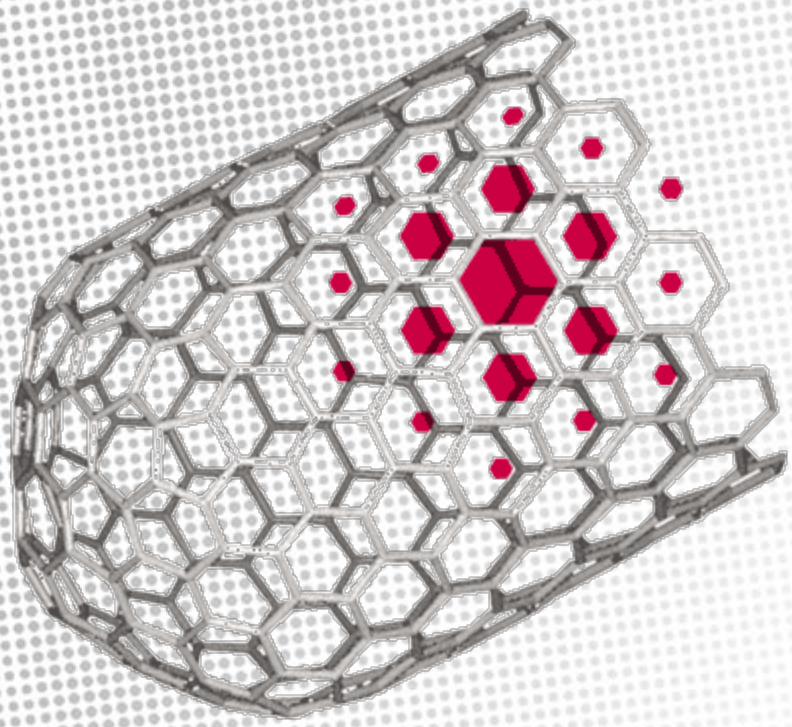


The importance and relevance of advanced electron microscopy in nanotechnology

Dr Debbie Stokes

FEI COMPANY™

TOOLS FOR NANOTECH

Overview

- Advanced electron microscopy and FEI Company
- Role of electron microscopy in nanotechnology
- Specific examples
  - Key challenges in nanotechnology

FEI facilities

Hillsboro, Oregon, USA
Corporate Headquarters
Fab Product Division
400 employees

Eindhoven NL
EO Product Division
475 employees

More than 1800 employees
in 41 countries

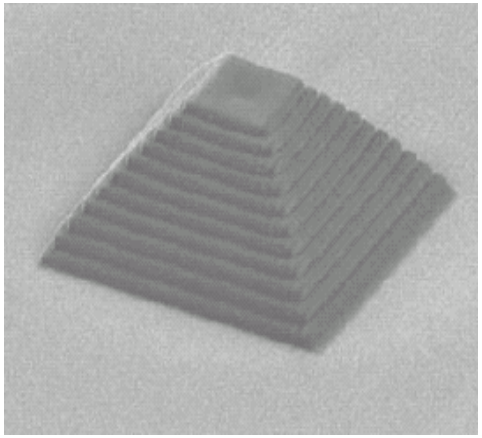
Brno CZ
'Subsidiary' of EO Product Division
200 employees

Tokyo, Japan

Plus Shanghai, China, just opened

Nanotechnology applications: nanofabrication

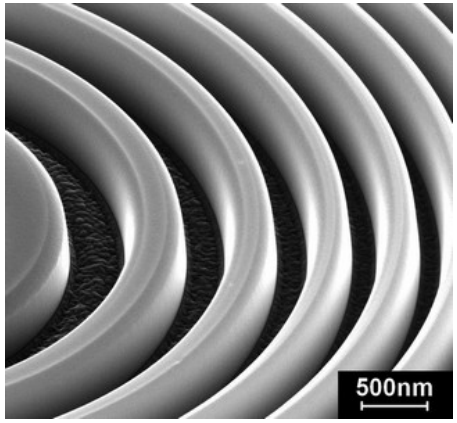
Deposition



FOV = 10x10 μm^2

Cap of piezo resistive pressure sensor (KU Leuven, Belgium)

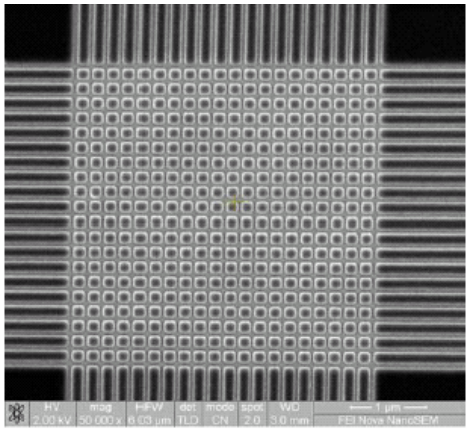
Milling



FOV = 2x2 μm^2

Fresnel Micro Lens

Lithography



FOV = 5x5 μm^2

Nano Arrays

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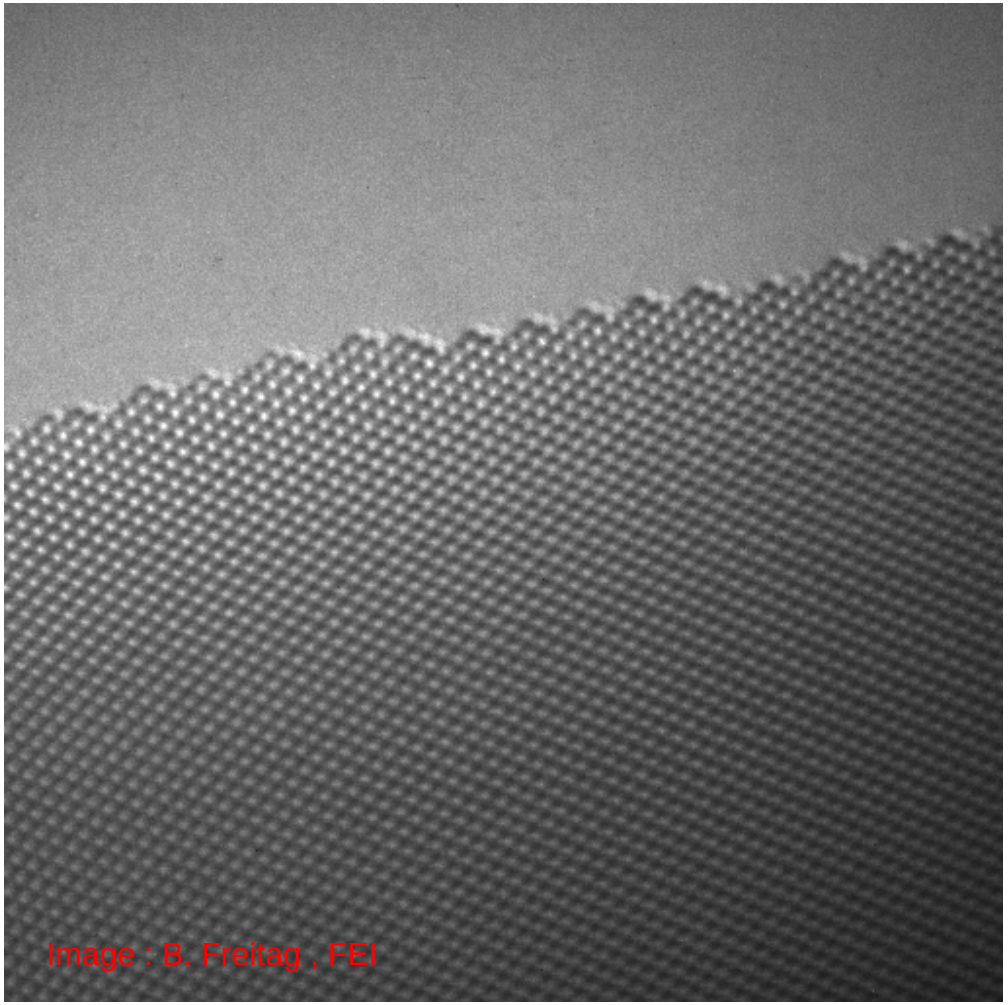
The NextGen TEM

FEI Company selected to work with five DoE labs:

- Berkeley
- Frederick Seitz
- Argonne
- Oak Ridge
- Brookhaven

Titan S/TEM

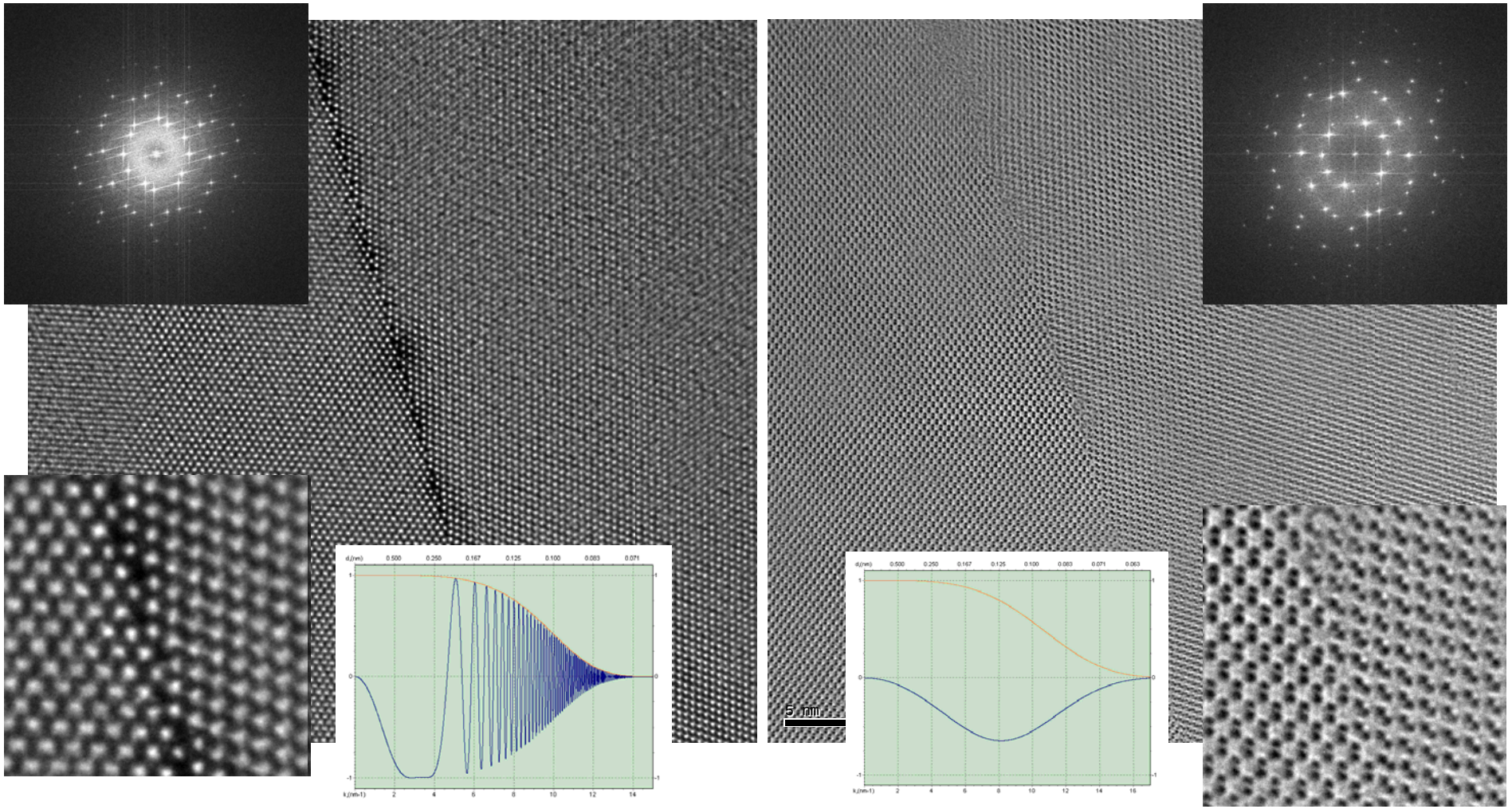


Movement of single atoms on surface can be monitored

Atoms are activated by focusing the beam maximal on the area

HR-TEM on Silicon <110>

TITAN image Cs-corrector vs. non-Cs corrected TEM @ 300kV



Images and FSR : B.Freitag, Sample J.Thibault, Marseille

Non-Cs-corrected HR-TEM

Cs corrected HR-TEM

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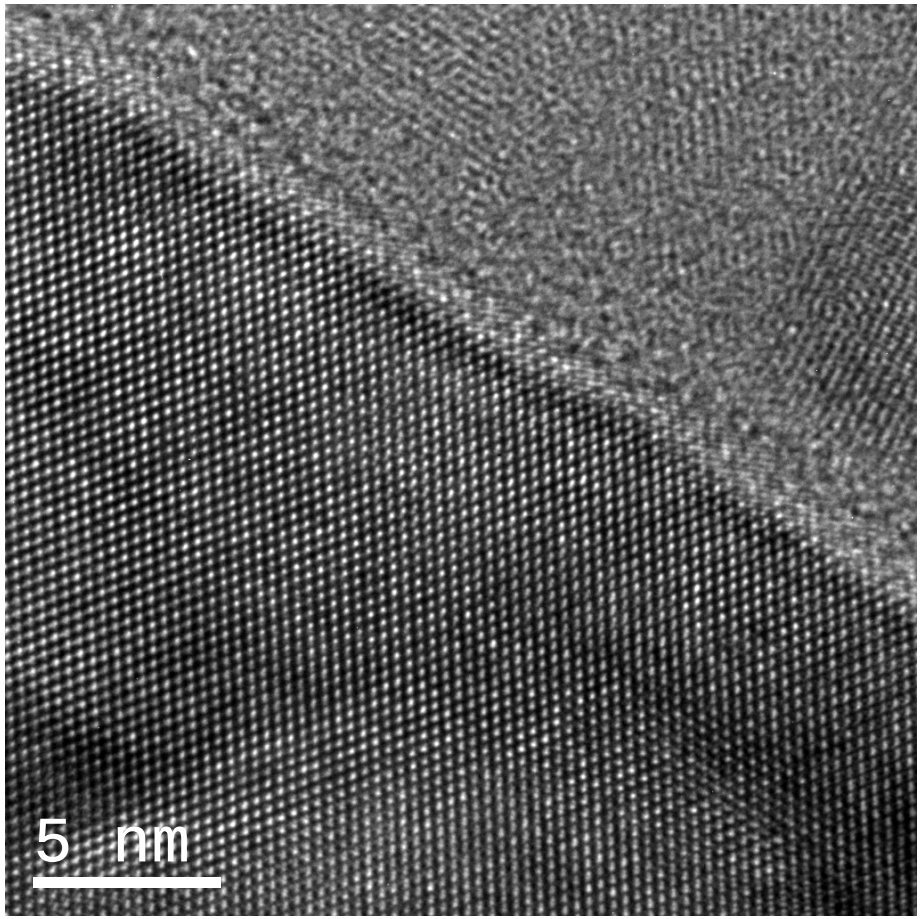
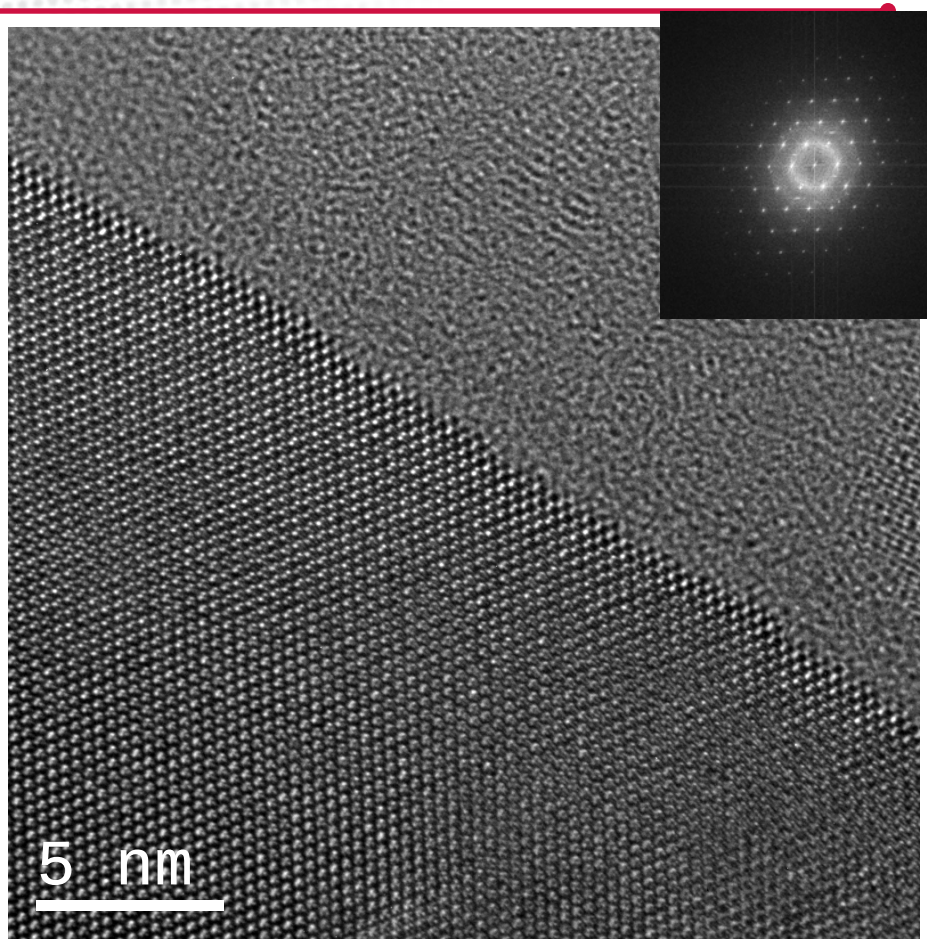
Transistor gate (TITAN C_s-corrected vs. non-corrected TEM @ 300 kV)





Non C_s-corrected HR-TEM

C_s-corrected HR-TEM

More accurate interface structure determination (roughness)

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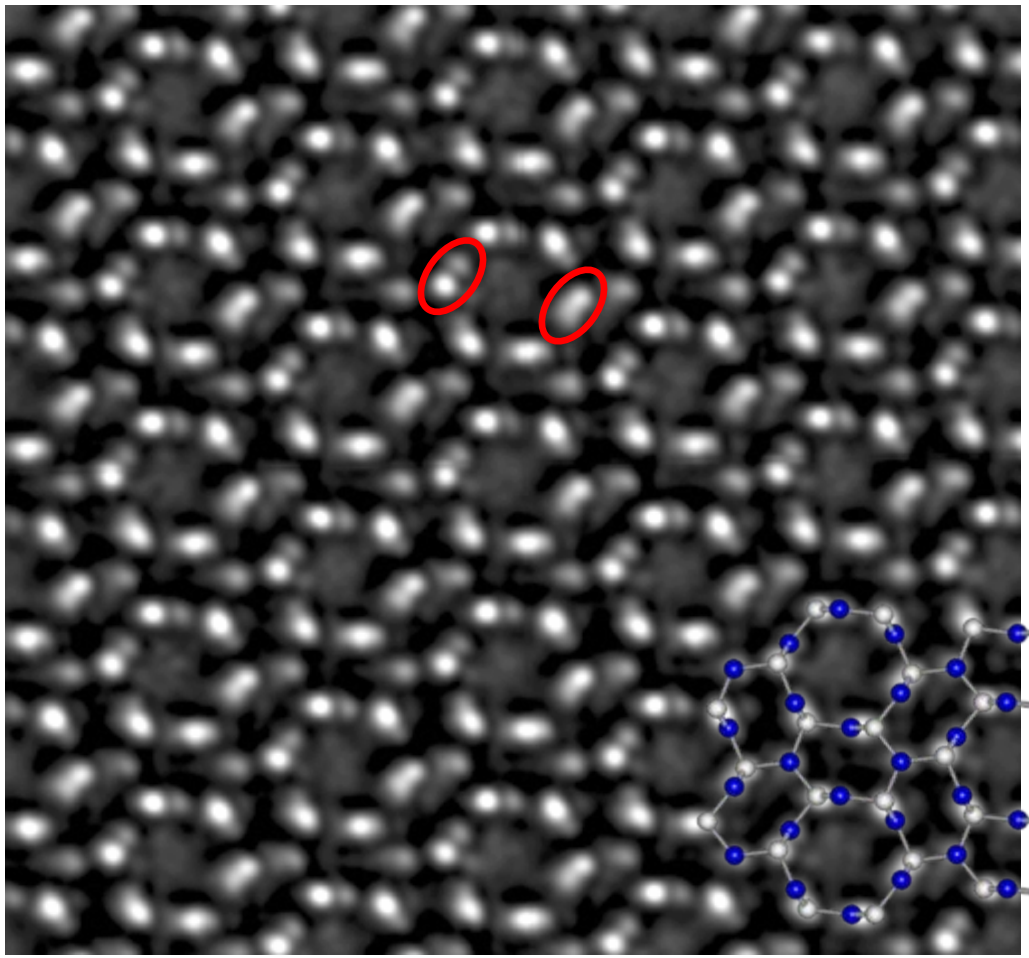
HR-TEM Example: Si_3N_4 (001), NCSI



TITAN 80-300

U = 300 kV

$1 / g_{max}$ = 0.8 Å

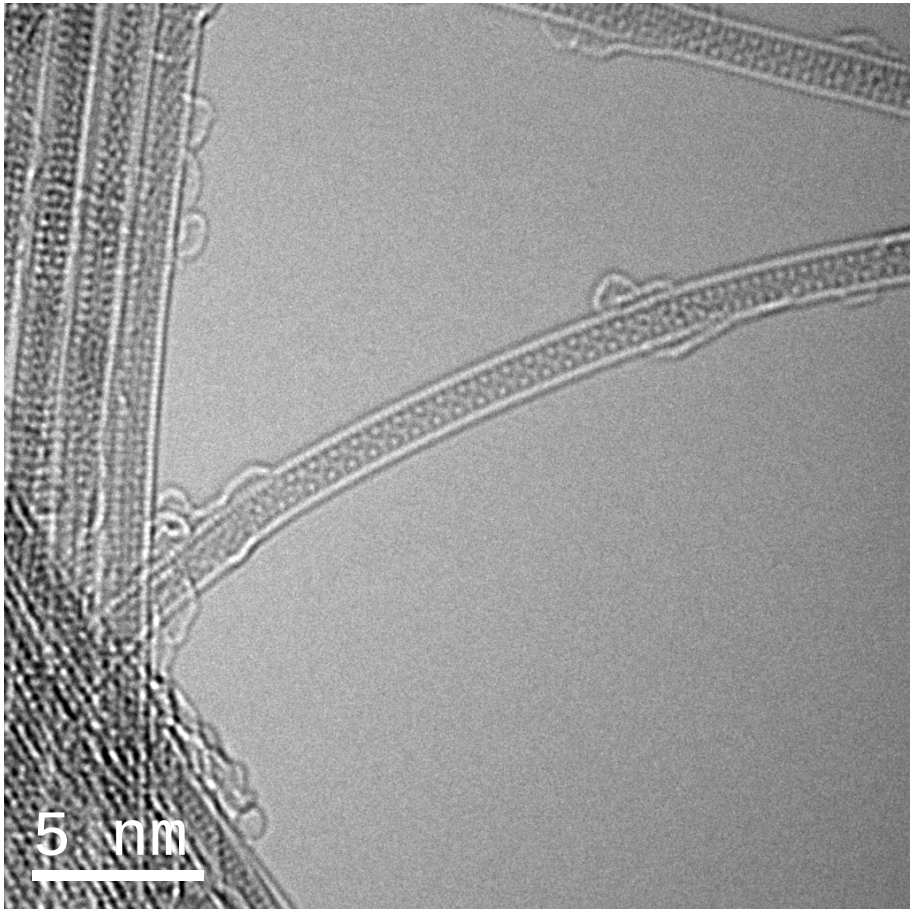
C_S = – 13 µm

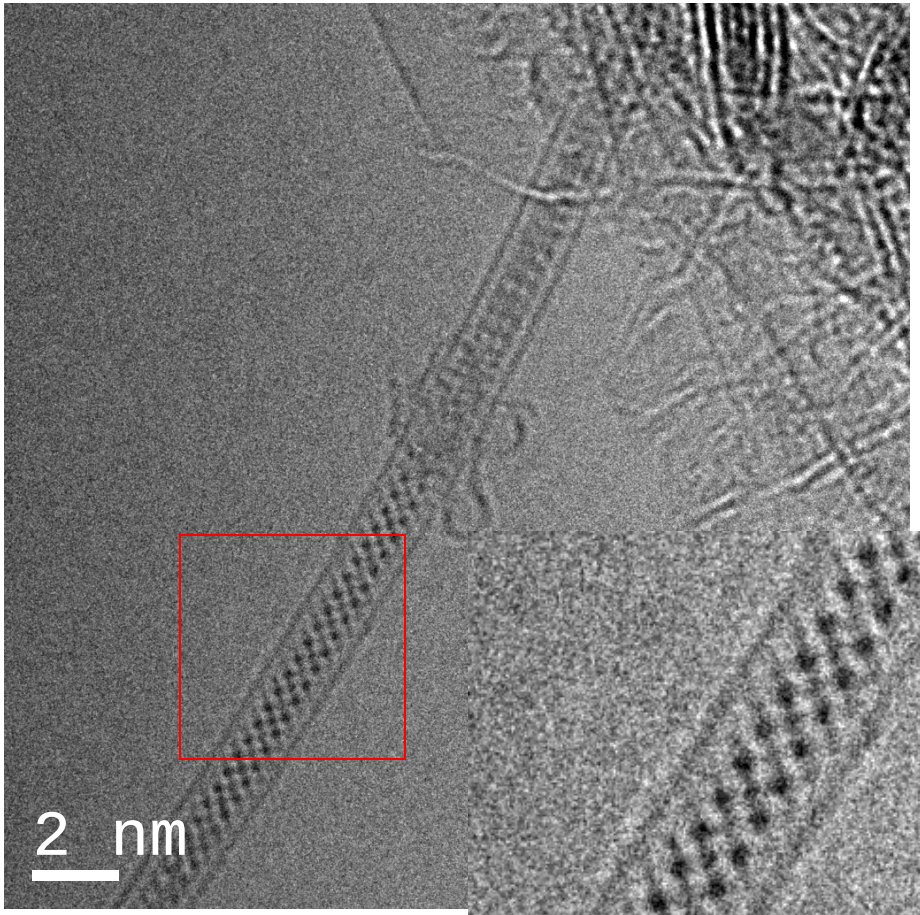
Z_{opt} = + 6 nm

Karsten Tillmann, Lothar Houben,

Sample courtesy of M. Svete, Bonn University

SWCNT PbTe and CuBr, C_s-corrected at 80 kV





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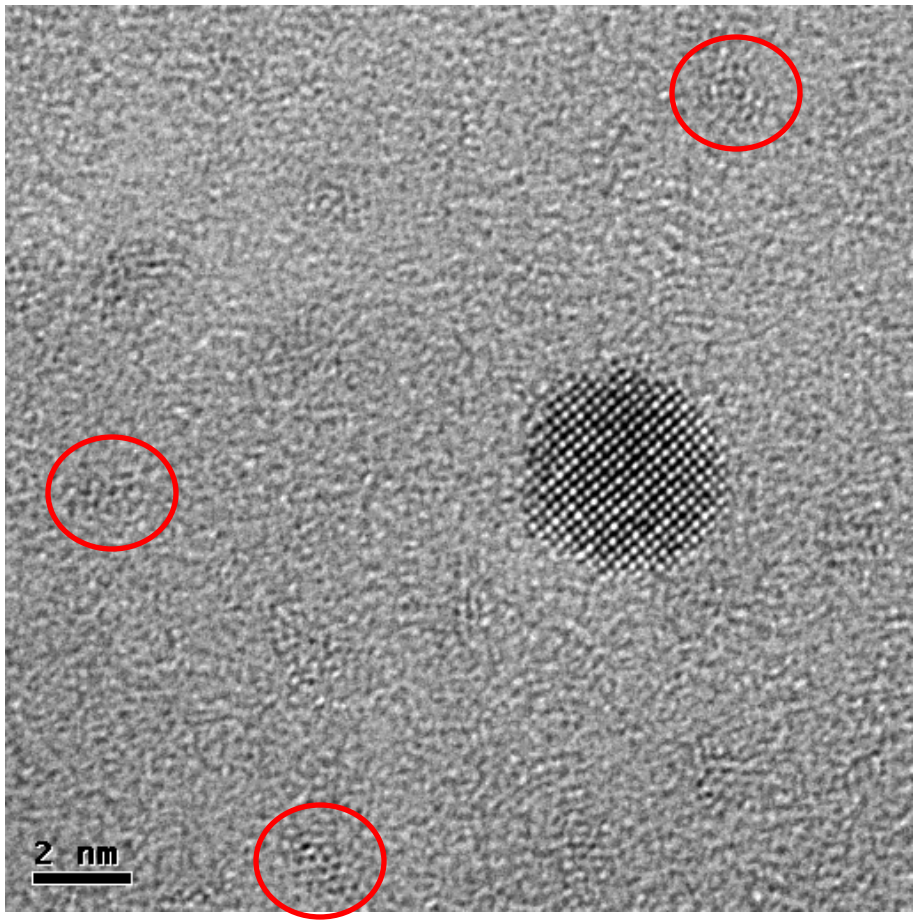
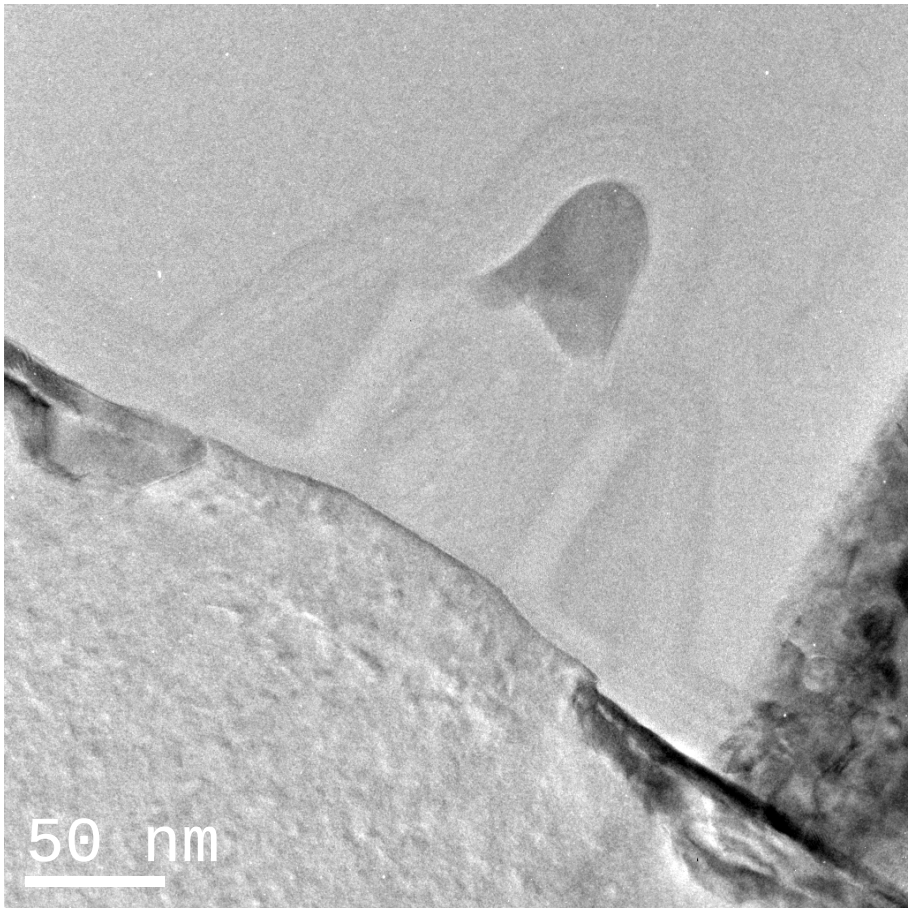
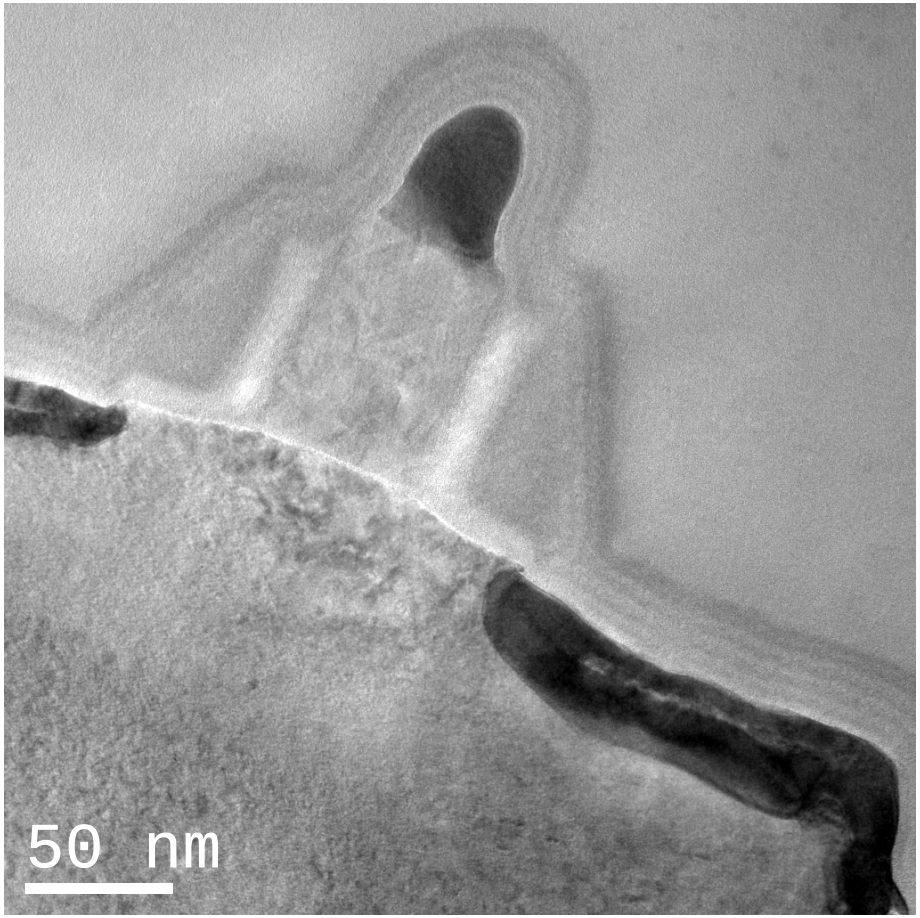
Nanoparticles with C_s-corrected TEM (gold nano-particles)



Better detection of small nano-particles (<1 nm) on carbon films

Contrast enhancement on silicon devices at 80kV





Cs-corrected HR-TEM at 300kV and 80kV

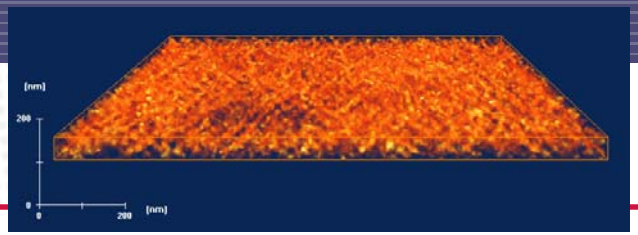
Clear contrast enhancement for layer thickness determination

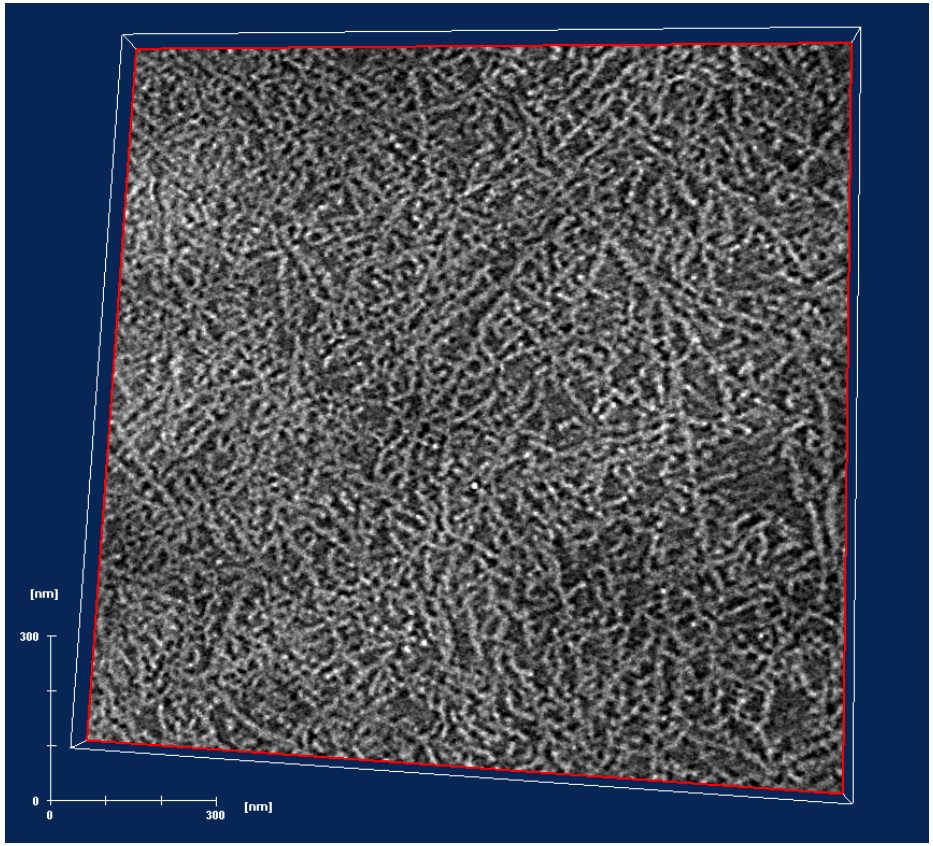
Key challenges in nanotechnology

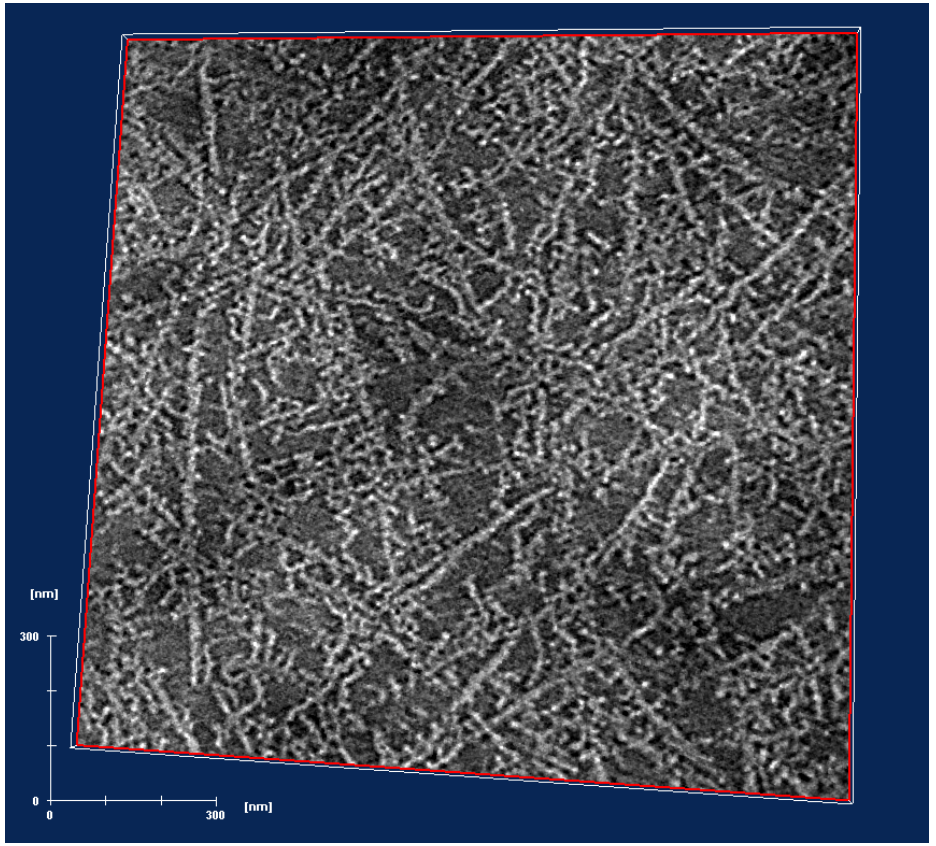
- Clean, sustainable energy
- Environment
- Health
- Security
- Etc…

- Energy & environment:
  - Efficiency
  - Cost
- Examples:
  - GaN LEDs – use energy efficiently
  - Organic LEDs, photovoltaics, etc – low cost
  - Catalysts – make processes more efficient
  - Fuel cells – use energy efficiently

Example: polymer photvoltaics







Close to bottom

Close to top

(P3HT/PCBM)

TU/e technische universiteit eindhoven

DPI DUTCH POLYMER INSTITUTE

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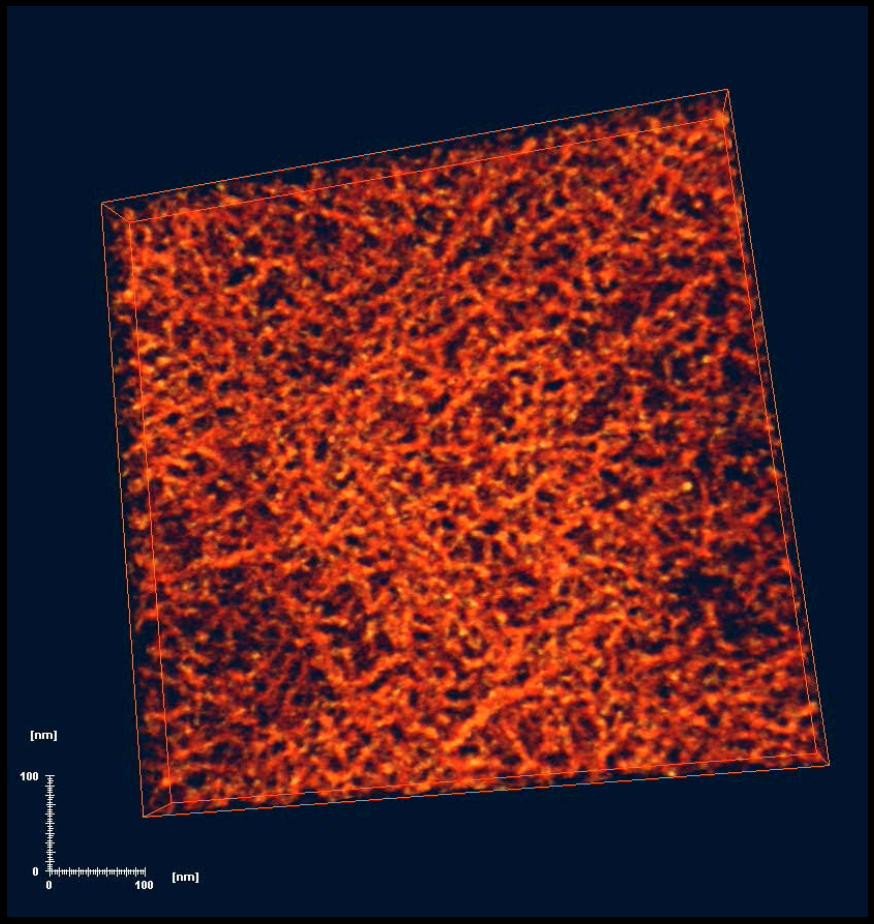


Volume reconstruction of the P3HT network

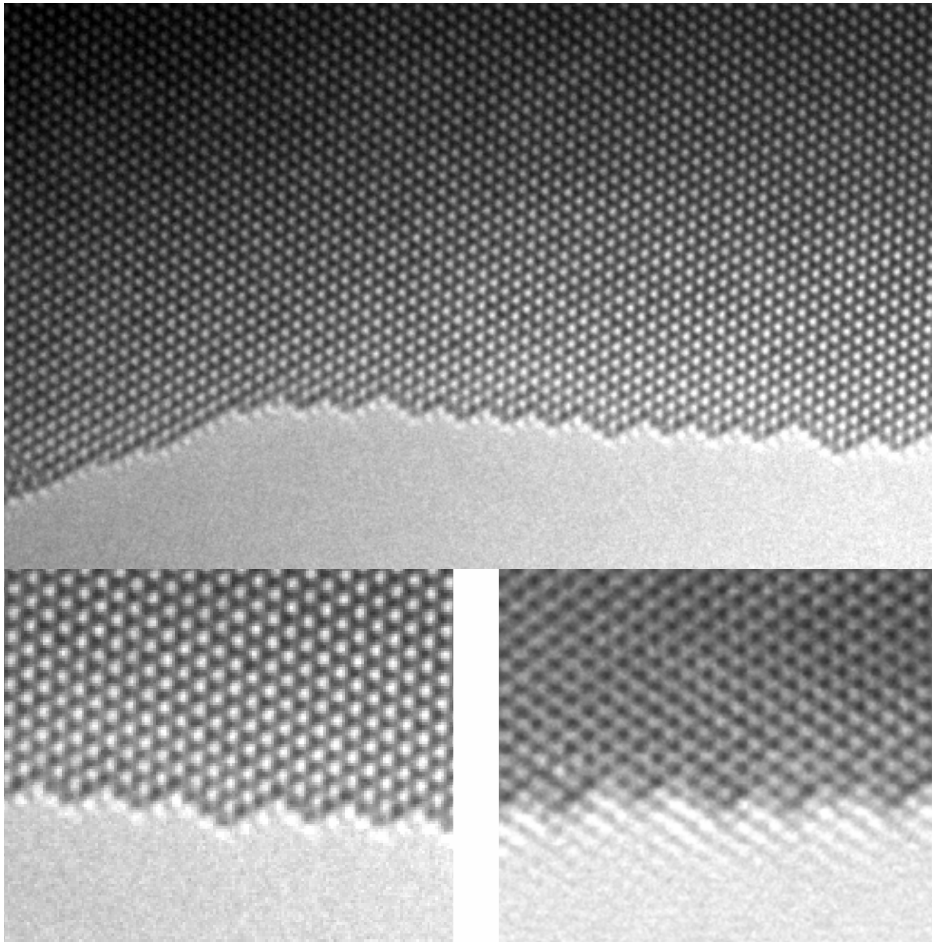
Example: catalysts

Delocalization effect: problem for surface imaging

Contrast delocalization is quantified by point spread function:

$R(G) = 2\pi (C_1 \lambda G + C_3 \lambda G^3)$

$G = \alpha / \lambda$ the spatial frequency



On Off

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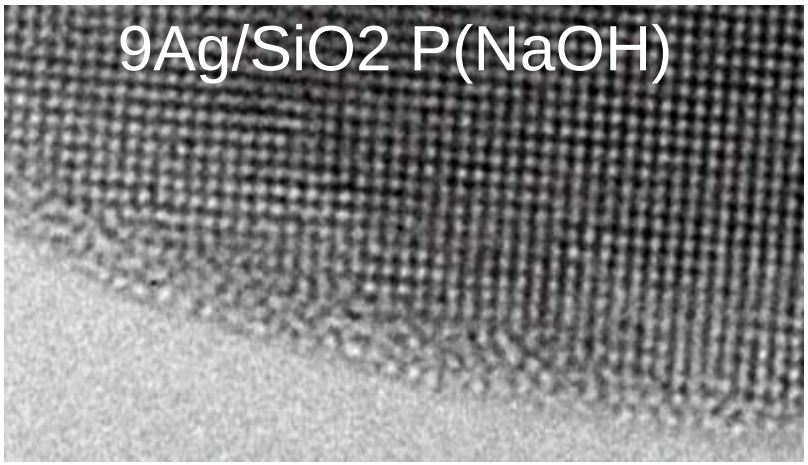
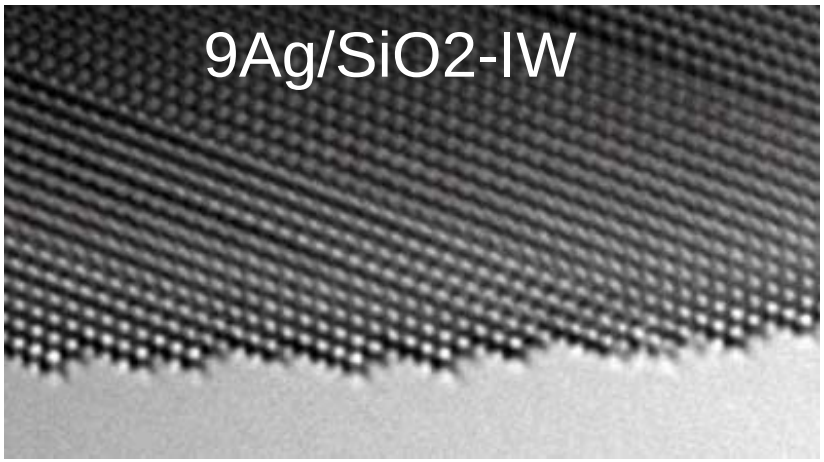
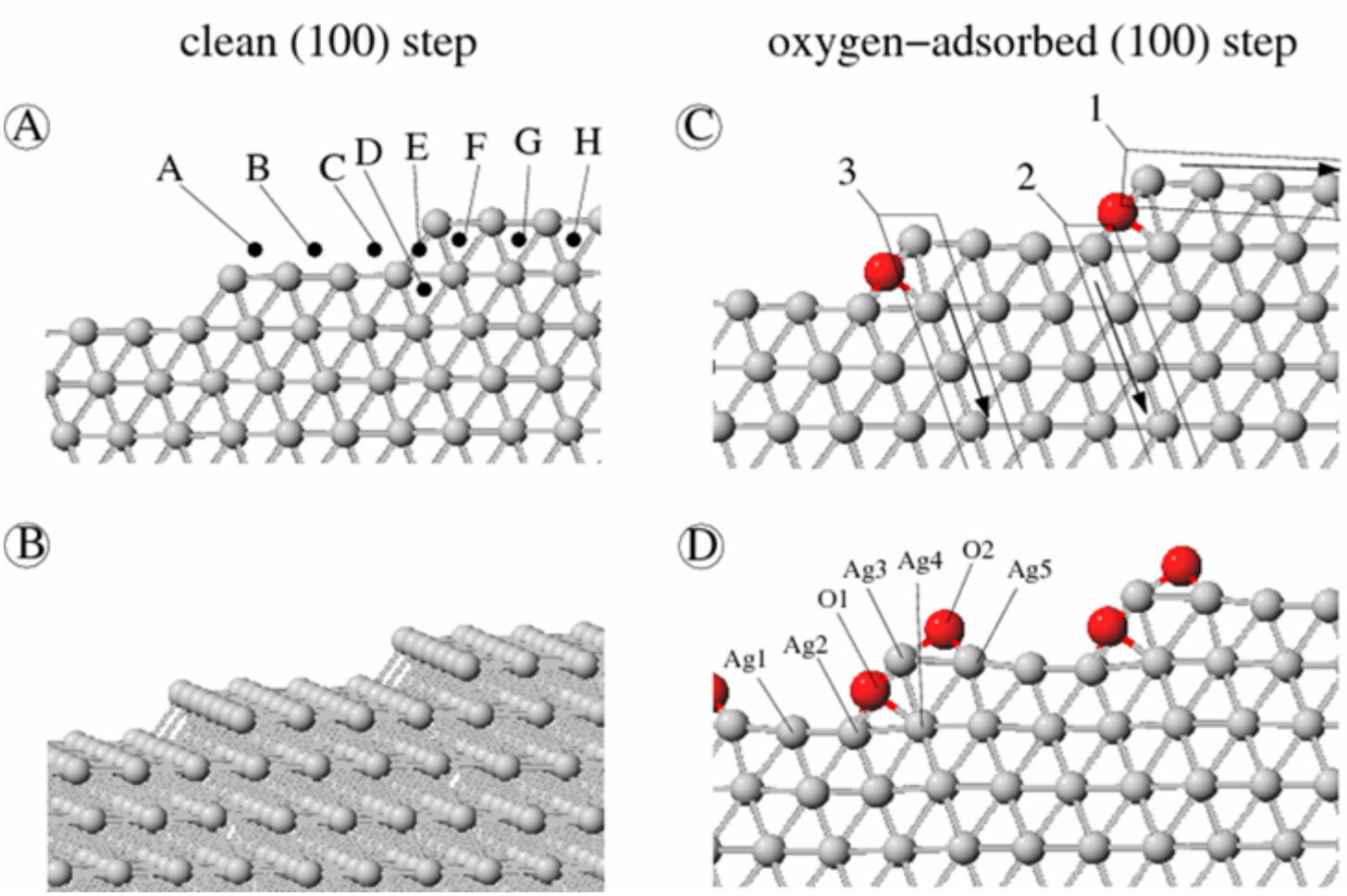
Silver nano-particles: comparison of surfaces





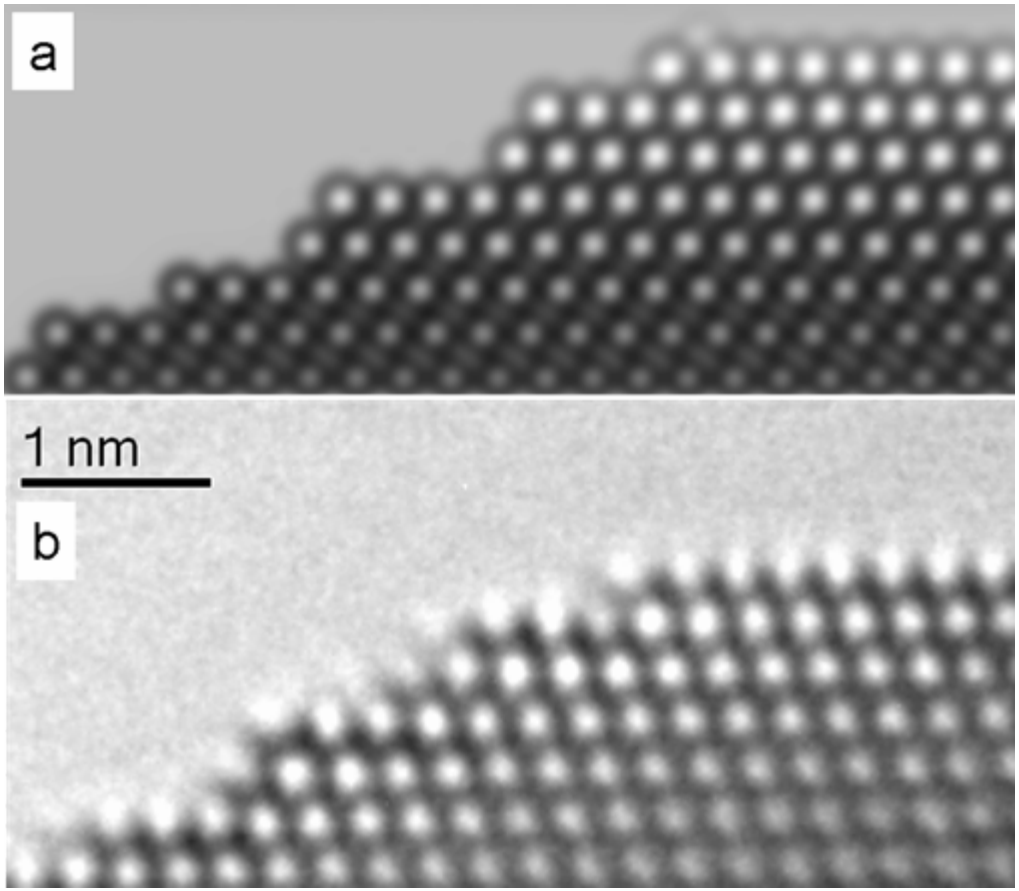
- Surface of particles prepared via incipient wetness show more kinks and edges than particles prepared via precipitation technique
- Atoms at kinks and edges favour the formation of AyOH, this explains the higher selectivity of sample 9Ag/SiO2-IW
- HR-TEM images of the surfaces clearly reveal the difference in the active sites of both samples

Modeling inter-atomic structure



Su, Jacob, Hansen, Wang, Schlögl, Freitag & Kujawa

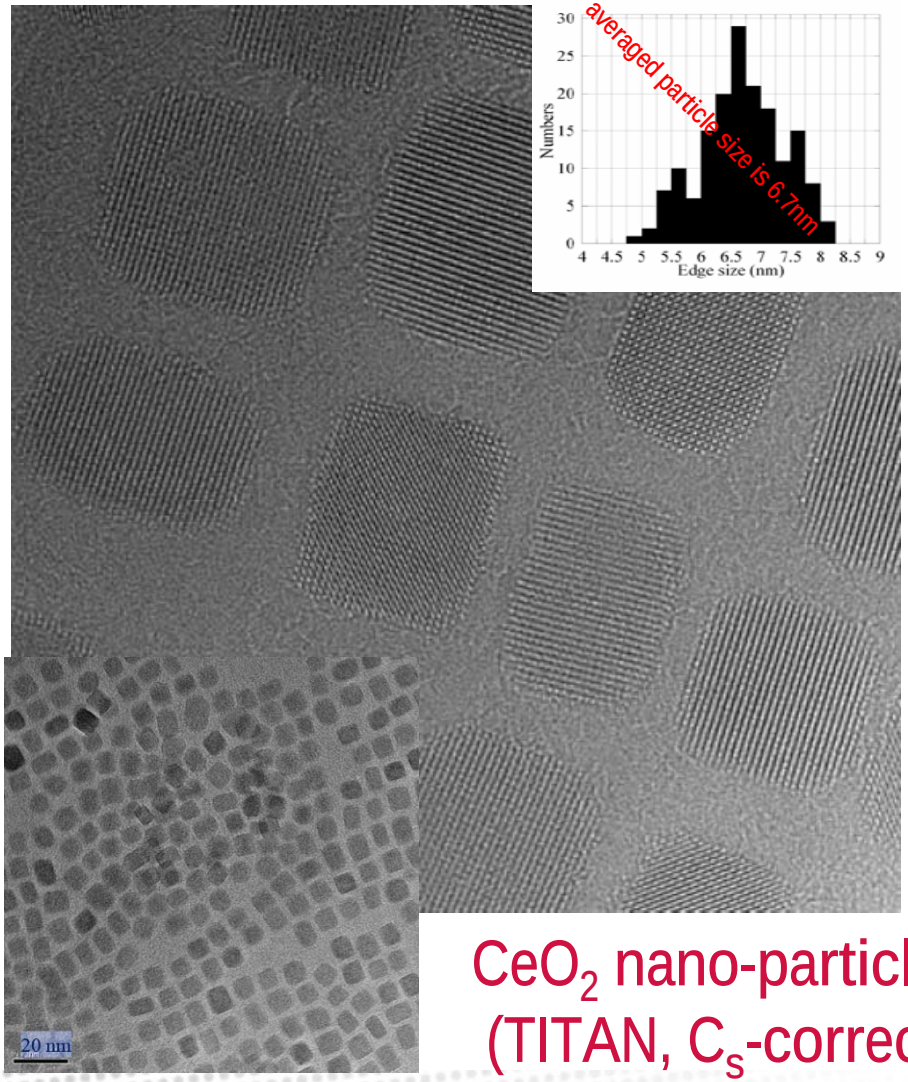
Visualising inter-atomic structure

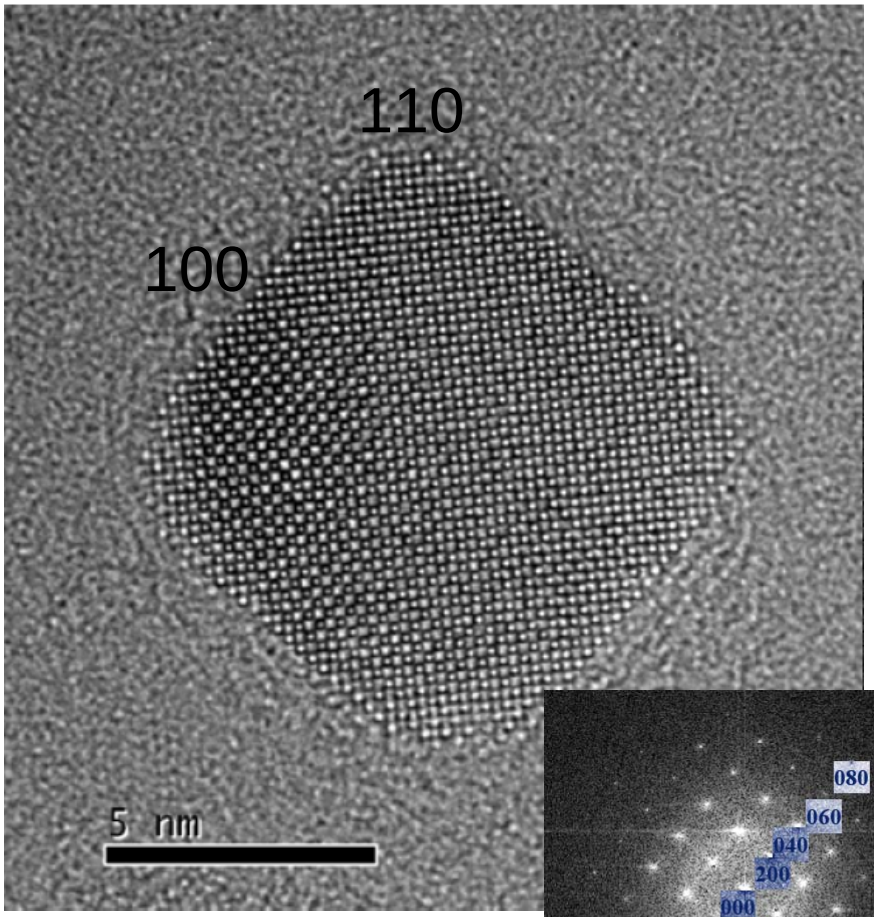


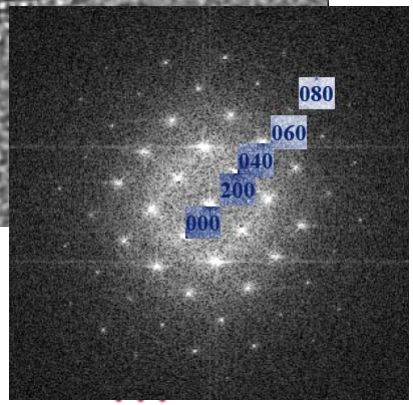
Simulation

Image

Example: solid oxide fuel cells







CeO_2 nano-particles
(TITAN, C_s-corrected @ 300 kV)

Determination of distribution, morphology and atomic structure

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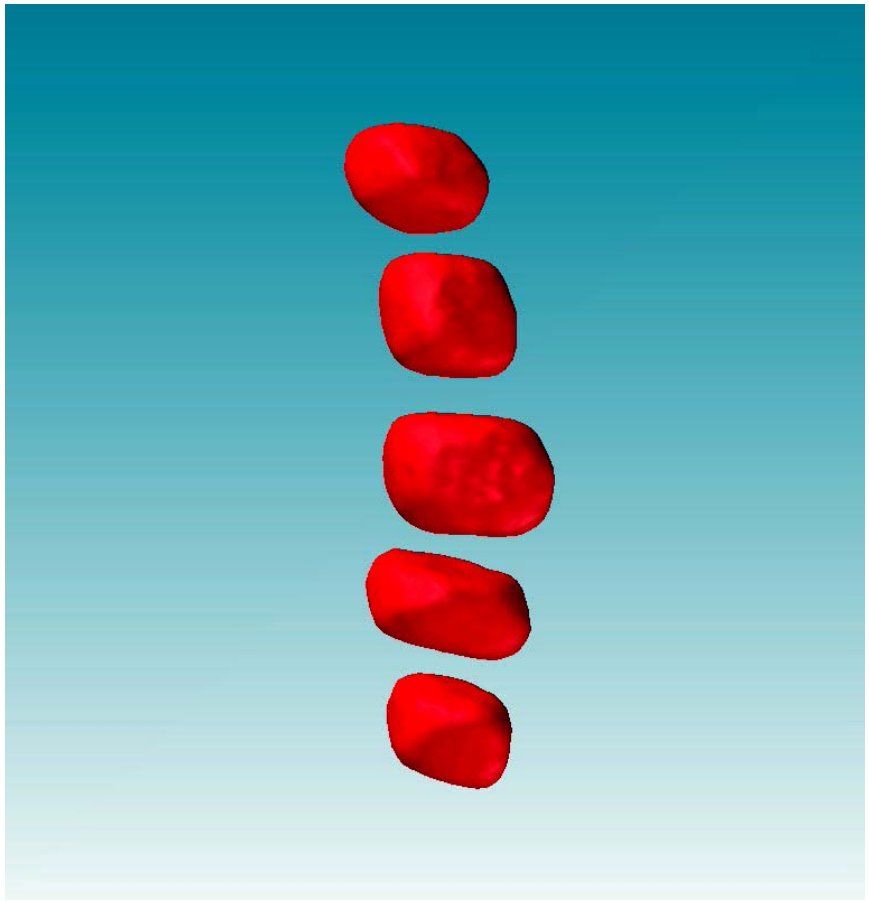
STEM tomography: CeO_2 nano-particles

Tomography gives greater morphological information



Conditions:

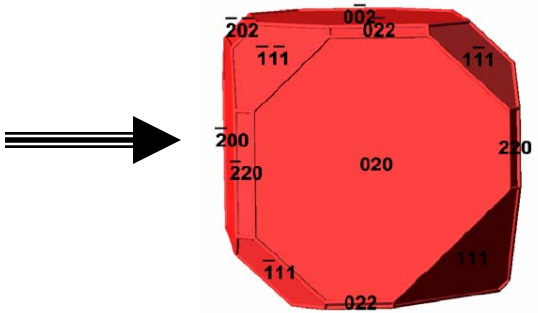
Tilting: -70° - 74°

Tilting step: 2°

Collected on a Tecnai F20

Reconstructed using FEI Inspect3D package

Visualization using Amira



Tomography reveals that particle morphology is more complex than shown by 2D data

FEI™

A new era with new challenges needs new results

FEI is committed to “innovate for knowledge” through

- New hardware
- New software
- New methods
- New applications
- New partnerships

And we need leading & passionate customers to make it happen!