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Improved Low Voltage SEM Image Resolution Through The Use of Restoration Techniques

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Previous Work: Improved Resolution of LaB_6

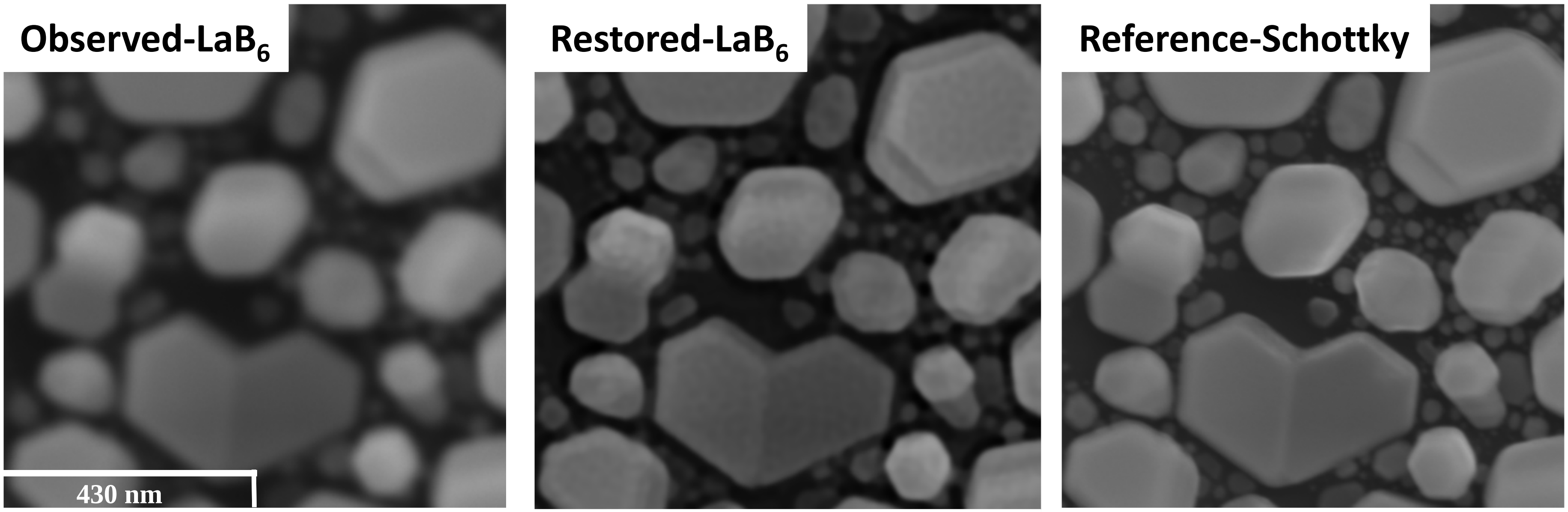

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Image Degradation: Convolution & Noise

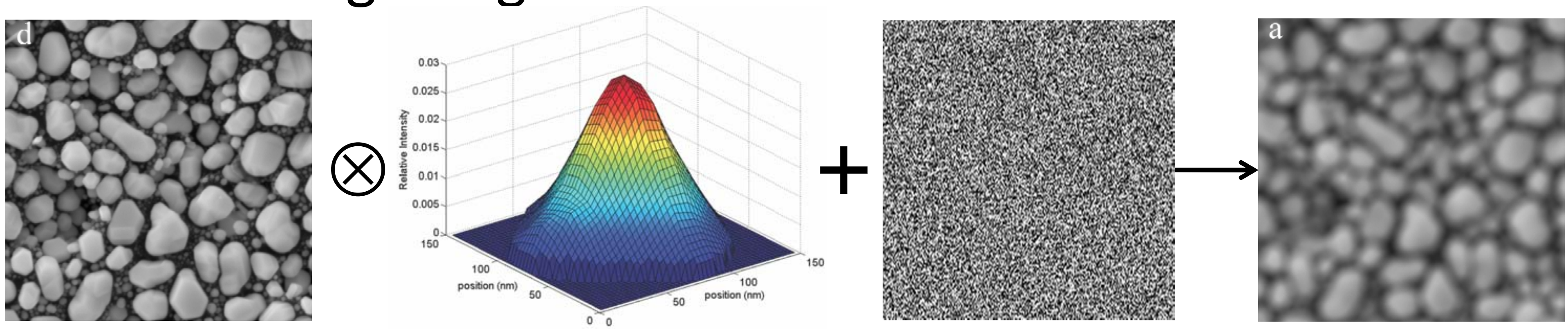
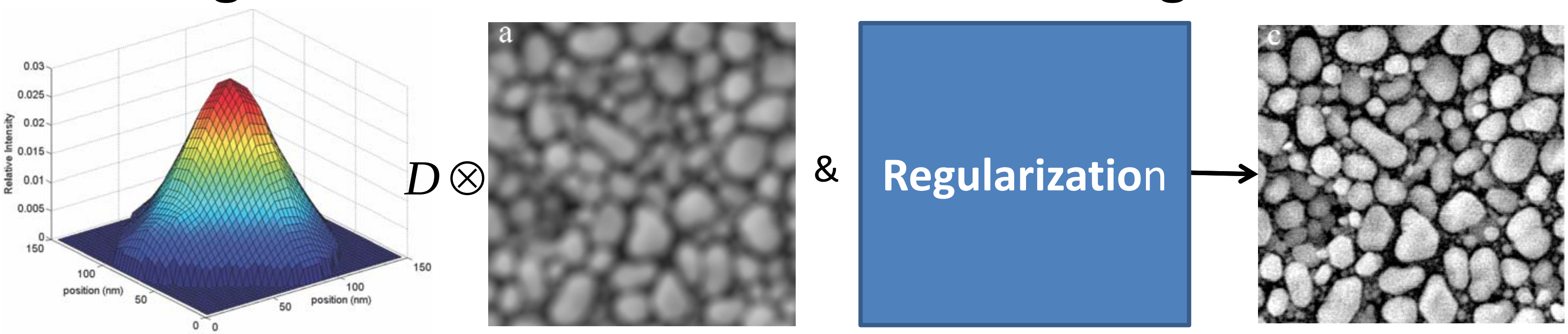


Image Restoration: Deconvolution & Regularization



Our Image Restoration Scheme

1. $I_{obs} = psf(x,y) \otimes I_{True} + \boldsymbol{k}$
2. $\vec{b} = \boldsymbol{A}\vec{x} + \vec{k}; \vec{x} \geqslant 0$
3. $f(x) = \underset{\boldsymbol{x}}{\operatorname{argmin}}\{\left\|\boldsymbol{A}\vec{x} - \vec{b}\right\|_2^2 + \lambda R(\vec{x})\} \quad s.t. \;\; \vec{x} \geqslant 0$

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For More on PSF Determination:

352 - Measurement of the Electron Beam Point Spread Function (PSF) in a Scanning Electron Microscope (SEM):

Session	A16.01 - Advances in Electron and Ion Scanning Microscopies
Location	B118
Date	Tuesday, Aug 4 2:00 PM
Duration	15 minutes

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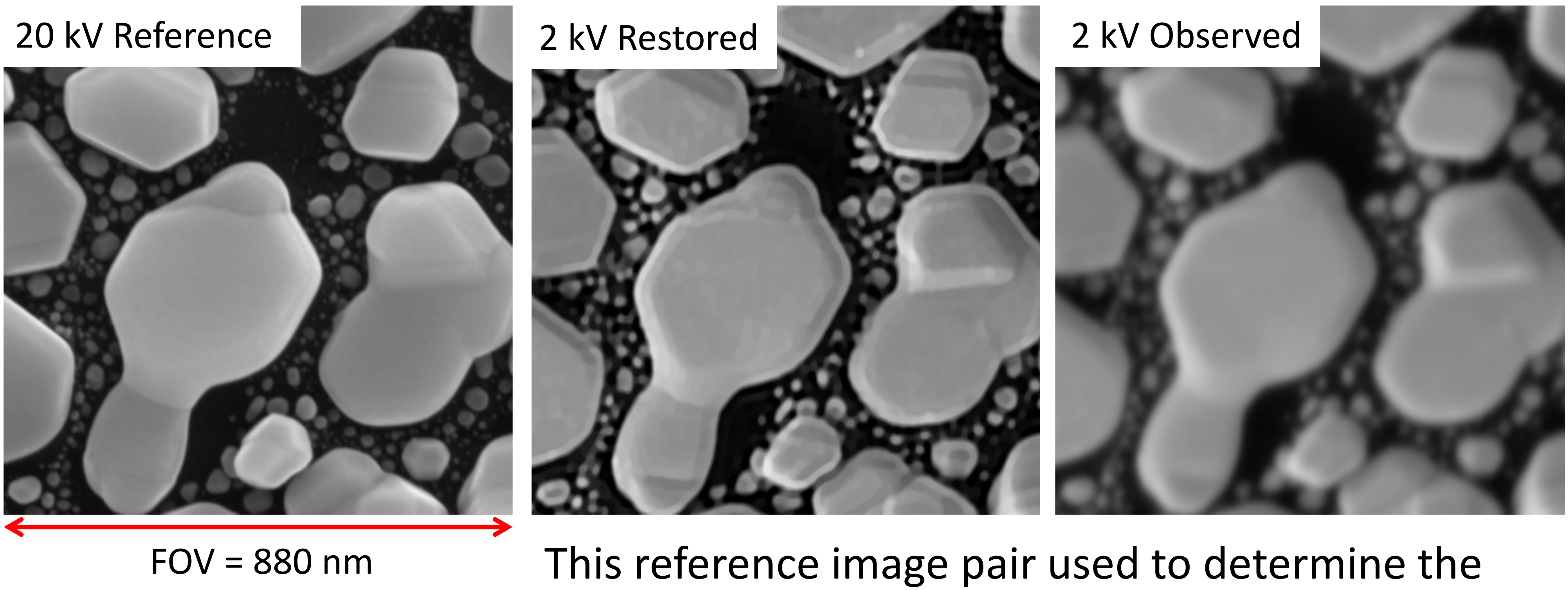
Process Flow

1. Obtain reference image with reference microscope for a standard sample area
2. Obtain observed image with same sample area on observation microscope
3. Determine the PSF of the observation microscope based on equation 1 of previous slide
4. Use the determined PSF of the observation microscope to restore images taken with similar operating conditions

Improved Low Voltage Operation

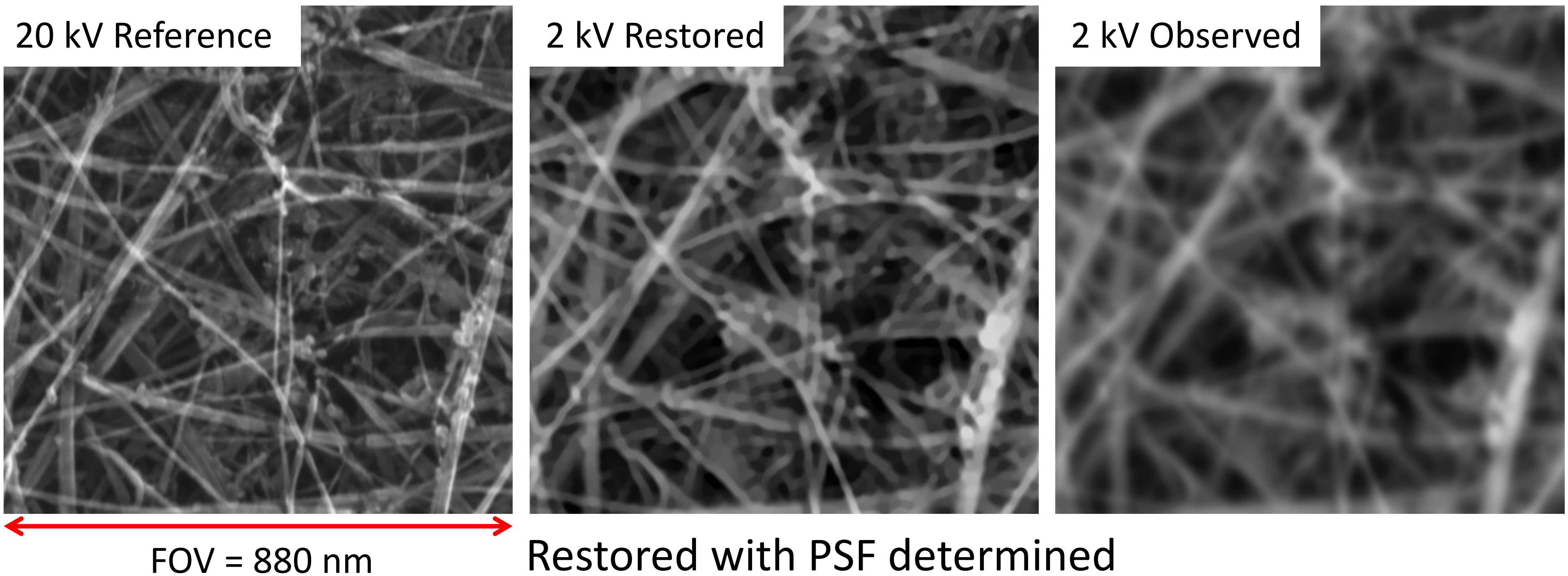
- Step 1: Use high kV, high resolution image as a reference for PSF determination for low kV observation.
- Step 2: Restore low kV, observed images using PSF determined from Step 1.
- Motivation:
  - Not every user has a beam decelerator for low kV operation
  - Beam deceleration may not be applicable to all samples

Schottky Low kV Restoration: Au



This reference image pair used to determine the PSF at low voltage

Schottky Low kV Restoration: C-Nanotubes



Restored with PSF determined from the Au sample!

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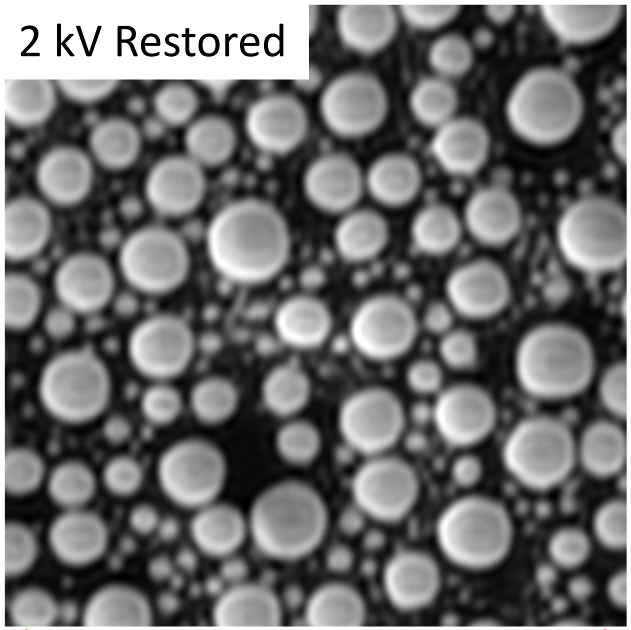
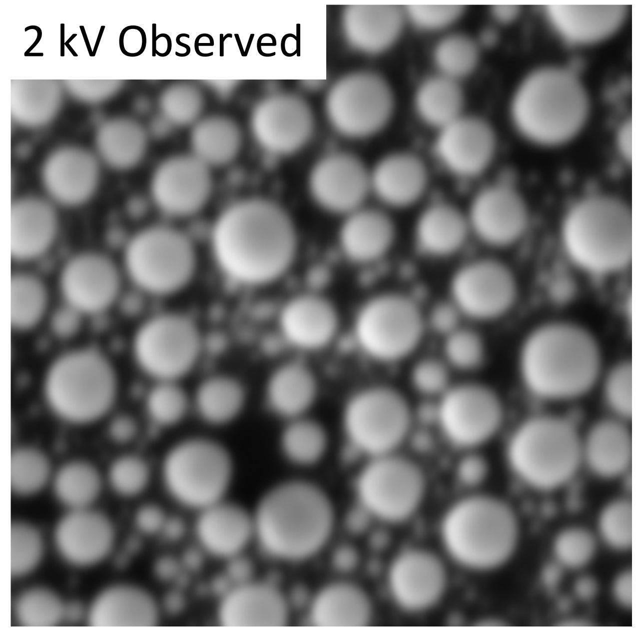
Schottky Low kV Restoration: Sn





FOV = 880 nm

Restored with PSF determined from the Au sample!

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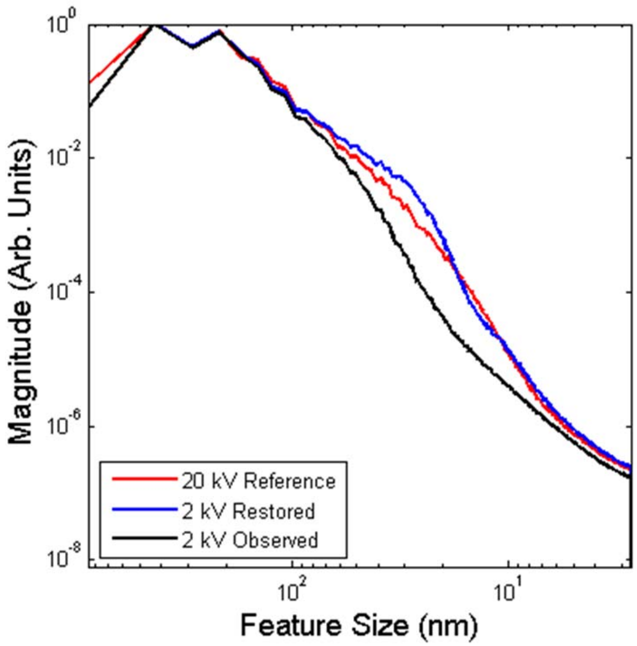
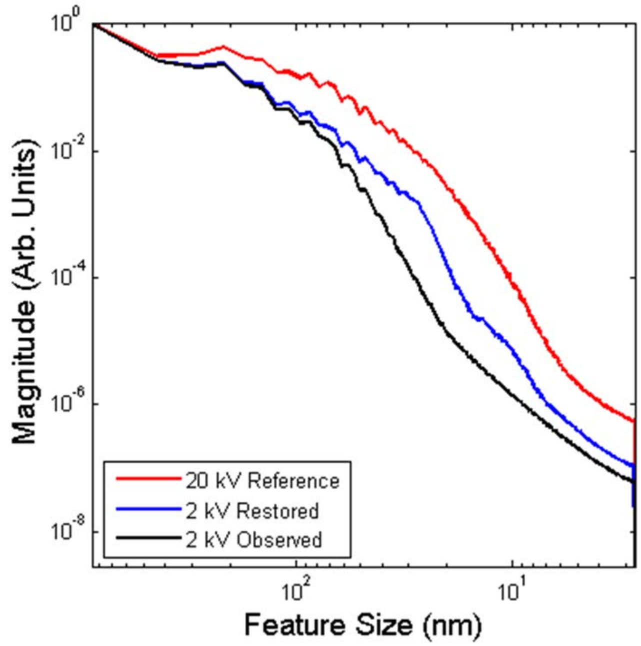
CTF Plots: Au, C-Nanotubes, Sn

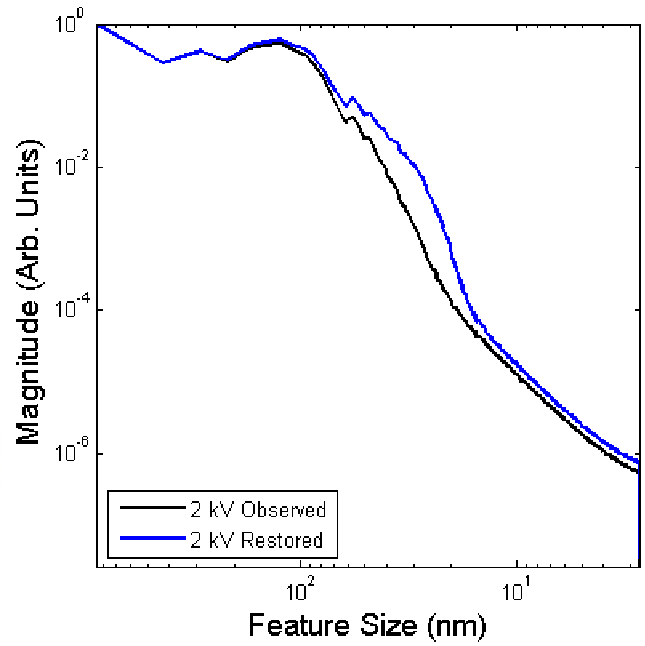
Au



C- Nanotubes



Sn



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Joy, D.C., J Microsc **208** (Pt1), 24-34 (2002)

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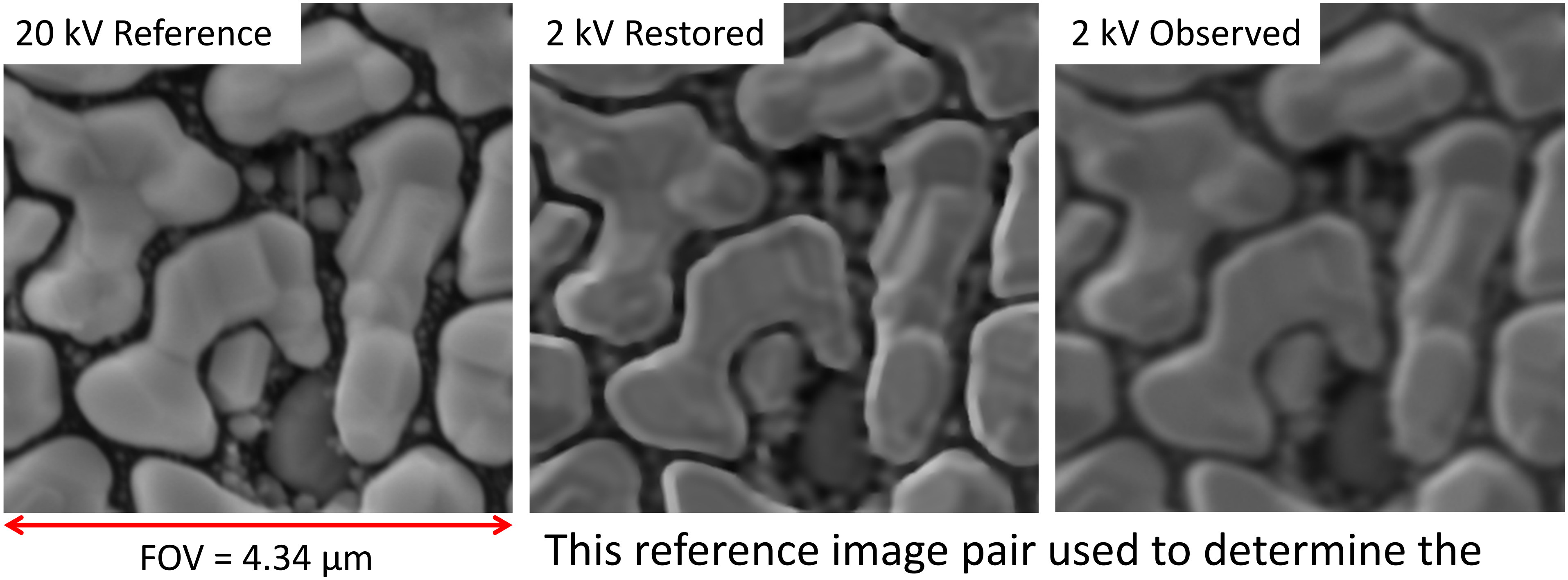
LaB_6 Low kV Restoration: Au



This reference image pair used to determine the PSF at low voltage

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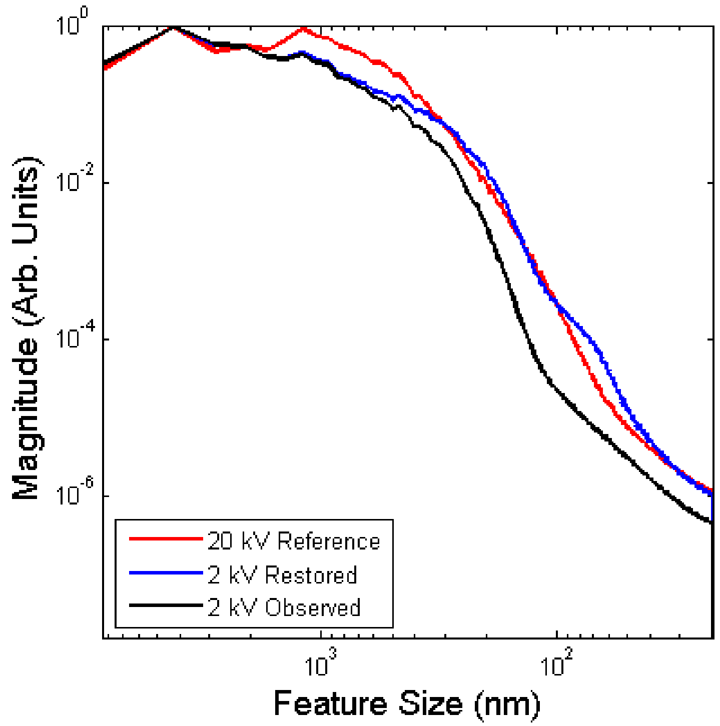
CTF Plot: LaB_6 Restoration



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Joy, D.C., J Microsc **208** (Pt1), 24-34 (2002)

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Conclusions

- Successfully shown that it is possible to use a single microscope to improve low kV performance without beam deceleration
- Even with different contrast mechanisms between kVs, we are able to determine useful PSFs
- Although thermionic sources are traditionally not used at low kV, our work opens the possibility of improved low kV imaging on such instruments

Future Work

- How low can we go in kV on a thermionic source and still achieve measurable improvement?
- Incorporate additional factors into restoration method:
  - Adjustments in secondary electron yield
  - SE1/SE2 ratio variation with voltage
  - Optimization of restoration algorithm

Acknowledgements

- Tescan
- Jeffery Moskin
- Sewei Lyu, PhD

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Questions?

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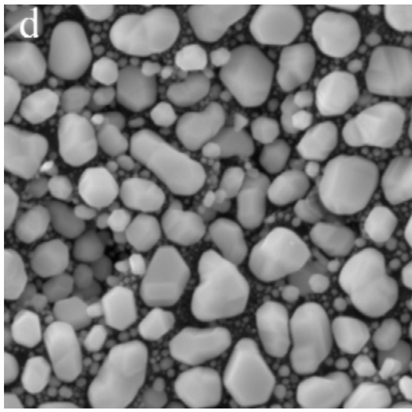
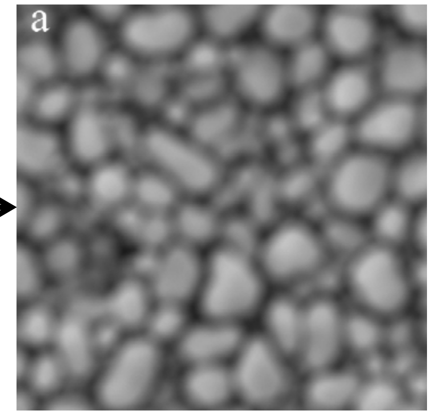
Image Restoration

Reference Image



Reference image pair

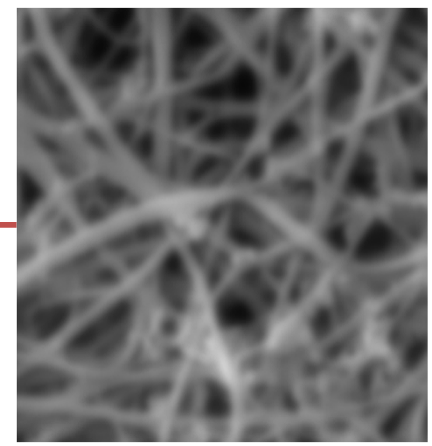
Image Degradation →



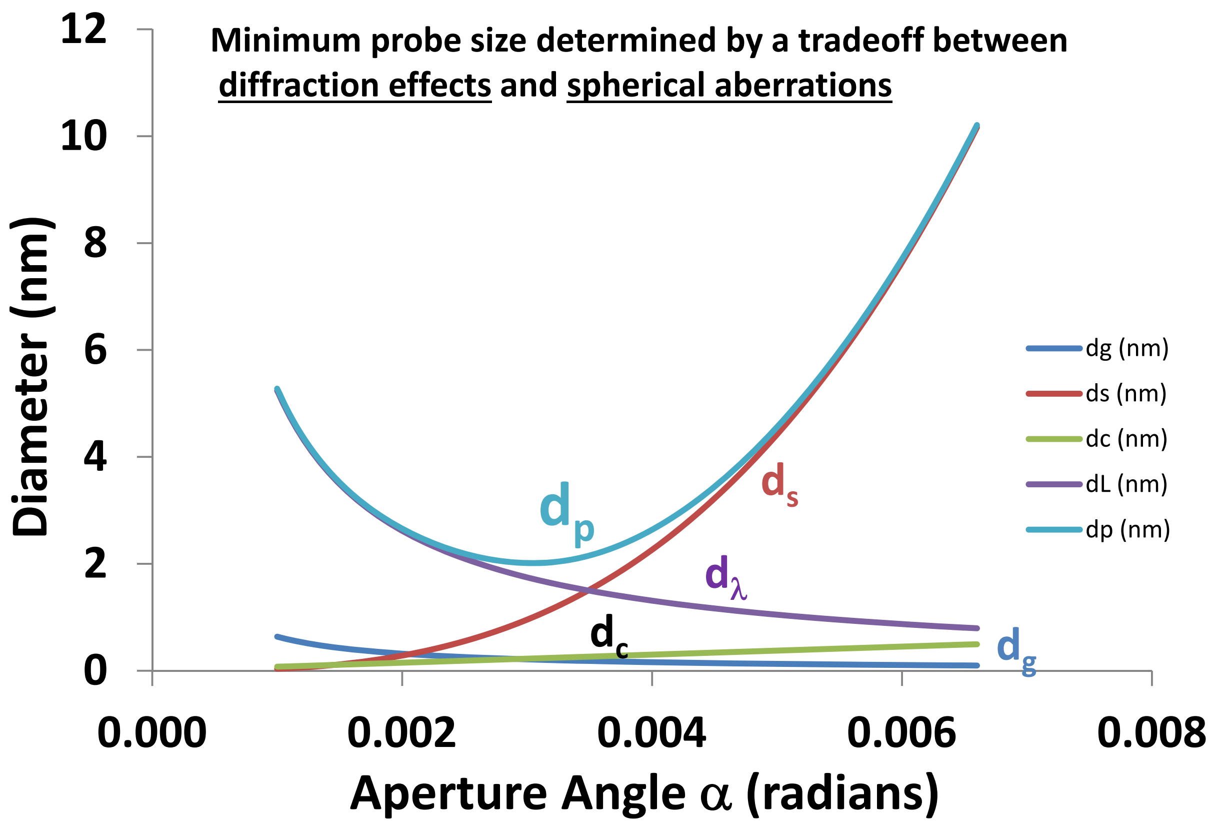
Observed Image

What is the best estimate given the reference pair of images?

Image Restoration ←



Probe Diameter tradeoff - Schottky 20 keV



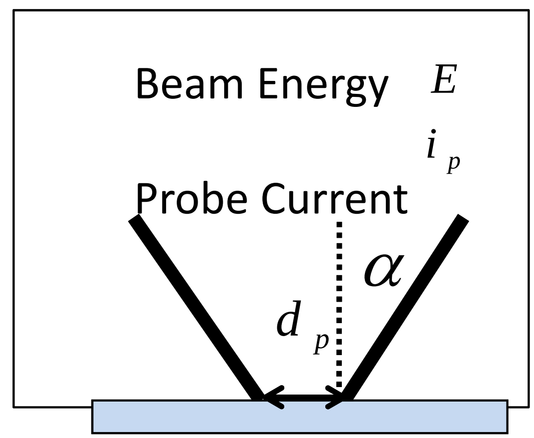
d_p – Probe Diameter

d_g – Source Demagnification

d_s – Spherical Aberrations

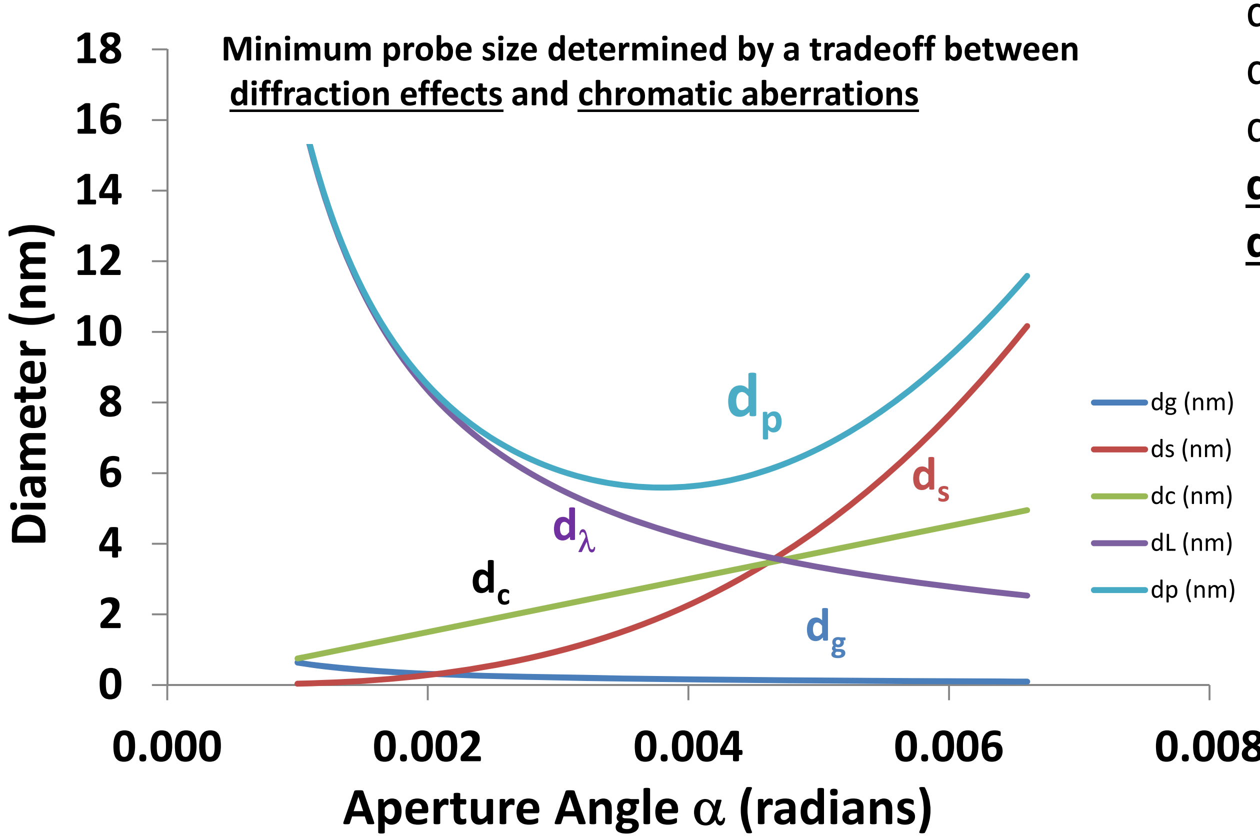
d_c – Chromatic Aberrations

d_λ – Diffraction Effects

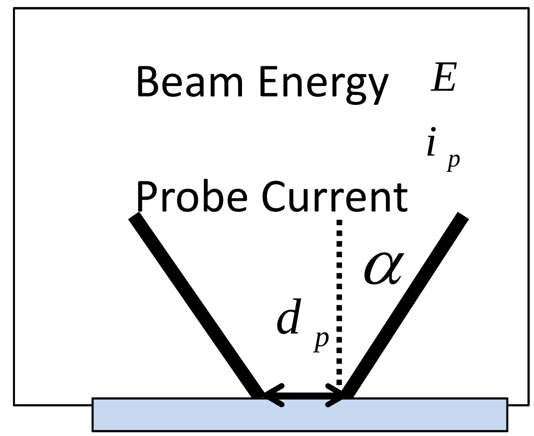


Schottky Source: E = 20 KeV, ΔE = .4 ev, β = 1 x 10^8 Amps/cm^2sr and ip = 10 pA

Probe Diameter tradeoff - Schottky 2 keV



d_p – Probe Diameter
d_g – Source Demagnification
d_s – Spherical Aberrations
d_c – Chromatic Aberrations
d_λ – Diffraction Effects

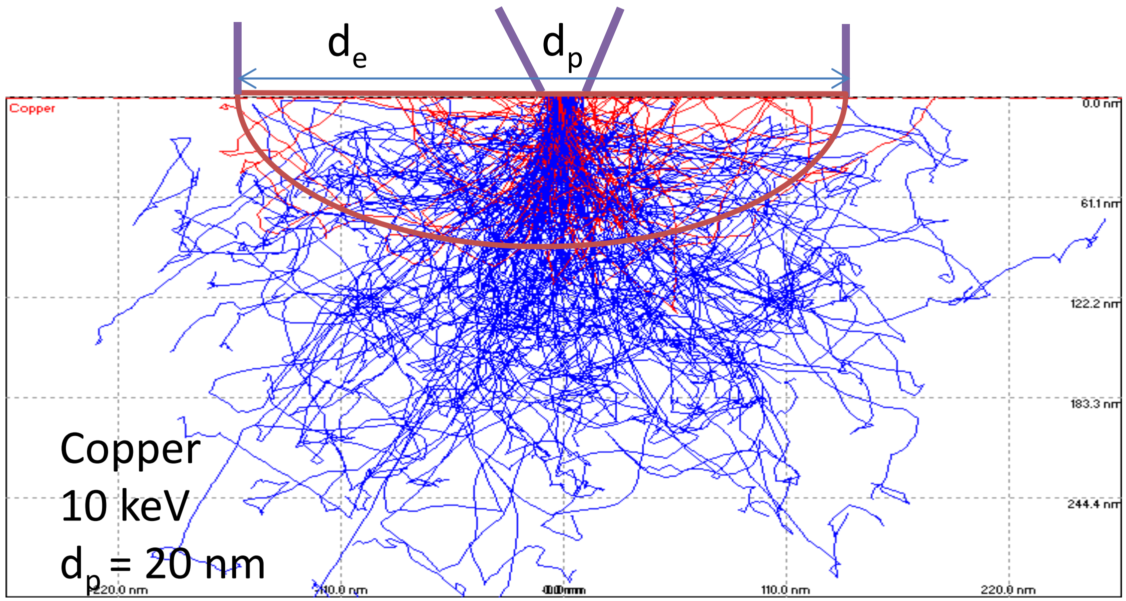


Schottky Source: E = 2 KeV, ΔE = .4 ev, β = 1 x 10^8 Amps/cm^2sr and ip = 10 pA

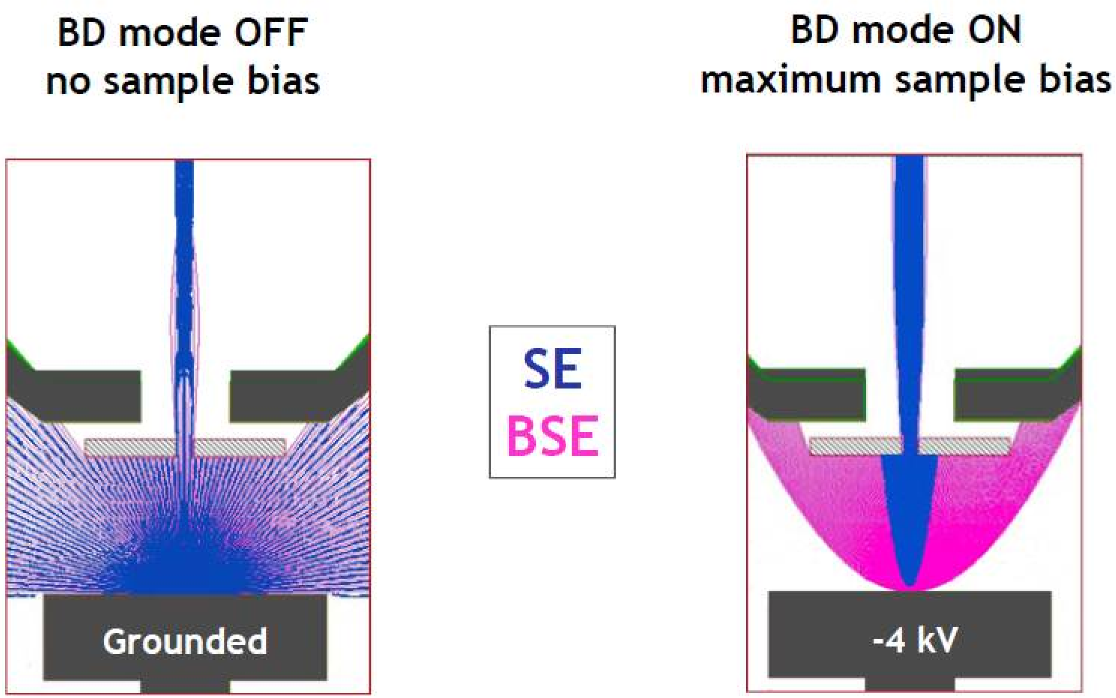
SEM resolution is limited by the probe size, d_p, surface morphology and excitation volume, d_e .

- For backscattered electrons d_e can be >> than d_p unless low kV are used
- For type 1 secondary electrons d_e can be almost equal to d_p

For planar samples d_p is not sample dependent. d_e is !



Conventional Techniques: Beam Deceleration



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What determines the probe size, d_p?

$$d_p = \sqrt{\left(d_g^2 + d_s^2 + d_c^2 + d_\lambda^2\right)}$$

where

Source Demagnification: $d_g = Md_0 = \sqrt{\left(\frac{4i_p}{\pi^2\beta}\right)}\alpha^{-1}$

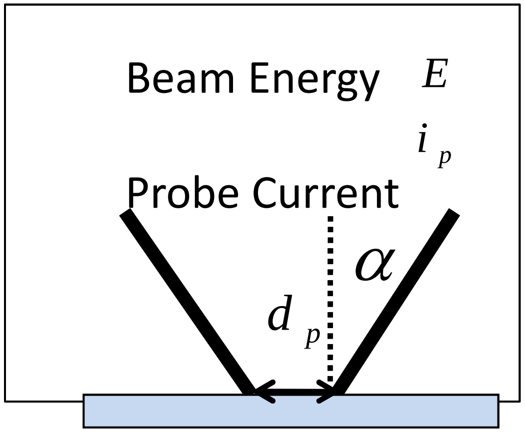
Spherical Aberrations: $d_s = \sqrt{\frac{C_s}{4}\alpha^3}$

Chromatic Aberrations: $d_c = C_c\left(\frac{\Delta E}{E}\right)\alpha$

Diffraction Effects: $d_\lambda = .61\lambda\alpha^{-1}$

Wavelength: $\lambda = h/mv = 1.226/\sqrt{E}$

Brightness: $\beta \cong \frac{j_c E}{\pi k T_c}$



λ = 8 pm at 30 KeV

d_λ = .8 nm for α =.006 radians

Outline

- Previous Work
- Image Restoration
- Application for Low kV
- Examples: Thermionic and Field Emission
- Future Directions