Slicing Through Thin Samples at Atomic Resolution

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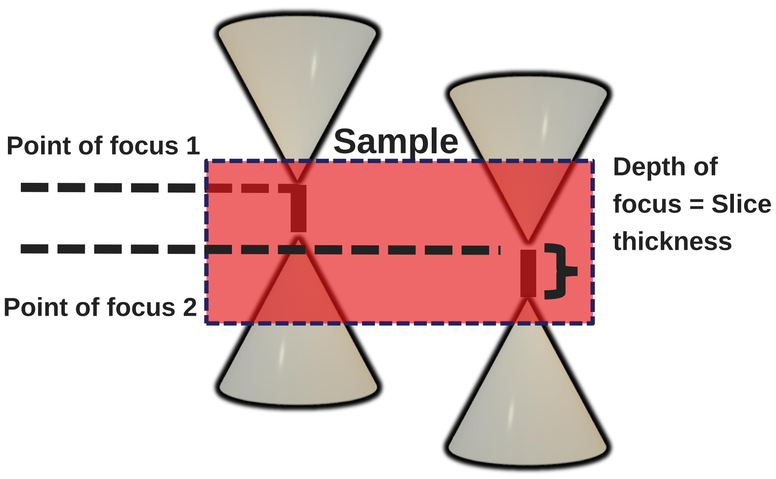
More info about TFS STEM

My details

Abstract: Through focus iDPC* STEM* is introduced as a complimentary method to conventional and analytical (EDS* or EELS*) tomography for recovering 3D information. STEM iDPC images contain information predominantly from a material slice with a thickness equal to the depth of focus. By changing the focus point of the beam via STEM defocus (objective lens excitation), a material can be examined in successive slices throughout its volume. Through focus iDPC presents unique differences and advantages compared to tomography:

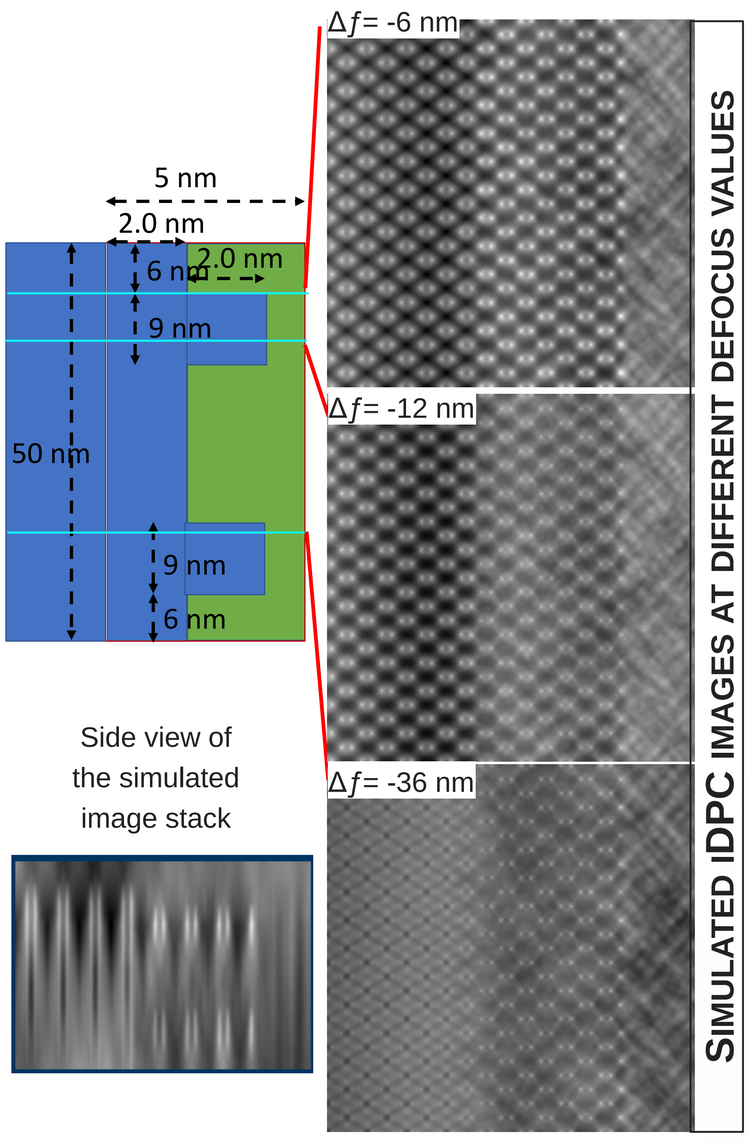
1. Serves smaller volumes – tomography can be used to reconstruct the volume of samples up to 1μm thick. Through focus iDPC is limited to sample thicknesses around 45nm
2. Represents < 3.5nm slices – the depth of focus depends on the HT* used, the beam convergence and the frequency of the information imaged. With a SCORR probe corrector, a Spectra STEM can easily correct the probe at 38mrad convergence at 200 or 300kV HT. The depth of focus then for sub-A frequencies is 3.5nm at 200kV and 2.73nm at 300kV. With adequate number of projections and small pixel size, tomography can lead to reconstructed volumes with 1nm voxels.
3. Atomic resolution in the x-y plane – while tomography typically provides reconstructions with 1nm voxel size, through focus iDPC slice images present the material in sub-Angstrom resolution
4. Significantly less dose – iDPC STEM offers excellent signal to noise ratio and even though the pixel density is much higher, for a 40nm thick sample and a 100nm FoV*, the dose for the iDPC method is 250-1200 time less than EDS tomography (depending on the EDS product**) and about 3 times less than ADF* tomography. It is important to perform metrology in 3D without worrying if the structure elucidated is a damaged version of the initial material
5. Linear Z-contrast to see all elements – iDPC STEM reproduces the potential projection of each slice and therefore offers contrast linear with the atomic number of each column, Z. Therefore, heavy and light elements can be visualised. When very similar materials are imaged in the same slice, the iDPC images offer very little or no contrast at very high convergence angles. However, iDPC STEM is recorded simultaneously with the ADF signal so similar materials can be easily segmented.

Theory and simulation



Schematic diagram of a STEM beam focused at different depths inside the sample. In iDPC and iCOM images, the signal from the slice is much stronger than the signal from the material above and below the slice (total sample thickness <45-50nm) and therefore we can discern the information of each slice. In (HA)ADF STEM, the signal from the slice becomes equal or weaker than the signal from the material above the slice at very shallow depth so TFS ADF STEM is only useful for the very thin specimens or for sample of low Z materials (e.g. a-C).

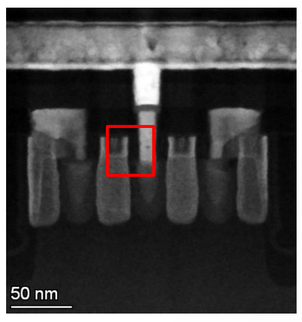
Multi-slice simulation, 300kV, 38mrad convergence

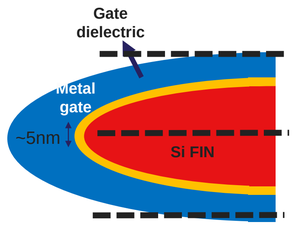


Side view of the simulated image stack

Experiment

FinFET Gate View

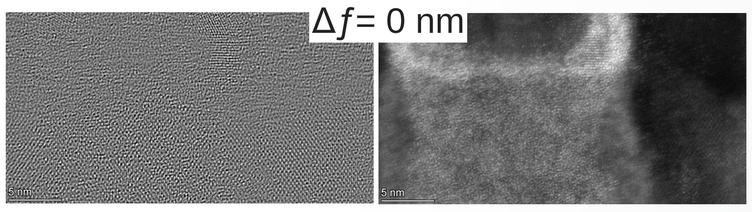




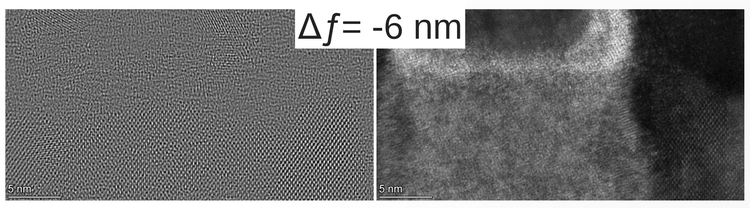
Δf= 0 nm

Δf= -6 nm

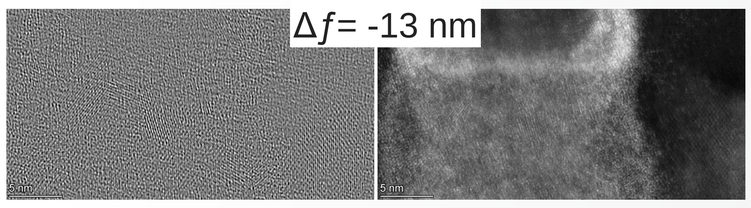
Δf= -13 nm



At zero defocus the beam is scanned just inside the top surface of the sample. Both images depict the polycrystalline metal gate



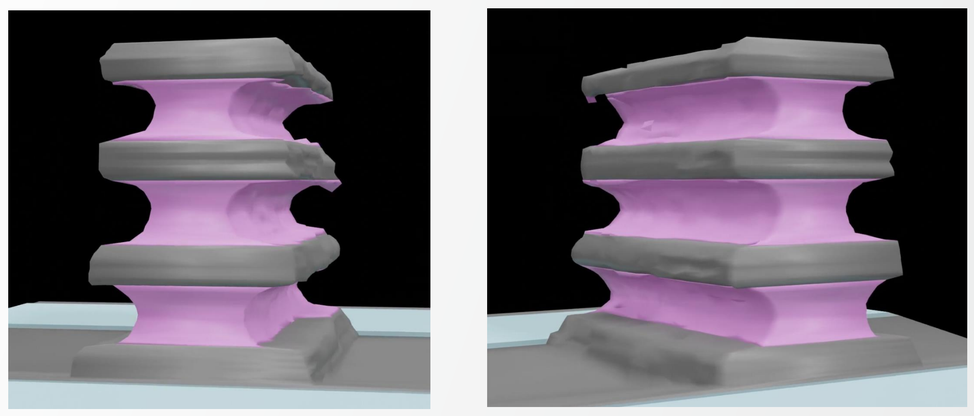
At -6nm defocus the beam is scanned at Si level (see the right-hand side of the HAADF image). However, the HAADF image is dominated by the electron scuttering by the heavy and dense gate metal. The iDPC image carries information mainly from a slice, its top defined by the point where the beam is focused and its thickness by the depth of focus. The unobstructed right-hand side part of Si is images with better resolution than the channel obstructed by the gate metal but Si is nevertheless well imaged across the whole structure.



As the beam is focused deeper inside the sample, the iDPC image depicts the polycrystalline metal gate at the back of the sample.

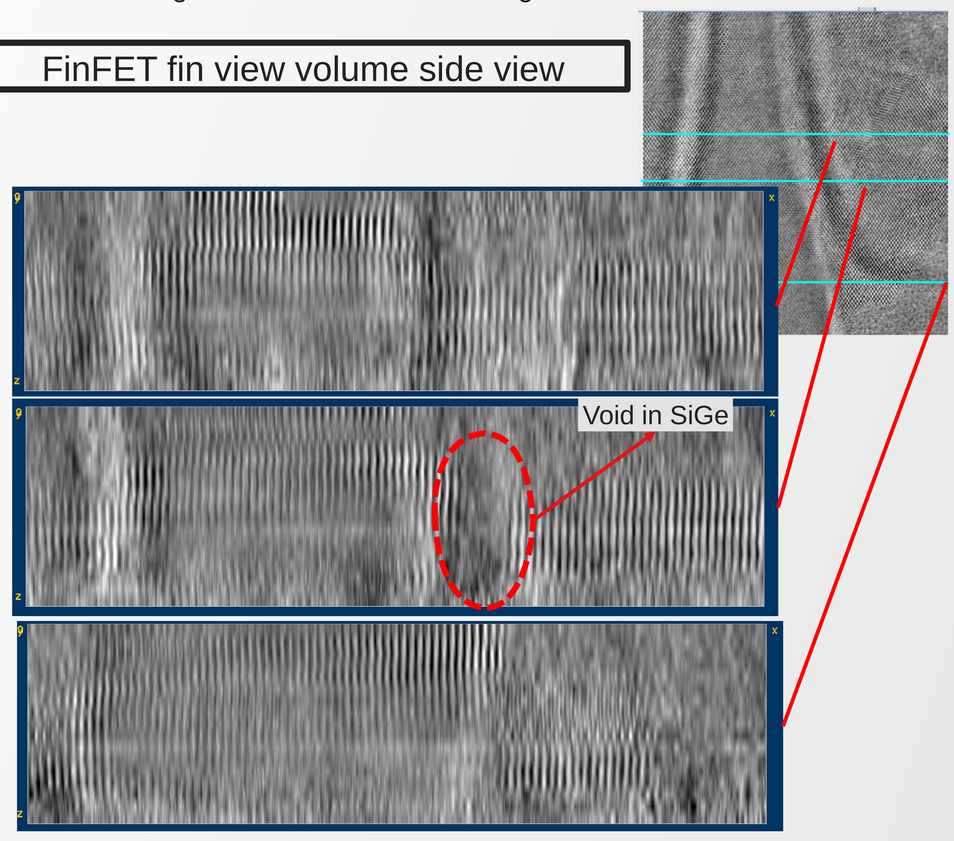
Visualisation and extra info

NW 3D visualisation



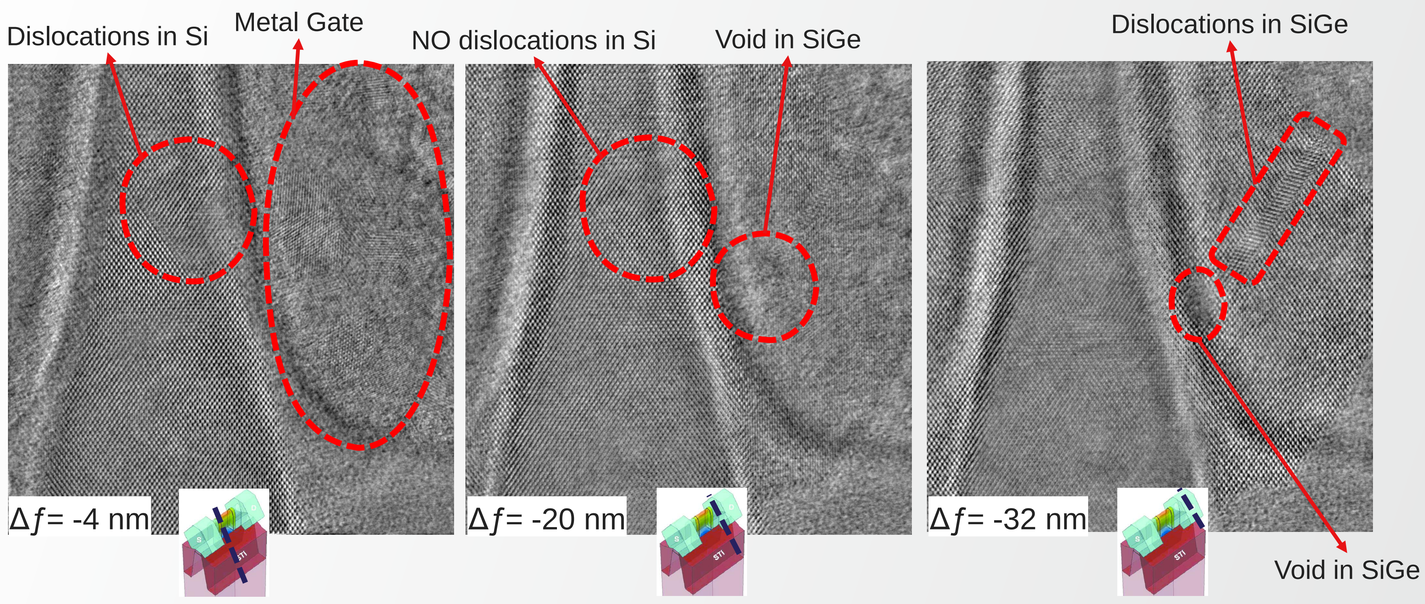
3D visualization of Si-SiGe NWs after “retreat” etch. All measurements were obtained from simultaneous ADF and iDPC STEM TFS data. At high convergence angle, iDPC STEM images offer little contrast between Si and SiGe so ADF images are used for Si-SiGe segmentation.

FinFET fin view volume side view



Experimental details
FinFET gate view: 200kV, 30mrad, 30pA, 4μs dwell, 19.2pm pixel size
FinFET fin view: 300kV, 38mrad, 40pA, 6μs dwell, 9.5pm pixel size

FinFET Fin View



*__Abbreviations:__ iDPC: integrated differential Phase Contrast; STEM: Scanning Transmission Electron Microscopy; EDS: Energy Dispersive Spectroscopy; EELS: Electron Energy Loss Spectroscopy; HT: High Tension; FoV: Field of View; ADF: Annular Dark Field; ** 1200x for Super-X, 600x for Dual-X, 250x for Ultra-X