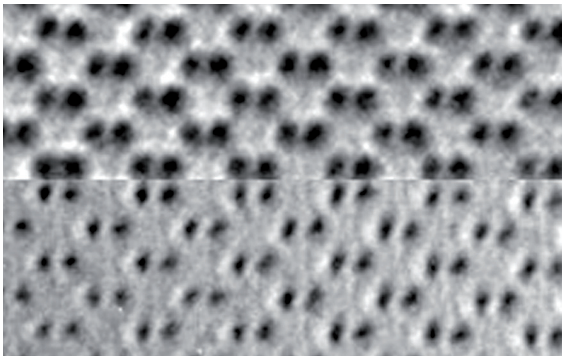
Application Note

Application results on Titan™ G2 and Titan^{3}™ G2 60-300

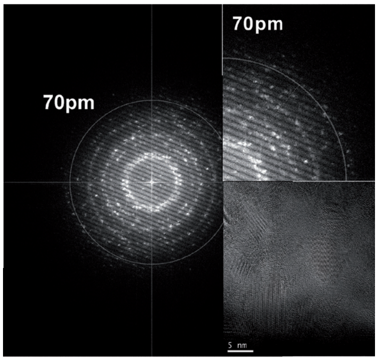
The power of high tension flexibility with C_s-correction and X-FEG in materials science

Key highlights

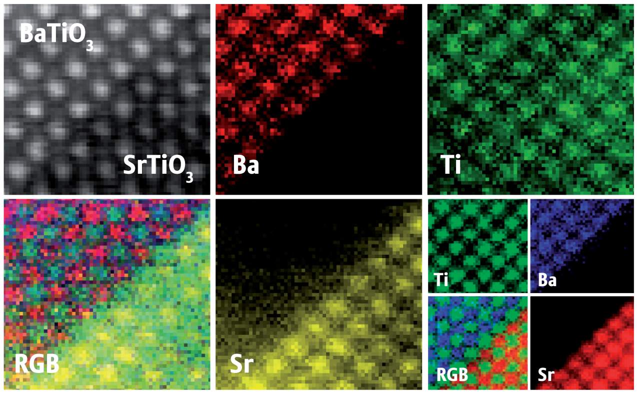
- The probe and image C_s-correction on Titan™ G2 enables deep sub-Ångström imaging performance to maximize your lateral resolution and your sensitivity for single atoms
- The X-FEG electron gun technology provides high coherence and high brightness in combination with stable emission to maximize your probe currents in analytical applications and your coherence in HR-TEM and holography applications
- The high tension flexibility (60 to 300 kV) allows you to optimize the voltage to the requirement of the experiment and material. At the highest acceleration voltage the lateral resolution and penetration power on thicker or denser materials is maximized, while at the lower voltages the chemical signal on ultra thin samples is maximized
- The Titan G2 platform provides a unique stability for your experiments with its constant power lenses for ultimate thermal stability during mode switches, low hysterics design to minimize cross-talk between lenses for high reproducibility of alignments and the large column diameter to minimize vibrations in the column
- The new 3 condenser lens illumination system indicates quantitatively the convergence angle and size of the illuminated area and gives a measure of the electron dose to reproduce experimental conditions with high accuracy and for better quantitative simulations
- The electron gun monochromator provides high probe currents with high energy resolution for bonding state and band gap measurements in EELS and an improved lateral resolution at low kV HR-S/TEM imaging (80 kV and below)



C_s-corrected HR-TEM image on Ge 110 at 300 kV acceleration voltage.
(upper image without monochromator dE = 0.7 eV).
(lower image with X-FEG monochromator dE < 0.2 eV).



Young's fringe experiment on gold X-grating at 300 kV showing 70 pm information transfer.



Atomic resolution STEM/EELS map on $BaTiO_3/SrTiO_3$ interface at 80 and 200 kV acceleration voltage.
Ba, Ti, and Sr map using 75 pA, probe current 64 x 64 pixel map with 40 ms/pixel dwell time (200 kV). In the lower right corner a map of 46 x 46 pixels with 30 ms/pixel dwell time using 60 pA, probe current is shown (80 kV).

Atomic resolution STEM/EELS on $BaTiO_3/SrTiO_3$ interface at 80 and 200 kV acceleration voltage

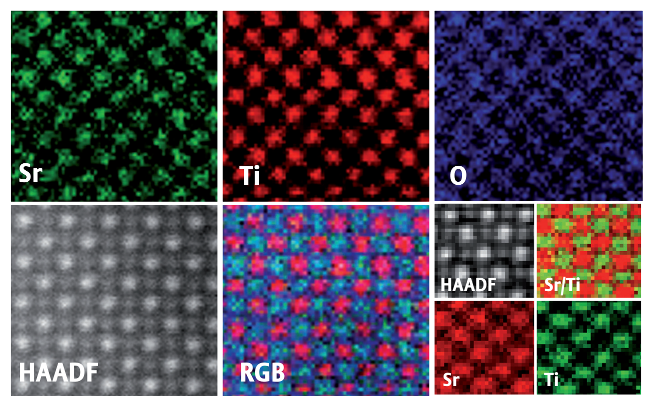
- The atomically sharp interface of $BaTiO_3/SrTiO_3$ shows no intermixing of Ba and Sr at the interface
- No change of the Ti concentration can be detected at the $BaTiO_3/SrTiO_3$ interface and the interface is invisible in the EELS maps of these elements
- The flexible projector system enables ultra-large collection angles in EELS to maximize the EELS signal, so that the dose on the specimen can be minimized to prevent artifacts

Sample courtesy of C.L. Jia, Ernst Ruska Centre, Research Centre Juelich, Germany. Image data courtesy of Prof. Gianluigi Botton and Sorin Lazar, McMasters University, Canada.

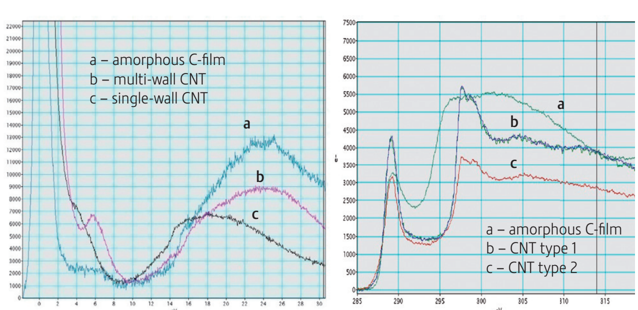
Atomic resolution STEM/EELS on $SrTiO_3$ at 80 and 200 kV acceleration voltage

- Titan G2 provides atomic resolution microscopy with 60 to 300 kV and provides the currents in small probes to acquire chemical maps using EELS with atomic resolution
- The probe C_s-corrector and the X-FEG increase the probe currents in small probes to acquire these maps in minutes to minimize the effect of environmental instabilities
- The high tension flexibility on Titan G2 (60 to 300 kV) allows you to adapt the acceleration voltage to low voltages in STEM/EELS to prevent beam damage (knock-on damage)
- At the highest acceleration voltage the lateral resolution and penetration power on thicker or denser materials is maximized, while at the lower voltages the chemical signal on ultra thin samples is maximized

Image data courtesy of Prof. Gianluigi Botton and Sorin Lazar, McMasters University, Canada.



C_s-corrected STEM/EELS at 80 and 200 kV on $SrTiO_3$.
Sr, Ti, O map using 70 pA probe current, 64 x 64 pixel map with 30 ms/pix dwell time (200 kV).
In the lower right corner a map of 32 x 32 pixels with 30 ms/pix dwell time is shown (80 kV).



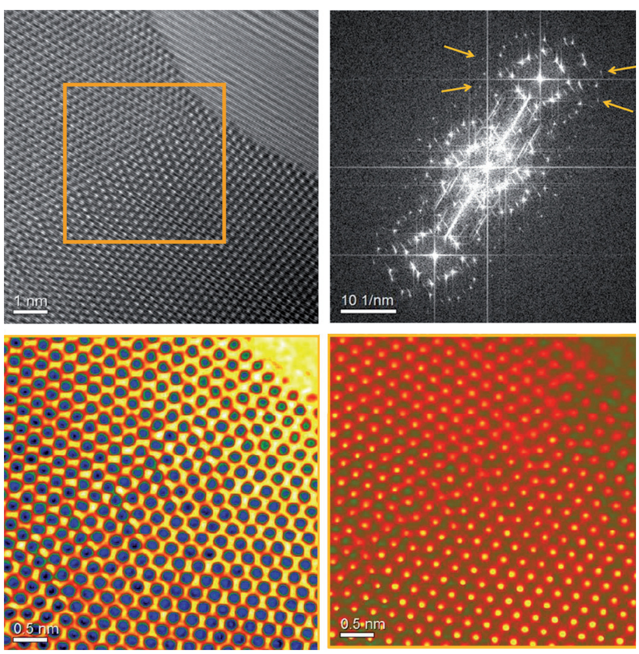
EELS spectroscopy on carbon nanotubes with monochromator at 80 kV acceleration voltage.
Intensity changes in π-peak between SWCNT and MWCNT (left) and energy shift of the Plasmon loss peak in SWCNT. Comparison of ELNES (right) of two differently treated CNT and an amorphous C-film.

EELS spectroscopy on carbon nanotubes with monochromator at 80 kV acceleration voltage

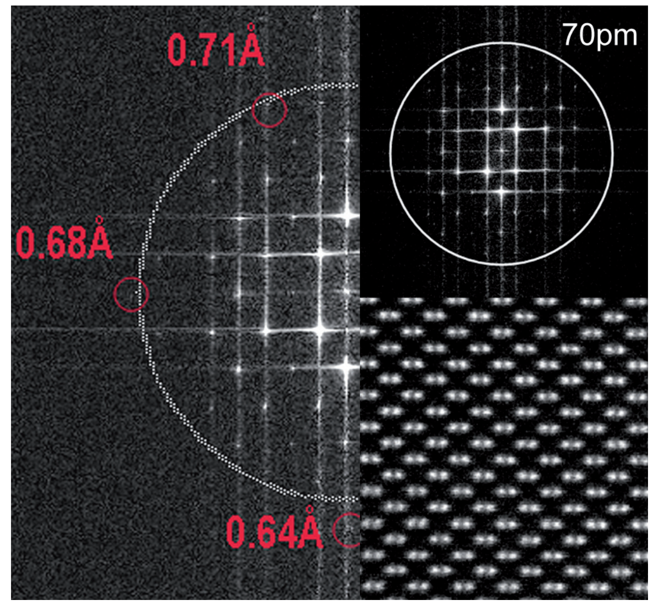
- At low accelerating voltages of 80 kV and below the reduced energy spread of the monochromator enables both high energy resolution EELS spectroscopy and atomic resolution imaging (resolution scales as $\delta E/E_0$, so narrow energy spread is required to maintain atomic resolution at low energy)
- The figures show the benefits of the monochromator in high energy resolution EELS. In the low loss spectrum intensity changes in the π-peak and energy shift of the plasmon loss peak are seen between SWCNT and MWCNT
- The monochromator enables changes to be seen in ELNES measurements of two differently treated CNT versus an amorphous C-film

Atomic resolution off axis holography on gold grain boundary

- The pictures show an atomic resolution off axis hologram and its reconstruction on a large angle grain boundary of gold in [110] direction
- The maximum acceleration voltage of 300 kV enables the highest penetration power on materials of heavy elements like gold
- Image C_s-correction makes the image directly interpretable and minimizes the delocalization effects in the image
- The X-FEG delivers the best coherence and highest brightness, which is determining the phase sensitivity in holography



In the upper part, the original hologram with interference fringes of 54 pm (left) is displayed and the corresponding Fourier spectrum (right) reveals the centerband and the two sidebands. The arrows mark {313}-reflections, which are related to a lattice plane spacing of 0.094 nm.
In the lower part, the reconstructed and corrected object exit wave in amplitude (left, display range (0..1.4)) and phase (right, display range 0..2 π) showing quantitative information on both the position and weight of atomic columns.
Courtesy of Prof. M. Lehmann, M. Linck,
Dr T. Niermann of TU Berlin, Germany, Prof. Hannes Lichte of TU Dresden, Germany, and Dr B. Freitag of FEI Company, The Netherlands.



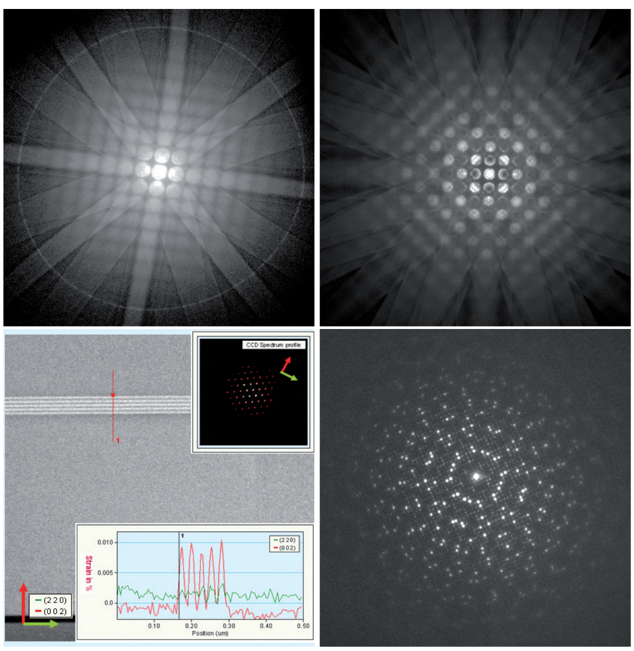
HR-STEM image on probe C_s-corrected Titan^3 G2 60-300 on silicon in 110 directions at 300 kV acceleration voltage. The lower right part shows the HAADF STEM image. The upper left part shows the Fourier transformed with a 70 pm circle. In the insert on the left a magnified part of the Fourier transformed is shown. The Fourier components in all directions with a transfer below 70 pm are marked with red circles.

HAADF STEM imaging on Silicon <110> at 300 kV acceleration voltage

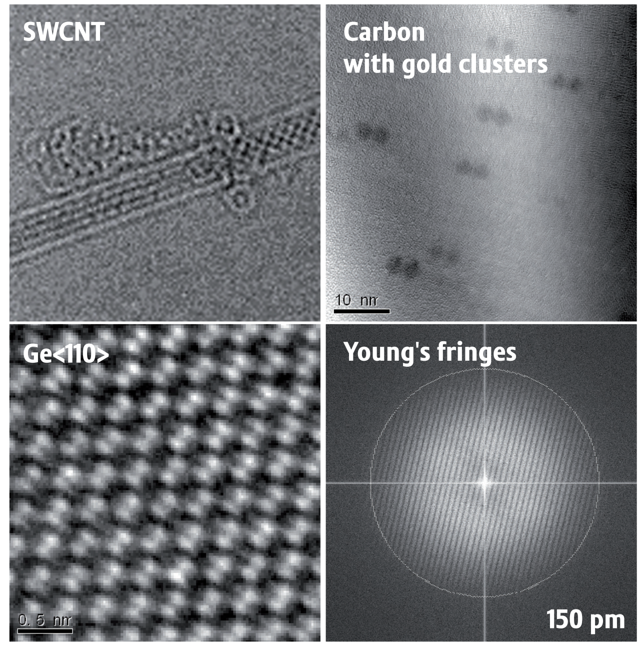
- Titan^{3}™ G2 60-300 provides atomic resolution z-contrast imaging down to 70 pm at 300 kV acceleration voltage
- The HAADF STEM image of the probe C_s-corrected Titan^3 G2 60-300 shows the stability and the optical performance of the platform by showing information transfer below 70 pm
- At 300 kV acceleration voltage the dynamic scattering can be reduced on thicker or denser samples compared to lower voltages due to the higher mean free path of the electrons
- The new 300 kV dodecapole probe C_s-corrector allows for higher opening angles in the illumination system to increase the probe current in small sub-Ångström probes for better S/N in the images and better signals in analytical applications

Energy filtered diffraction at 300 kV acceleration voltage

- The unique EFTEM lens series in combination with a post column filter allows you to optimize the transmission angle in energy filtered diffraction well above 100 mrad half angle, so that a large field of view energy of filtered diffraction patterns can be obtained
- The image C_s-corrector improves the transmissivity of the energy filter to reduce the size of the energy selecting slit (in the example below dE = 5 eV)
- The high tension flexibility on Titan G2 (60 to 300 kV) allows the scattering angle of the material in diffraction to be optimized according to the unit cell dimension and the desired information
- The new quantitative 3 condenser lens illumination system allows from nanometer sized parallel beams for NanoDiffraction in strain analysis measurements in combination with FEI's TrueCrystal strain software package



Zero loss filtered CBED on Si [100] (left) and $SrTiO_3$ [100] (right) at 300 kV acceleration voltage (upper micrographs).
Strain profile in NanoBeam diffraction on SiGe Si multilayers (lower left).
Zero loss filtered NanoBeam diffraction on polycrystalline gold (lower right).



C_s-corrected HR-TEM at 60 kV.
Atomic resolution on SWCNT (upper left corner).
Ge 110 dumbbell HR-TEM image (lower left corner).
Young's fringe experiment on carbon (right side).

Atomic resolution at 60 kV acceleration voltage

- Low voltage S/TEM can prevent beam damage (knock-on damage) on delicate ultra-light materials like graphene and carbon nanotubes
- Titan G2 provides atomic resolution microscopy with 80 and even 60 kV acceleration voltage, when using X-FEG monochromator and C_s-corrector configuration
- The change of acceleration voltage changes the elastic and inelastic scattering power of the material examined. This flexibility allows you to optimize the voltage for the properties of the material, such as thickness, density and beam stability, and the application like imaging S/TEM, analytics, diffraction and holography

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