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COMPUTATIONAL LITHOGRAPHY INFRASTRUCTURE & DEVELOPMENTS

2nd SPIE Leti litho workshop | S. BERARD | 28 February 2019

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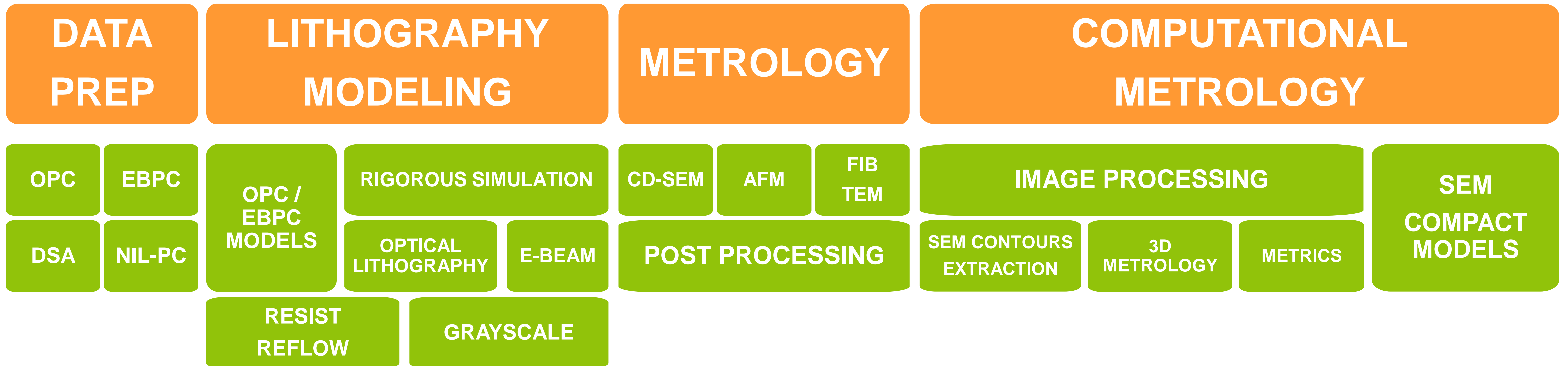
OUTLINE

- **The Computational Lithography Group**
  - Who are we ?
  - And what for ?
- **Focus examples on 2019 patterning activities**
- **Computational Metrology – 2D activities**
- **Towards 3D Computational Metrology**
- **Conclusions**

COMPUTATIONAL LITHOGRAPHY GROUP – OVERVIEW

- **Our missions:**
  - **Support Data-Preparation needs** for LETI silicon technologies platform activities
  - **Develop** innovative computing / modeling / data treatment solutions



COMPUTATIONAL LITHOGRAPHY GROUP – ECOSYSTEM OVERVIEW

EDA partners

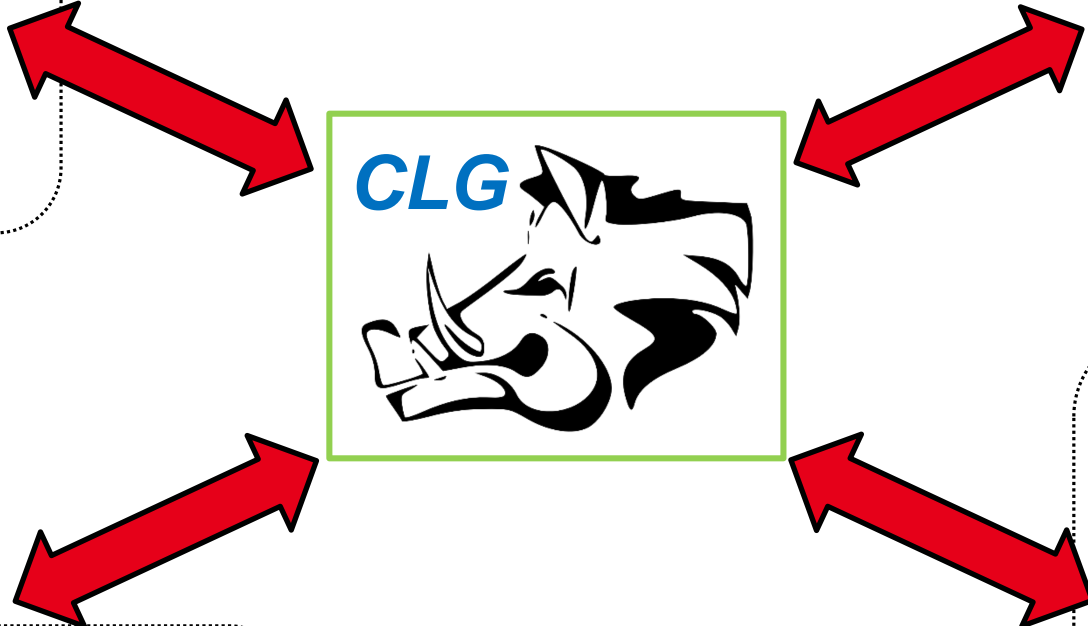
aselta NANOGRAPHICS

Mentor Graphics

SYNOPSYS

Maskshop

TOPPAN



End-Users

cea tech leti

ST life.augmented

GLOBALFOUNDRIES

Suppliers

ASML

Nikon

Canon

APPLIED MATERIALS

HITACHI Inspire the Next

BRUKER

OUTLINE

- **The Computational Lithography Group**
- **Focus examples on 2019 patterning activities**
  - Imagers application
  - 3D Metrology
- **Computational Metrology – 2D activities**
- **Towards 3D Computational Metrology**
- **Conclusions**

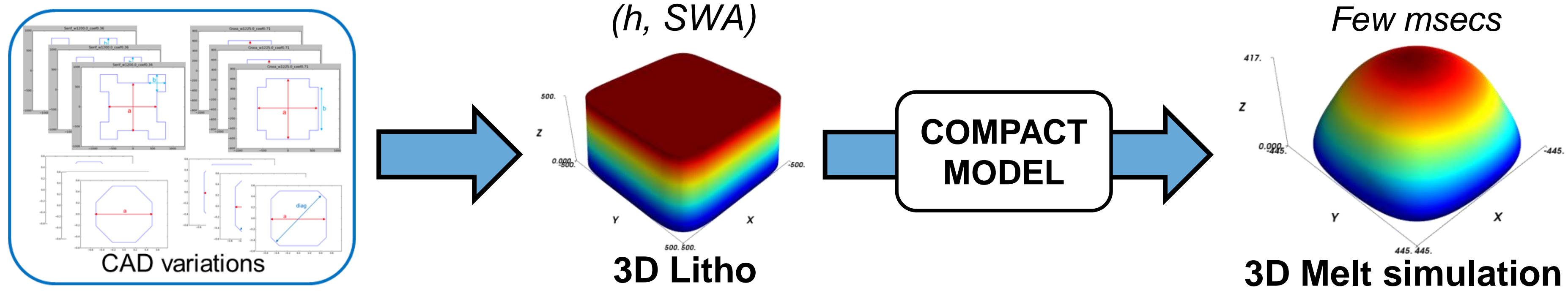
CLG – LITHO MODELING @ SPIE 2019

Joint work with ST life.augmented

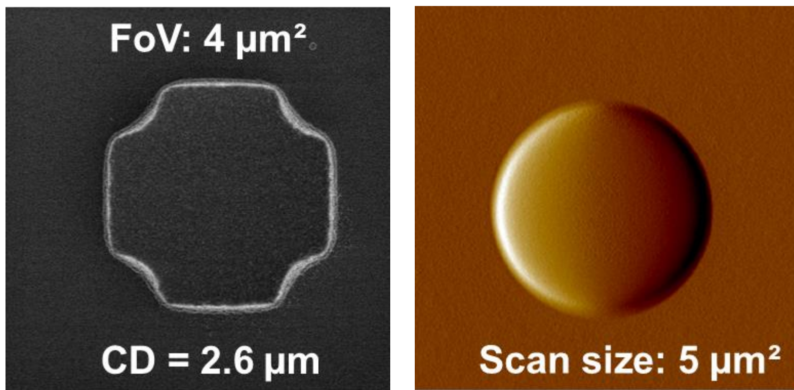
LITHOGRAPHY MODELING

OPC / EBPC MODELS | RIGOROUS SIMULATION | OPTICAL LITHOGRAPHY | E-BEAM | RESIST REFLOW | GRAYSCALE

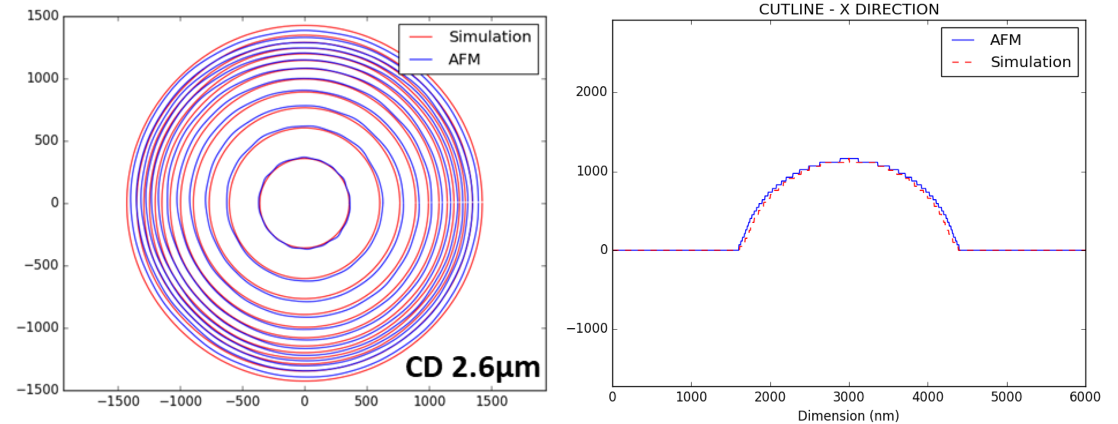
- **Low cost simulation flow for microlens shape optimization**
  - **Reflow compact model** calibrated on 300mm CD-SEM & AFM data



Experimental



Predicted



3D resist reflow compact model for imagers microlens shape optimization

S. Bérard-Bergery, CEA-Grenoble [10962-16]

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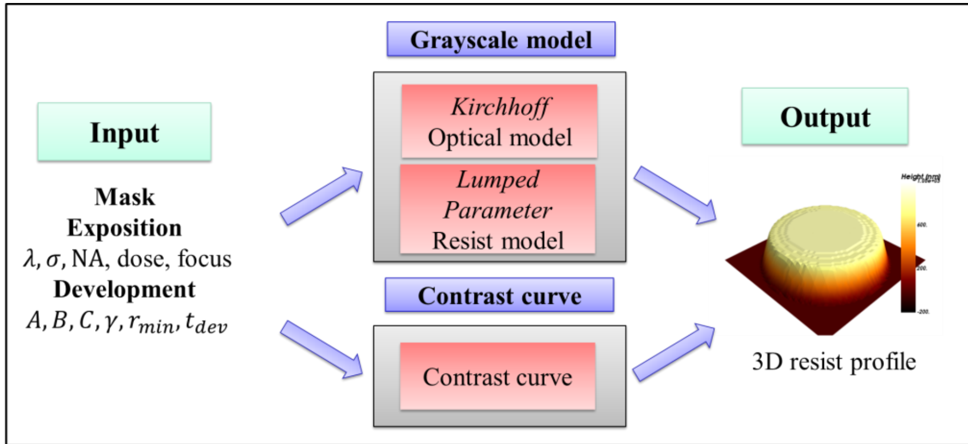
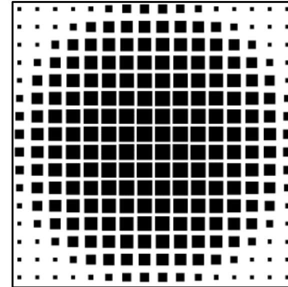
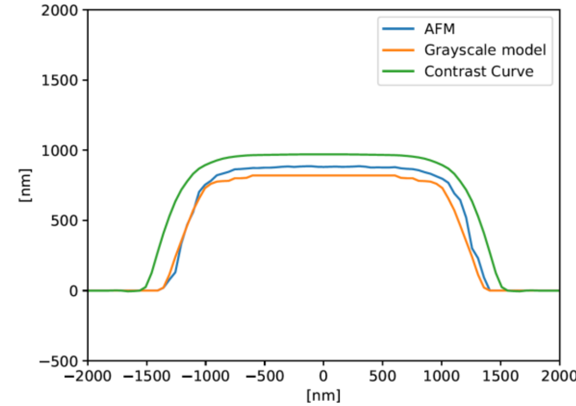
LITHOGRAPHY MODELING

OPC / EBPC MODELS | RIGOROUS SIMULATION | OPTICAL LITHOGRAPHY | E-BEAM | RESIST REFLOW | GRAYSCALE

Grayscale data-preparation side

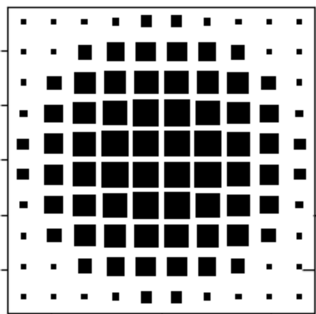


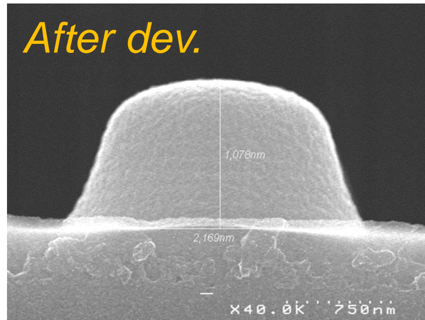


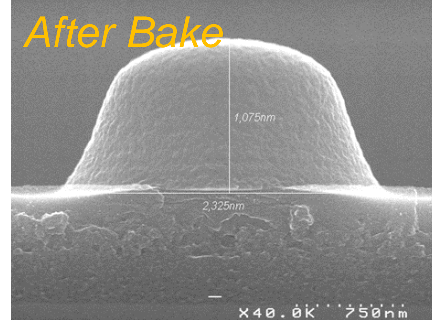


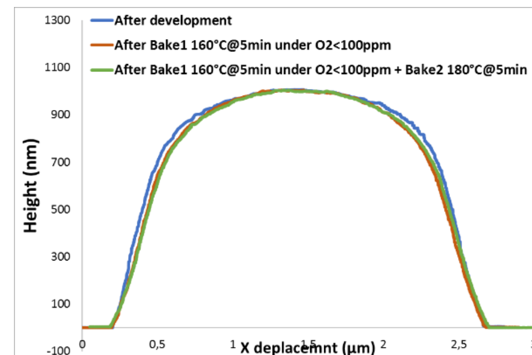
Beyond contrast curve approach: a grayscale model applied to sub-5µm patterns
P. Chevalier, STMicroelectronics S.A. - [10958-49]

Grayscale lithography process side









Grayscale lithography process study for sub 5µm microlens patterns
N. Allouti, CEA-Grenoble [10958-8]

CONTINUOUS WORK @ LETI

- **300mm lithography capability**
- **Pursue Grayscale technology development**

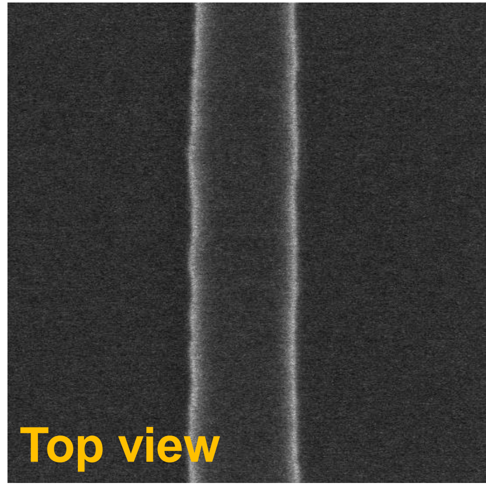
CLG – COMPUTATIONAL METROLOGY @ SPIE 2019

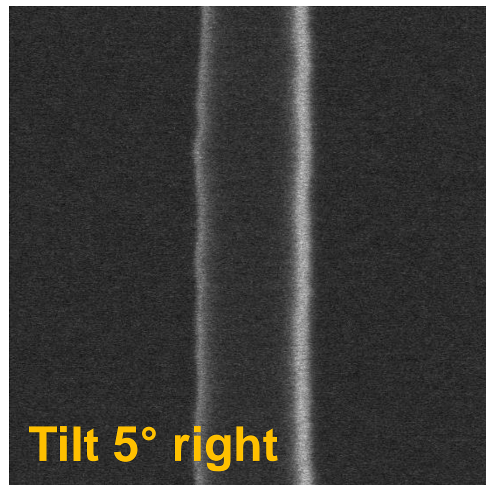
COMPUTATIONAL METROLOGY

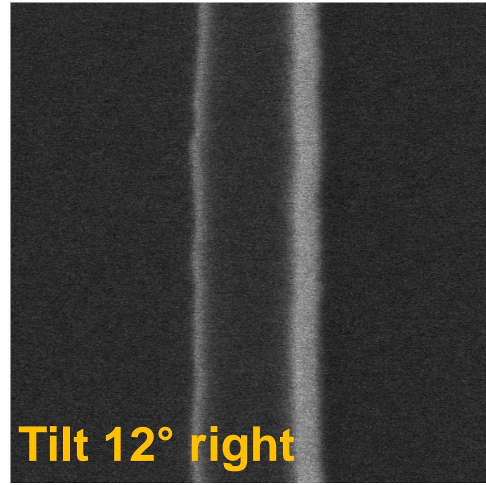
IMAGE PROCESSING | SEM SYNTHETIC IMAGES

SEM CONTOURS EXTRACTION | 3D METROLOGY | METRICS

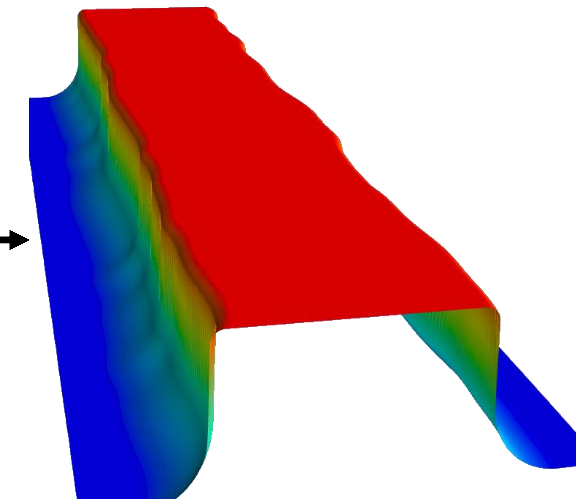
- **3D topography information recovery**
  - Using tilted beam CD-SEM Verity tool



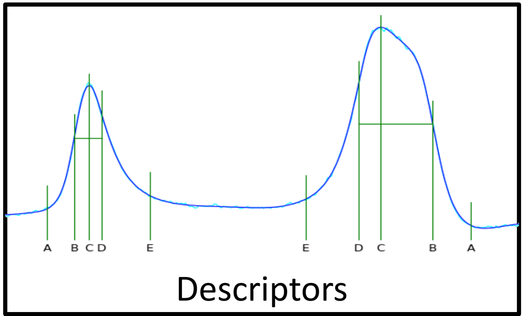


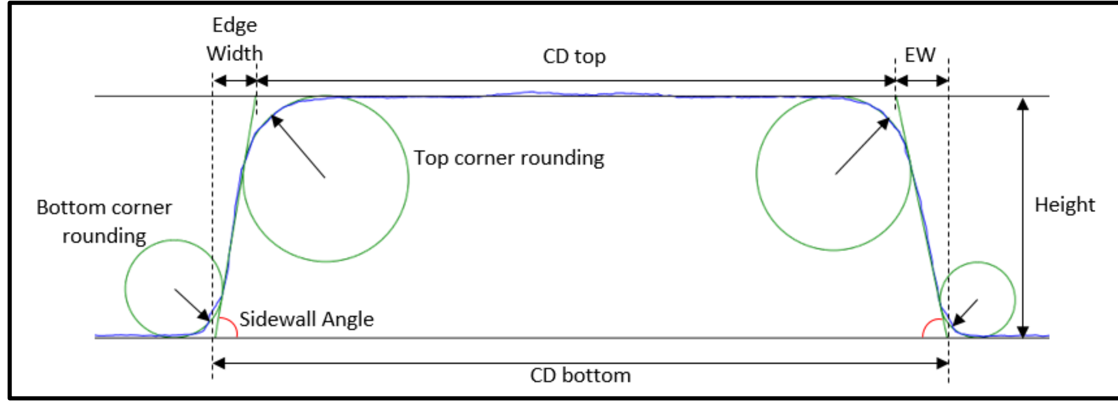


Model



Continuous work for the coming years.





Tilted beam SEM, 3D metrology for industry

C. Valade, STMicroelectronics S.A. [10959-32]

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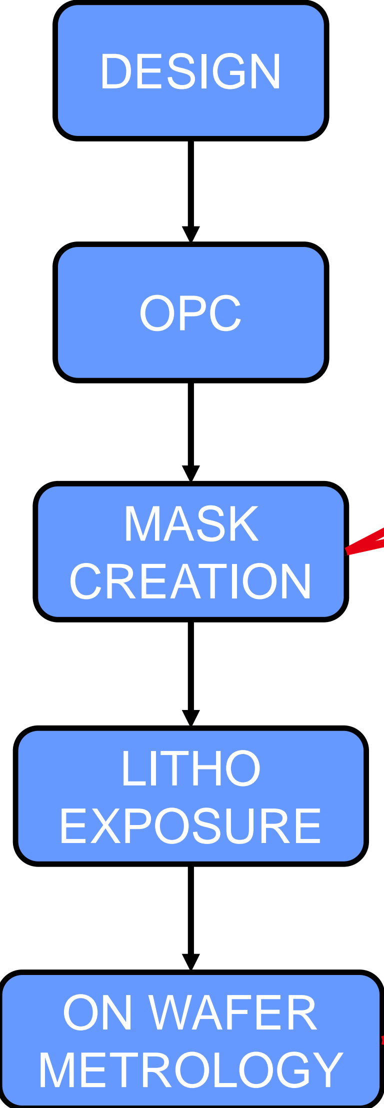
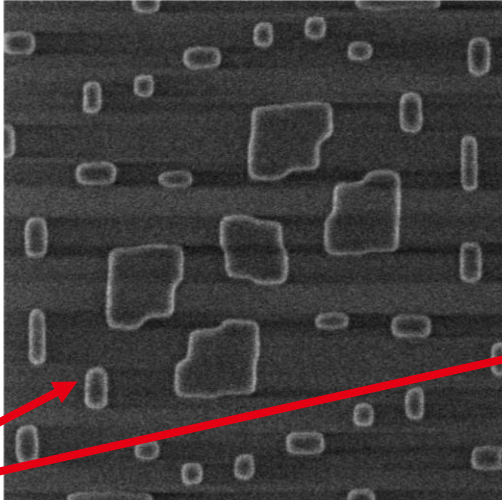
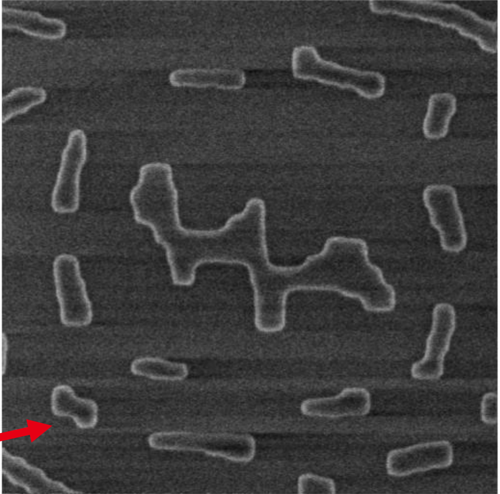
2D COMPUTATIONAL METROLOGY - WHICH NEEDS ?



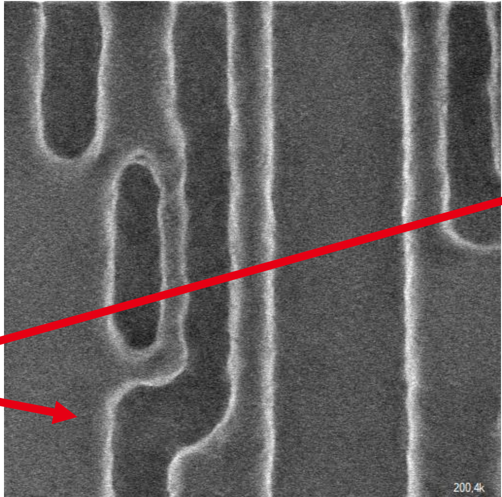
Conventional OPC

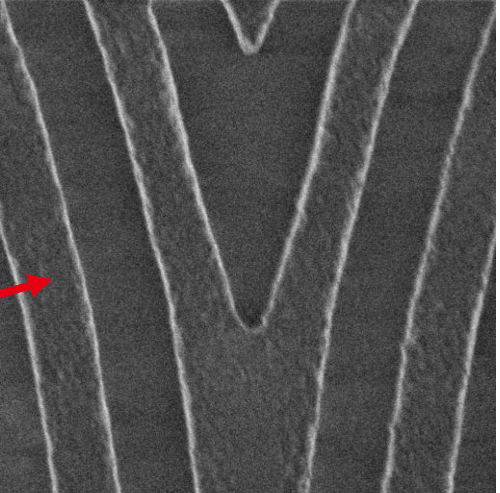




ILT output

Product Hotspot





Photonics waveguide

Maskshops can make it.

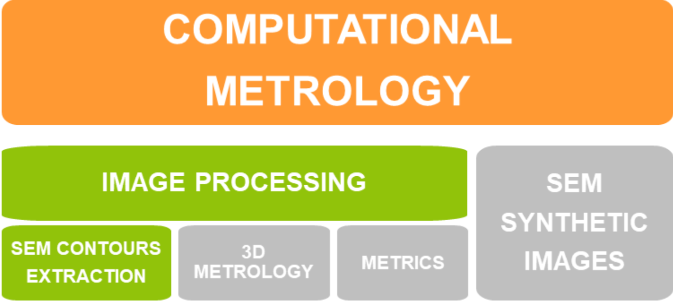
But how to control and measure it?

SEM contours

But how to control and measure it?

Lithographers can print it.

COMPUTATIONAL METROLOGY – MASK SEM IMAGES



- Lithography **full flow expertise** → from OPC to lithography exposures…
- …but advanced lithography requires great attention !

ILT OPC output → *Mask images* → *SEM contouring*

15 mask contours

LETI contour extraction solution

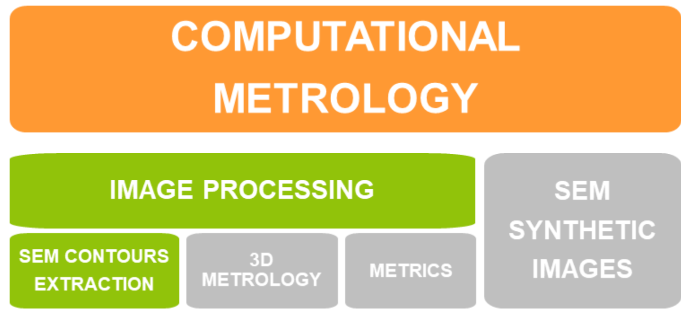
Industrial transfer to aselta NANOGRAPHICS

Algorithm solution for mask SEM images

Robust to noise & charging effects

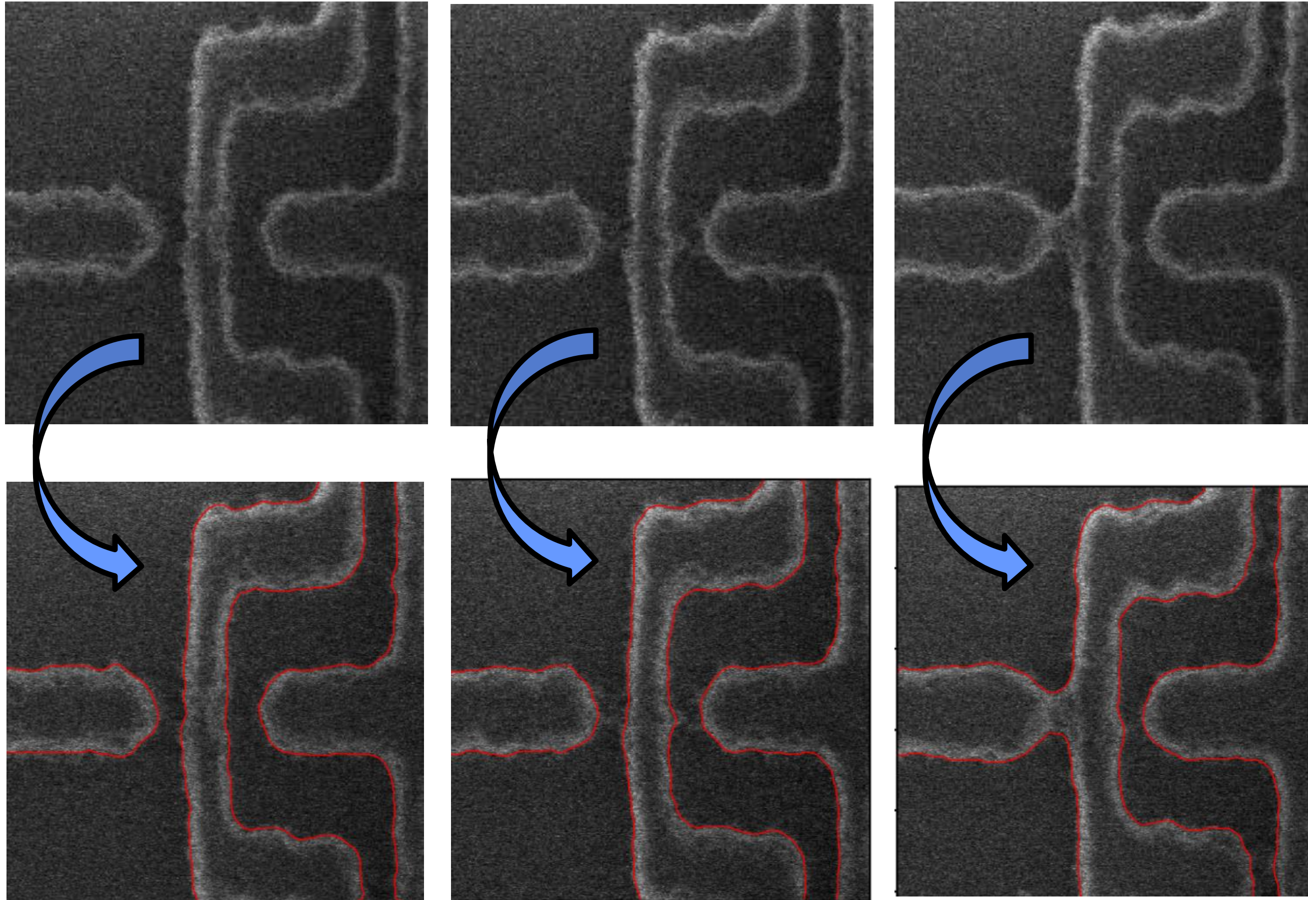
Non CAD aware

COMPUTATIONAL METROLOGY – WAFER SEM IMAGES

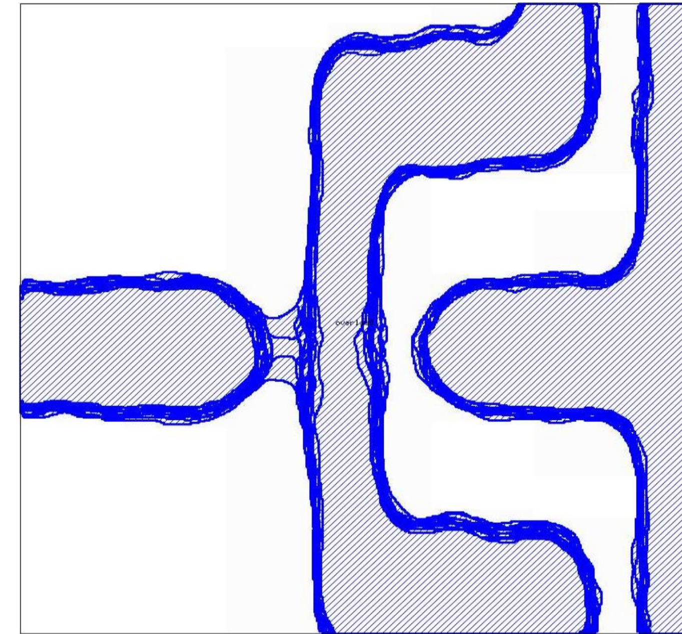


- Lithography **full flow expertise** → from OPC to lithography exposures…
- …but advanced lithography requires great attention !

Low frame CD-SEM images



Algorithm solution for contour detection



LETI contour extraction solution

Transfer to aselta NANOGRAPHICS

Application case GLOBALFOUNDRIES

- **Robust solution to noisy images**
- **Unaffected by topology changes**
- **Non CAD aware**

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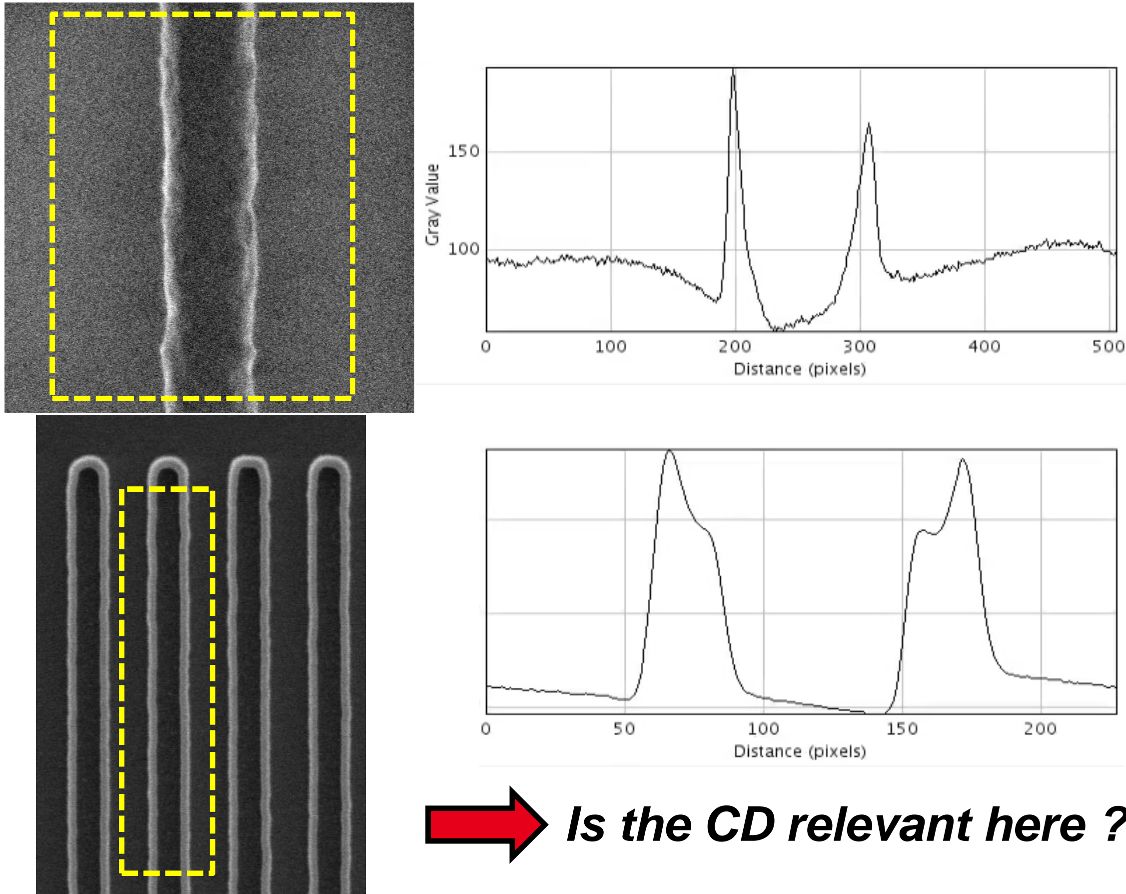
TOWARDS 3D COMPUTATIONAL METROLOGY

- **Metrological challenges evolution**

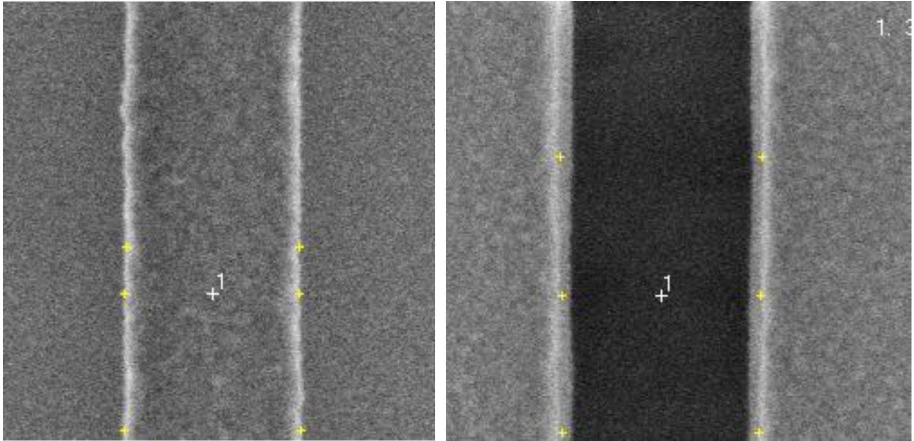


Is the CD relevant here ?

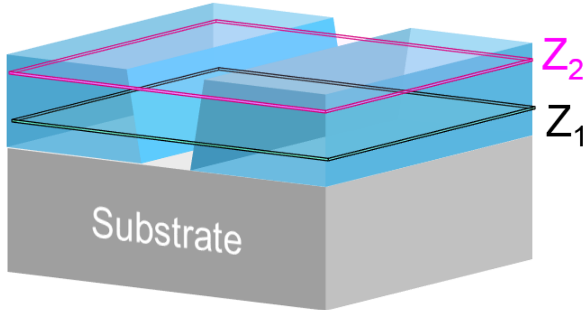
- Isn't the 3D information contained in the CD-SEM images as important as the CD ?

Any other interest to have access to 3D information ?

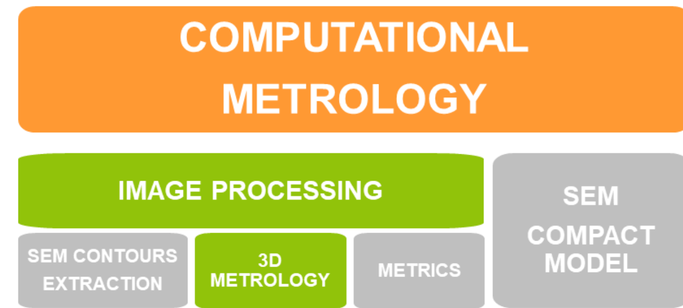
- Example: OPC resist model calibration



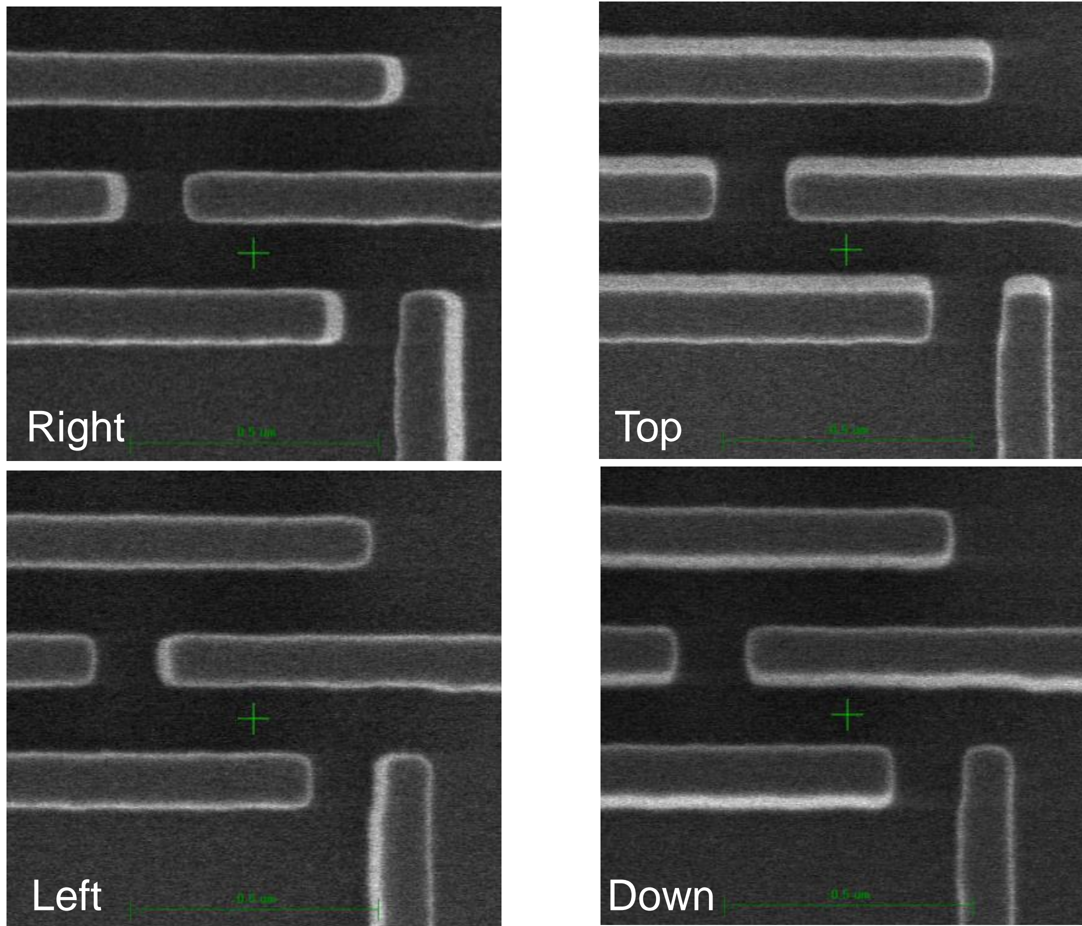
2 CD measured, but not at the same height.



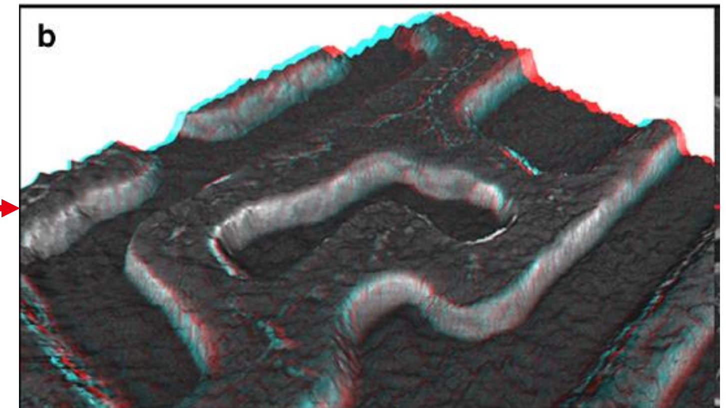
COMPUTATIONAL 3D METROLOGY



- **3D topography reconstruction method using…**
  - Azimuth tilted beam CD-SEM images from Verity tool
  - Stereophotogrammetry technique

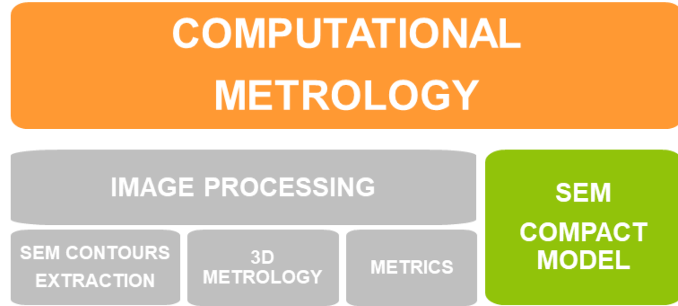


3D reconstruction from geometrical considerations



Three-Dimensional (3D) Nanometrology Based on Scanning Electron Microscope (SEM) Stereophotogrammetry
V. Tondare, J. Villarubia and A. Vladar (2017)

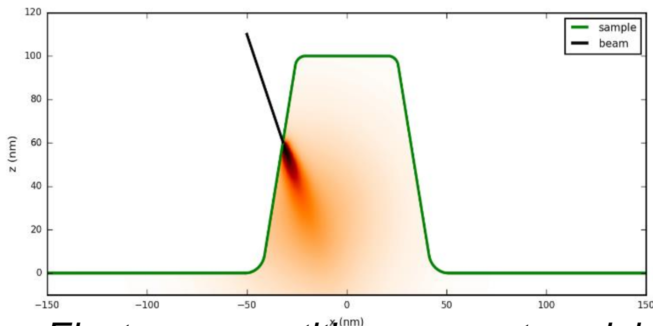
COMPUTATIONAL METROLOGY – SEM COMPACT MODEL



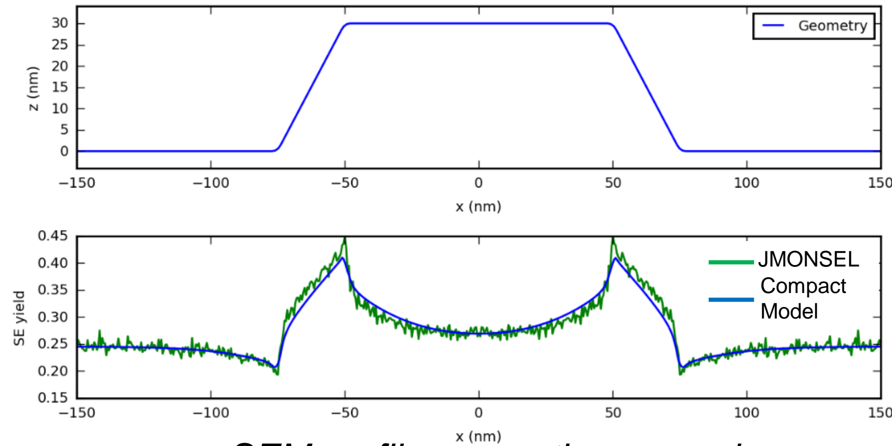
- **Double objectives**
  - 3D topography information from **electron diffusion inversion**
  - Fast SEM images synthesis

Collaboration with John Villarubia NIST

JMONSEL Monte Carlo simulations for calibration



Electrons repartition compact model

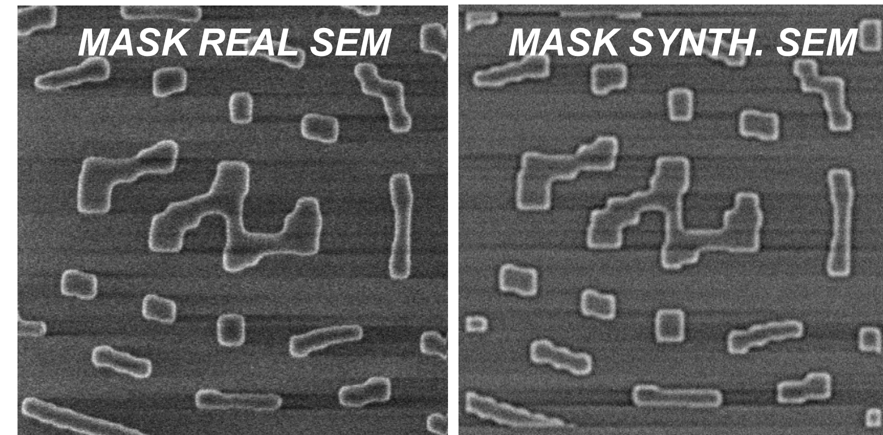


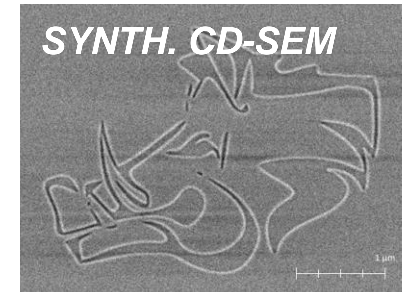
SEM profile generation example

- *Which 3D geometrical information contained in CD-SEM images ?*
- *With which precision ?*

Limits of model-based CD-SEM metrology
J. Bélissard et al., EIPBN 2018

SEM images synthesis with charging effects





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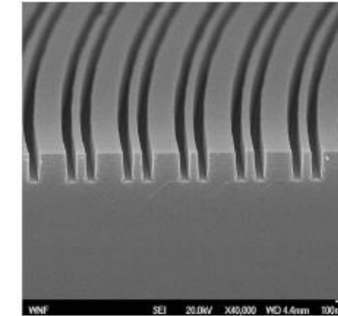
CONCLUSIONS

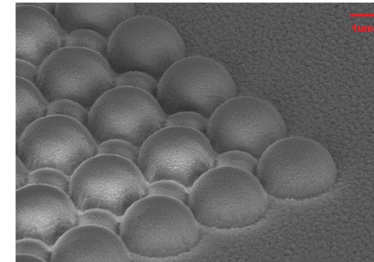
- **Computational Lithography & Metrology expertise**

Data Preparation *(optical, e-beam)*	Compact Models *(resist, SEM)*	Image Processing Data Treatment	Computational Metrology *(2D & 3D)*

- **2019 direct topics of interest**
  - **Silicon Photonics**
    - **Data-preparation:** OPC solutions, fracturing & mask writing
    - **On-wafer results:** correlation between mask & wafer level results
    - **Curvilinear 2D metrics** development



  - **Imagers support: microlens definition**
    - **Push Grayscale** alternative lithography technique
    - Resist thermal reflow compact modeling



  - **Computational Metrology**
    - Close colaboration on 2D & 3D

Industrial transfer

End Users

and others …

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THANK YOU FOR YOU ATTENTION

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