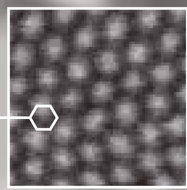
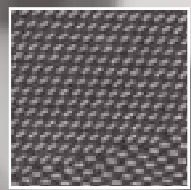
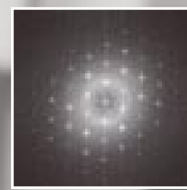
APPLICATION NOTE

FEI COMPANY™
TOOLS FOR NANOTECH







Application results on the Titan™ 80-300 platforms

Conquering the sub-Ångström era

The Titan™ 80-300 is available with a variety of configuration options, each of which provides specific performance benefits. Options include a monochromator to reduce the energy spread of the electron beam and spherical aberration correctors for TEM imaging and/or STEM probe formation. The monochromator and either or both correctors can be added, alone or in any combination, as part of the original configuration or as a field upgrade to an existing instrument. The images below provide a basis for comparing the Titan's performance with each option to its performance in the base configuration.

The Titan 80-300 platforms for correctors and monochromator

Titan 80-300 platform for single C_S-corrector and monochromator

Titan 80-300 platform for double C_S-corrector and monochromator

Techniques

HR-TEM
Focus series reconstruction (TrueImage™)
HR-STEM
EELS/ELNES
EDS
Lorentz microscopy
Holography
EFTEM
SAED/CBED/nano-diffraction
S/TEM-tomography
80 - 300 kV choice

Accessories

EDS-detector
EELS/EFTEM energy filter
CCD-camera
TV-camera
BF/DF-STEM detector
HAADF-STEM detector
BSE detector
Auto-align detector
Dynamic experiment holders
(heating, cooling, straining, AFM/STM)
Remote operation

Titan 80-300

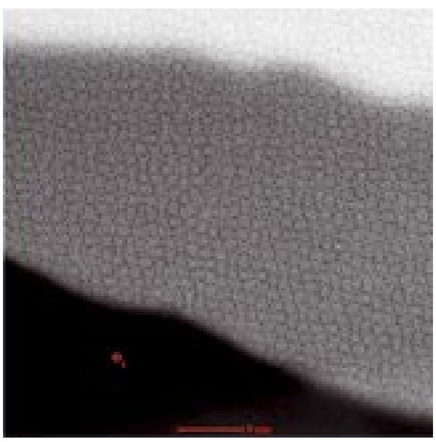
BF

Bright field STEM on silicon (110) at 300 kV.

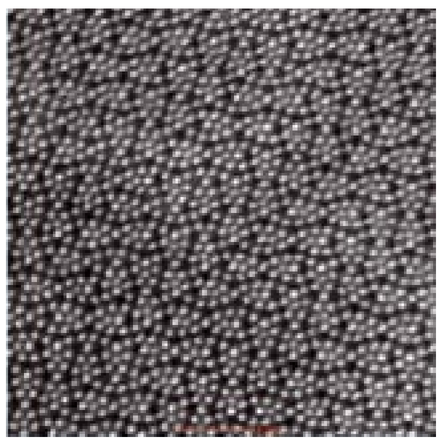
HAADF

HAADF STEM on silicon (110) at 300 kV.

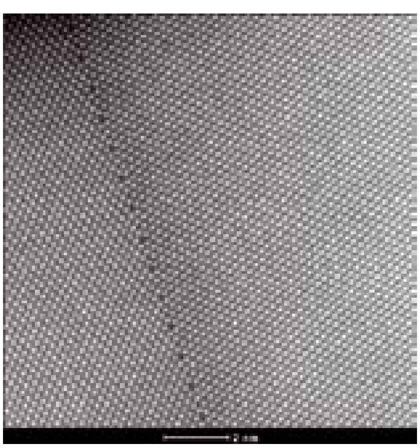
HAADF

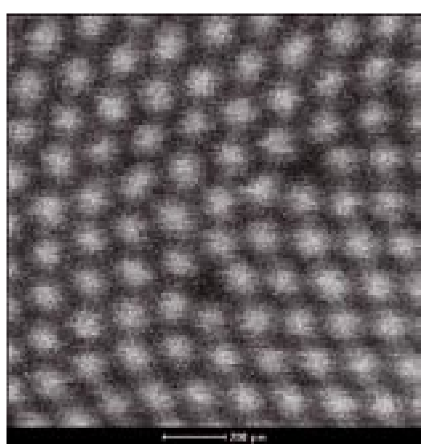


HAADF



HAADF-STEM images on $Nb_7W_{10}O_{47.5}$ at 300 kV.

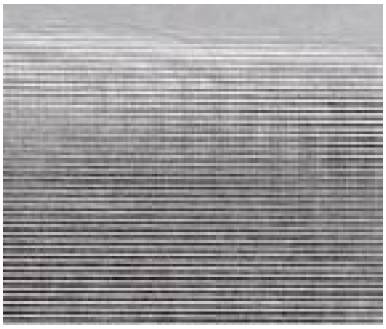


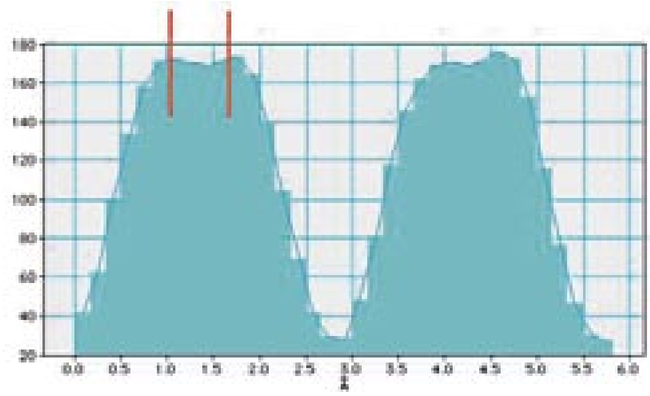


HAADF-STEM images of gold grain boundary at 300 kV.
Sample courtesy of C. Kisielowski (NCEM, UC Berkley).

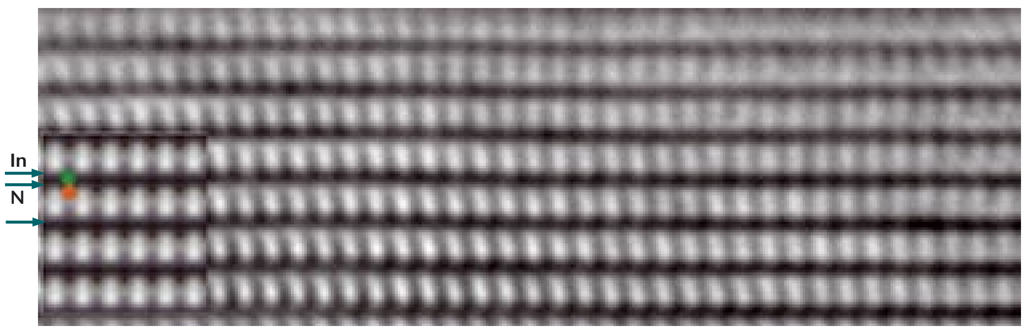
Titan 80-300

Sub-Ångström resolution in HR-TEM on InN at 300 kV





d(0008) = 0.71 Å (In-N distance).



Titan: InN [10$\bar{1}$0]
C_s= 1.2 mm, 300 kV.

Simulation:
t = 6 nm; Df = -298 nm.

Image: C. Kisielowski (NCEM), B. Freitag (FEI).

Sub-Ångström HR-TEM of silicon in <112> direction at 300 kV

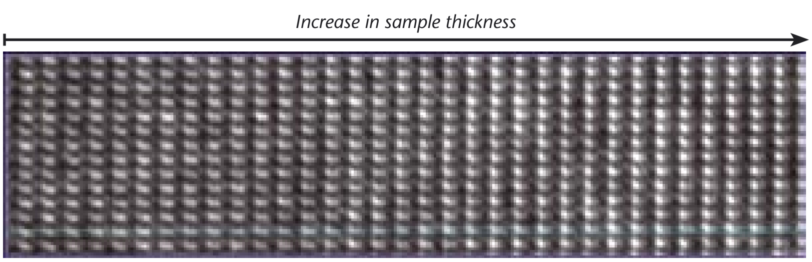
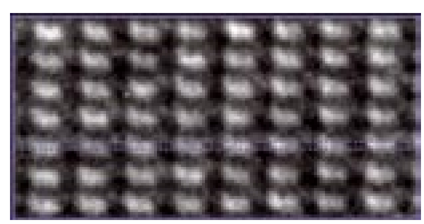
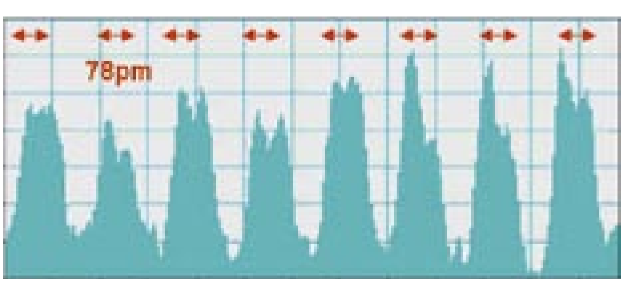


Image: R. Erni, B. Freitag (FEI).

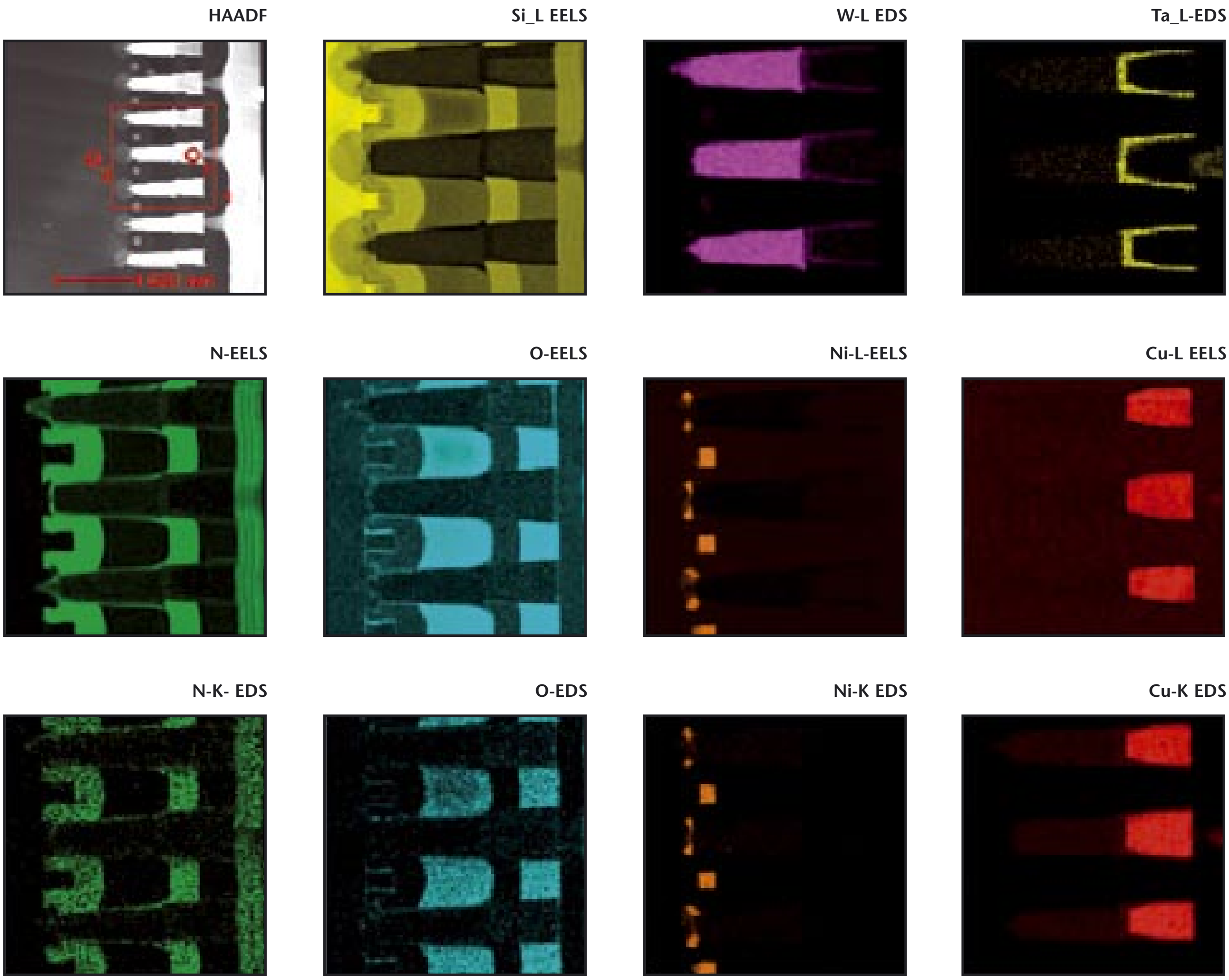


t = 5 nm; f = -250 nm.



Dumbbell distance in Si <112> is 78 pm.

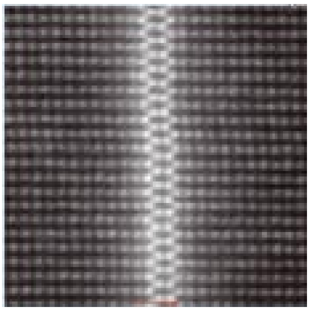
Titan 80-300

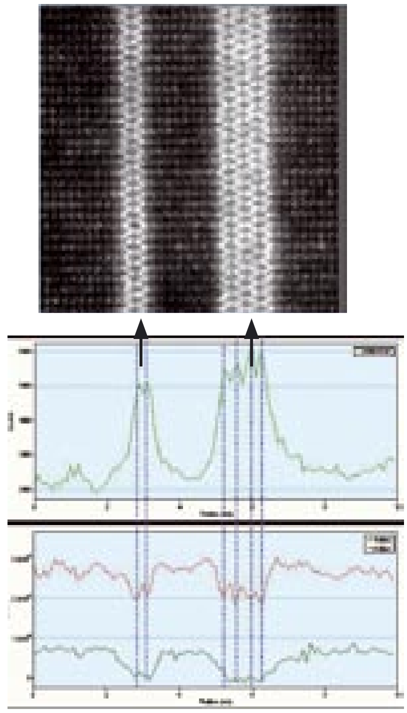


Simultaneous EDS and EELS map on IC device at 300 kV.
Spectrum image: 150 x 150 pixels.
Exposure time: 0.15 s per pixel.
Probe size: 1 nm.

Titan 80-300

HAADF STEM and EELS line-scan on precipitates in TiB_2-WB

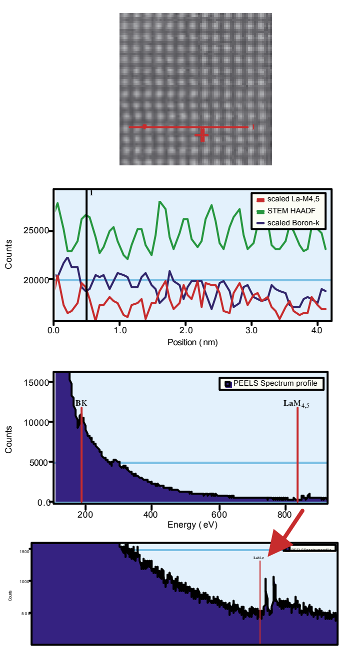


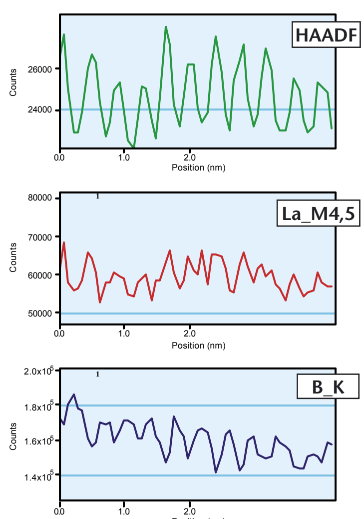


Parameters:
EELS line-scan of 100 pixel on 10 nm length.
Exposure time: 2 s per pixel.
Probe size: 0.3 nm.
Two and four missing boron layers in WB precipitates can be detected in EELS line profile.
Distance between the layers is ~0.4 nm.

Image: B. Freitag (FEI).

Atomic resolution HAADF STEM and EELS line-scan on LaB_6



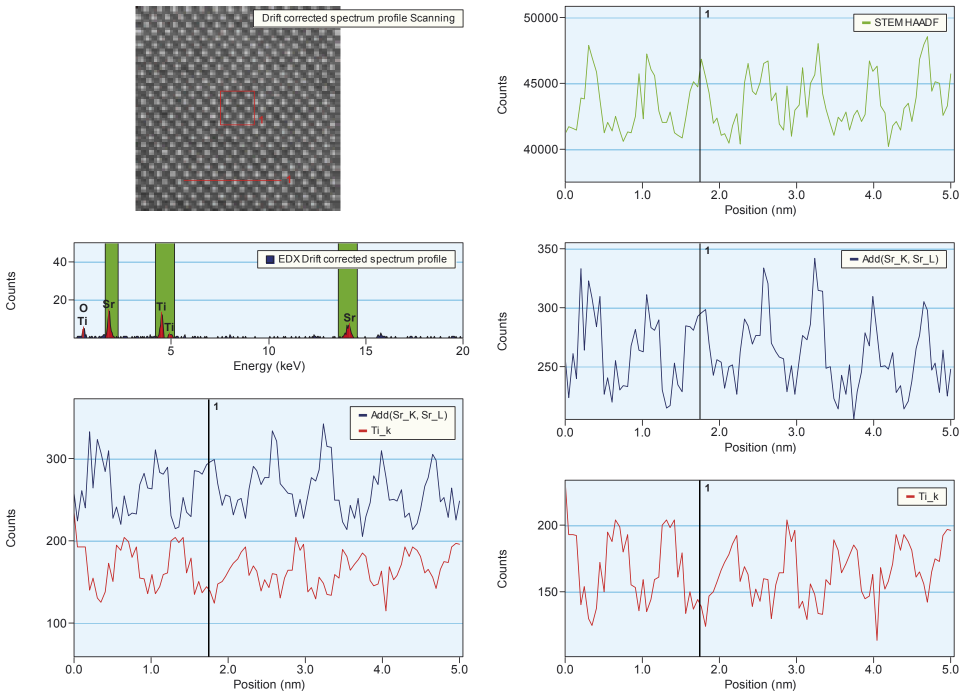


EELS signal of La-M,4,5 above 800 eV energy loss can be acquired with a 0.3 nm probe.

Parameters:
HR-STEM image with EELS line-scan of 150 pixel on 4 nm length.
Exposure time: 2 s per pixel.
Probe size: 0.3 nm.
The unit cell distance of ~415 pm can be resolvedin B and La signal.
An intensity modulation in the La_M4,5 edge is following the Z-contrast signal nicely.

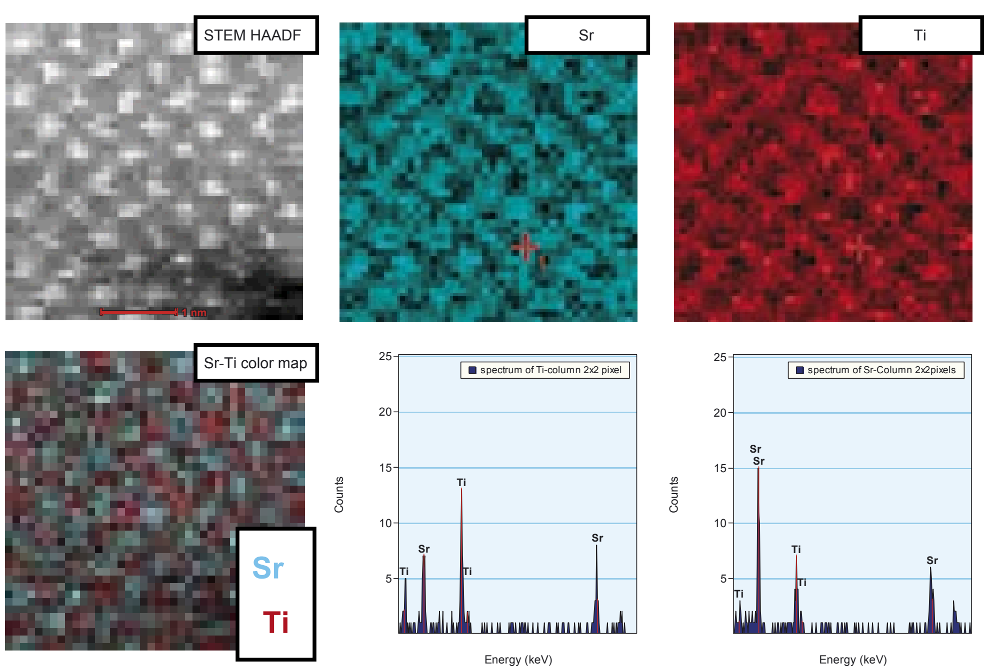
Titan 80-300

HAADF STEM image and EDS line-scan on $SrTiO_3$



EDS and HAADF signal has been acquired at the same time. Drift correction using cross correlation methods has been used on the marked red square. The red line indicates the profile position in the HAADF image.

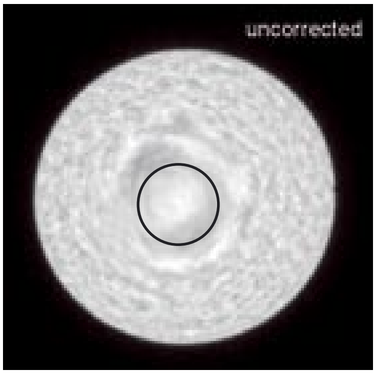
HAADF STEM image and EDS map on $SrTiO_3$

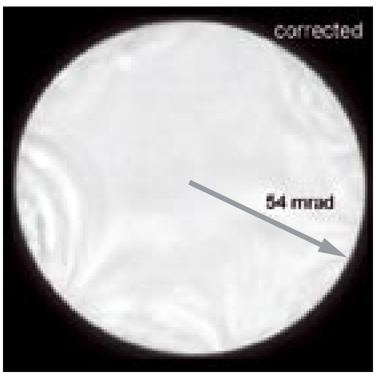


Direct imaging of the Sr and Ti sub-lattice with EDS in $SrTiO_3$ in <100> direction. EDS and HAADF signal has been acquired at the same time. Drift correction using cross correlation methods has been used on the marked red square. The spectra shown indicate the EDS signal at the Sr and Ti position of the lattice. The color map shows clearly the sub-lattice of Sr and Ti in the unit cell.

Titan with probe C_S-corrector

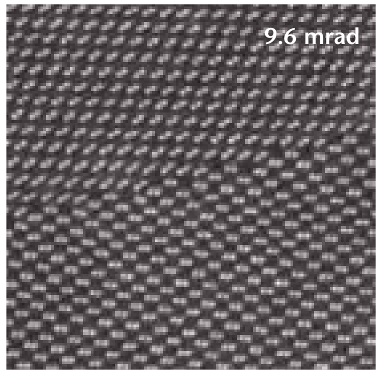
Ronchigram on amorphous material





Ronchigram on amorphous Ge: "flat" area shows a radius of ~30 mrad.

HAADF STEM on silicon 110



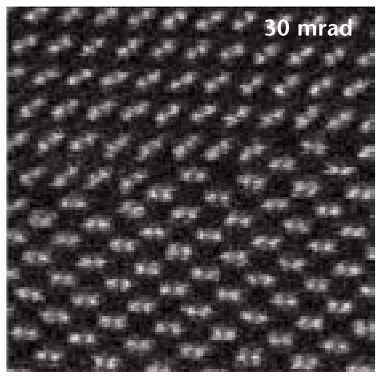
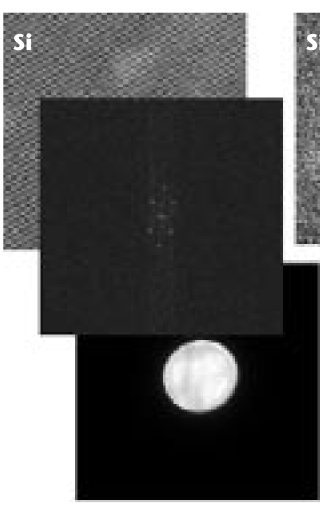


Image: R. Erni (FEI) and P. Hartel (CEOS).

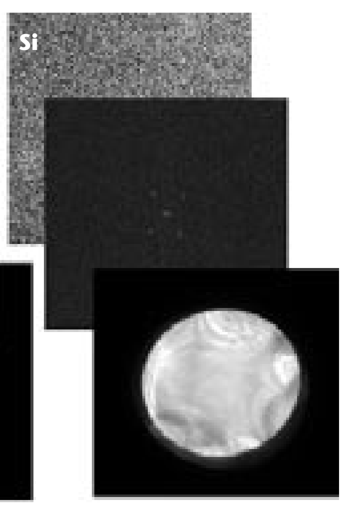
Probe current performance

Normal



Opening half angle 27 mrad.
Current: 300 pA.
Size: 2A in FT and image.

Ultimate



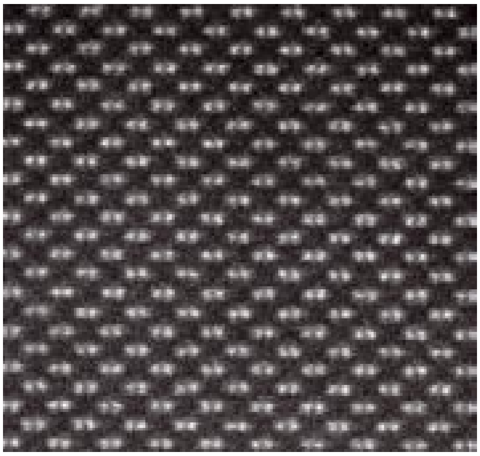
Opening half angle 58 mrad.
Current: > 600 pA.
Size: 2A in FT and image.

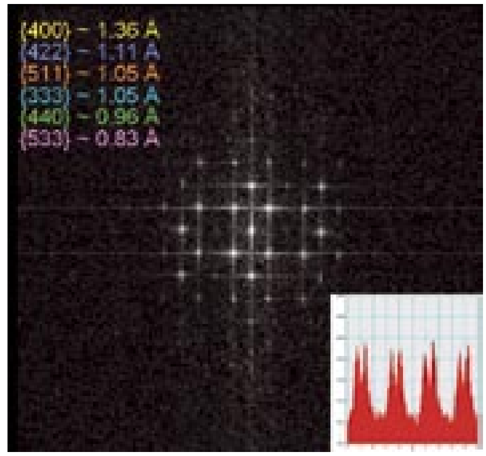
Probe current at 200 & 300 kV:

200 kV 0.2 nm	Normal	> 150 pA
	Ultimate	> 400 pA
300 kV 0.2 nm	Normal	> 300 pA
	Ultimate	> 600 pA

Titan with probe C_S-corrector

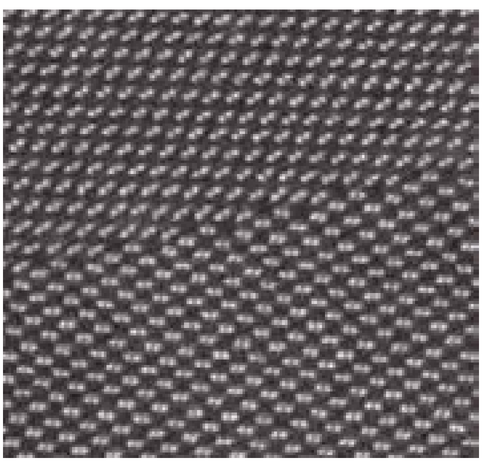
HAADF-STEM resolution on silicon <110>

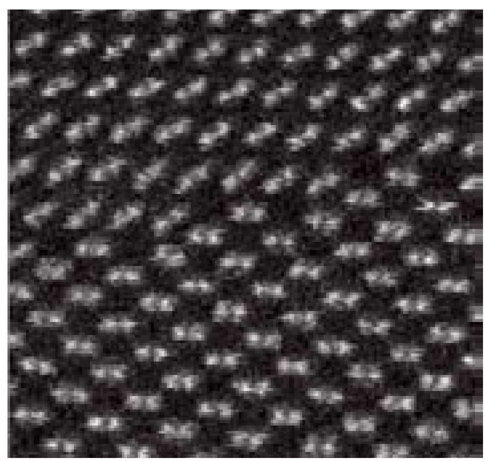




Images: R. Erni, H. v. Lin, M. v.d. Stam (FEI) and P. Hartel (CEOS).
Sample courtesy of: C. Kisielowski (NCEM).

HR-STEM imaging on silicon grain boundary at 300 kV

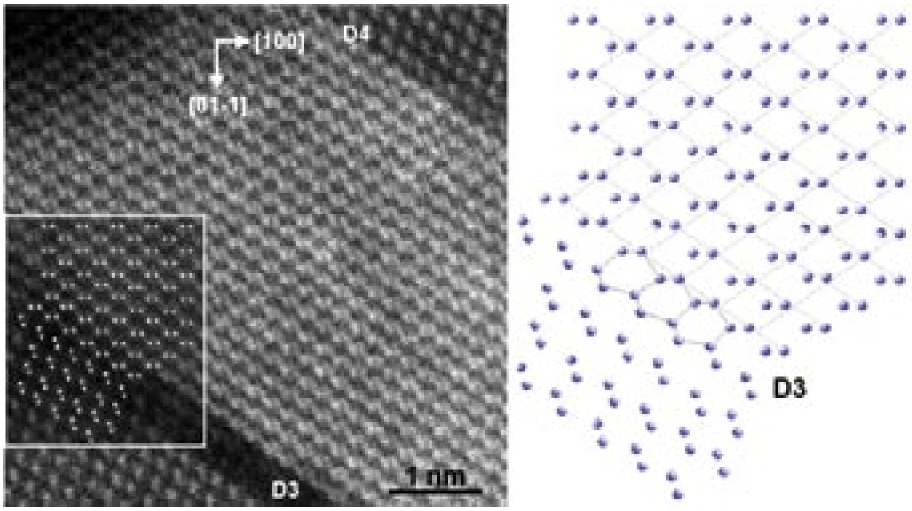




Images: R. Erni, B. Freitag (FEI).
Sample courtesy of: J. Thibault, Marseille.

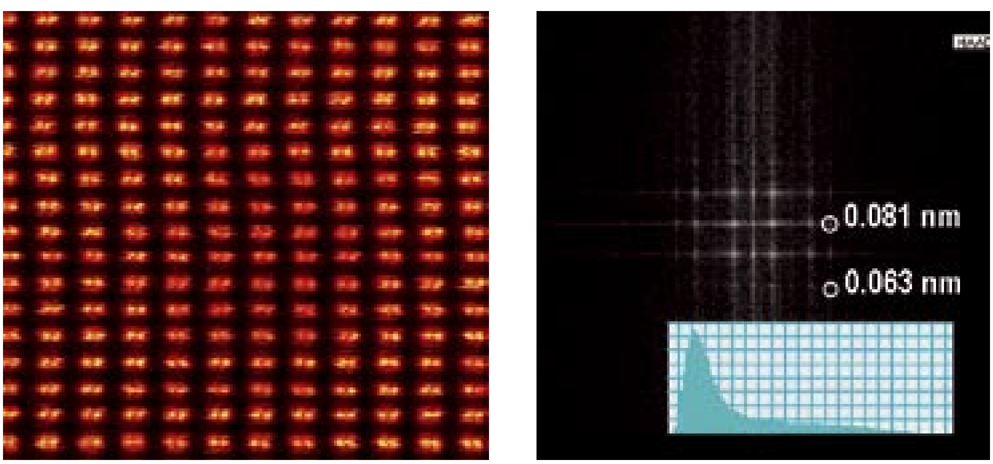
Titan with probe C_S-corrector

HAADF-STEM on diamond <110> dumbbell structure of 89 pm



The atomic structure of the defect line D3 as determined from the micrograph is overlaid and separately shown on the right. The defect line D3 does not show the ideal symmetry of a S3 CSL twin boundary.

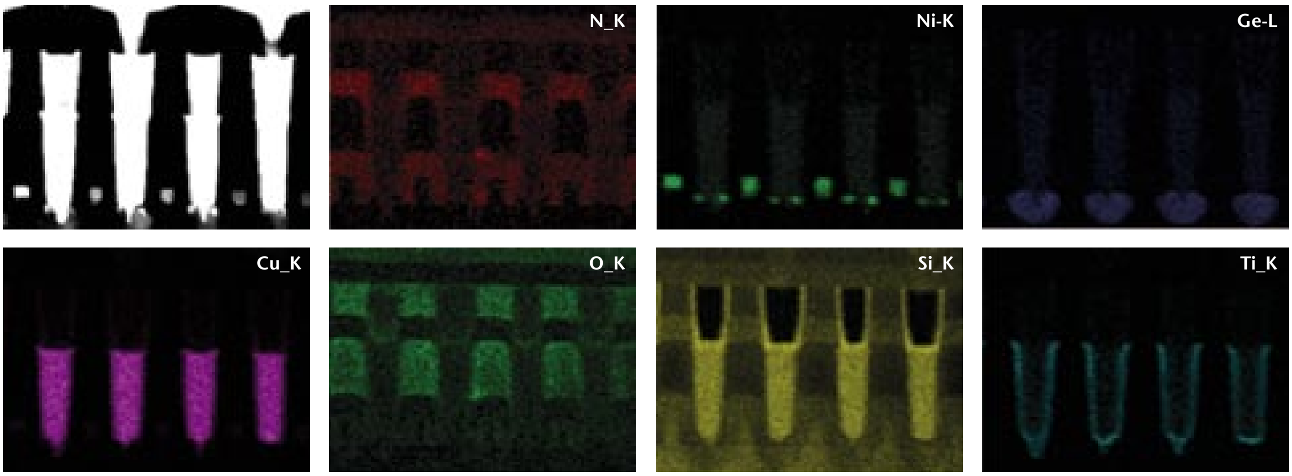
HAADF-STEM on Ge<112> dumbbell structure of 81 pm



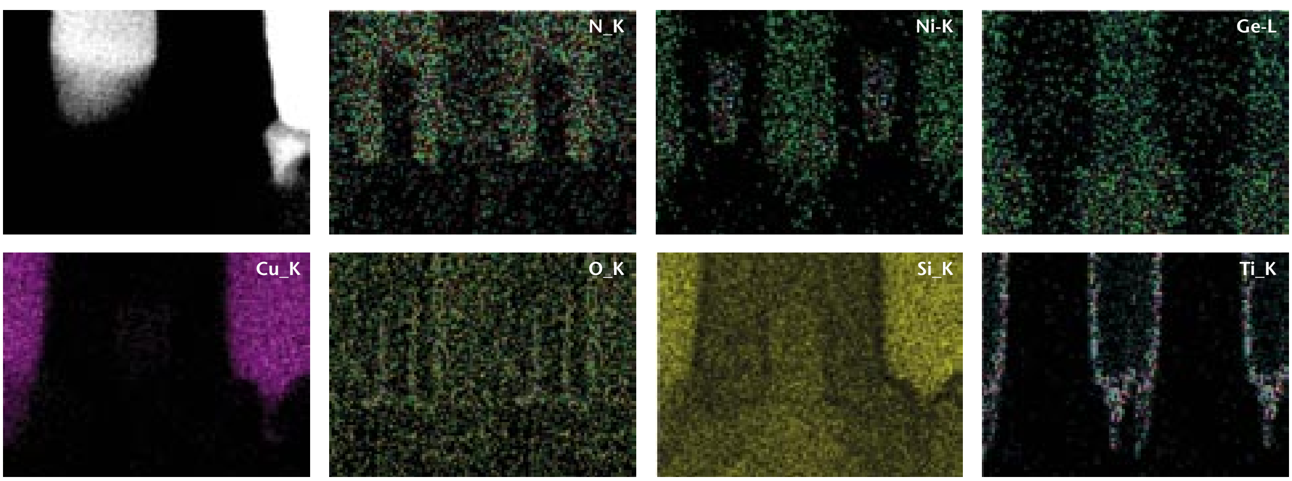
Ge 112: acquisition time 20 s, frame size 512 × 512 pixels; FFT shows up to 0.63-Å resolution.
Histograms confirms that the signal is not clipped (probe semi-angle 25 mrad).
Image: S. Lopatin (FEI).
Sample courtesy of: K. Urban ER-C (Juelich Germany).

EDS - Fast mapping

Fast-EDS maps on IC-device using EDS spectroscopy in combination with a probe C_s-corrector



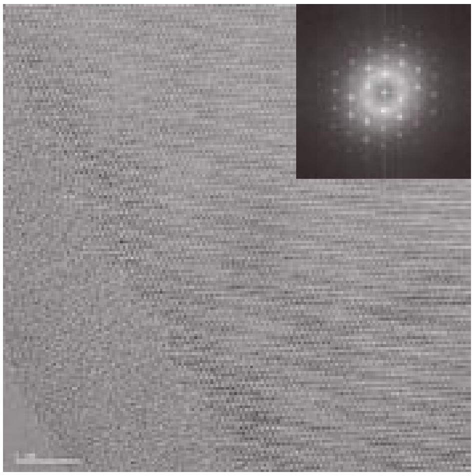
EDS map with 3 nA probe current 256 x 200 pixel, 0.2 ms per pixel 64 times -> 11 minutes. *Images: B. Freitag (FEI)*

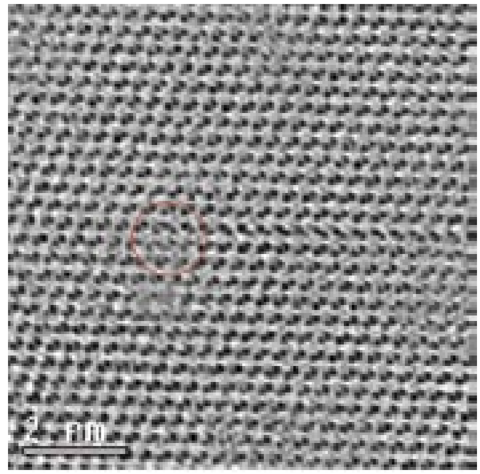


EDS-map with 3 nA probe current 128 x 100 pixel, 0.2 ms per pixel 32 times -> 1½ minutes. *Images: B. Freitag (FEI)*

Titan with image C_S-corrector

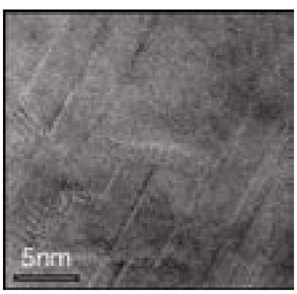
HR-TEM imaging on defects in: GaAs <110> at 300 kV

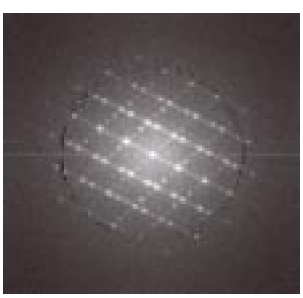


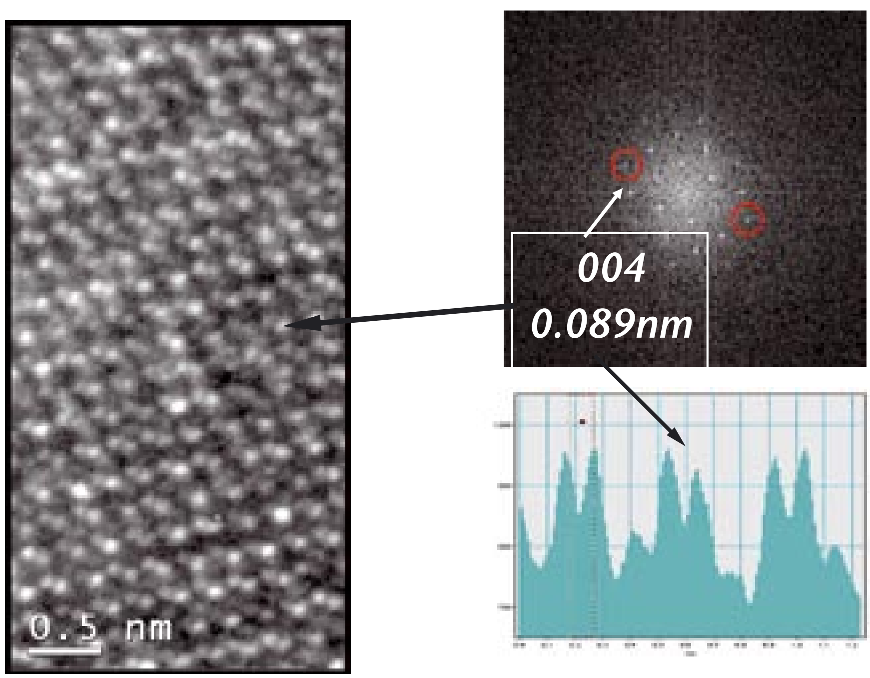


Images: B. Freitag (FEI)

Sub-Ångström resolution HR-TEM on Twins in Diamond <110>





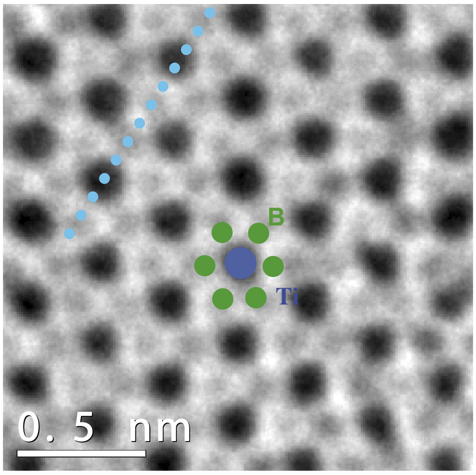


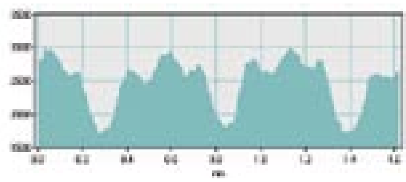
The dumbbell distance of 89 pm can be resolved.

Images: B. Freitag (FEI)

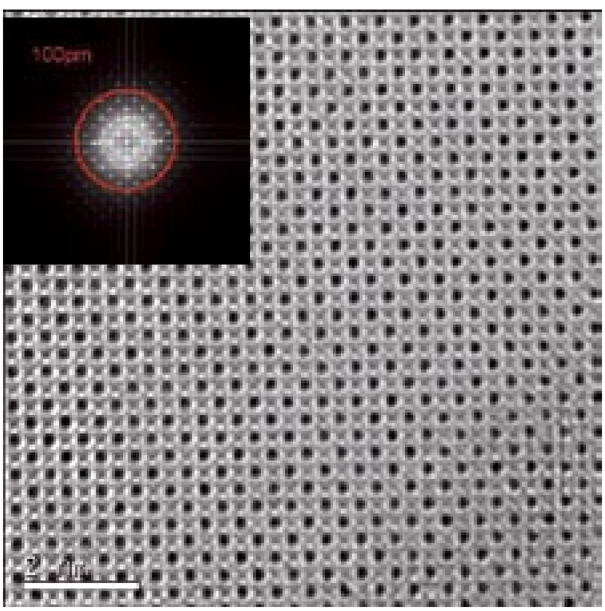
Titan with image C_S-corrector

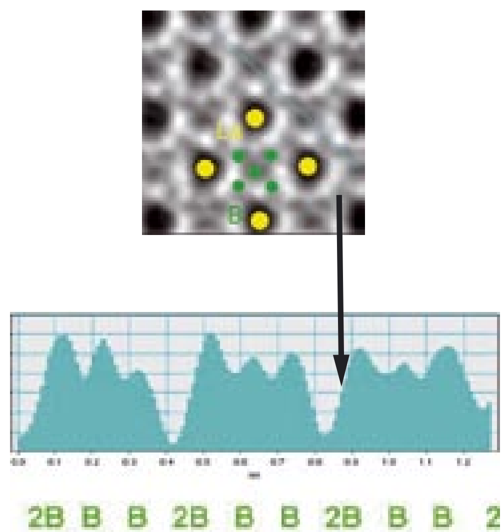
Direct imaging of boron atoms in the [0001] zone axis of TiB_2





High sensitivity HR-TEM imaging of boron lattice in LaB_6

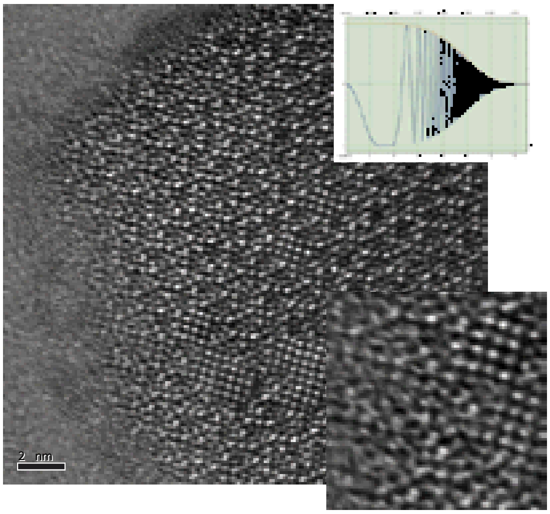




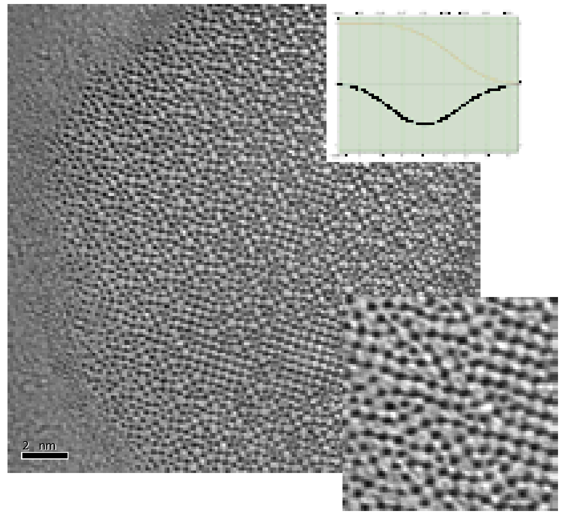
Direct imaging of boron atoms in the [001] zone axis of LaB_6. Boron distance of ~120 pm can be resolved. A contrast difference between differently occupied boron columns (single and double in unit cell) is noticeable.

Titan with image C_S-corrector

Non C_S-corrected HR-TEM



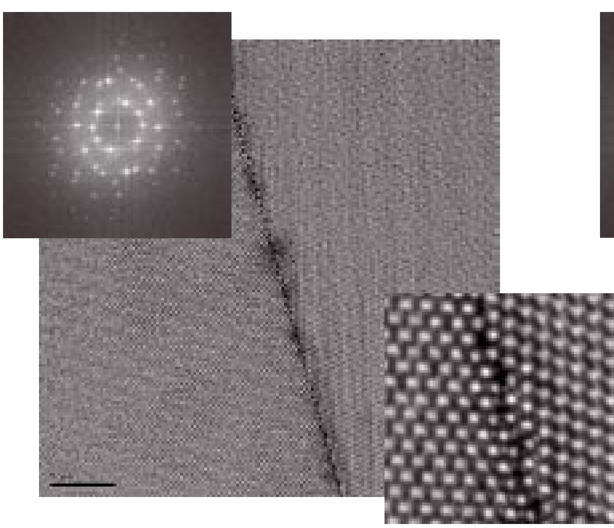
C_S corrected HR-TEM

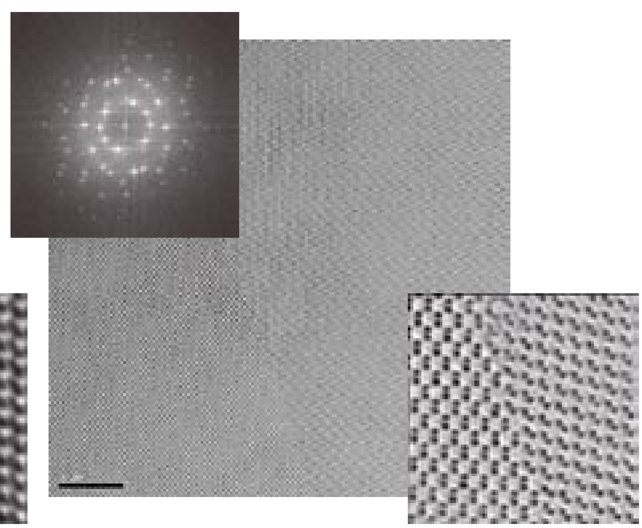


Comparison of HR-TEM images on the same area of $Nb_7W_{10}O_{47.5}$ at 300 kV.
The determination of the atomic position in the corrected images is easier, because every atomic distance is transferred with the same contrast (see the contrast transfer function).

Image: B. Freitag (FEI)

Non C_S-corrected

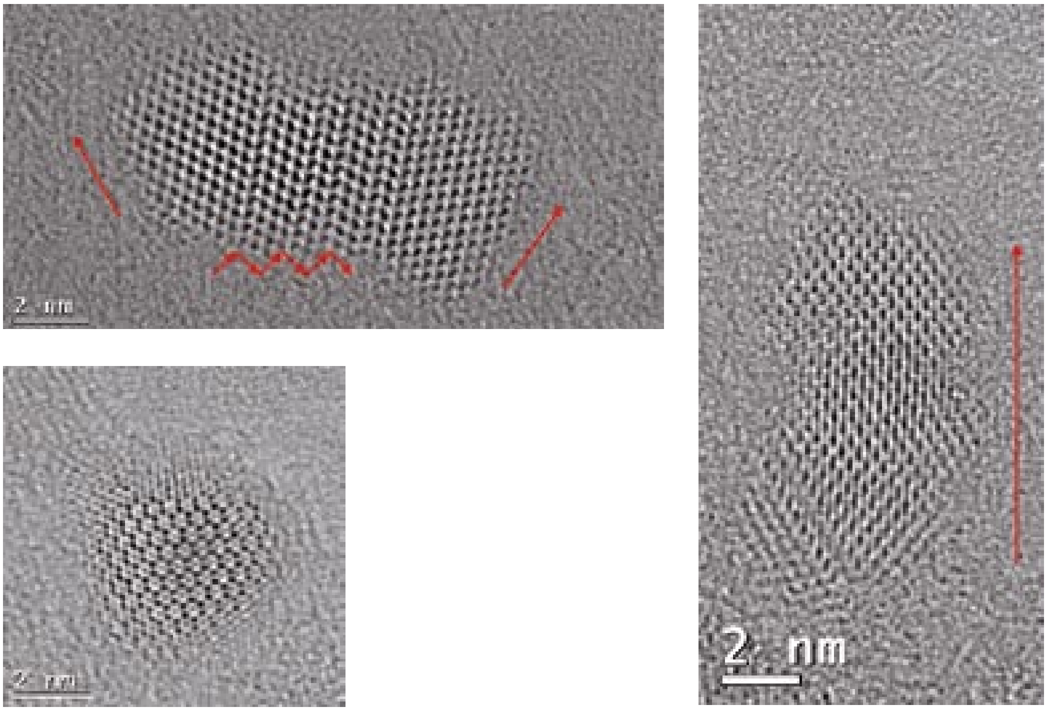




Comparison of HR-TEMs with and without C_S-correction on the same Si<110> grain boundary at 300 kV.
Images: B. Freitag (FEI).
Sample courtesy of: J. Thibault, Marseille.

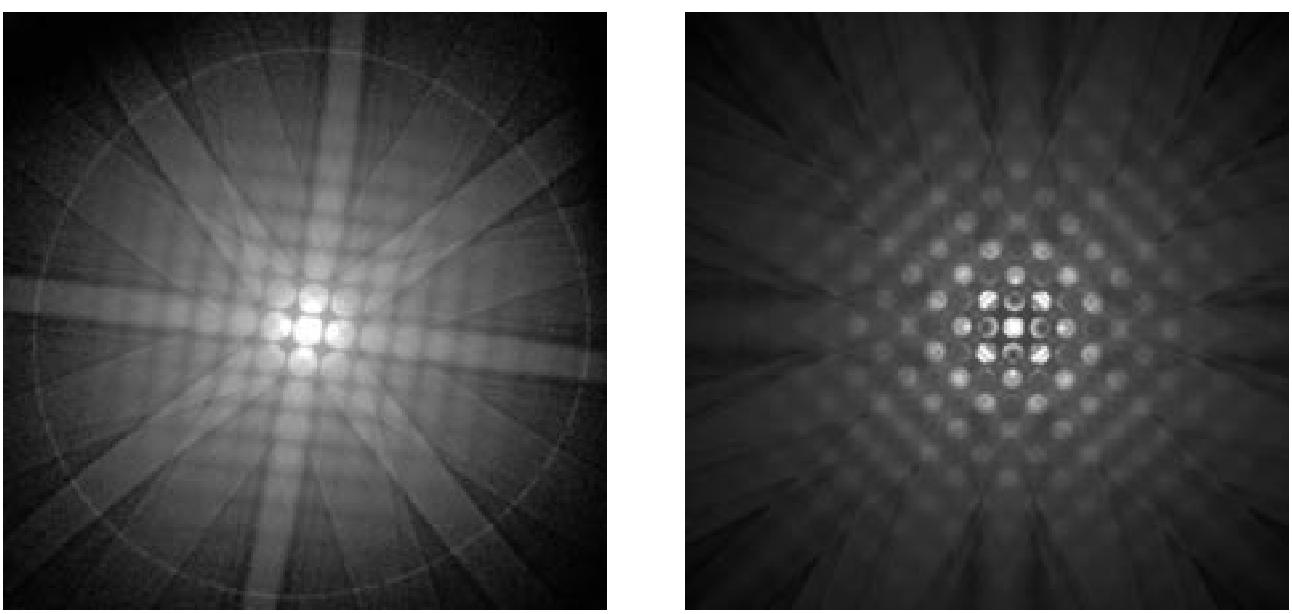
Titan with image C_S-corrector

The dumbbell structure of CdTe can be resolved in the nano-particles



Different morphology indicating different growth processes of the particles.
Image: B. Freitag (FEI).
Sample courtesy of: Prof. Weller (University Hamburg Germany).

Energy filtered convergent beam diffraction

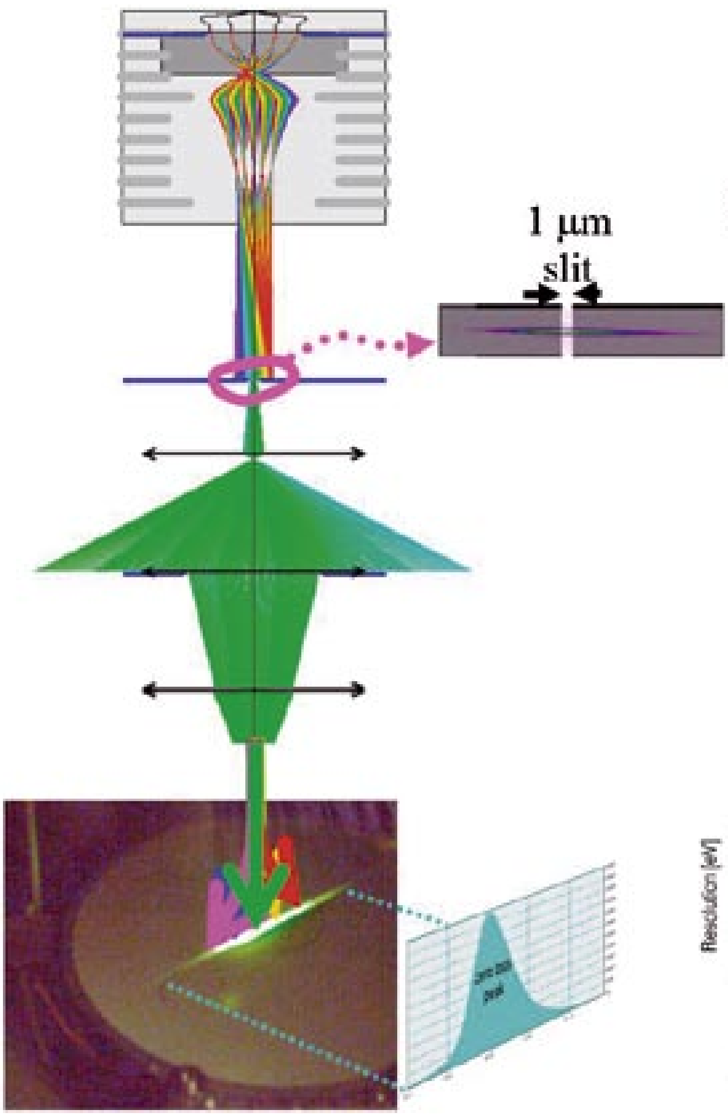


Energy filtered convergent beam diffraction.
Energy filtered CBED pattern of silicon [100] (left) and $SrTiO_3$ [100] (right).
Energy selecting window: 10 eV.

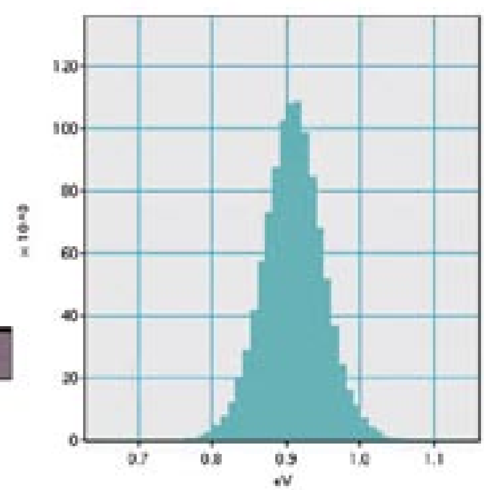
Images: B. Freitag (FEI)

Titan with monochromator

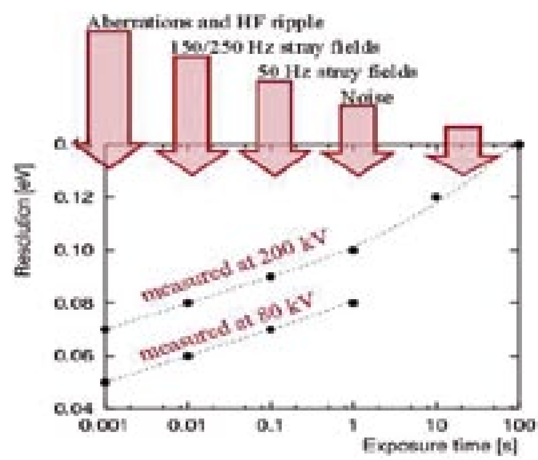
Optics



Zero-loss



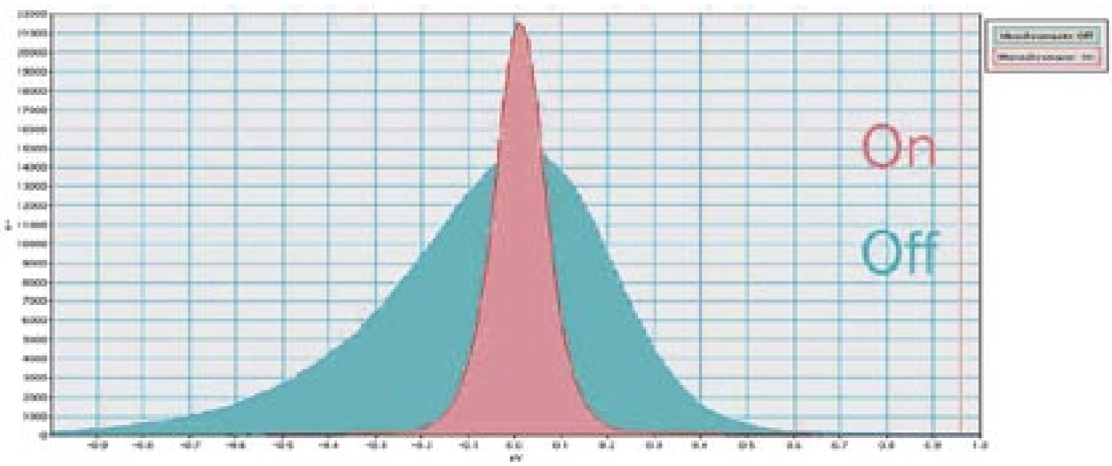
Stabilty



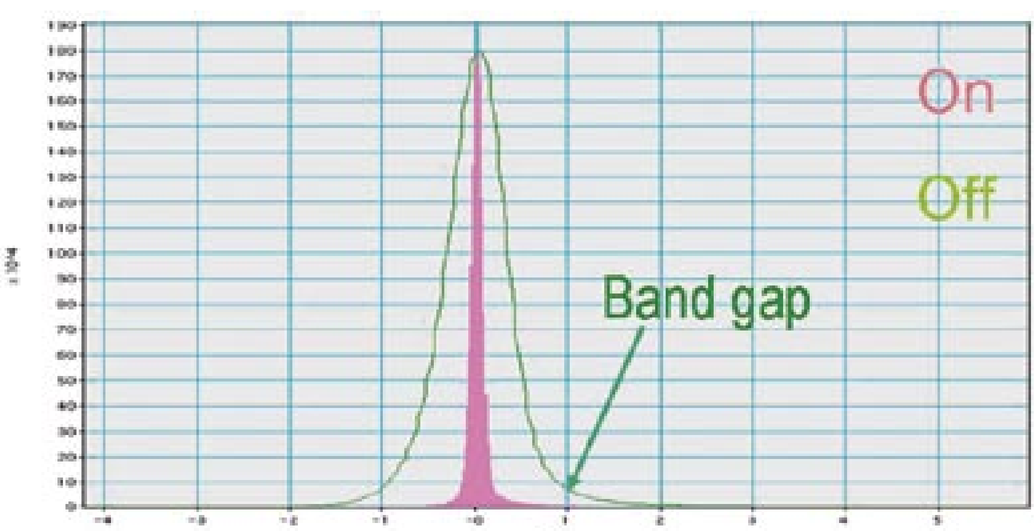
Ultra stable Wien-filter type monochromator with energy resolution < 0.2 eV.

Titan with monochromator

Zero loss measurements monochromator On/Off @300 kV



Energy resolution @ 300 kV using FEI monochromator with Gatan Tridiem 866.
Monochromator On 0.14 eV @ 1.0 s.
Monochromator Off 0.51 eV @ 1.0 s.

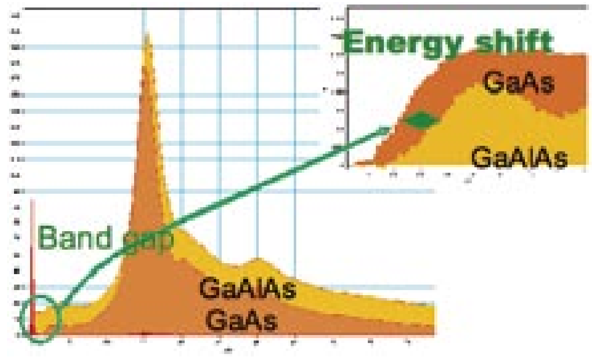


The long tail of the zero-loss reaches into the area of the band gap energy and increases the background in the area. The monochromator reduces the background dramatically in the area of the band-gap energies (1 - 3 eV).

Titan with monochromator

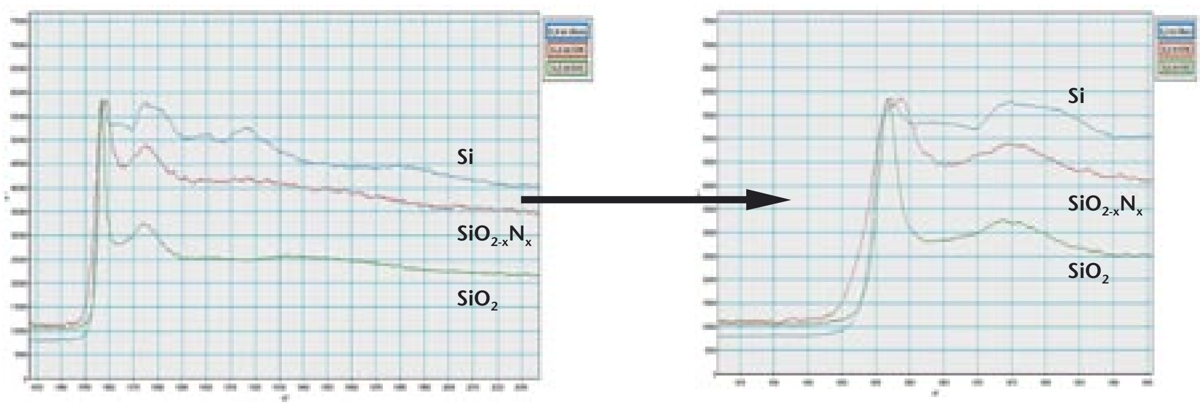
Band gap measurement on GaAs-GaAlAs multilayer

HR-STEM image of GaAs-GaAlAs multilayer.



Shift in band gap energy and plasmon loss due to Al-dopant can be measured.

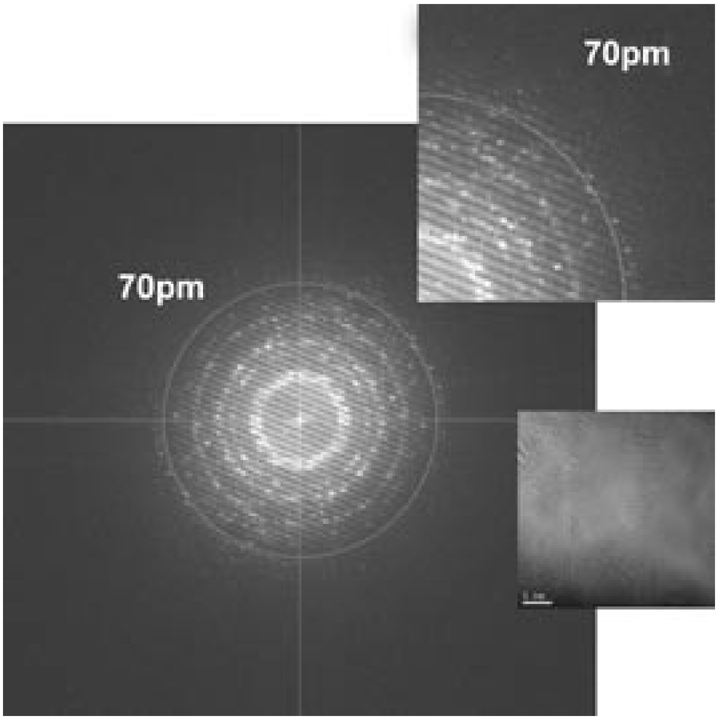
ELNES mesurements of different silicon compounds



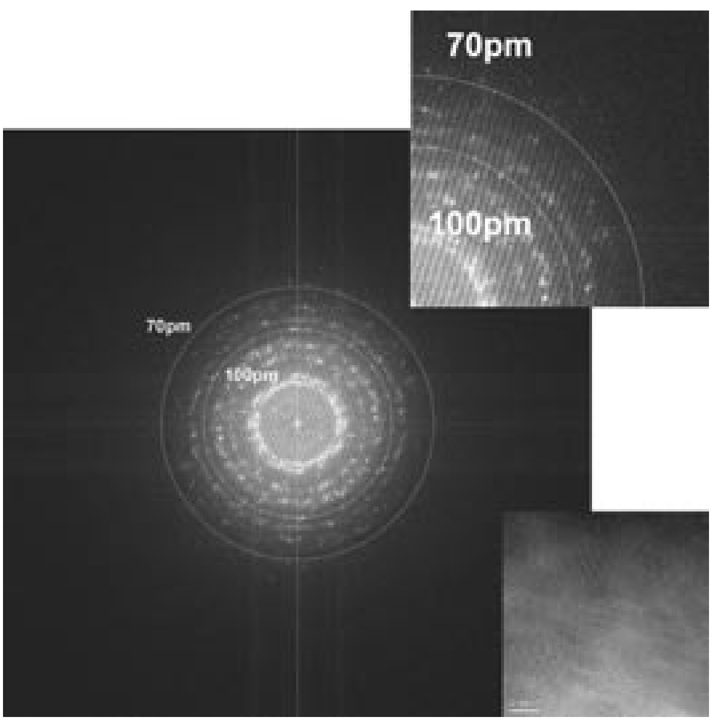
ELNES of silicon-k edge (DE = 1860 eV) in Si, SiO_2 and SiON.
Monochromator On mode with an exposure time 8 s per spectrum.

Titan with monochromator and image C_s-corrector

HR-TEM



Mono On & C_s-corrector On.



Mono Off & C_s-corrector On. Sub-Ångström Young fringe experiment on gold cross grating on a monochromized corrected Titan at 300 kV.

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