Scatterometry for the measurement of Nano Imprint Lithography Process

BLANCQUAERT Yoann – 11/05/23

Summary

1. **Metrology techniques for micro-electronic lithography processes**

2. **The Scatterometry technique**

3. **The scatterometry for nanoimprint lithography**

4. **Advanced capabilities**

1. Metrology techniques for micro-electronic lithography processes

- Lithography processes
- Metrology techniques

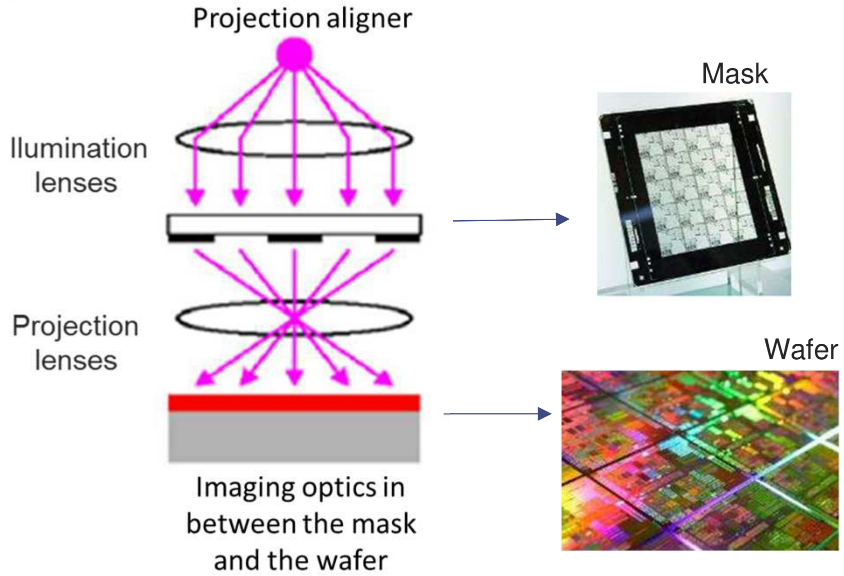
The main lithography processes in micro-electronics field

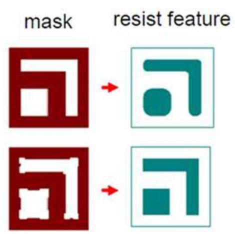
- <u>Photo-lithography</u>:
  - Technique widely used in industry and development Institute
  - Principle:
    - photo-lithography = lithography with light
    - Reproducing a pattern from a model

    - Depending on the Rayleigh criterion for the resolution:

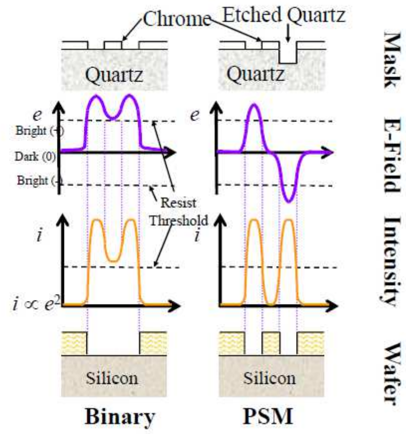
$$\delta = 0.61 \frac{\lambda}{n \sin \theta} \quad \text{or} \quad \delta = k1 \frac{\lambda}{NA}$$

      - To decrease K1: Optical Proximity correction (OPC), Phase Shift Mask (PSM), …
      - To Increase NA:
        - $n \sin \theta$: from air to water (between projection lenses and substrate)
      - To decrease illumination wavelength (λ)
        - From λ =365nm to 13nm with EUV





OPC



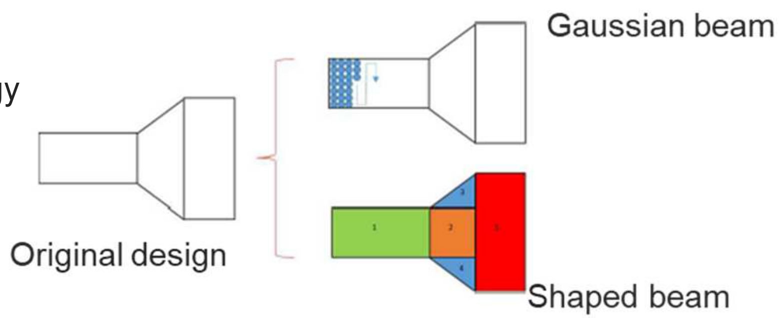
PSM

The main lithography processes in micro-electronics field

- <u>Ebeam lithography:</u>
  - Photolithography is a lithographic technique widely used, particularly for its throughput, but limited by its resolution (Rayleigh criterion)
  - Principle:
    - Scanning an electron beam across the surface of a resist-coated substrate → localized modification of the resist chemistry → the exposed surfaces can be used to generate small structures directly.
  - Ebeam lithography is an alternative with:
    - High resolution (few dozen nanometers)
    - High flexibility[1]: direct writing with an electron beam (no mask)
  - But: relative long exposure time, low throughput …

Gaussian beam

- Projection of a spot with a Gaussian energy profile
- Point by point writing
- High resolution (beam size ~20nm)



Shaped beam

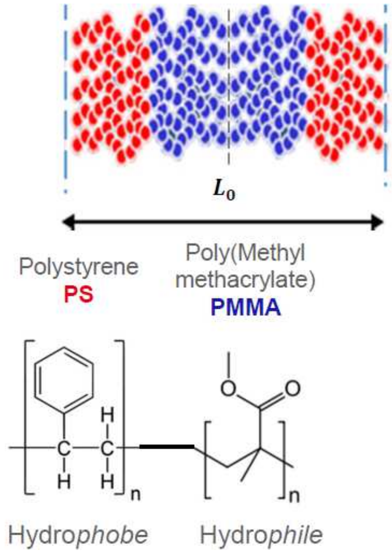
- A wide, homogeneous beam deflected, passes through two sets of patterns to obtain an elementary shape
- Faster writing
- Lower resolution (~30 nm)

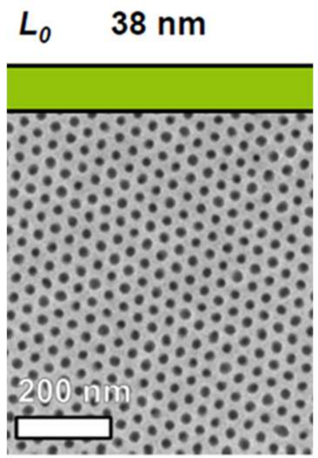
1- Servin, I. Blancquaert, Y., "Process development of a maskless N40 via level for security application with multi-beam lithography", SPIE, V.10584, (2018).

The main lithography processes in micro-electronics field

- <u>Direct Self Assembly (DSA):</u>
  - The self-organization of block copolymers is an original approach[1] to the fabrication of nano-objects. This material has the property of organizing itself into dense networks of ordered objects within thin films. The attractive dimension described by the organized networks (5 to 50 nm) has integrated block copolymers into semiconductor nanolithography technologies.
  - Principle:

Block copolymers composed of two blocks of the monomers





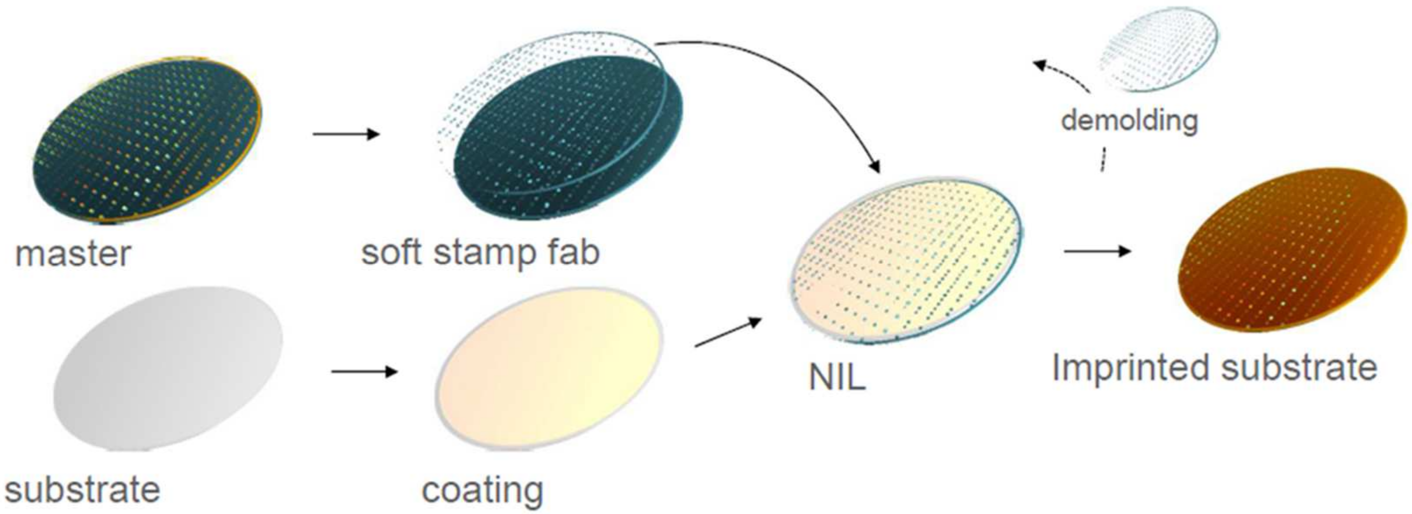
CD-SEM measurement

Courtesy of Lithography LETI team

1- Landis, S. Blancquaert, Y., "Nanoimprint, DSA, and multi-beam lithography: Patterning technologies with new integration challenges", SPIE, V.10149, (2017).

The main lithography processes in micro-electronics field

- Nano-imprint at CEA-LETI[1]:
  - A method in which a stamp pressed onto a film of polymeric material lets a nano-sized pattern
  - Principle:
    - Printing to wafer size using a flexible mould



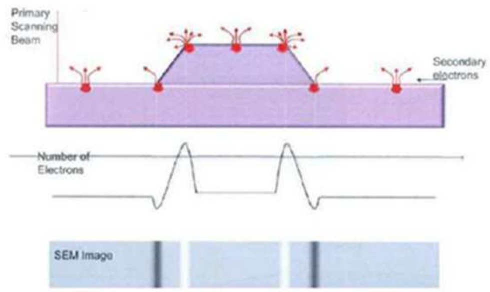
Courtesy of H.Teyssèdre (CEA-LETI)

1- Teyssèdre, H., et al "A full-process chain assessment for nanoimprint technology on 200-mm industrial platform", Advanced Optical Technologies, V.6, pp227-292 (2017).

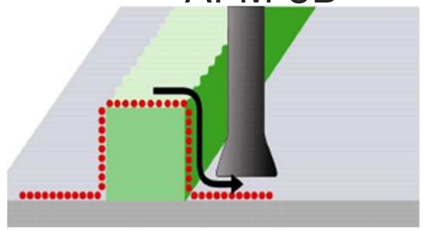
Metrology techniques for micro-electronic lithography processes

- Different Metrology
  - For material caracterization
    - X-Ray, Raman spectroscopy, ellispometry…
  - For surface topography
    - Atomic Force Microscopy (AFM), interferometry, …
  - For defectivity
    - SEM-EDX, …
  - We focus only on metrology techniques for patterning step (lithographie + Etching)[1]:
    - In the microelectronics industry
      - CD-SEM (Topview SEM) / Scatterometry (OCD)
      - AFM-3D[2]
      - TEM + FIB, SEM (X-section)

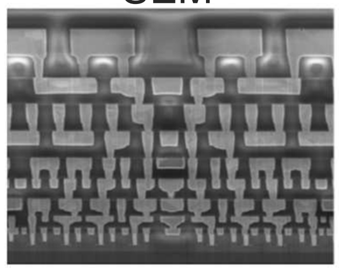
CD-SEM



AFM-3D



SEM



Cross-sectional view of CMOS transistor

1- Ma, Z. Seiler D.G., "Metrology and diagnostic Techniques for Nanoelectronics (1st ed.)", Jenny Stanford Publishing (2016).
2- Foucher, J., " From CD to 3D sidewall roughness analysis with 3D CD-AFM", Metrology, Inspection, and Process Control for Microlithography XIX, SPIE, (2005)

Metrology techniques for micro-electronic lithography processes

- In R&**D**
  - CD-SEM
  - MEB
  - AFM-3D
  - Scatterometry (OCD)

- Pros and Cons

Techniques	Destructive	Throughput	Time to solution	Statistic	3D-information	Measuring capability[1]
CD-SEM	+	+	+ +	-	-	+
OCD	-	+ +	- -	+ +	+ +	+
AFM-3D	-	-	+	-	+ +	+
MEB	+ +	- -	-	- -	+ +	+

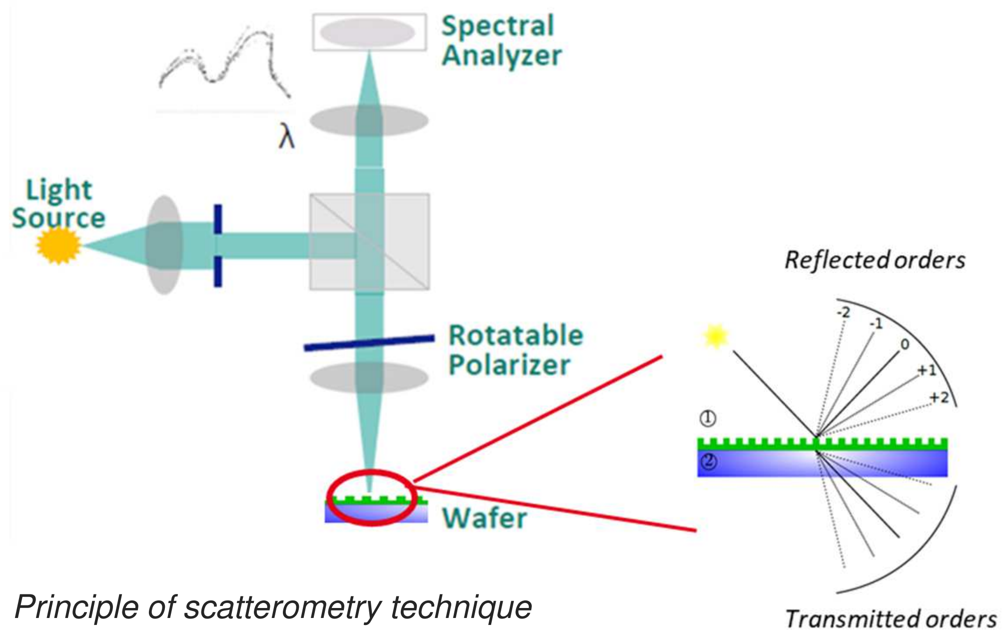
1- *Calaon, M., "Replication fidelity assessment of large area sub-µm structured polymer surfaces using scatterometry", Surf. Topogr. Metrol. Prop (2015)*

2. The Scatterometry technique

- Principle
- Method
- Study case

The Scatterometry technique

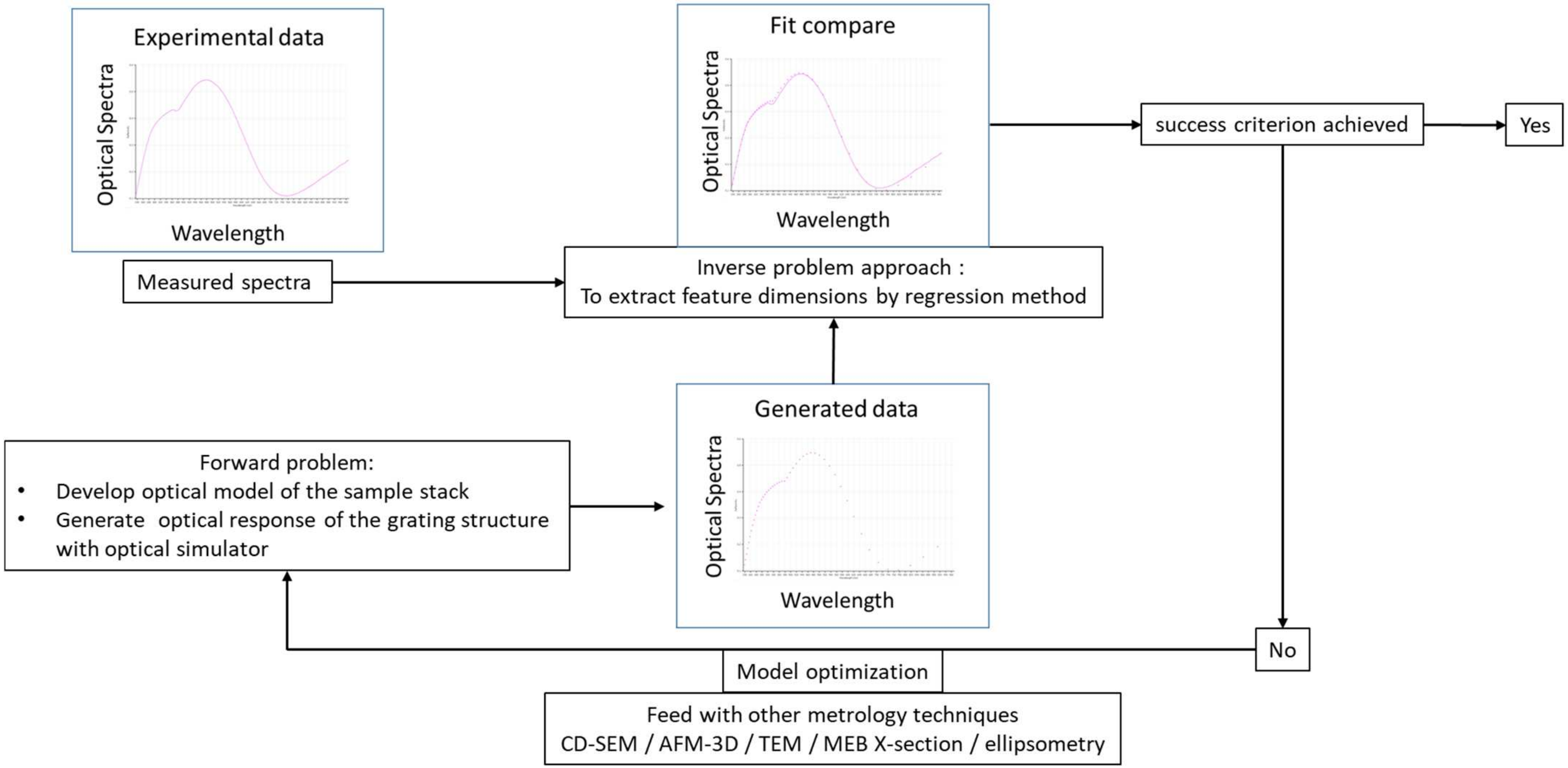
- Principle:
  - Scatterometry is an optical diffraction-based metrology technique used for measuring the feature dimensions of complex grating structures.
  - It is based on ellipsometric measurements coupled with highly advance modeling and fitting algorithms used to deduce feature dimensions from the phase and amplitude difference of the reflected beam.
  - scatterometry can be defined as the **measurement and characterization of light diffracted from periodic structures**



Principle of scatterometry technique

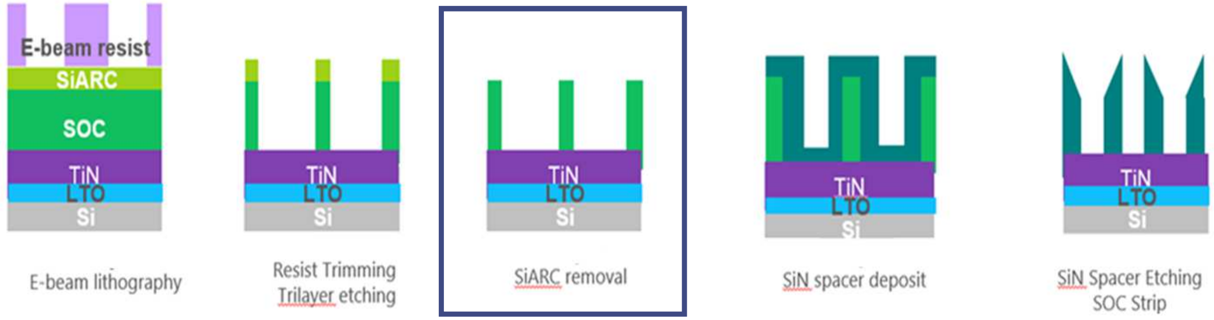
The Scatterometry technique

- Overview of scatterometry way of working:

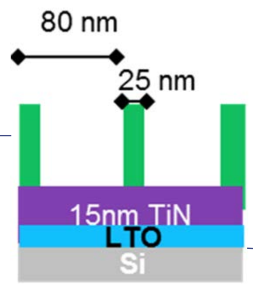


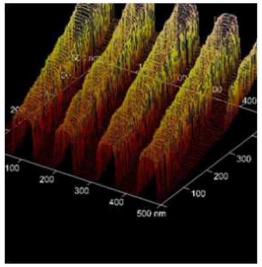
The Scatterometry technique

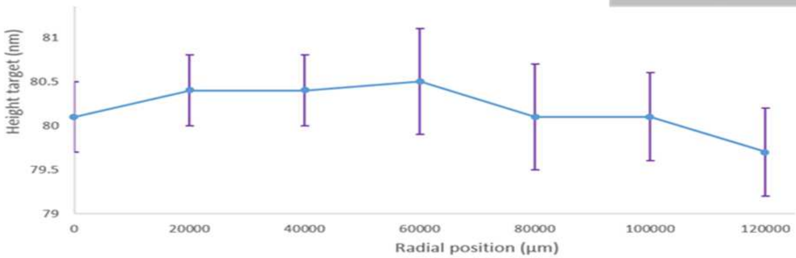
- Study case : measurement of advanced FD-SOI technology[1]



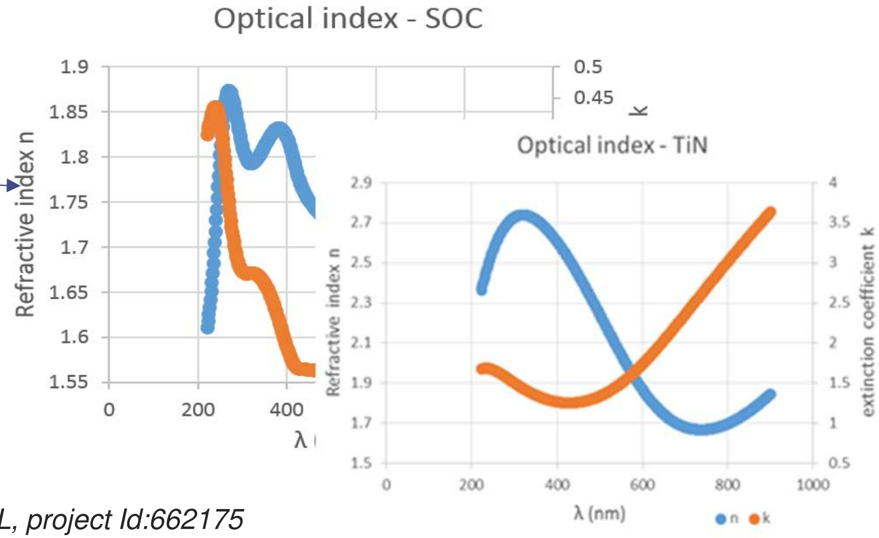
AFM-3D: The <u>3D view</u> in a 0.5x0.5µm² area and the <u>lines height</u> averaged with the associated dispersion.







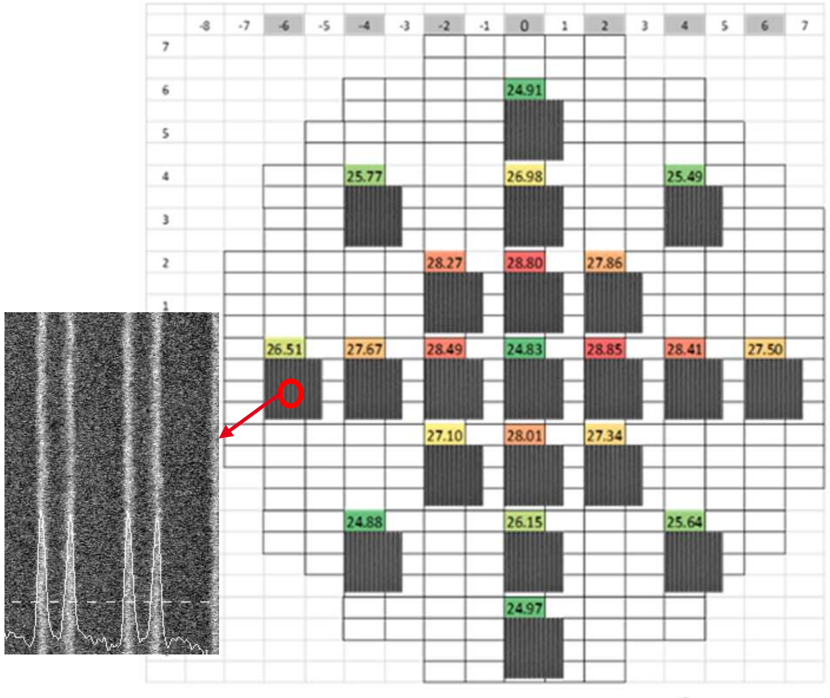
Ellipsometry: Optical index obtained from the ellipsometer with 3 different angles of the illumination



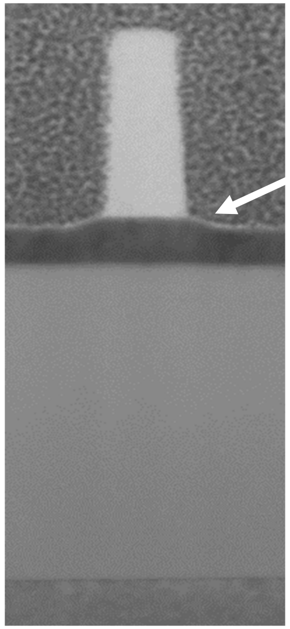
WayToGoFast, D1.3.0.4 " Scatterometry implementation on advanced FD-SOI technology , ECSEL, project Id:662175

The Scatterometry technique

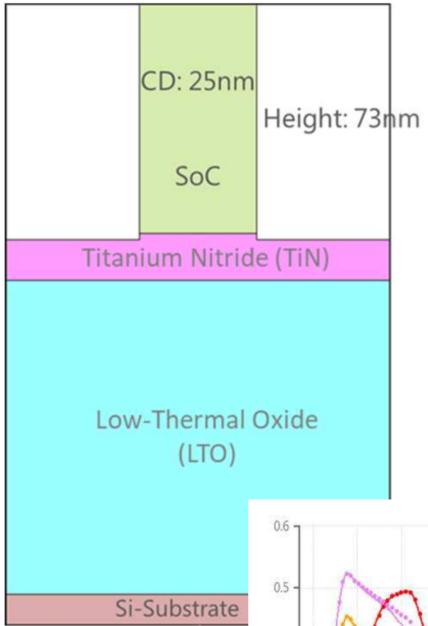
- Study case : measurement of advanced FD-SOI technology



CD-SEM mapping measurement. Reported values correspond to the average of 25 measurements.

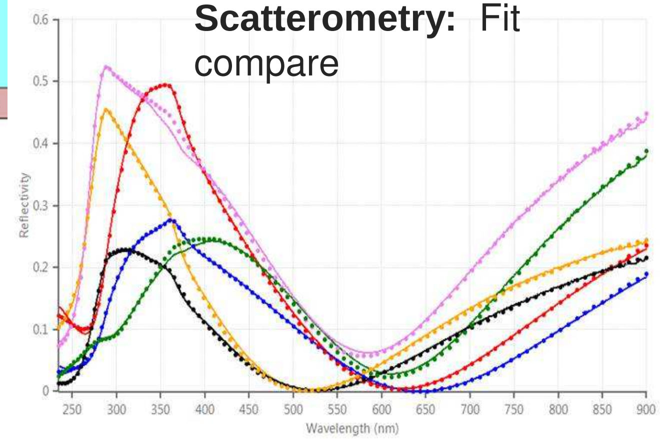


TEM image



Scatterometry: a two-dimensional geometrical stack to describe the SiARC Removal process step

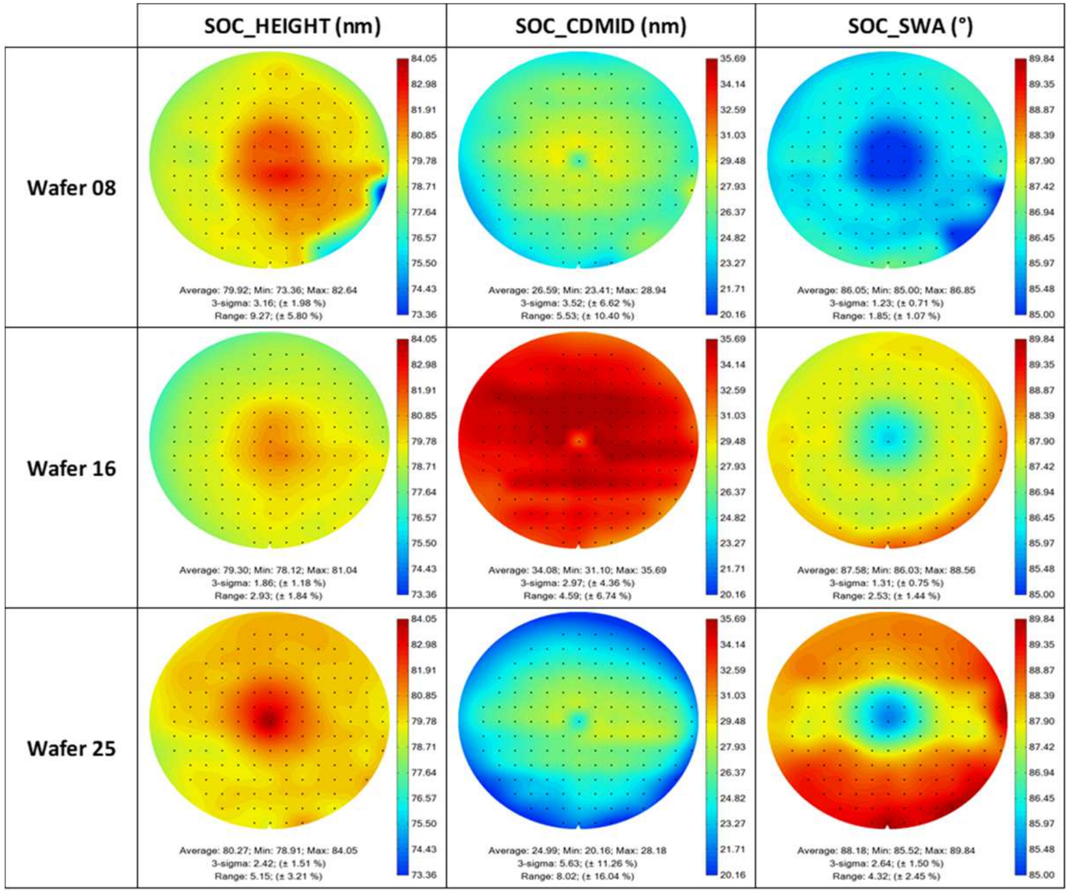
Scatterometry: Fit compare



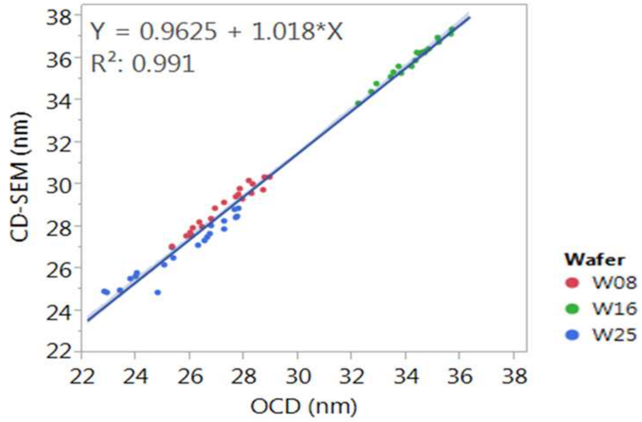
The Scatterometry technique

- Study case : measurement of advanced FD-SOI technology

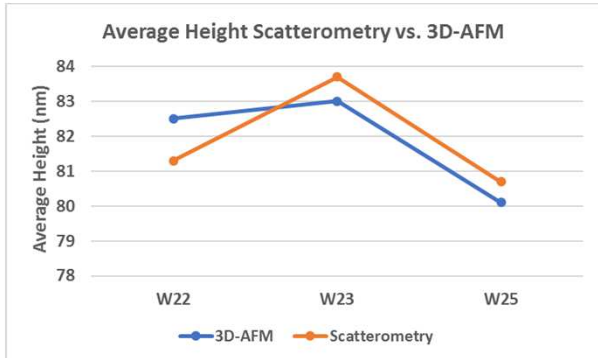
Results measurement mapping



Correlations with other metrology techniques



CD-SEM



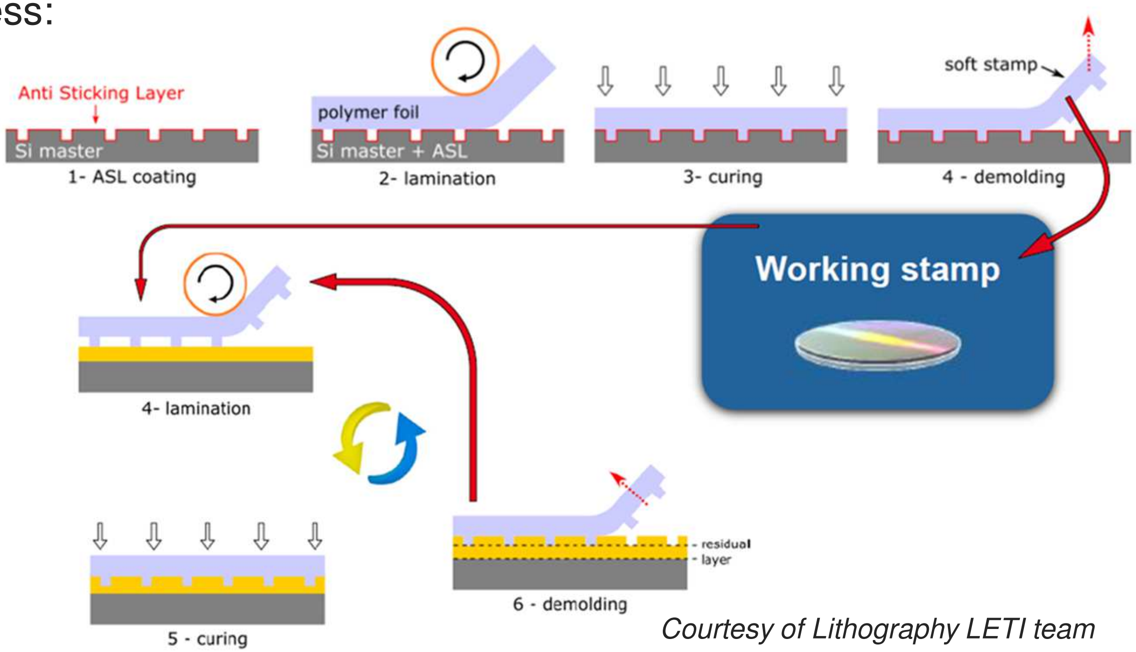
AFM-3D

3. The scatterometry for nanoimprint lithography

- Nano-imprint process at CEA-LETI
- Scatterometry development

The scatterometry for nanoimprint lithography

- Soft Stamp Nanoimprint Process:



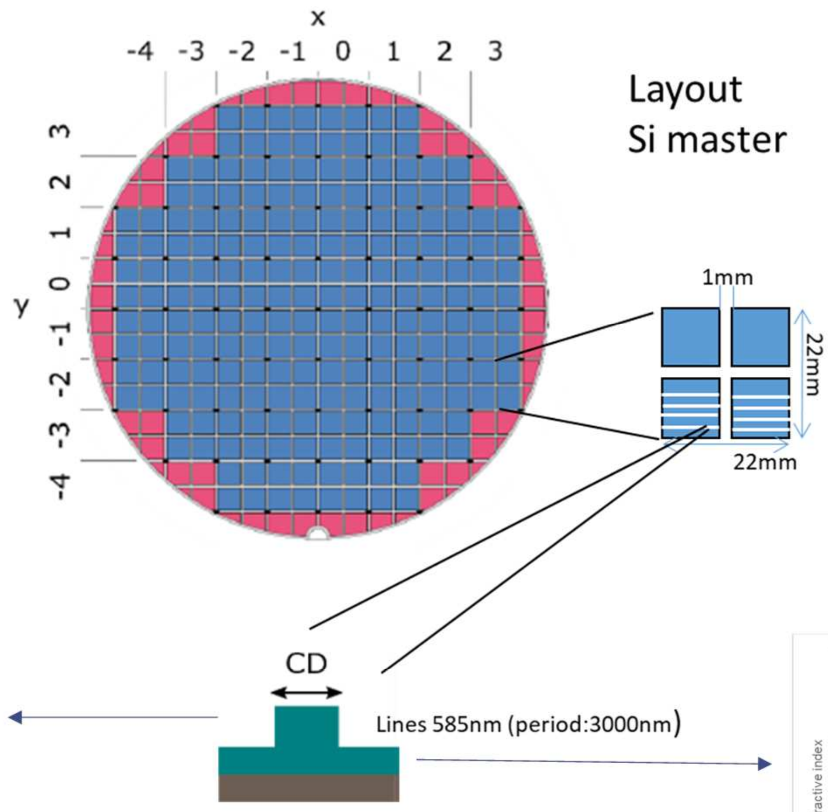
Courtesy of Lithography LETI team

- Identification of drifts imprint with regard to the design
- Investigate the link with physical mechanism
- CD uniformity (CDu) analysis to height and Residual Layer Thickness (RLT) on the wafer
  - analyzing CDu mapping to prepare the design rules for master' corrections
  - Link local variations with the distortion maps
- Metrology for massive measurements

The scatterometry for nanoimprint lithography

- Scatterometry development :

Samples: 200mm silicon wafer



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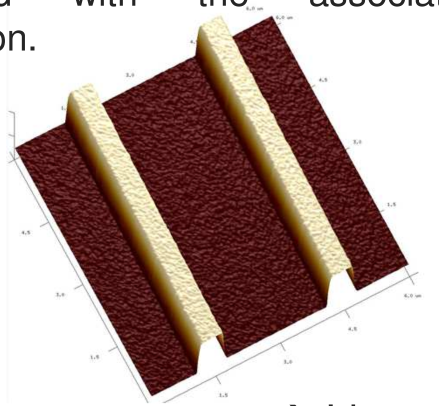

→ Lines height: 225nm

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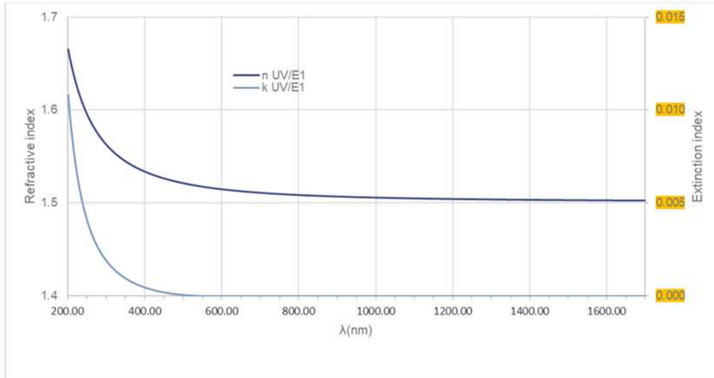
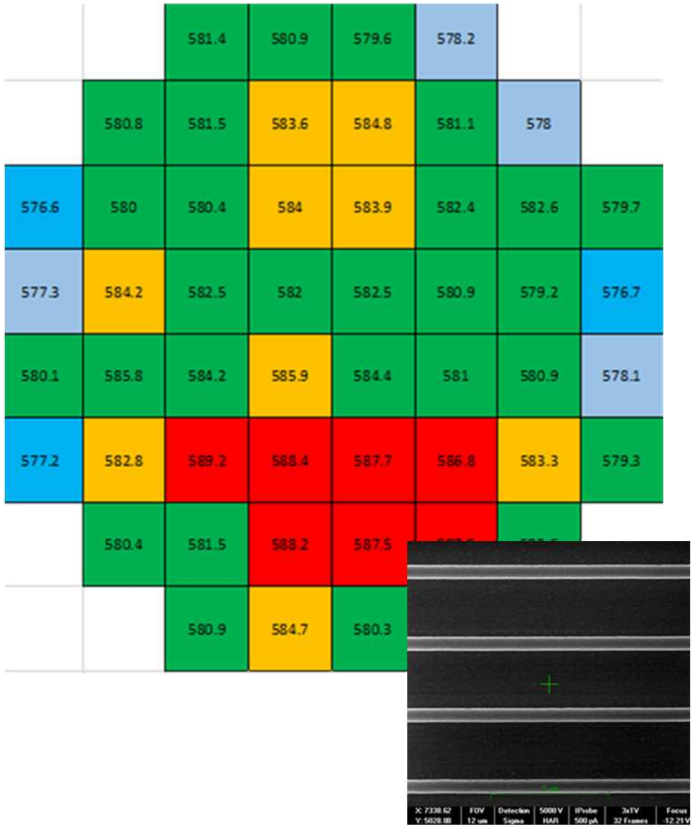
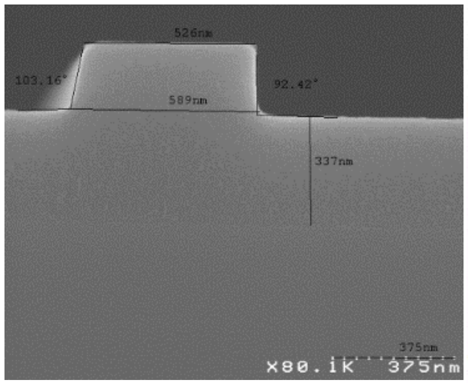


The scatterometry for nanoimprint lithography

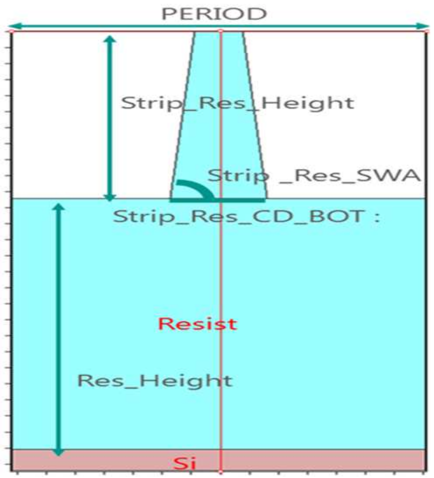
- Scatterometry development



CD-SEM mapping measurement.

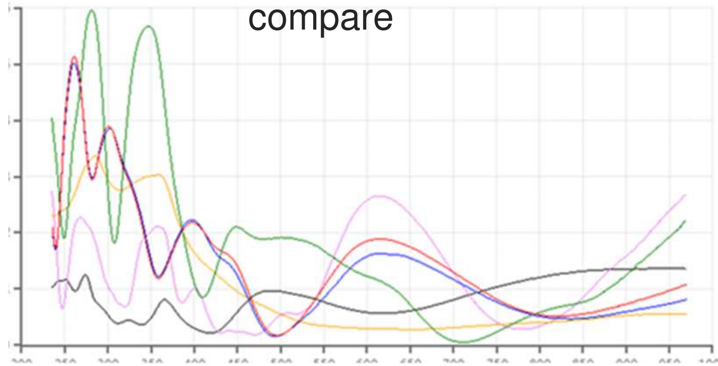


TEM image



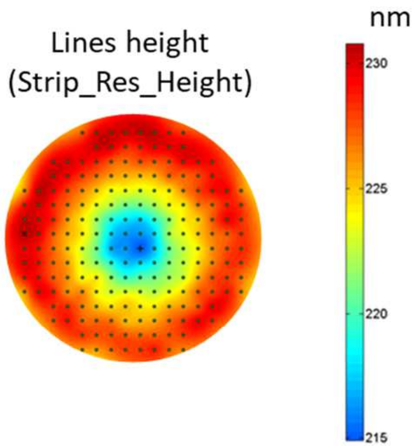
Scatterometry: a two-dimensional geometrical stack to describe the NIL process

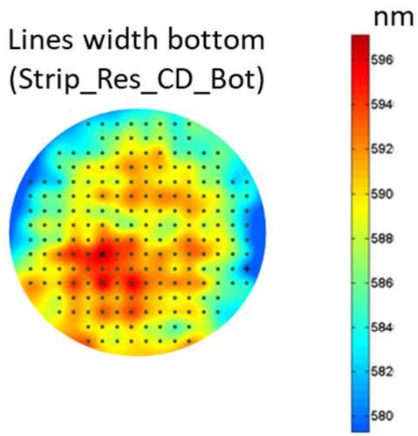
Scatterometry: Fit compare

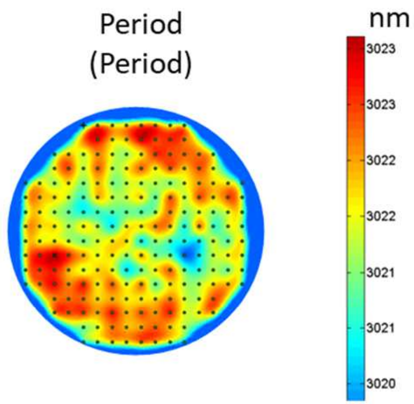


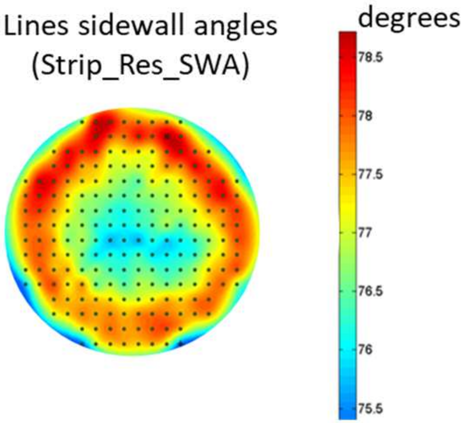
The scatterometry for nanoimprint lithography

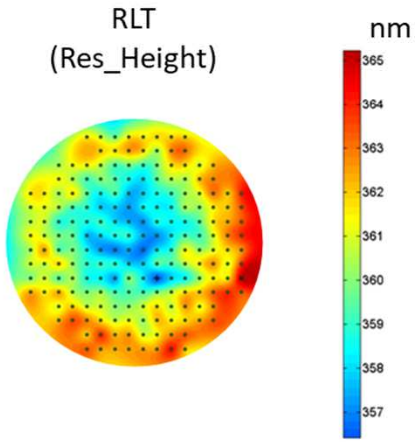
- Scatterometry development: **Results measurement mapping**











High sensitivity to the lines shape and Residual Layer Thickness (RLT) :

- Height, sidewall angles and lines width

- Radial fingerprints observed

Summary

- A first step with other metrology techniques is needed to have a **robust scatterometry measurements**
- **Statistical method** that allows complete mapping of samples

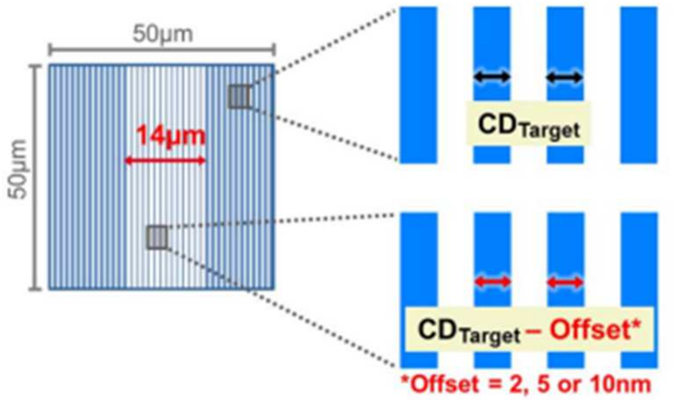
4. Advanced capabilities

- Scatterometry-based machine learning

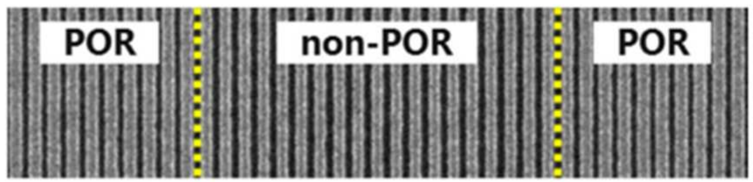
Advanced capabilities

- Scatterometry-based machine learning to control Multiple electron beams lithography[1]

The problematic: will scatterometry be able to detect non-uniformities in its acquisition area (50x50µm²)? **i.e. detection of one defect beam in multi-beam lithography**

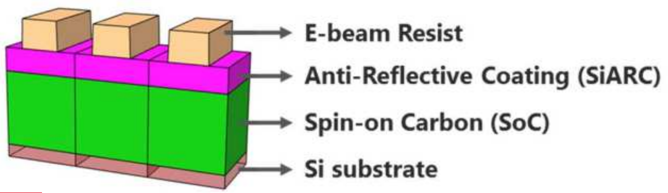


CD-SEM Measurement intra-target.

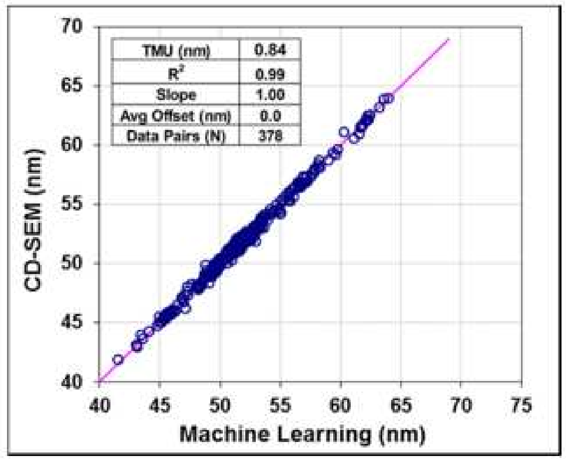


Scatterometry measurements + **Machine learning** (classify the different signature)

Stack used in this work



Correlation OCD machine learning based and CD-SEM



1- Figueiro, N., Blancquaert, Y., "Application of scatterometry-based machine learning to control multiple electron beam lithography", ASMC, IEEE (2018)

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