Frontiers in CD-SEM metrology

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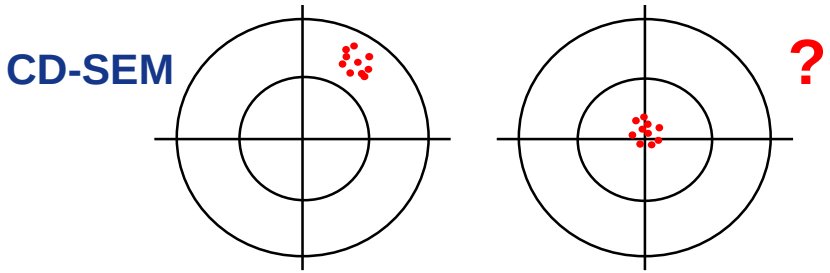
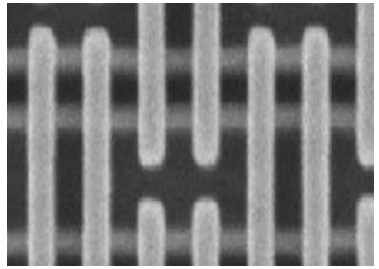
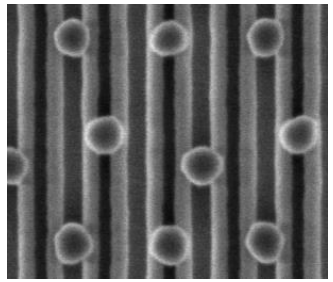
CD-SEM in semiconductor

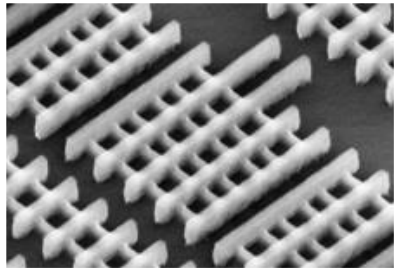
- **CD-SEM is an indispensable part of the semiconductor industry**
  - In volume manufacturing
  - In R&D and process development



- **New challenges for CD-SEM**
  - Accuracy, in addition to repeatability
  - Robust contour and CD extraction from images of multiple layers
  - Overlay capability
  - 3D information about circuits







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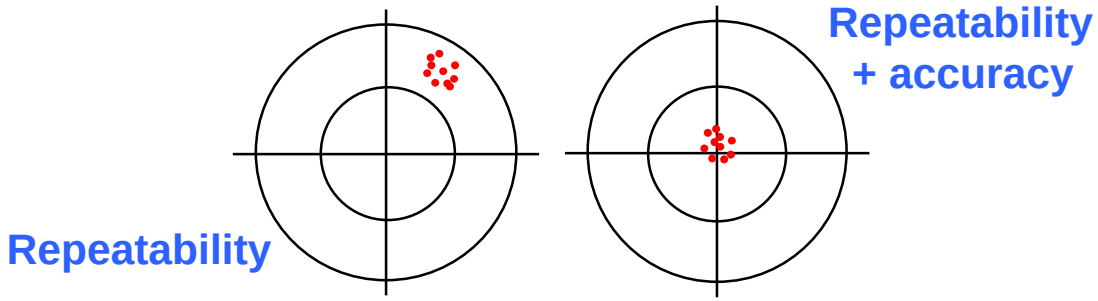
SEM metrology: accuracy problem



Typical repeatability is <0.1 nm

Typical CD uncertainty is 3-4 nm

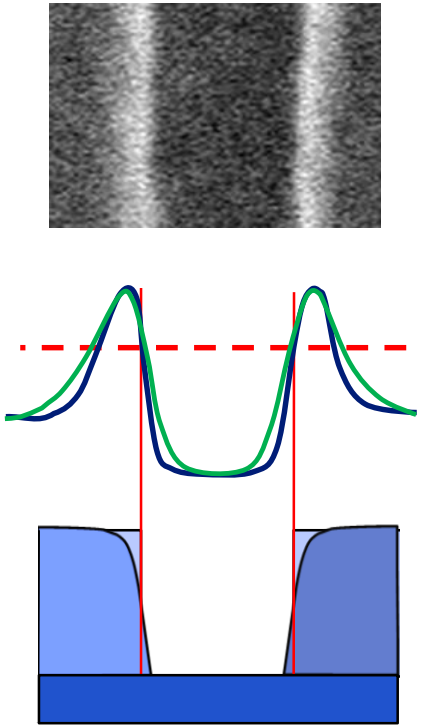


Image brightness ≠ feature shape

An image is the result of complex physics, including properties of the e-beam, materials, 3D geometry, etc.

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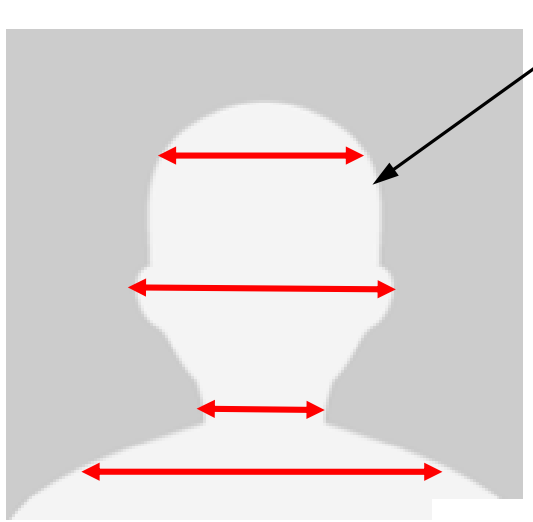
CD-SEM: 22 nm. What does this mean?

Wafer features are 3D



Where was 22 nm measured?

CD-SEM: not known

This uncertainty is perfectly OK for high volume manufacturing!

What about design?
Technology development?
OPC calibration?

Accuracy!

The next generation

in SEM image analysis

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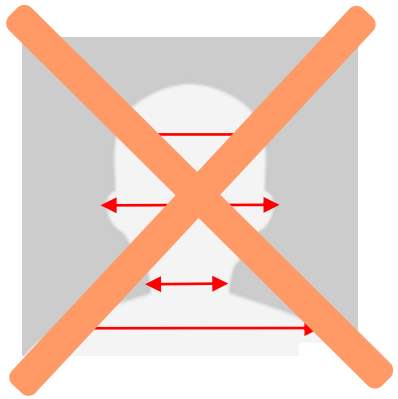
Summary of aBeam's development

SEM image analysis:

- **Based on e-scattering model: improved accuracy**
- **A lot of automation: No recipe needed!**
  - **Finds contours and measures CDs without recipe**
  - **Superior contour extraction**
- **Always know where the CD is measured:**
  - top, bottom or middle
- **Capability for side wall angles from top down images**



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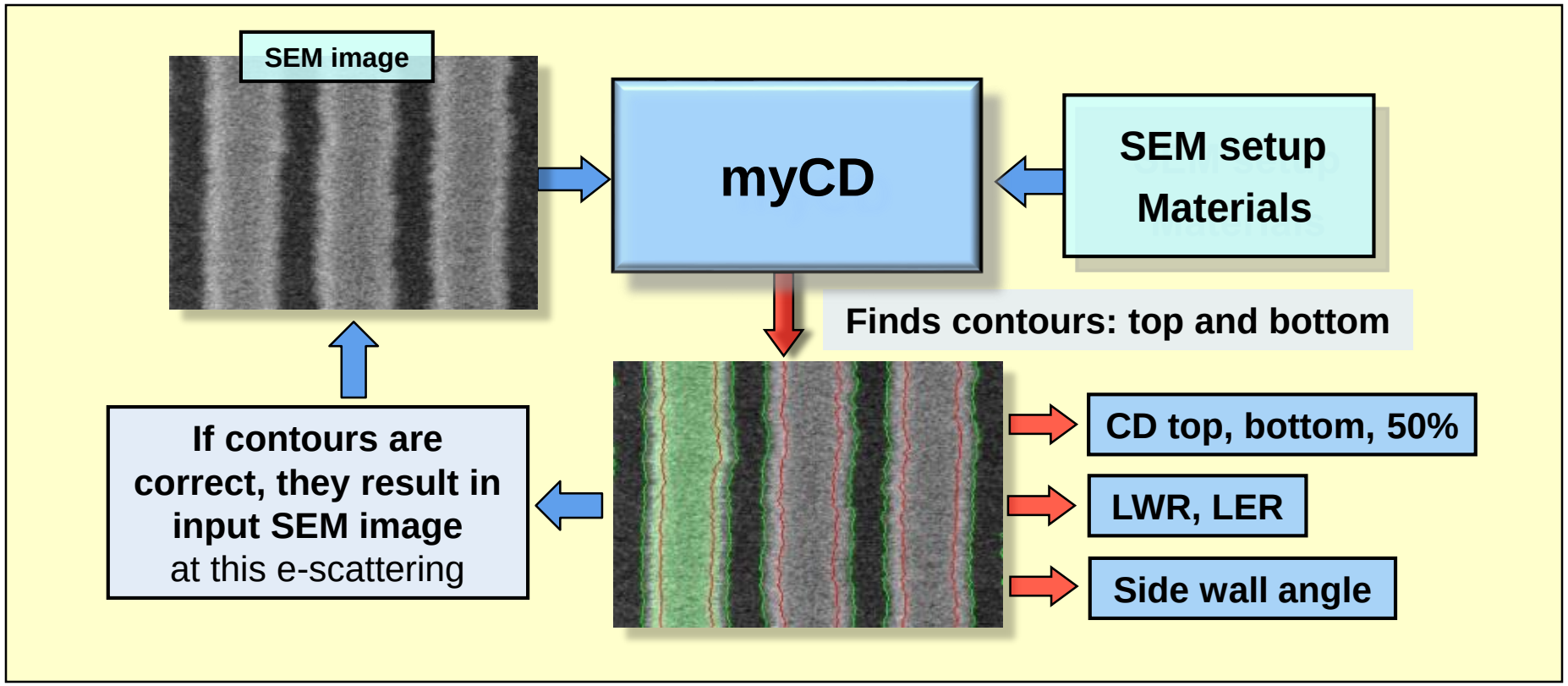
Model based image analysis

Solves reverse task: where should the contours be to produce an input SEM image



Electron scattering is simulated in real time; no libraries

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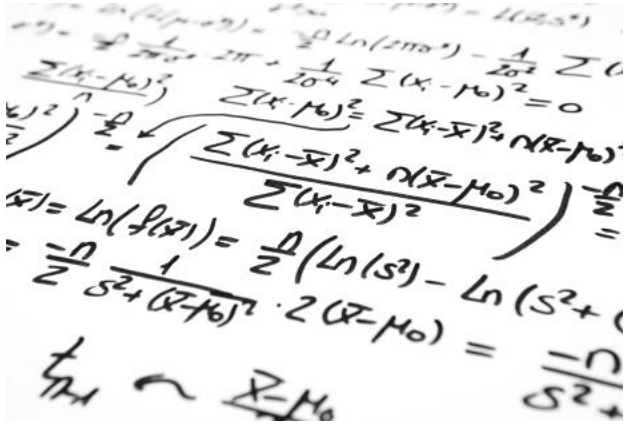
Electron scattering model

- myCD software uses an analytic model of electron scattering

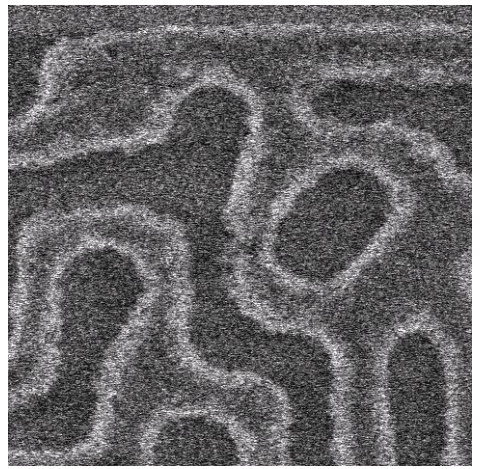
Why analytic, not Monte Carlo?

- Monte Carlo takes too long
- Analytic model is fast, builds on the fly
- No need for libraries!

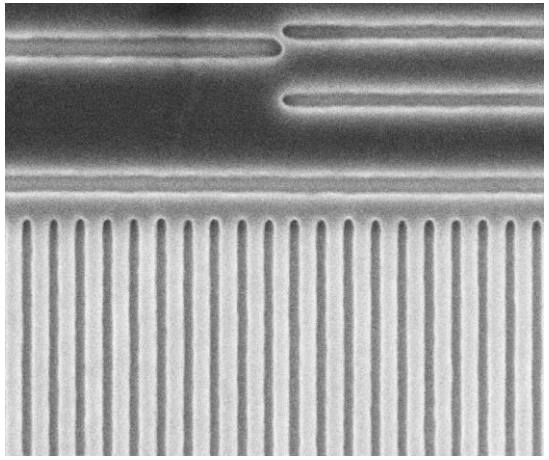


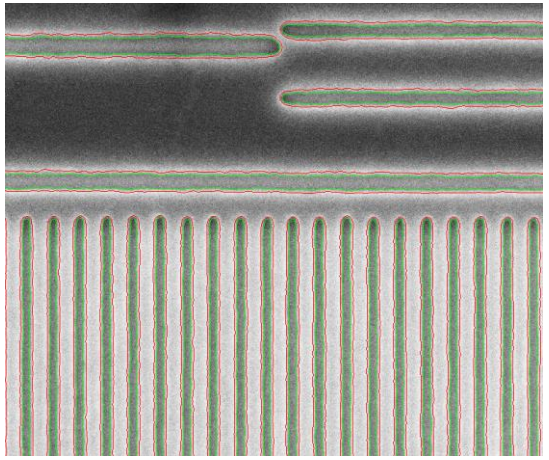
Automation in image analysis

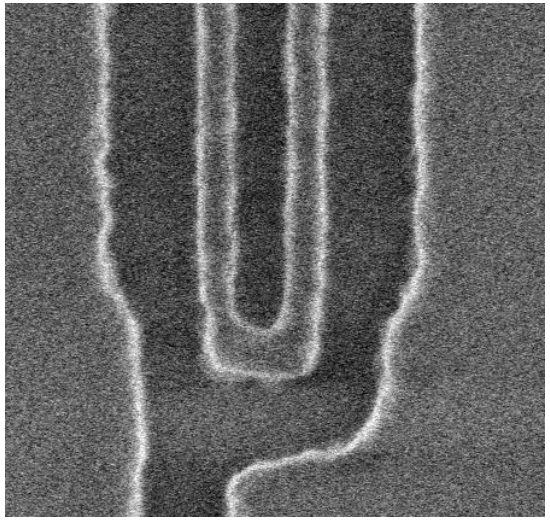
- **CD-SEM engineers spend a lot of time creating recipes**
  - **CD results depend on the recipe**
  - **Easy to adjust CDs, 2 - 5 nm or more**
- **Automation may exclude user's induced uncertainty**
  - **Also, greatly reduces the need for recipe creation**
- **A lot of automation in myCD:**
  - **Finds contours and measures CDs without recipes**
  - **No need for GDS to find contours**
  - **Often works on low quality images where other software fails**

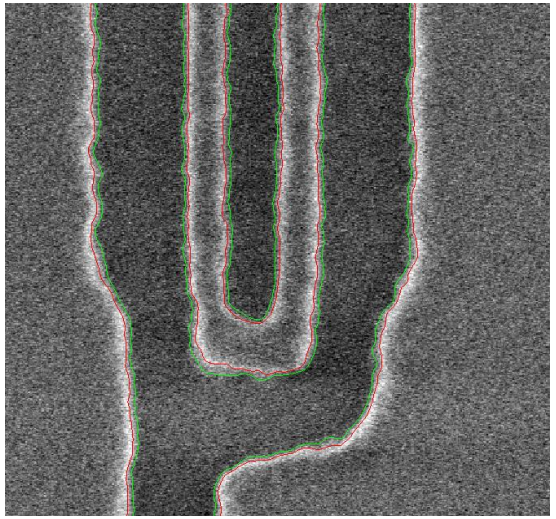


Contour and CD measurement: auto









SEM images

Contours extracted

Automation:

- Finds contours
- Finds where to measure CDs
- Measures CDs

Model based,

no recipe

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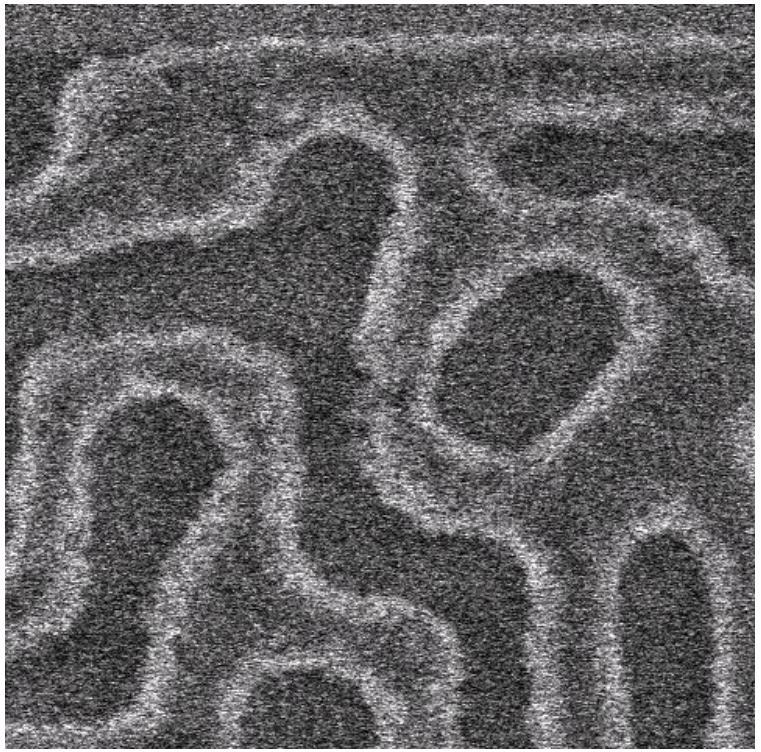
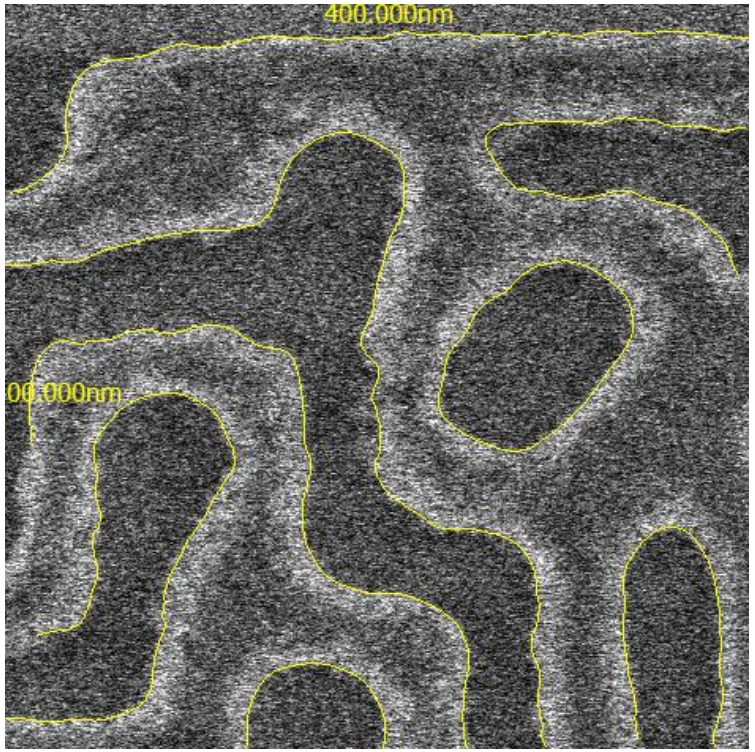
Low current images for OPC

- OPC requires low dose to reduce resist shrinkage



Low current > fuzzy image



myCD works OK

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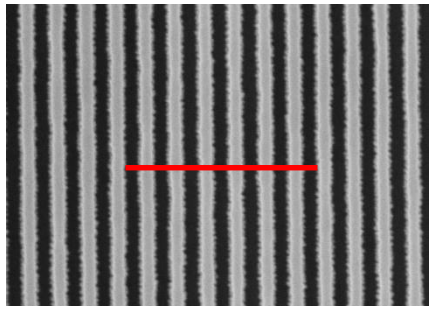
Verification of accuracy

- **Multiple verifications: 100% confirmed improved accuracy**

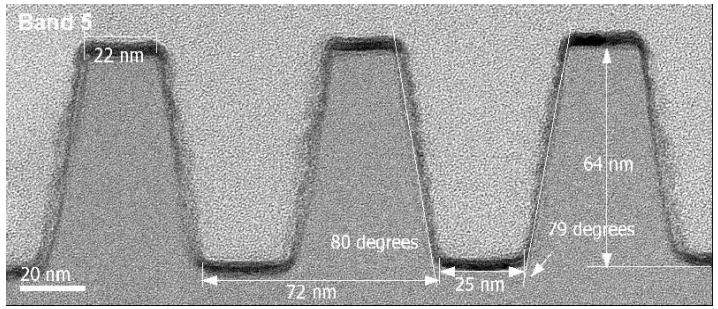


SEM images, quartz NIL template

myCD

Extracted CDs, SWA

Comparison: top down vs TEM



TEM, used as reference

Seagate: JVST B28 6 C6H1 2010

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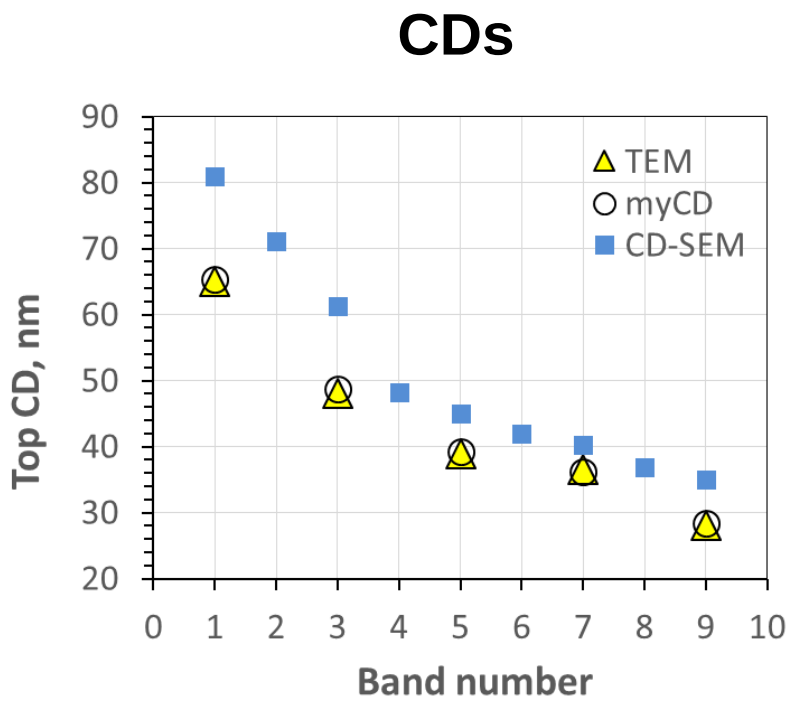
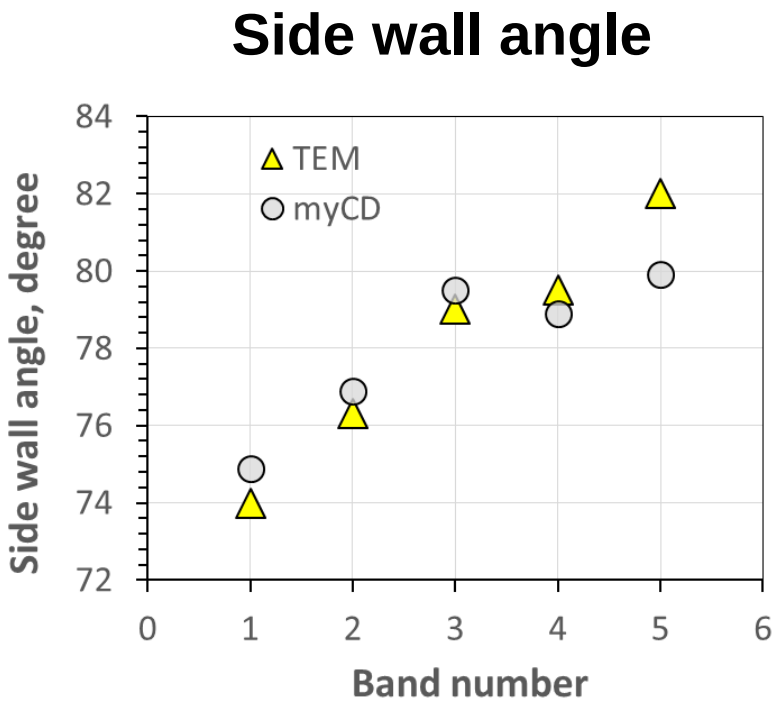
Verification: top down vs TEM





- Threshold: variable error 4…16 nm, depends on feature size
- Model based software was accurate
- Side wall angle capability

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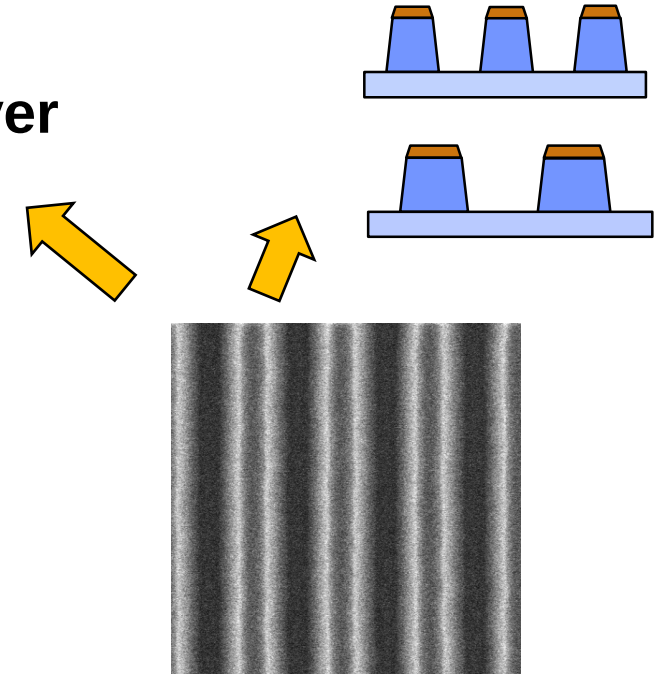
Metrology of double layers

- **Etch development needs:**
  - **CDs at the top and bottom of each layer**
  - **Side wall angle for each layer**
- **Metrology: mostly TEM**
  - **Expensive**
  - **Long time to provide feedback**

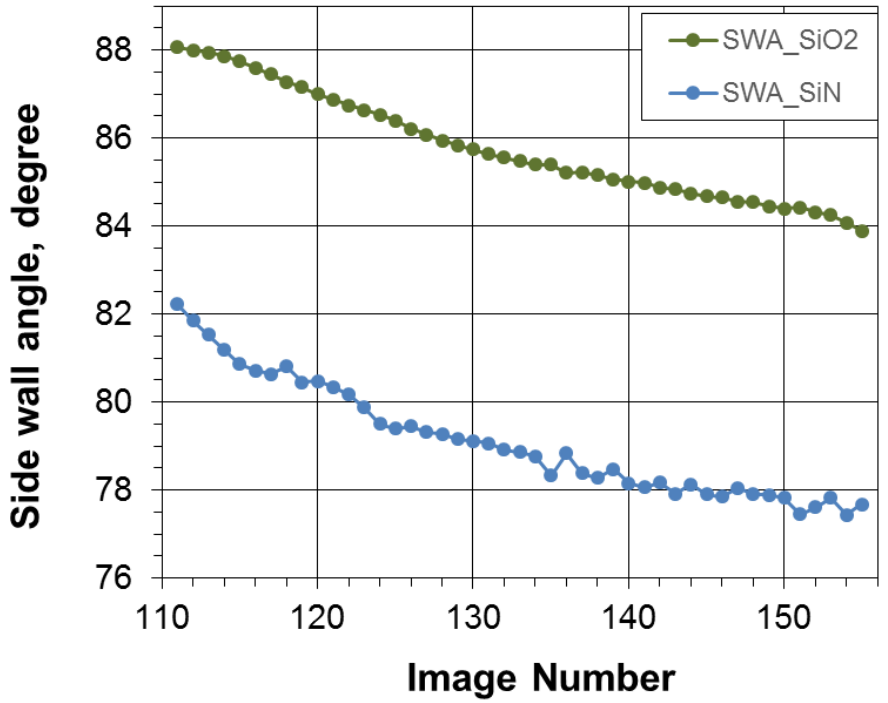


Can CDs and SWA be measured from top down SEM images?

If so, this means fast feedback and considerably lower cost!

Side wall angle, both layers

- CDs were measured for both layers, top and bottom, trench CD and pitch
- Side wall angles: the results are very repeatable: **0.4 degree (3-sigma)!**



Also, at tomorrow's poster session;
N.Rana will present SWA results for
his structures; 0.15 degree repeatability

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SEM simulation tools

Indispensable part of SEM business

SEM simulations

- Equipment makers: optimize SEM design
- Factories: optimize SEM parameters for specific layers

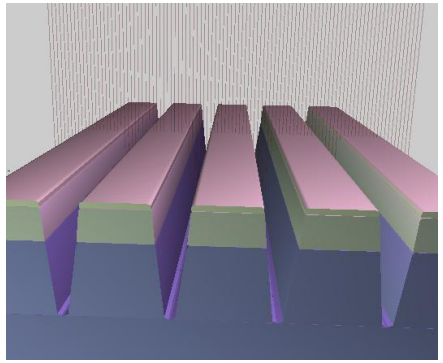
- Monte Carlo simulator, CHARIOT
- Fast analytic simulator of SEM, aSEM

Both have pretty comprehensive models of SEM image formation

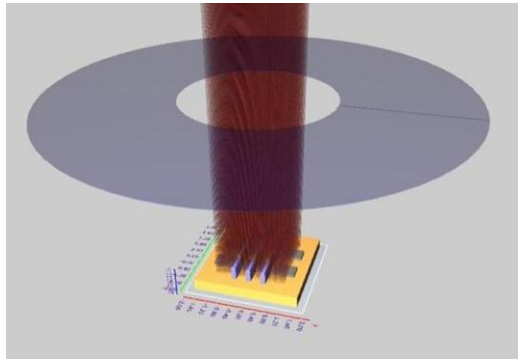
Monte Carlo SEM modeling

- **Simulation of SEM images from first principles**

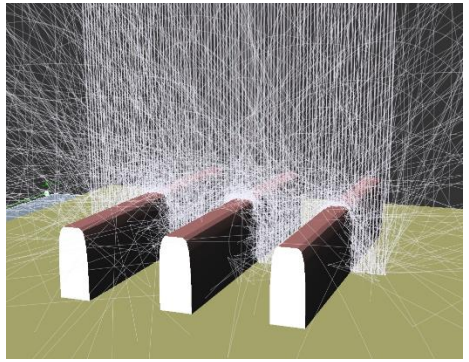
De-facto standard in semiconductor industry



3D pattern

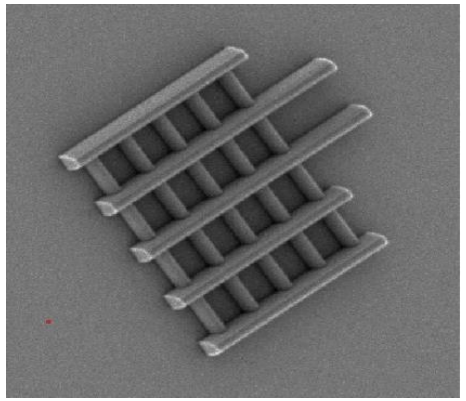


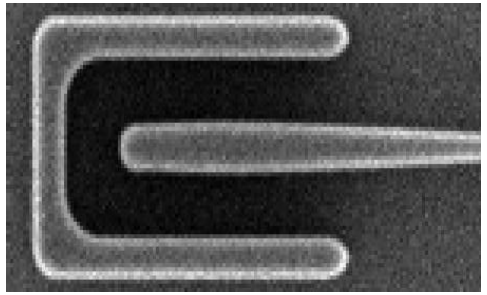
Beam and Detector



e-scattering

Simulated SEM images





CHARIOT key features:

- **Low voltage electrons**
- **Charging**

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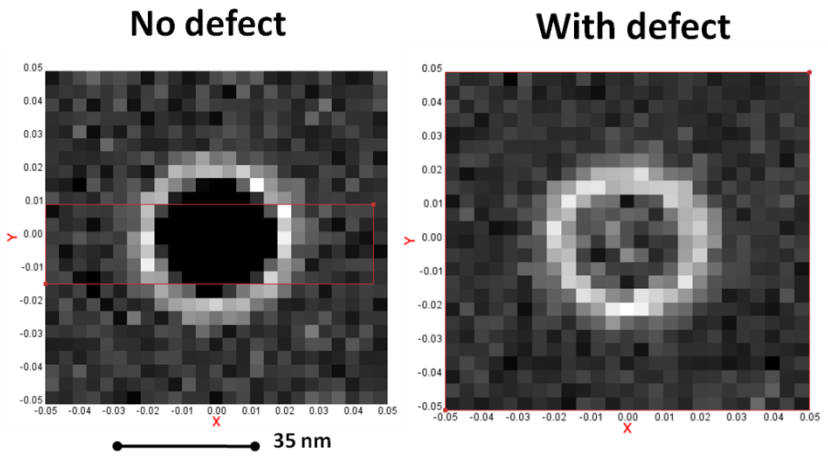
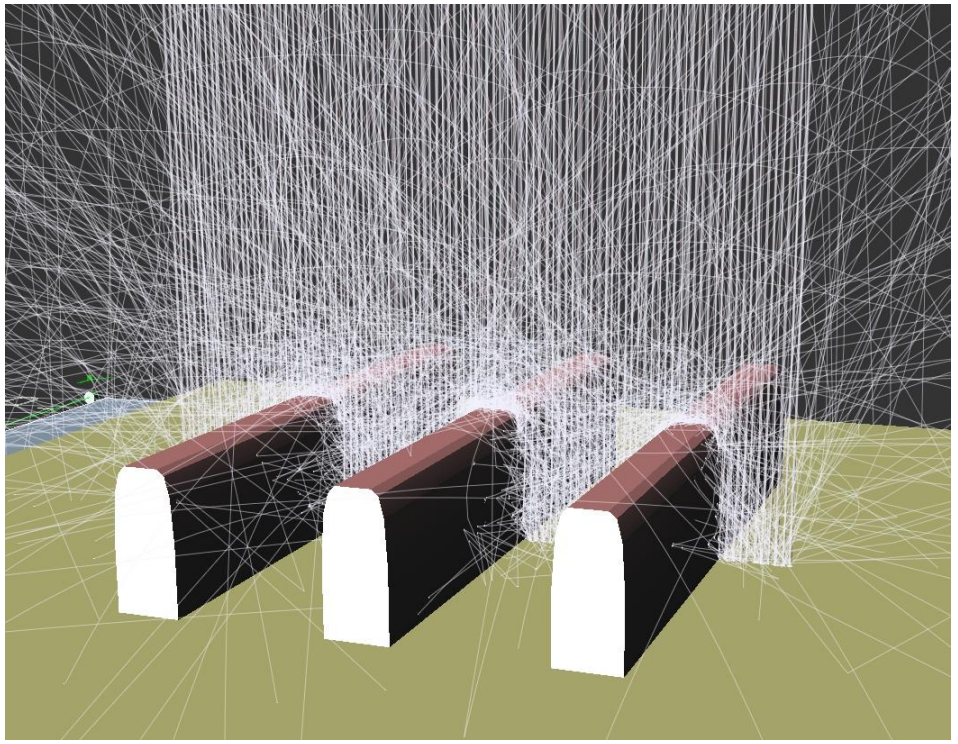
Examples, Monte Carlo

DI



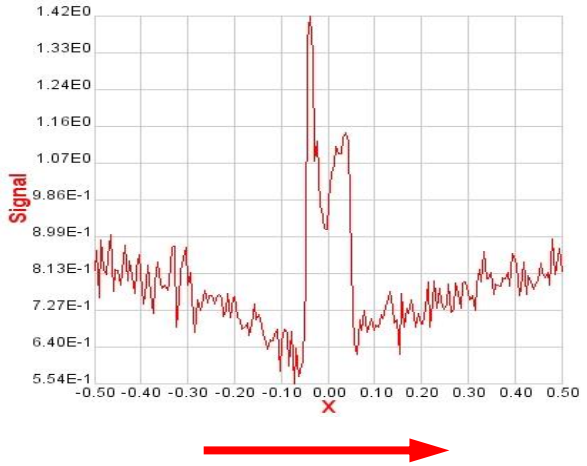
High aspect ratio 32 nm contact hole with pre-charge



Electron trajectories with charging

CD-SEM

Resist line with charging



Direction of scan

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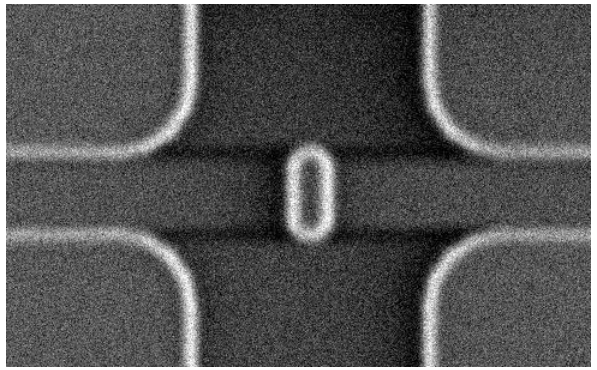
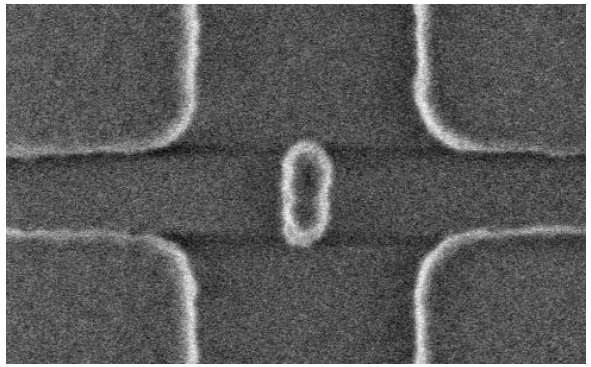
Analytic SEM: fast simulator

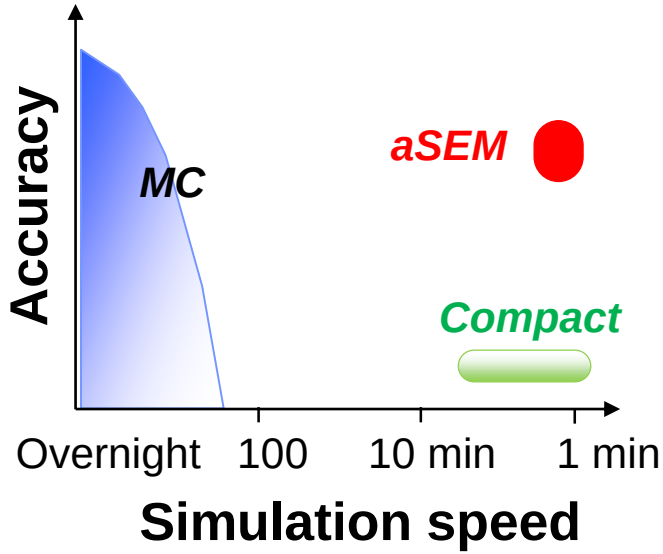
- **Comprehensive model:**
  - **includes electron scattering, charging, e-field, detectors**



Simulation with charging



actual SEM image



More at the exhibition and today's poster session

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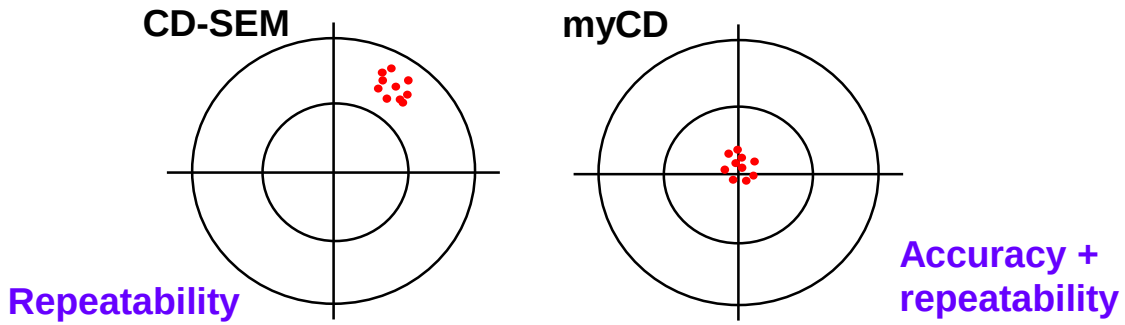
Summary: next gen SEM image analysis

- **Automation greatly reduces human factors in results**
  - **Finds contours and CDs without recipes and without GDS**
  - **Often works on low quality images where other software fails**
- **Using the model, the CD accuracy was greatly improved**



- **Capability for side wall angle from top down images**

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Thank you for your attention!