COVALENT METROLOGY

Welcome

COVALENT METROLOGY

ADVANCED ANALYTICAL SCANNING TRANSMISSION ELECTRON MICROSCOPY (STEM), AND FUTURE DIRECTIONS

SPEAKER:
Patrick Phillips, PhD
Asst. TEM Product Manager,
JEOL USA

March 24, 2022 | 11am PT

JEOL Solutions for Innovation

COVALENT METROLOGY

COVALENT ACADEMY

Advancements in Instrumentation Series

Episode 31

COVALENT METROLOGY

Silicon Valley-based analytical labs and platform delivering quality data and expert analysis for advanced materials and device innovation

Comprehensive Solutions Stack

50+ cutting-edge instruments, offering 100+ Techniques

Analytical Services

Advanced Modeling

Method Development

Temp. Staffing Solutions

Affordable and Fast

Fast Turnaround Times

Volume Savings

Instant Access to Data and Reports in Secure Portal

Flexible Business Model

Custom Consulting Solutions and Certified Onsite Support

Training and Certification on Instrumentation

Co-op and Tool-Share Opportunities

Laboratory Audits

Rigaku
Anton Paar
ThermoFisher SCIENTIFIC
Asylum Research an Oxford Instruments company
KEYENCE
J.A. Woollam
TA Instruments
PVA TePla
TELEDYNE CETAC TECHNOLOGIES Everywhereyoulook
HORIBA Scientific
Digital Surf
JEOL Solutions for Innovation

Rich Network of Partnerships

Partner to World's Leading Instrument Manufacturers and Labs

Expanding Instrumentation, Lab Connections and Learning

Who We Are, Who We Serve

500+ Clients, 40-60 Added / Quarter

60+ People, 16 PhDs

Cutting-edge Analytical Capabilities

Lab Location: Sunnyvale, CA

Covalent Technical Groups and Organization

COVALENT METROLOGY

PCBA, Semiconductor, and Electronic Device Metrology & Failure Analysis

- DPA / Mechanical Cross-section
- Dye & Pry Test
- EBIC / OBIC failure analysis
- Hot Spot Detection
- IR Imaging / Emission Microscopy
- NIR Imaging
- Root-Cause Failure Analysis

Electron Microscopy and Scanning Probe Microscopy

- AFM & Advanced AFM Modes (EFM, KPFM, MFM, PFM)
- Scanning Acoustic Microscopy (SAM)
- SEM (+ EDS)
- FIB-SEM (+ EDS)
- S/TEM (+ EDS / + EELS)
- Nano-indent / Nano-scratch

Optical Microscopy & Spectroscopy

- Chromatic Aberration
- Digital Optical Microscopy
- FTIR and ATR-FTIR
- Laser Scanning Confocal Microscopy
- Spectral Ellipsometry
- UV-Vis-NIR Spectroscopy
- White Light Interferometry

X-Ray Characterization

- X-Ray Diffraction (XRD)
- X-Ray Reflectometry (XRR)
- Micron-spot ED-XRF
- WDXRF
- Micro-computed X-ray Tomography (Micro-CT)
- 2D X-ray Inspection & X-ray Radiography

Elemental / Chemical Composition Analysis

- EPMA
- GD-OES
- GC-MS
- ICP-MS and LA-ICP-MS
- Raman Microscopy & Spectroscopy
- NMR (1D or 2D; solid / liquid)

Particle Analysis

- Dynamic Light Scattering (DLS)
- Laser Diffraction Particle Size Analysis (PSA)
- Particle Zeta Potential

Material Property Characterization

- DSC
- DMA & TMA
- Rheometry
- TGA
- Surface Zeta Potential
- Porometry
- Porosimetry / Gas Adsorption
- Gas Pycnometry
- Foam Density
- Tap Density

Surface Spectroscopy Analysis

- Dynamic-SIMS
- ToF-SIMS (Static-SIMS)
- Ion Scattering Spectroscopy (ISS)
- Ultraviolet Photoelectron Spectroscopy (UPS)
- X-ray Photoelectron Spectroscopy (XPS)

Covalent Partners

JEOL Solutions for Innovation

- **JEOL** is a global leader in cutting-edge microscopy, analytical chemistry, and materials characterization instrumentation
- **New JEOL USA demonstration facility** opened within Covalent's Silicon Valley lab to deepen JEOL presence in the region
  - **Hosts top-of-line electron microscopes and spectrometers** from JEOL, installed throughout 2021 – 2022
- Partners will collaborate to deepen understanding of Silicon Valley markets' analytical needs and **guide the development of next-generation hardware, software, and applications research**

Other Covalent Partners

- Rigaku
- ThermoFisher Scientific
- Anton Paar
- KEYENCE
- J.A. Woollam
- PVA TePla
- Asylum Research an Oxford Instruments company
- TA Instruments
- Digital Surf
- HORIBA Scientific
- TELEDYNE CETAC TECHNOLOGIES Everywhereyoulook™

Patrick Phillips

Assistant TEM Product Manager, JEOL USA

- PhD in Materials Science and Engineering in 2012 from The Ohio State University
- Research Assistant Professor at the University of Illinois – Chicago
- Joined JEOL USA in 2016
- Previous research projects and current interests include:
  - Cs-Corrected STEM/EELS/EDS of metals
  - Battery materials
  - Oxides
  - 2D structural characterization

Advanced Analytical STEM and Future Directions

JEOL USA

Brief Outline

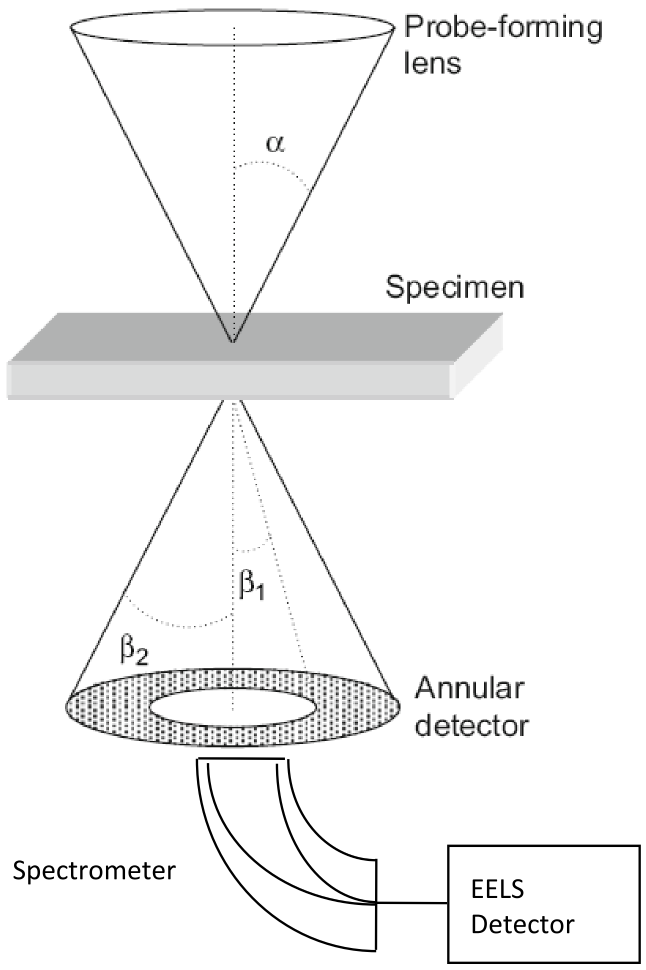
- Introduction/Current Capabilities
- Critical Technology
- How Far Can We Go with “Workhorse” S/TEMs?
- Looking Beyond

    Advanced Applications and Cs-correction

Why Scanning Transmission Electron Microscopy?

- Robust to thickness and defocus changes (no contrast reversals)
- Thick specimen imaging
- Defect analysis
- Structural determination
- Changing β yields multitude of signals
  - HAADF (~Z^2 intensity)
  - LAADF (strain contrast)
  - ABF (light element contrast)
- Wealth of structural, chemical, and electronic information at the atomic scale
- Spatially-resolved analytical information with EDS/EELS

Simplified Lens system for STEM

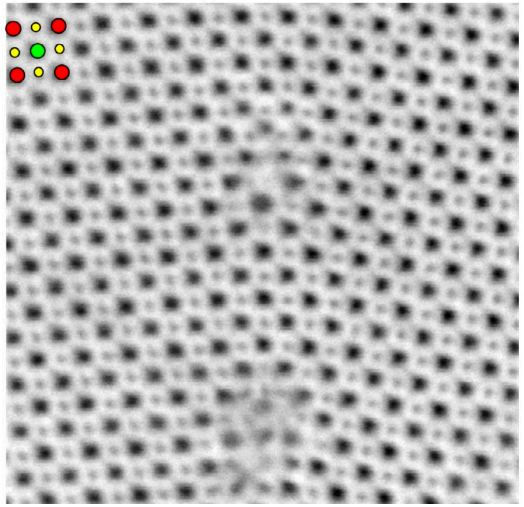


The Needs of Analytical Microscopy

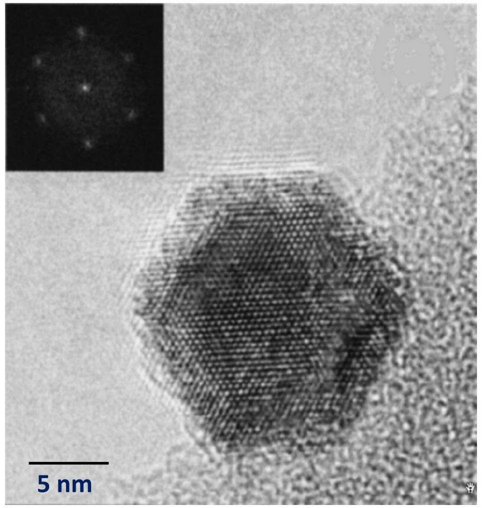
- Good source of electrons
- High spatial resolution
- Analytical characterization
  - Chemical sensitivity
  - Fine structure
- Good sampling rates
- Reduced beam damage

Can we do all this in a "workhorse" S/TEM??

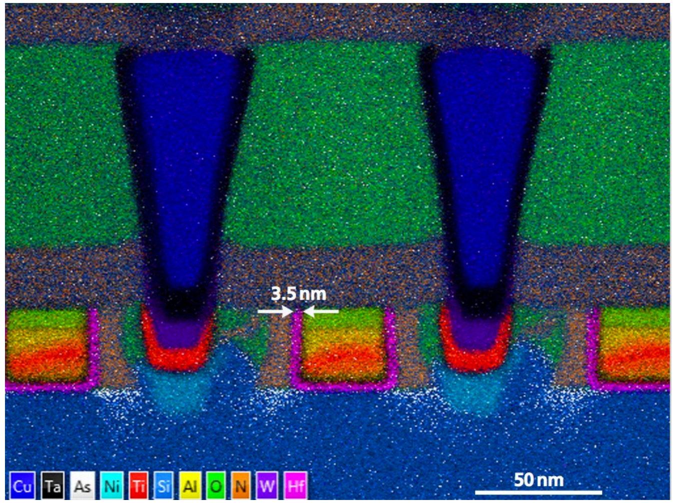
Dislocation core in STO:



HRTEM of Nanoparticle:



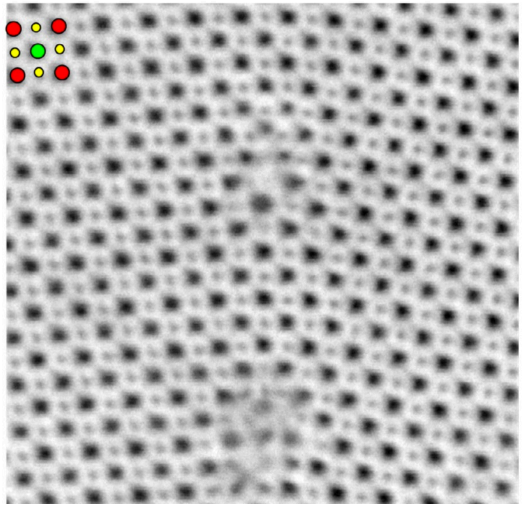
Chemical analysis of semiconductor:



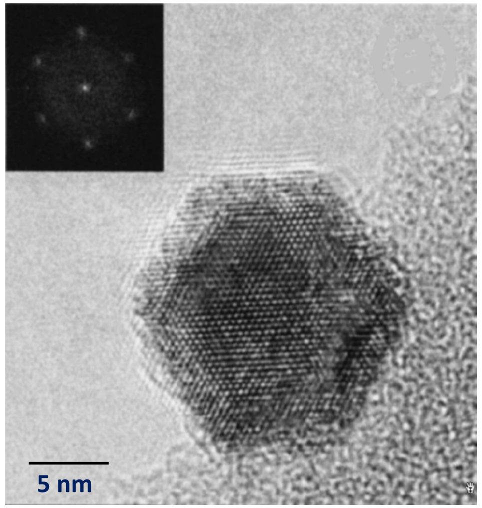
Common Perceptions of "Workhorse" Instruments

- ***Low Spatial Resolution***
- ***200 kV only to maintain spatial resolution***
- ***EDS Spectroscopy***
  - Time consuming
  - Low magnification
  - Lack of probe current/resolution capabilities for high-mag mapping
- ***Electron Energy Loss***
  - Core-loss mapping OK
  - Fine structure determination not possible

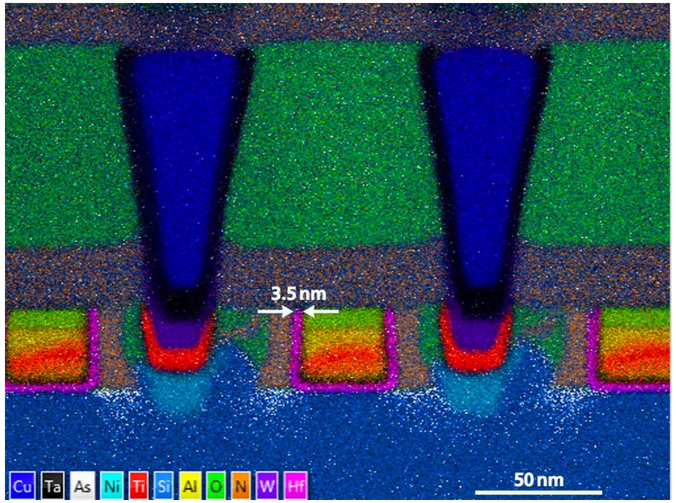
Dislocation core in STO:



HRTEM of Nanoparticle:

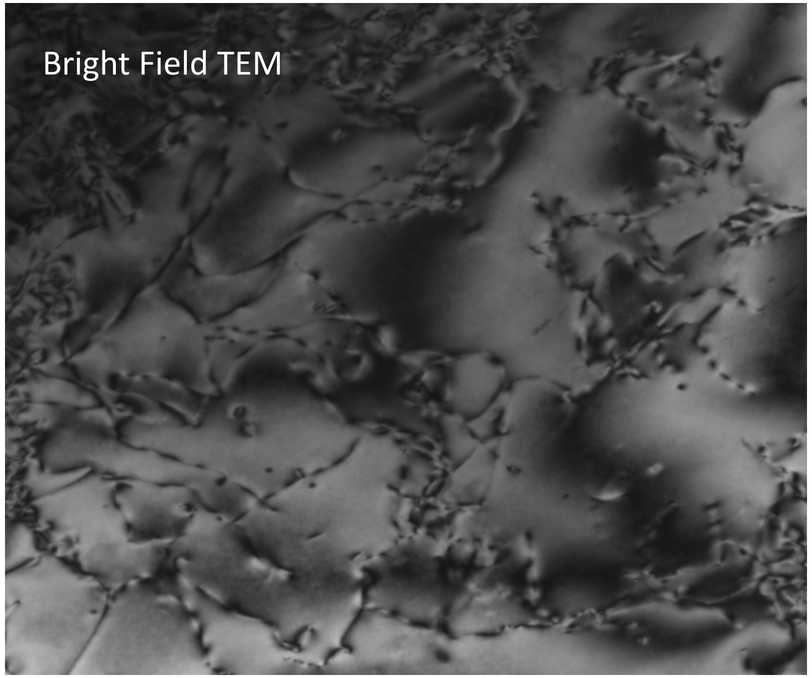


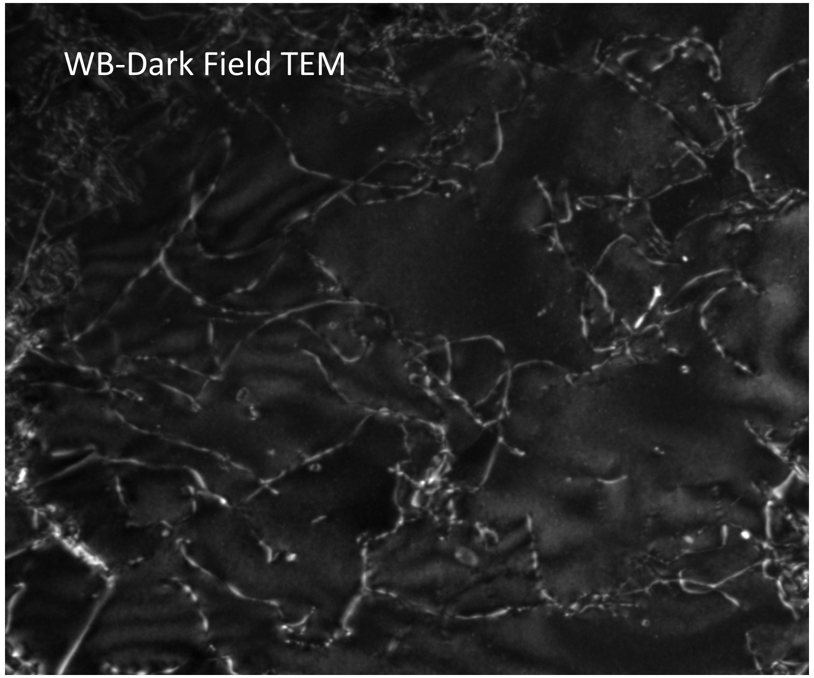
Chemical analysis of semiconductor:



"Workhorse" S/TEM in Reality…

- ***High Spatial Resolution***
  - Cold FEG, redesigned electron optics, highly stabilized column
  - Conventional TEM

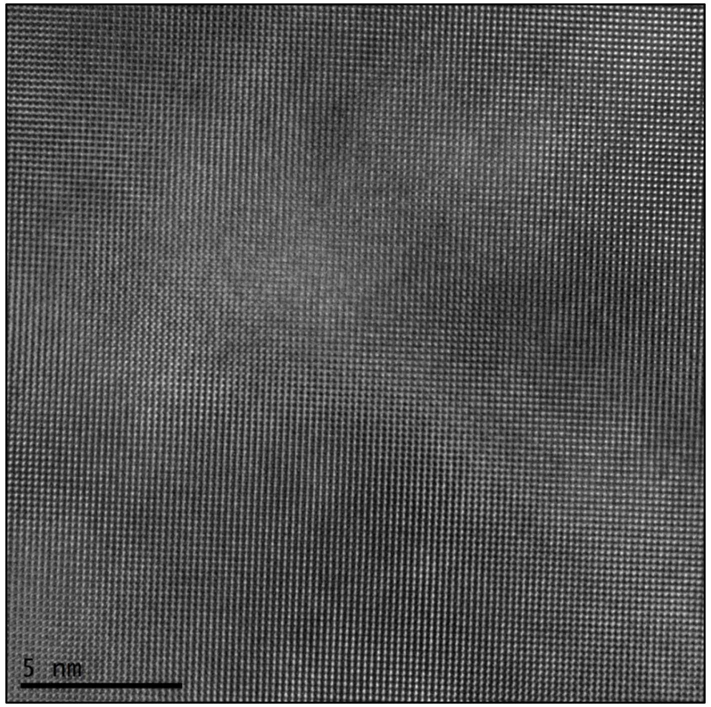




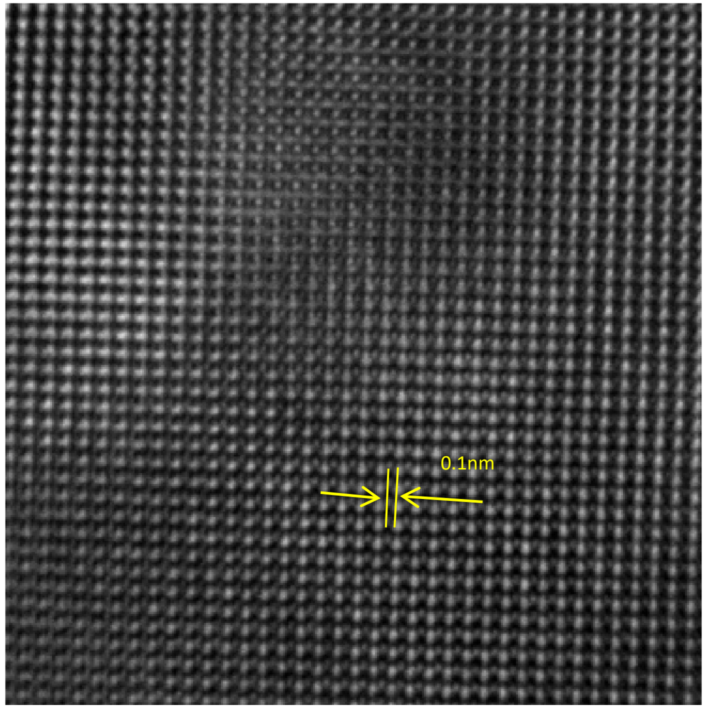
Overaged Al alloy, incident beam parallel to [110]
200kV

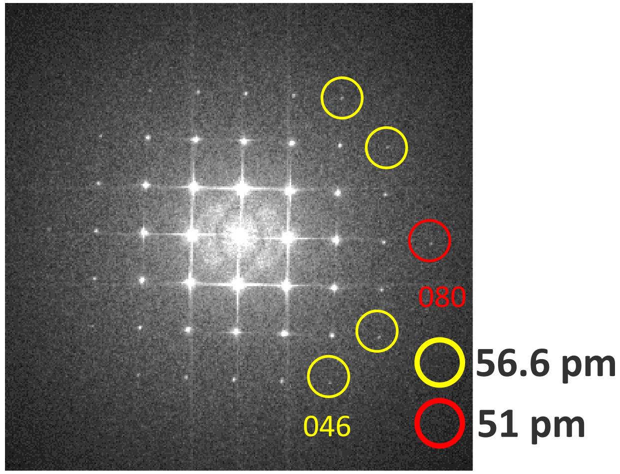
"Workhorse" S/TEM in Reality…

- ***High Spatial Resolution***
  - Cold FEG, redesigned electron optics, highly stabilized column
  - Conventional TEM
  - High-resolution TEM



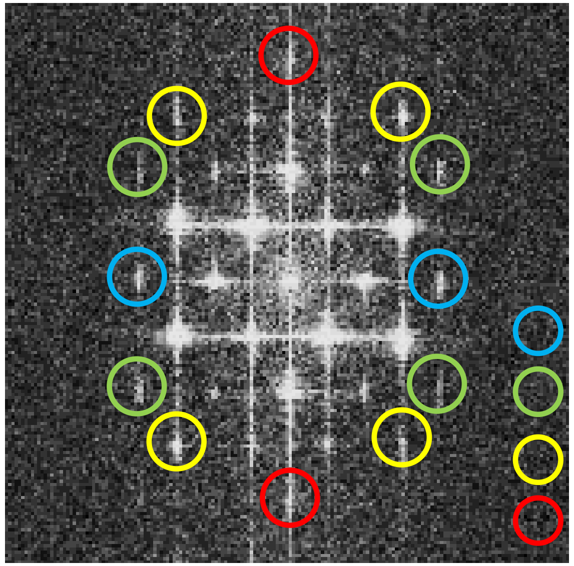
Au [100]
200kV



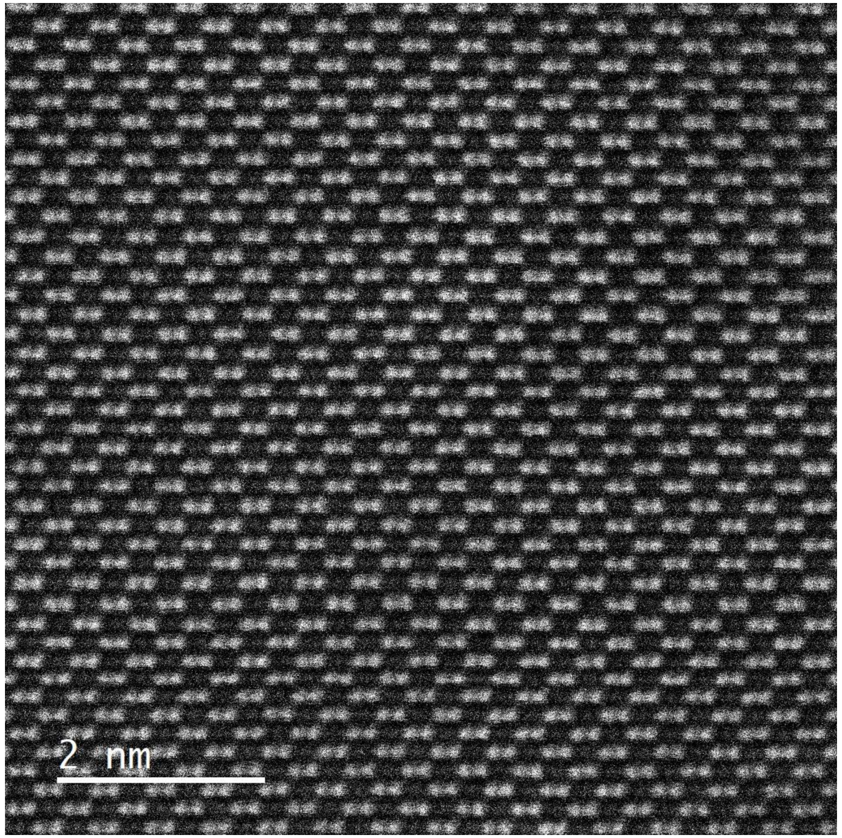


"Workhorse" S/TEM in Reality…

- ***High Spatial Resolution***
  - Cold FEG, redesigned electron optics, highly stabilized column
  - Conventional TEM
  - High-resolution TEM
  - High-resolution STEM



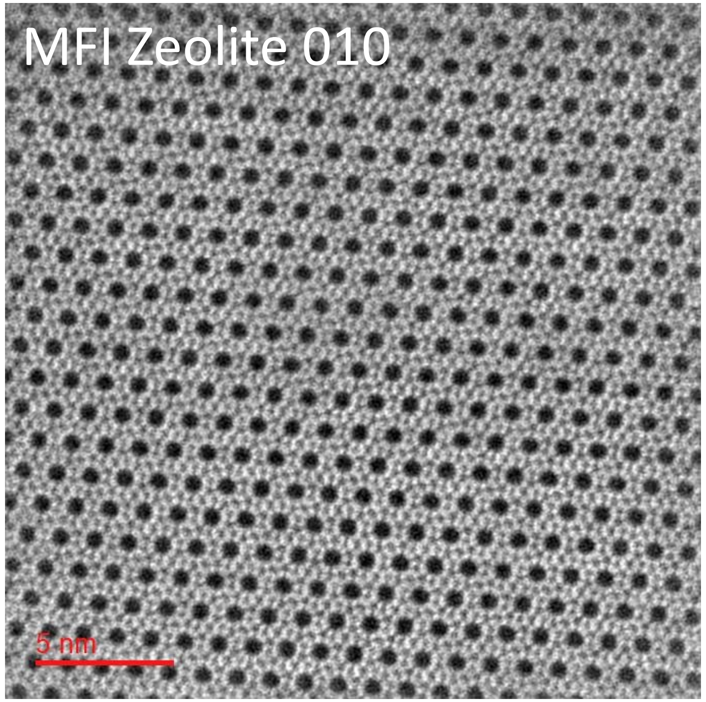
136 pm
111 pm
104.5 pm
96 pm

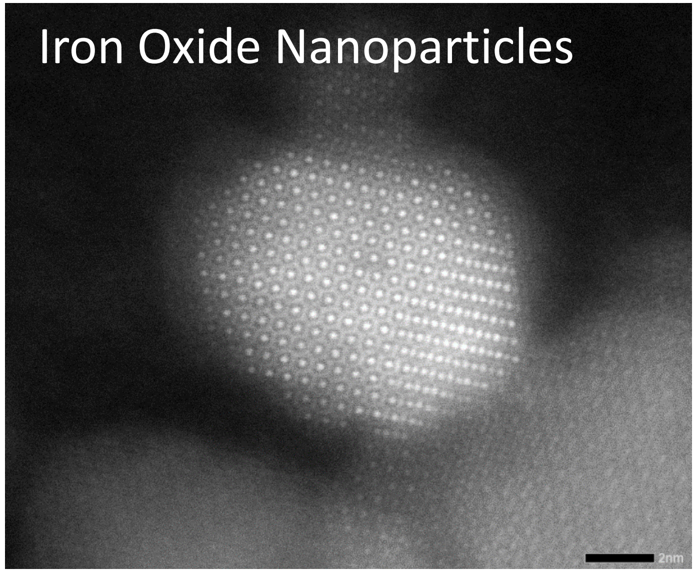


Sample : Si(110)
Acc. : 200 kV
Probe current : 21 pA
N. of pixel : 1024 x 1024

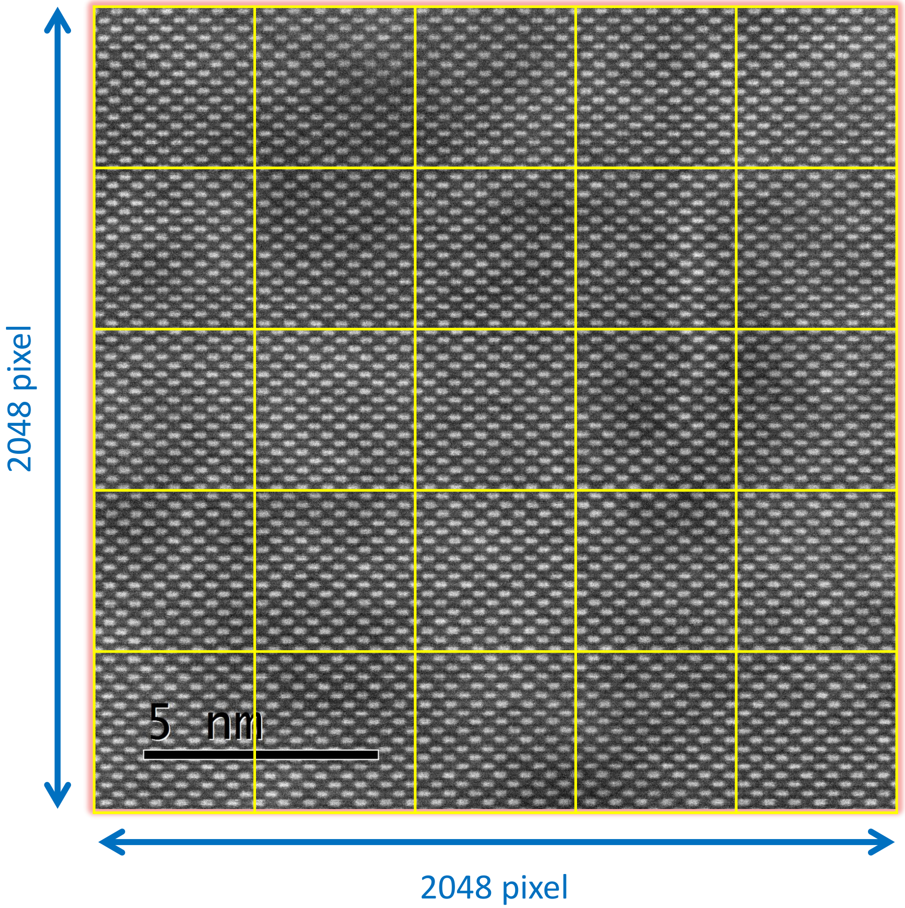
"Workhorse" S/TEM in Reality…

- ***High Spatial Resolution***
  - Cold FEG, redesigned electron optics, highly stabilized column
  - Conventional TEM
  - High-resolution TEM
  - High-resolution STEM





probe current : 1 pA

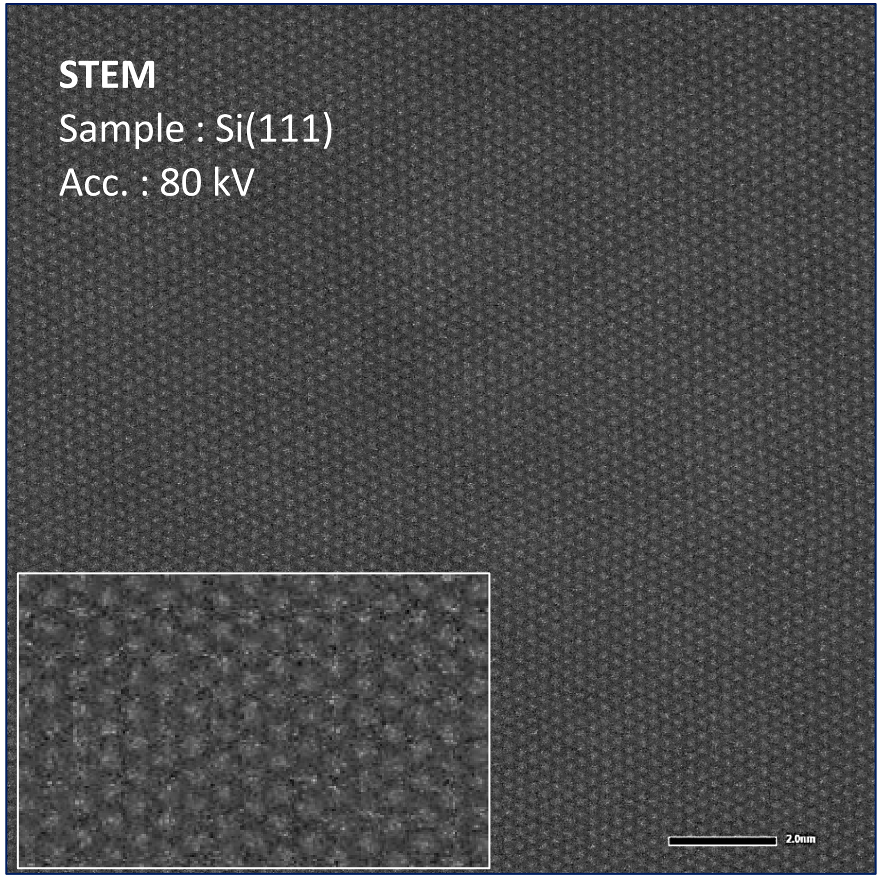


Sample : Si(110)
Acc. : 200 kV
N. of pixel : 2048 x 2048

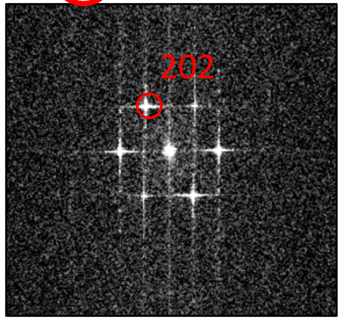
Total acquisition time 2min 45sec

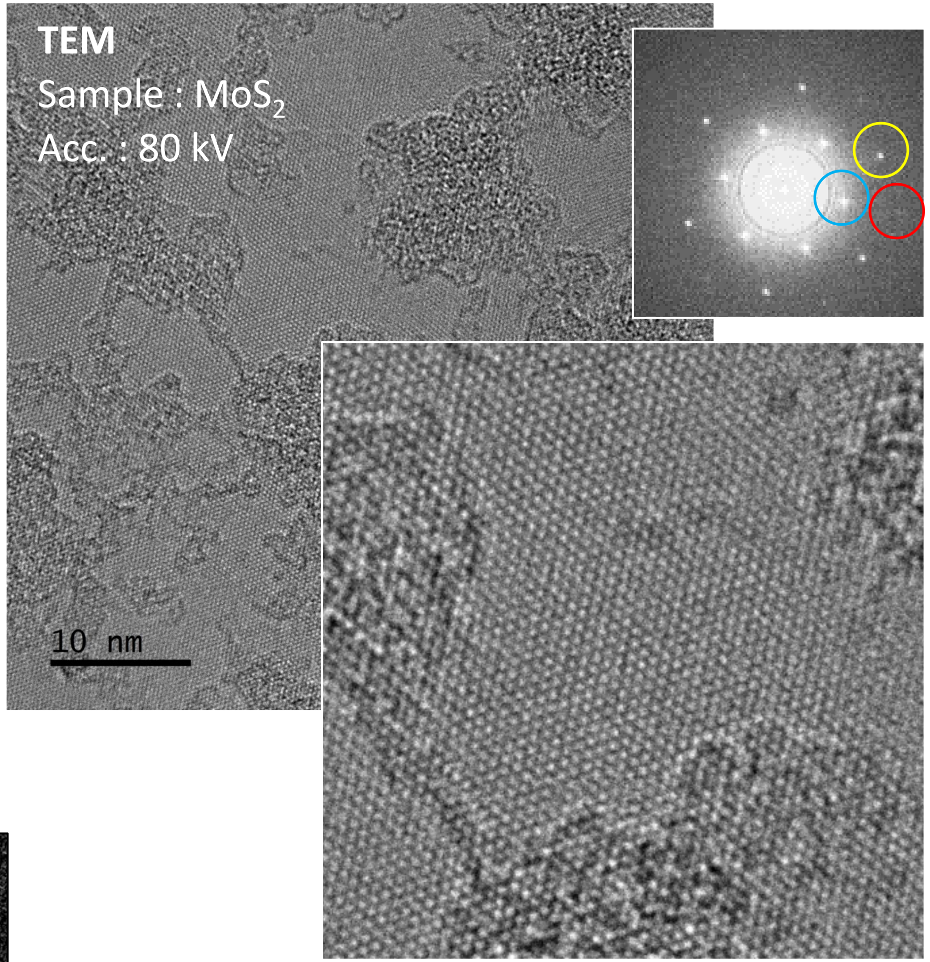
"Workhorse" S/TEM in Reality...

- ***Low kV OK***
  - Cold FEG helps retain spatial resolution at lower voltage



192 pm



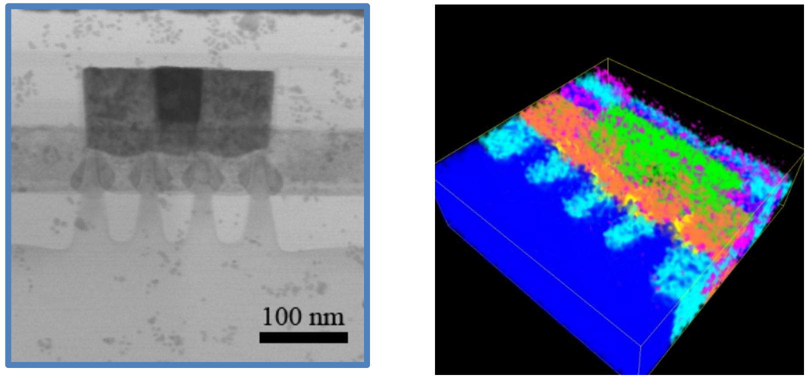


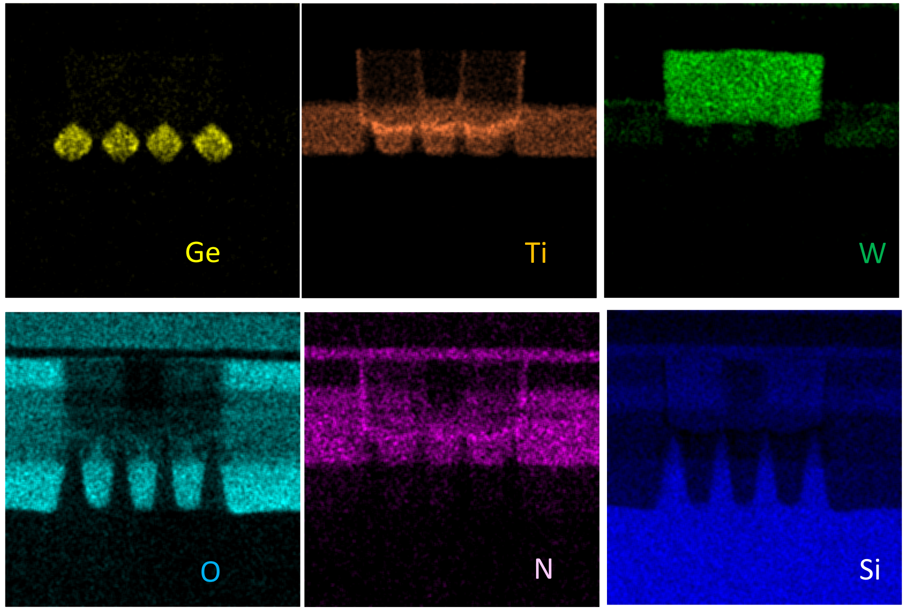
274 pm
158 pm
137 pm

"Workhorse" S/TEM in Reality…

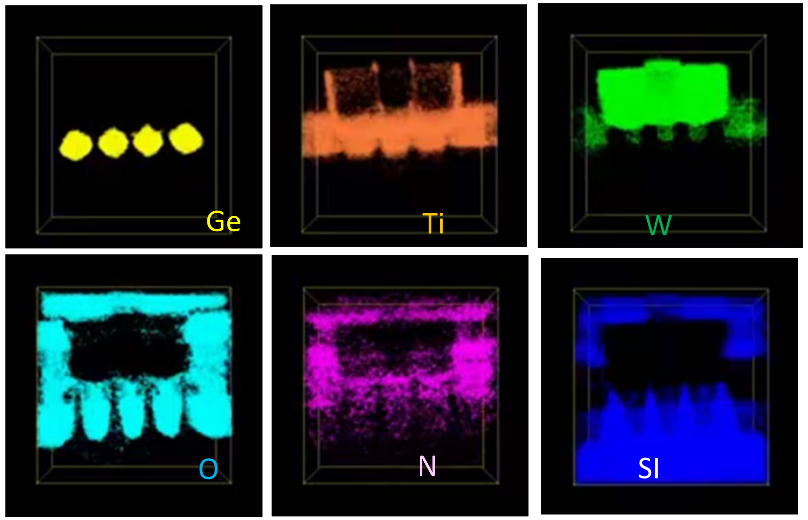
- ***EDS Spectroscopy***
  - Flexible probe current conditions which maintain spatial resolution
  - Advanced detector technology
  - Routine, large-area maps, 3D Tomography reconstructions

Semiconductor Device





2D elemental Maps

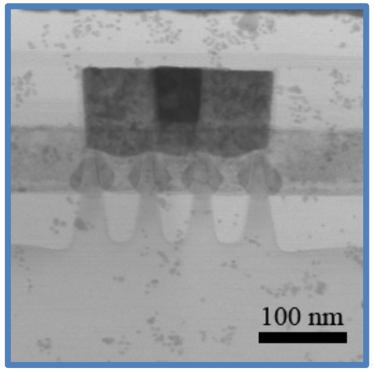


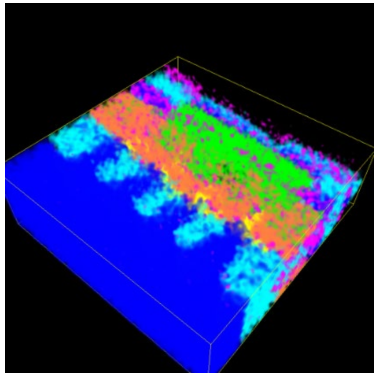
Reconstructed 3D EDS maps

"Workhorse" S/TEM in Reality…

- ***EDS Spectroscopy***
  - Flexible probe current conditions which maintain spatial resolution
  - Advanced detector technology
  - Routine, large-area maps, 3D Tomography reconstructions

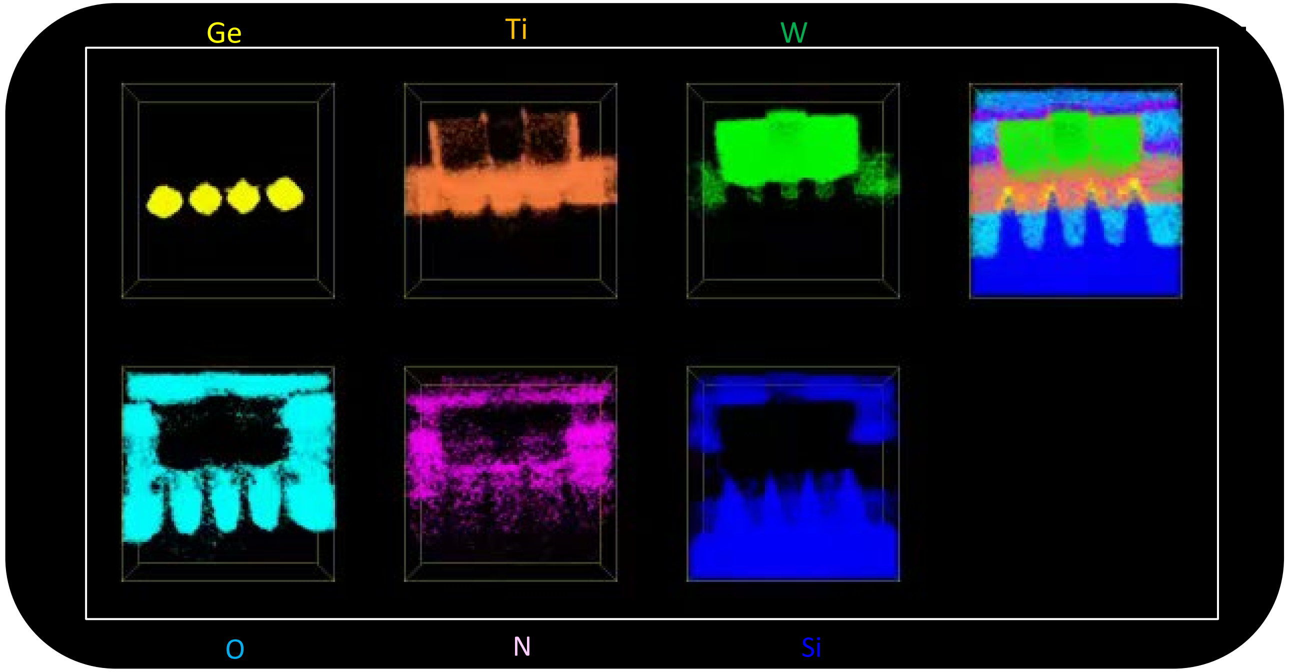
Semiconductor Device





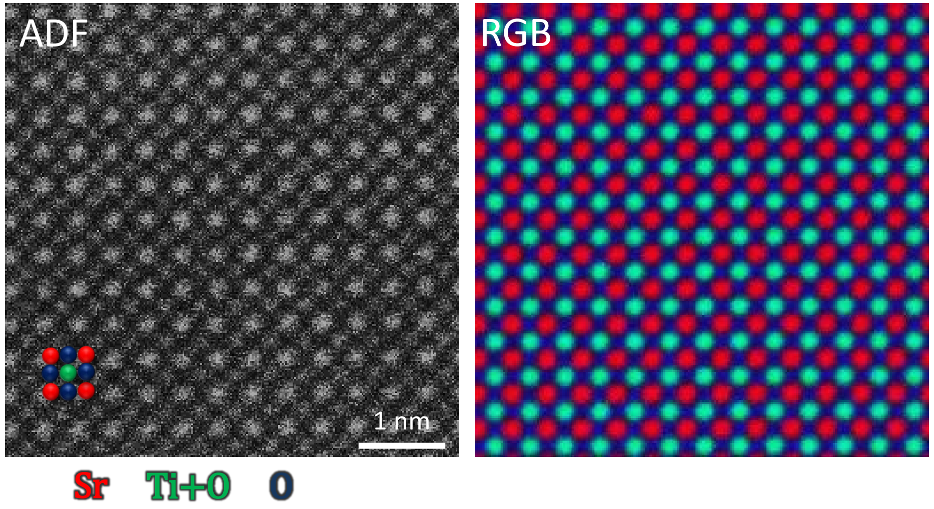
EDS Tomography Reconstruction

Volume = 313 x 313 x 100 nm^3

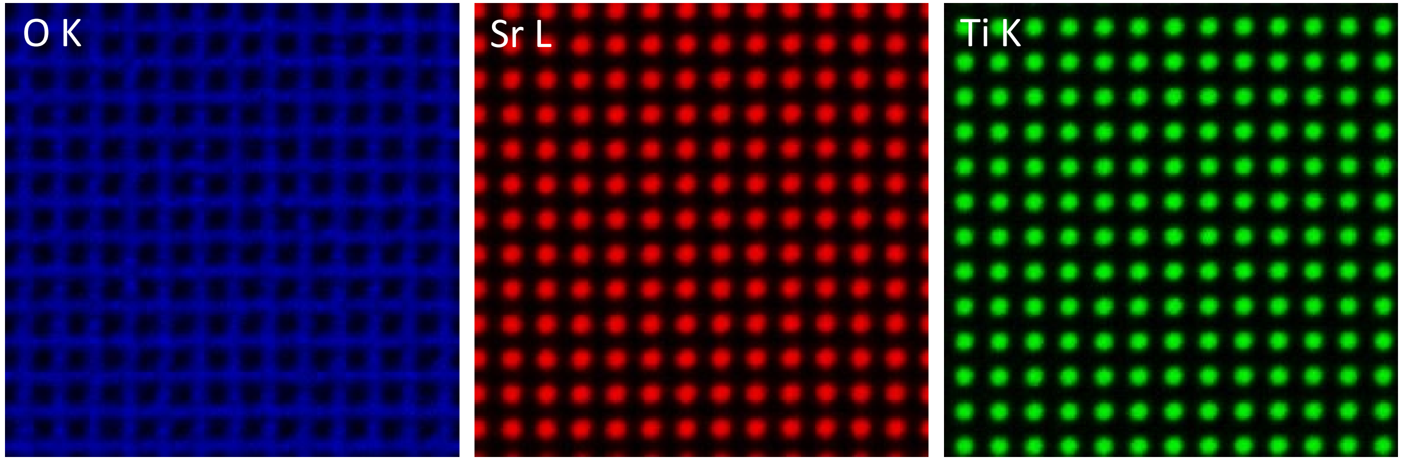


"Workhorse" S/TEM in Reality…

- ***EDS Spectroscopy***
  - Flexible probe current conditions which maintain spatial resolution
  - Advanced detector technology
  - Routine, large-area maps, 3D Tomography reconstructions
  - Atomic-resolution mapping



Sample : **$SrTiO_3$[100]**
Probe currents : 50.2 pA
N. of pixels : 256 x 256
Acquisition time : 10 min

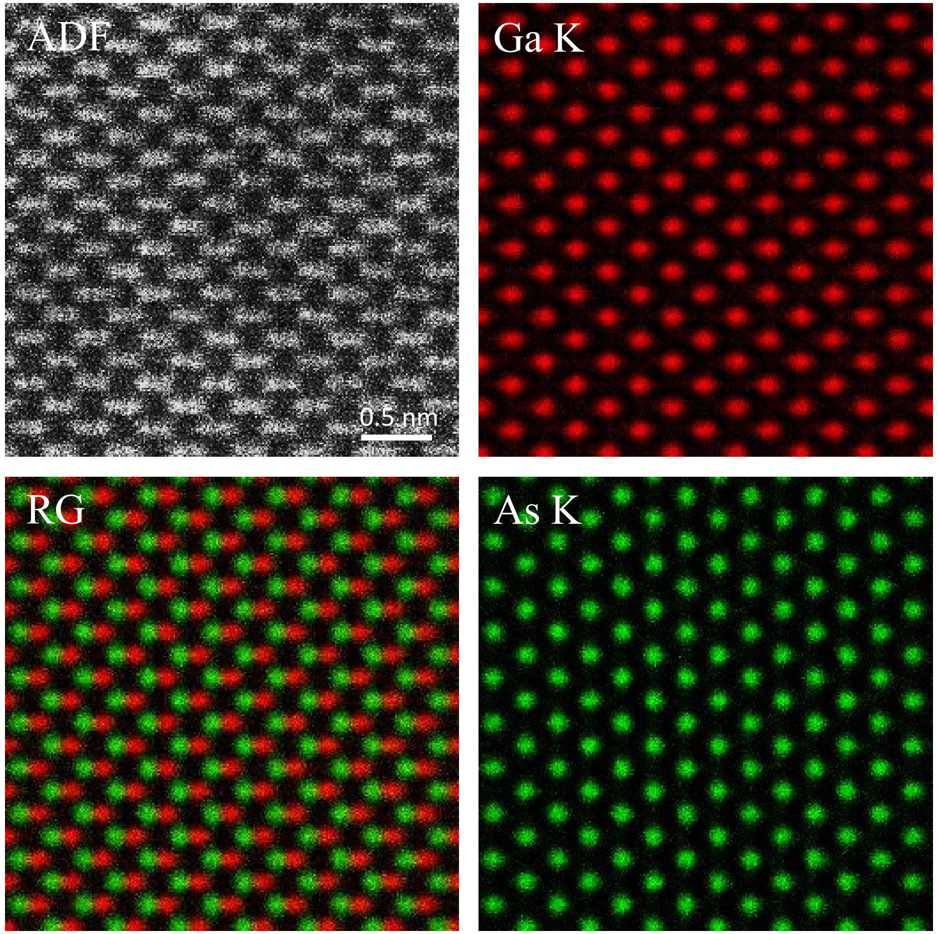


Not only Sr and Ti, but also O atomic sites can be visualized.

"Workhorse" S/TEM in Reality…

- ***EDS Spectroscopy***
  - Flexible probe current conditions which maintain spatial resolution
  - Advanced detector technology
  - Routine, large-area maps, 3D Tomography reconstructions
  - Atomic-resolution mapping

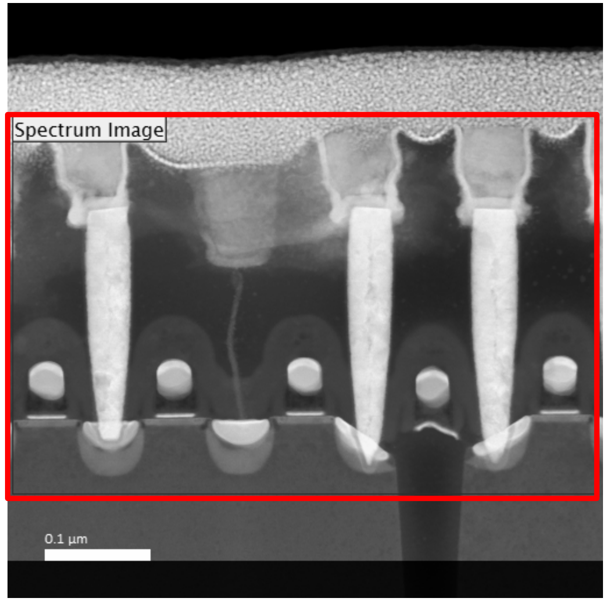
Sample : **GaAs[110]**
Probe currents : 20.5 pA
N. of pixel : 256 x 256
Acquisition time : 10 min



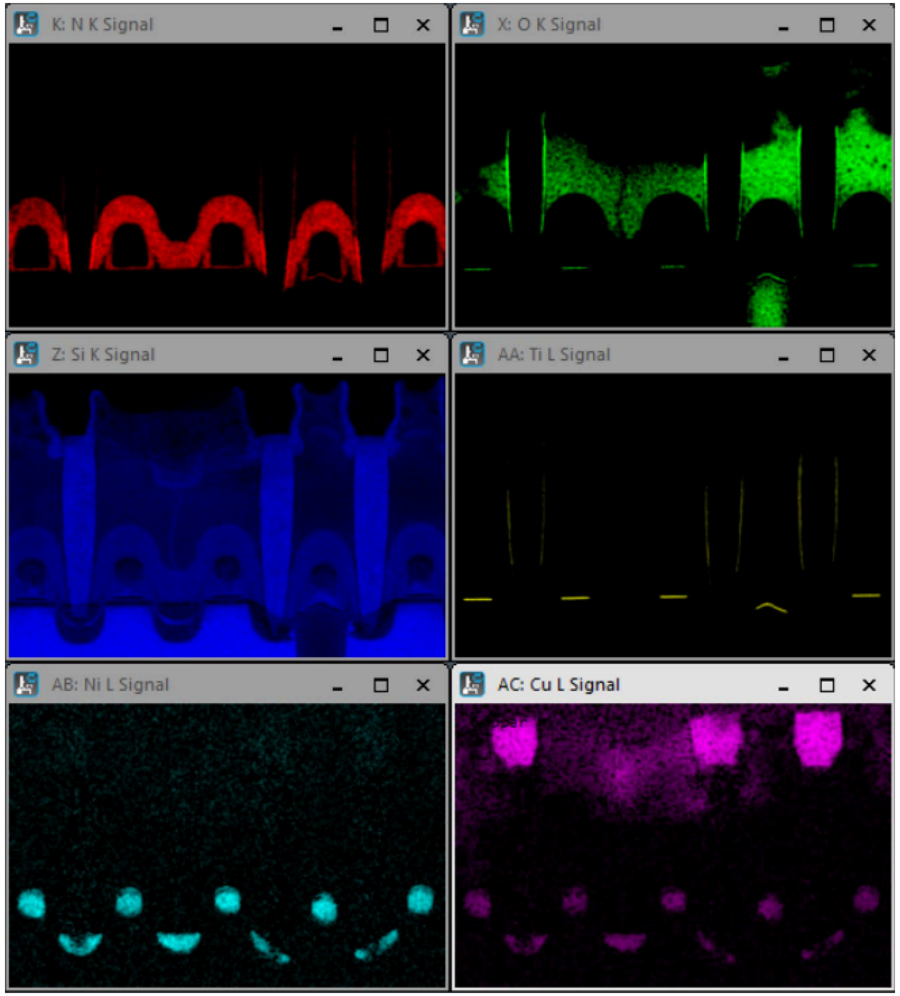
The dumbbell structure of Ga and As (0.14 nm) can be visualized by EDS.

"Workhorse" S/TEM in Reality...

- ***Electron Energy Loss***
  - CFEG energy resolution of 0.33 eV
    - 2-3x better than TFEG
    - Probe current and spatial resolution retained for mapping and fine structure
  - Core-loss

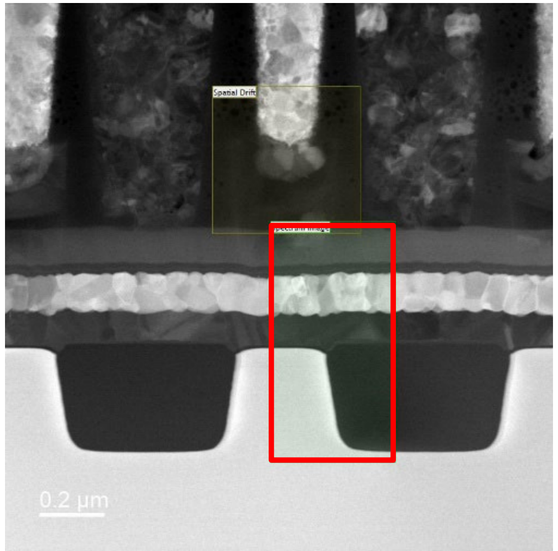


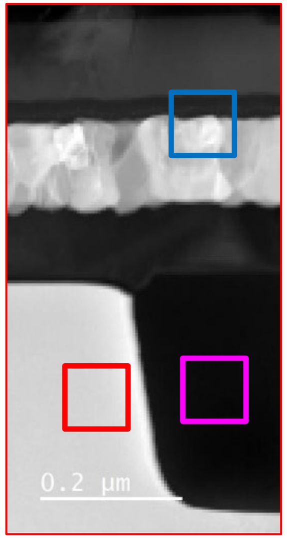
Semiconductor Device



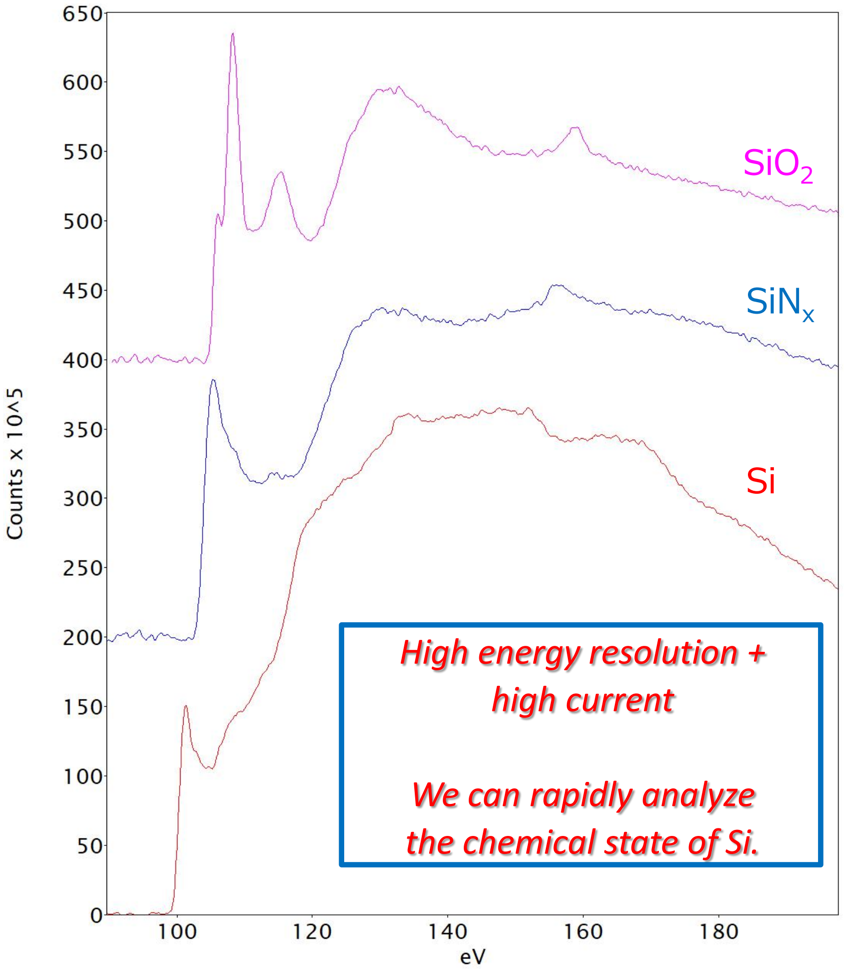
"Workhorse" S/TEM in Reality…

- ***Electron Energy Loss***
  - CFEG energy resolution of 0.33 eV
    - 2-3x better than TFEG
    - Probe current and spatial resolution retained for mapping and fine structure
  - Core-loss
  - Fine structure





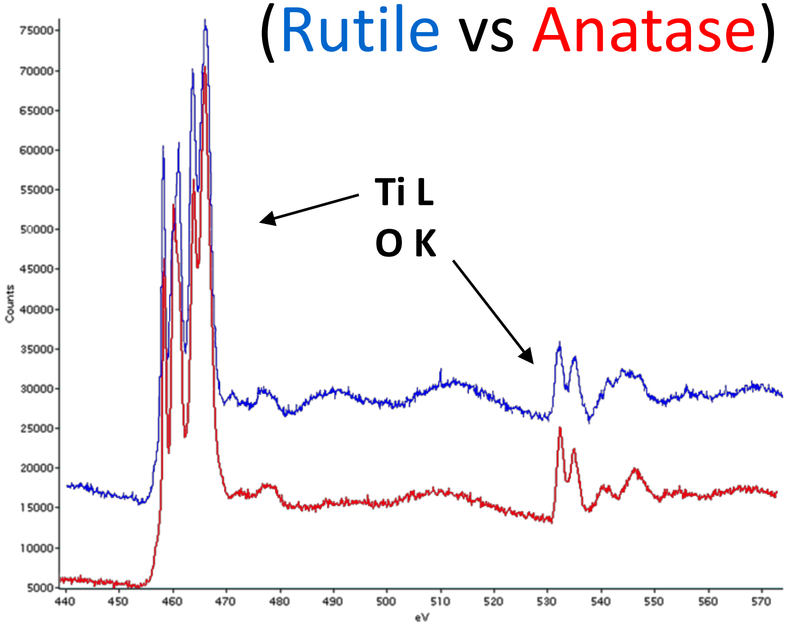
Energy resolution : 0.35eV
Probe current : 400pA
N. Of pixels : 128 x 256
Dwell time : 0.01s



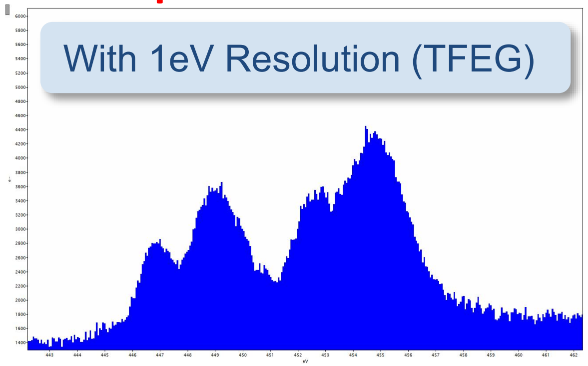
"Workhorse" S/TEM in Reality…

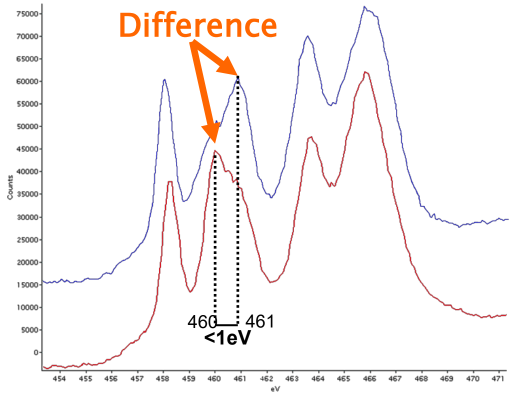
- ***Electron Energy Loss***
  - CFEG energy resolution of 0.33 eV
    - 2-3x better than TFEG
    - Probe current and spatial resolution retained for mapping and fine structure
  - Core-loss
  - Fine structure

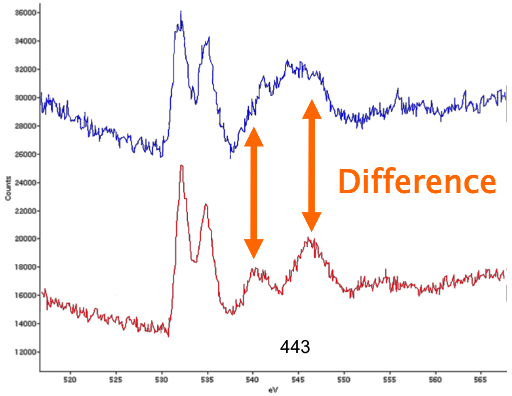
TiO_2 EEL spectrum (Rutile vs Anatase)



Not possible with TFEG

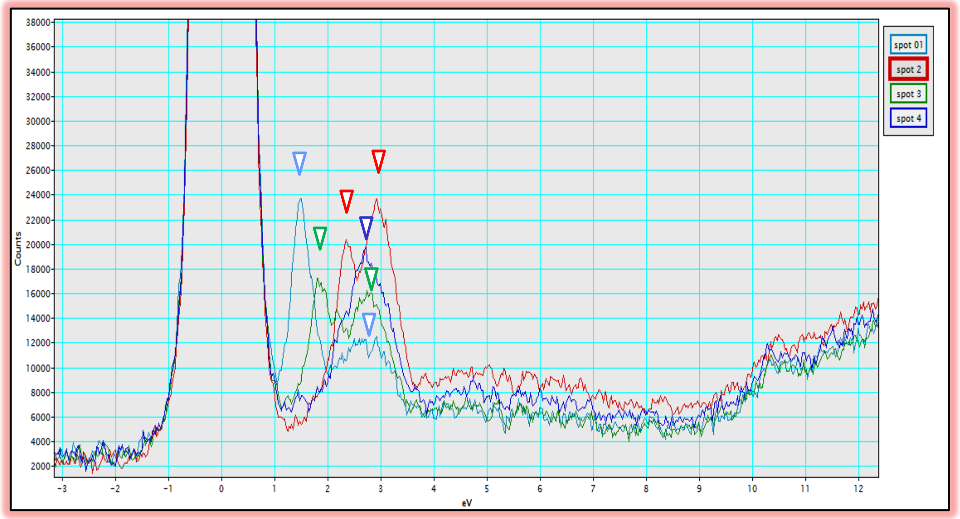






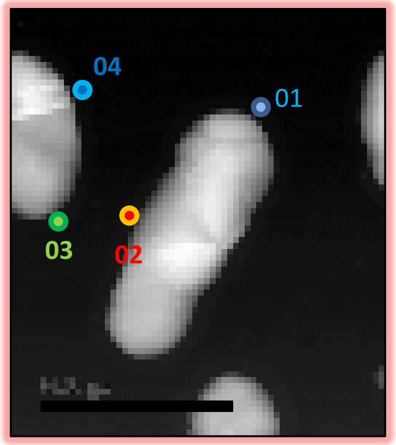
"Workhorse" S/TEM in Reality…

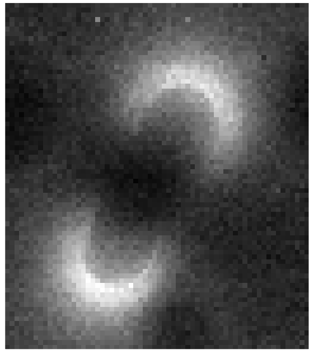
- ***Electron Energy Loss***
  - CFEG energy resolution of 0.33 eV
    - 2-3x better than TFEG
    - Probe current and spatial resolution retained for mapping and fine structure
  - Core-loss
  - Fine structure
  - Plasmon resonance (low-loss regime)



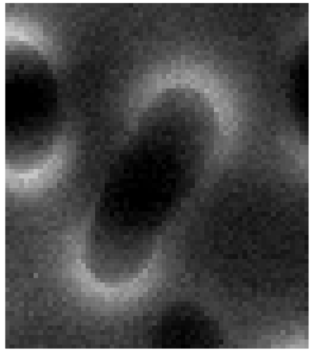
Surface Plasmon Resonance of Ag

Courtesy of Dr. T Sannomoiya
Tokyo institute of Technology

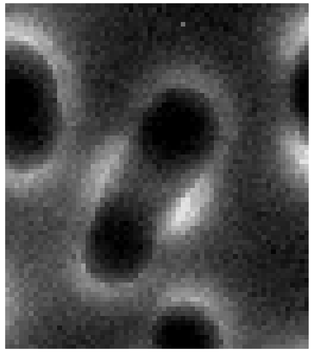




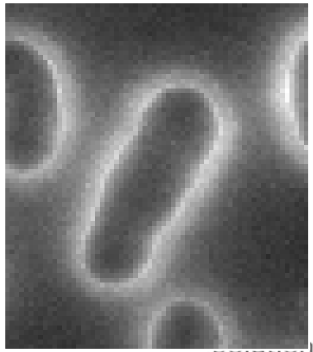
1.1 -1.3 eV



1.6 -2.0 eV



2.0 -2.4 eV



2.8 -3.3 eV

How Did We Get Here?

- Introduction/Current Capabilities
- **Critical Technology**
- How Far Can We Go with "Workhorse" S/TEMs?
- Looking Beyond

    Advanced Applications and Cs-correction

”Workhorse” S/TEM…Where are we?

***1. Smart design**:*

Redesigned electron optics; design combining ease of use, high performance, high stability

***2. Quad-Lens condenser system**:*

Easy selection of illumination conditions; Spot size/convergence angle remain independent

***3. Advanced Scan system**:*

High stabilized multifunction STEM

***4. Improved Cold FEG** :*

High brightness with small energy spread

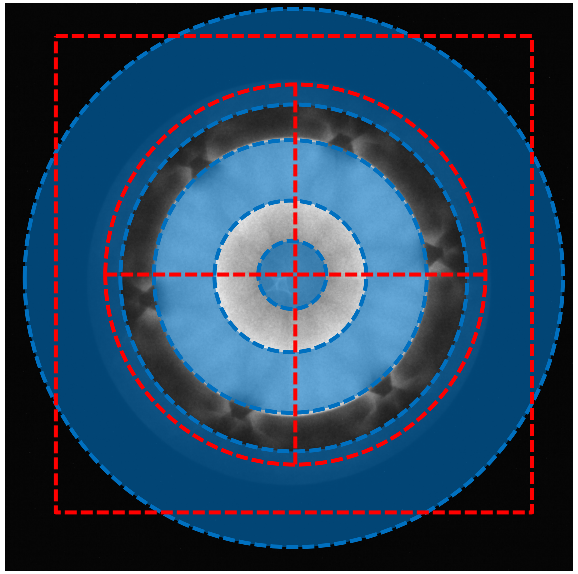
***5. Dual EDS**:*

Highly efficient analysis

JEM-F200

STEM Detection Methods

Diffraction Pattern (STEM)



ADF:

Z-contrast

Robust, Easy to Understand

BF:

Close to conventional TEM

Phase Contrast (not straightforward)

ABF:

Enhanced contrast for light elements

Robust, Easy to Understand

Segmented STEM:

DPC imaging for E/B field

Post-Process (limited)

Pixelated STEM:

All information of diffraction pattern

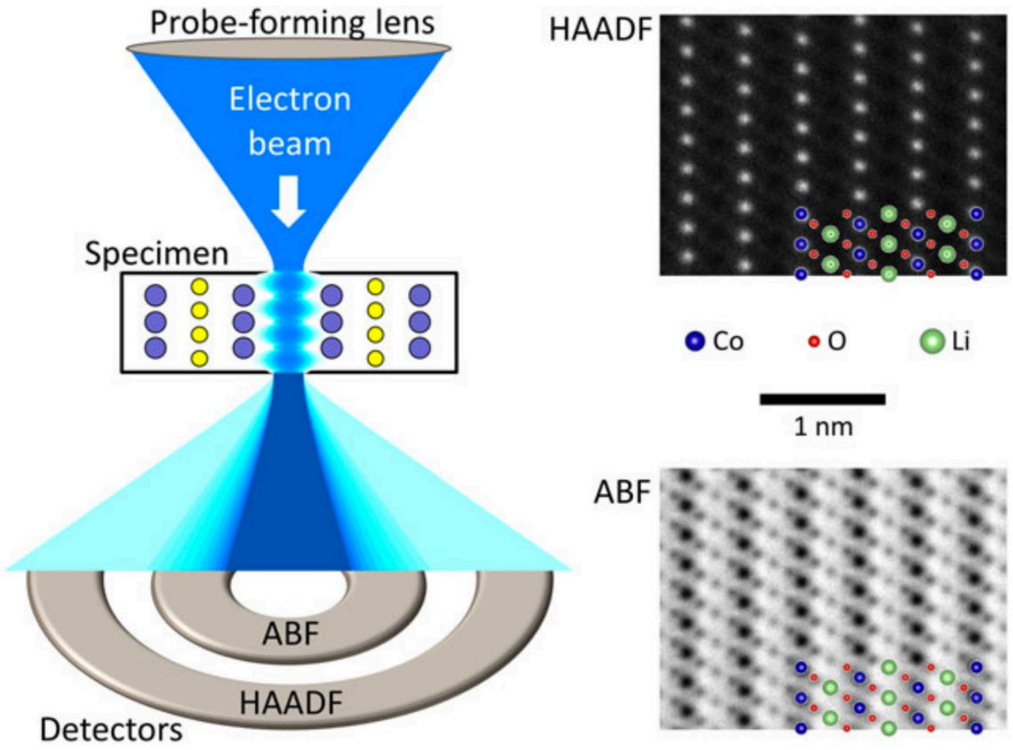
Post-Process

- Standard detector (ADF, BF, …) gives ***Integrated*** signals only.
- Quantitative analysis ⇒ ***Fine Structure*** of diffraction patterns.

More on Detectors Later…

STEM Detectors

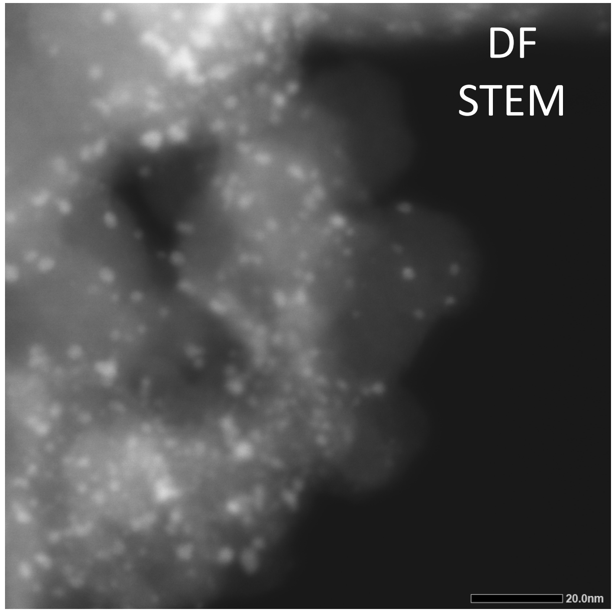
- ***HAADF***
  - Z-contrast
- ***ABF***
  - BF-STEM/HR-TEM has strong dependence on thickness/defocus; suffers contrast reversals
  - ABF is more robust to these parameters; more directly interpretable
  - Light element imaging at atomic resolution (O, Li, H...)
  - Collection angle typically ½θ_c- θ_c
- ***SE/BE***
  - Surface-sensitive
  - Morphology



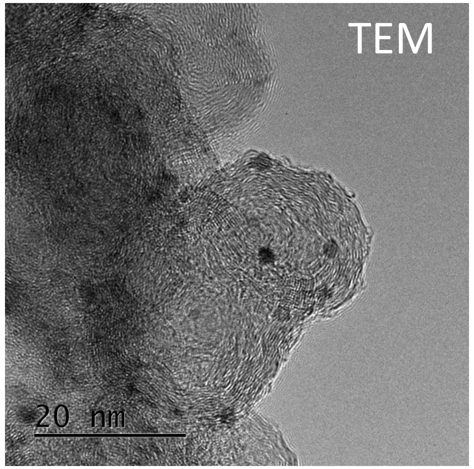
Findlay et al., Microscopy 2017
Findlay et al., Ultramicr 2010

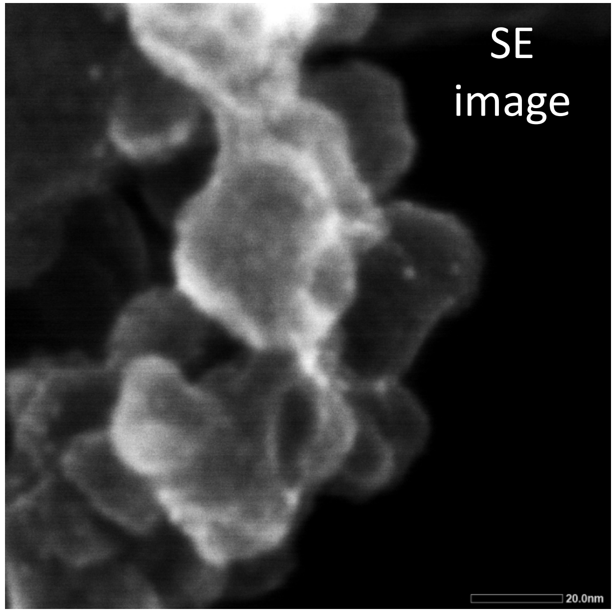
SE/BE Detectors

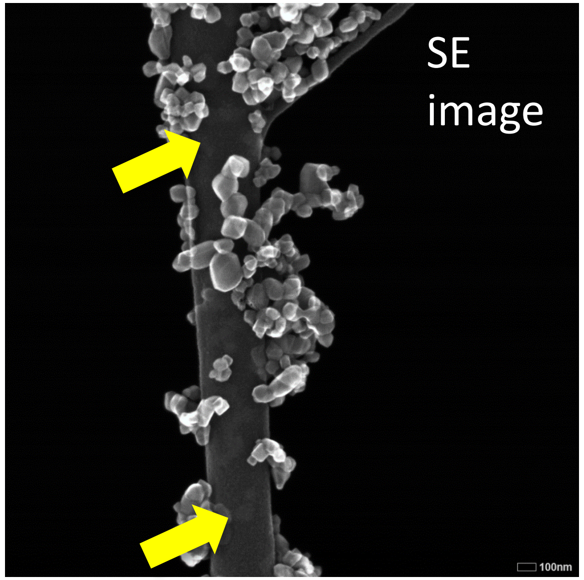
Detection of Surface Features…

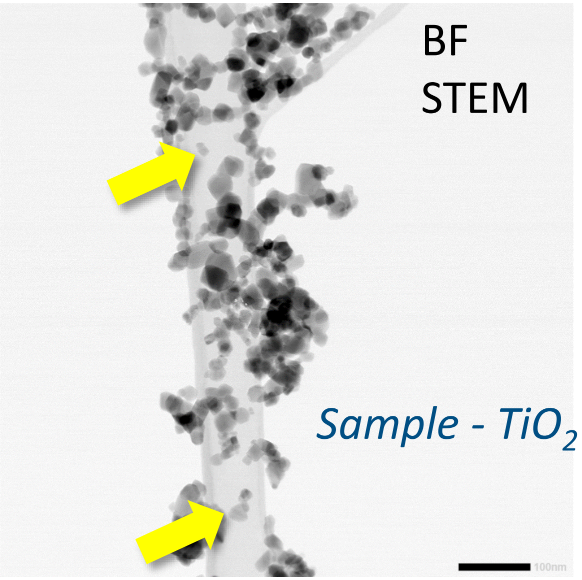


PtRu / graphite
80 kV





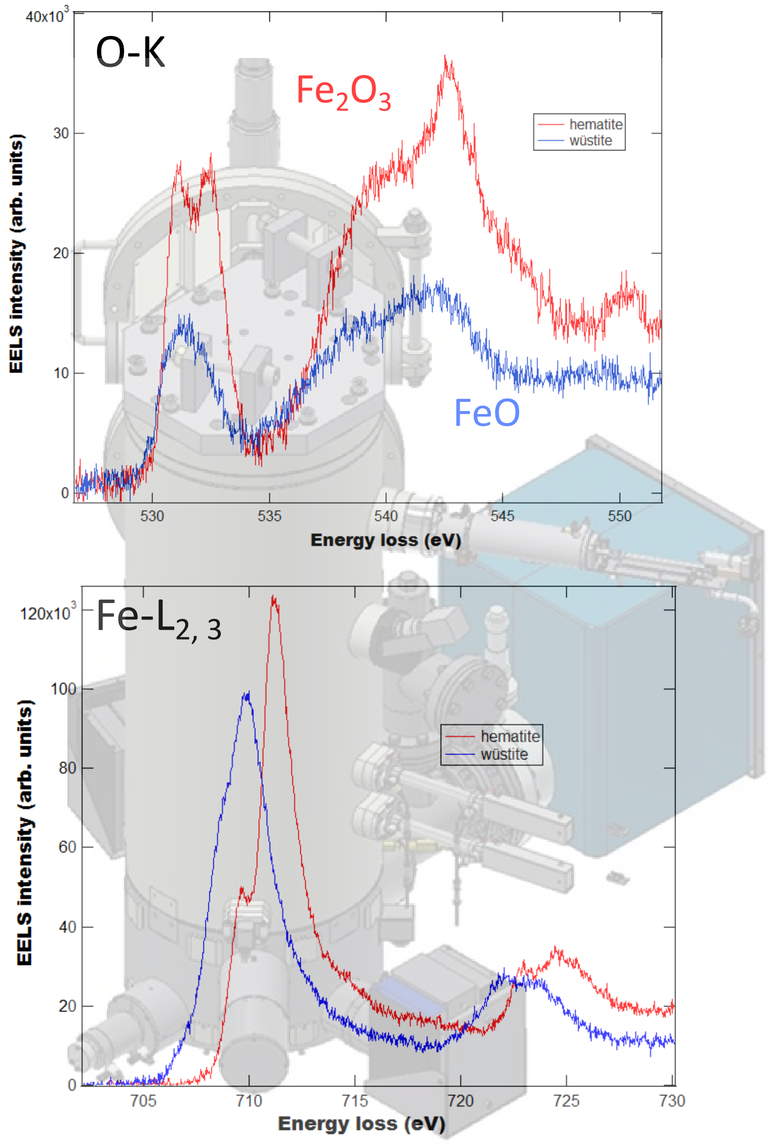




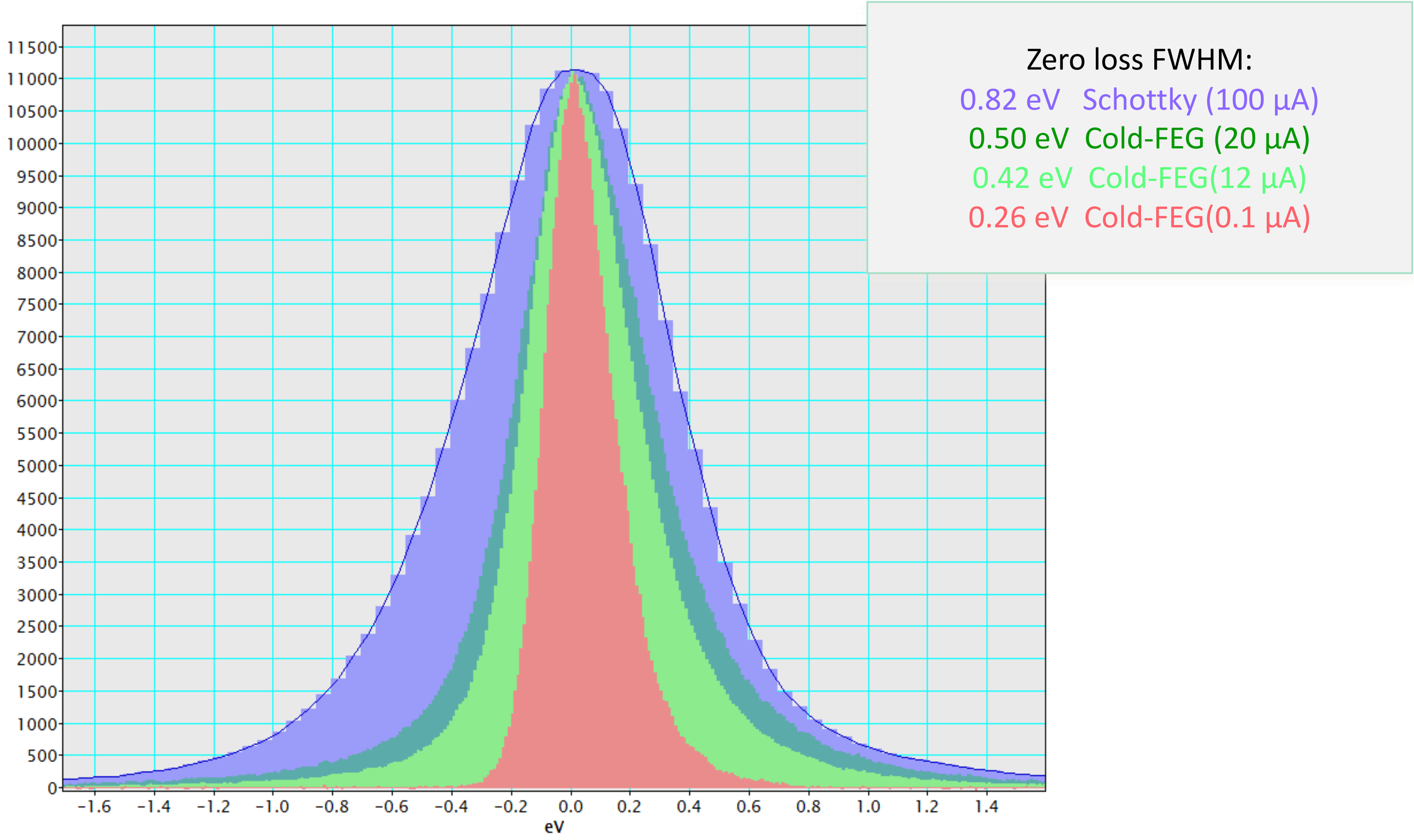
Sample - TiO_2

CFEG Benefits

- Small energy spread
  - 0.33 eV, compared to 0.8-1.0 eV for TFEG
  - Improved EELS resolution
  - Fine structure determination
- More current in smaller probe
- Improved spatial resolution; particularly low kV work
- Highly stable probe current and vacuum system



Probe Current Flexibility



- Highly tunable probe current and energy resolution
- Important to retain the spatial resolution

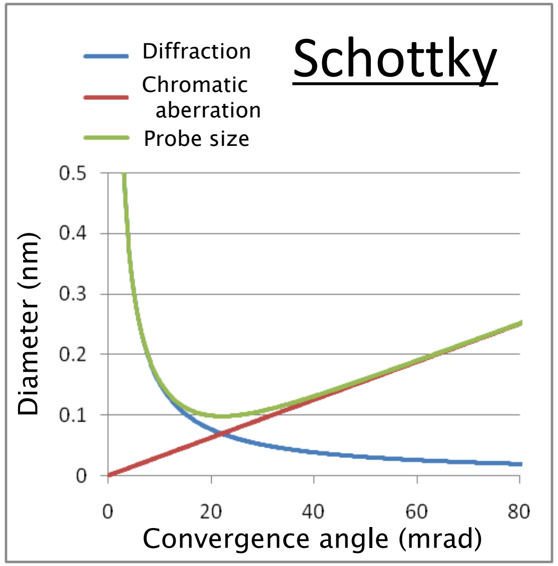
Improved Energy Spread and Probe Size

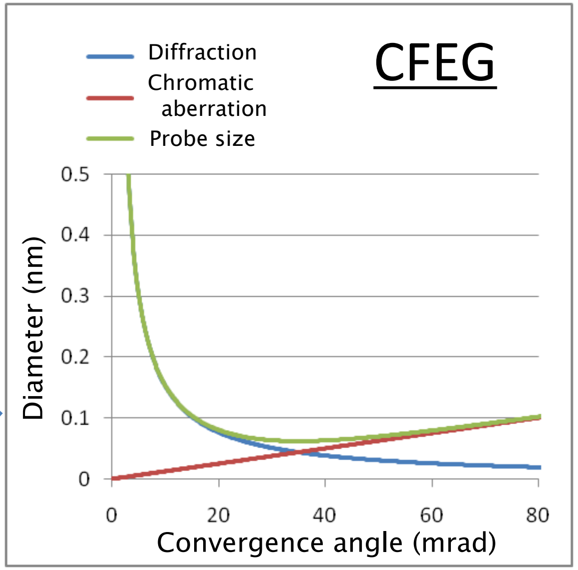
Why we prefer a CFEG source for analytical work

Diffraction Limit $R_D = \frac{0.6 \times \lambda}{\sin \alpha}$

Chromatic Aberration $R_C = C_C \times \frac{\Delta E}{E} \times \alpha$

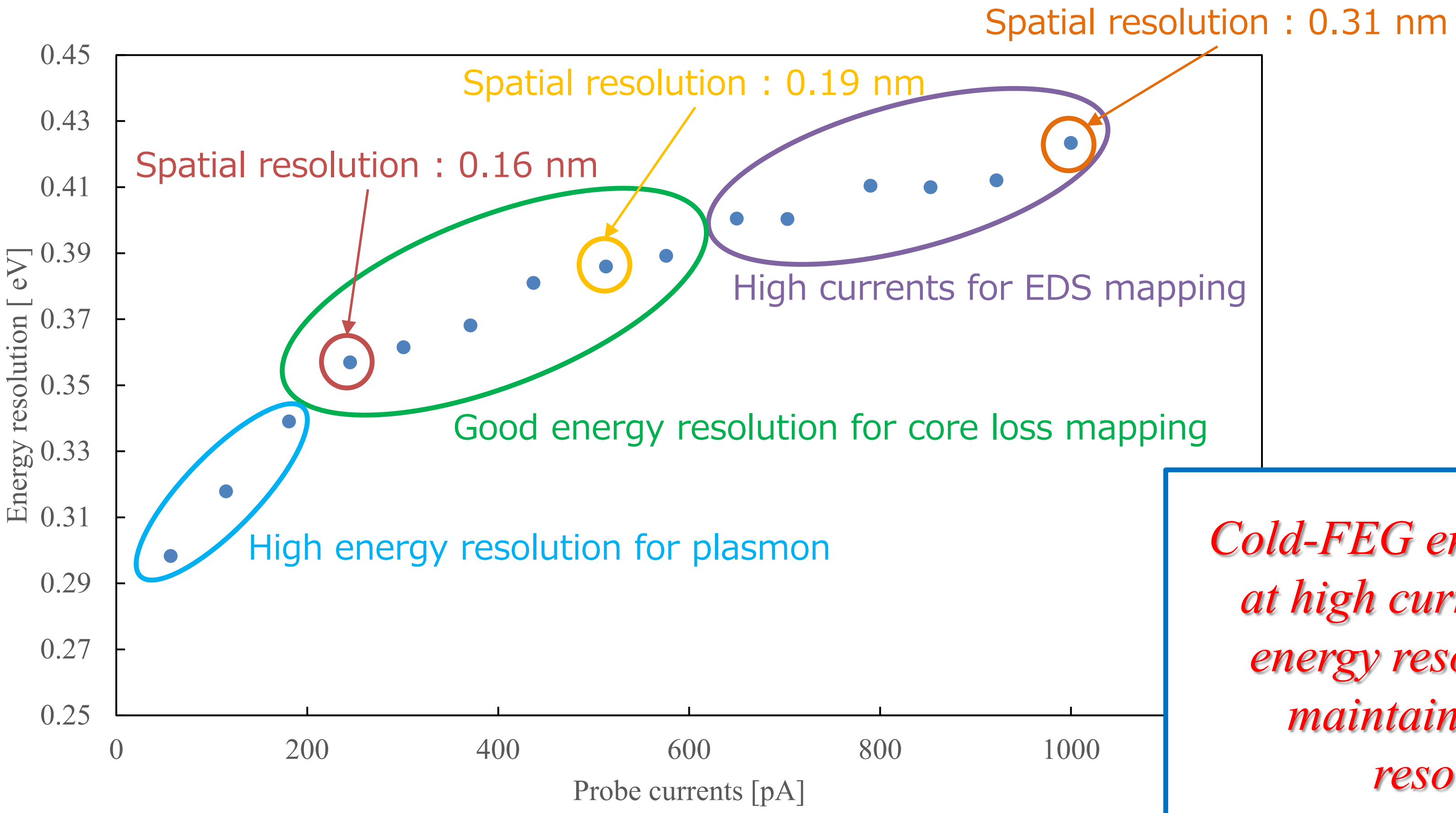
α : convergence angle
ΔE : energy spread
λ : wavelength
C_c : coef. of chromatic aberration





Smaller probe size
Larger aperture

Probe Current Flexibility

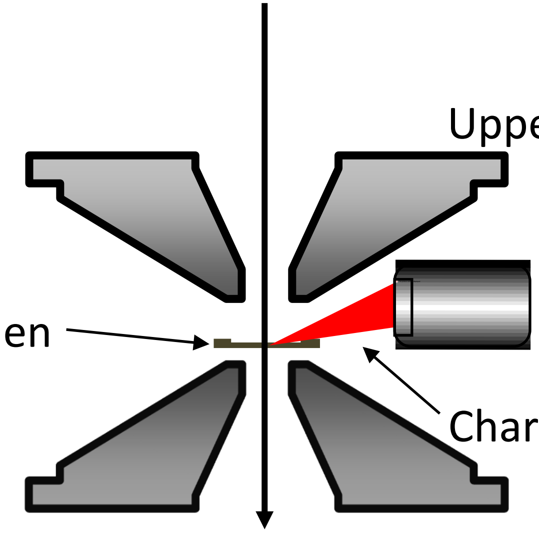


Cold-FEG enables analysis at high current and high energy resolution while maintaining spatial resolution.

- Highly tunable probe current and energy resolution
- Important to retain spatial resolution
- Multiple avenues to change probe current/probe size/energy resolution

EDS in the STEM

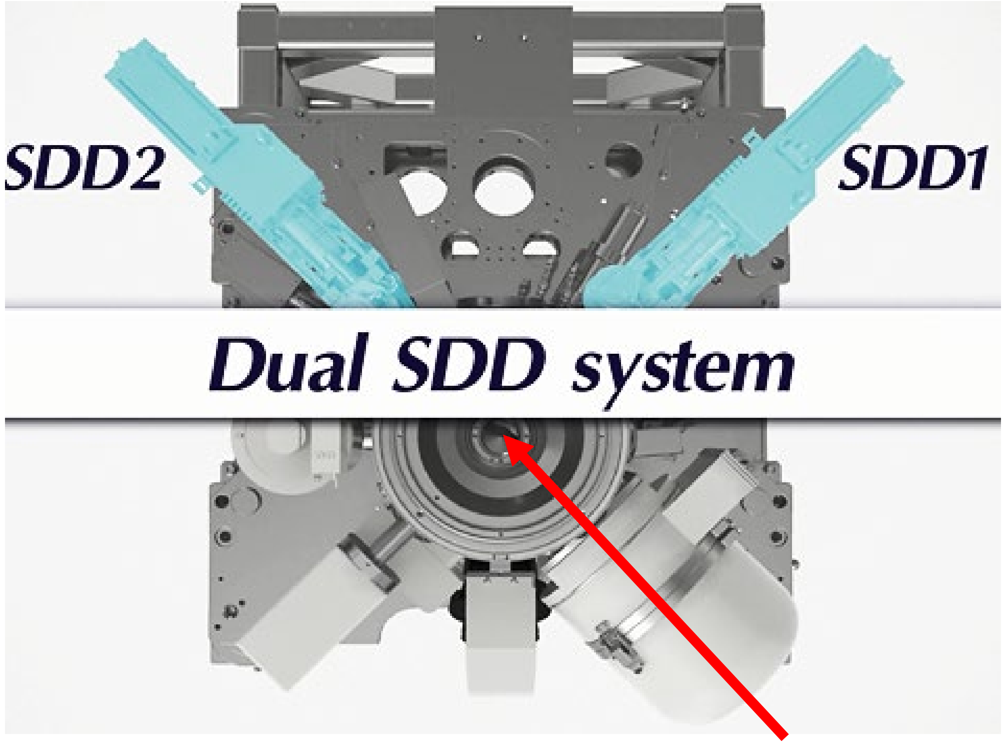
- Inherently inefficient
- Pole piece obstructions, sample proximity, etc.
- Best to avoid prolonged scanning or very high probe currents
  - Sample damage



EDS – Clean and Efficient Signal

- Solutions
  - Holders and Pole Pieces designed specifically for EDS geometry
  - Dual Silicon Drift Detectors (SDDs) for efficiency
- Large detectors, clean signal
  - 1.7sr solid angle
- P/B > 4000
- < 1% Spurious Peaks

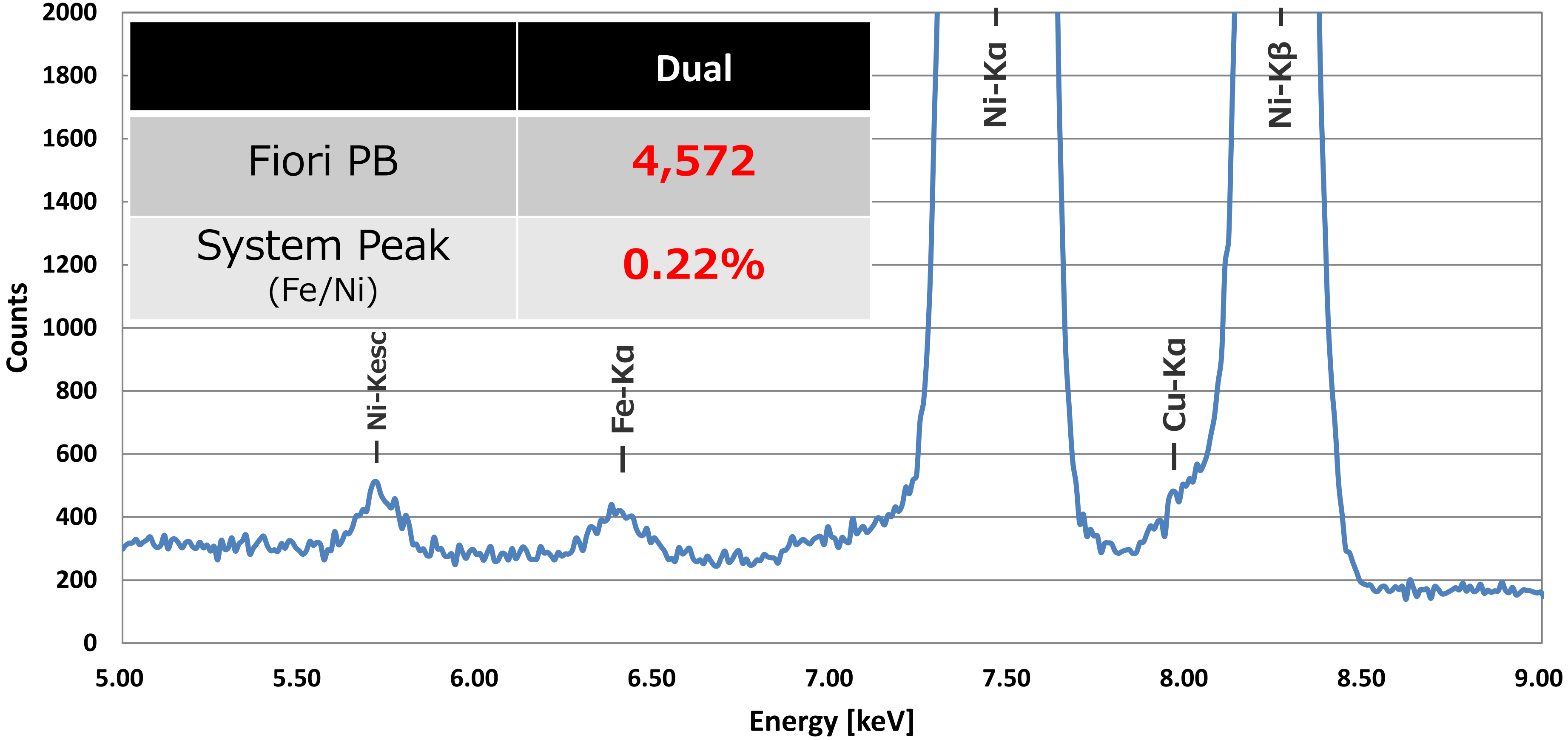
Top-down view of column



Specimen Holder

EDS – Clean and Efficient Signal

	Dual
Fiori PB	4,572
System Peak (Fe/Ni)	0.22%



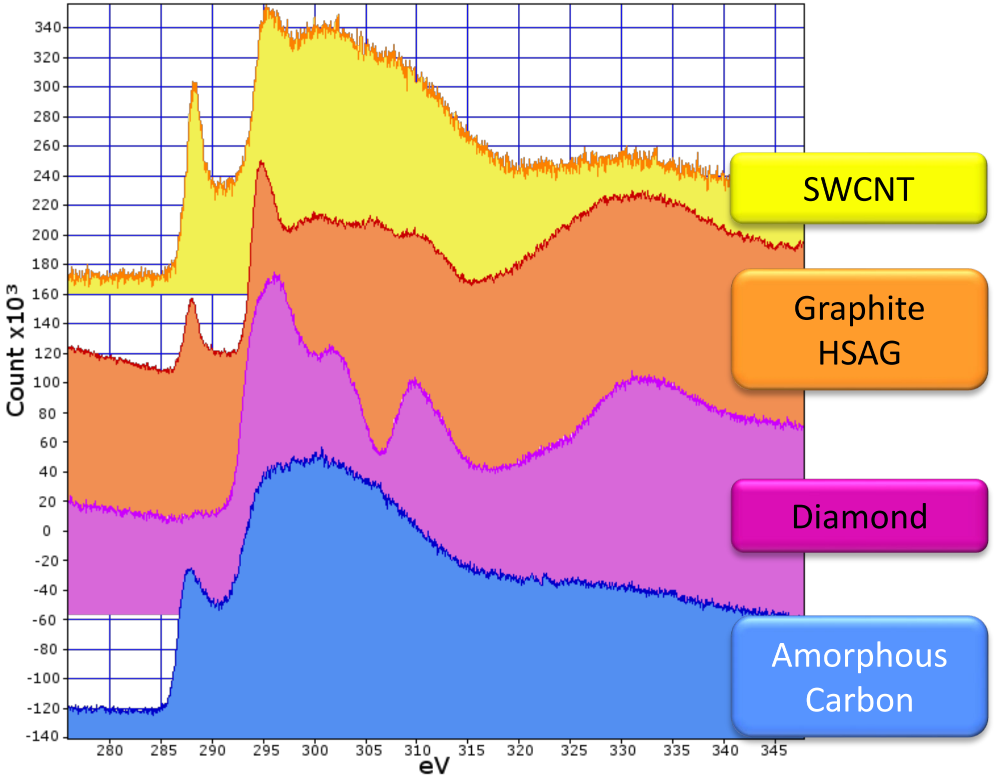
Brief Outline

- Introduction/Current Capabilities
- Critical Technology
- **How Far Can We Go with “Workhorse” S/TEMs?**
- Looking Beyond:

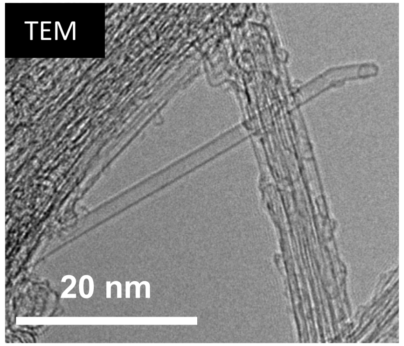
    Advanced Applications and Cs-correction

Low kV - Energy Resolution and Fine Structure

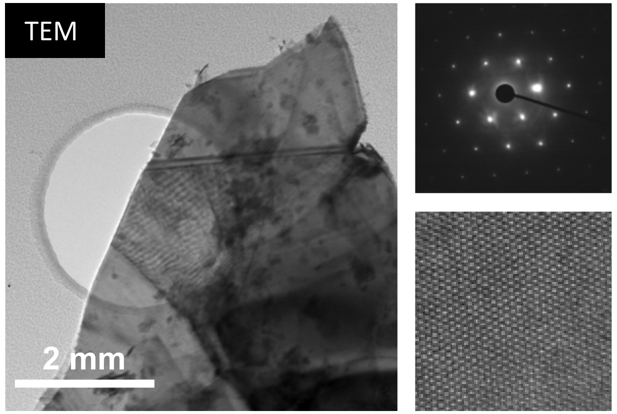
Carbon - 80 kV



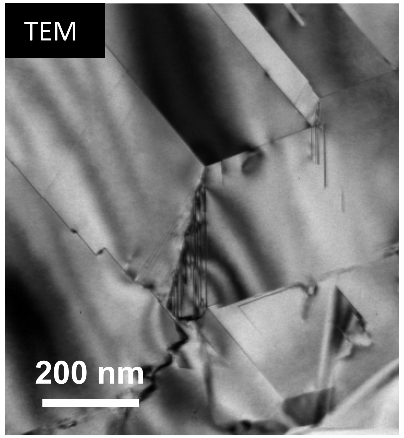
(a)



(b)



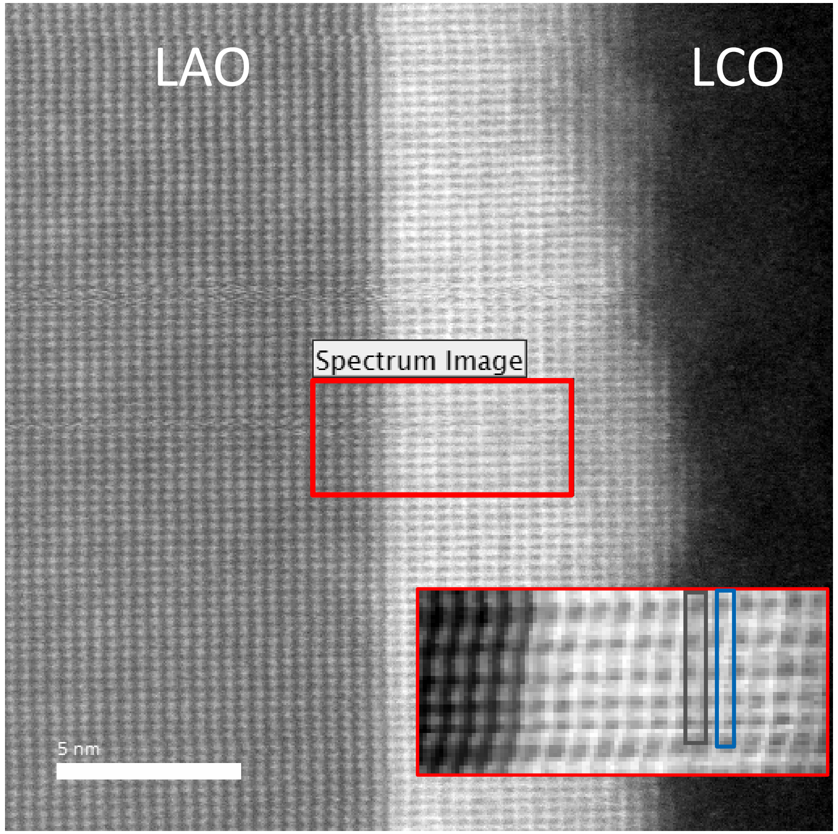
(c)

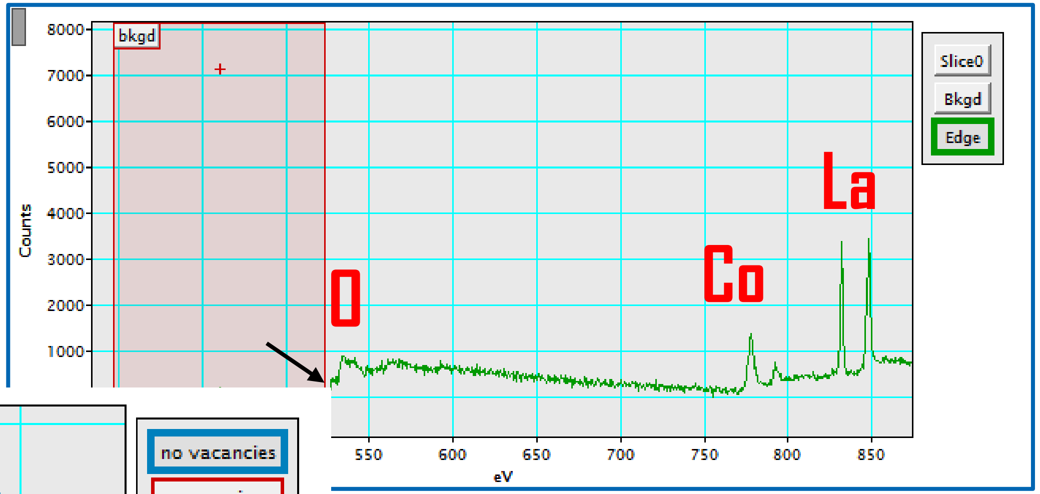


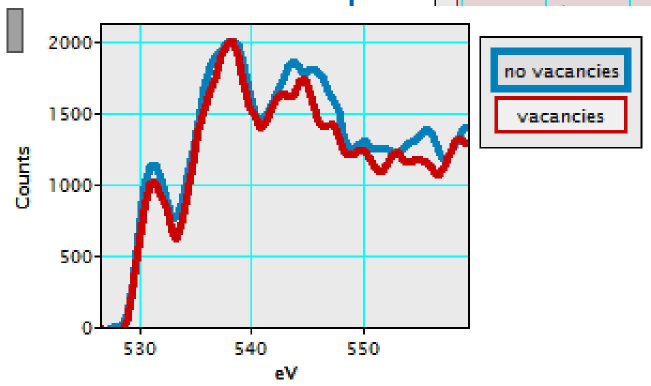
Pushing the Limits

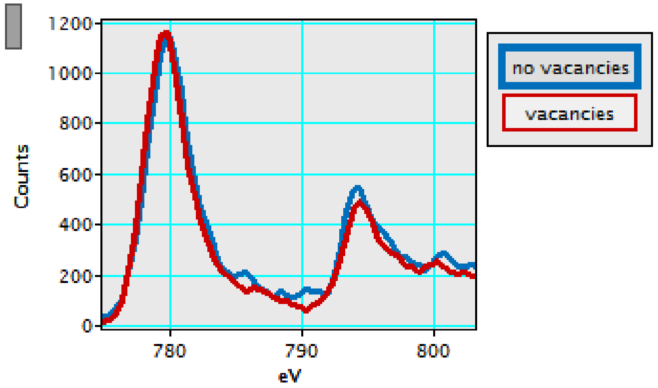
LSCO-LAO Superlattice

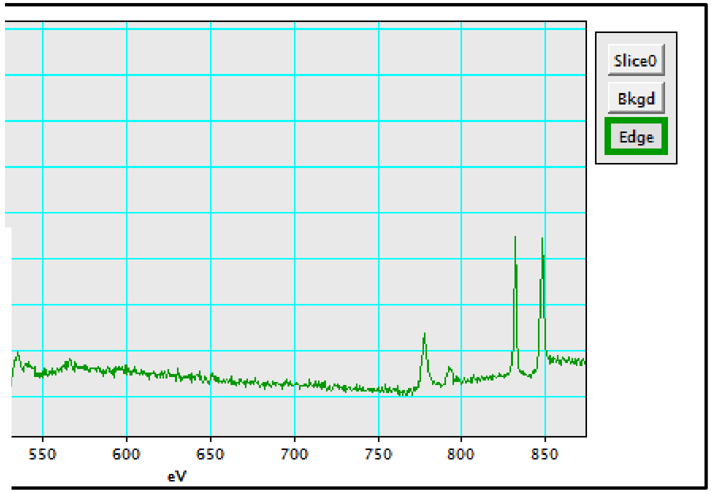
High-resolution STEM and EELS/EDS
Resolving O-vacancies and fine structure
pre-peak changes with position











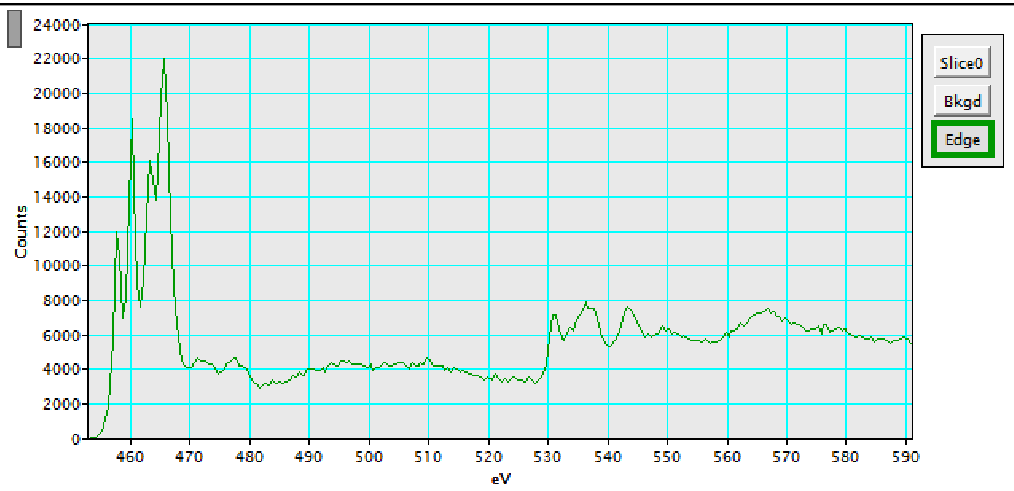
Specimen/Data courtesy Gatan/UIC

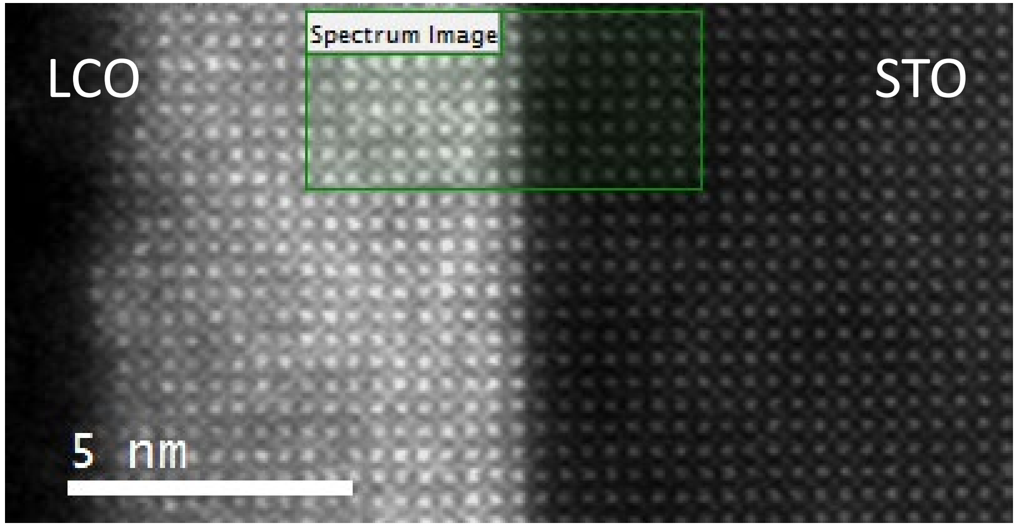
Pushing the Limits

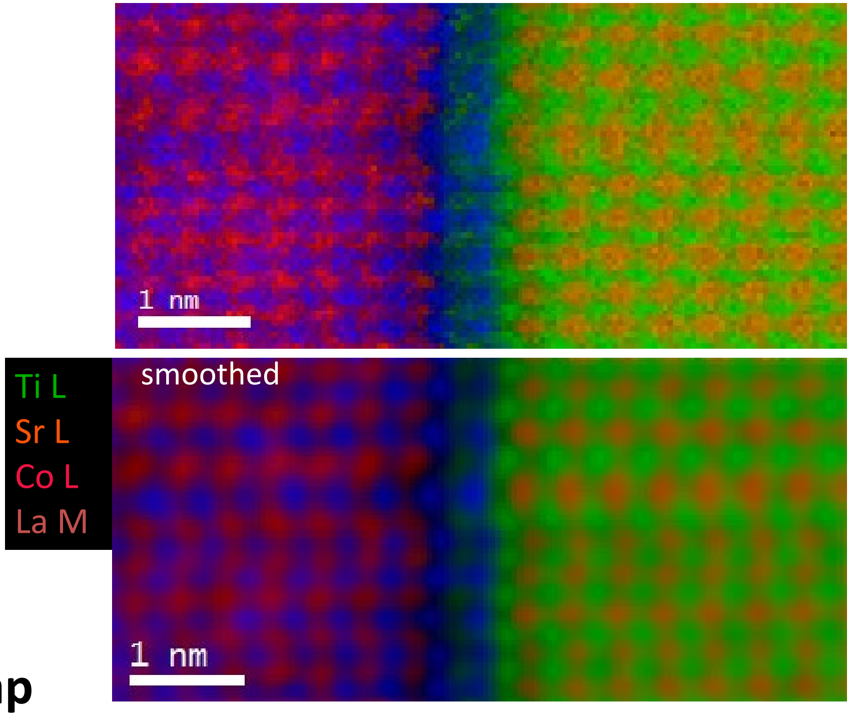
LSCO-STO Superlattice

High-resolution STEM and EELS/EDS
Ti and O fine structure – Ti4+

Atomic-resolution spectroscopy without a Cs corrector







EELS Color Map

LSCO-STO Superlattice

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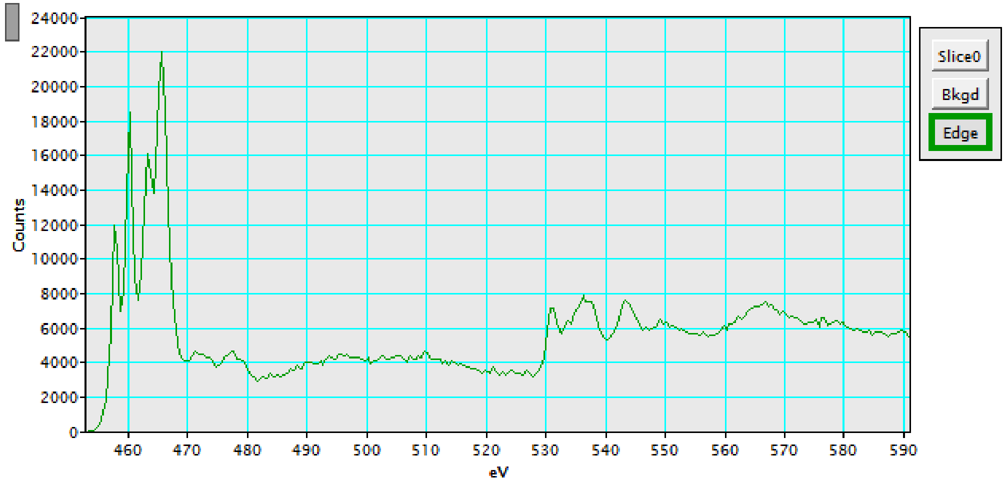
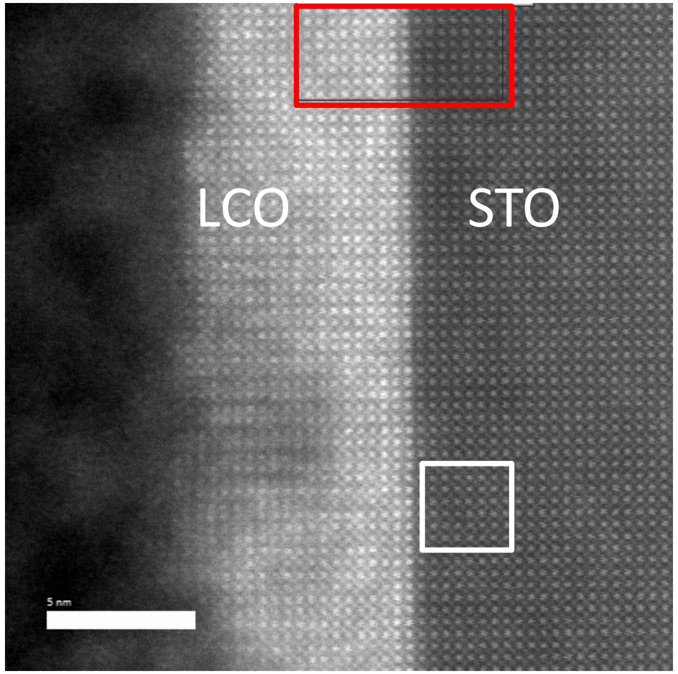
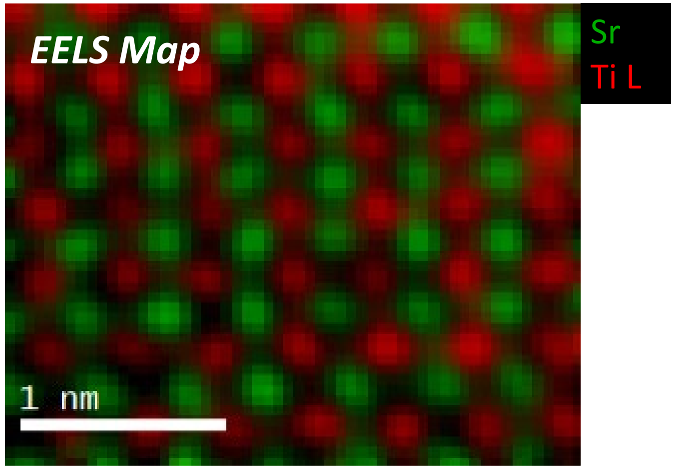






Multi-Signal Approach

Meteoritic Hibonite – *$CaAl_{12}O_{19}$*

Role of Mg/Ti in defect structure observed at atomic resolution

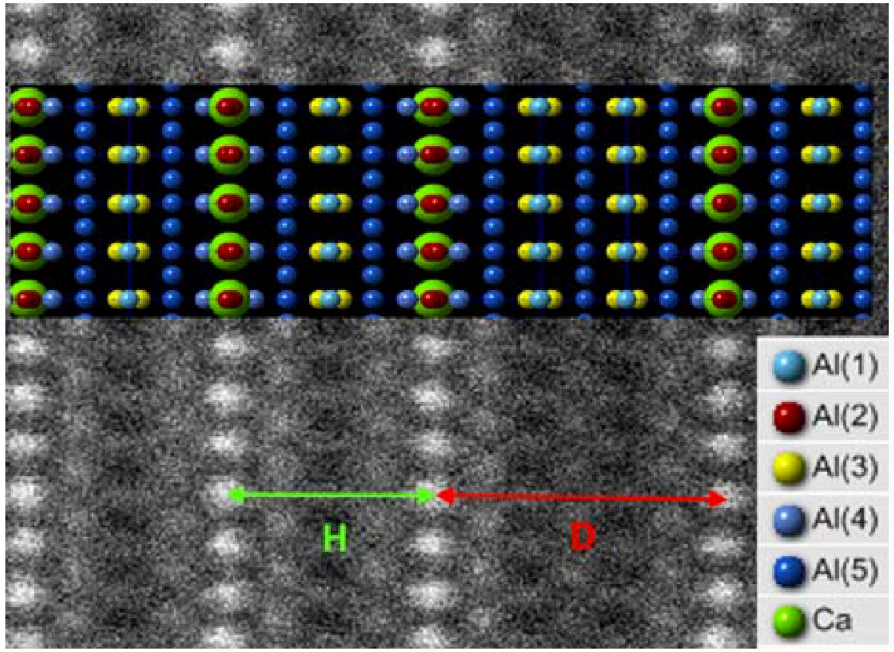
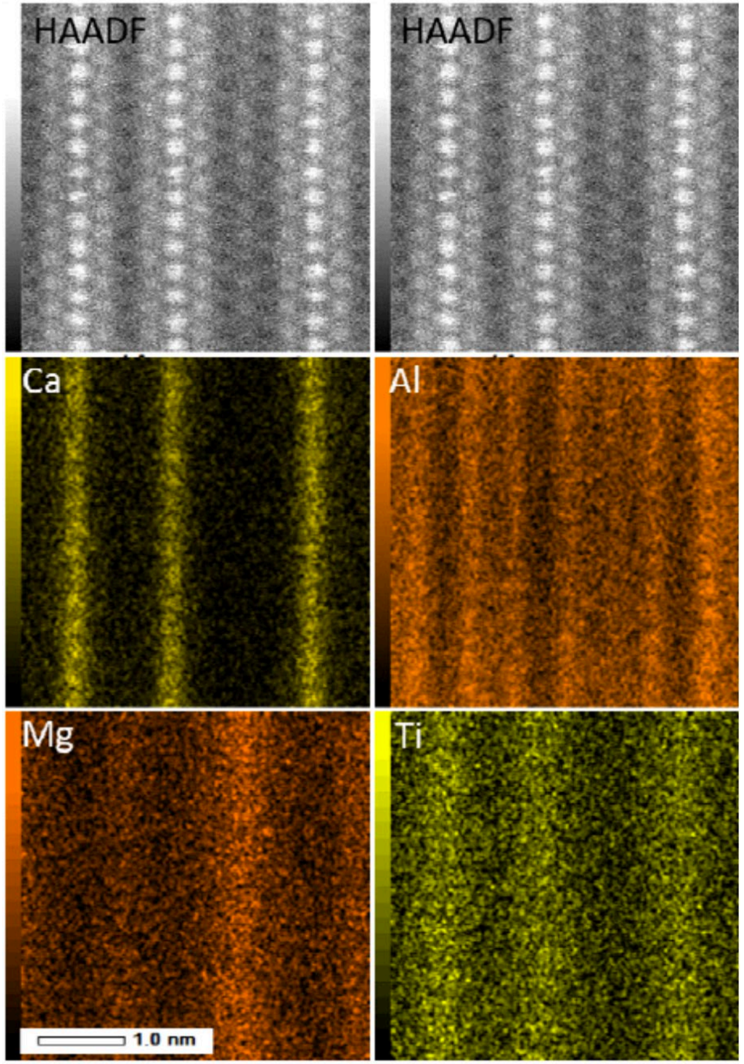


Figure 1. HAADF image from the [110] of hibonite showing stoichiometric hibonite (H) and an extended defect (D). The inset shows the distribution of heavy elements in hibonite and our model for the atomic arrangement in the defect.

L.P. Keller et al., 49th Lunar and Planetary Science Conference 2018

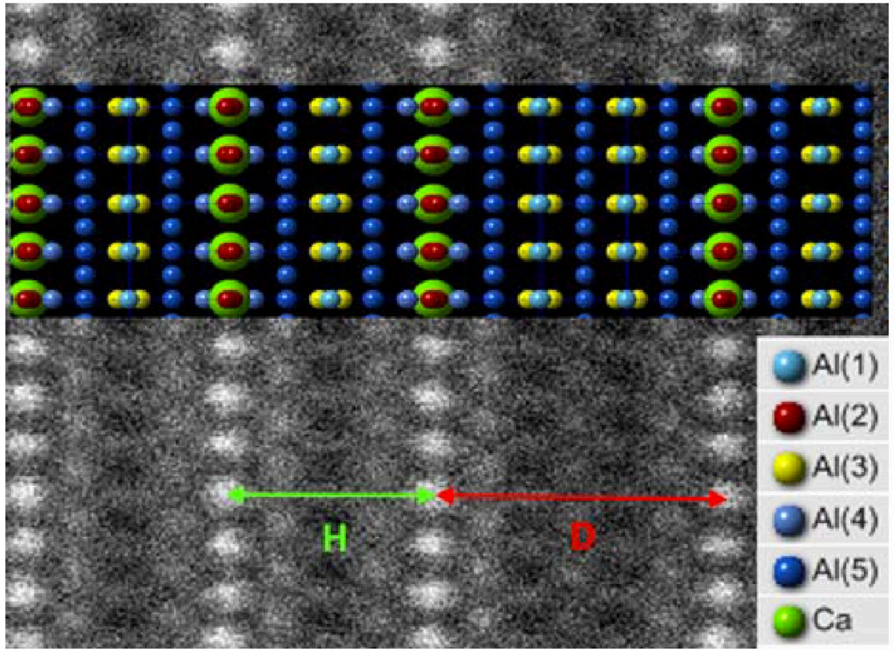


Mg-rich defect

Multi-Signal Approach

Meteoritic Hibonite – $CaAl_{12}O_{19}$

Role of Mg/Ti in defect structure observed at atomic resolution



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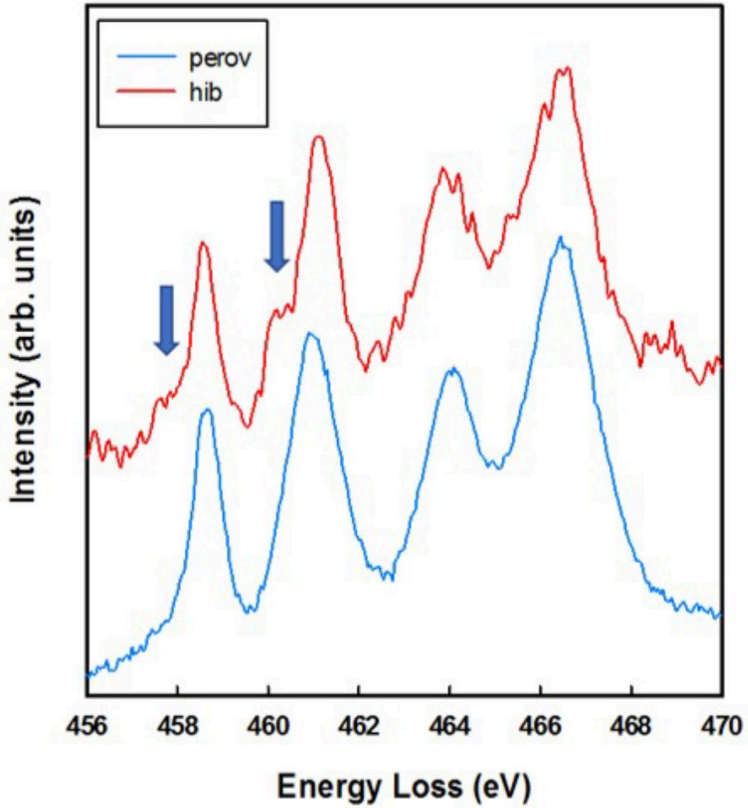


Figure 3. EELS spectra from the Ti $L_{2,3}$ edge in meteoritic perovskite (blue) and hibonite (red). The low energy shoulders indicated by blue arrows are consistent with the presence of Ti^{3+} in hibonite.

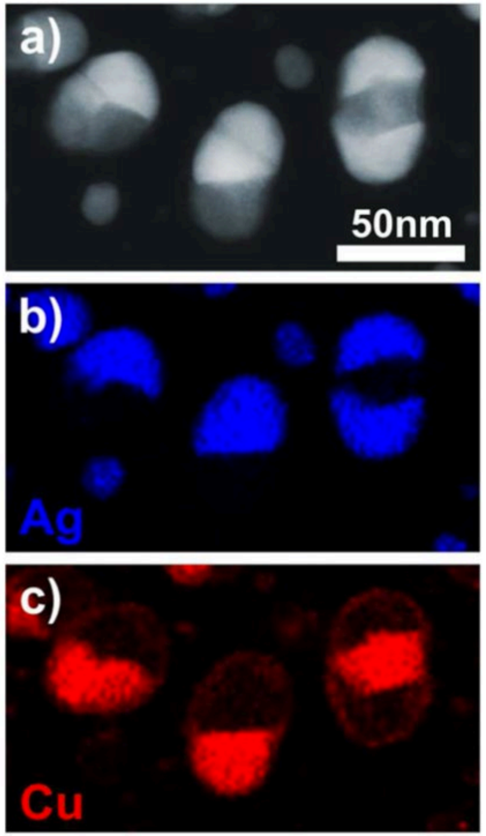
Ti^{3+} contribution

L.P. Keller et al., 49th Lunar and Planetary Science Conference 2018

Multi-Signal Approach

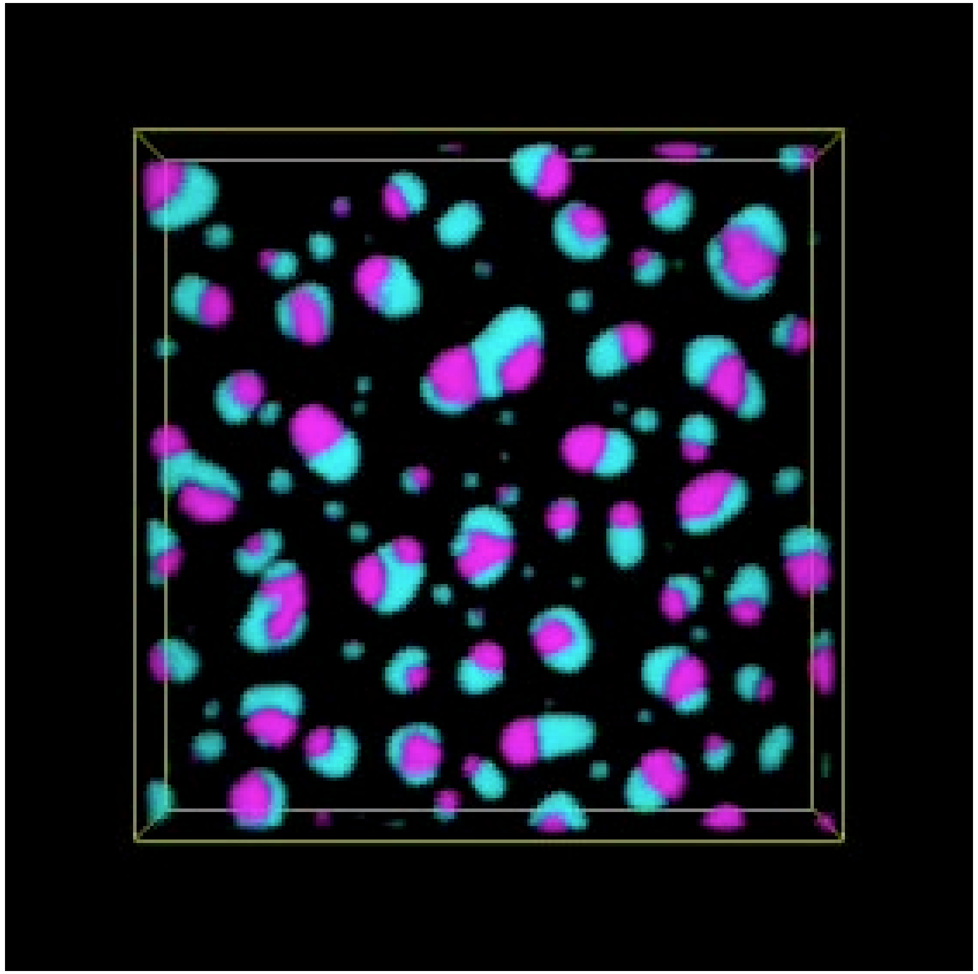
Plasmonics

Phase-separated Ag-Cu nanoparticles



EDS Maps

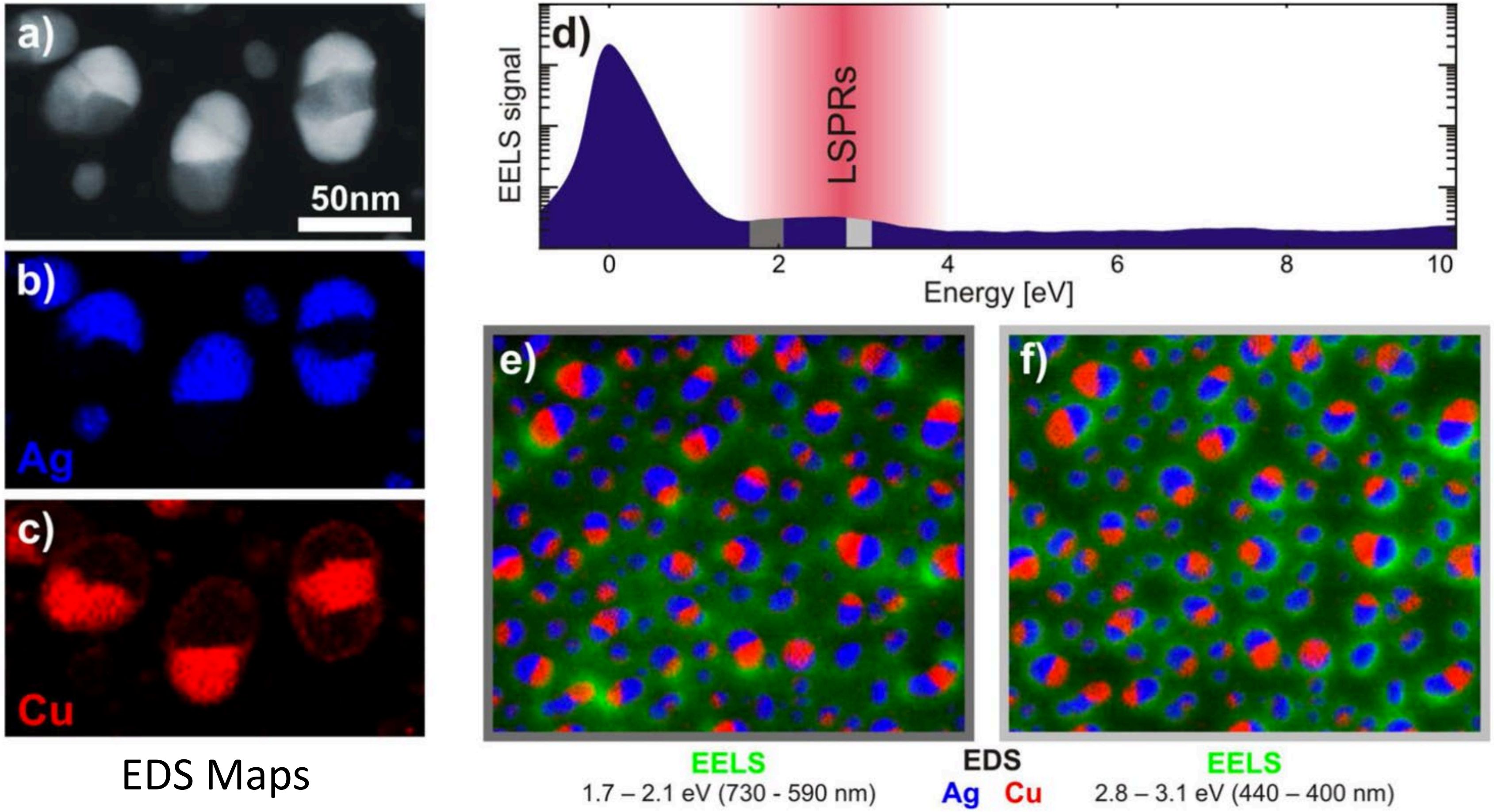
Tokyo Institute of Technology
J. Phys. Chem. C 2017, 121, 27029–27035



Multi-Signal Approach

Plasmonics

Phase-separated Ag-Cu nanoparticles



EDS Maps

Tokyo Institute of Technology
J. Phys. Chem. C 2017, 121, 27029−27035

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- Introduction/Current Capabilities
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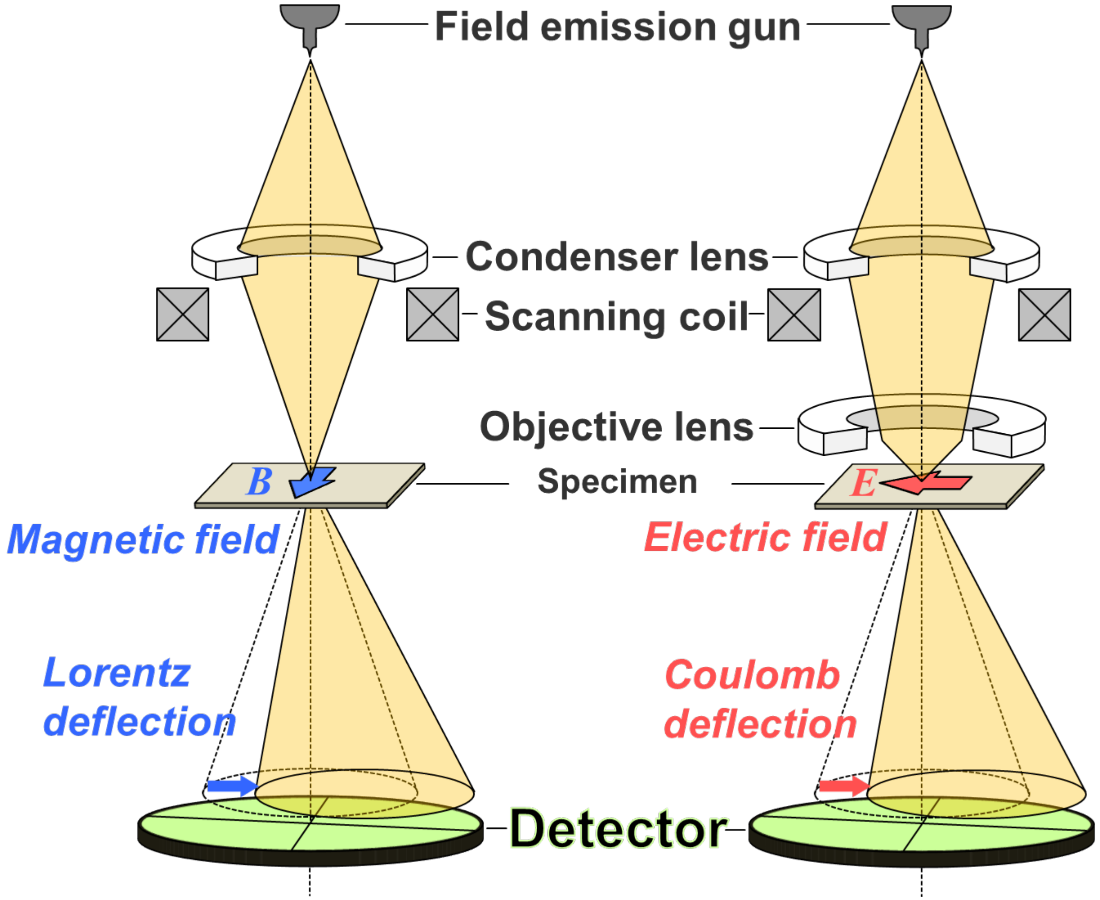
- **Looking Beyond:**

  Advanced Applications and Cs-correction

DPC STEM

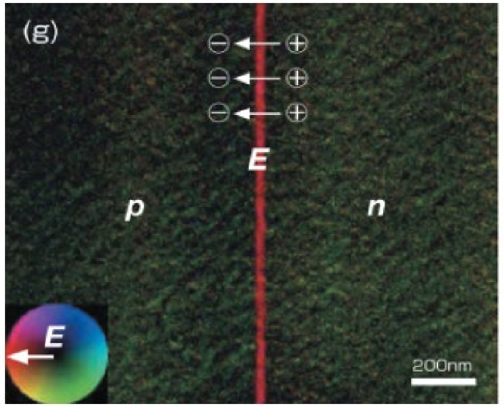
Differential Phase Contrast (DPC)
Detect local *Electrical / Magnetic fields*
through incident beam deflections



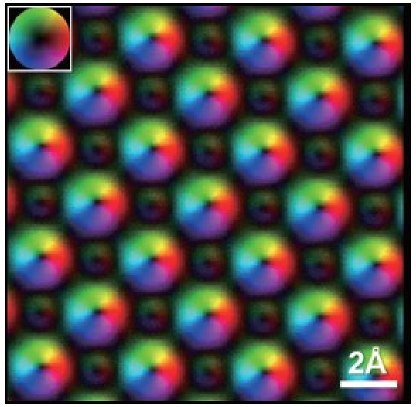
Courtesy of Professor Naoya Shibata, University of Tokyo

Electrical Field Detection

Using STEM differential phase contrast (DPC) it is possible to directly observe the local electromagnetic fields within a material. The image on the left is an example of an analysis of the internal electric field of a pn junction in a semiconductor. The image on the right is the result of an atomic-resolution DPC observation of $SrTiO_3$.



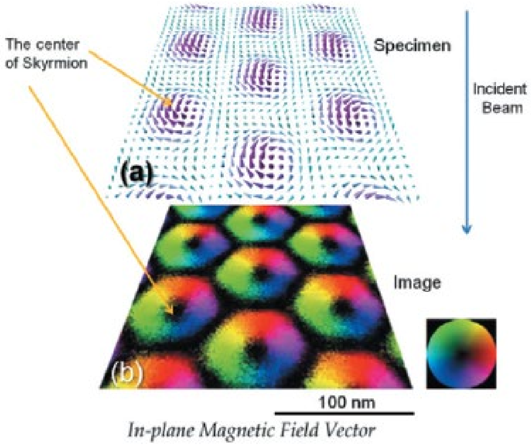
N. Shibata et al.; 2015; *Scientific Reports*

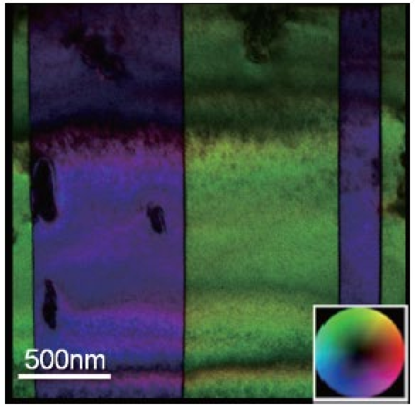


N. Shibata et al.; 2017; *Nature Comm.*

Magnetic Field Detection

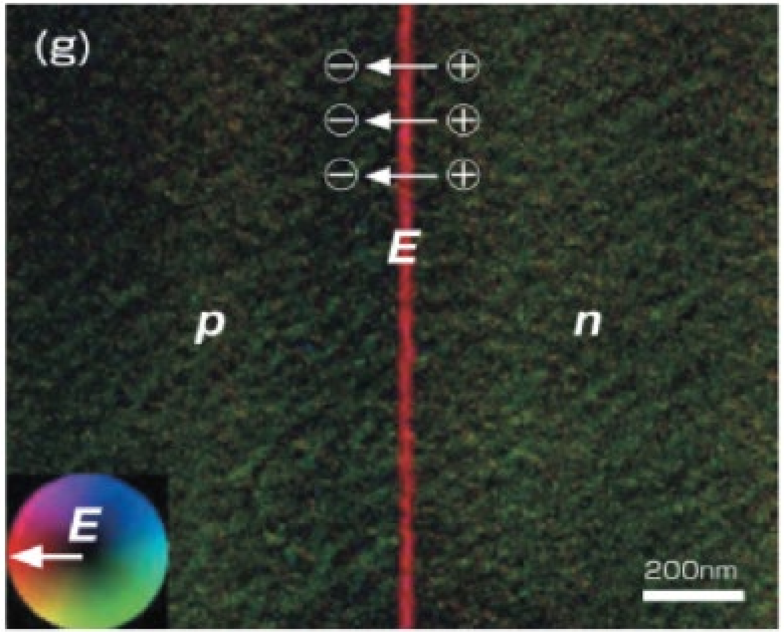
Using the DPC method it is possible to see the various magnetic structures as well as the quasi-particle "skyrmions" (left), which have a vortex-like magnetic structure. The image on the right is an example of magnetic domain structures in rare earth metal dysprosium (Dy).





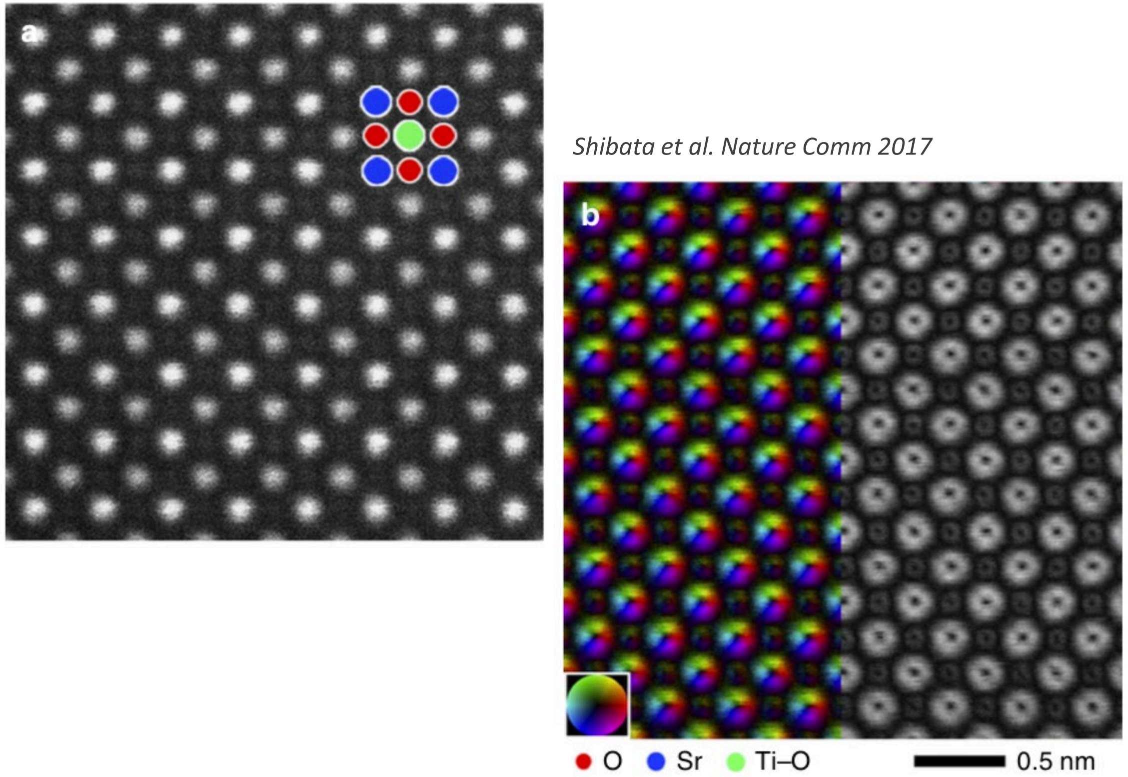
N. Shibata et al.; 2017; *Acc. Chem. Res.*

Field Observations



N. Shibata et al.; 2015; *Scientific Reports.*

Shibata et al. Nature Comm 2017



Analysis for Electromagnetic Field:

- SAAF + STEM Lorentz (OL OFF)
- Semiconductor, Magnetic Material
- Easy operations as in standard STEM

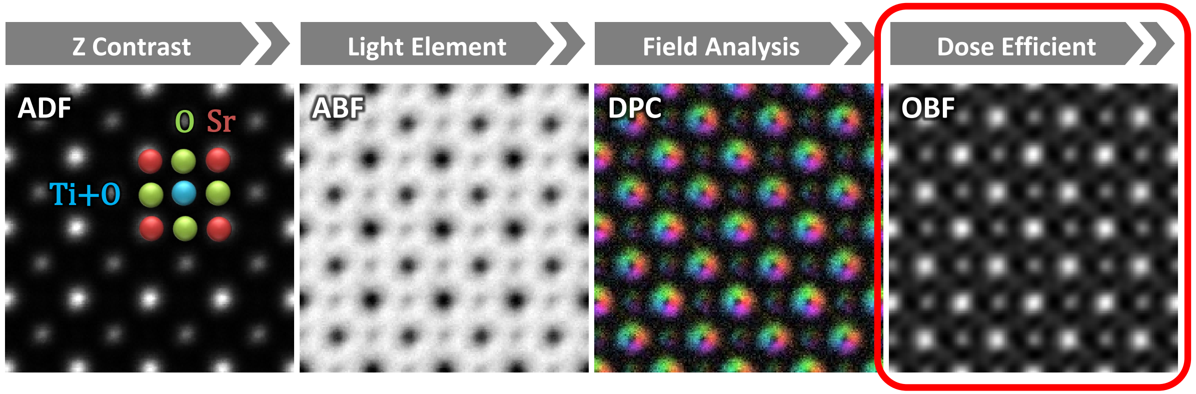
Atomic Resolution DPC:

- SAAF + STEM Cs Corrector
- Atomic scale information of localized field
- No changes in optical system

OBF STEM – extension of DPC

New imaging mode – Optimum BF STEM

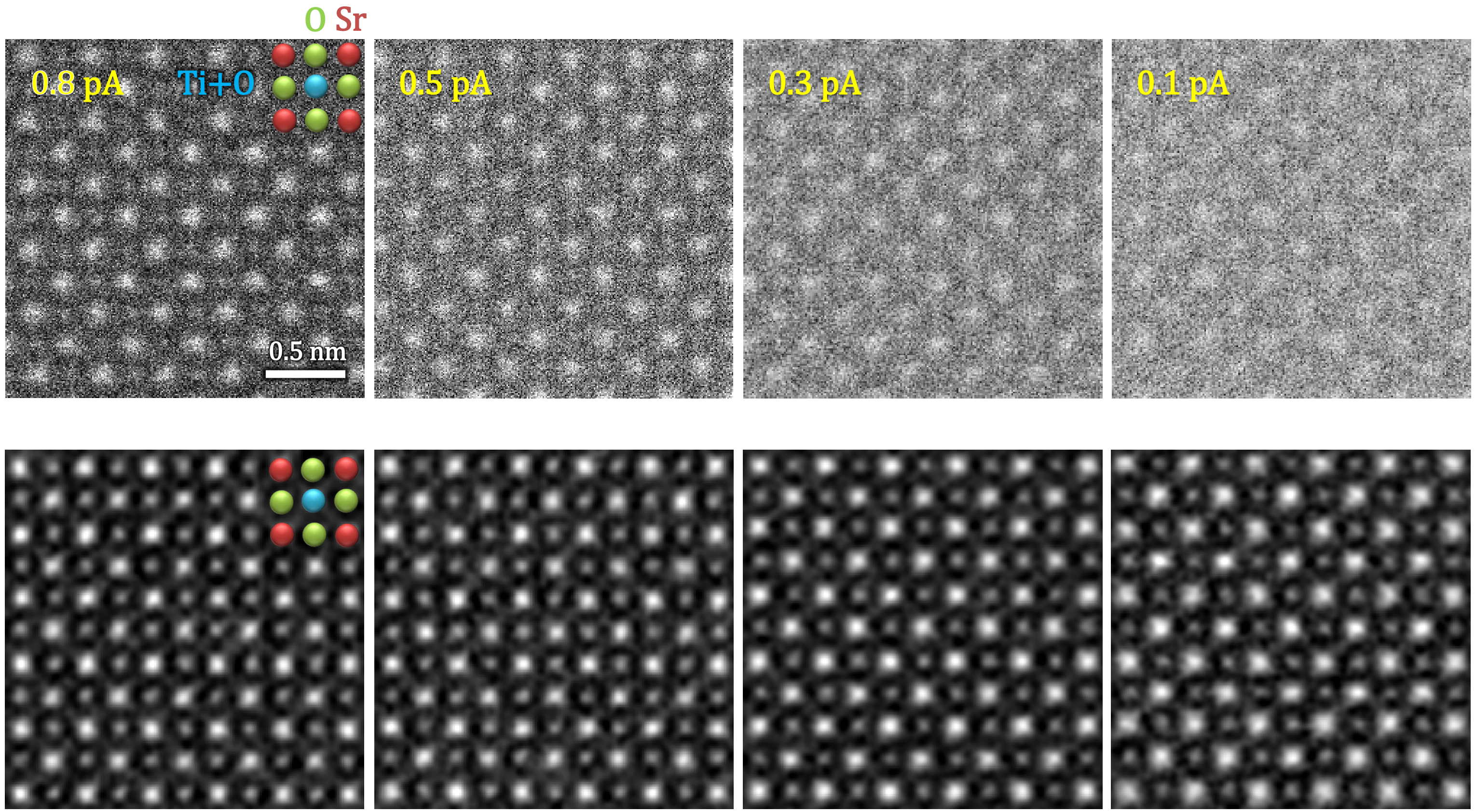
- Maximum S/N
- Low dose
- Light Element Detection
- Live



K. Ooe *et al.*, *Ultramicroscopy* 220, 113133 (2021)

OBF – Dose-Efficient Imaging

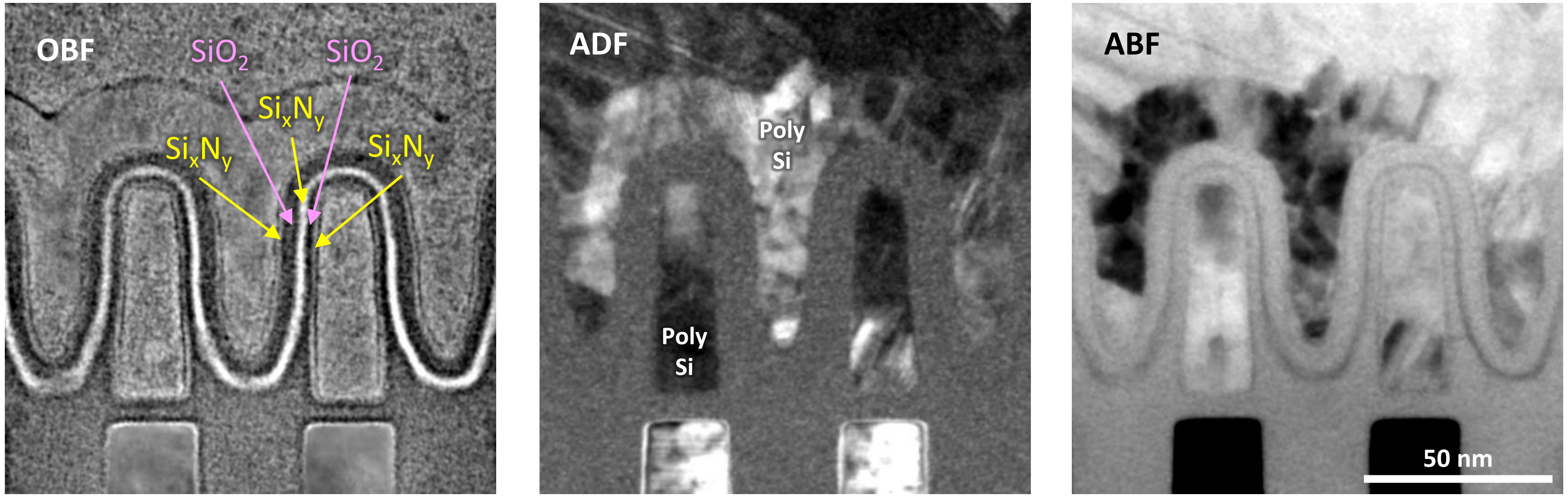
$SrTiO_3$ [001]



300kV, alpha = 24 mrad

High Contrast – Small Convergence

Semiconductor material

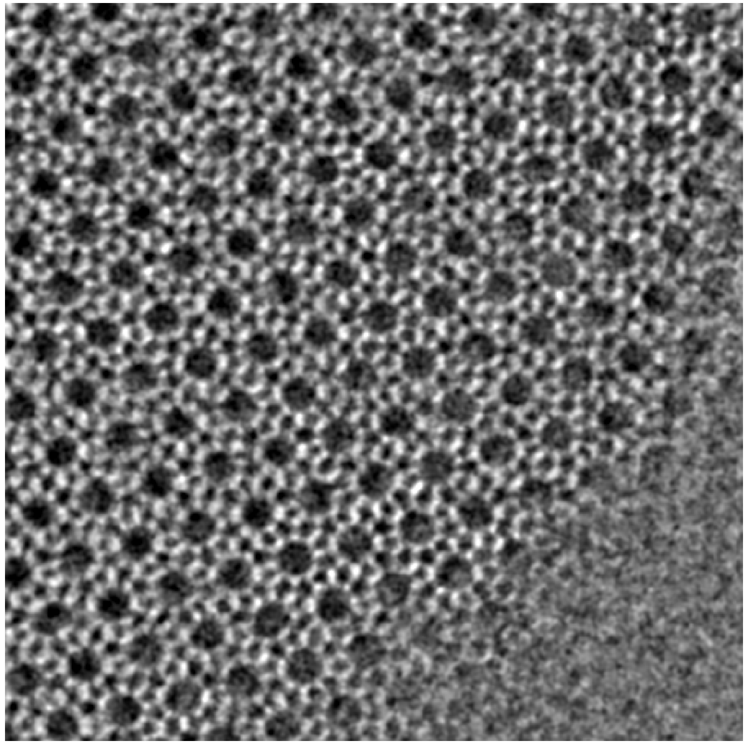


Accelerating Voltage : 200 kV
Convergence Semi-angle : 2 mrad

- High contrast under small convergence angle conditions
  - Non-corrected, Lorentz mode, etc.
- Light Element Detection

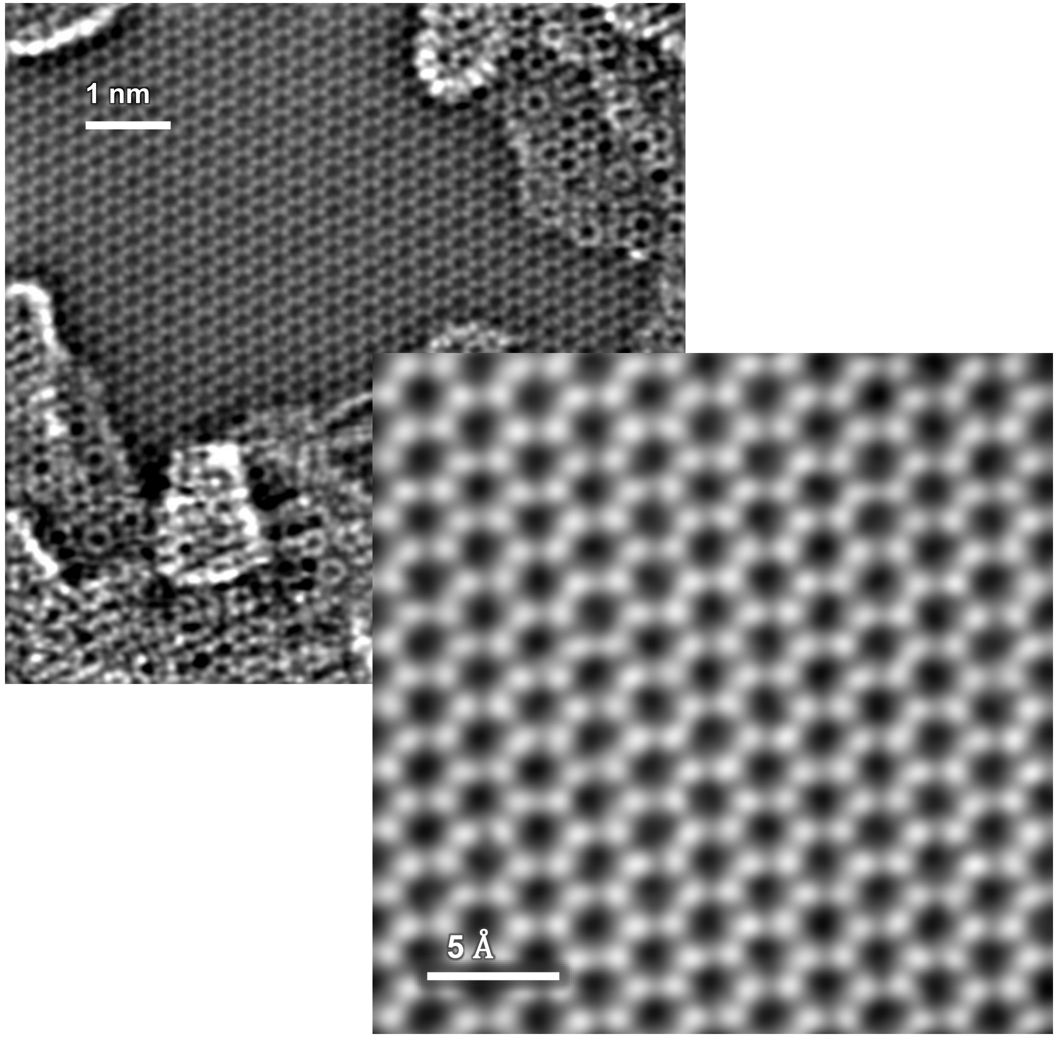
Low Dose, Low Scattering Conditions

Zeolite



ARM300F2 300kV, alpha = 16 mrad

Probe current = 0.5 pA

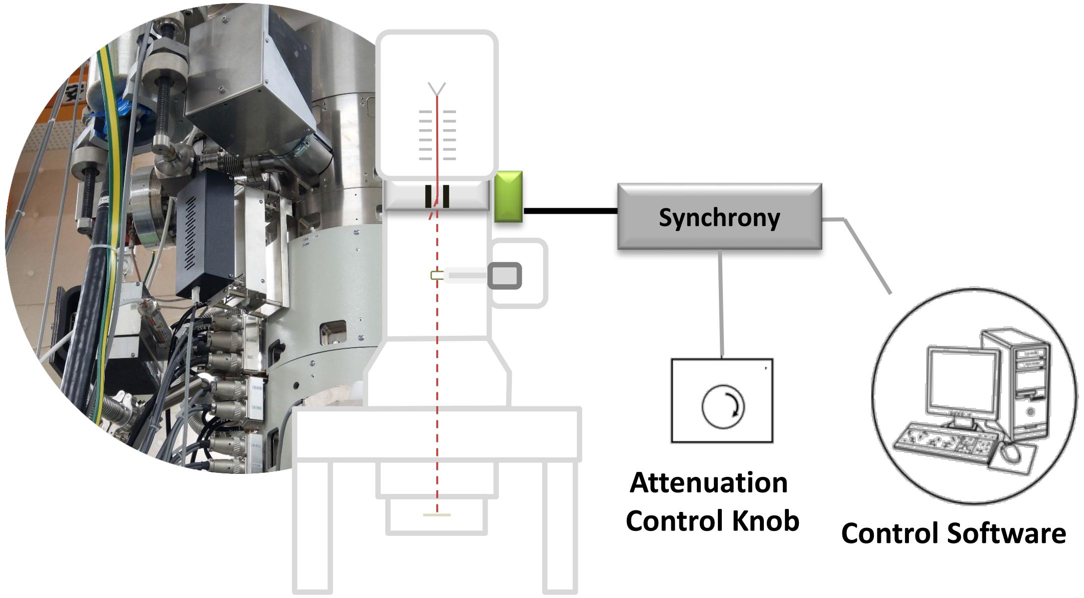


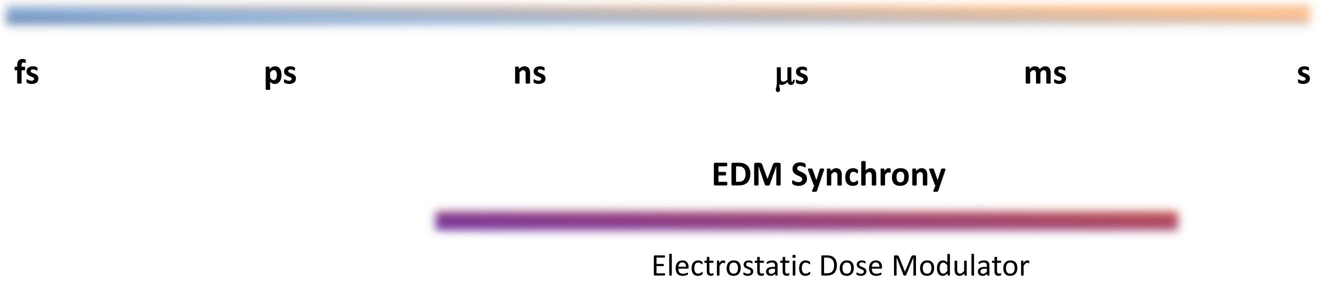
Single Layer Graphene

NEOARM 60kV, alpha = 35 mrad

IDES Integrated Technology

- IDES technology dramatically expands microscope flexibility and functionality
  - Beam damage mitigation
  - Speed
  - Optical illumination
- ***EDM*** - Electrostatic Dose Modulator





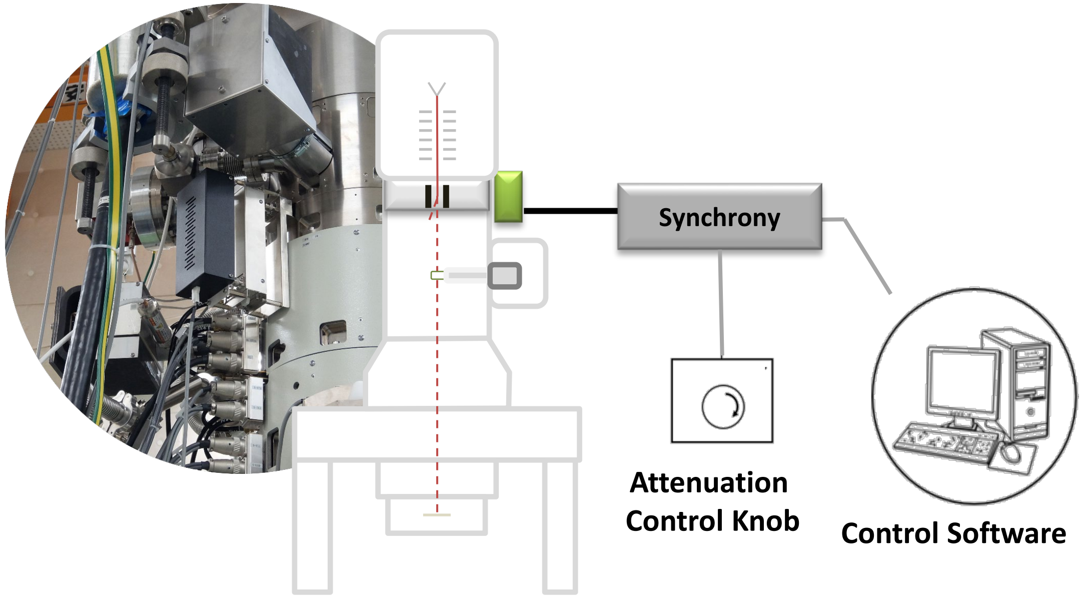
EDM with Synchrony

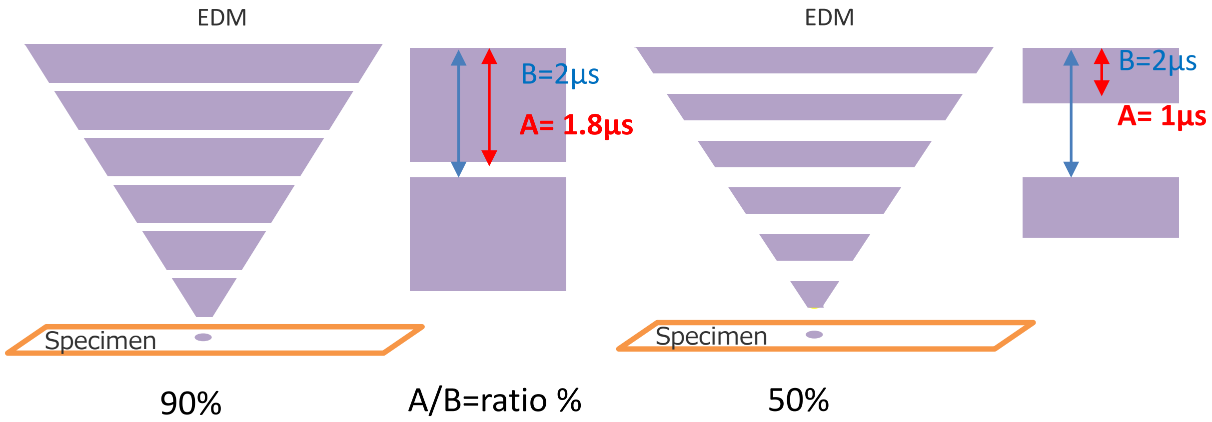
EDM Electrostatic dose modulation

- Electrostatic shutter gives 10^5x increase in beam blanking speed (50ns vs 5ms magnetic blanker)
- On-the-fly dose control without affecting imaging conditions

Synchrony Nanosecond timing control

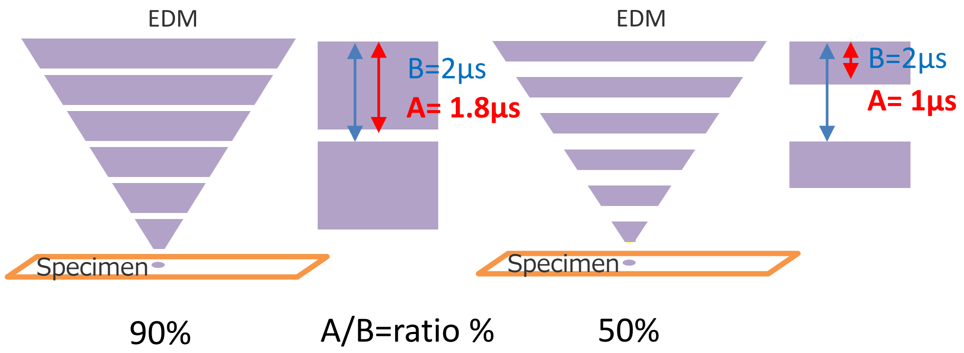
- STEM synchronization
- Programmable dose structuring

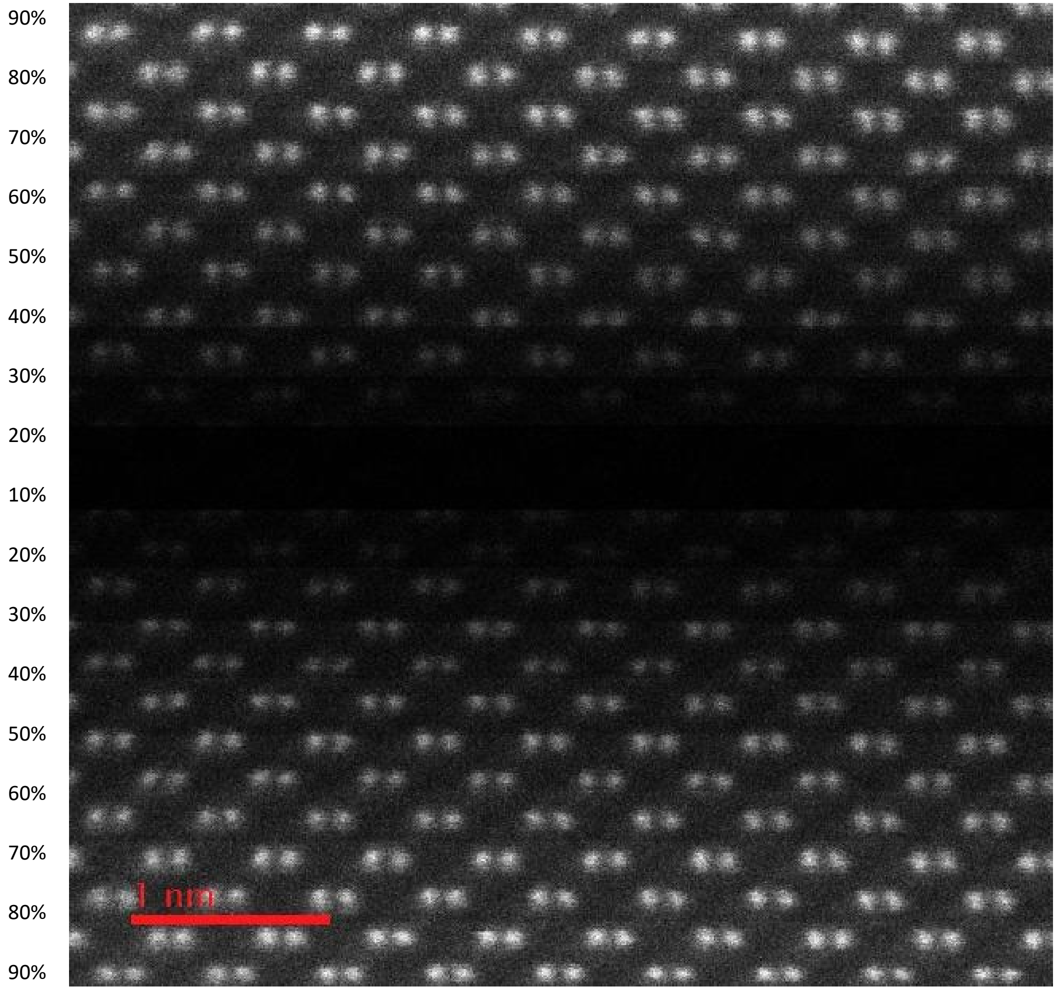




EDM with Synchrony

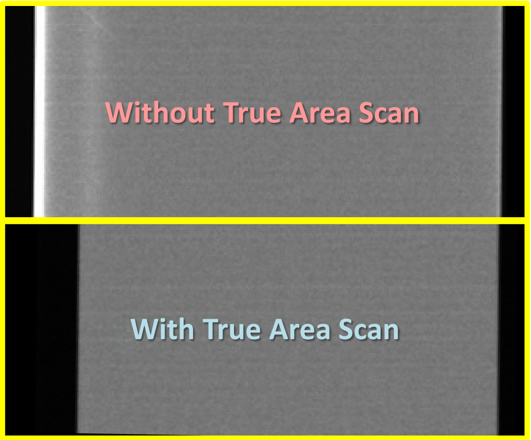
- Single scan STEM Image
  - Si [110] HAADF, 300kV
- Changing duty ratio from
  - 90% -> 10% -> 90%
- Frequency of 500 kHz (2 µs)
- Pixel dwell time with 19 µs/pix (1024x1024 pixels)



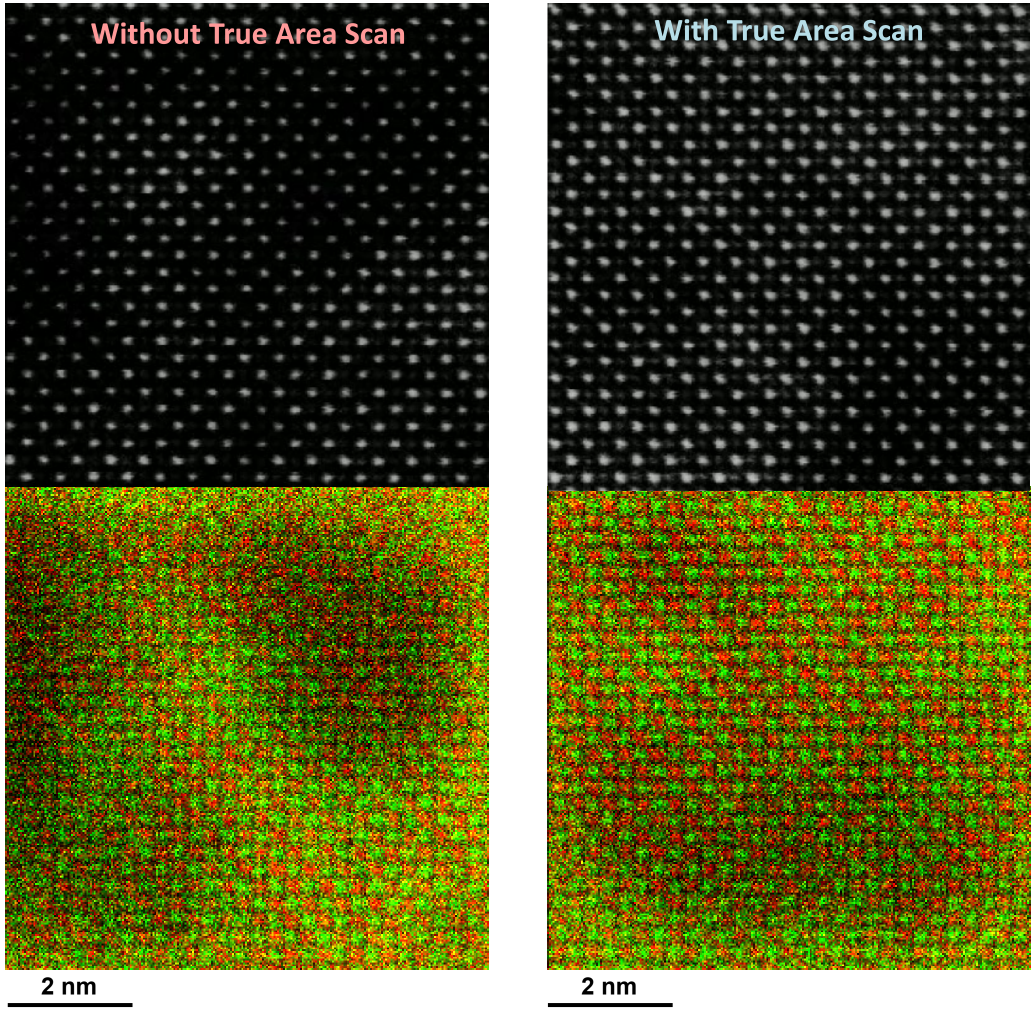


EDS + EDM – True Area Scan

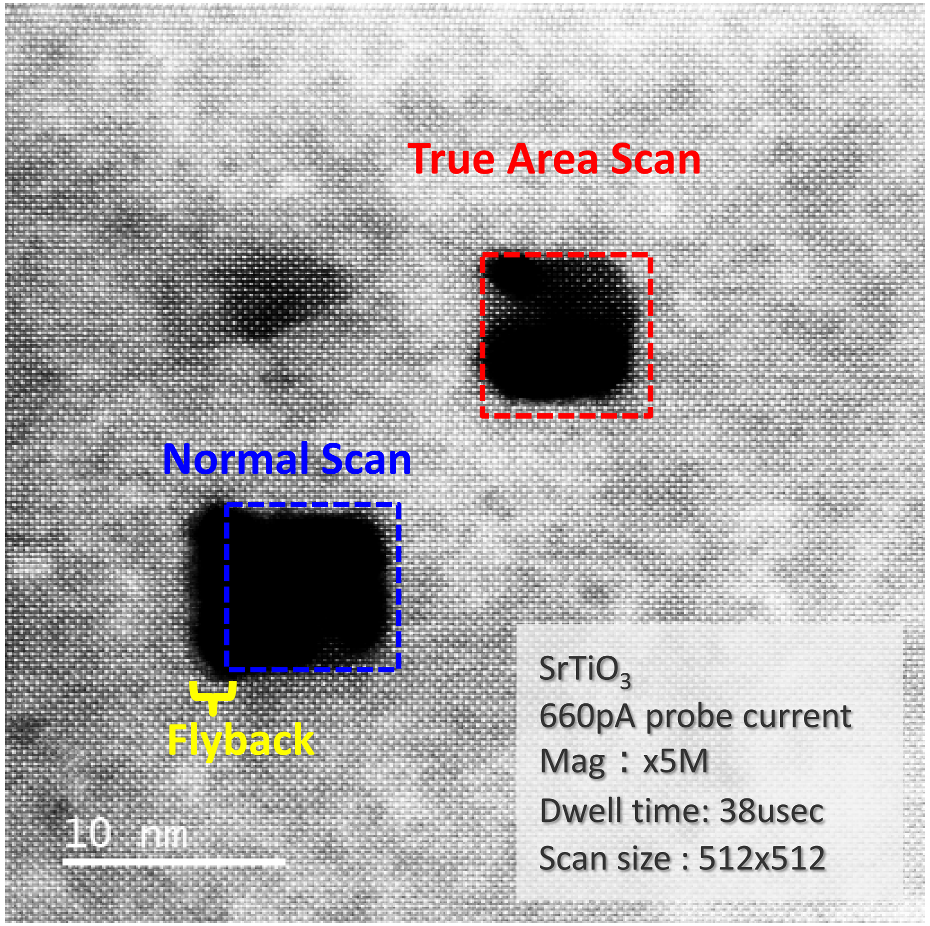
- True Area Scan
- Integration with JEOL EDS software and scanning system
- True Area Scan automatically removes illumination during flyback
- Reduces specimen damage and coincidence loss

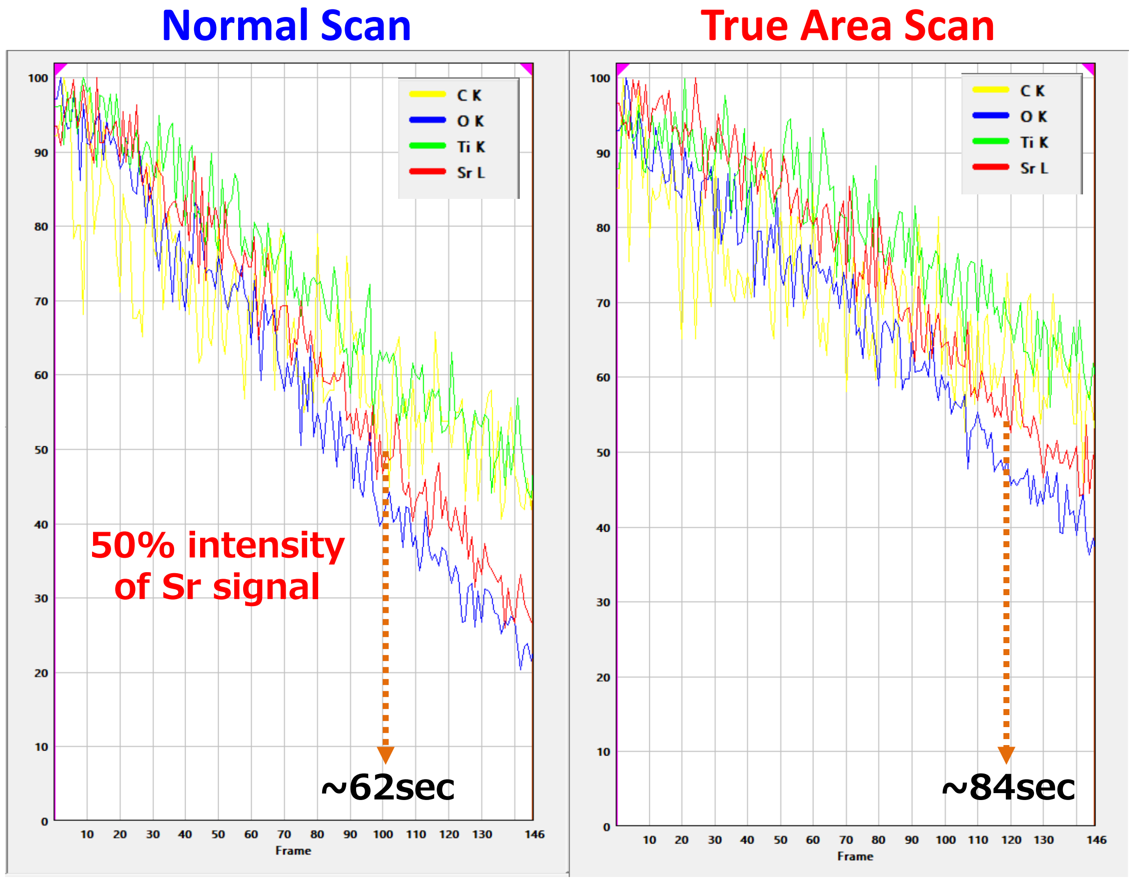


[TEM] JEM-ARM300F2
[EDS] 158SQmm Dual SDD
[Acc. Volt] 300kV
[Current] 660pA
[Magnification] x25M
[Specimen] ST_3O_3
[Image Size] 256 x 256 pixel
[Fly back] 128 pix



EDS + EDM – True Area Scan

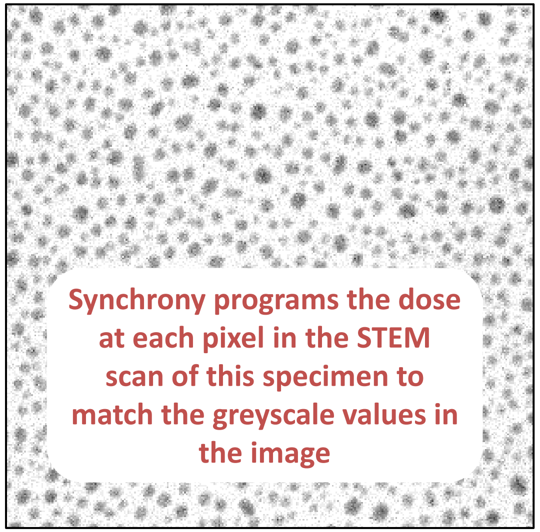


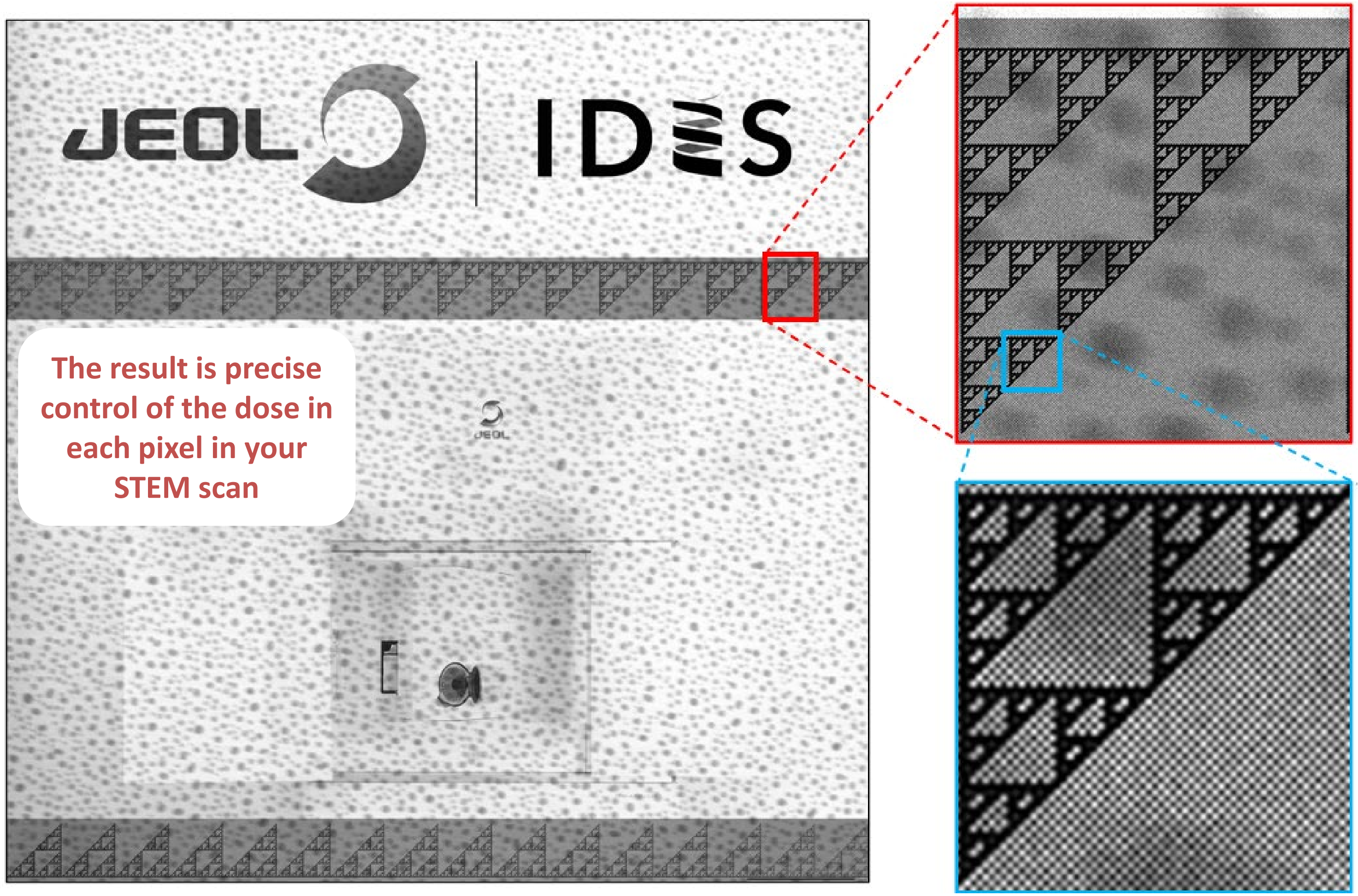


EDM Synchrony

This is unprocessed STEM data showing a dose pattern programmed by EDM Synchrony that includes the JEOL IDES logo, fractal patterns, and a checkerboard pattern.

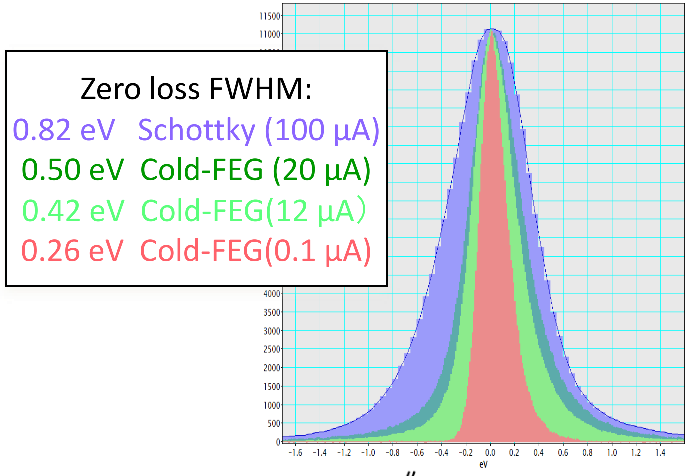
Specimen – Au particles

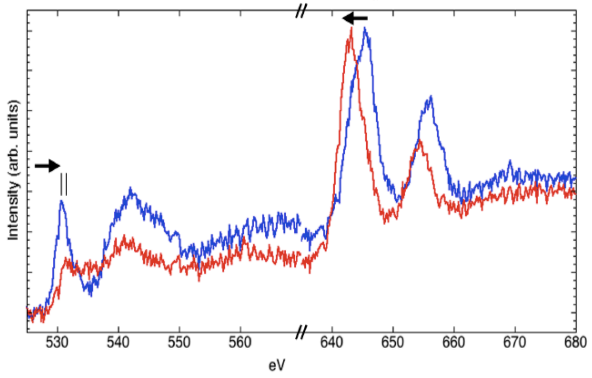


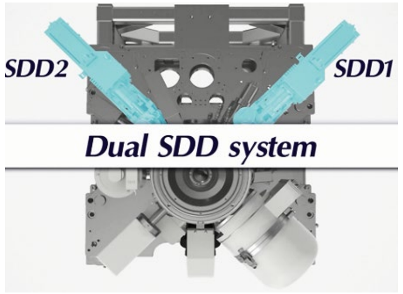


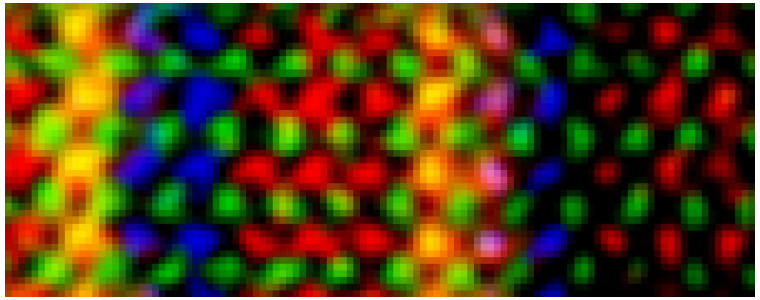
Extreme Functionality of “Workhorse” S/TEM

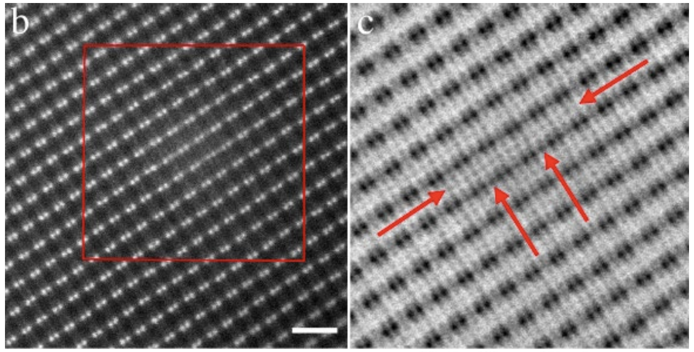
- CFEG
  - High probe current
  - Maintain energy resolution for EELS fine structure analysis
- Efficient EDS
  - High-throughput
  - Decreased dwell time
- Atomic-resolution imaging and spectroscopy











Coming Up…

COVALENT METROLOGY

On May 19

CHARACTERIZATION OF CLIMATE BENEFICIAL MATERIALS BY GAS SORPTION

SPEAKER:
Mark Thomas, PhD
Lead Scientist,
Anton Paar Quantatec

May 19, 2022 | 11am PT

Anton Paar

COVALENT METROLOGY

On June 23

Nanoscale Secondary Ion Mass Spectrometry (NanoSIMS) Analysis

In partnership with
Toray Research Center, Inc.

Survey and Sign-Up for Calendly Appointments

Thank you for joining us! To show our appreciation

We’re offering attendees a **Special One-time Discount**

10% Attendee Discount

for your next S/TEM Project

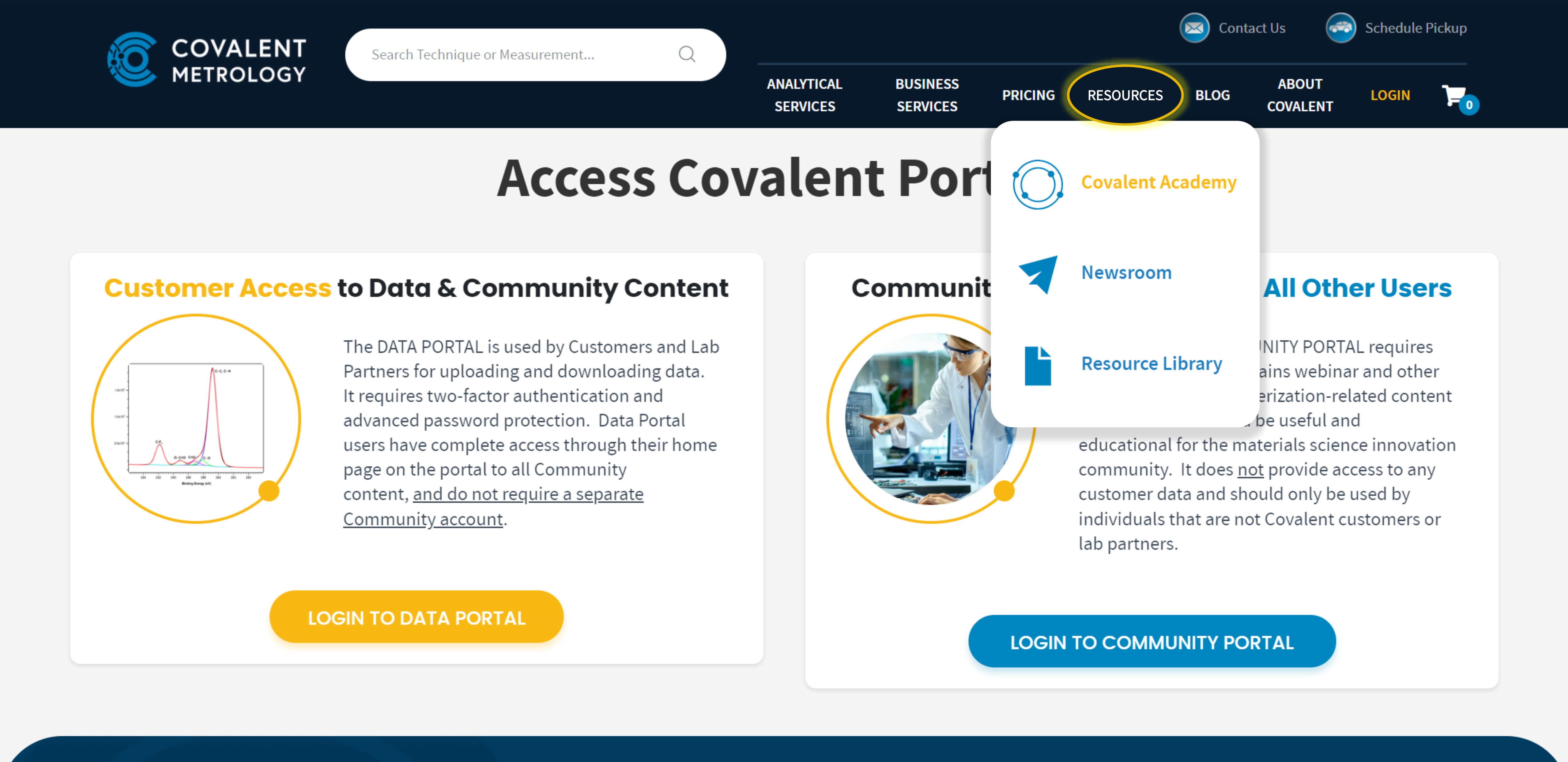
Schedule a free **Discovery Appointment**

to talk with a Covalent Expert

Calendly link is shared in the chat

Login to Access this Recording

COVALENT METROLOGY



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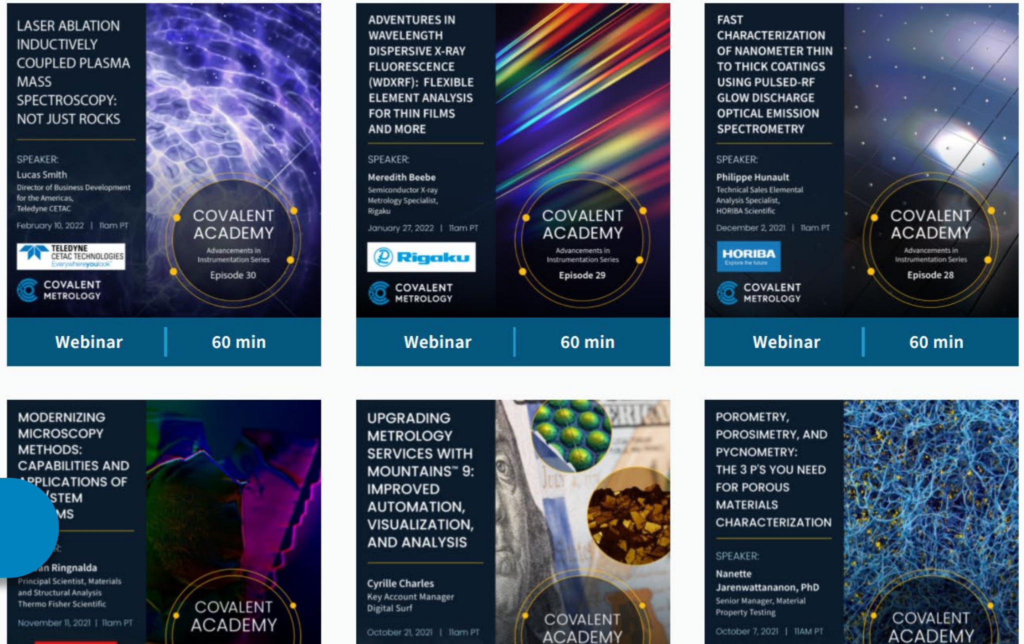

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https://academy.covalentmetrology.com

Q & A Session

COVALENT METROLOGY

Thank you