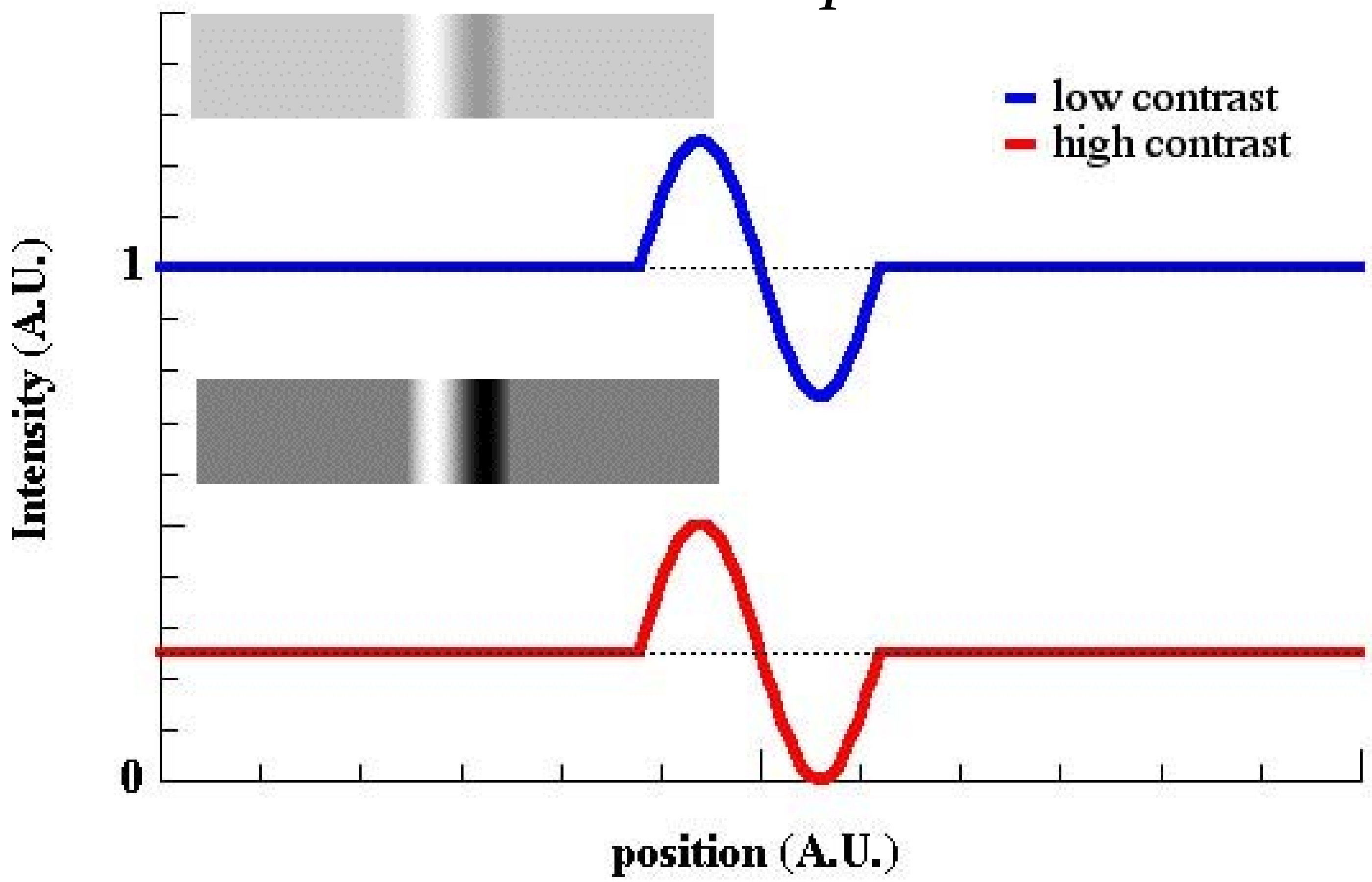
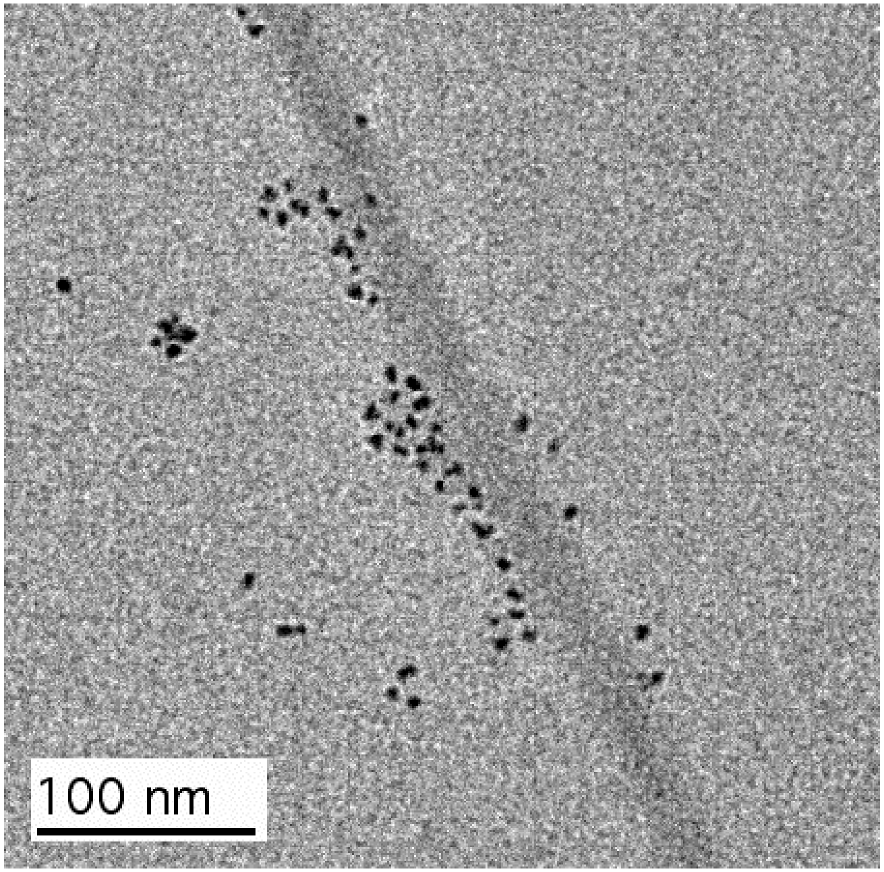
Definition of Contrast

$$\text{contrast} \equiv \frac{\Delta I}{\overline{I}}$$



Example: Cellulose + CdSe NPs



Mass-Thickness Contrast

- Primary contrast mechanism for amorphous materials
- Incoherent, elastic scattering
- Enhance by: 1) staining, 2) smaller objective aperture

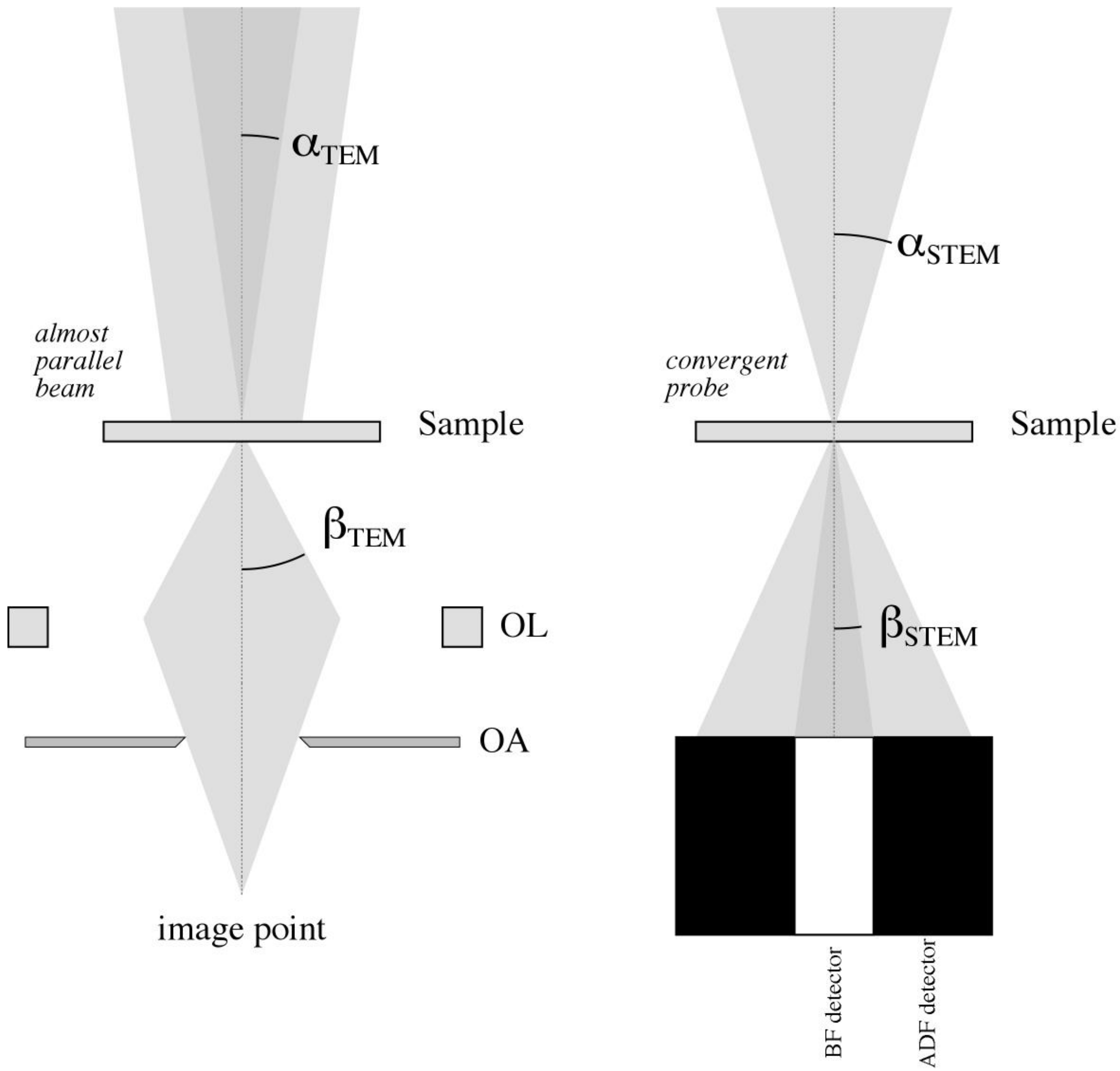
$$I(T) = I_0 e^{-\mu T}$$

$$\mu = \frac{N_0 \cdot \rho \cdot \sigma_0}{A}$$

$$\mu T = \left(\frac{N_0 \sigma_0}{A} \right) \cdot (\rho T)$$

$$\rho T : \text{ mass-thickness } \left(\mathrm{g/cm^2}\right)$$

Theorem of reciprocity



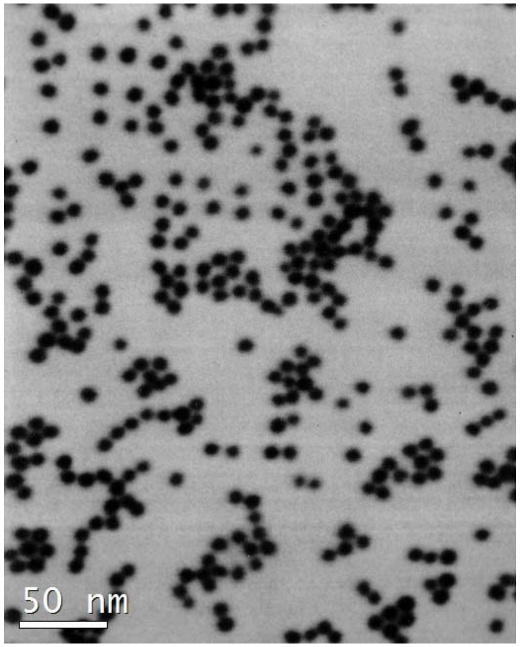
$$\alpha_{TEM} \leftrightarrow \beta_{STEM}$$
$$\beta_{TEM} \leftrightarrow \alpha_{STEM}$$

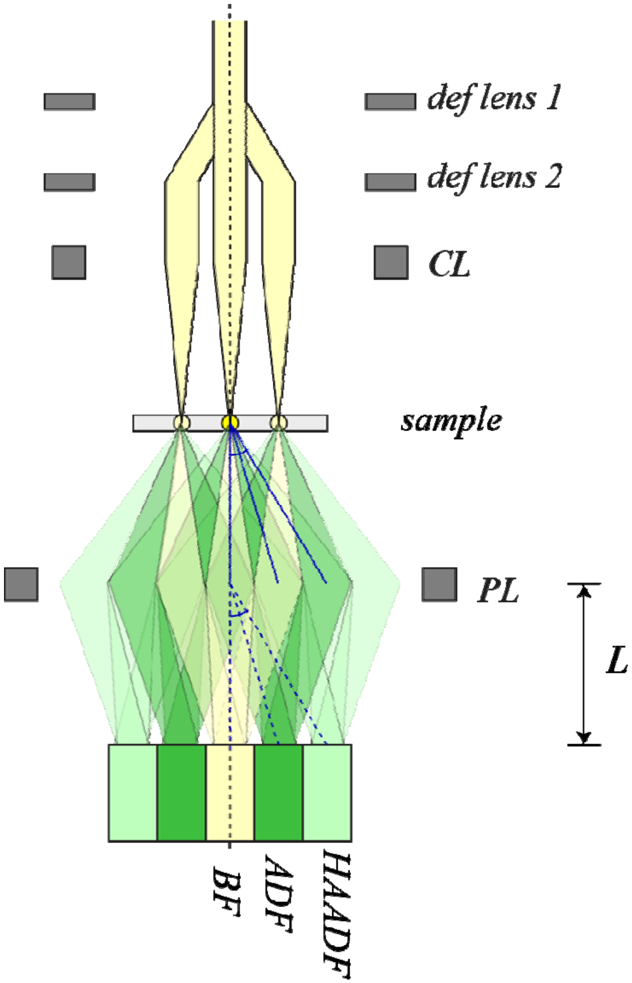
STEM image contrast is related to TEM image contrast

STEM BF/ADF

- No significant post-specimen focusing in STEM
- Eliminates post-specimen chromatic aberration
- Bright-field and annular dark-field detectors
- Photomultipliers or solid-state detectors

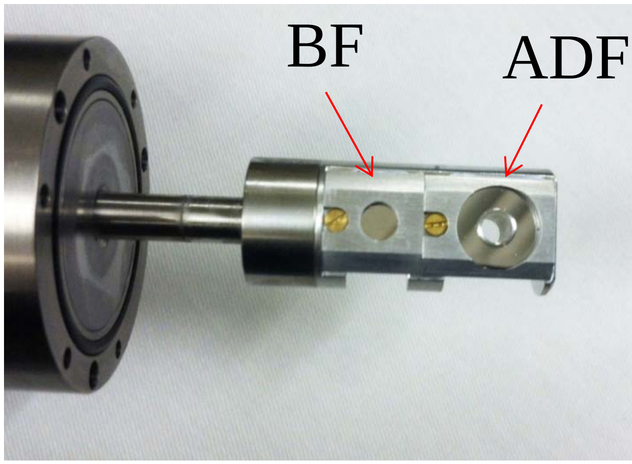
BF STEM of 10-nm Au



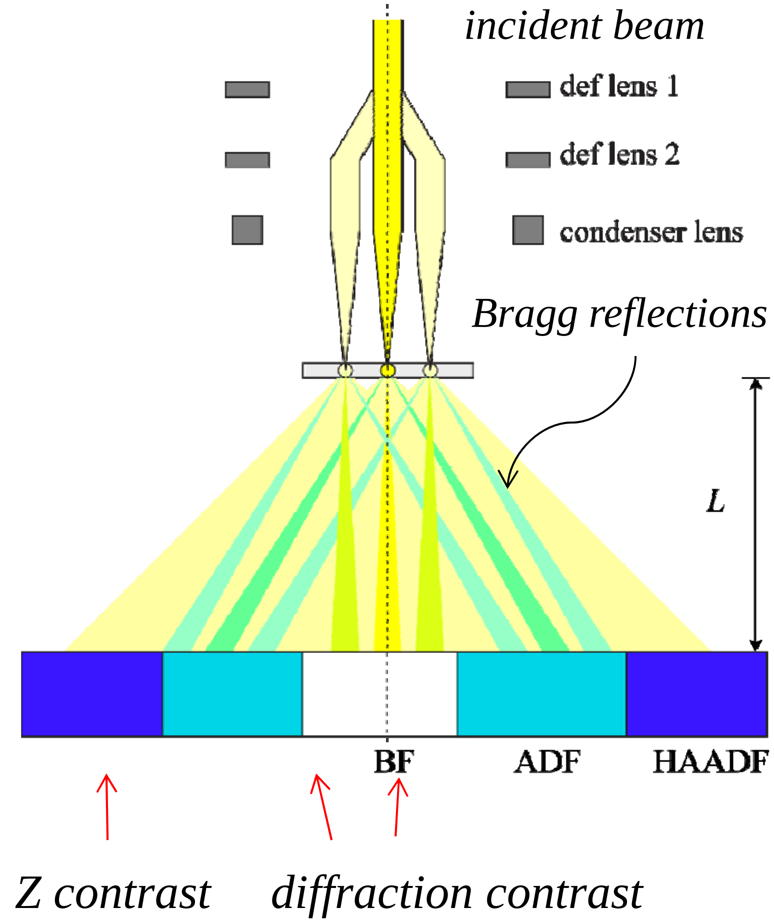


Retractable STEM detector

top



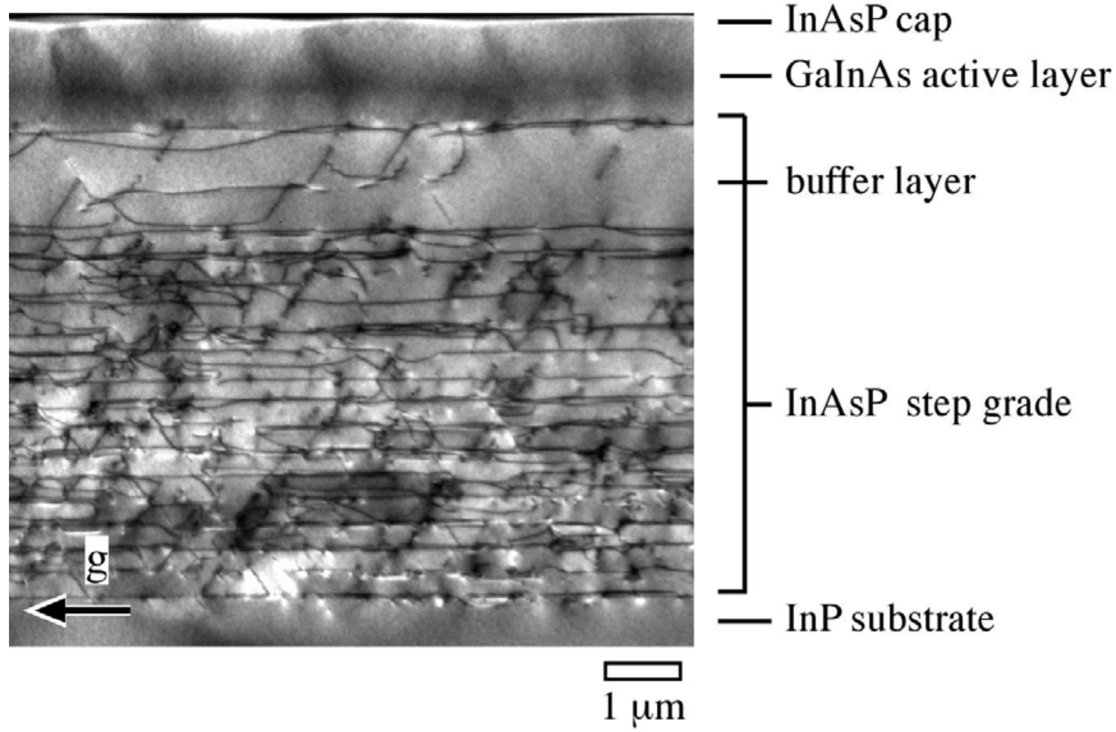
side



Diffraction Contrast

- Nearly always contributes to images of crystalline materials
- Coherent, elastic scattering

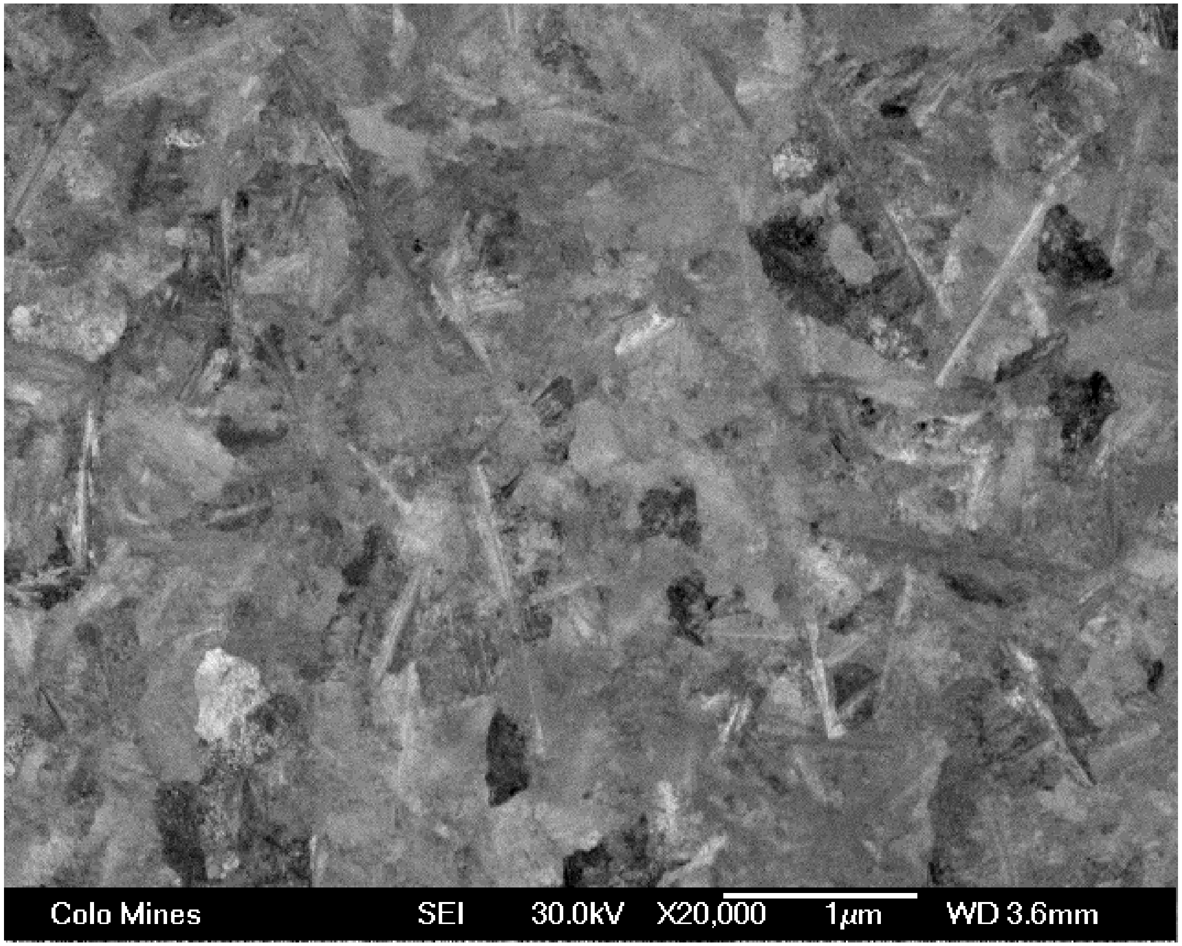
Useful to image:
- Dislocations/defects
- Chemical interfaces
- Structural phases



For crystalline materials, always show the direction of **g**

STEM in an SEM

STEM Image of Recrystallized Si



Acquired in an SEM (with STEM detector)!

Z-contrast imaging

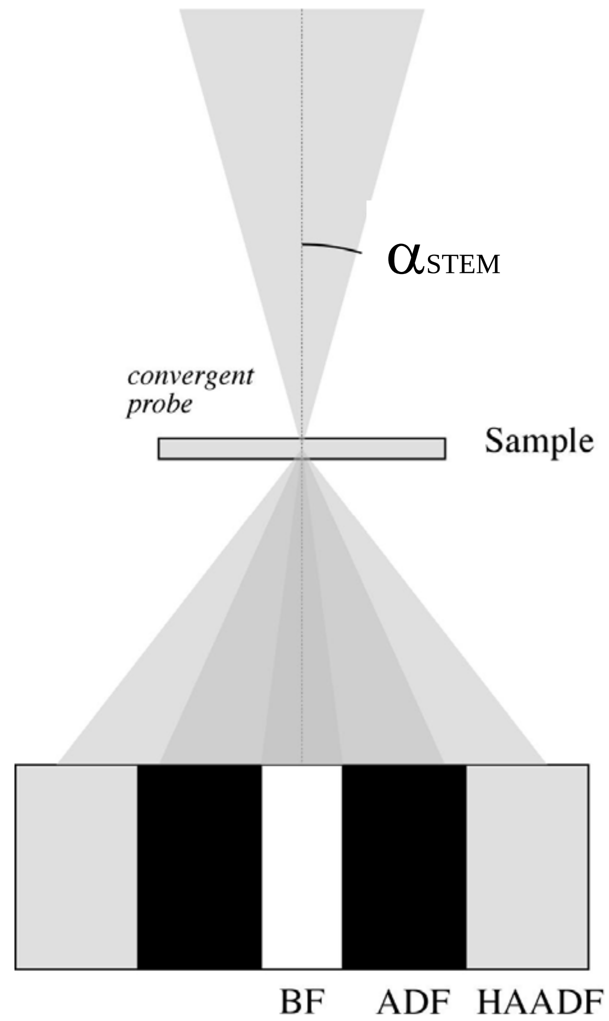
- Uses a high-angle annular dark-field (HAADF) detector
- Incoherent, elastic scattering
- Eliminates diffraction contrast
- Enhances chemical contrast
- Best *not* to cool sample

$$\frac{d\sigma}{d\Omega}(\theta) = \left| f(\theta) \right|^2$$

$$f_e(\theta) = \frac{\lambda^2 Z e^2 m}{8\pi h^2 \varepsilon_0} \cdot \left[\frac{1}{\sin^2(\theta/2) + \sin^2(\theta_0/2)} \right]$$

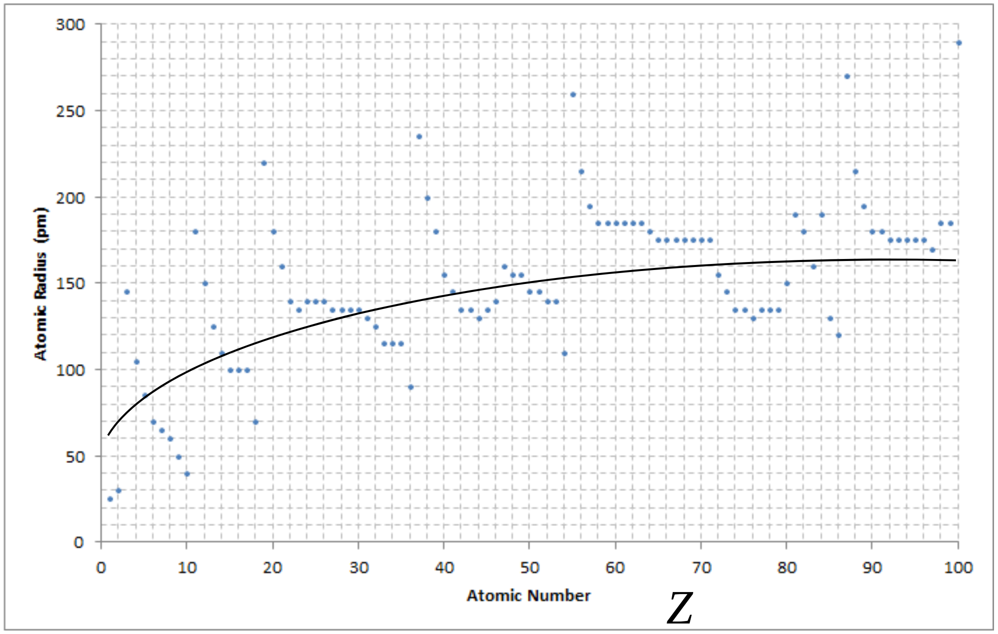
$$f_e(\theta) \propto \frac{Z}{\sin^2(\theta_0/2)}$$ (low angle, screened)

$$f_e(\theta) \propto \frac{Z}{\sin^2(\theta/2)}$$ (high angle, unscreened)



Screening and Atomic Radius

r_0



http://en.wikipedia.org/wiki/Atomic_radius#mediaviewer/File:Atomic_number_to_radius_graph.png

$$\varphi(r) = \frac{Ze}{4\pi\varepsilon_0 r} e^{-r/r_0}$$ //Thomas-Fermi model for screened electrostatic potential of atom

$$4\pi \sin(\theta_0/2) = \frac{\lambda}{r_0} \qquad \lambda \ll r_0 \longrightarrow \qquad \theta_0 \approx \frac{\lambda}{2\pi r_0}$$

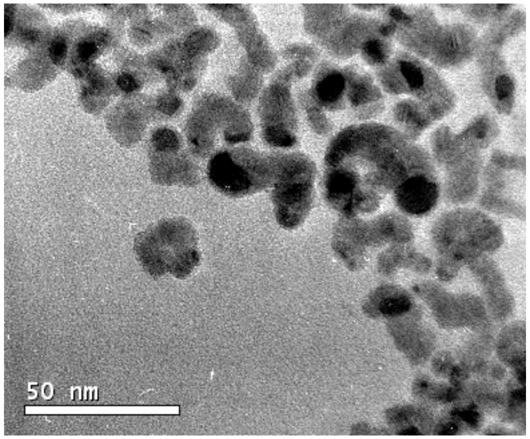
$$r_0 \approx \frac{a_B}{Z^{1/3}}$$ //Wentzel atom model $\longrightarrow$ $\theta_0 \propto Z^{1/3}$ $\longrightarrow$ $f_e(\theta) \propto Z^{1/3}$

(low angle, screened)

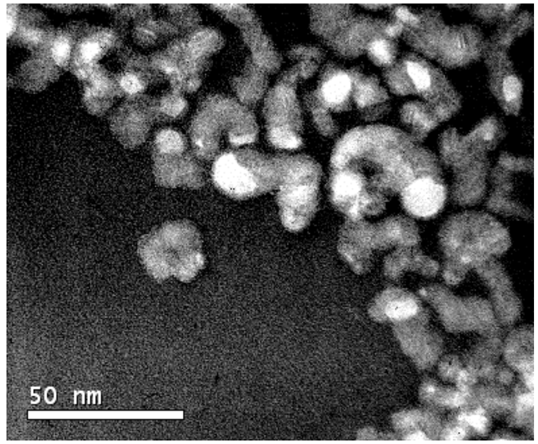
HAADF examples

InAs Synthesized with Au Catalysts

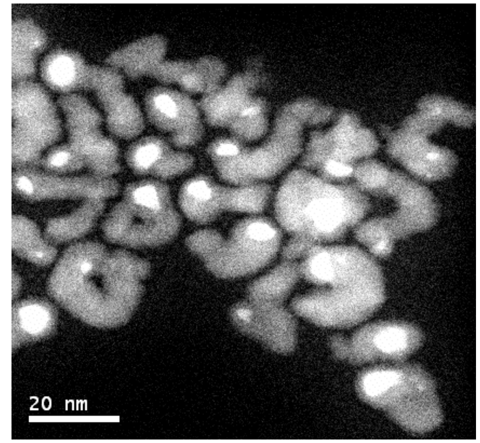
Conventional BF



Inverted Contrast



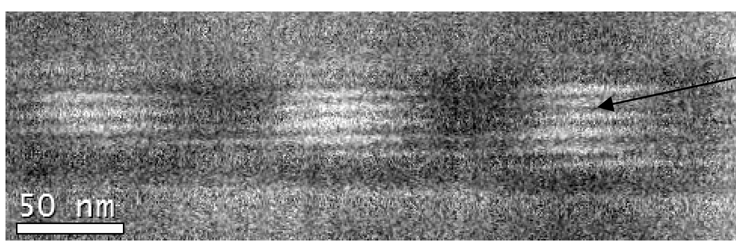
HAADF



No diffraction contrast

GaAs/GaPAs QD superlattice

"HAADF"



GaAs