Choosing the Best EPIC-SEM for Your Experiment

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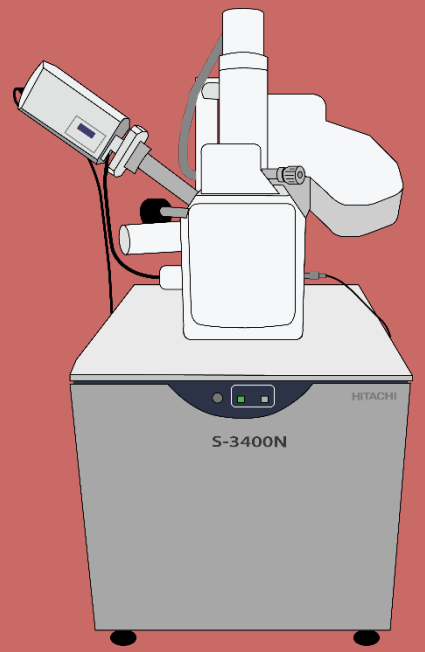
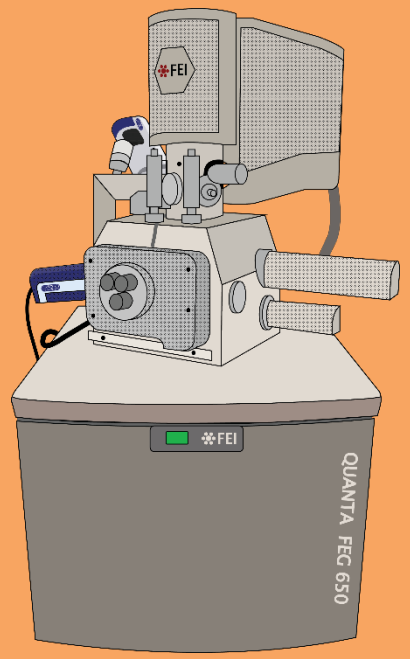
2023

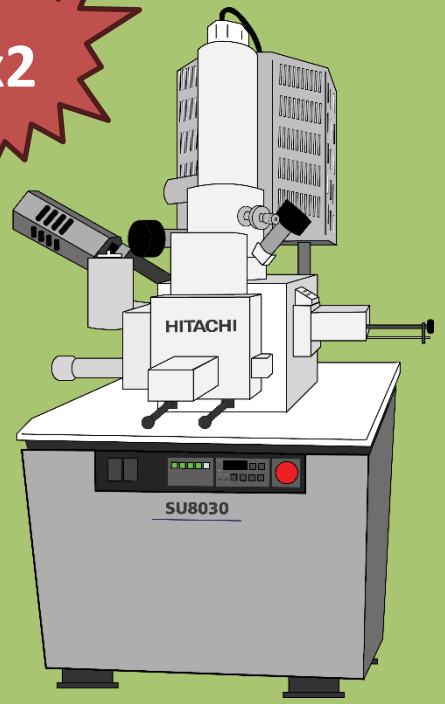


Hitachi S-3400N

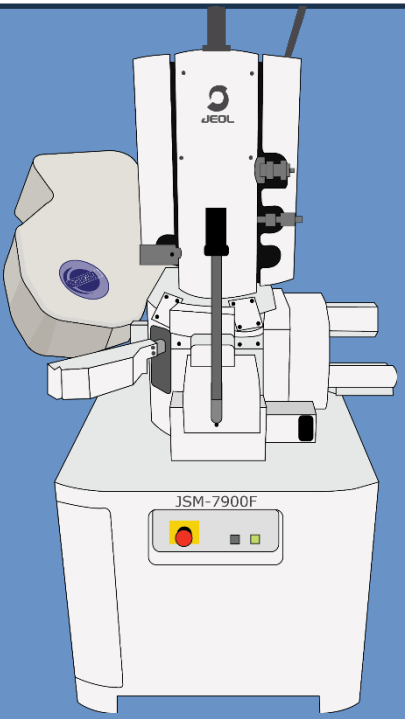


Quanta 650 FEG

x2



Hitachi S-4800 and SU8030



JEOL JSM-7900F

Overview

Background	What is SEM and how does it work
Electron Detectors	Image generation with different signals electron-specimen interaction
SEM Modes and Techniques	Advanced imaging and microanalysis techniques
SEM's at NU*ANCE*	The different SEM's with strengths and weaknesses

Background

Figure from MyScope.com

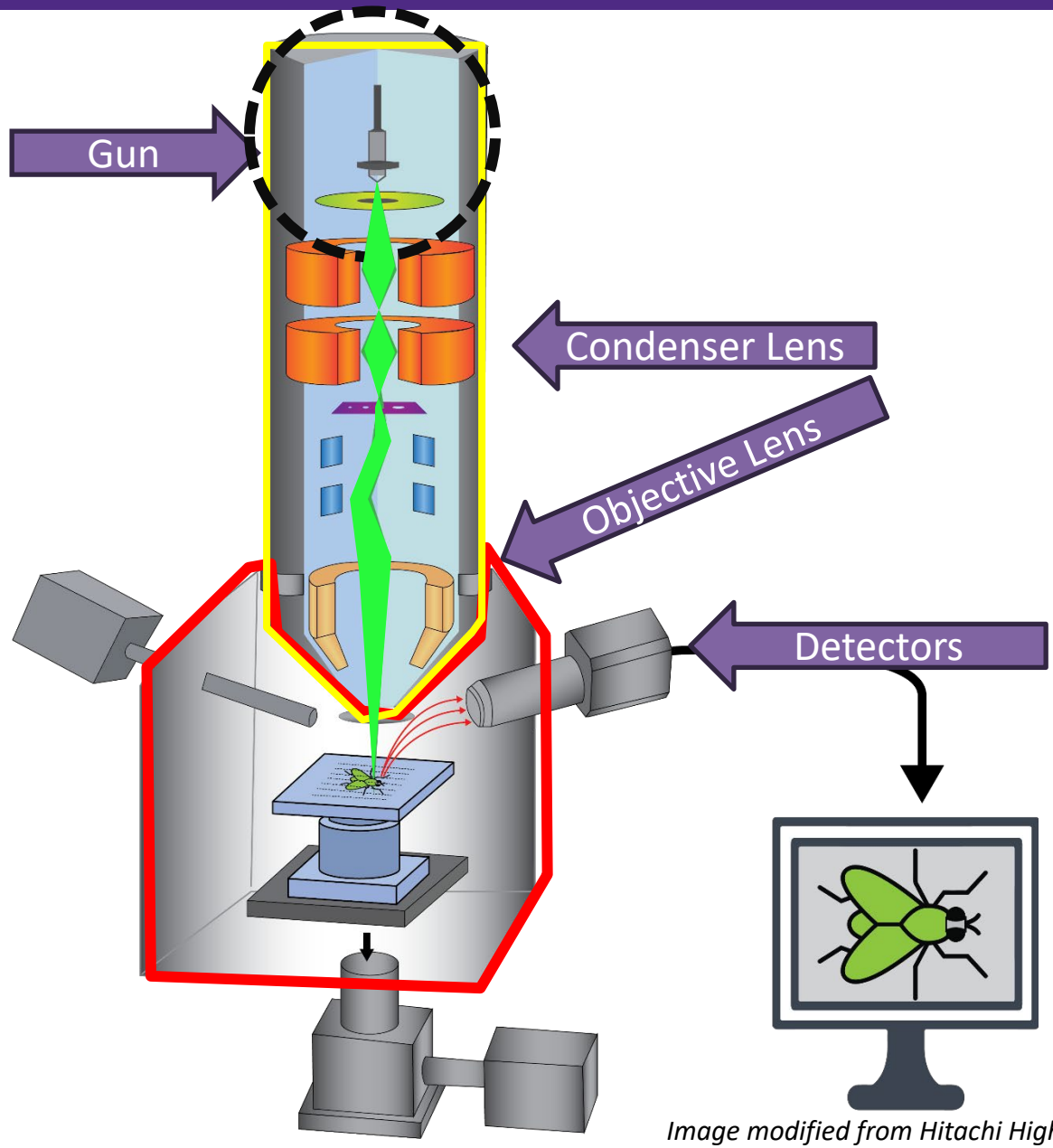
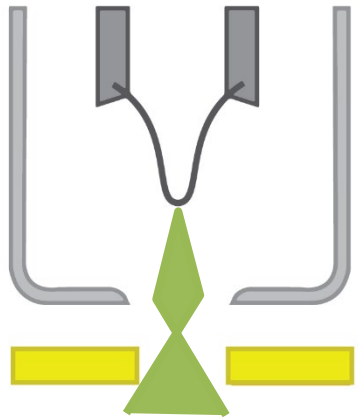
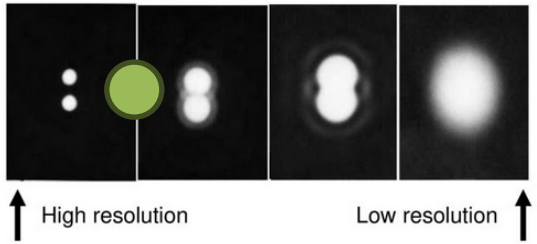
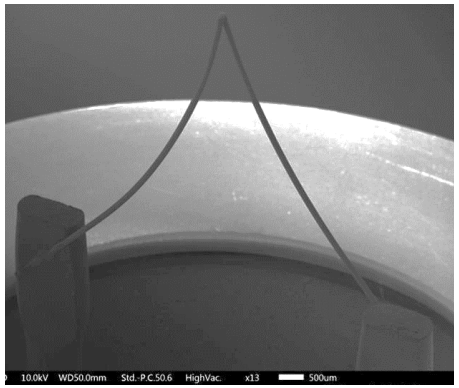


Image modified from Hitachi High-Tech

Tungsten Filament

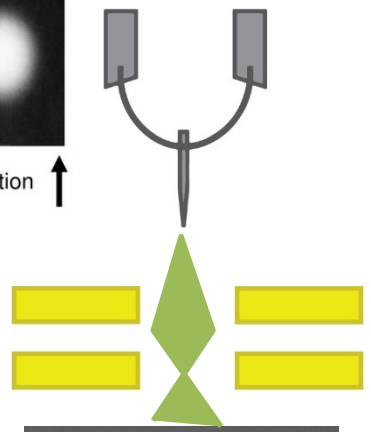


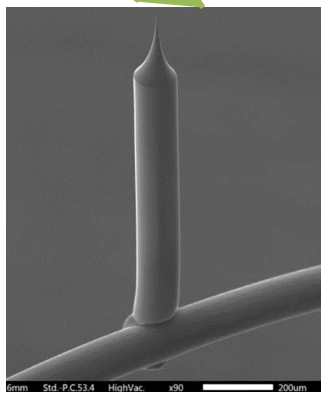




Source Diameter	Resolution	Brightness	Energy Spread	Stability
↑	↓	↑	↑	↑

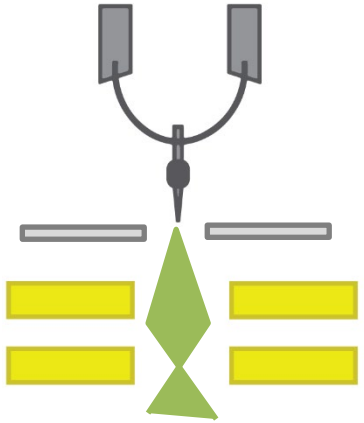
Cold Field Emitter

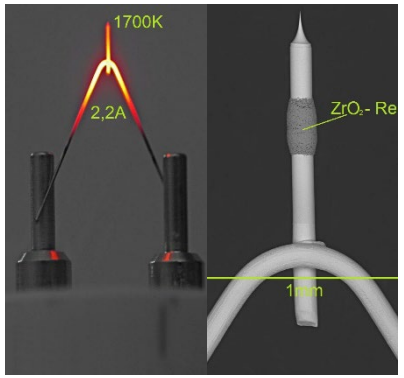




Source Diameter	Resolution	Brightness	Energy Spread	Stability
↓	↑	↑	↓	↓

Schottky Emitter



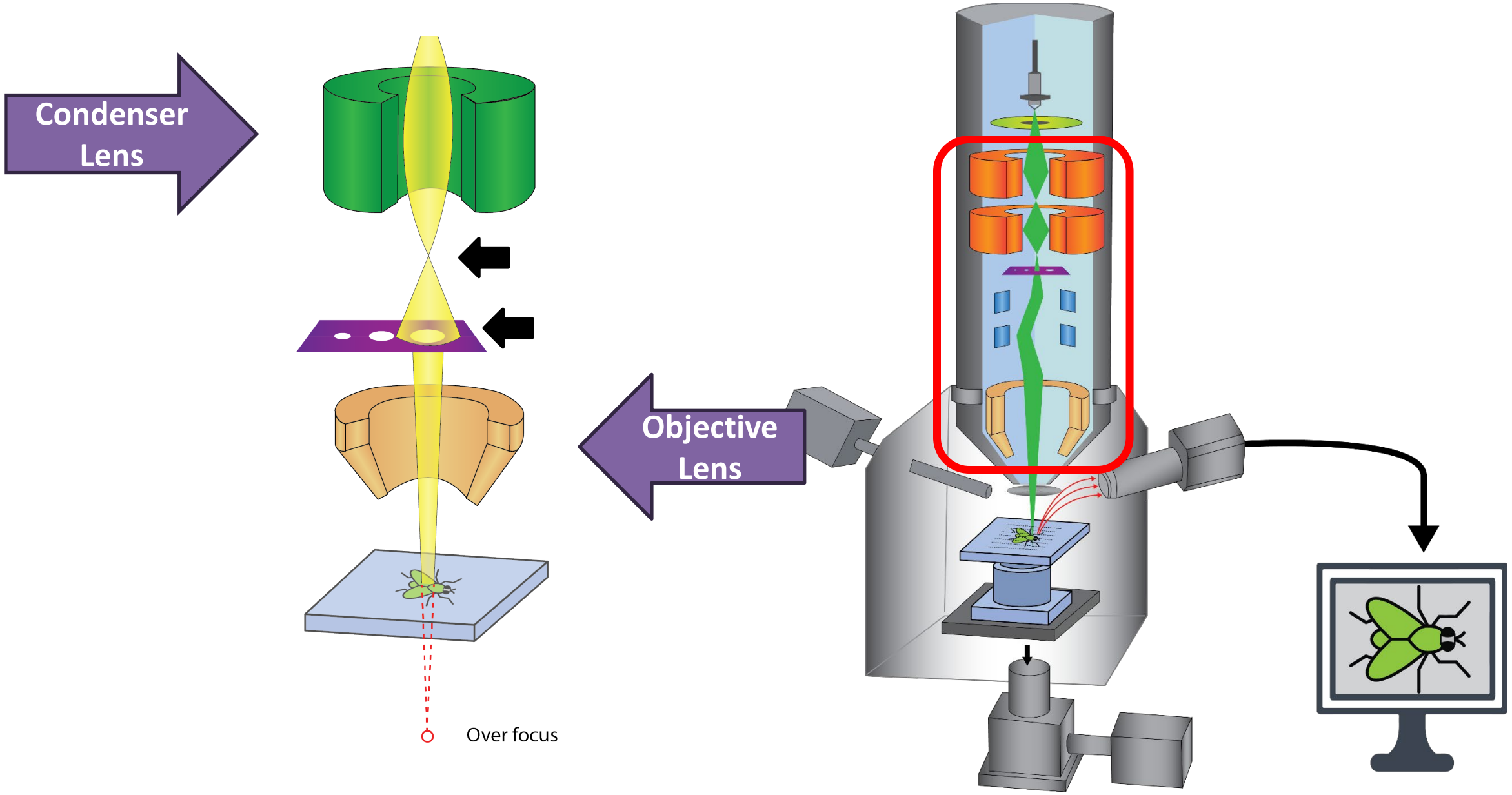


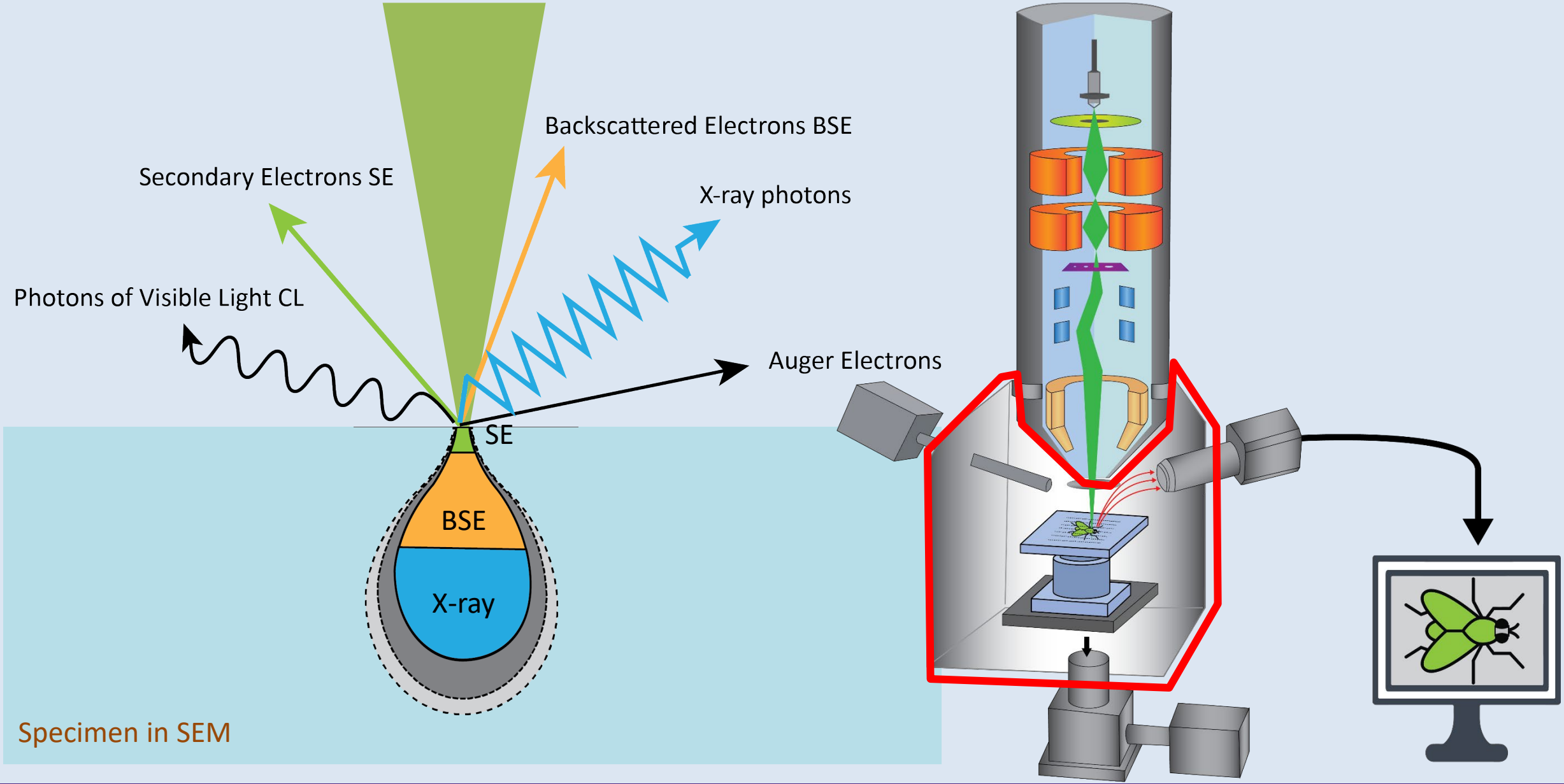
Source Diameter	Resolution	Brightness	Energy Spread	Stability
↓	↑	↑	↓	↑

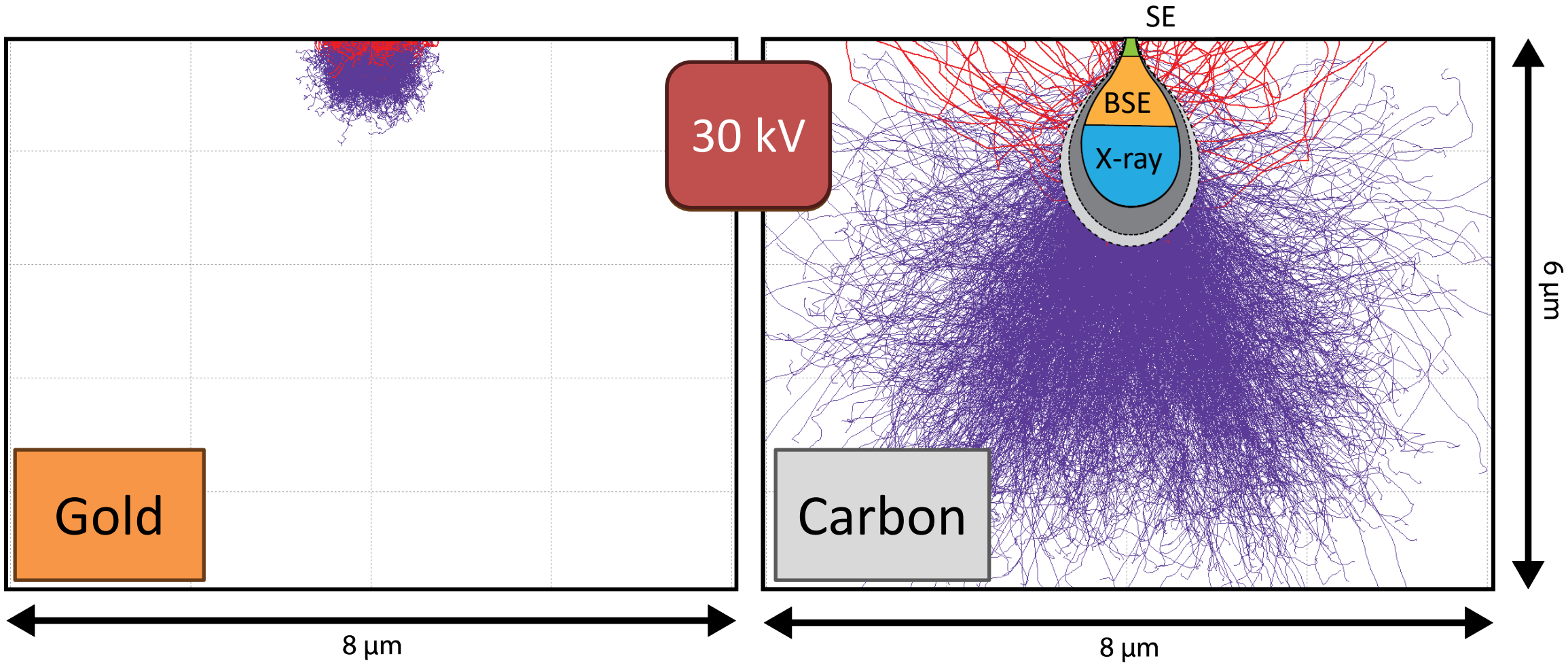
Anode 1

Anode 2

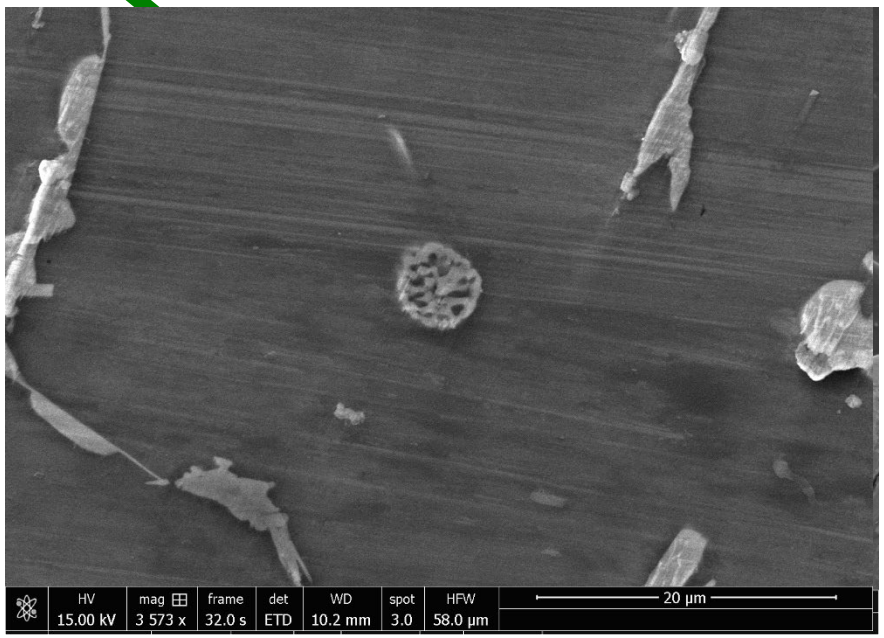
Images from Anwar 2018

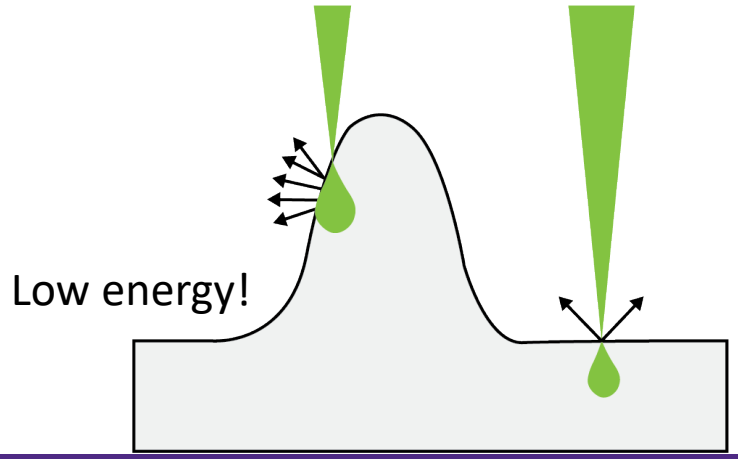

Condenser Lens
Objective Lens
Over focus

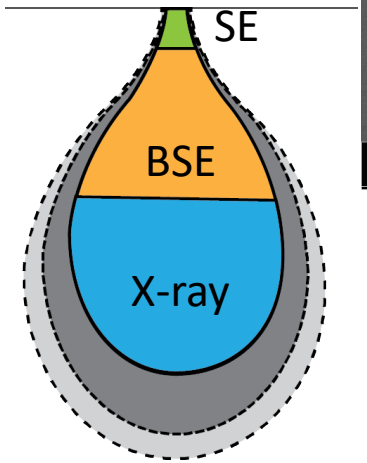

Backscattered Electrons BSE
Secondary Electrons SE
X-ray photons
Photons of Visible Light CL
Auger Electrons
SE
BSE
X-ray
Specimen in SEM


SE
30 kV
BSE
X-ray
Gold
Carbon
6 µm
8 µm
8 µm

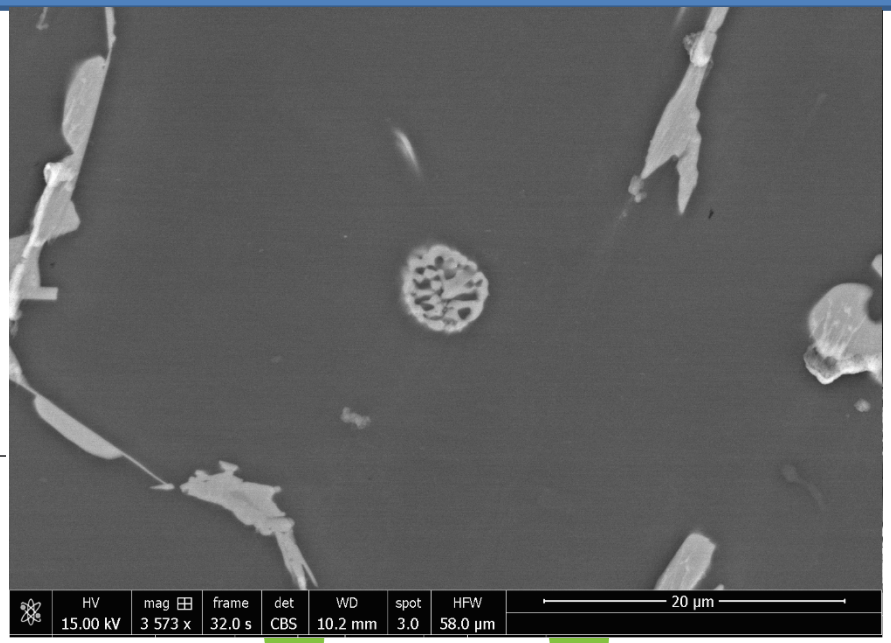
Secondary Electrons

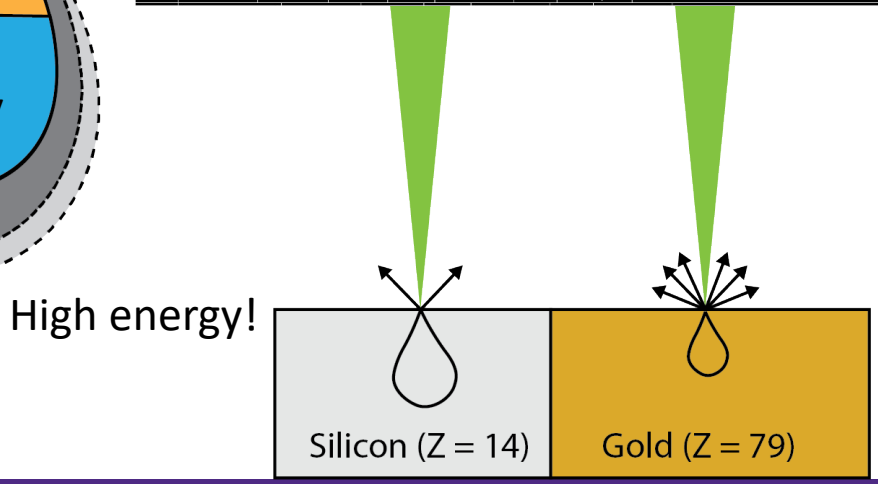






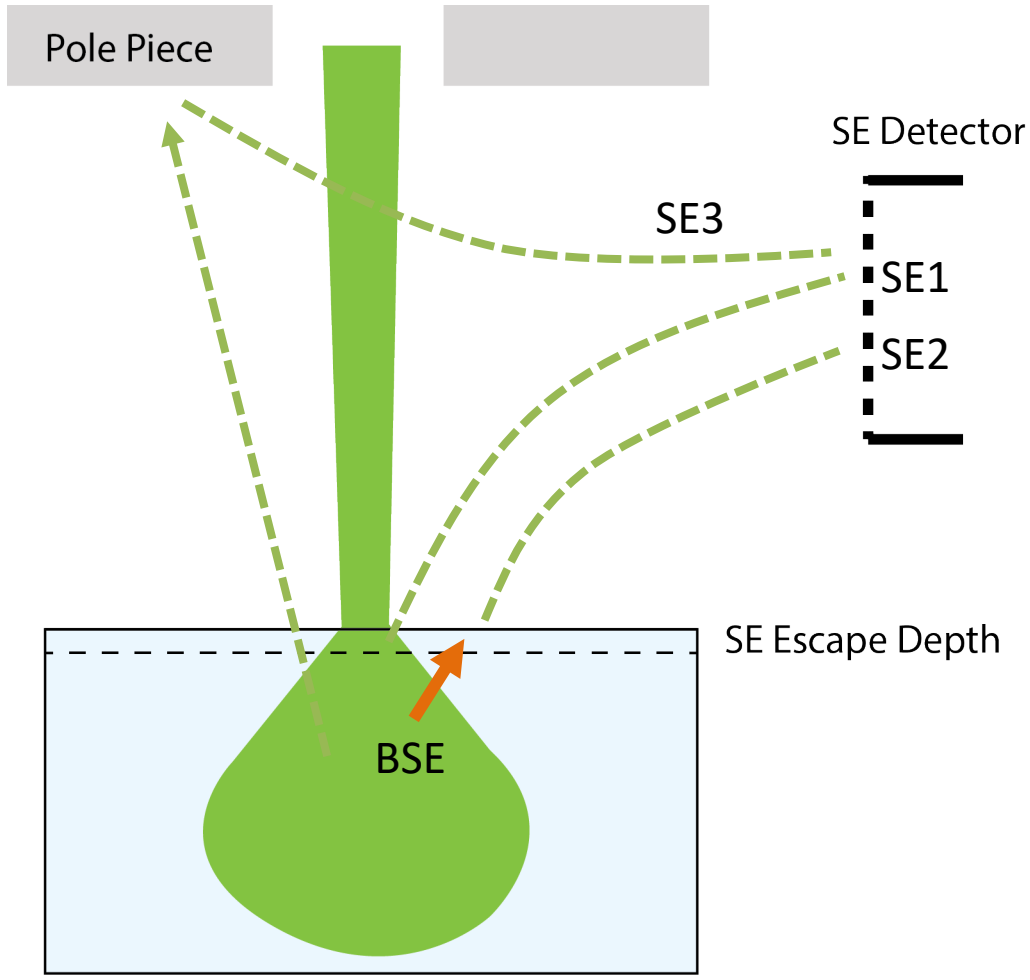
Backscatter Electrons



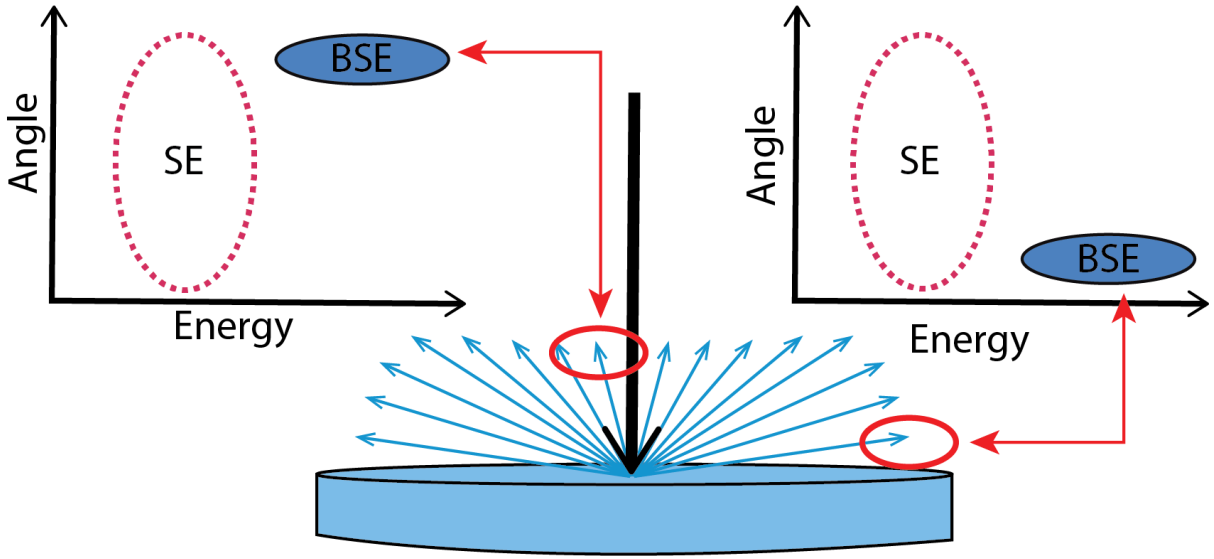


Secondary Electrons

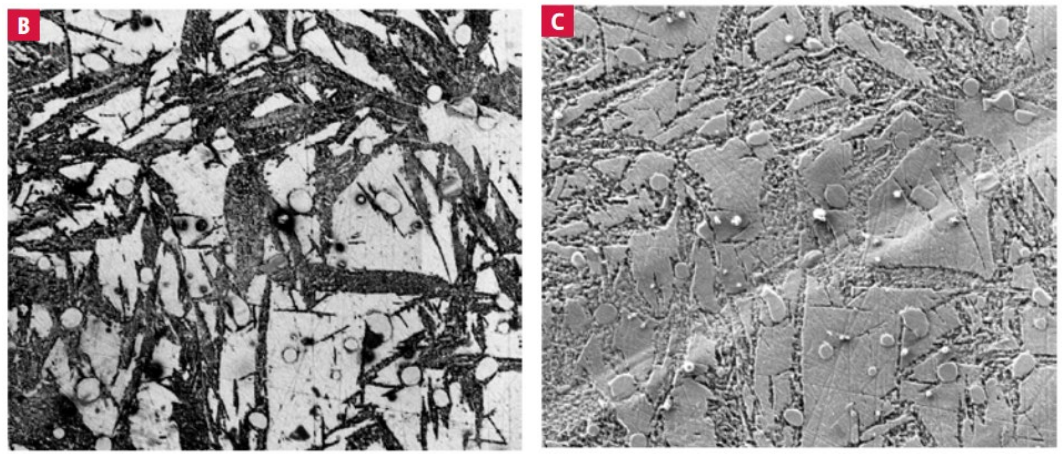
SE1	Incident probe	Most surface sensitive, high res
SE2	BSE Leaving the sample generating SE	Low res, some compo information
SE3	BSE hitting walls of chamber	Noise



Backscatter Electrons



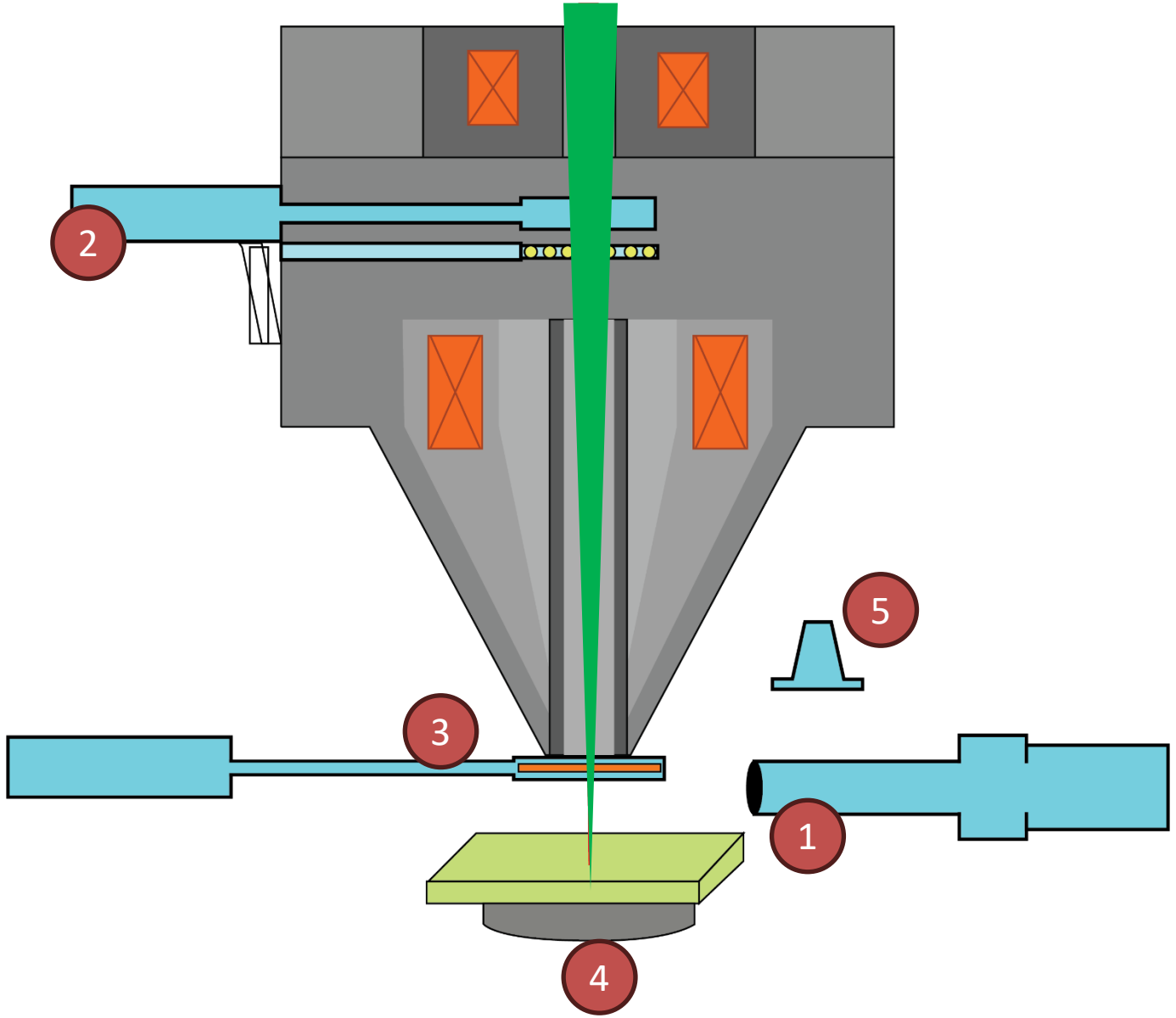
- Angles of elastic scattering range from 0-180 degrees



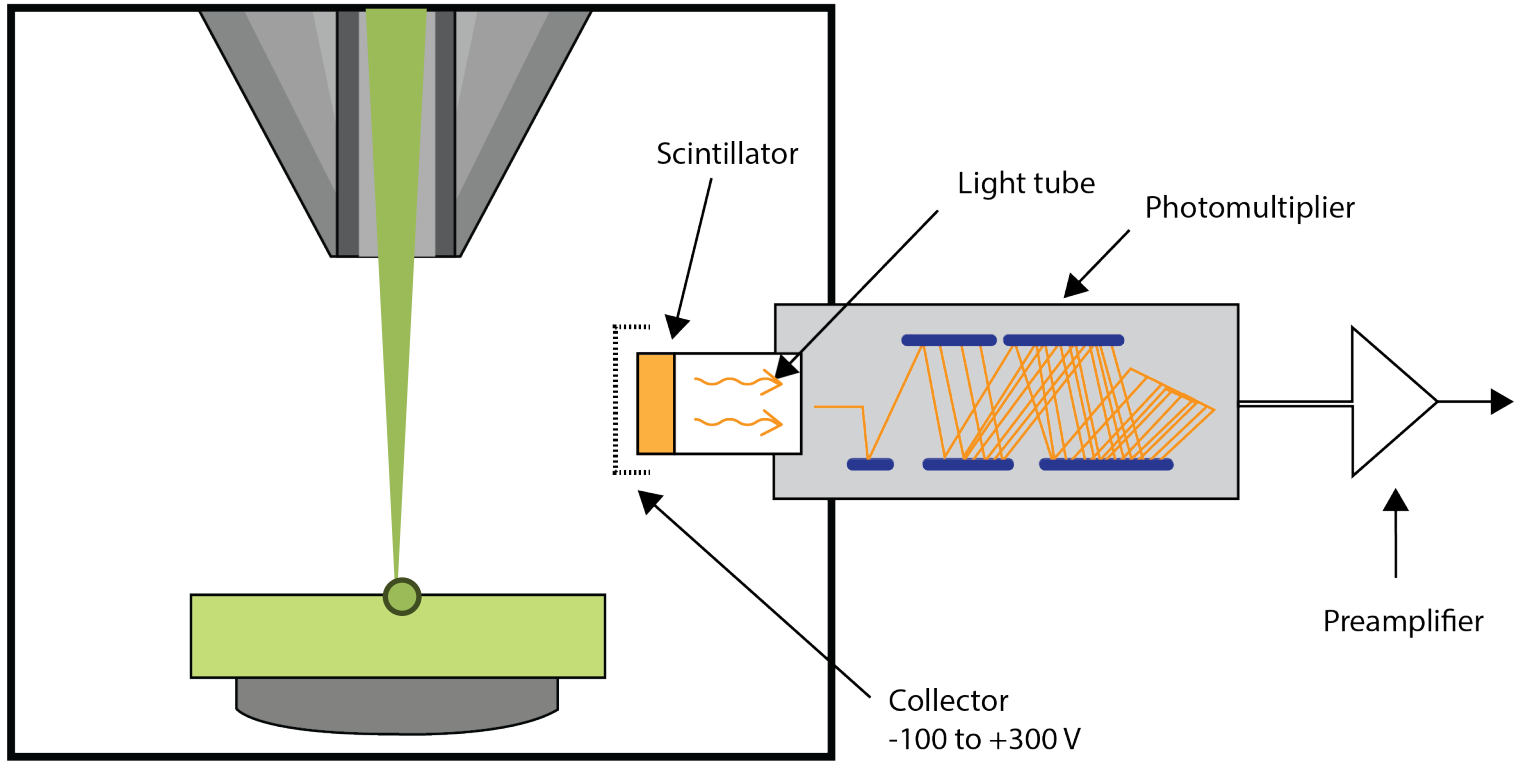
Steel sample (B) high angle BSE showing z contrast and (C) low angle BSE showing topography (photos from FEI)

Electron Detectors

1. Lower SE Detector (EHT detector)
2. In-Lens (upper) SE Detector
3. Backscatter Electron Detector
4. STEM Detector
5. Others (Low Vac, etc.)



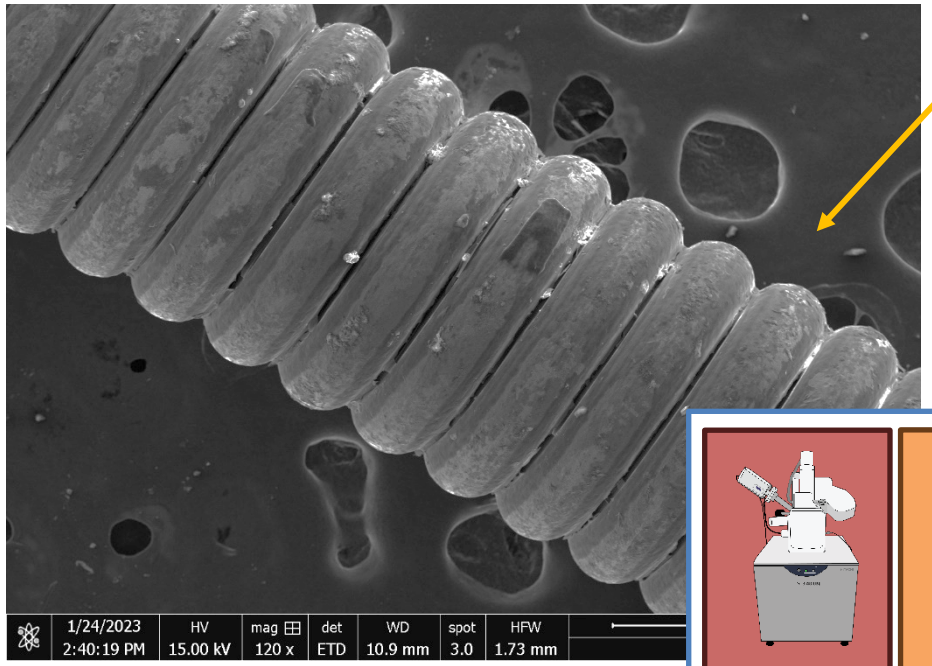
1. Lower Secondary Electron Detector

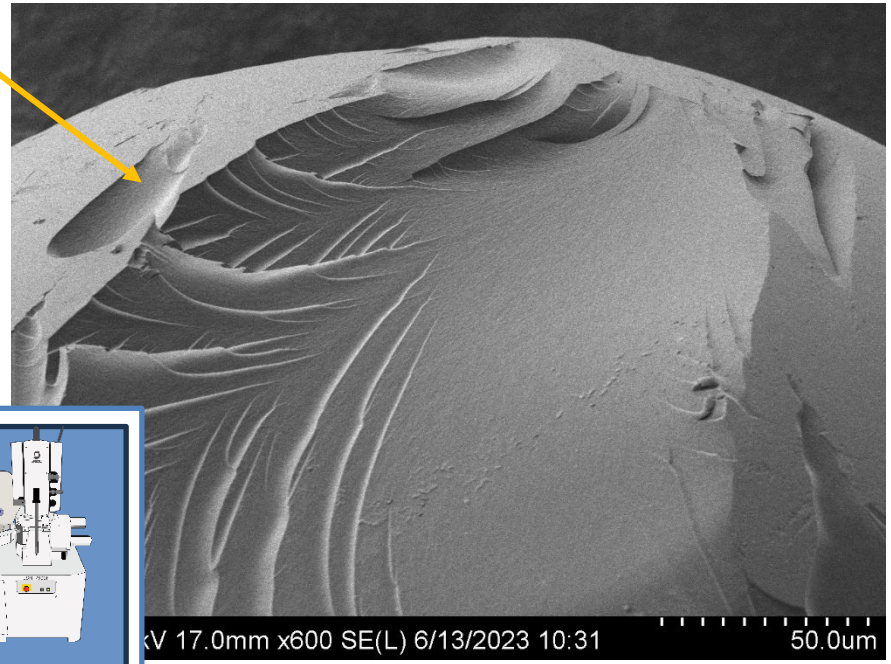


- Directional illumination due to detector geometry
- Rapid characterization of surface topography
- Decreased signal at short WD (< ~10 mm)
- Reduced charging effects

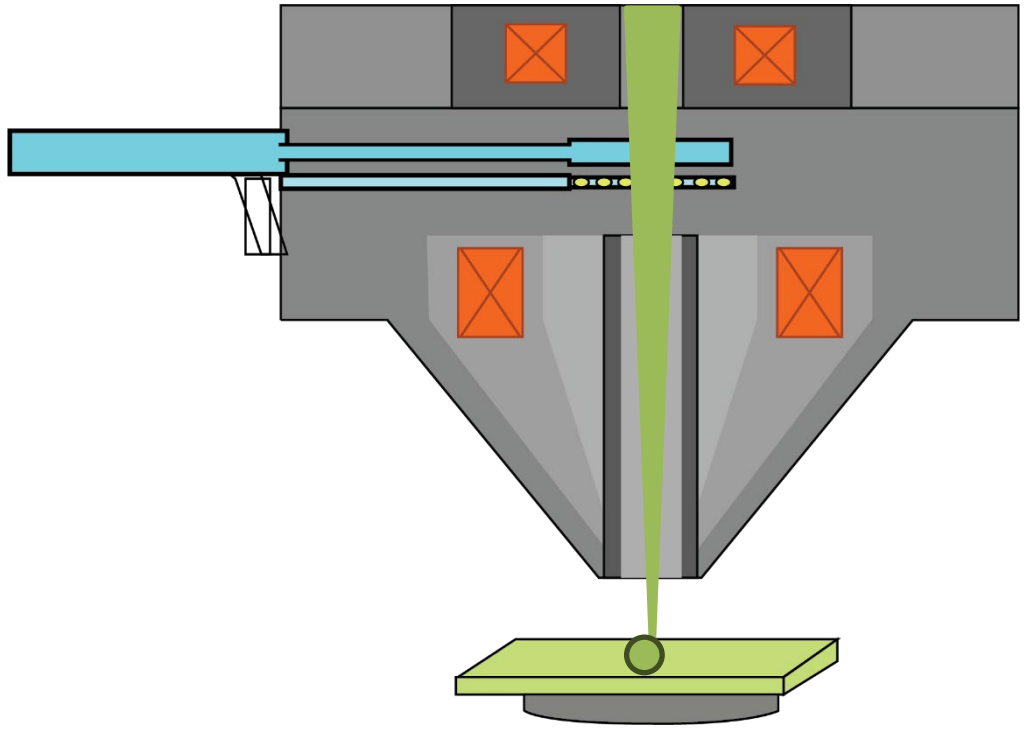
Lower detector: ~ 40% SE3, 45% SE2, about 15% SE1 (and some direct BSE signal)

SE Detector Examples





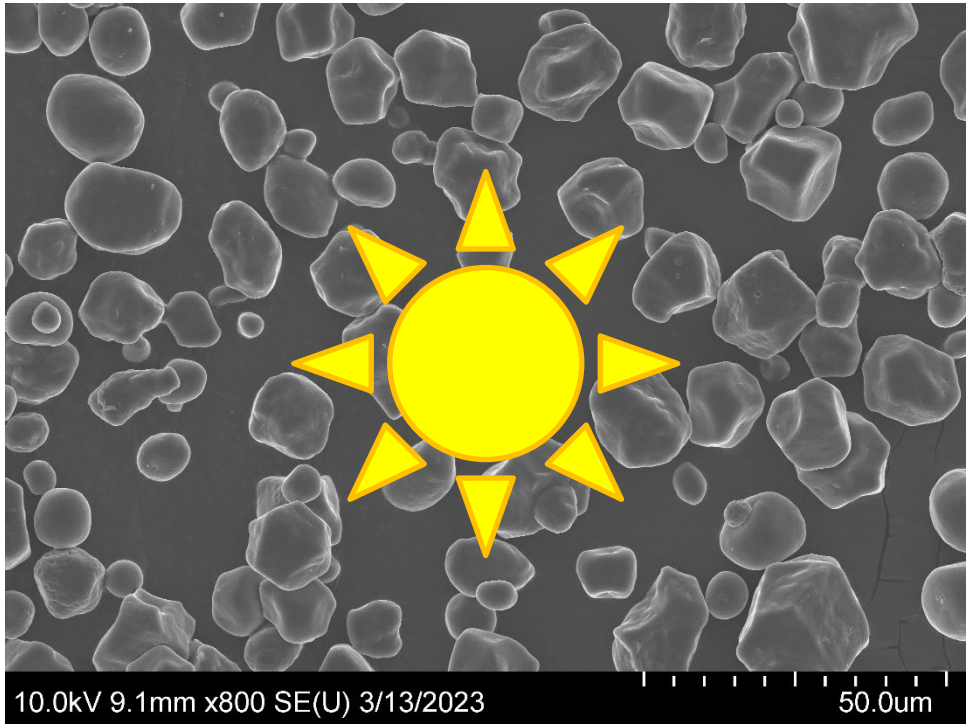
2. In-Lens (upper) Secondary Electron Detector

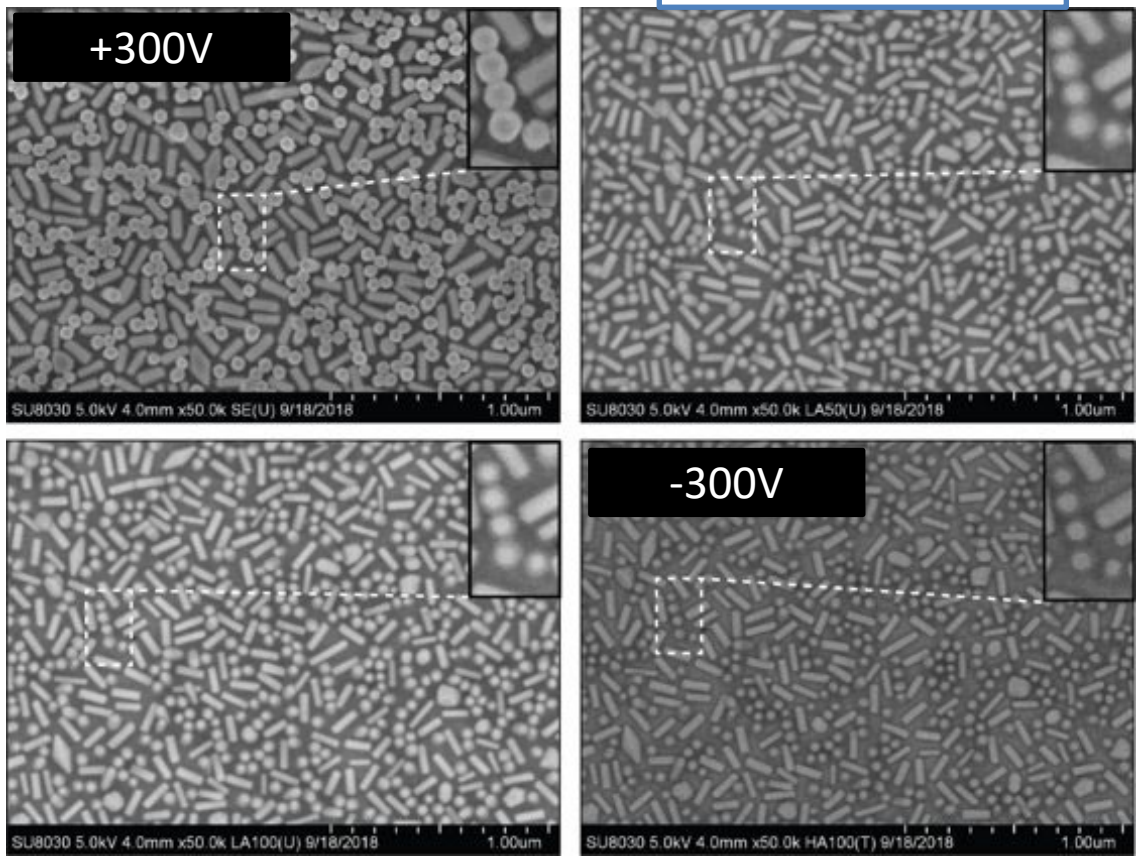


Upper detector: ~75% SE2 and 25% SE1.

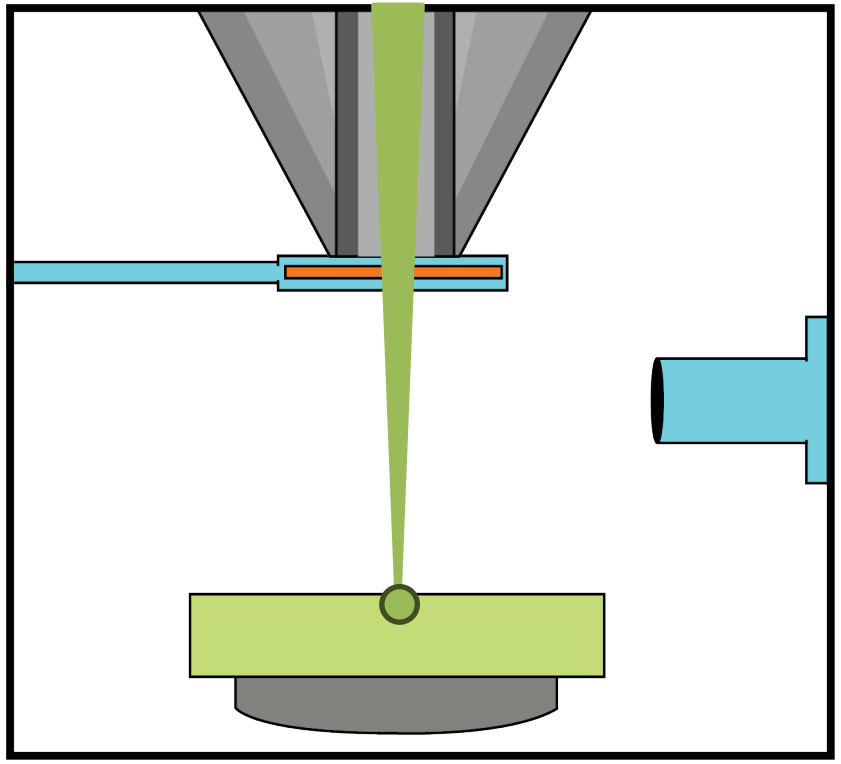
- Signal Varying Mechanism - detect both SE and BSE
- Higher resolution imaging
- Optimum performance at shorter WD (< ~10 mm)
- More uniform illumination than lower SE Detector

Examples – upper SE

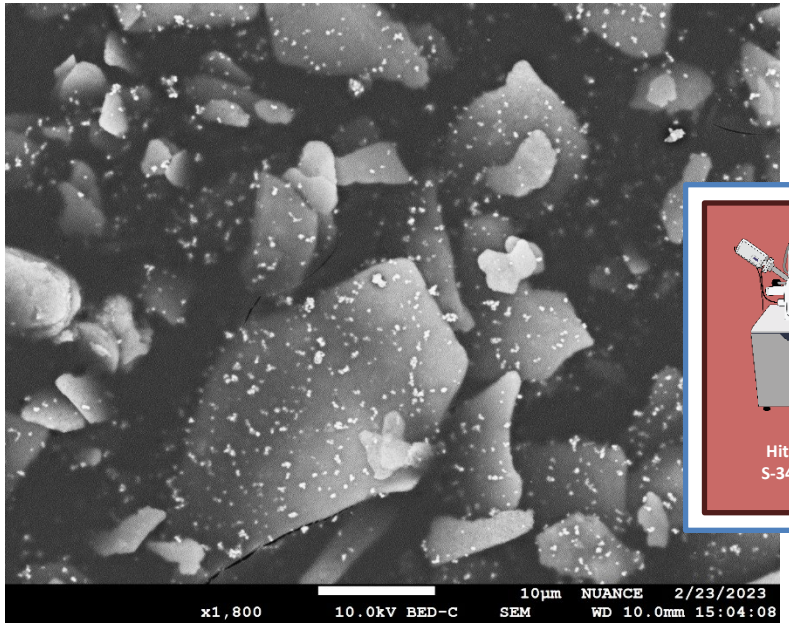


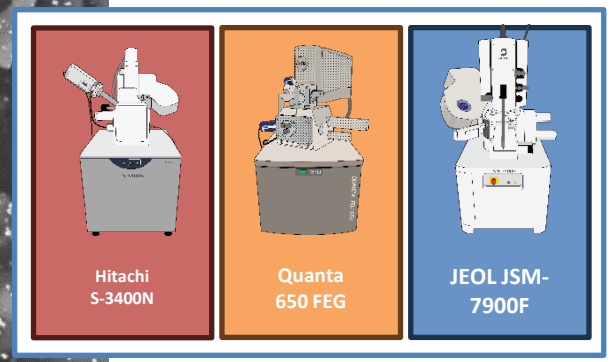


3. Backscatter Electron Detector

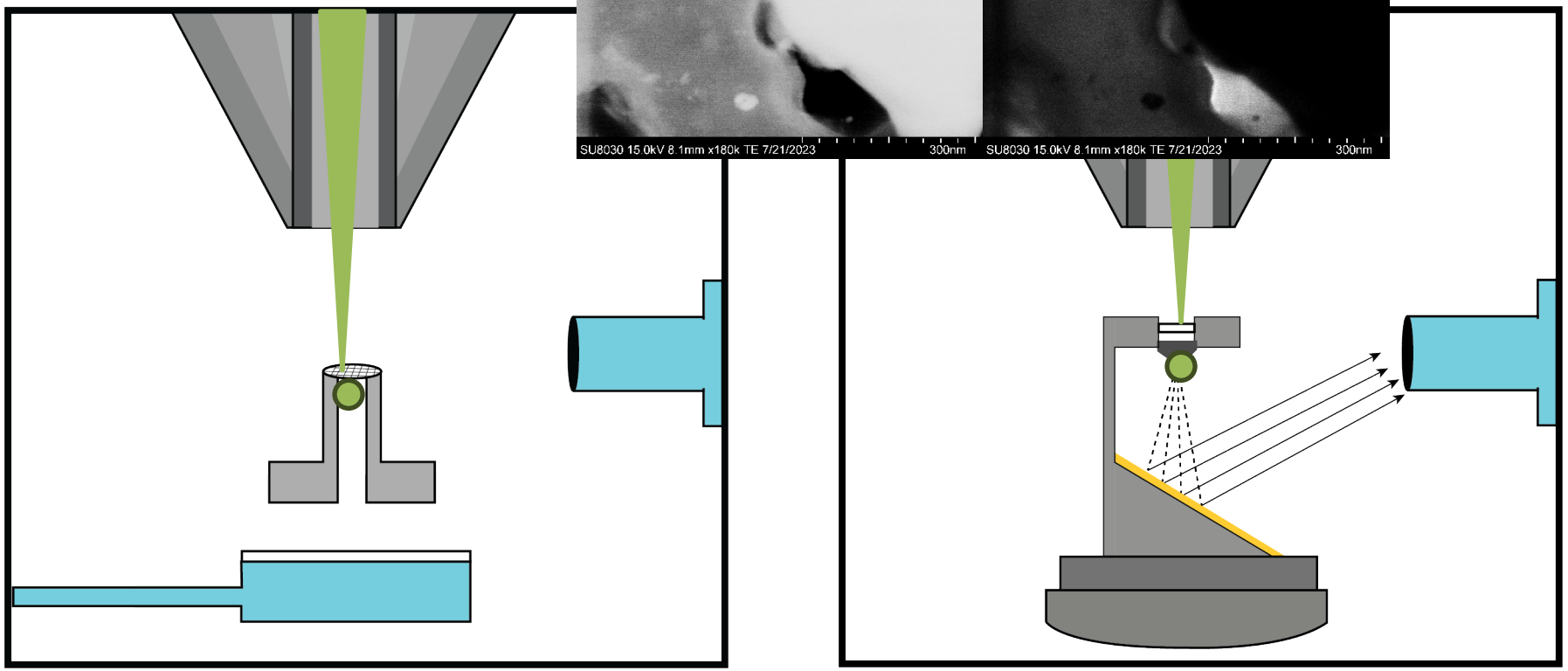


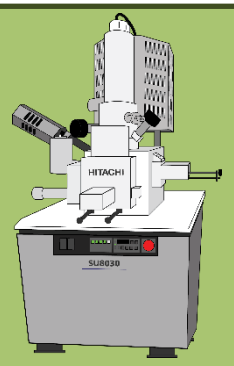
- More signal than energy filtered BSE for most electron energies
- More effective at showing compositional (Z) contrast
- Not as good at very short WD (< ~5 mm) or very low electron energies (~ < 3 keV)





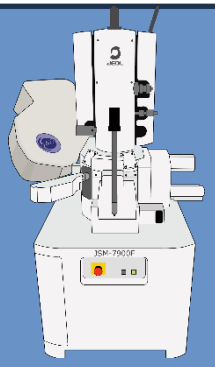
3. STEM Detectors





Hitachi SU8030

- Powerful nano-particle characterization
- Reflected or transmitted imaging
- Good at very high electron energies (30 keV)

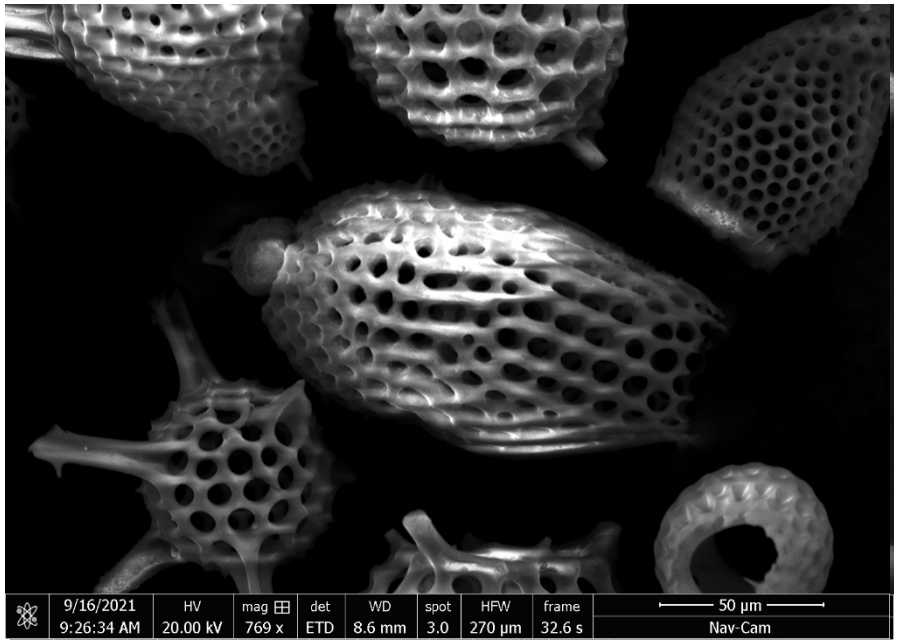


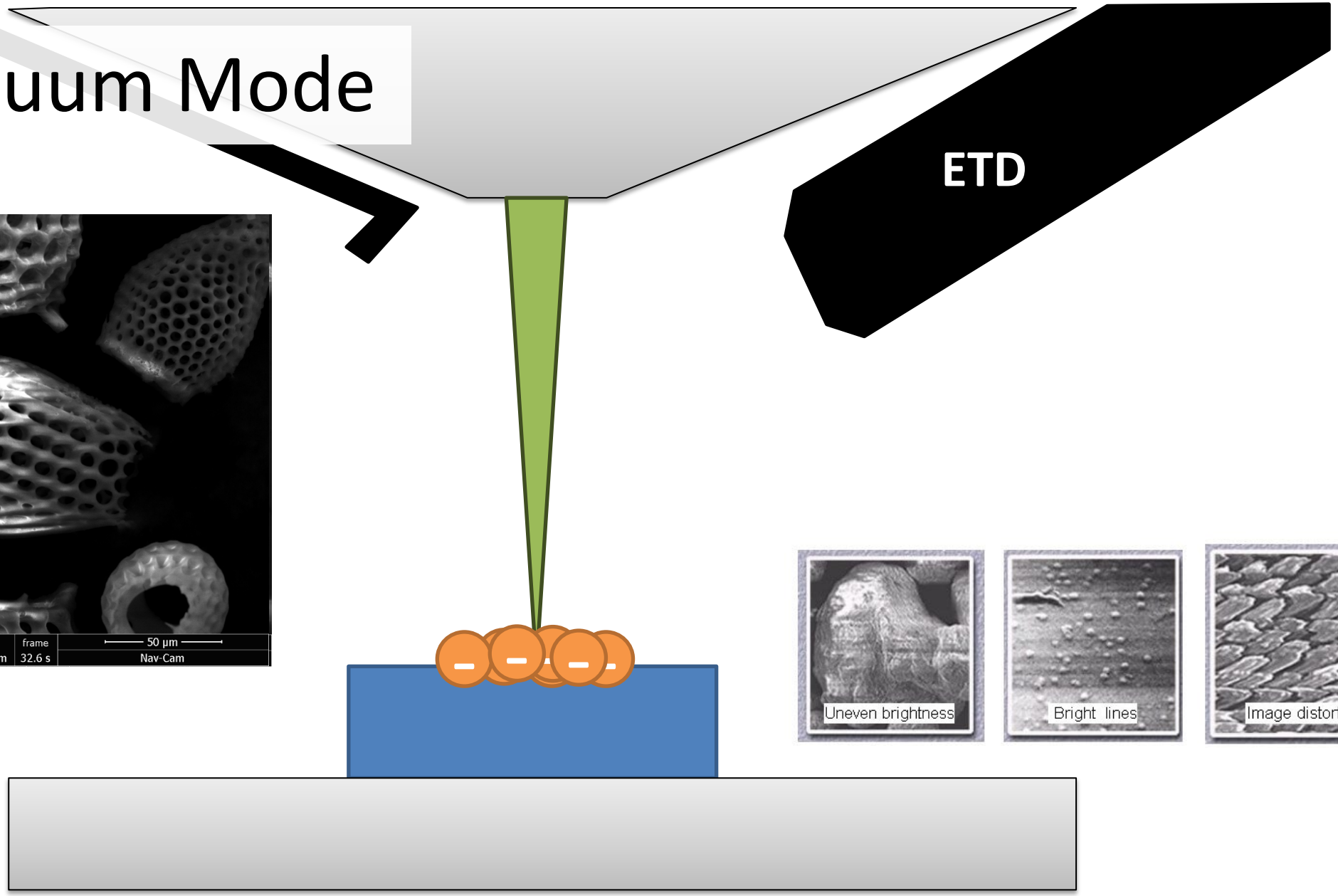
JEOL JSM-7900F

SEM Modes and Techniques

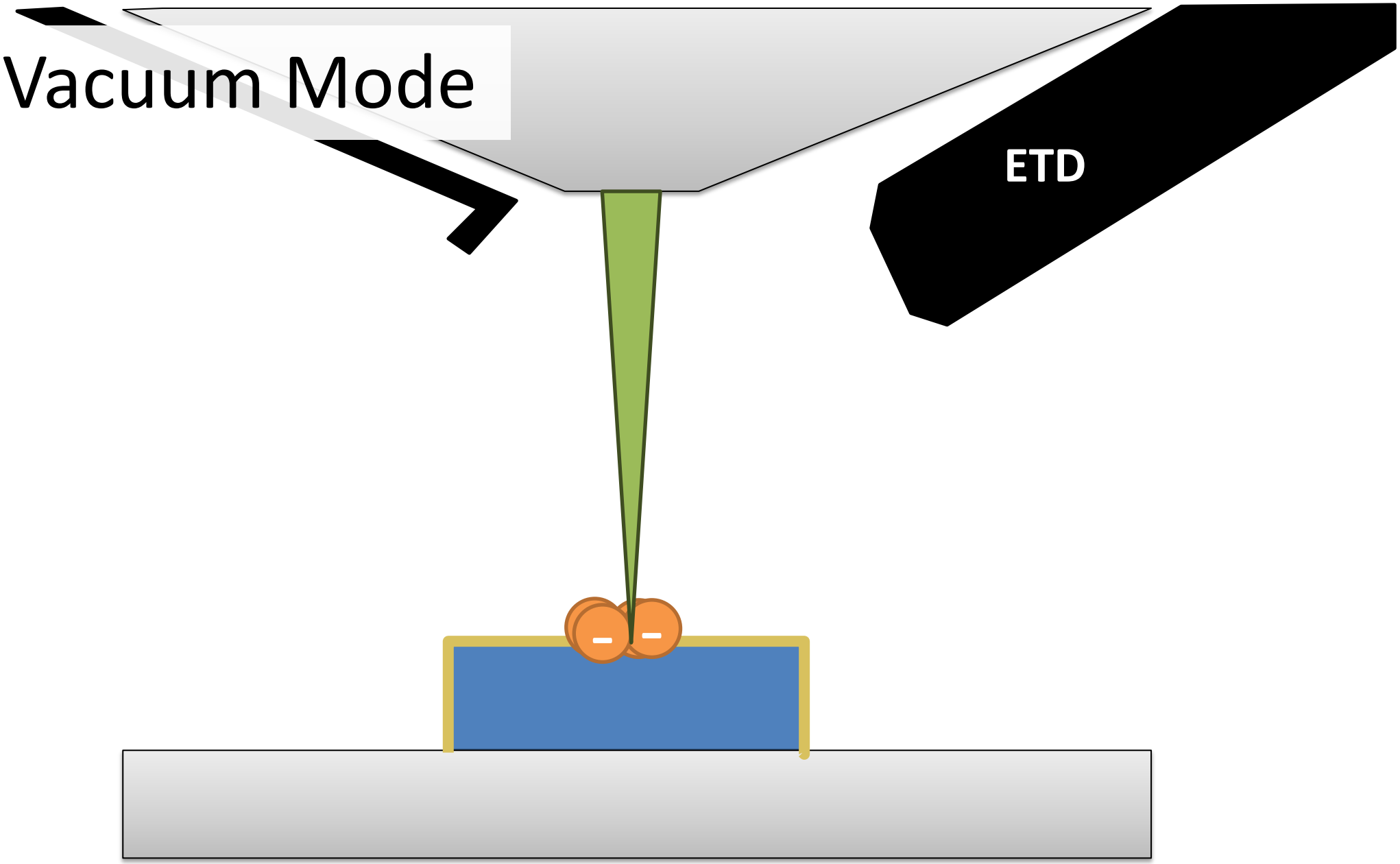
- Variable Pressure Mode (Low Vac)
- Beam Deceleration Mode
- X-ray Microanalysis
- Electron Backscatter Diffraction
- In-situ Heating and Cooling
- Electron Beam Lithography (eBL)

Low-Vacuum Mode

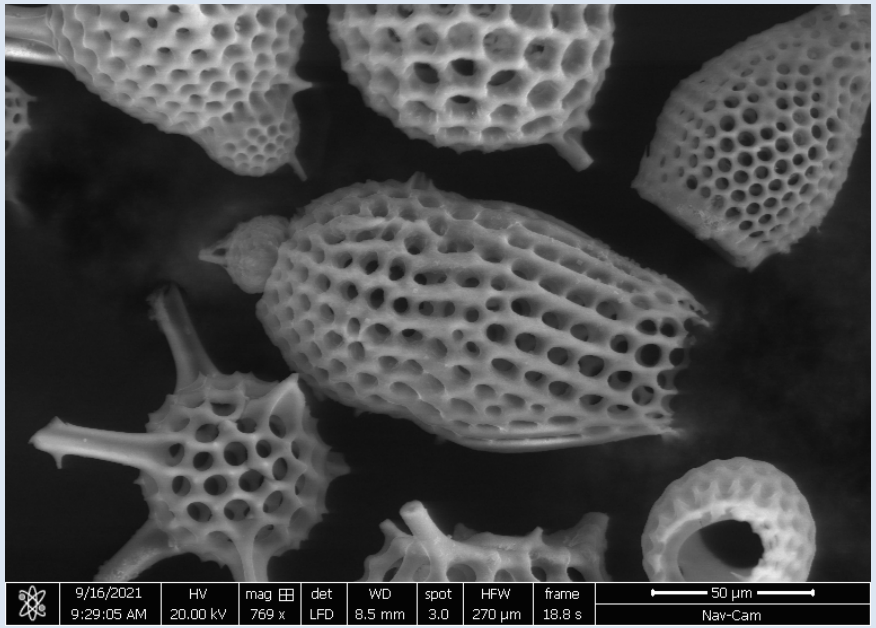


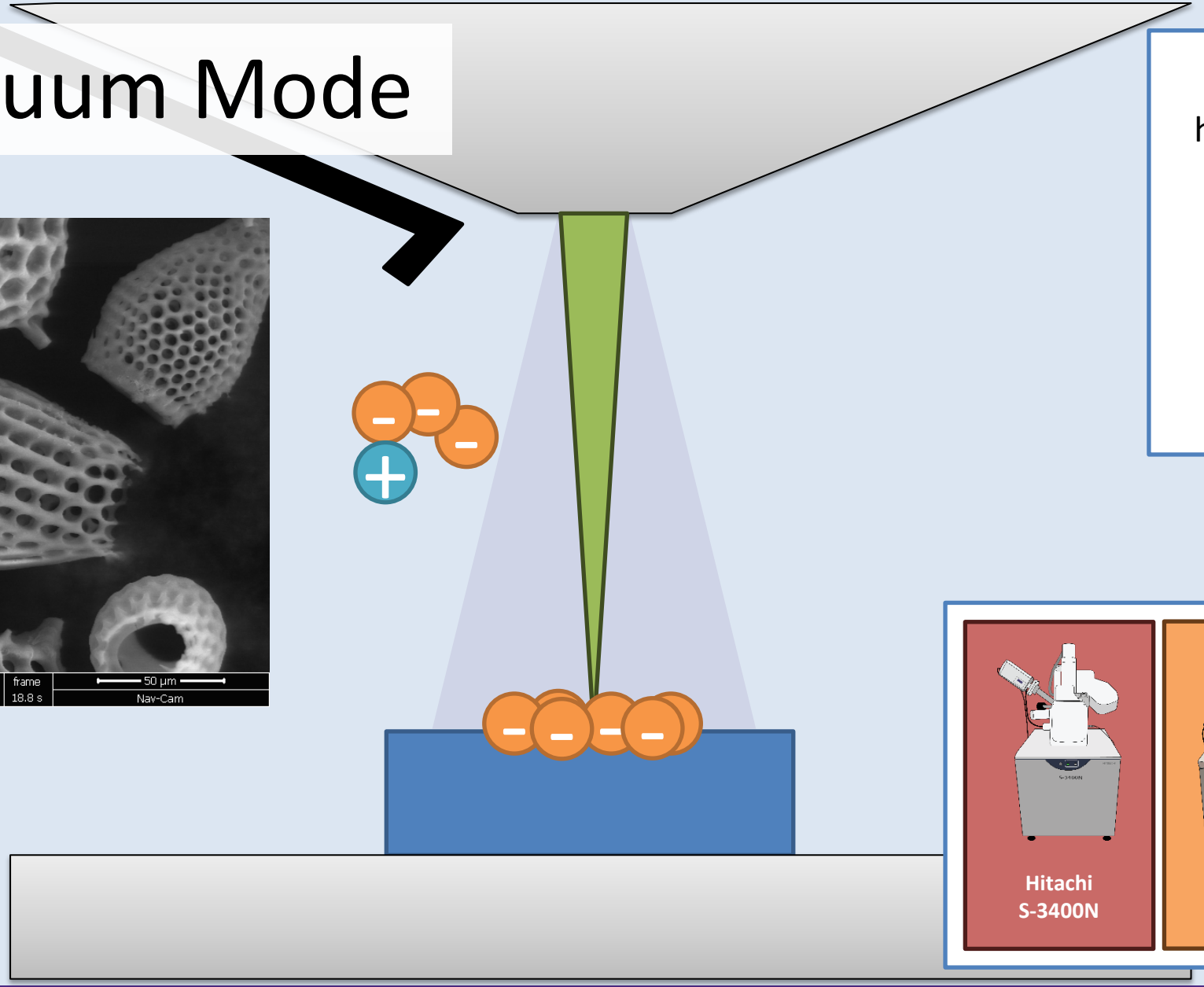


Low-Vacuum Mode

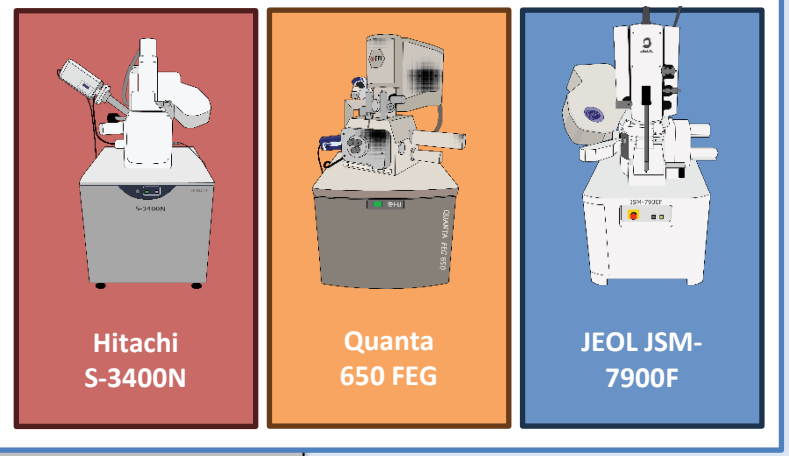


Low-Vacuum Mode

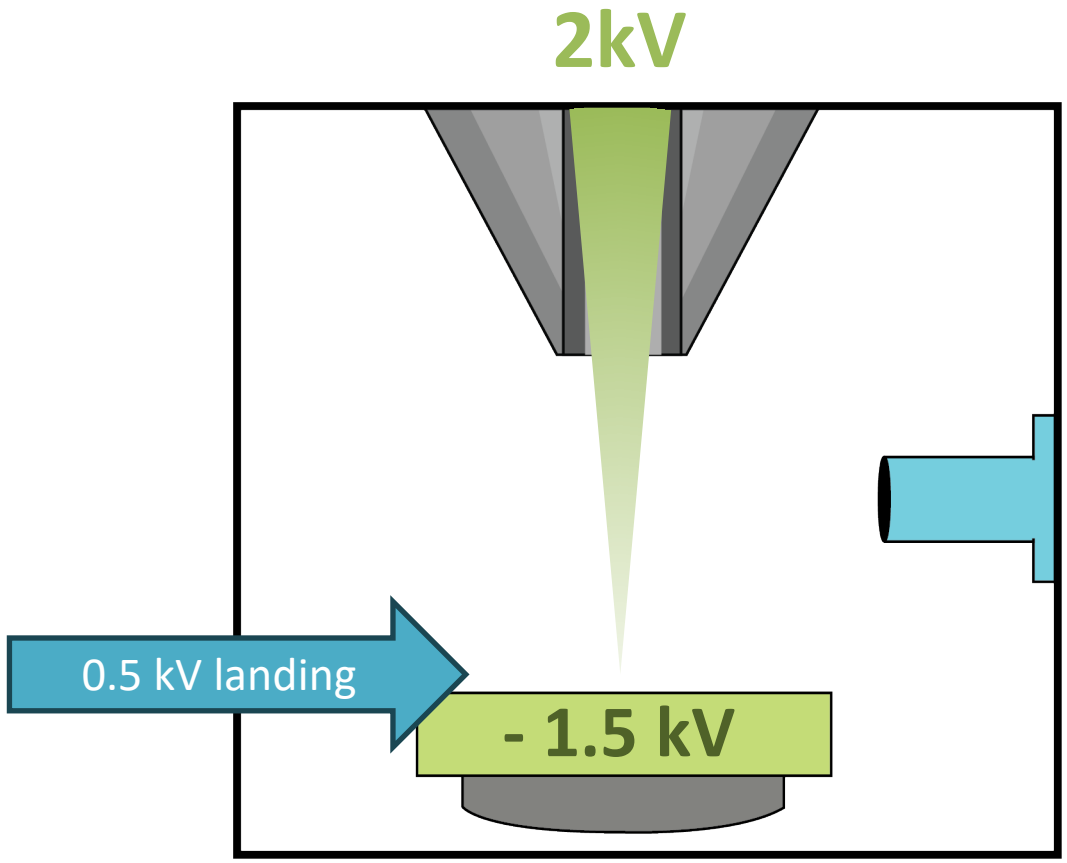




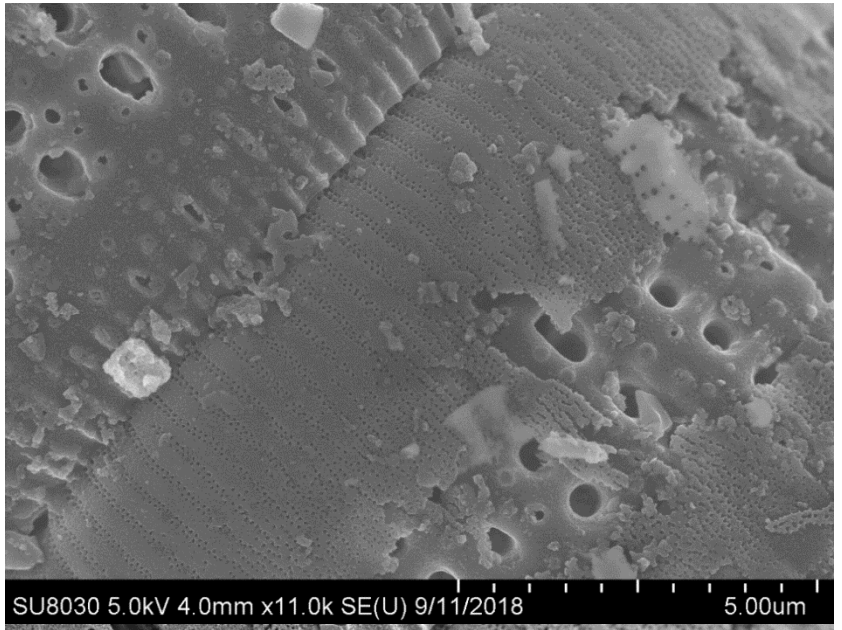
Learn more about heating and Cooling

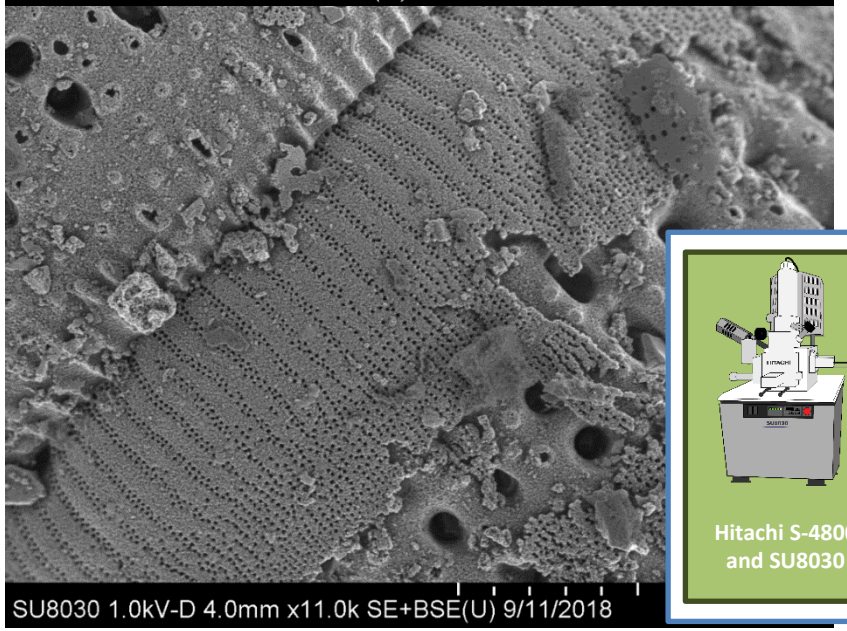


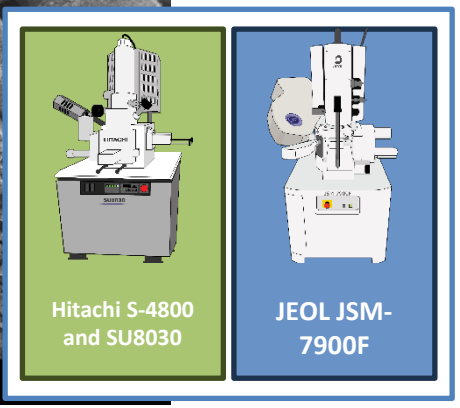
Beam Deceleration



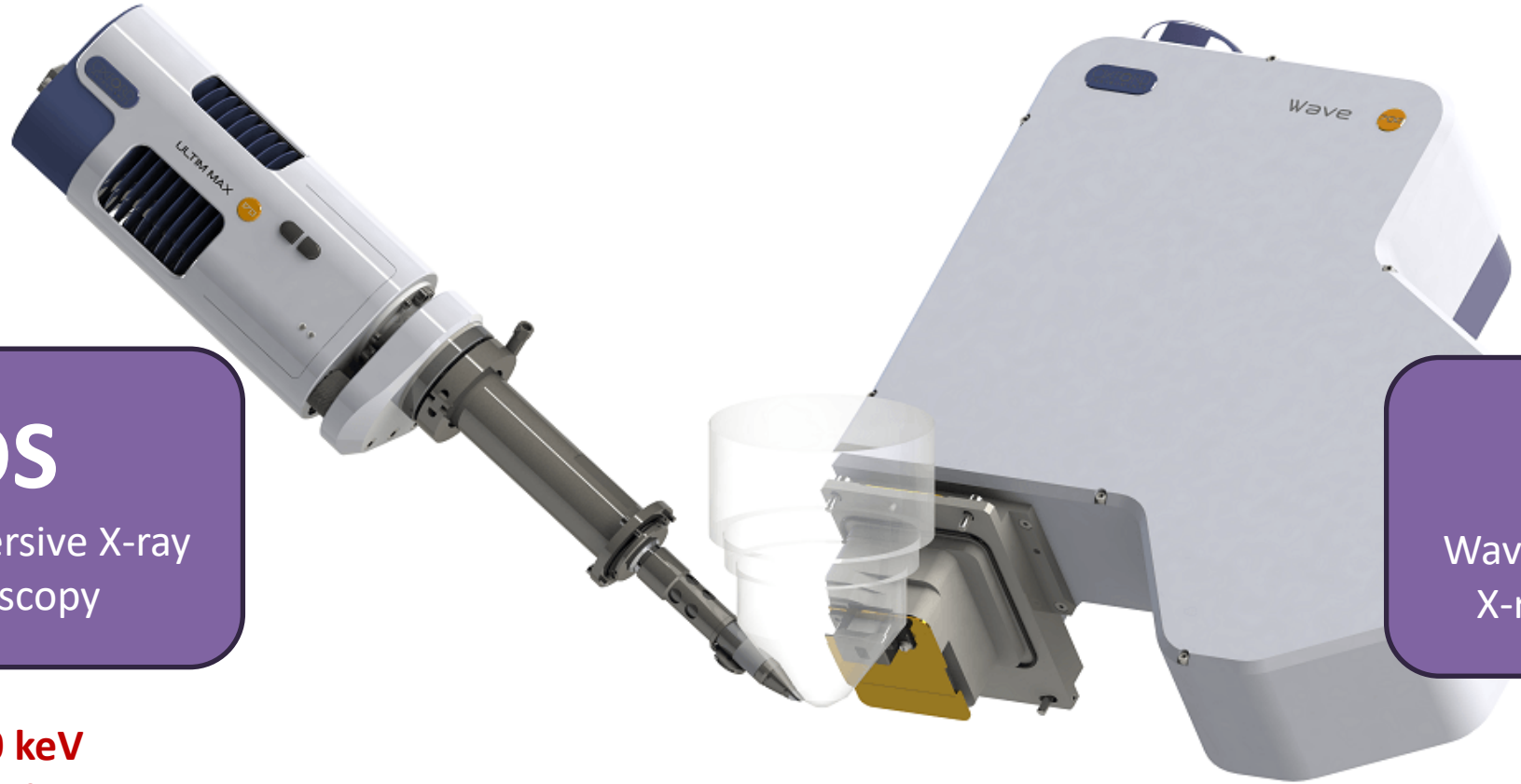
- Reduces interaction volume while maintaining high resolution imaging
- Reduces affects of lens aberrations on low kV beam







X-ray Microanalysis



EDS

Energy Dispersive X-ray Spectroscopy

Si Kα = 1.740 keV
Fe Kα = 6.405 keV

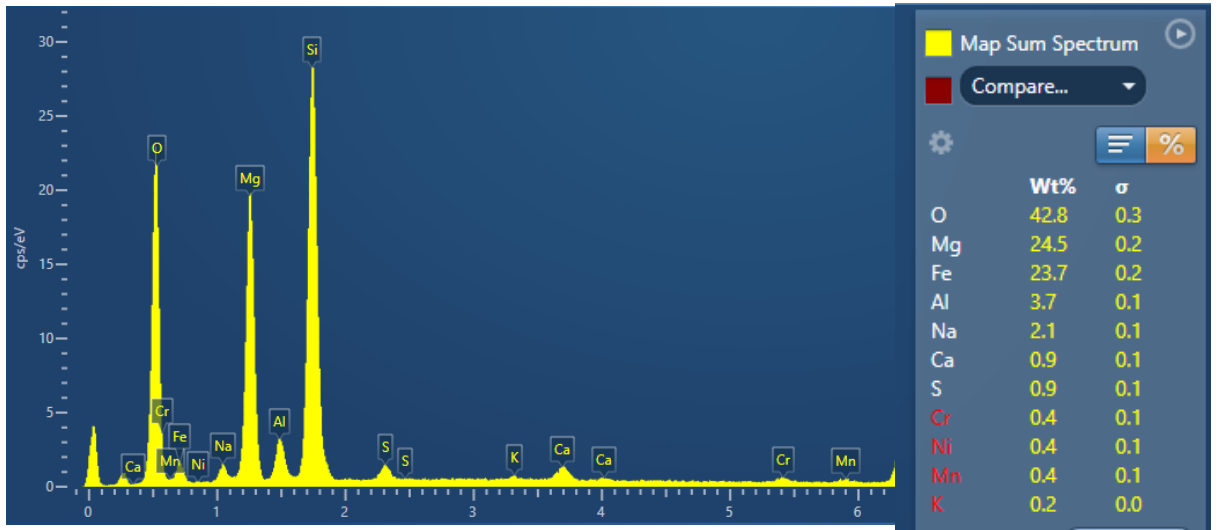
WDS

Wavelength Dispersive X-ray Spectroscopy

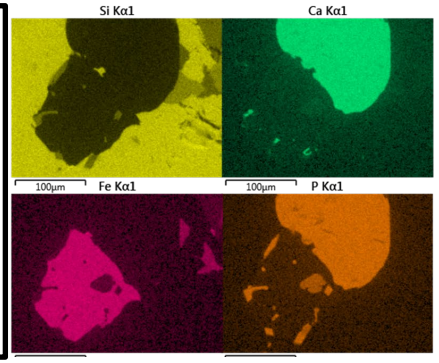
Si Kα = 7.13 Å
Fe Kα = 1.94 Å

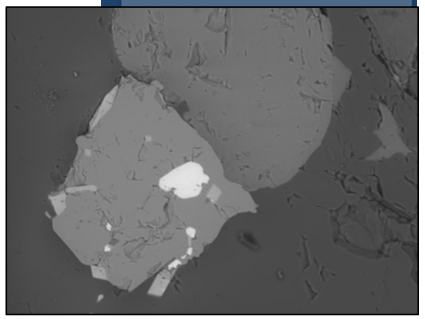
EDS

Energy Dispersive X-ray Spectroscopy



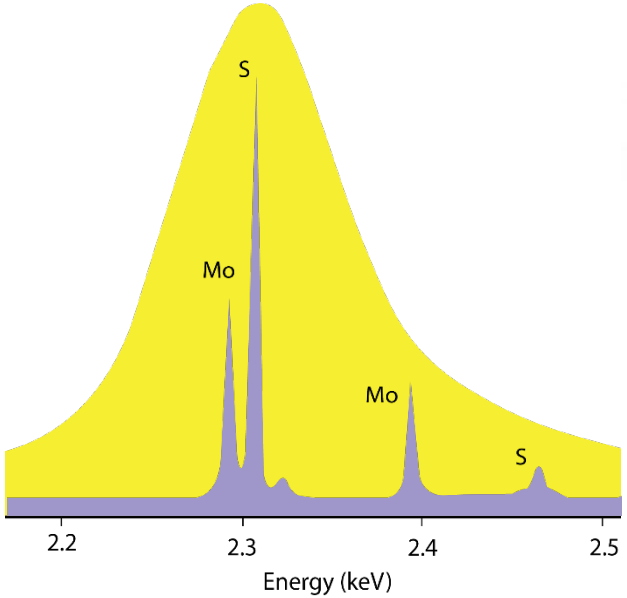
Sign up for EDS Training Demo

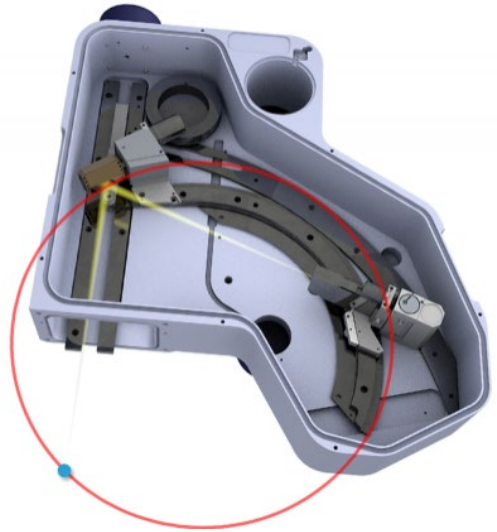




WDS

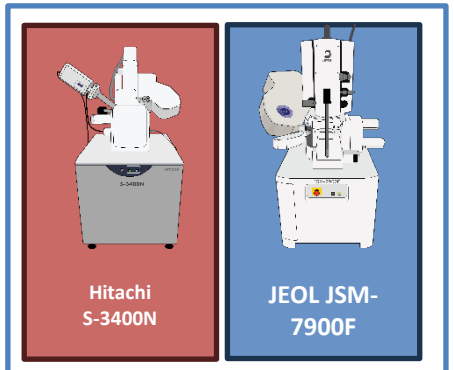
Wavelength Dispersive X-ray Spectroscopy





S Kα = 2.3 keV

Mo Lα = 2.29 keV



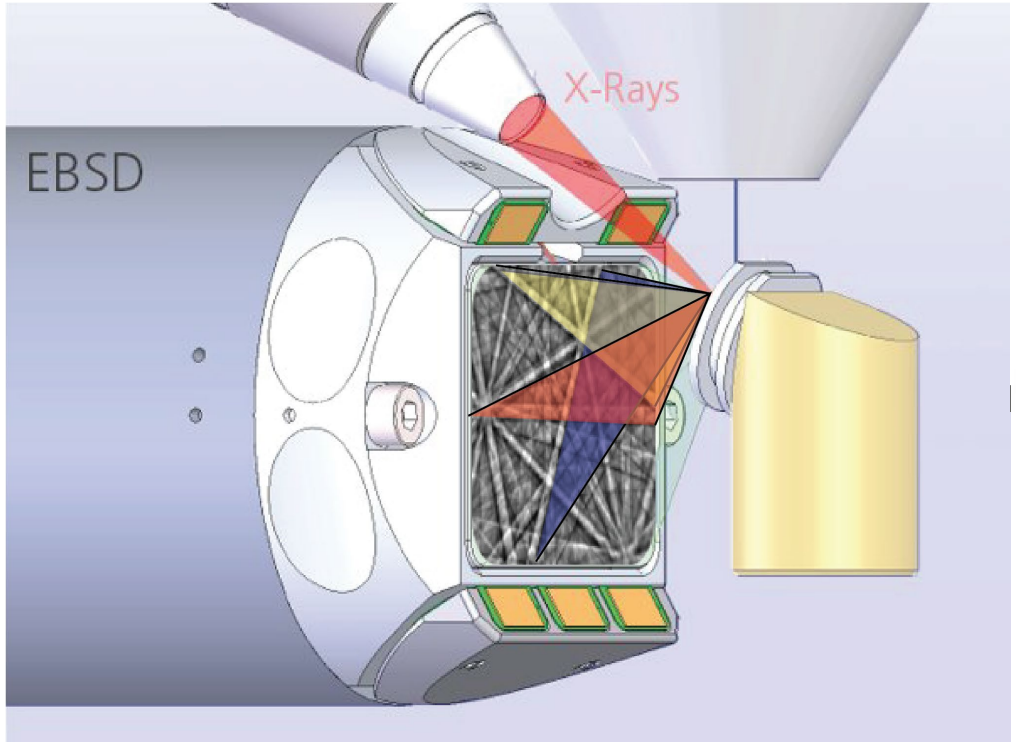
Learn more about WDS

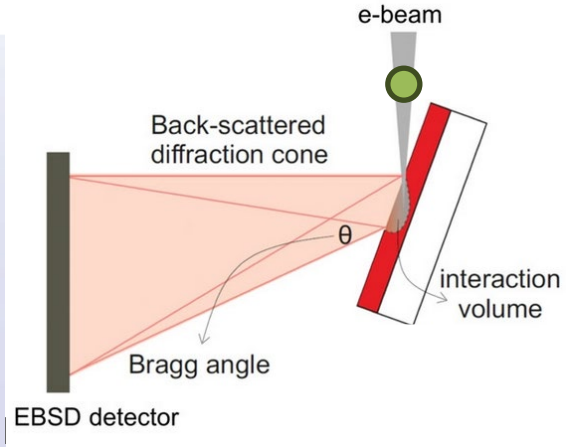
NUANCE
Northwestern University Atomic and Nanoscale Characterization Experimental Center

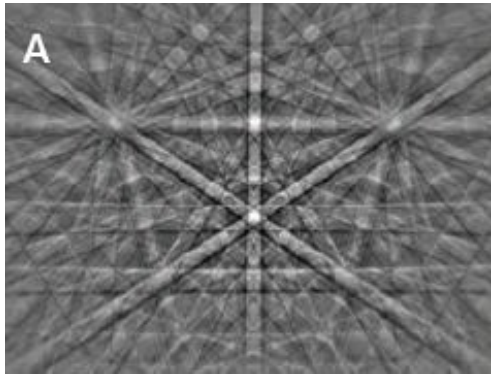
SHyNE
Soft and Hybrid Nanotechnology Experimental Resource

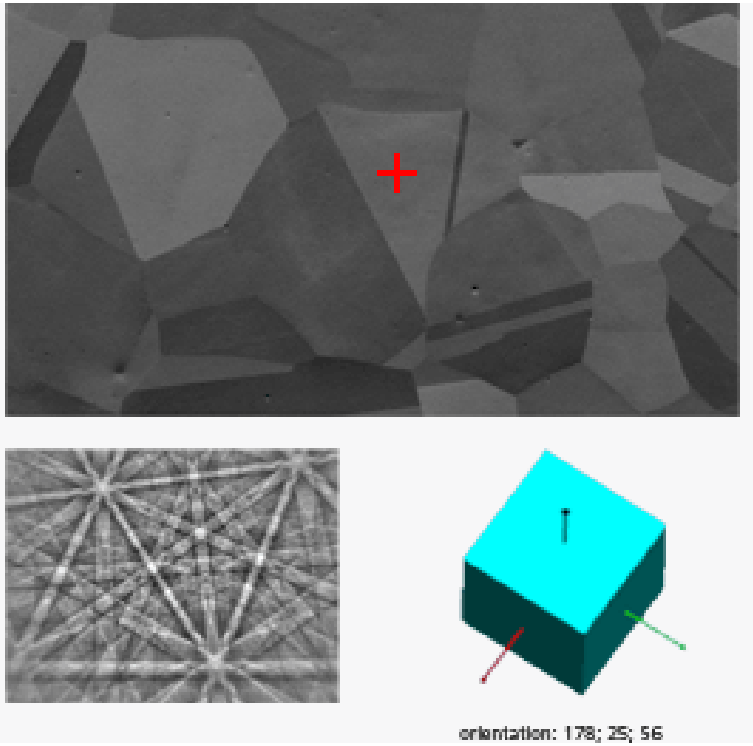
Northwestern
EXPLORING INNER SPACE

Electron Backscatter Diffraction (EBSD)



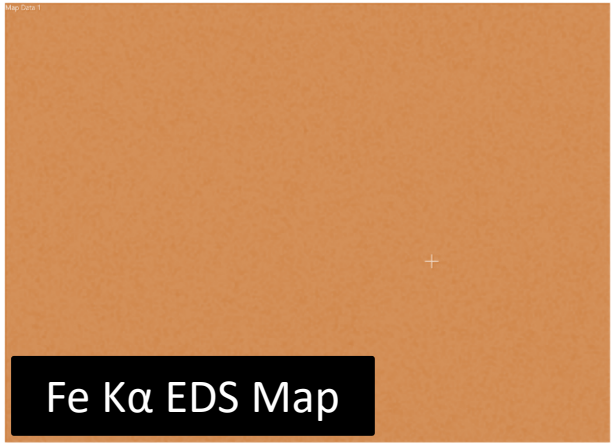


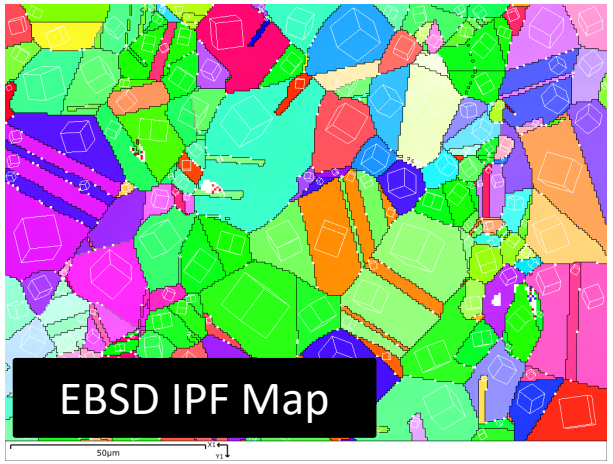


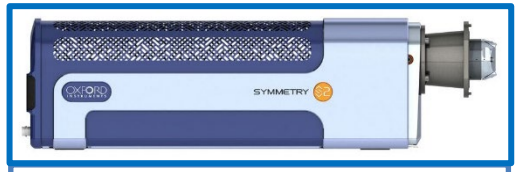


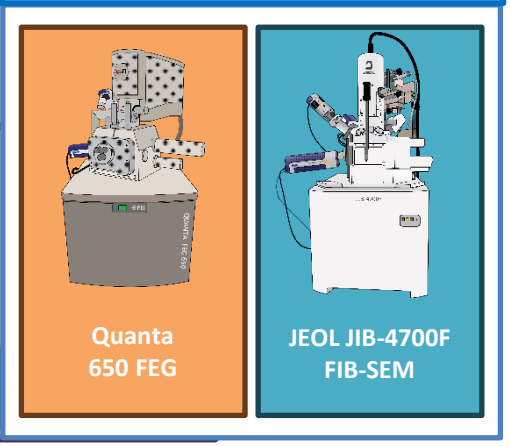
Electron Backscatter Diffraction

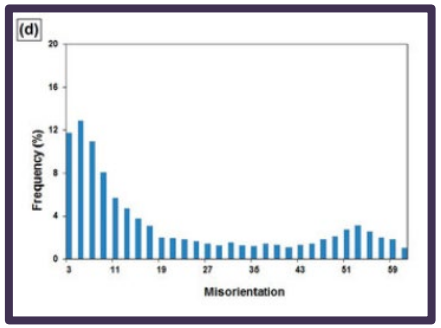
Learn more about EBSD



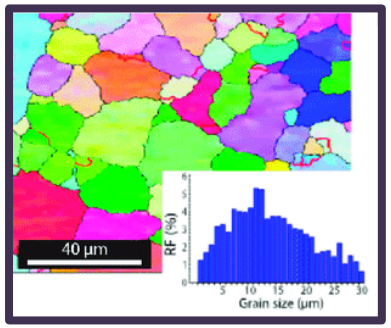




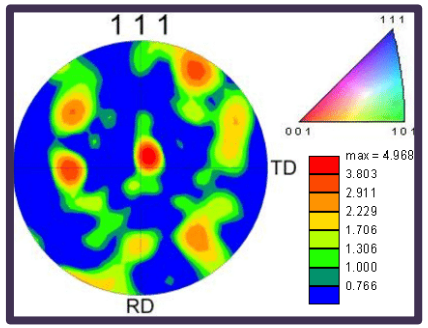




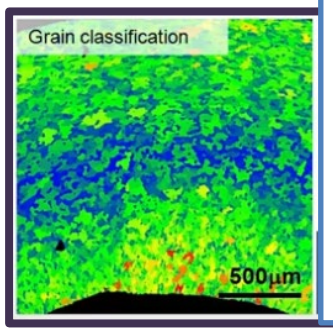
Boundary Characteristics



Grain Size

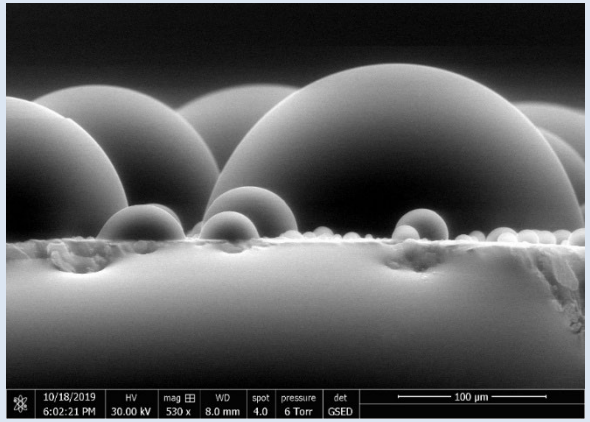


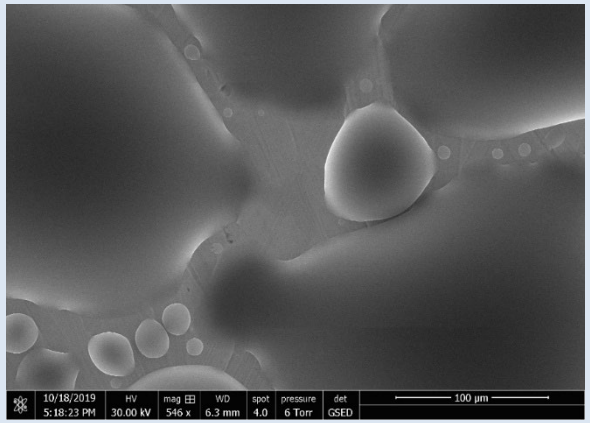
Texture/CPO

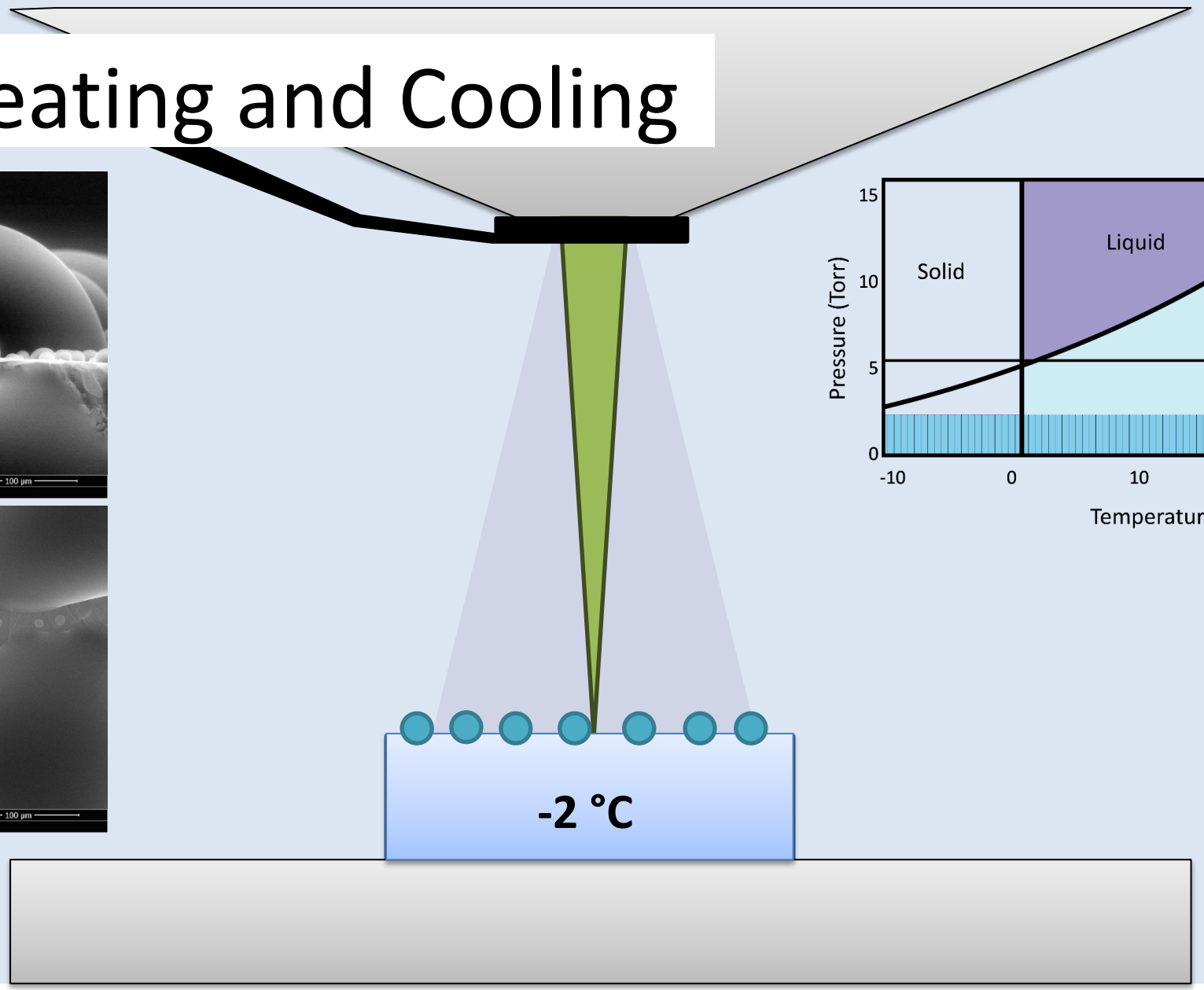


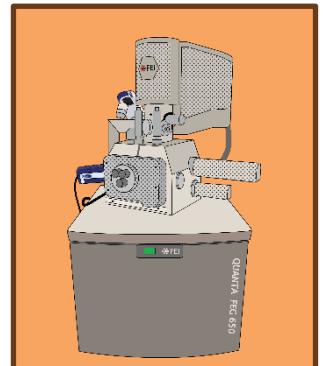
Deformation

In-situ Heating and Cooling





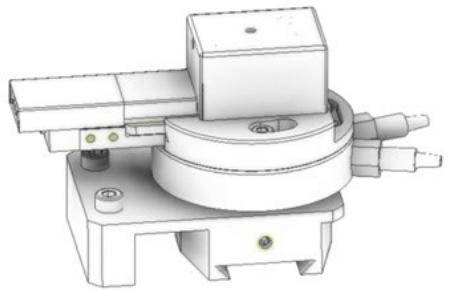


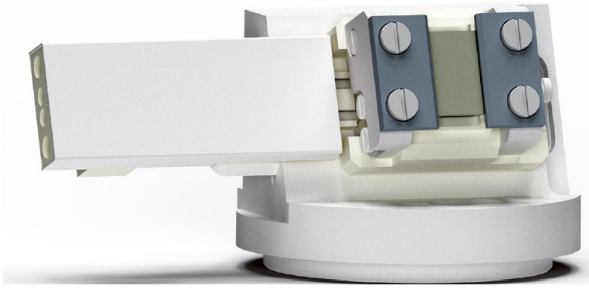


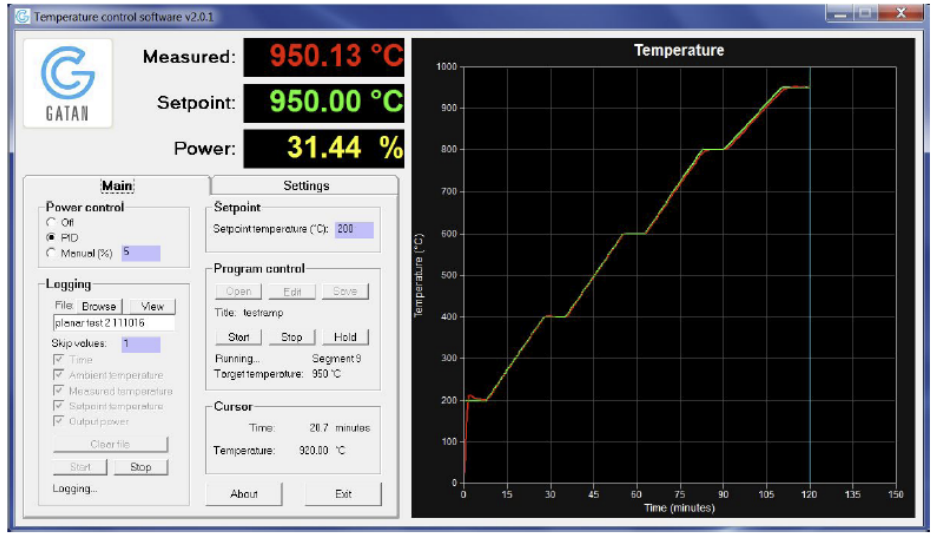
Quanta
650 FEG

In-situ Heating and Cooling

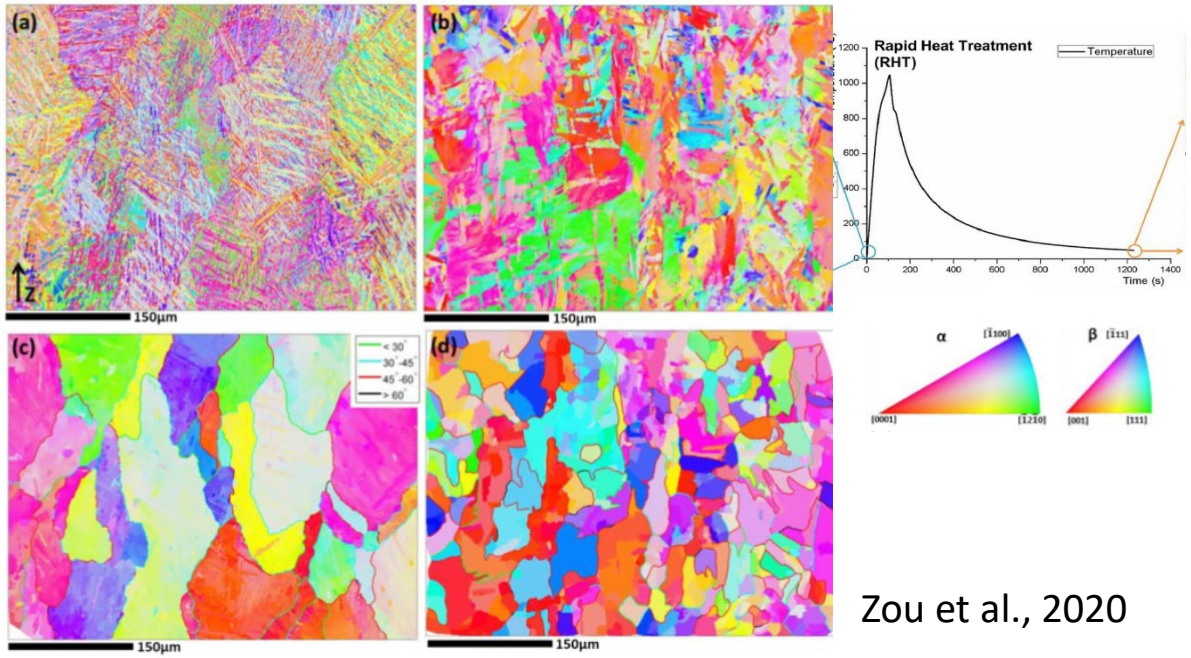
- Rapid heating and cooling (>100 C/min) of specimens up to several mm in size
- Can heat up to 950 °C
  - Resistance heating
- Excellent temperature control and data logging
- Imaging and EBSD holder



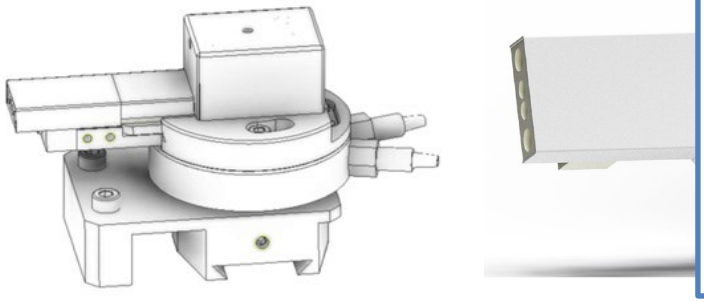


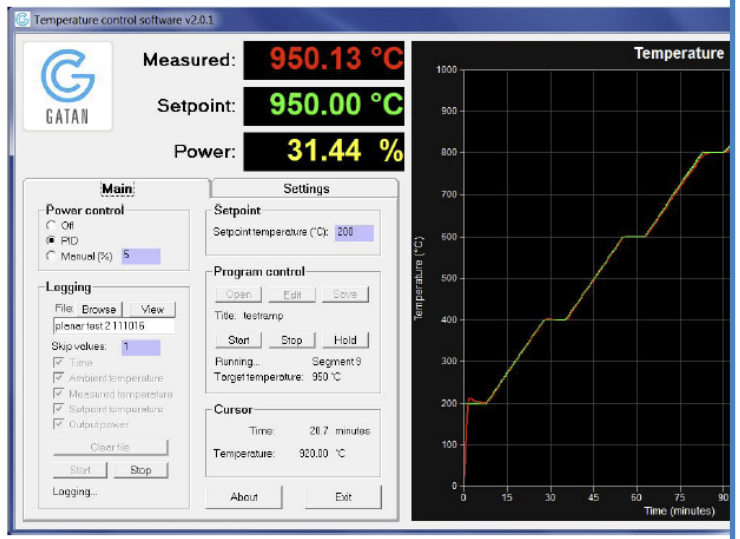


In-situ Heating and Cooling

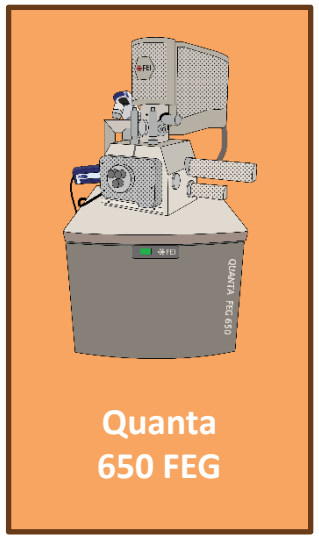


Zou et al., 2020

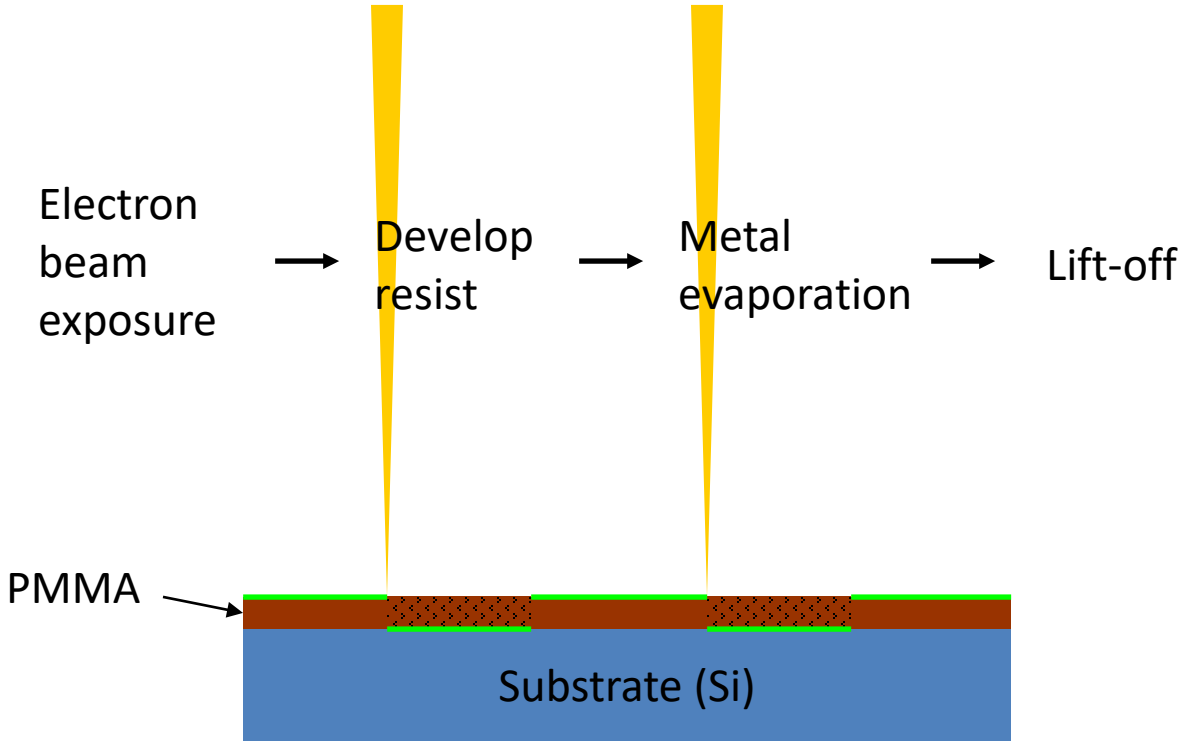




Learn more about heating and Cooling



Electron Beam Lithography

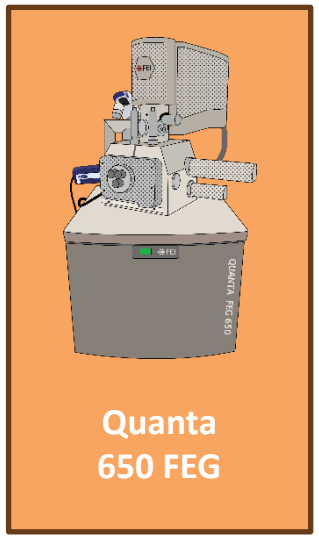


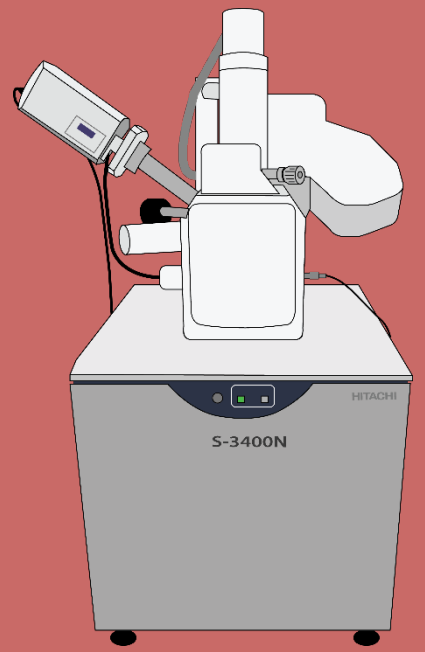
Electron Beam Lithography

Electron beam exposure → Develop resist → Metal evaporation → Lift-off

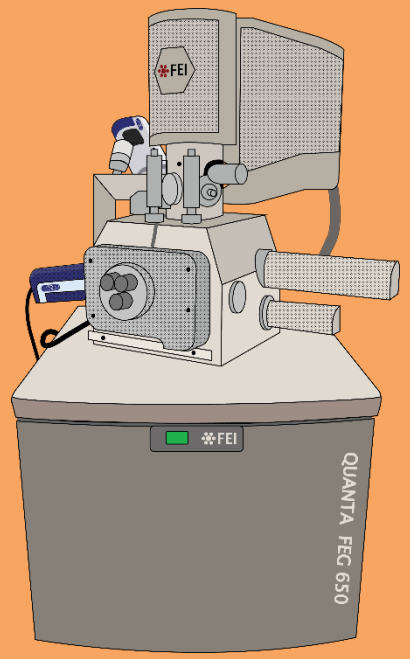
PMMA →

eBL and NUFAB



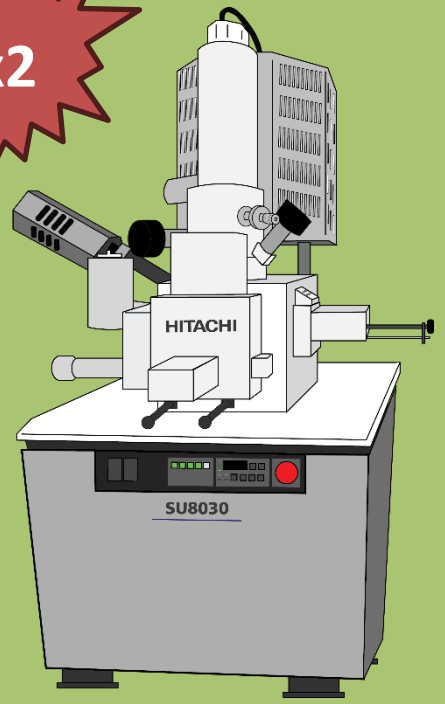


Hitachi S-3400N

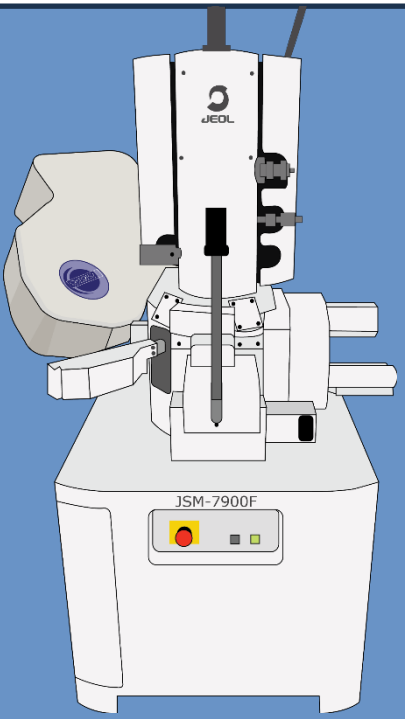


Quanta 650 FEG

x2



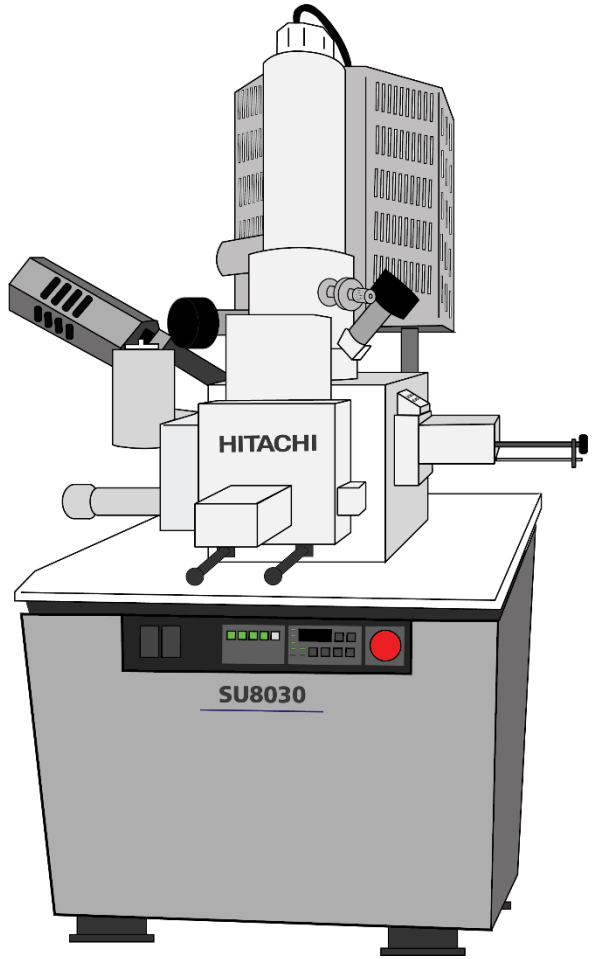
Hitachi S-4800 and SU8030



JEOL JSM-7900F

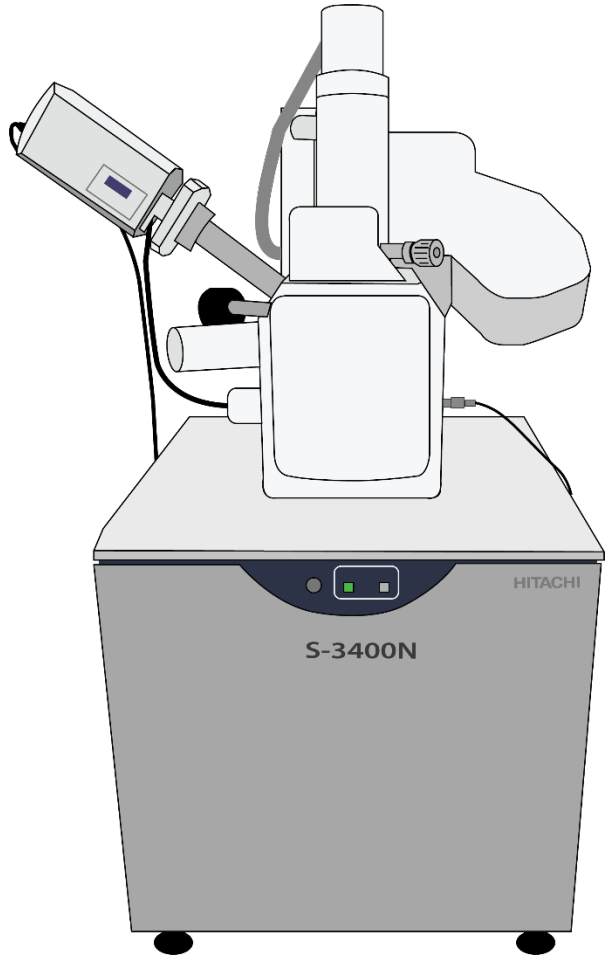
Hitachi S-4800 and SU8030

S-4800	Both	SU8030
• 1.5kV beam decel.	• cFEG electron gun	• 2.5kV beam decel.
• Oxford INCA SiLi EDS system	• Double condenser optics	• Oxford X-max 80 SDD EDS Detector
• Leica Cryo stage with VCT100 transfer system	• In-Lens (upper) SE Detector and ExB filter	• Additional Top (upper) SE Detector
	• SE Detector (lower)	• Low kV STEM Detector
	• Compucentric stage	
	• Vibration isolation table	



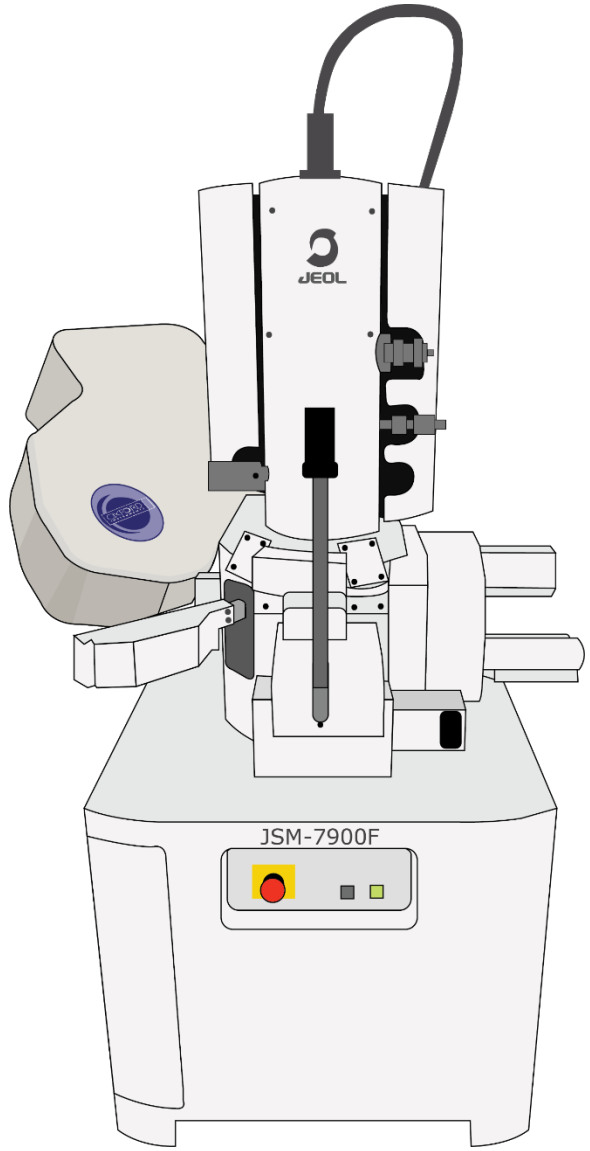
Hitachi S-3400

- Tungsten filament electron gun
- Large specimen chamber (up to 8” diameter, 85 mm tall specimens)
- Compucentric stage
- ESED II Detector for low vacuum imaging
- 5 segment solid state BSE Detector with 3D reconstruction capability
- Oxford INCAx-act SDD EDS
- Oxford WAVE 500 WDS system



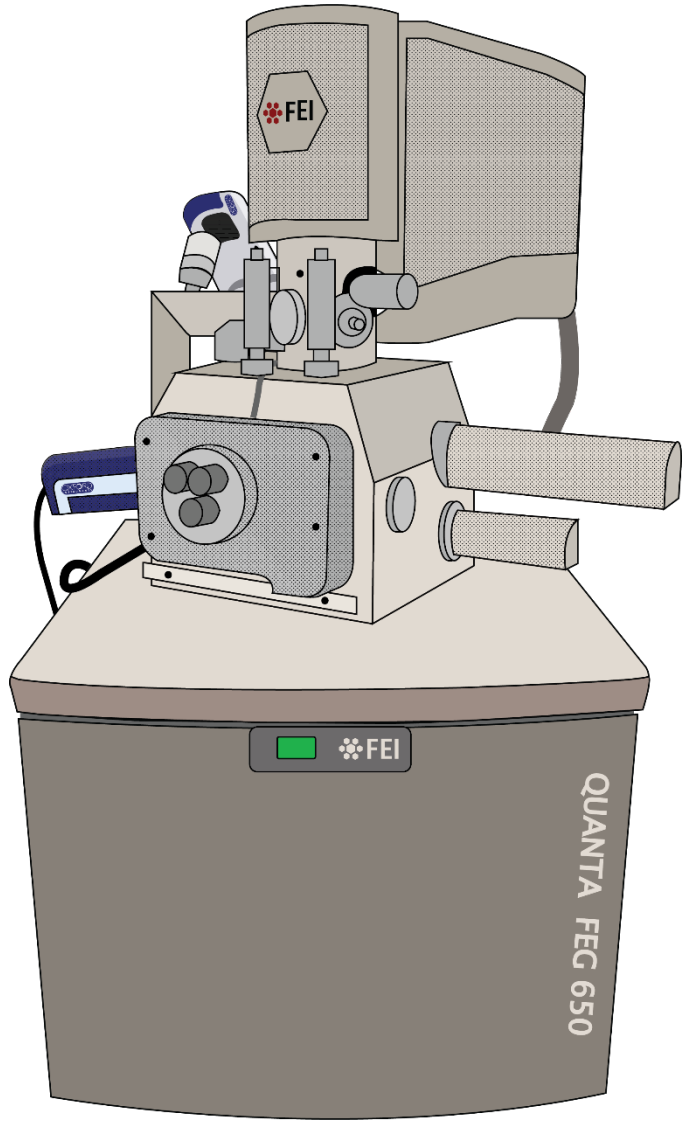
JEOL JSM-7900F

- Schottky Plus field emission gun with low aberration condenser lens
- Ultralow kV in-lens (upper) detectors
- GENTLEBEAM™ Super High mode, up to 5kV beam decel.
- Super Hybrid (electrostatic) Lens (SHL) enabling magnetic material analysis
- High sensitivity retractable BSE detector
- Oxford Ultimax 65 SDD EDS Detector
- Oxford WAVE 700 WDS system
- Low vacuum mode
- Low kV STEM imaging



Quanta 650F

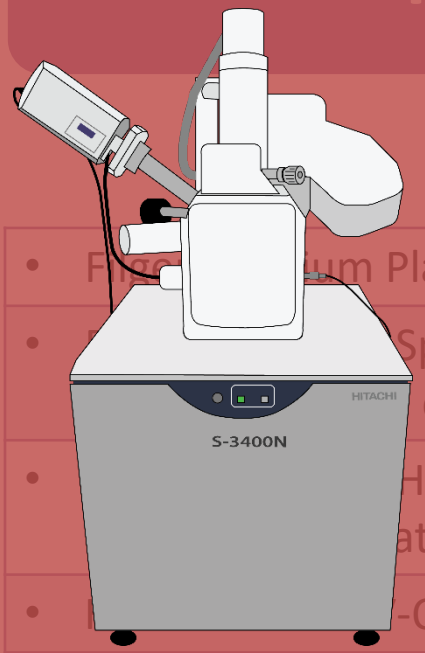
- Schottky field emission gun
- Standard SE (lower), SS concentric BSE (retractable), 2 gaseous SE, and gaseous BSE Detectors
- Large chamber and programmable stage with 6” wafer capacity
- Low vacuum mode up to 4000 Pa chamber pressure
- Oxford SDD EDS and EBSD system
- eBL setup including beam blanker, NPGS software, and integrated beam current measurement system
- Gatan Murano heating/cooling stage



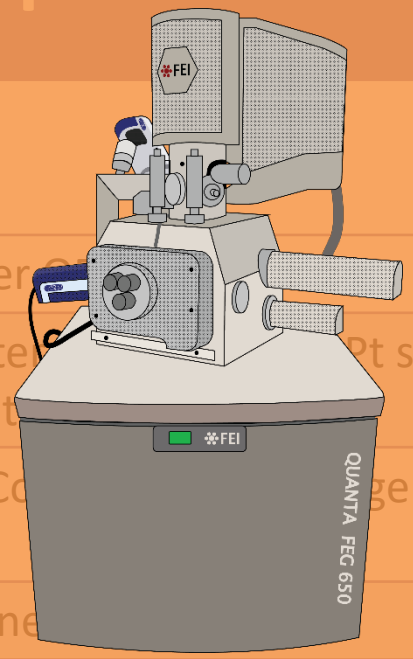
Sample Preparation

- Fi… …um Plasma Coater
- … Sputter Coater … Pt sputter coating … carbon coat…
- … HR Sputter Co… …ge for Au, Pt/P… …ating
- … -Ozone Cleane…
- South Bay Technology PC2000 Plasma Cleaner

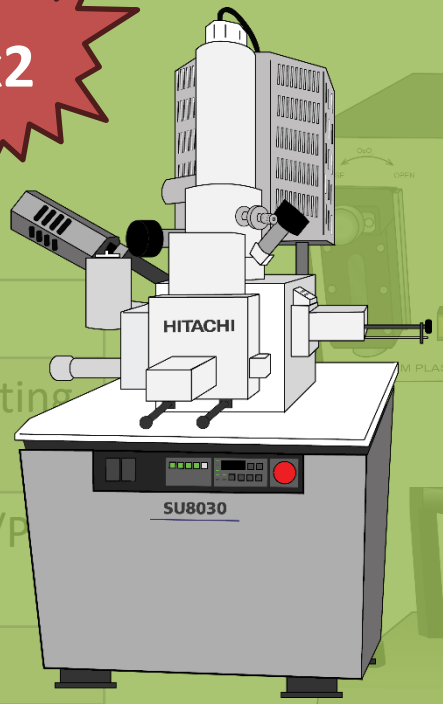
x2



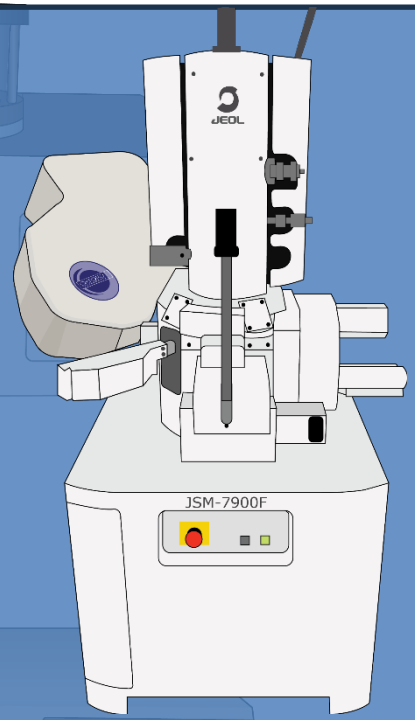
Hitachi S-3400N



Quanta 650 FEG



Hitachi S-4800 and SU8030



JEOL JSM-7900F

Thank you!

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Learn more about heating and cooling

Learn more about EBSD

Learn more about WDS