STEM imaging on Tescan's TENSOR

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AlN/GaN nanowire from:
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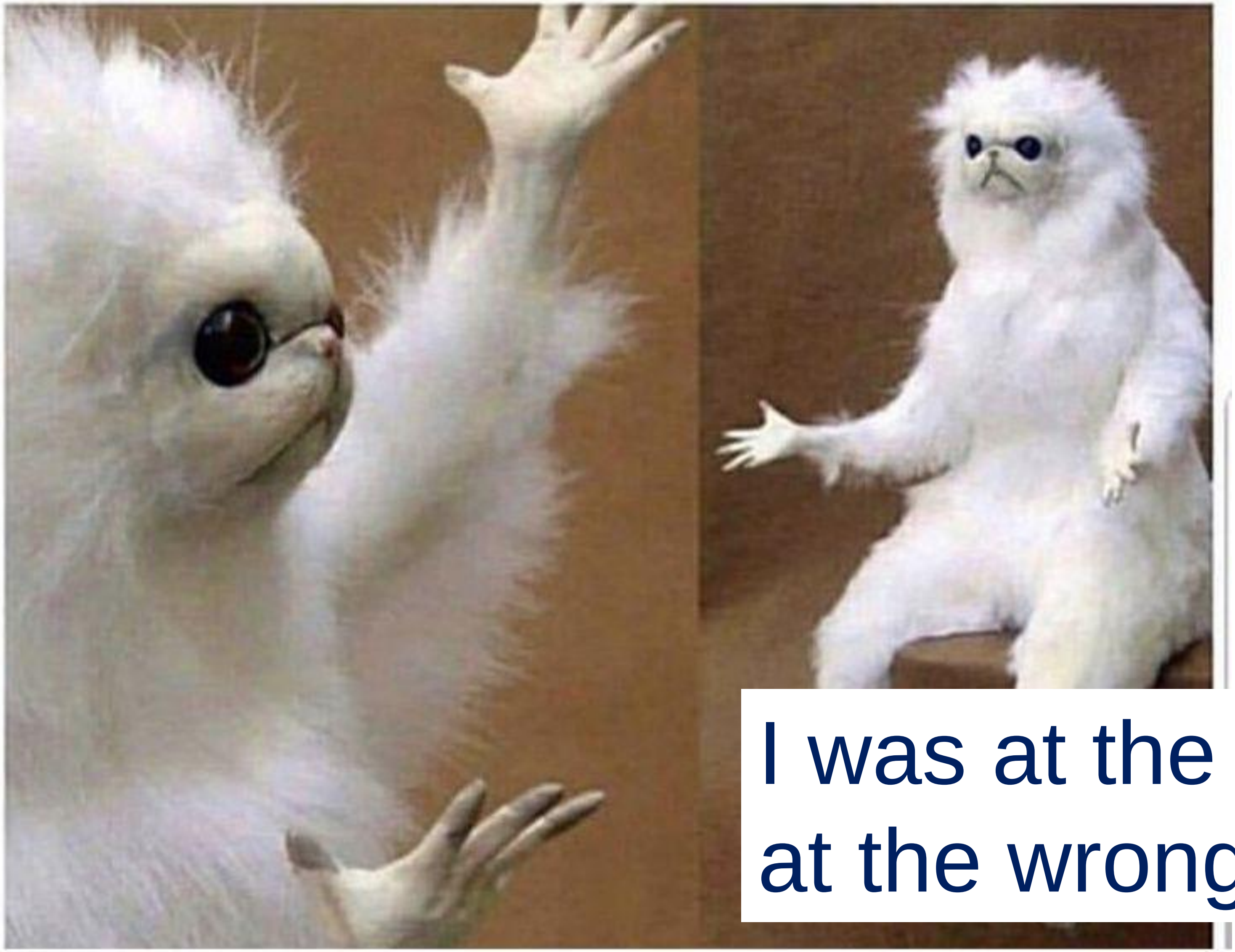
Why me?



I was at the wrong place
at the wrong time

Summary

Introduction:

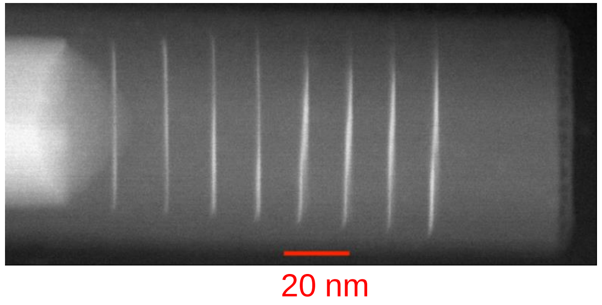
STEM imaging: some information on the physics behind
A description of the sample: GaN/AlN heterostructure in nanowires

Experiment:

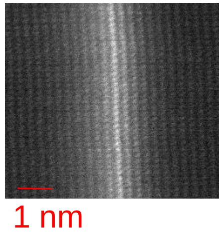
Setup the microscope (look at a ronchigram)
Try HAADF imaging. Need of tilting to a zone axis
Try MADF to see diffraction effects
Try ABF (maybe we can see N atoms?)
Some 4D-STEM “virtual” imaging
Can we find a inversion-domain in a nanowire?

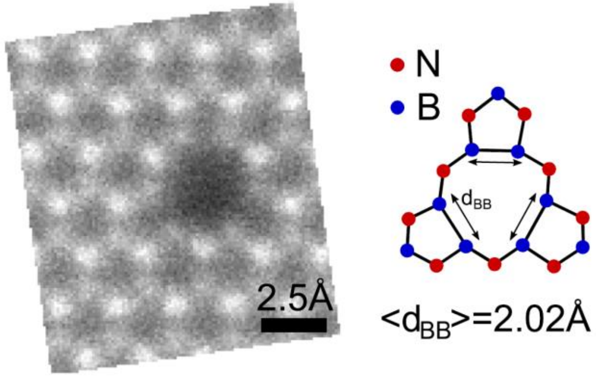
Electron scattering: imaging and spectroscopy

Elastic scattering (imaging)

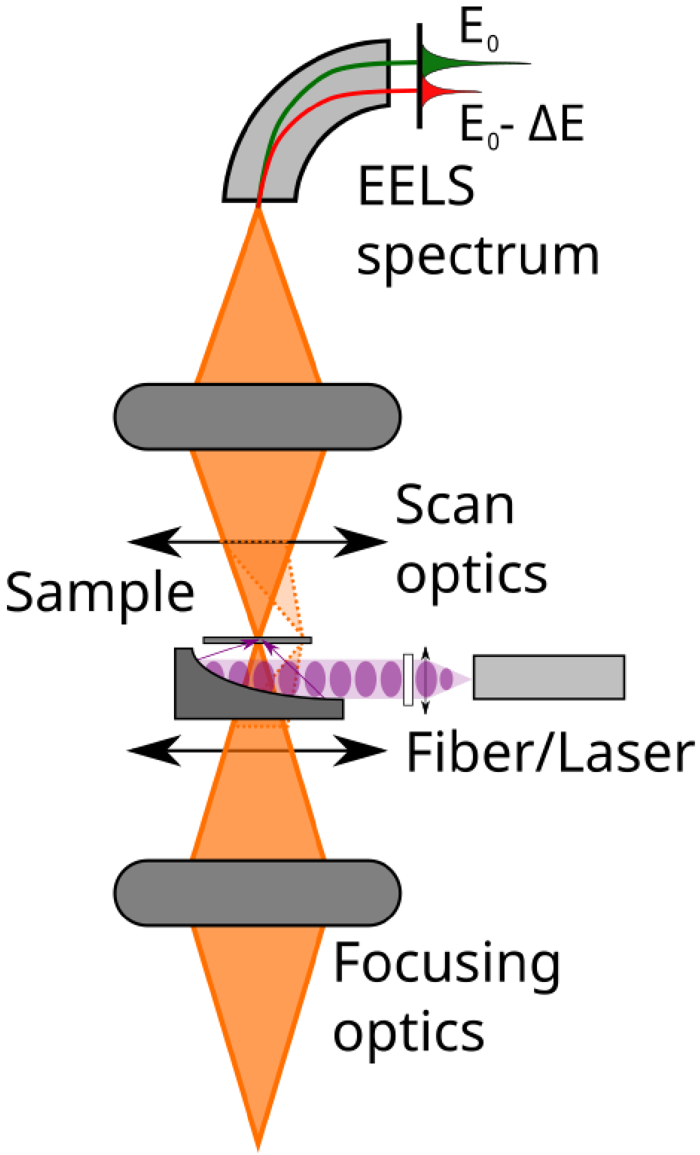


Crystal structure
Atomic number
Morphology





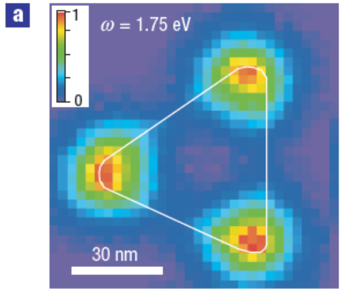
O. Cretu, et al *Phys. Rev. Lett.* (2015)



CL: L.F. Zagonel and M. Kociak *Ultramic.* **176** 112(2017)
EELS: J. Garcia de Abajo, *Rev. Mod. Phys.*, **82,** 209 (2010)

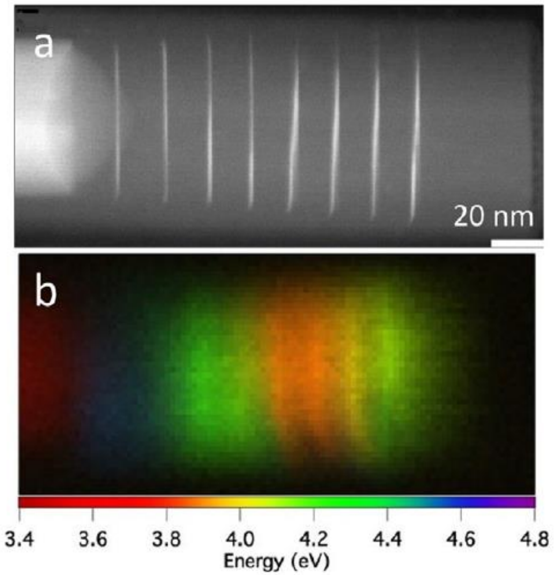
Inelastic scattering (spectroscopy)

EELS: absorption



J. Nelayah, *et al. Nat. Phys.* **3** 348 (2007)

CL: excitation of a decay channel probability



Also EEGS, EDS, Auger …

HAADF, MADF, BF and ABF: a matter of angles

Imaging as a function of scattering angle

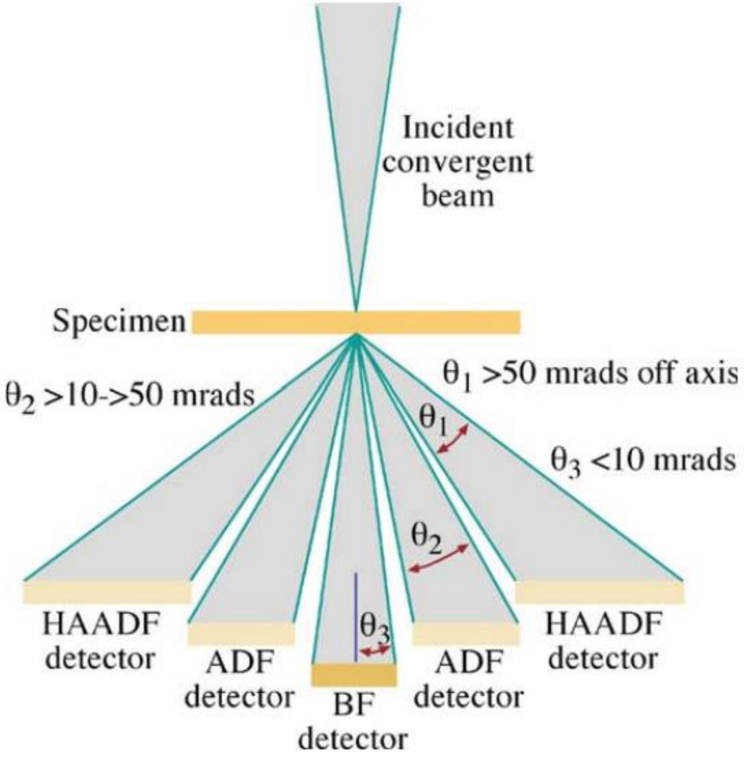


FIGURE 22.13. Schematic of the HAADF detector setup for *Z*-contrast imaging in a STEM. The conventional ADF and BF detectors are also shown along with the range of electron scattering angles gathered by each detector.

Williams and Carter, *Transmission electron microscopy* (1991/2010)
(you can win one on the final quiz)

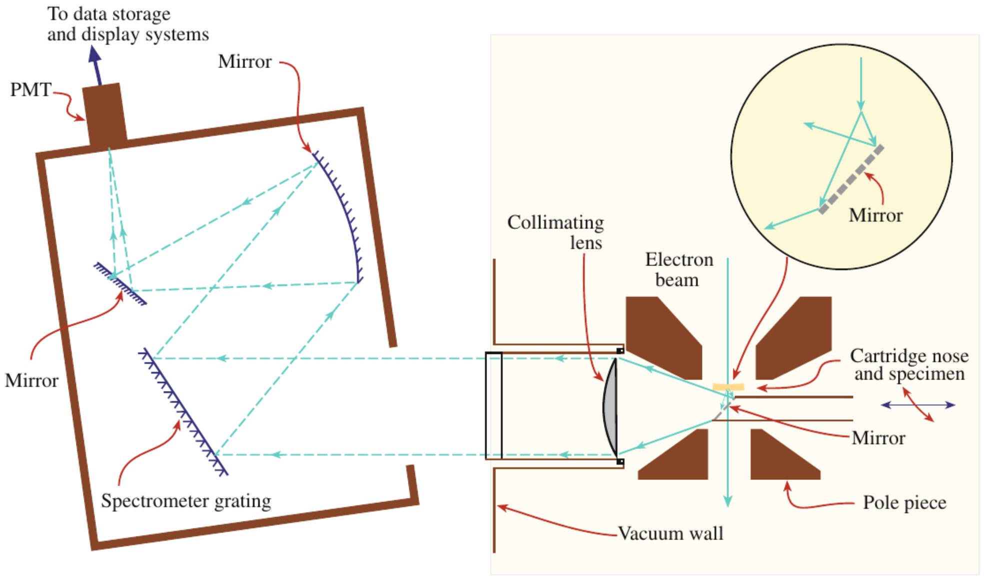
HAADF physics: Rutherford scattering

$$\frac{d\sigma_{el}}{d\Omega} = \frac{4Z^2R^4(1+E/E_0)^2}{a_H^2}\frac{1}{[1+(\theta/\theta_0)^2]^2}$$

$$\text{with } \theta_0 = \frac{\lambda}{2\pi R};\ R = a_H Z^{-1/3}.$$

Kohl and Reimer, *Transmission electron microscopy: Physics of image formation* (1984/208)
(Very nice book)

How to detect electrons?



Williams and Carter, *Transmission electron microscopy* (1991/2010)
(you can win one on the final quiz)

HAADF, MADF and ABF: examples

HAADF imaging without aberration correction (300 keV)

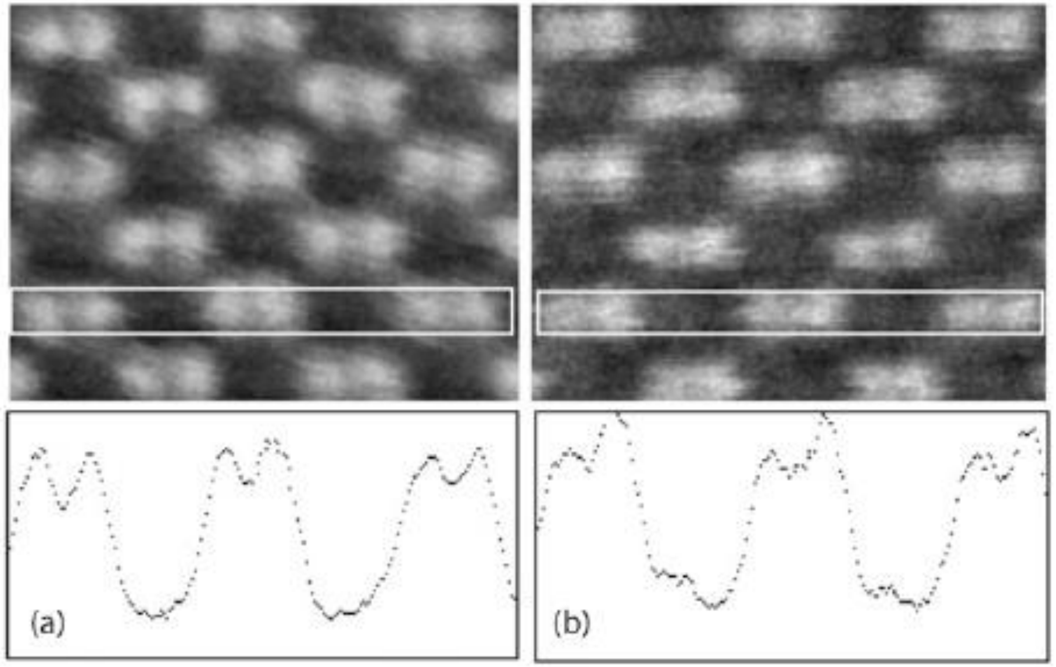


Figure 1–27. Sublattice sensitivity in a 300 kV VG Microscopes HB603U STEM. Z-contrast images of (**a**) Si and (**b**) GaAs ⟨110⟩ with line traces averaged vertically within the *white rectangles*, adapted from Pennycook et al. (1996).

HAADF imaging with aberration correction (100 keV)

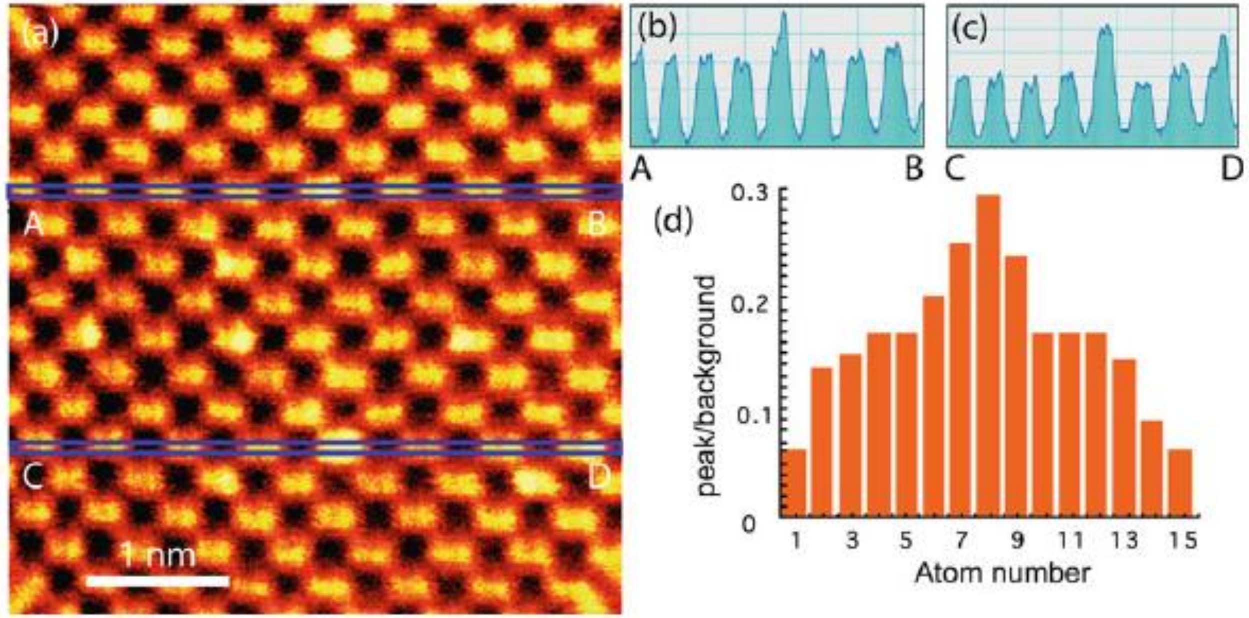


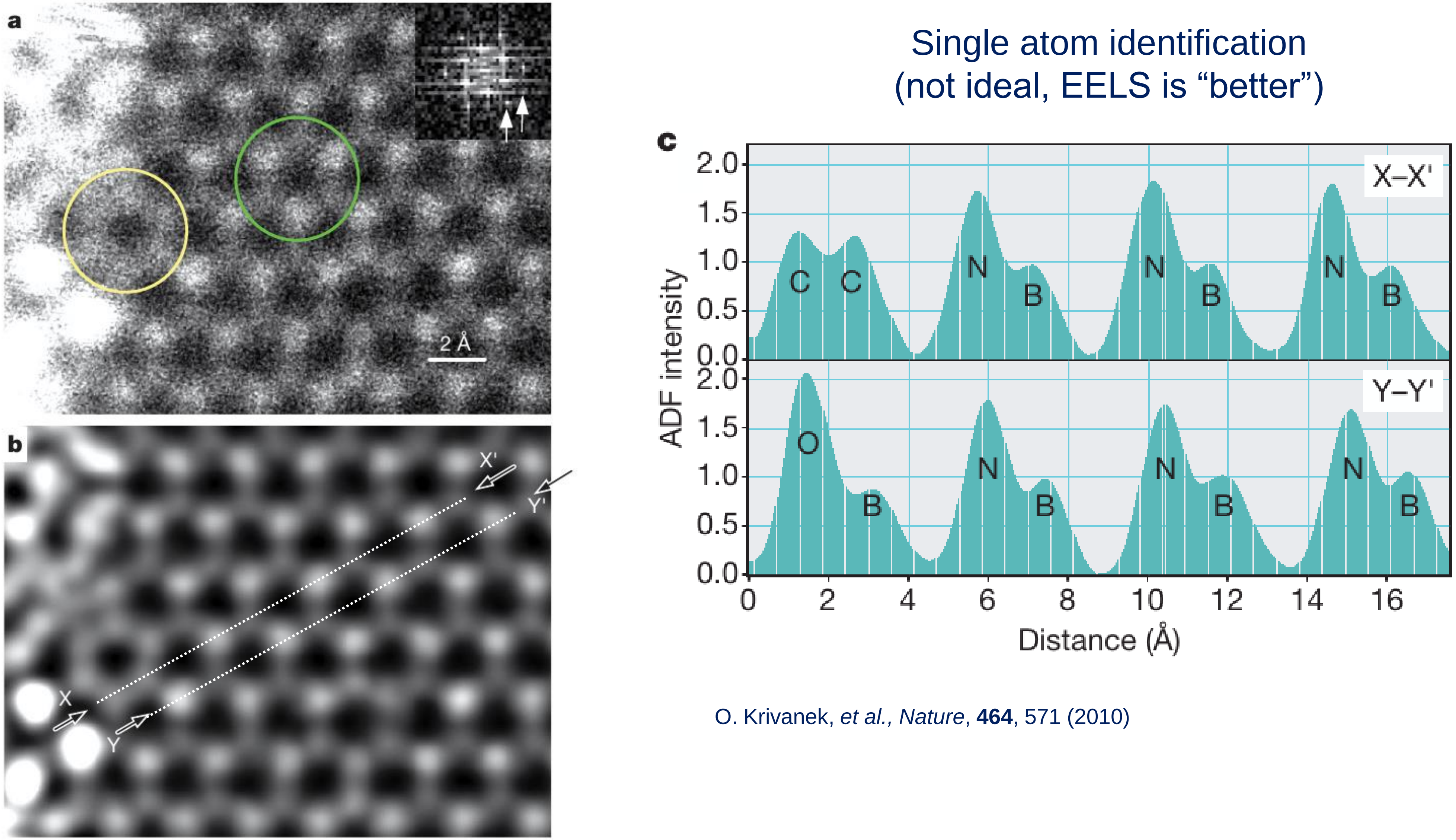
Figure 1–33. Z-contrast image of Bi-doped Si ⟨110⟩ taken with a VG Microscopes HB501UX with Nion aberration corrector operating at 100 kV, revealing columns containing individual Bi atoms. The upper intensity profile shows a Bi atom on the *right-hand column* of a Si dumbbell and the lower profile shows a Bi atom in each of the two columns of a dumbbell. Reproduced from Lupini and Pennycook (2003) and Pennycook et al. (2003b).

Pennycook and Nellist, Scanning Transmission Electron Microscopy. (2011)

Si dumbells distance = 0.136 nm

HAADF, MADF and ABF: examples

Single atom identification
(not ideal, EELS is “better”)



O. Krivanek, *et al.*, *Nature*, **464**, 571 (2010)

HAADF, MADF and ABF: examples

HAADF and ABF of TiO_2 and $SrTiO_3$

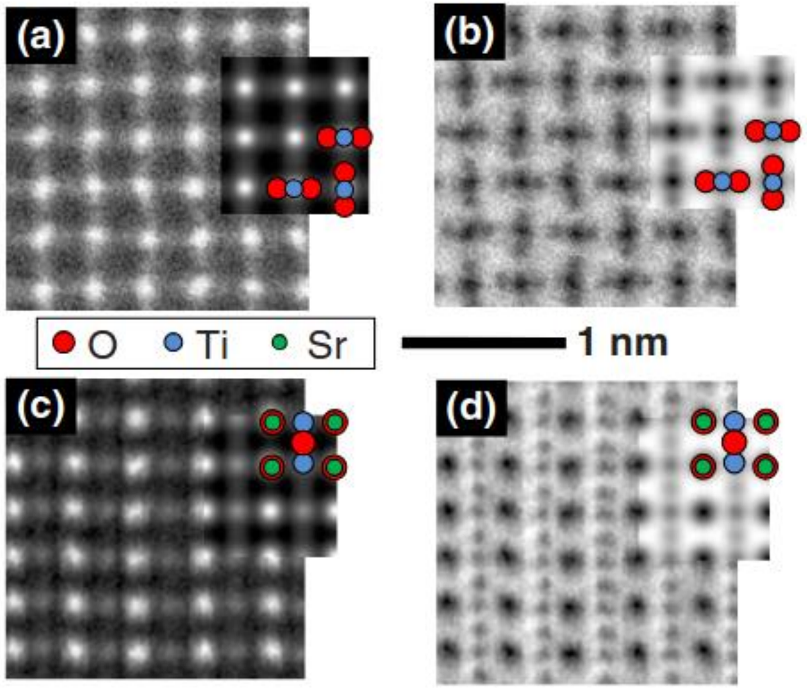


FIG. 1. (Color online) HAADF (left) and ABF (right) images (raw data) of (a) and (b) TiO_2 [001], and (c) and (d) $SrTiO_3$ [110]. Simulations and projected structures are given in the insets.

Simulation, sample thickness and defocus are the key

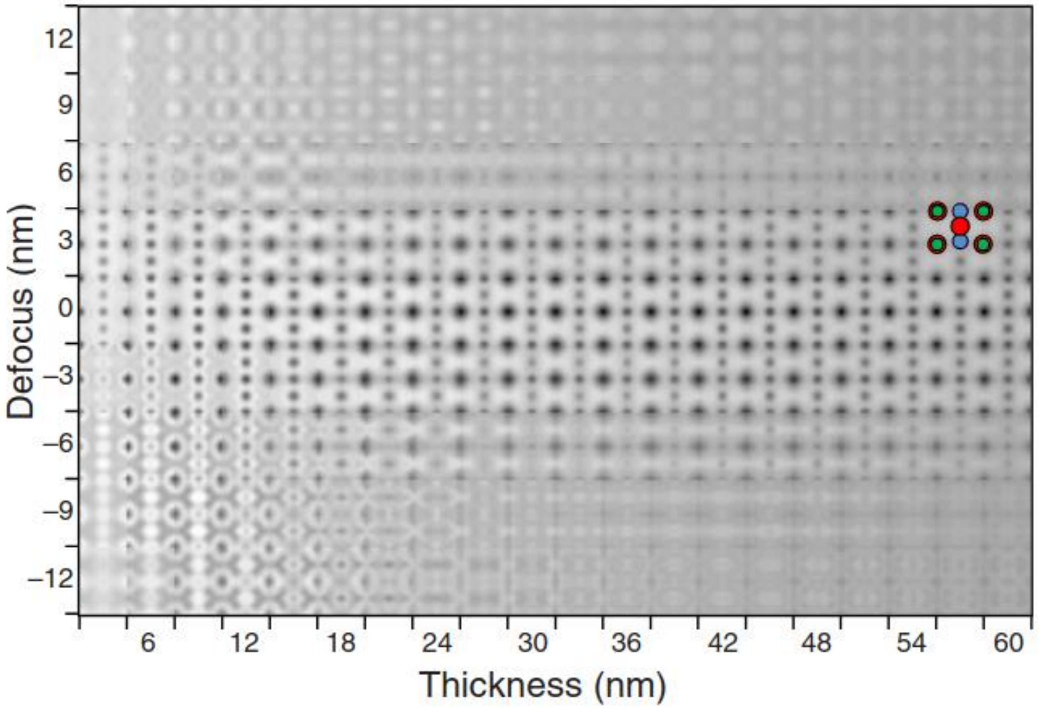
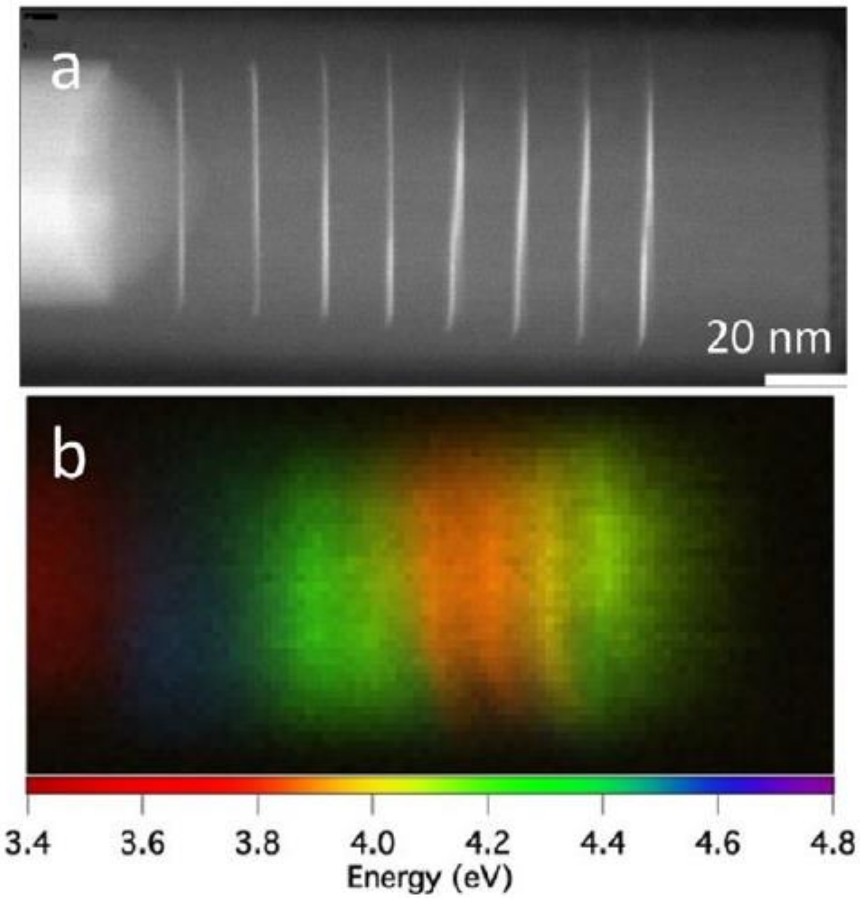


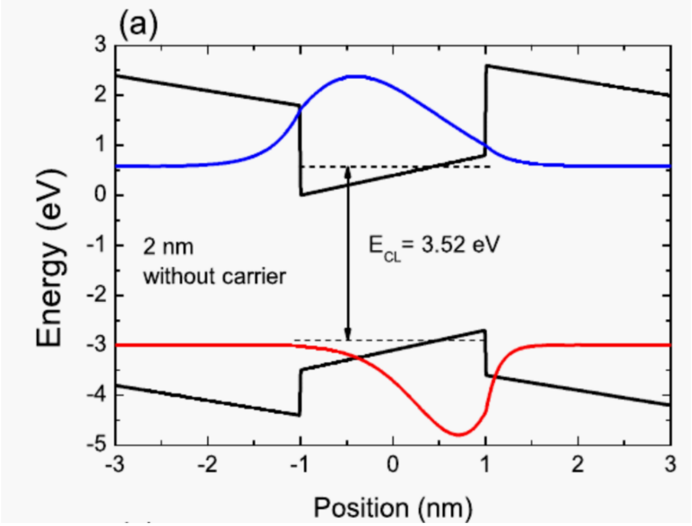
FIG. 2. (Color online) Defocus-thickness map for ABF images of $SrTiO_3$ viewed along [110]. The same imaging parameters as for Fig. 1 are assumed, excepting finite source size effects.

CL GaN quantum disks in AlN nanowires

Light emission occurs due to electron and hole (missing electron) pair recombination, possibly with excitonic effects



S. Meuret, *et al. ACS Photon.* **3** 1157 (2016)



1) Electron and holes are represented by **wavefunctions** of a given size (nanometric here)
2) In a bulk material, the difference in energy between electrons and holes is the forbidden energy band gap (consequence of crystal structure + Schrödinger equation)
3) When they are in a **confined** space, their **energy is increased** (consequence of Schrödinger equation)
4) So the **emission energy** depends on the quantum well size

N. Ashcroft and N. D. Mermin, Solid State Physics
M. Cardona, Fundamentals of Semiconductors

To experiments!