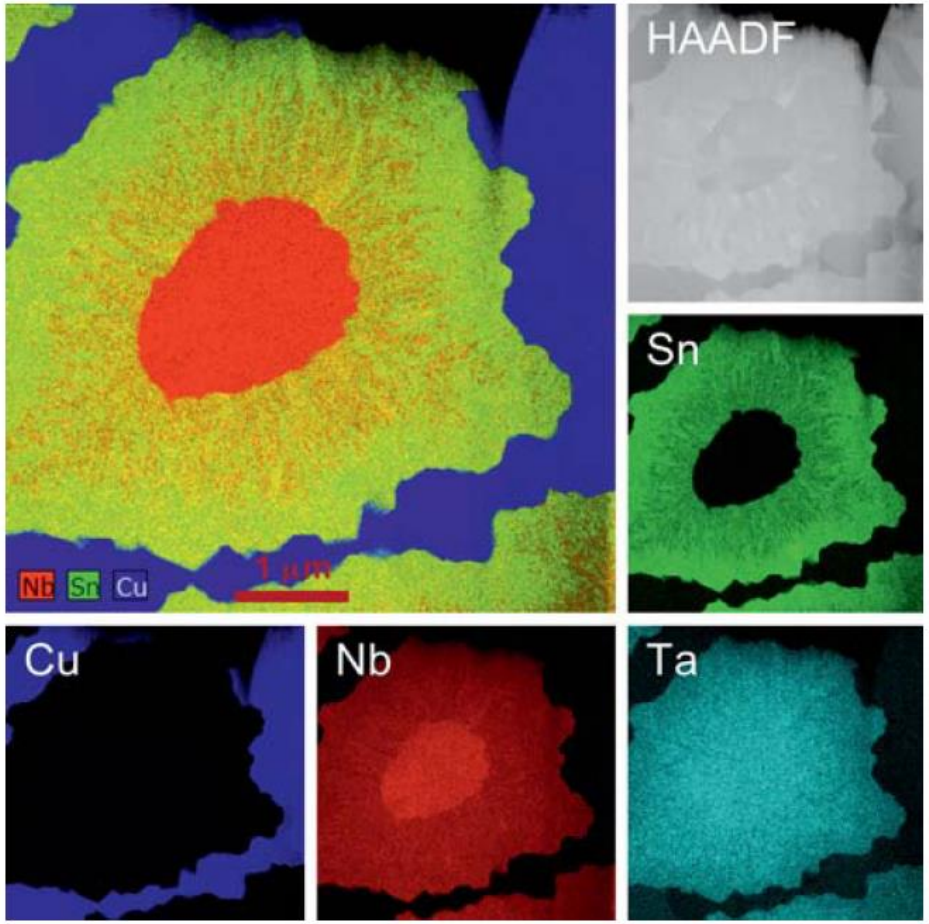


Prof. ShengChun Yang, Xi'an Jiaotong University, China.

Spectroscopy in TEM - EDS

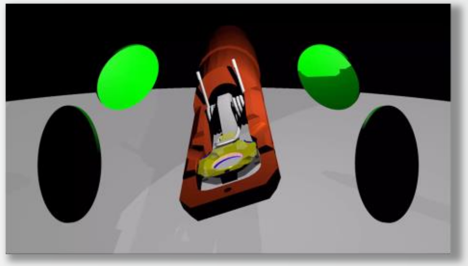
Super-X Fast EDS Mapping

Nb_3Sn superconducting cable, 11 min acquisition time, 400*400 pixels, 2.5nA probe current

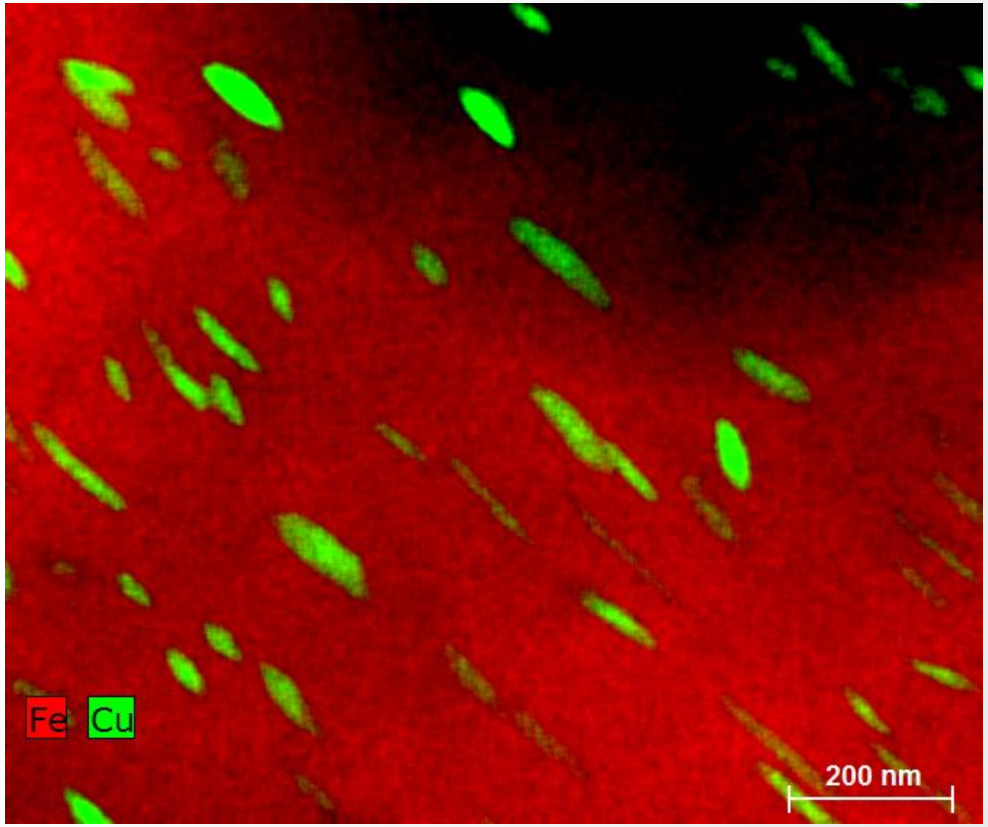


Sample courtesy: Marco Cantoni (EPFL Lausanne, Switzerland)

KYUSHU UNIVERSITY



Rolled steel with copper precipitates.
Acquired in 5min with >200kcps X-ray count rate



Sample courtesy: Dr. Satoshi Hata and Dr. Toshihiro Tsuchiyama, Kyushu University and Dr. Mitsuhiro Murayama, Virginia Tech

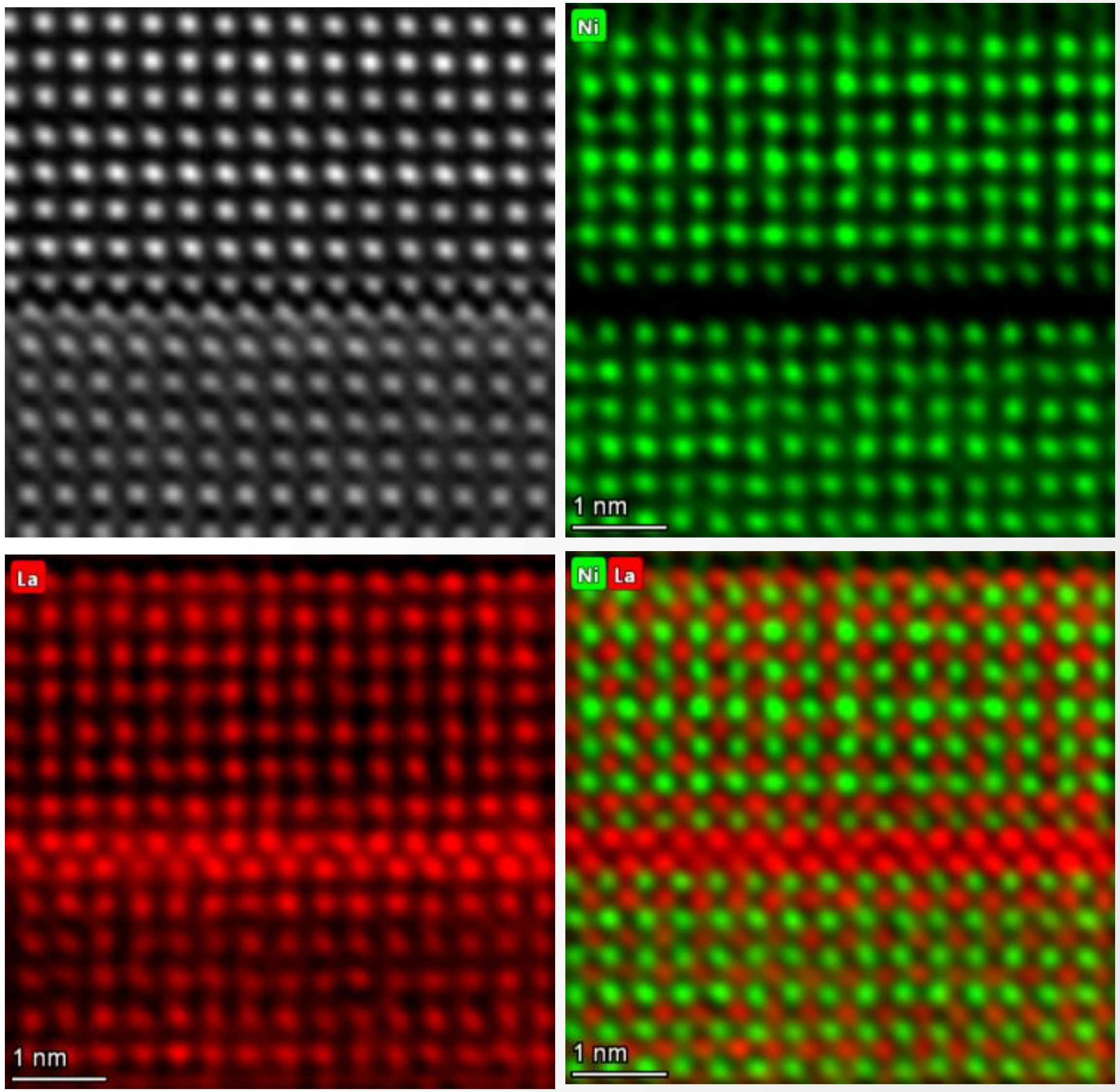
Spectroscopy in TEM - EDS

EDS Mapping at Atomic Resolution

$LaNi_{0.99}Rh_{0.01}O_3$

- Rh too low to get spatial resolution
- O is light elements, need more time to get the spatial resolution

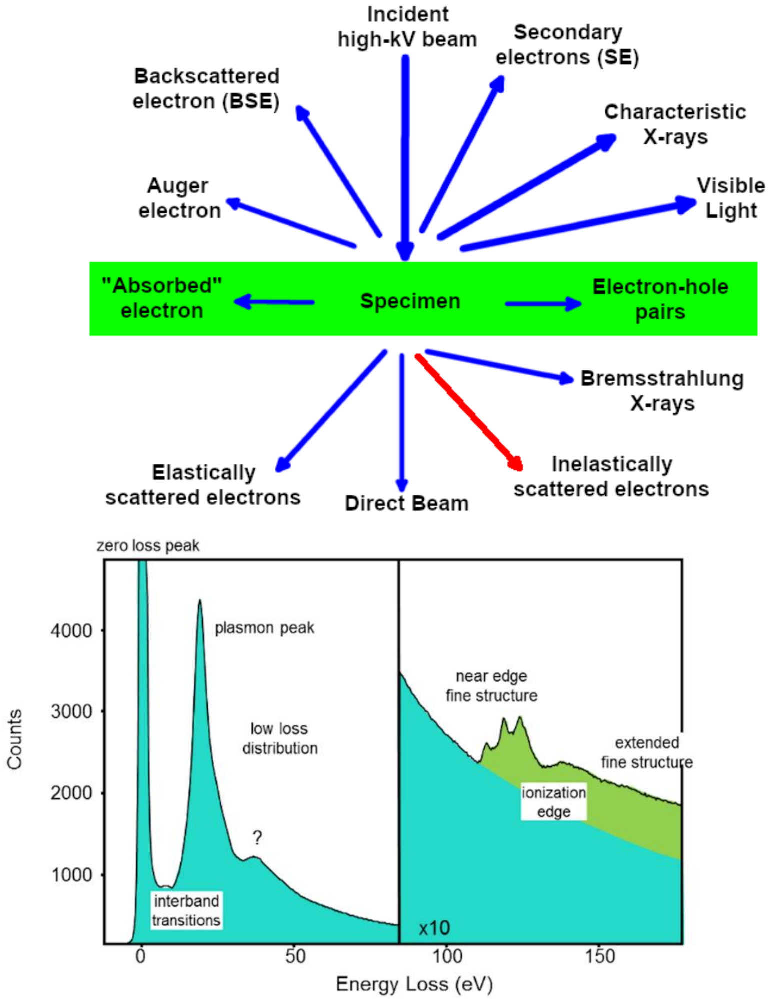
Talos F200X



Sample courtesy Nikolla Lab, Wayne State University

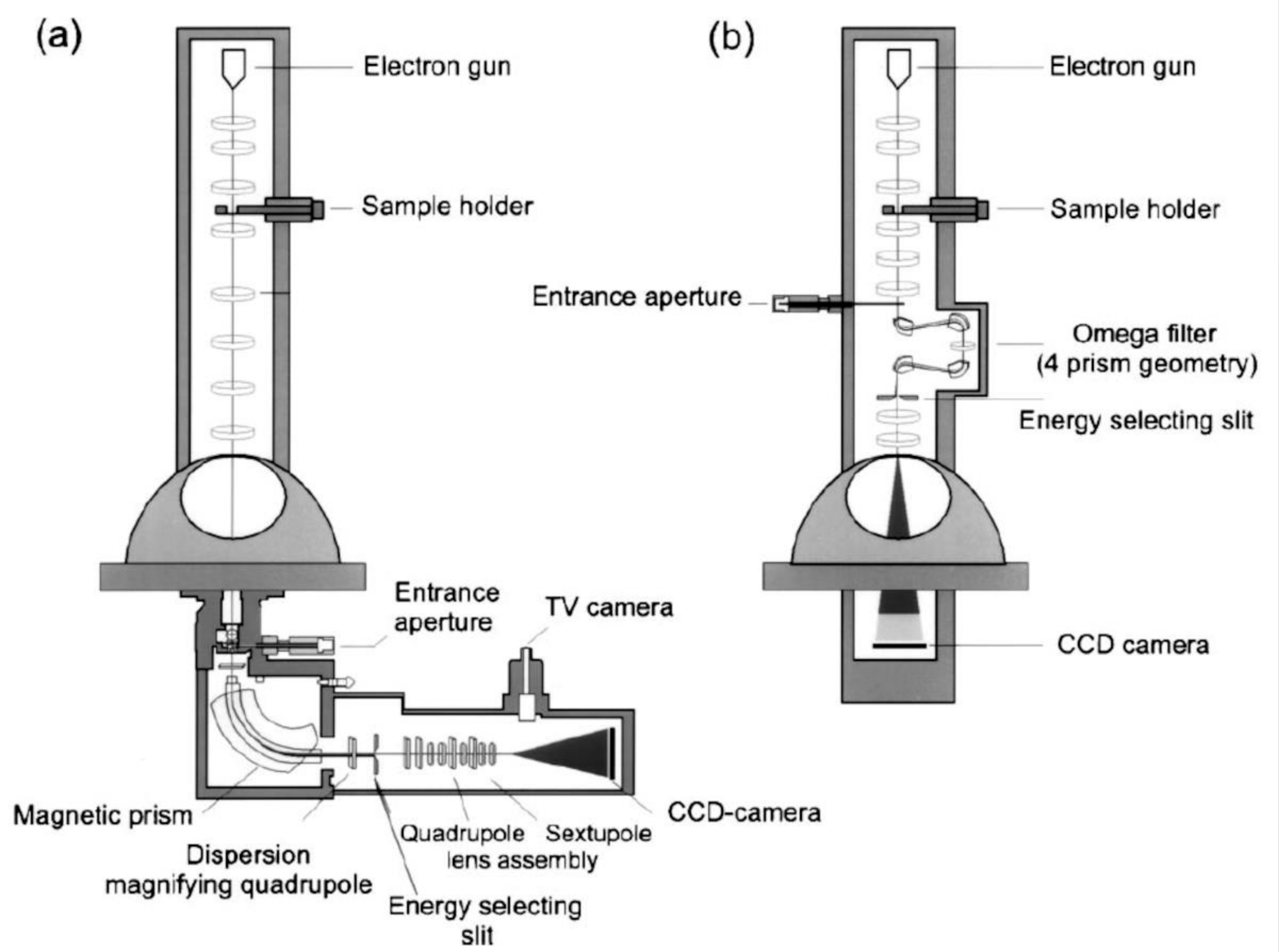
Spectroscopy in TEM - EELS

Electron Energy Loss Spectroscopy (EELS) in TEM: EELS Setup



Post-Column Filter

In-Column Omega Filter



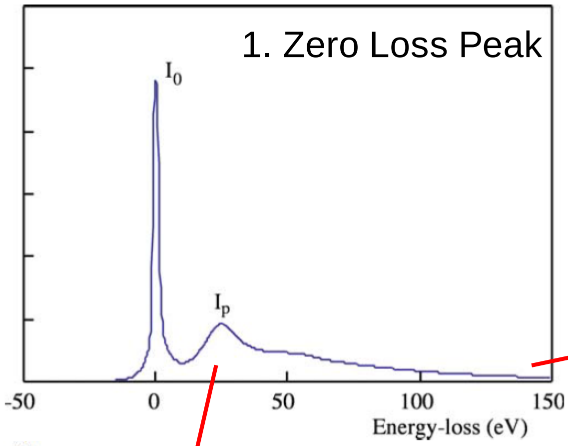
https://eels.info/about/overview

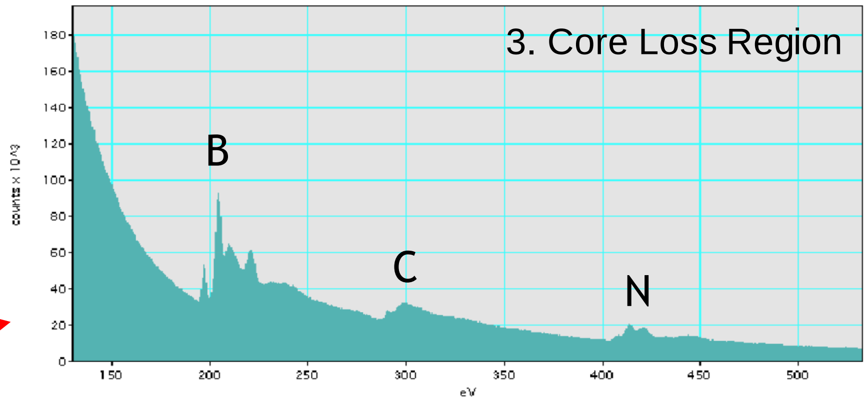
F. Hofer, Mikrochim, Acta 132, 273-288 (2000)

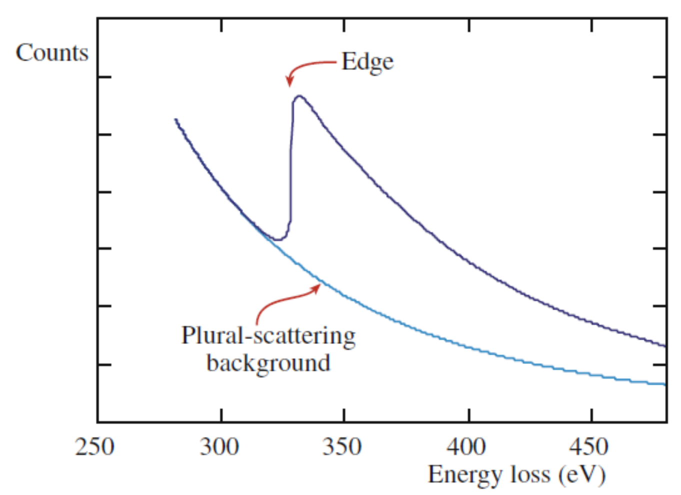
Spectroscopy in TEM - EELS

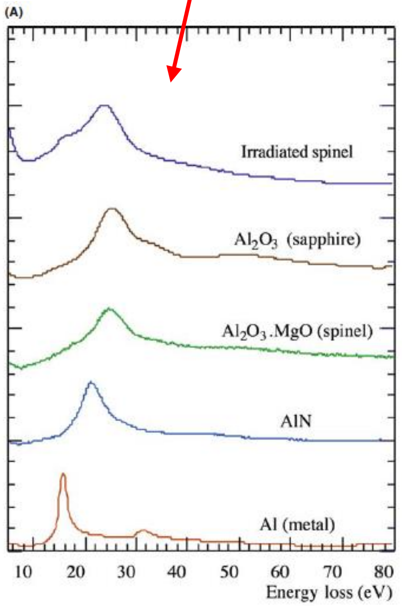
Thermo Fisher SCIENTIFIC

EELS Spectrums Regions



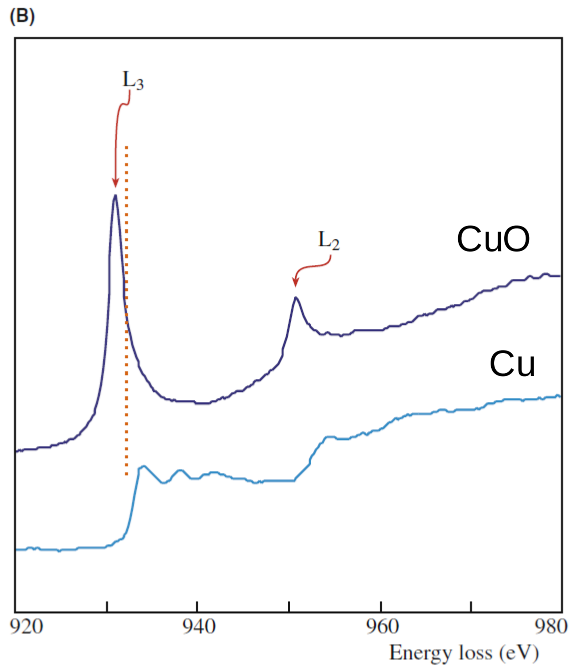






2. Low Loss Region
1eV~75eV

Change in the Cu $L_{2,3}$ edge structure as Cu metal is oxidized

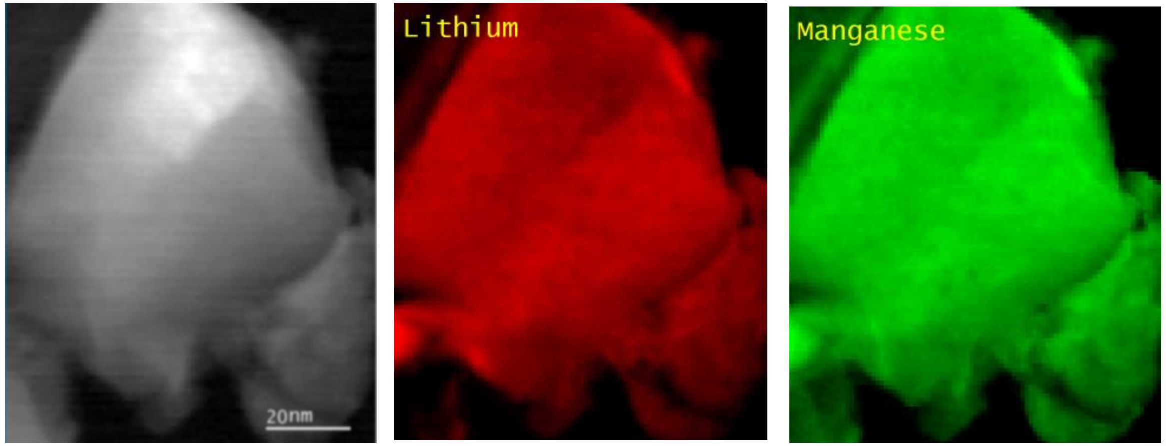


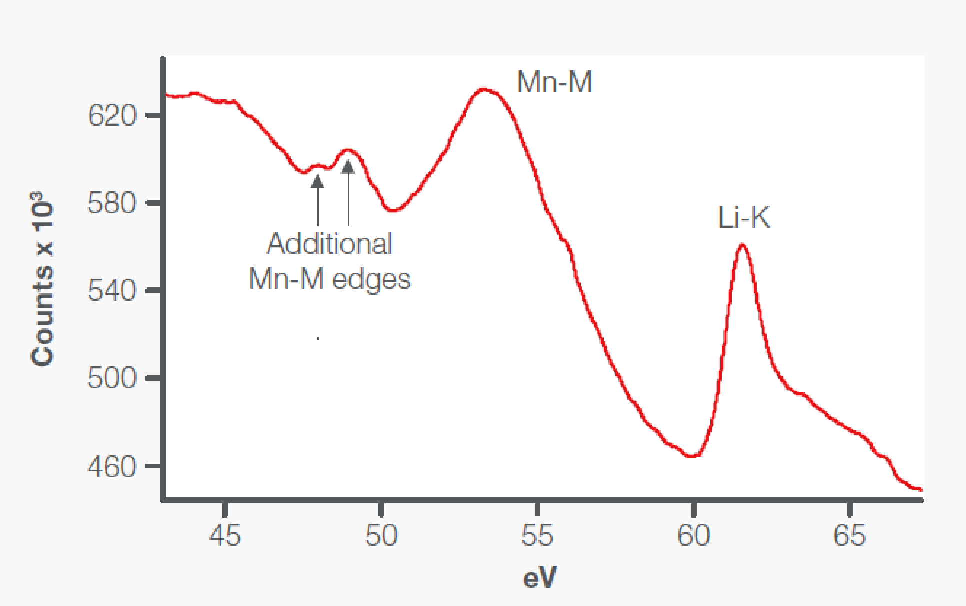
An “edge” in the spectrum corresponds to energy absorption from an electron in a certain element.

Spectra taken from the book “Transmission Electron Microscopy” by Williams and Carter

Spectroscopy in TEM - EELS

STEM and EELS Analysis: Spectrum Imaging (EELS Mapping)





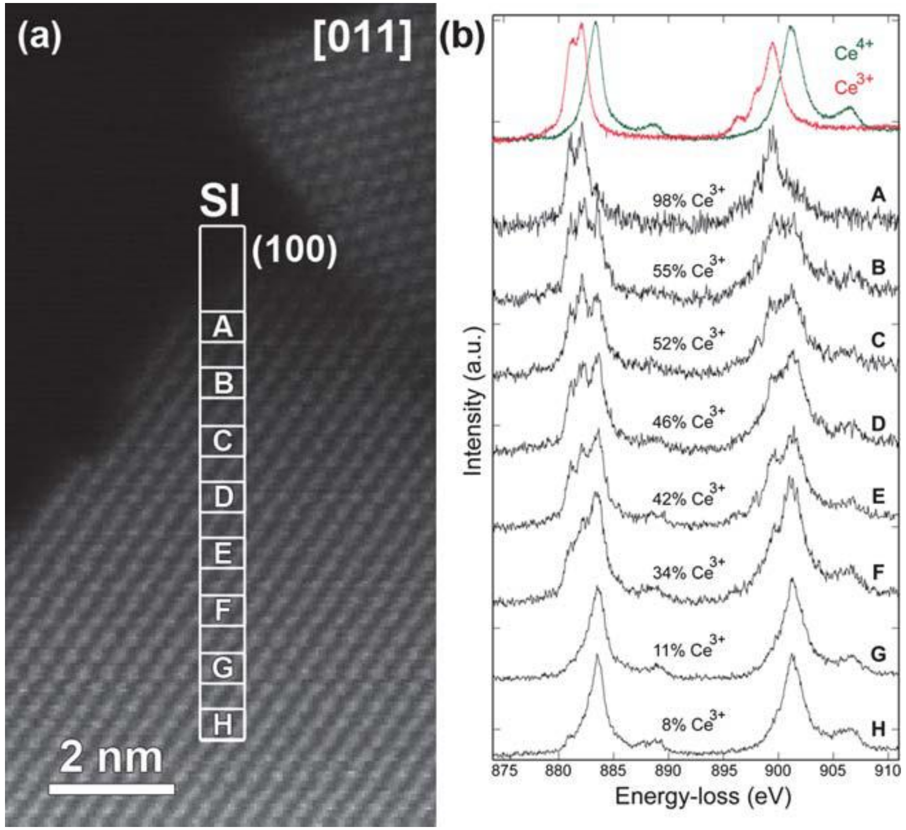
The Mn-M edge fine structure and Li-K edge in the Li battery are distinguished.

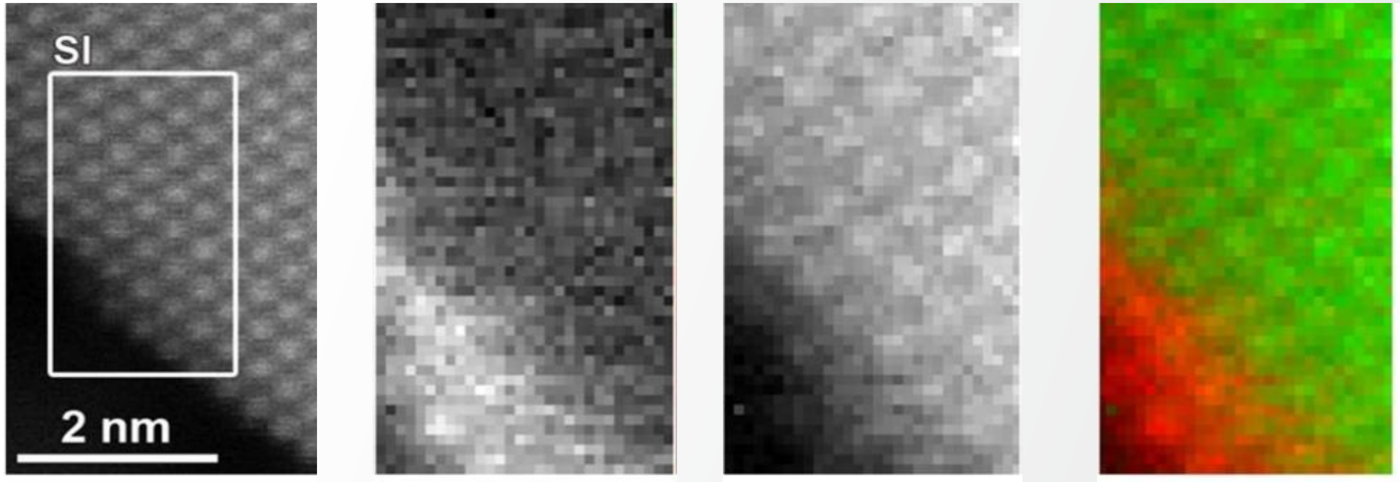
Talos F200X

Sample courtesy: Dr. Chongmin Wang, at Pacific Northwest National Laboratory (PNNL).

Spectroscopy in TEM - EELS

STEM and EELS Analysis: Oxidation State Mapping





Ce^{3+} Ce^{4+}

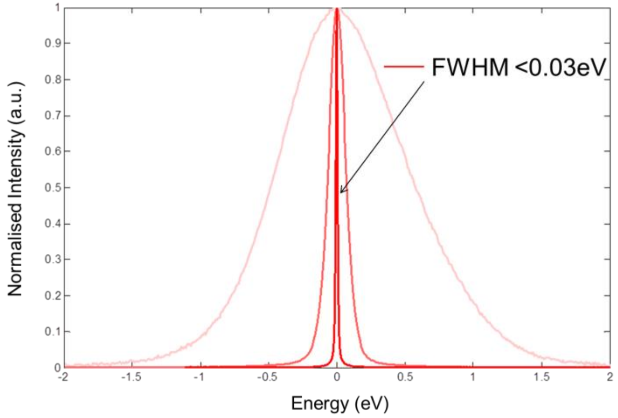
- 0.2 eV
- 60 pA
- 0.1 nm resolution

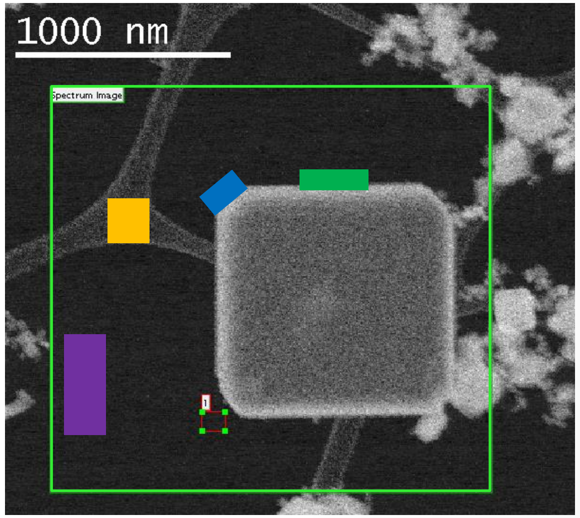
Spectra Ultra
X-FEG + Monochromator

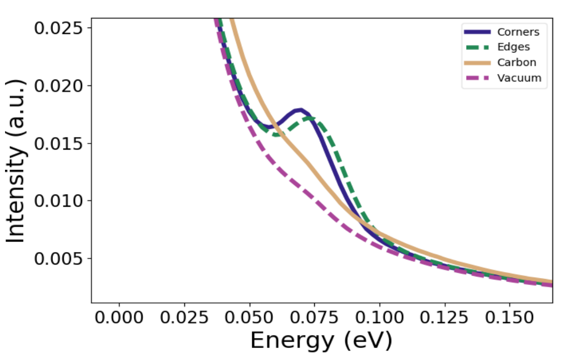
Spectroscopy in TEM - EELS

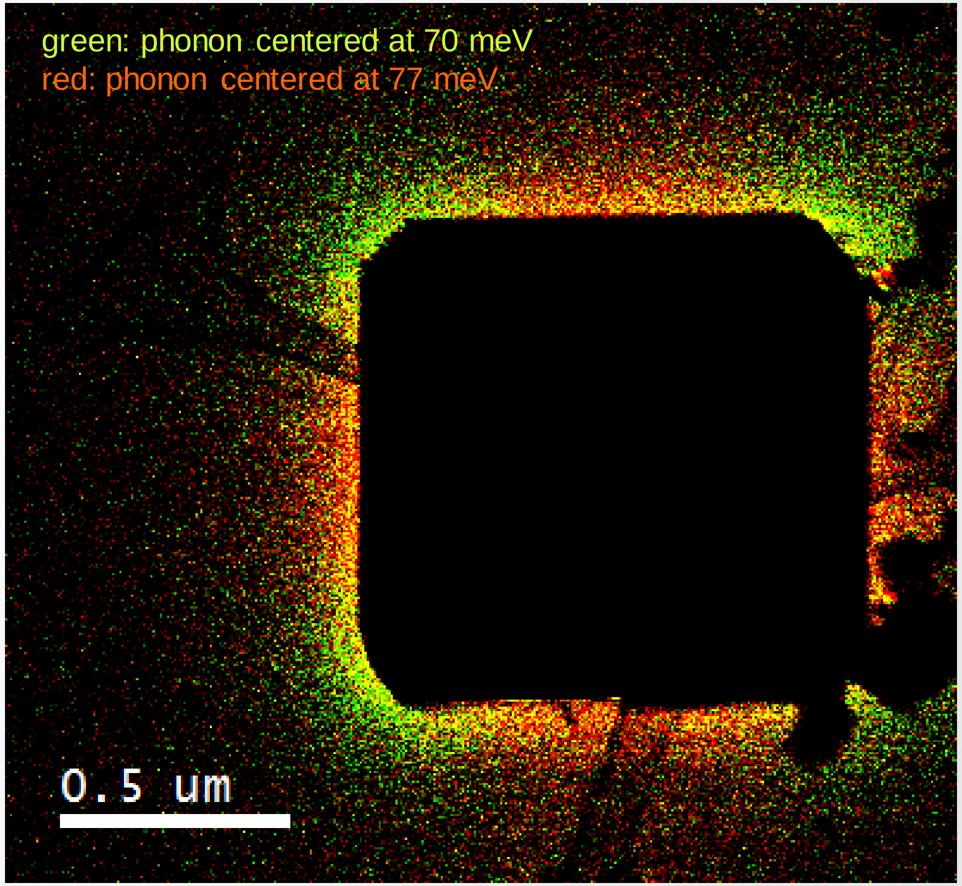
STEM and EELS Analysis: Surface Phonons

Surface phonons:
- Energy spread <0.025 eV
- De-scan coils standard on Spectra 300 column
- Continuum 1066
- 8-minute acquisition









MgO Surface Phonons imaged at 60kV

Spectra Ultra - X-FEG + Monochromator

Sample: Prof. G. Botton
Canadian Centre of Electron Microscopy, McMaster University

Thermo Fisher SCIENTIFIC

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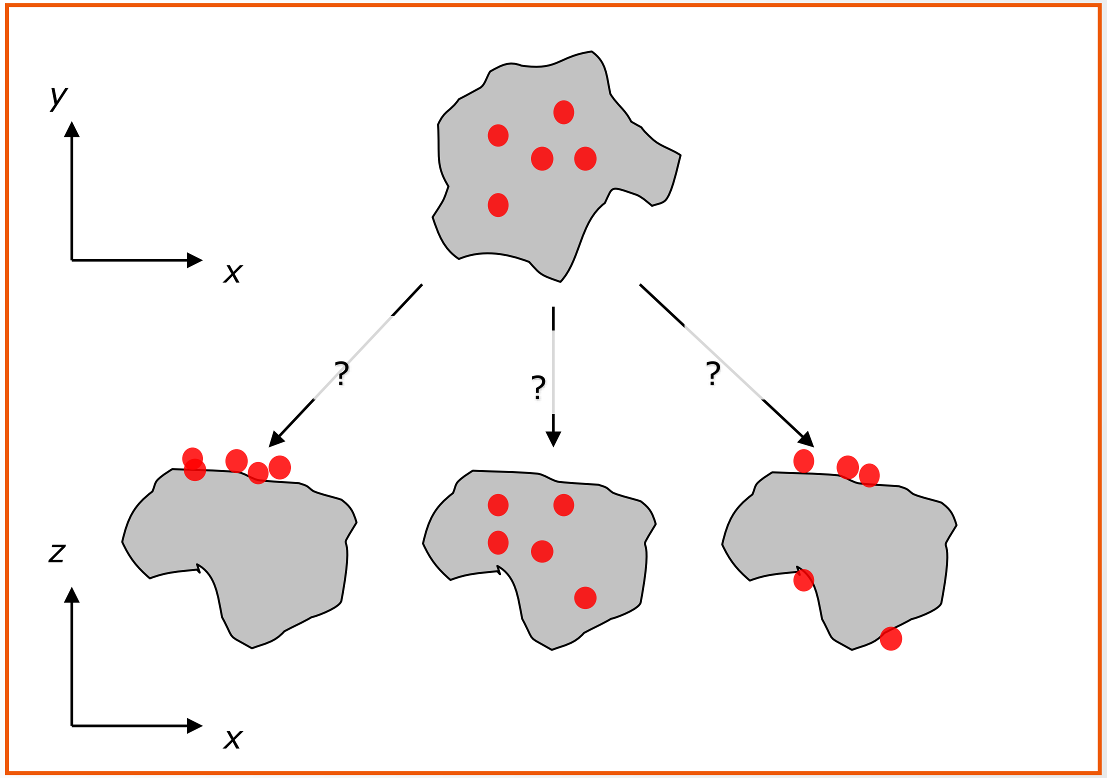
Tomography in TEM: For 2D to 3D Imaging

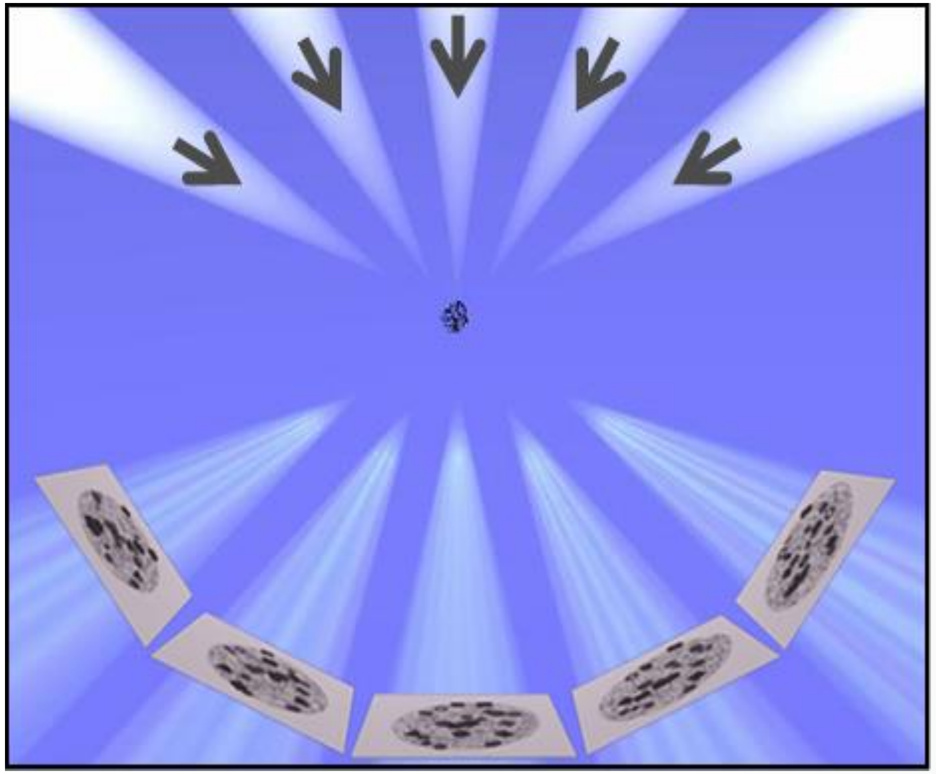
Third Dimension on TEM Specimens

- 2D projections:
  - Miss out on important information
  - May given erroneous information

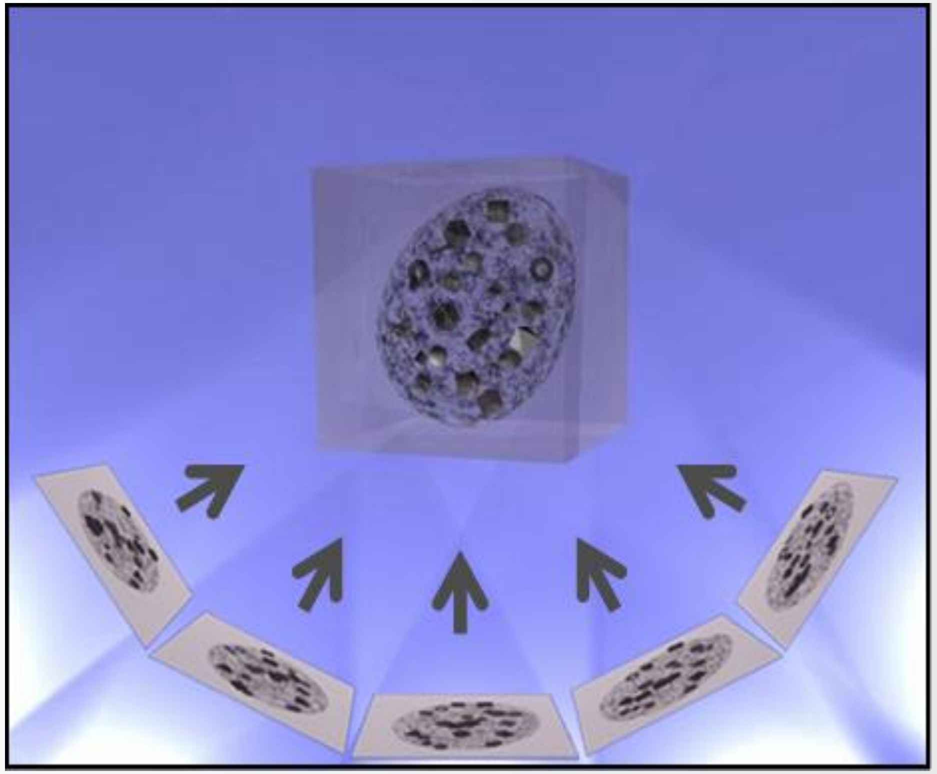


Tomography in TEM: For 2D to 3D Imaging

From 2D to 3D Information



3D object ⇒ set of 2D projections

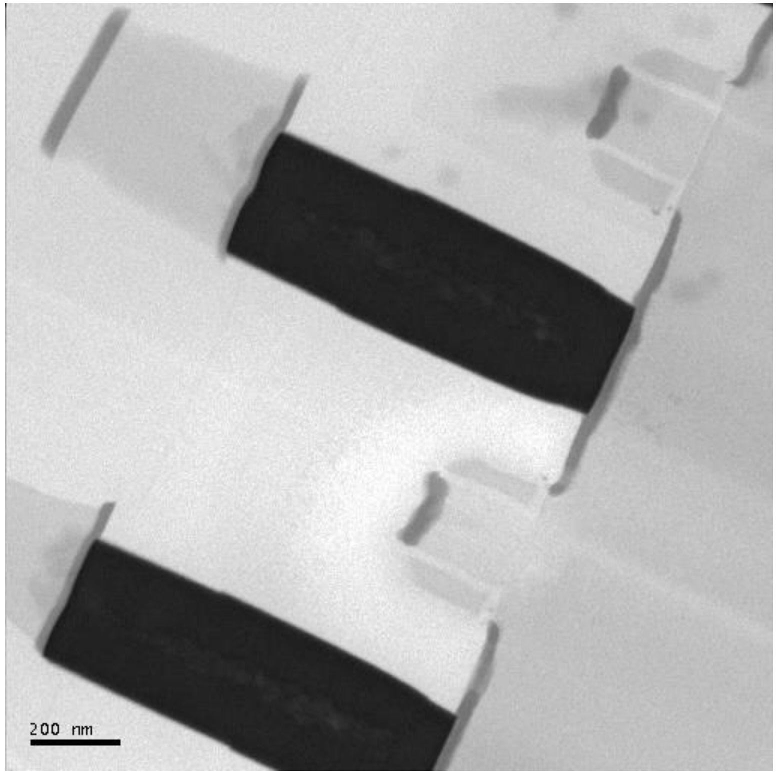


2D projections ⇒ 3D reconstruction

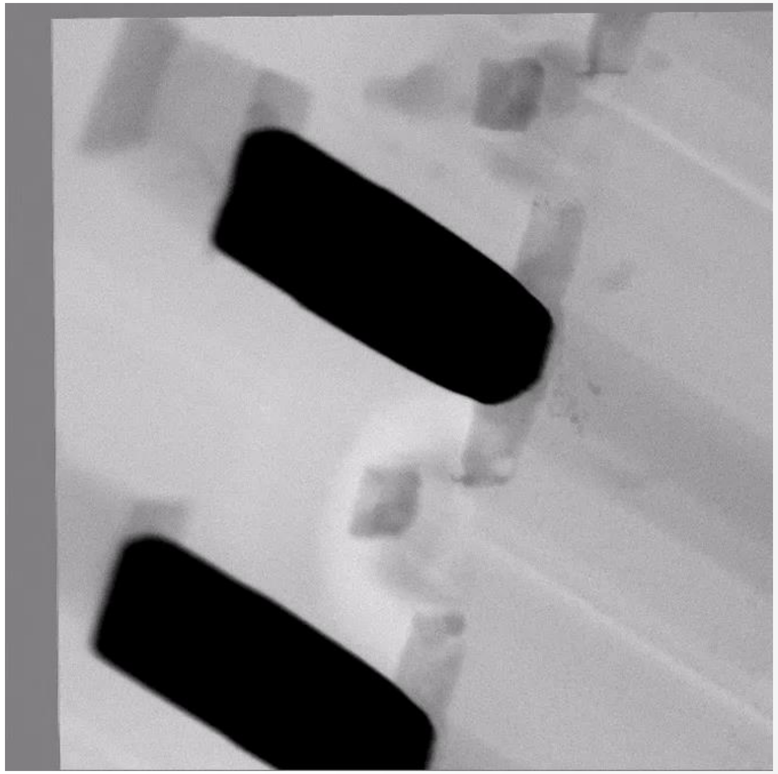
Common acquisition: ±70 deg, 1° increments, 141 images

Tomography in TEM: For 2D to 3D Imaging

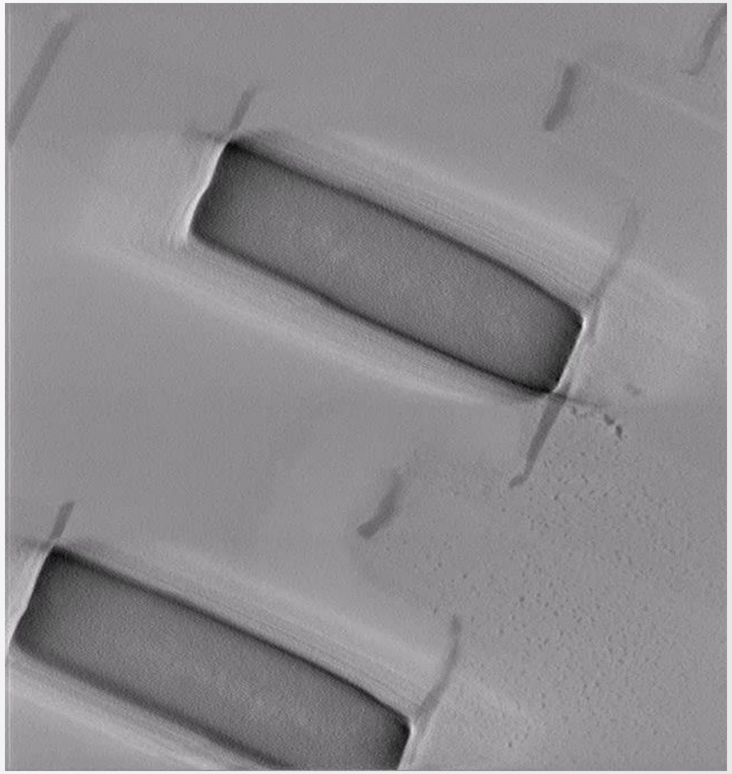
2D vs 3D Imaging: High Crystalline Semiconductor Device



STEM-BF



Tilt-Series



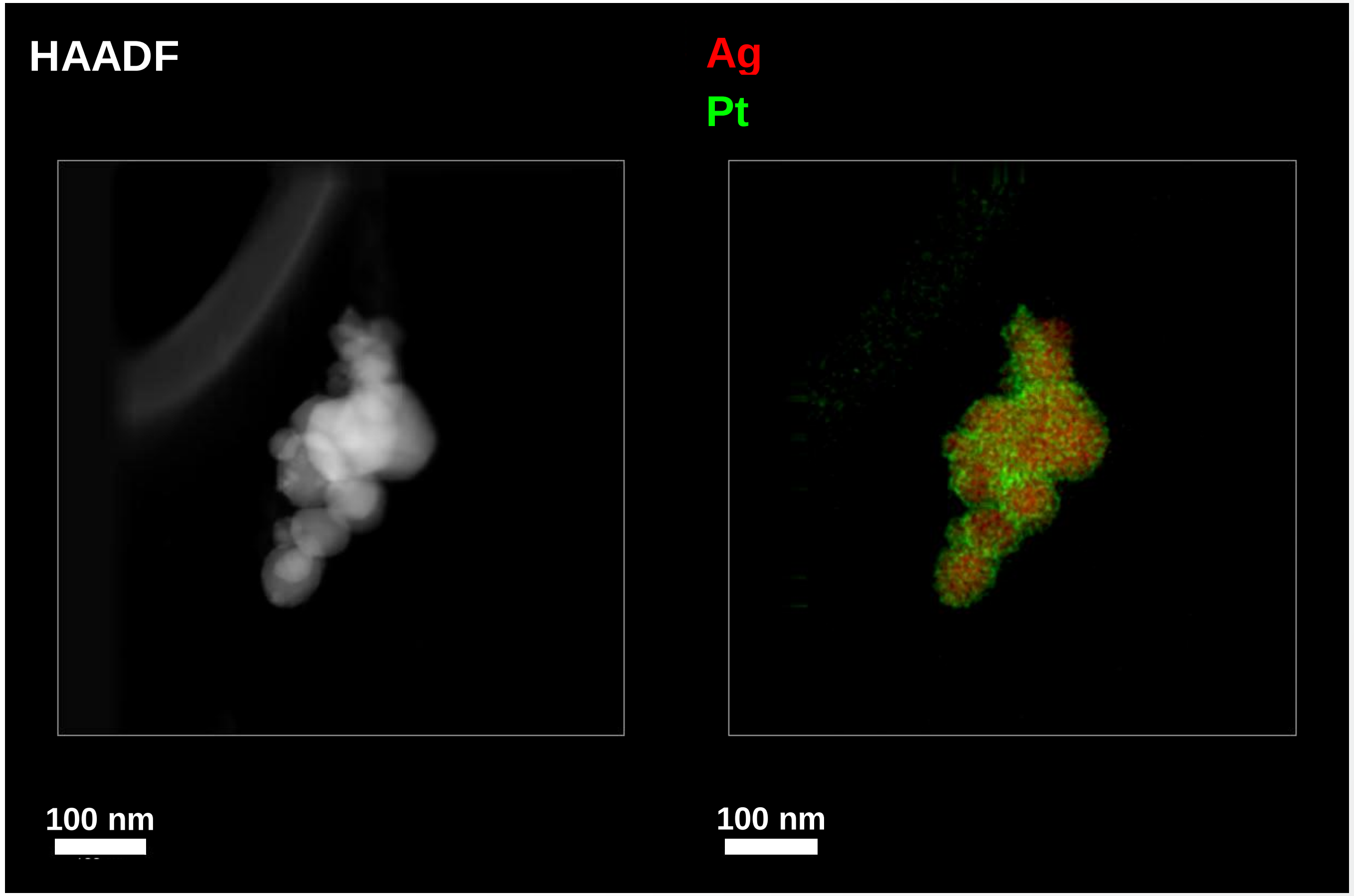
Reconstruction

Tecnai F20

C. Kübel et al. Microsc. Microanal. 11 (2005) 378-400

Tomography in TEM: For 2D to 3D Imaging

High resolution; Ag-Pt core-shell catalyst particles

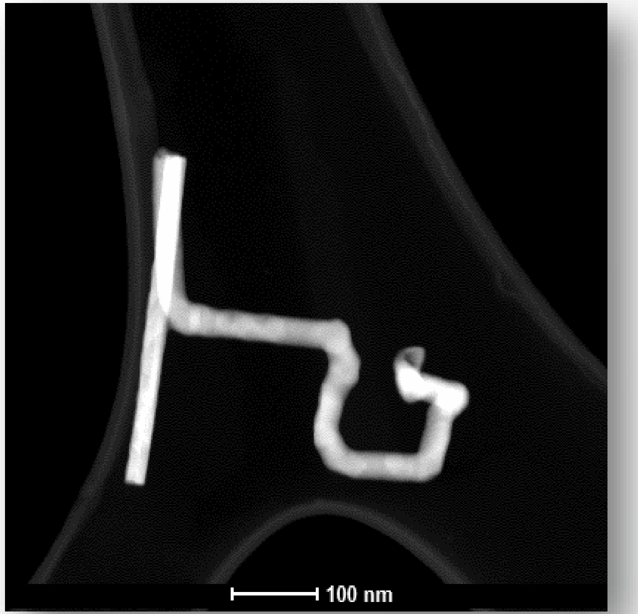


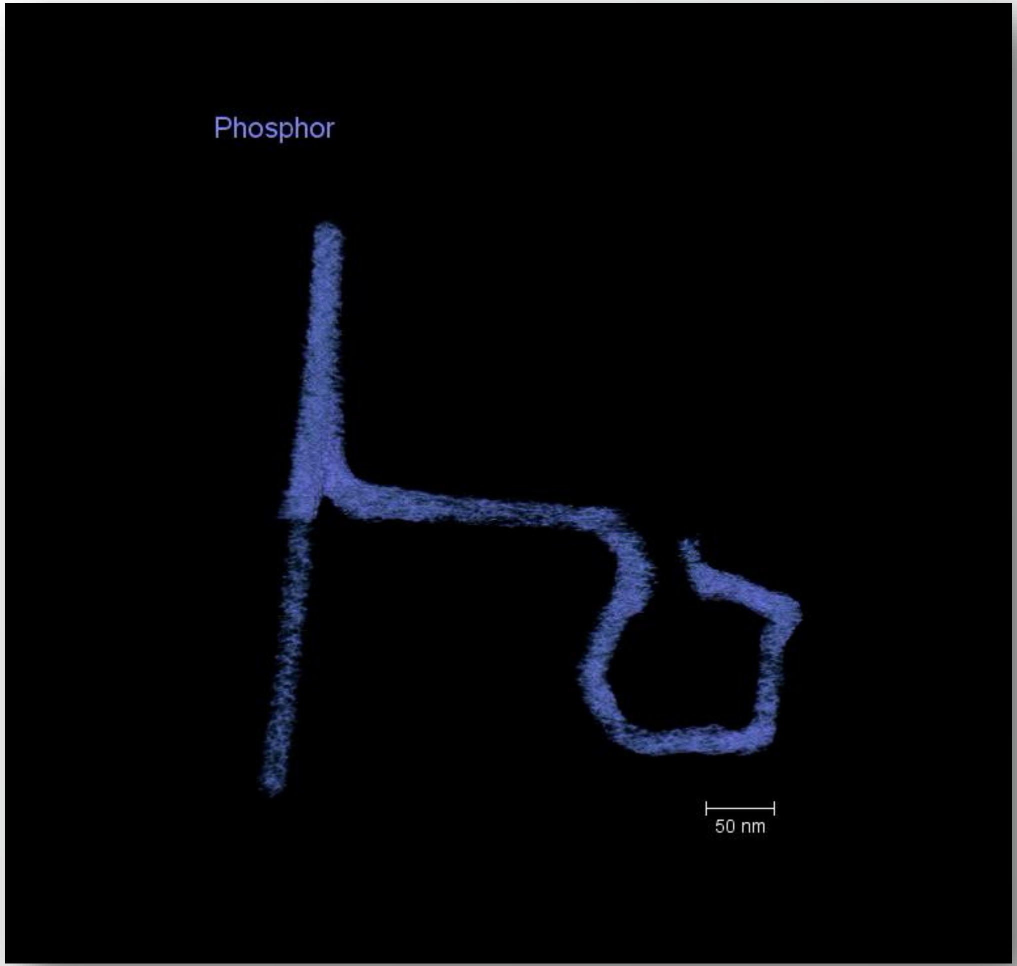
Aligned Tilt Series

Sample courtesy Prof. Yi Ding and Prof. Jun Luo, Center for Electron Microscopy, Tianjin University of Technology

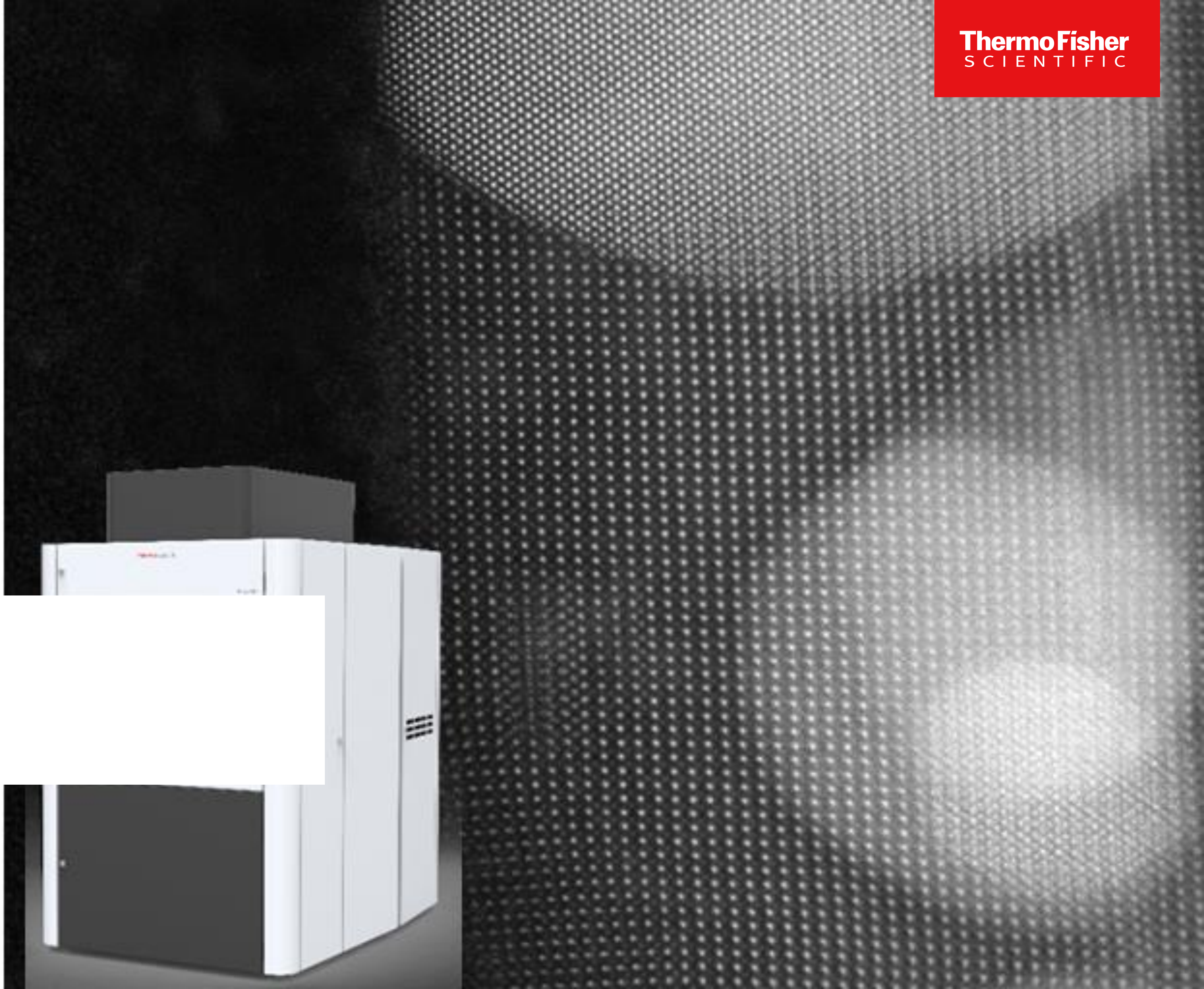
Tomography in TEM: For 2D to 3D Imaging

Electrode material for Na-ion and Li-ion batteries





Sample Courtesy Michigan Tech University, Dr Reza Shahbazian Yassar



Examples

Video on TEM Operational – Talos F200X

Talos F200X

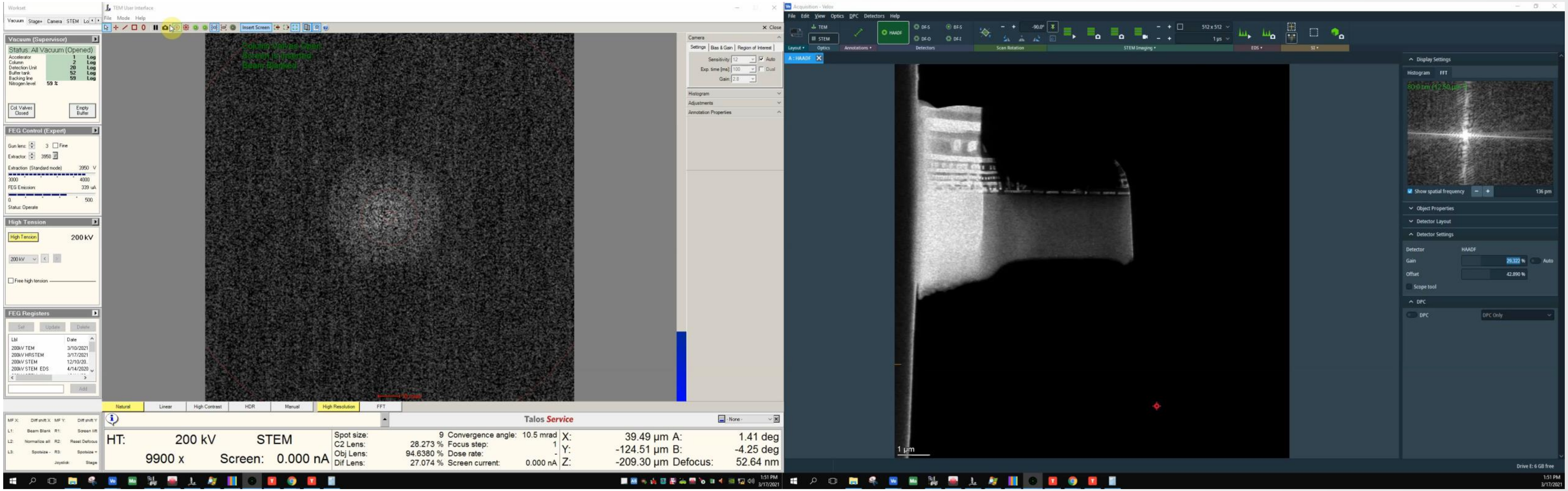
Video on TEM Operational – Talos F200X

Holder Insertion

 mohamadriza.iskandar@thermofisher.com | 16-February-2023

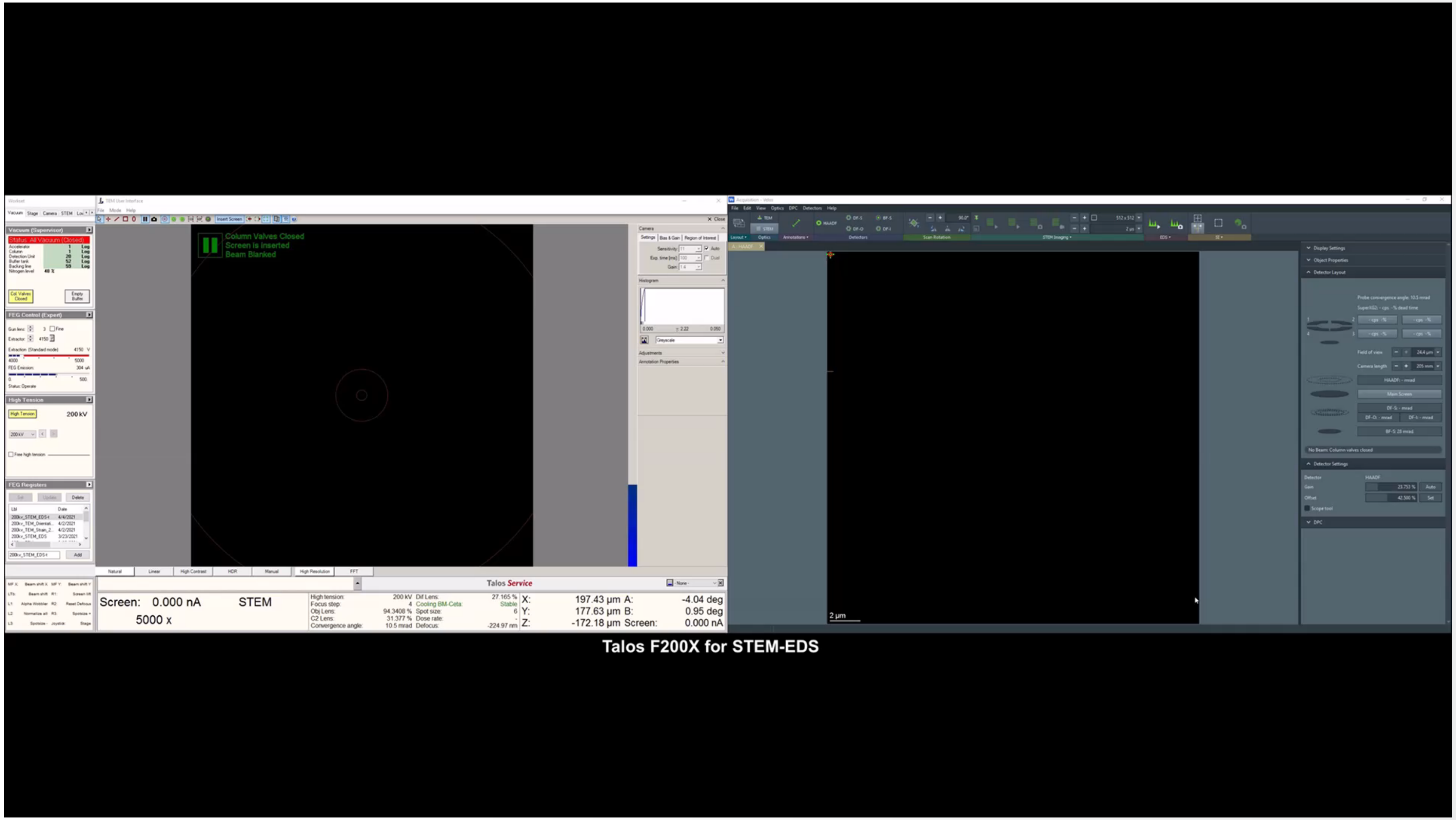
Video on TEM Operational – Talos F200X

STEM Imaging

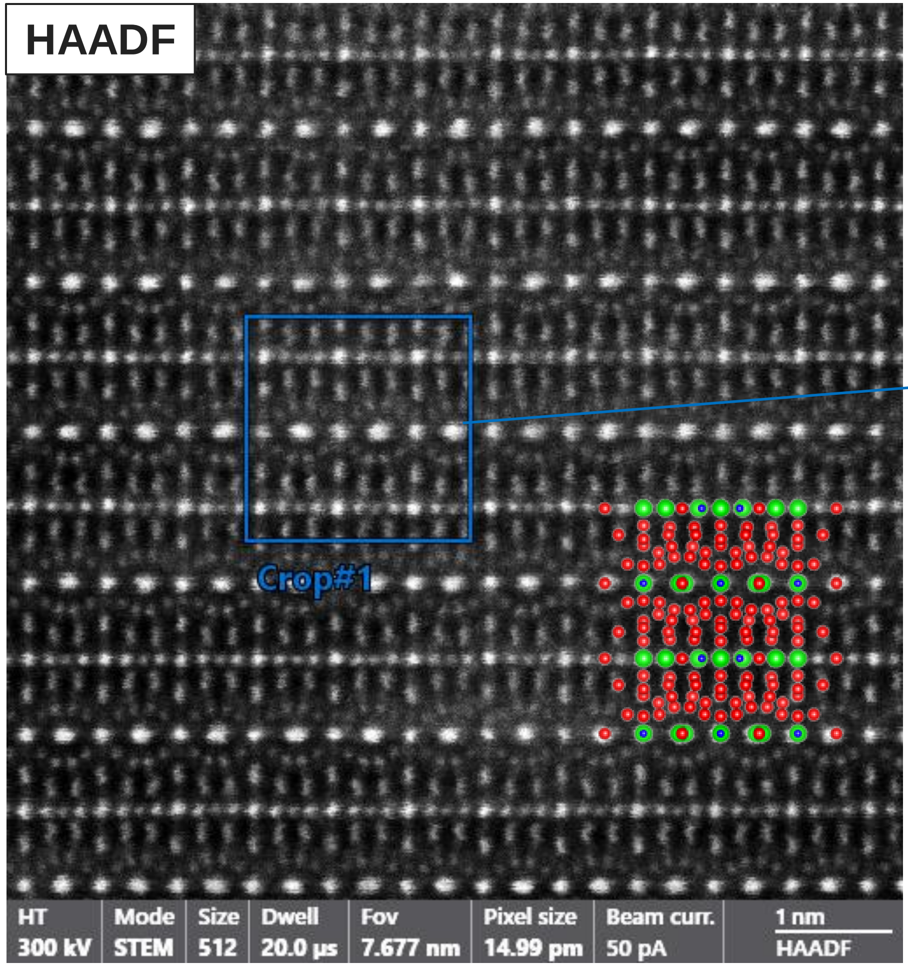


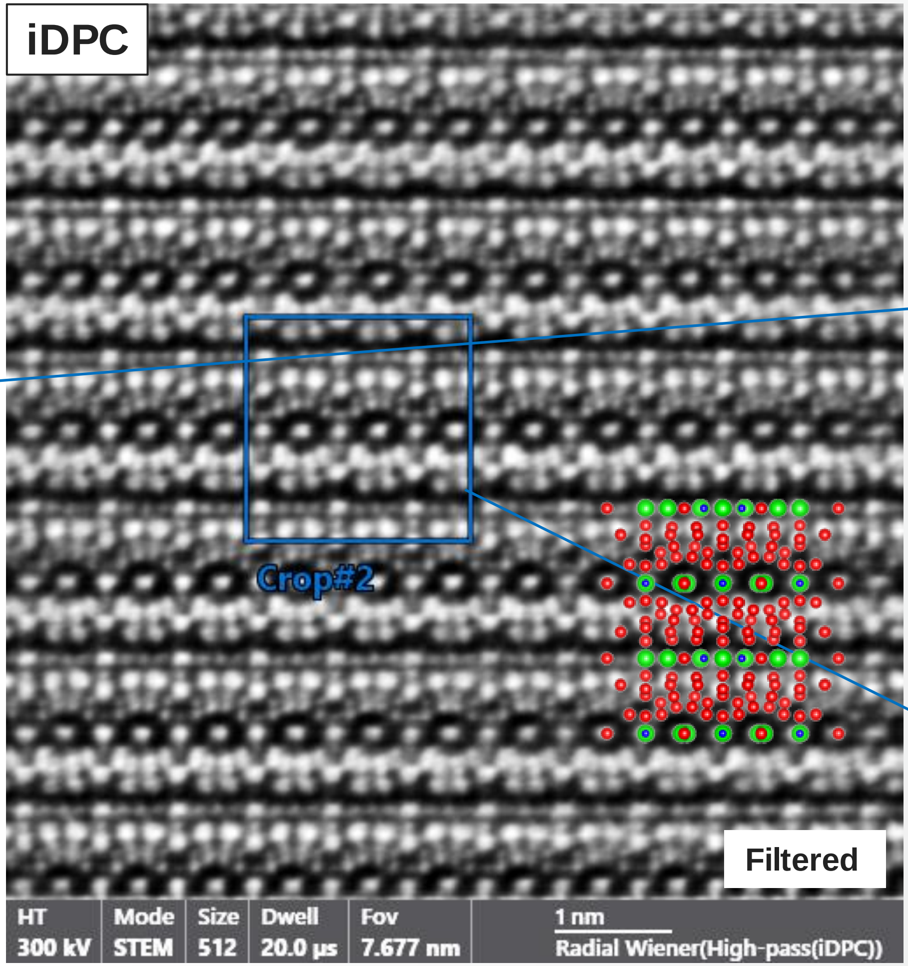
Video on TEM Operational – Talos F200X

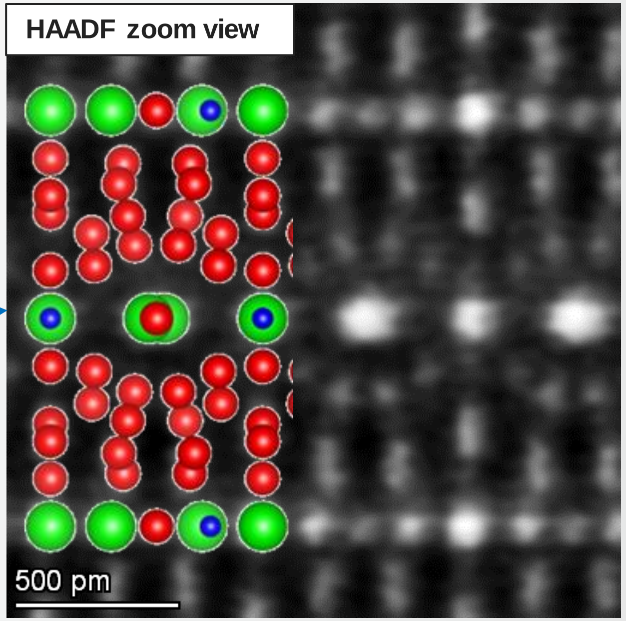
STEM EDS

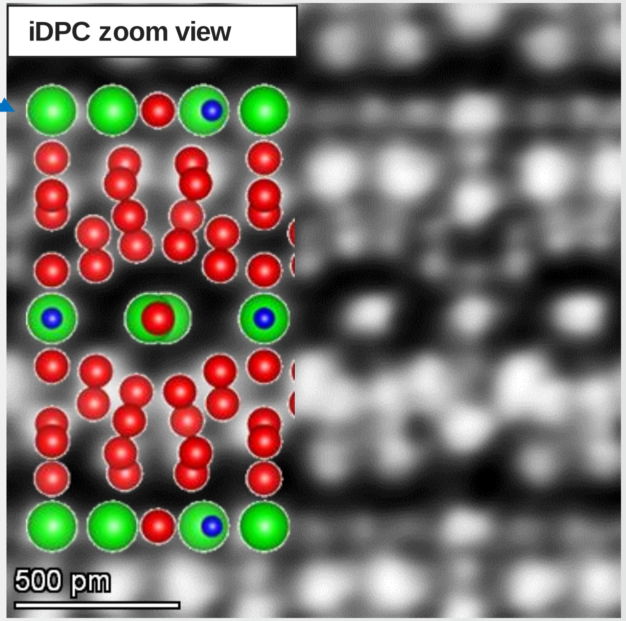


Complex Structure Investigation









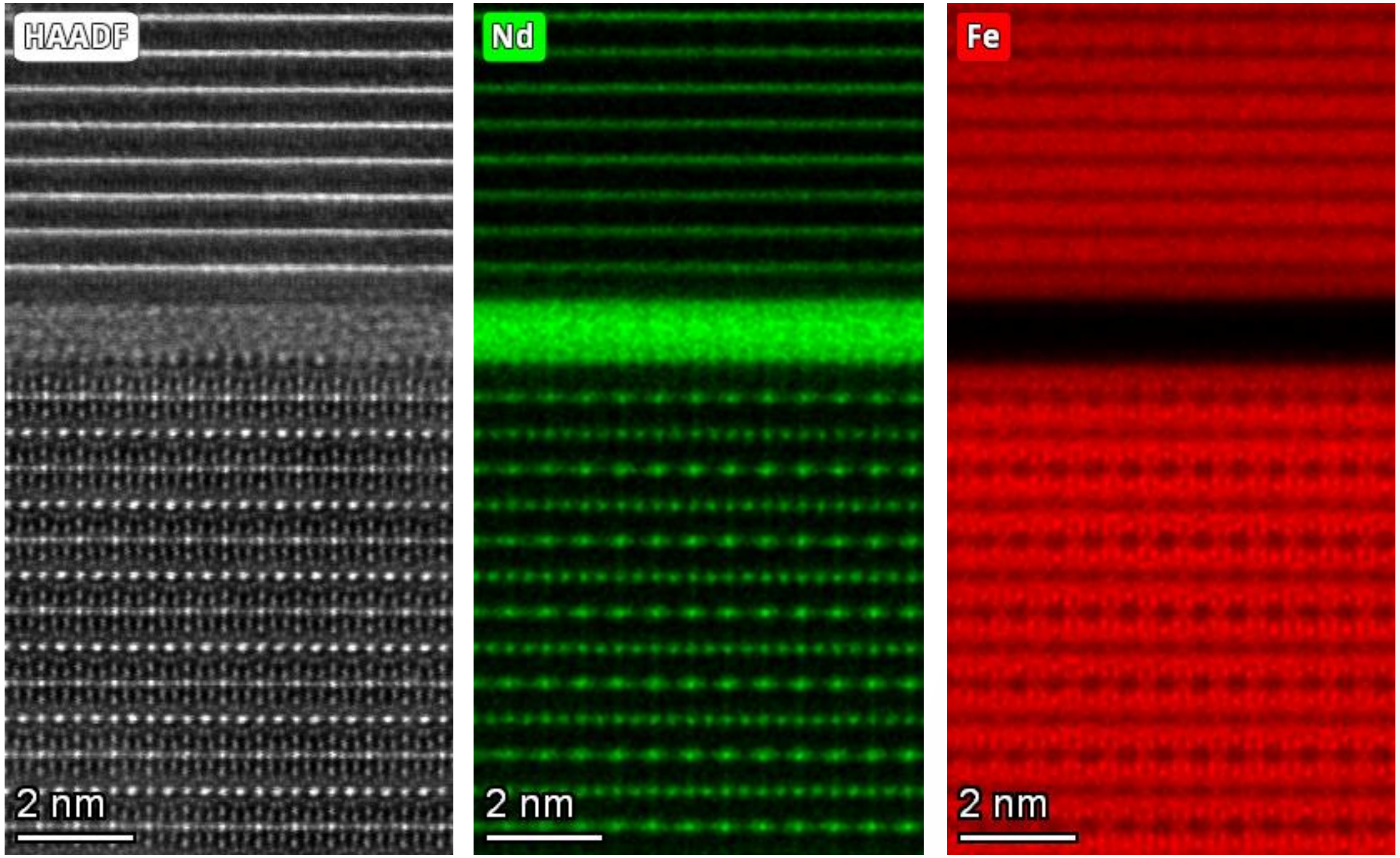
HAADF/iDPC STEM

$Nd_2Fe_{14}B$ [110]

Sample courtesy: National Institute for Materials Science, Tsukuba, Japan

Complex Structure Investigation

$Nd_2Fe_{14}B$



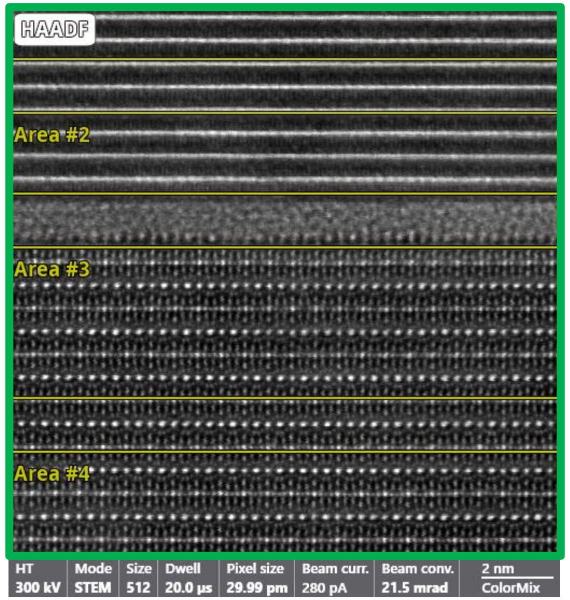
System	Spectra Ultra X-CFEG, 300 kV
Beam current	280 pA
Acquisition time	9' 18"
Filter	Gaussian & radial Wiener Filter

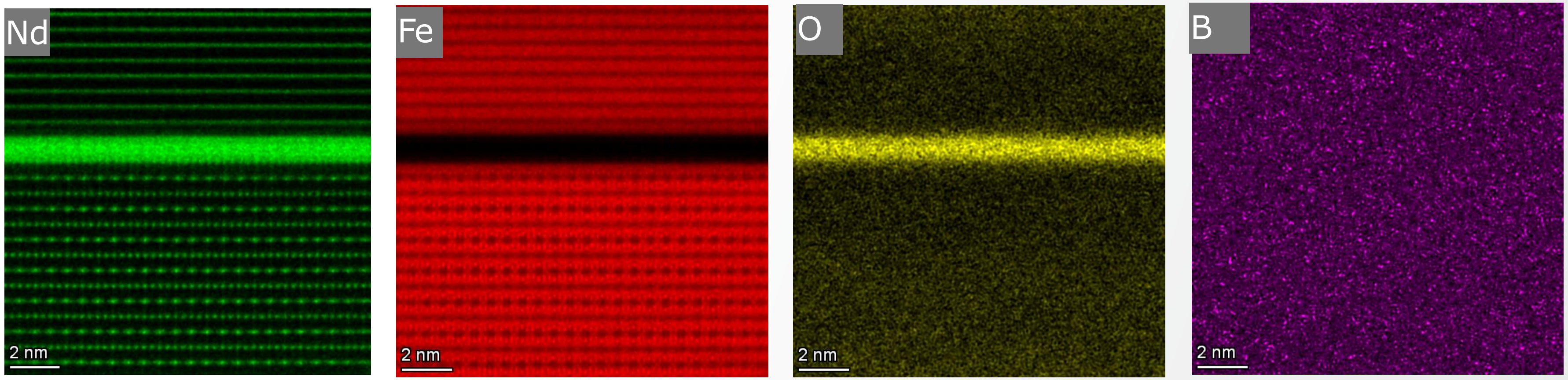
- Fast acquisition of large maps out of a complex structure

Sample courtesy: National Institute for Materials Science, Tsukuba, Japan

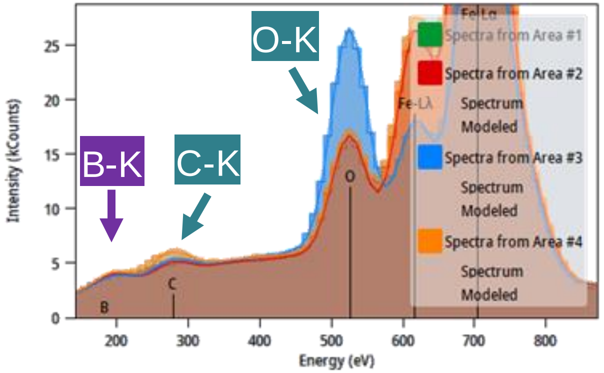
Complex Structure Investigation

$Nd_2Fe_{14}B$





Extracted EDX spectra from regions 2, 3 and 4



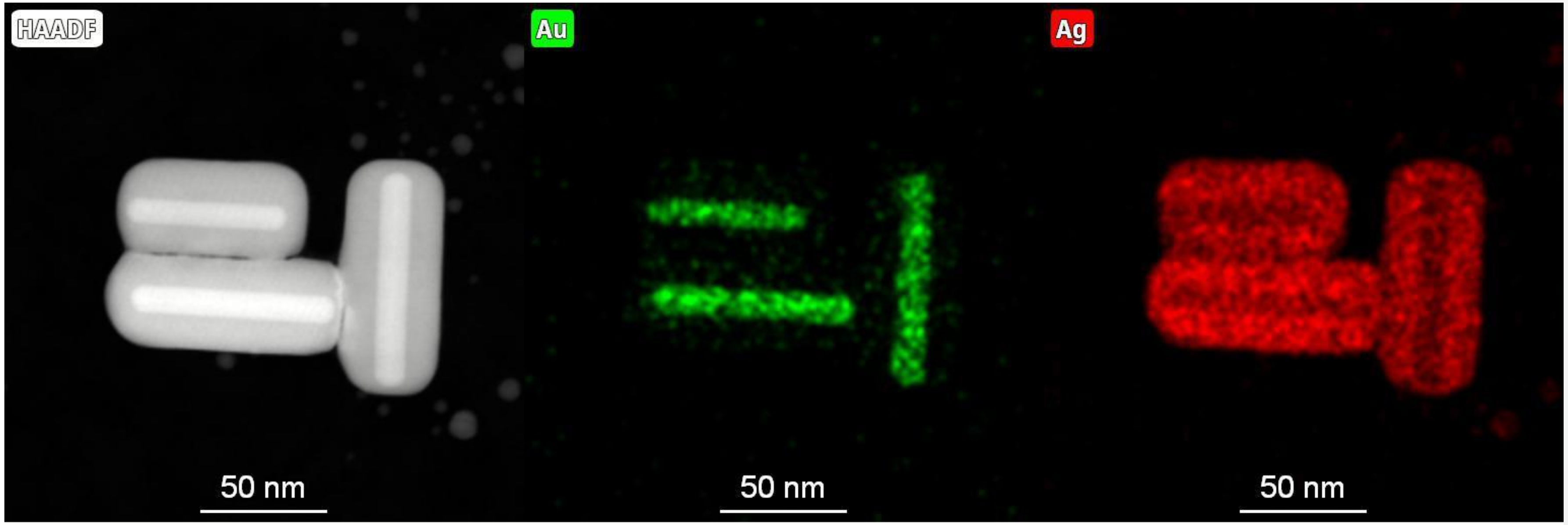
- Fast acquisition of large maps out of a complex structure and lightweight elements sensitivity.

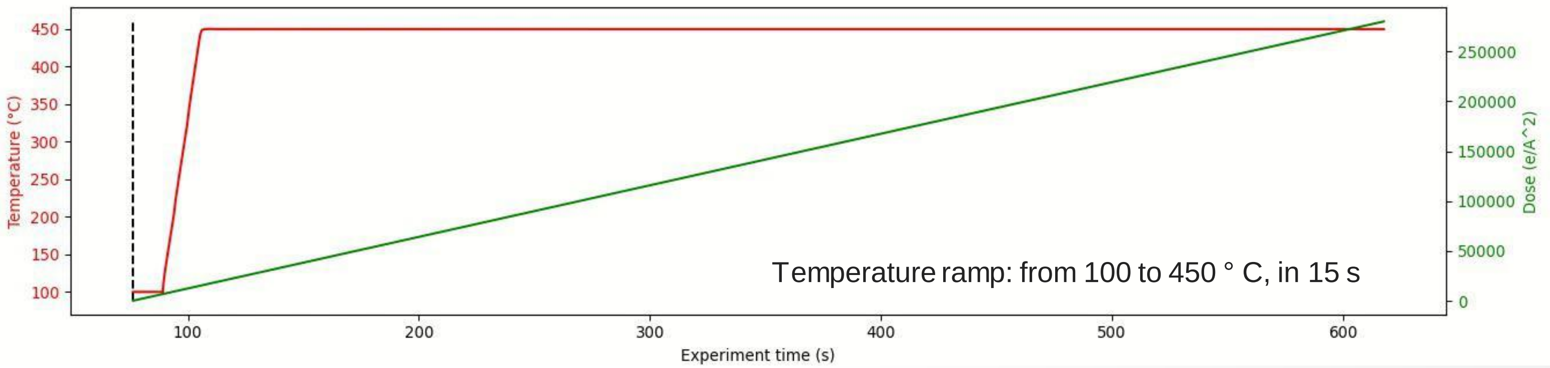
No significant variation of boron content is observed across the material.

Sample courtesy: National Institute for Materials Science, Tsukuba, Japan

Dynamic in situ EDS

Au-Ag Nanorods in situ Heating Experiments





System	Spectra Ultra X-CFEG, 300 kV
In situ holder	DENSsolutions Wildfire
Acquisition time	Total: 490 s, **EDS frames: 7.8 s each**
Maps size	256x256 pixels, pixel 818 pm
Dose per EDS frame	**4500 e^- / A^2**
Filter	Gaussian & radial Wiener

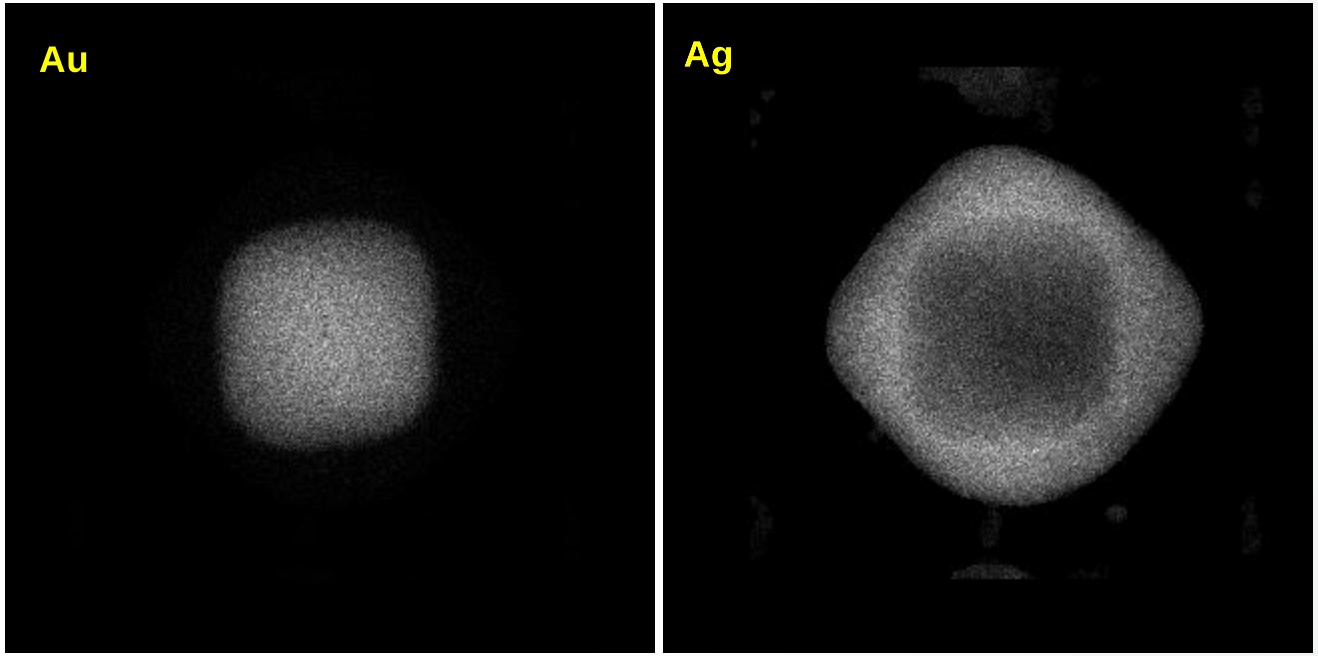
- The Ultra X EDS detector enables TRUE live chemical in situ imaging, fast and with the lowest electron dose.

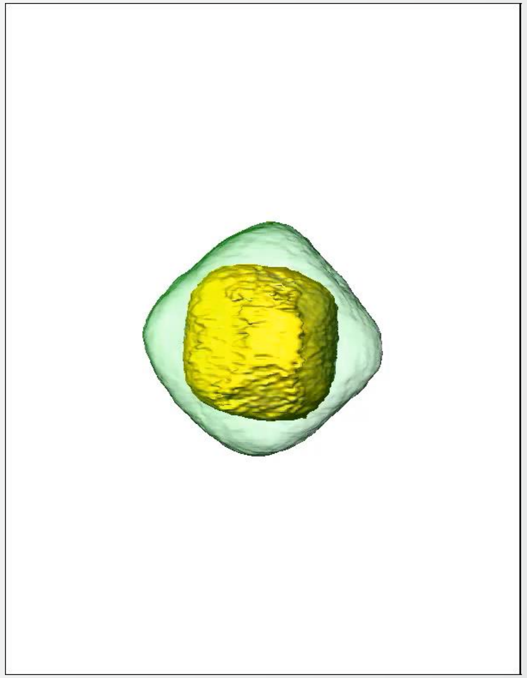
Acquisition: Cigdem Ozsoy-Keskinbora, TFS

EDS Tomography

AgAu-Octahedral Core-Shell

	HAADF-STEM	EDS maps
HT / Beam Current	200 kV, 150 pA	200 kV, 150 pA
Tilt Range	-72°~72° (3° step)	-70°~70° (10° step)
Size	1024*1024	256*256
Frame time	4 s	5 min
Pixel size	0.193 nm	0.386 nm





Quantified reconstructed EDS volume

Samples: Prof. Luis Liz-Marzán
Data analysis: Prof. S. Bals

CIC biomaGUNE MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE
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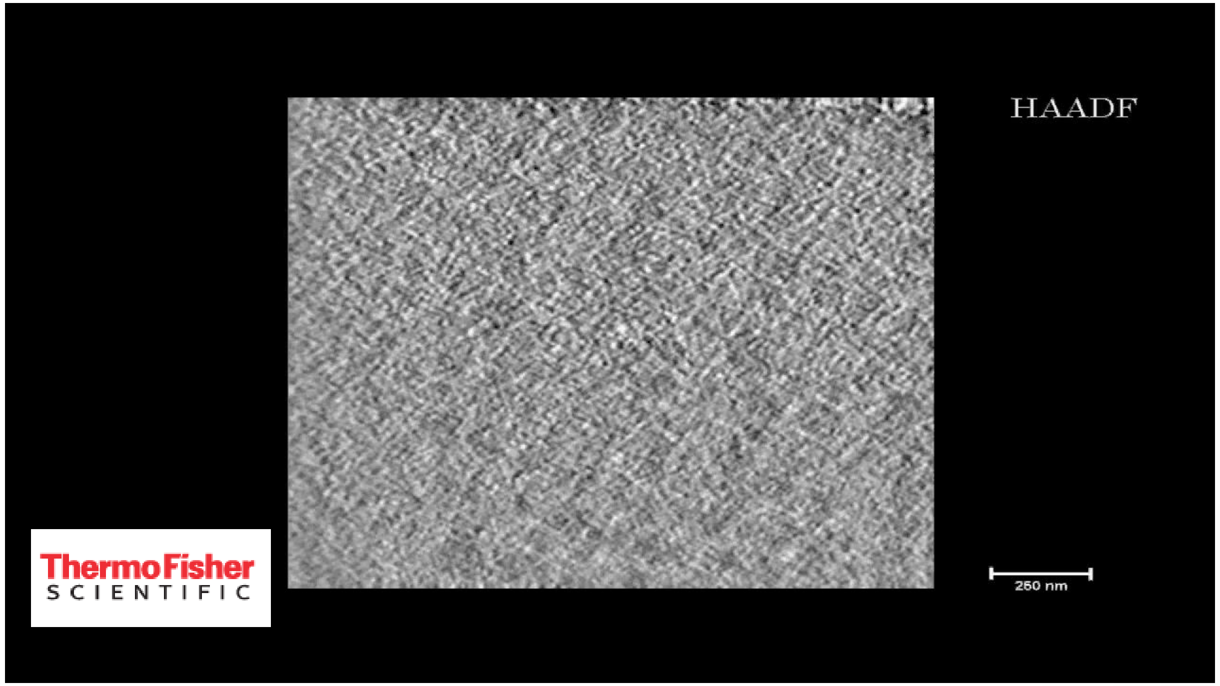
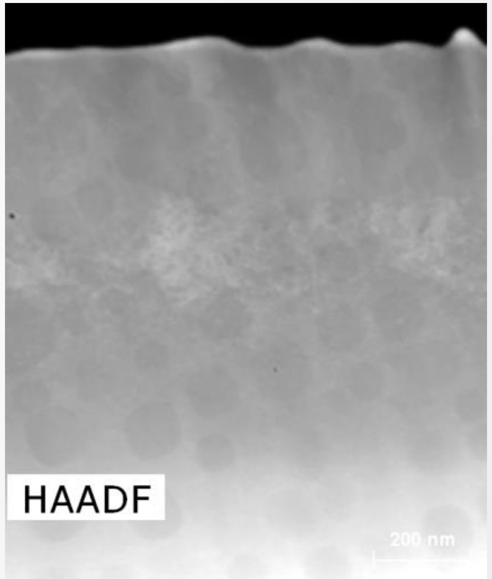
EMAT

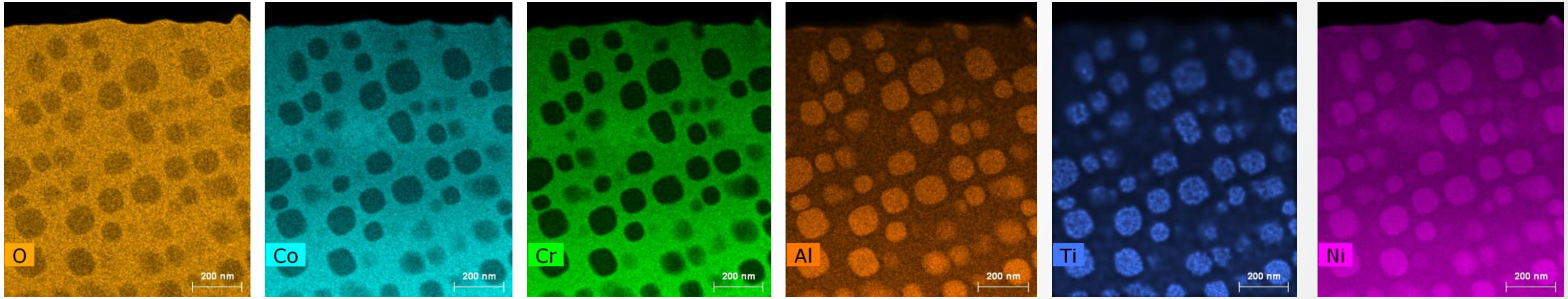
EDS Tomography

ThermoFisher SCIENTIFIC

3D EDS Compositional Map for the Super Alloy Sample

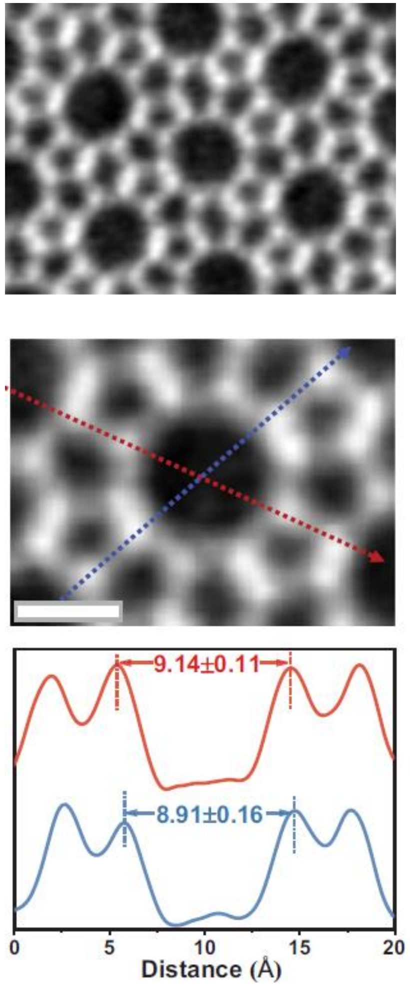


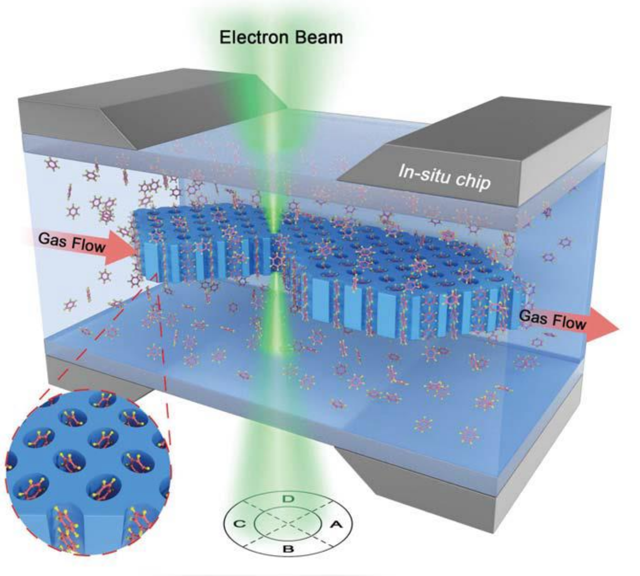




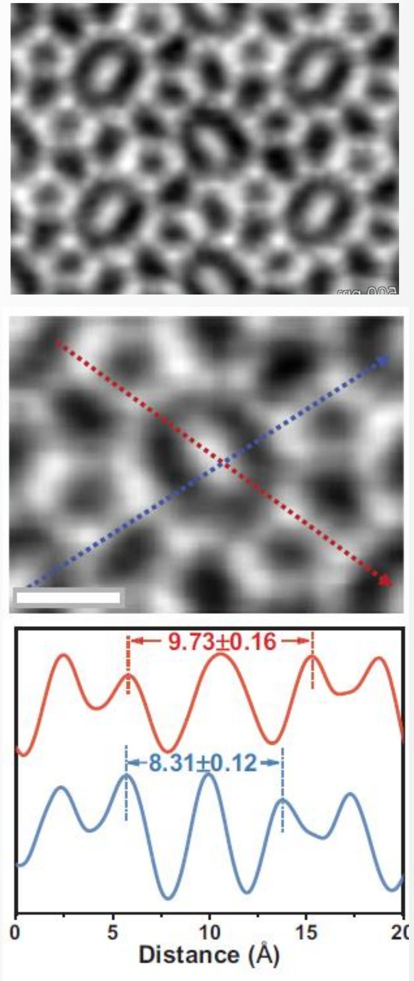
In Situ iDPC STEM

High Contrast Low Dose Imaging





The adsorption-induced deformation of the pores, occurring when benzene is flown over the ZSM-5 zeolite, can easily be tracked by live i-DPC.

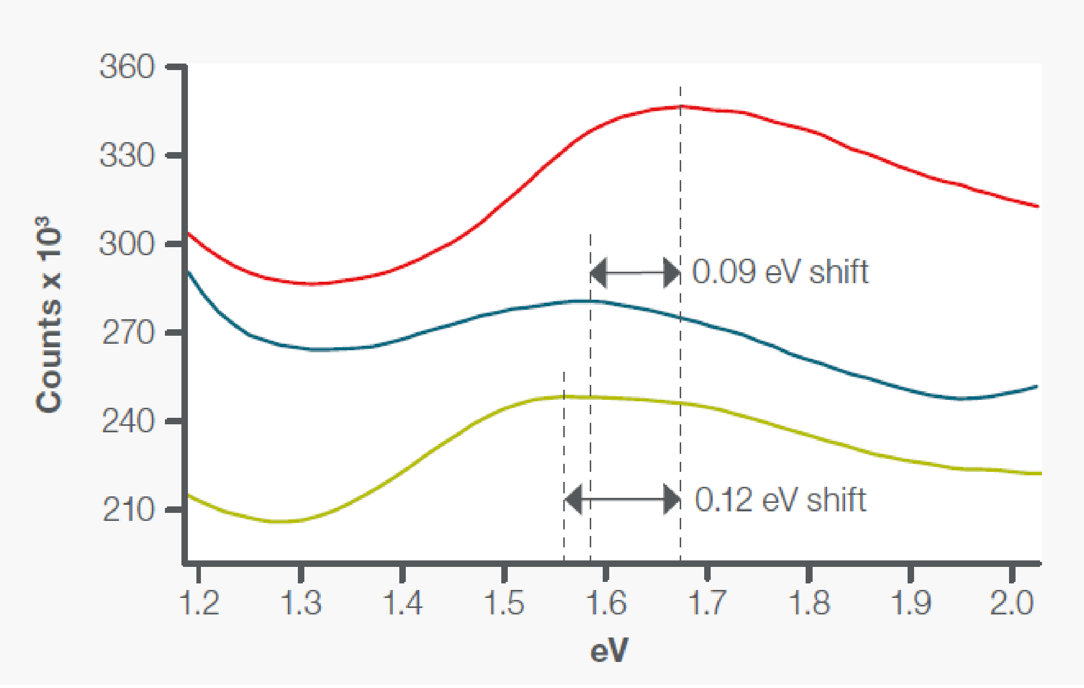


Accelerating Voltage	300 kV
Beam Current	0.1 pA
Total Dose	**$636\ e^- / A^2$**

ZSM-5 Zeolite, Xiong et al., Science (2022), 376, Issue 6592, pp 491-496. Tsinghua University

High-Resolution EELS

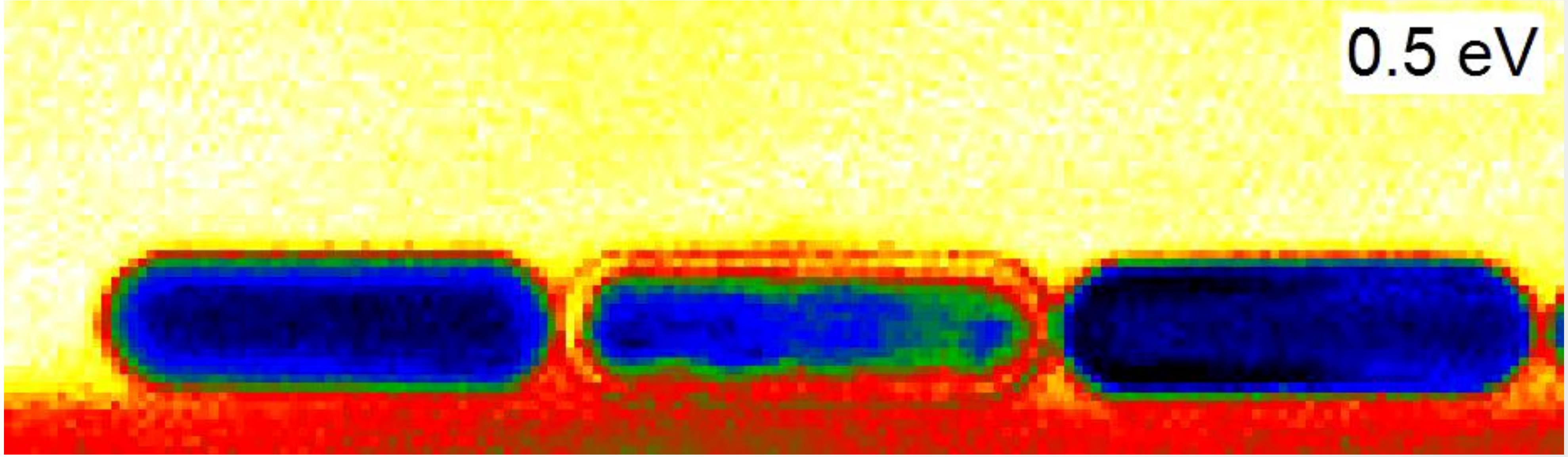
Gold Nanorods: Surface Plasmon Resonances



Sample courtesy: Prof. Sara Bals, University of Antwerp

High-Resolution EELS

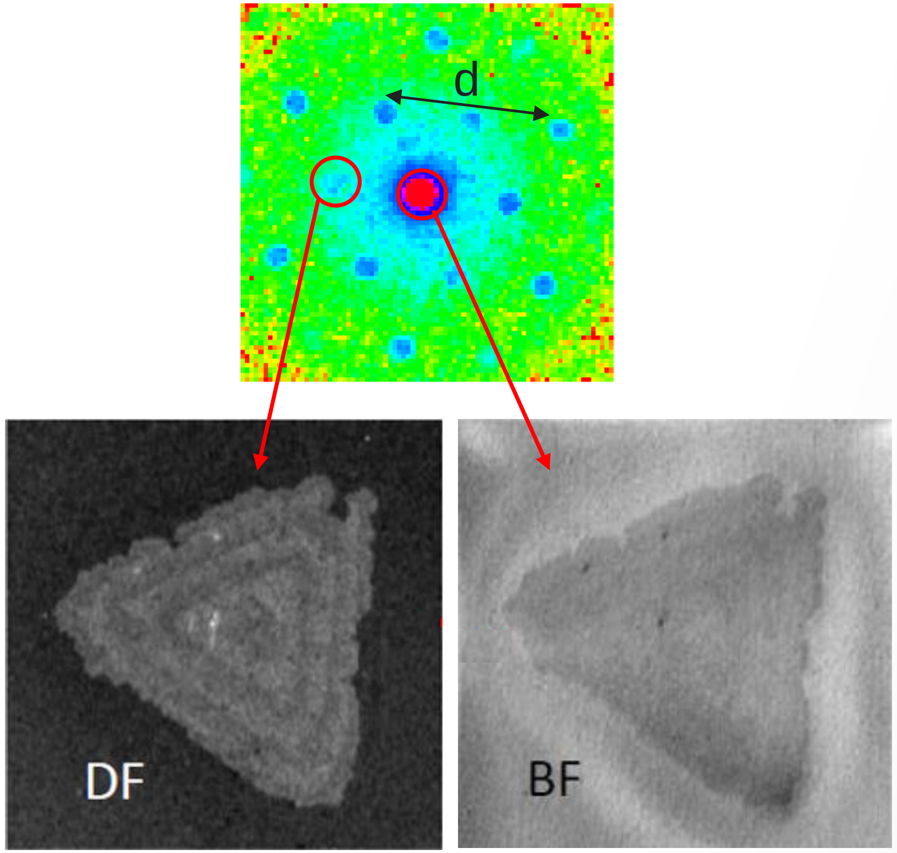
Gold Nanorods: Surface Plasmon Resonances



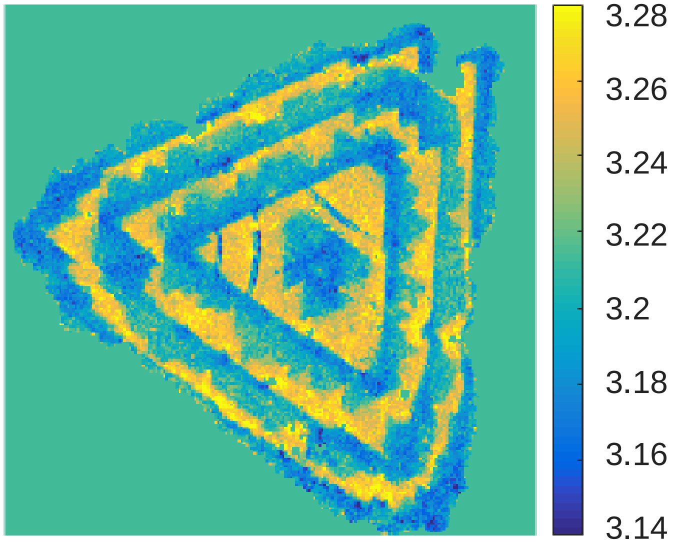
Sample courtesy: Prof. Sara Bals, University of Antwerp

Electron Microscope Pixel Array Detector (EMPAD)

EMPAD Diffraction Mapping: Monolayer WS_2/WSe_2 Heterostructure on 10 nm Silicon Nitride



d-spacing map



Lattice constant (Å)

Data courtesy: David Muller, Cornell University

Thank you