International Workshop on Advanced Patterning Solutions

IWAPS

IEEE

An Optical Critical Dimension (OCD) Study with Standard Structures

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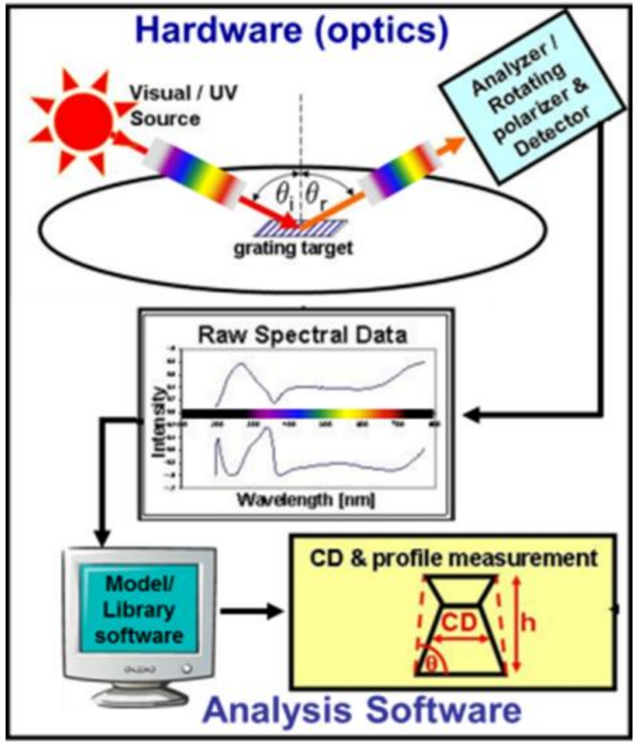
Optical Critical Dimension(OCD) Technique in Semiconductor Metrology

	<--Imaging Techniques				Spectroscopic Techniques-->				
Application	CD-SEM	E-SEM/ LLBSE-SEM/ HV-SEM	HeIM	CD-AFM	OCD	T-SAXS	GI-SAXS	TSOM	MBIR
MAM time	okay	okay	okay	high	excellent	very high	high	excellent	okay
Area of measurement	excellent	excellent	excellent	excellent	okay	okay	very high	okay	okay
Destructiveness	okay	high	very high	excellent	excellent	excellent	excellent	excellent	excellent

Pros

- ✓ fast, non-destruction and contamination free
- ✓ in-line-compatibility and process integrable
- ✓ structure profile sensitive and good 3D capability, multi-parameters
- ✓ comparison with local methods to eliminate random errors



Cons

- ☐ Parametric correlation, unambiguity
- ☐ Non-uniqueness of solutions for inverse light scattering problem
- ☐ Inapplicable to isolated lines

Brief Introduction of OCD technique

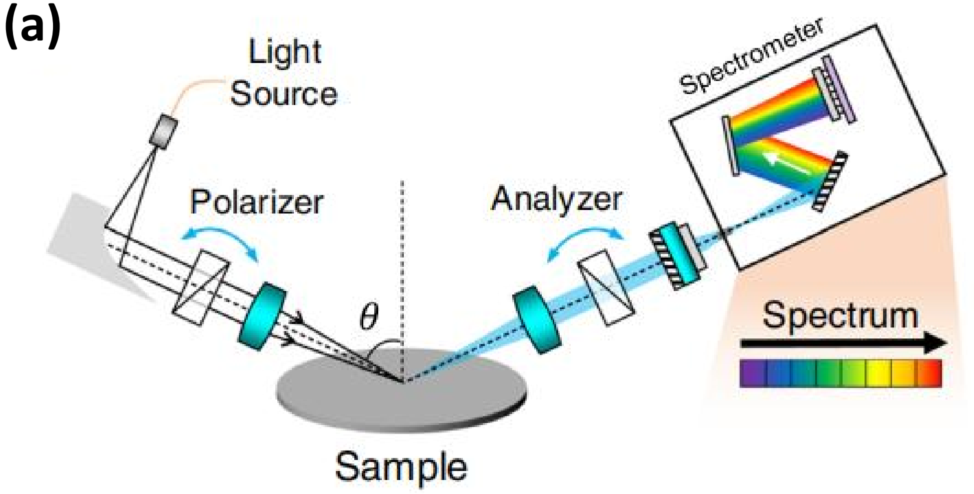
OCD technique measures property changes of the light caused by the interaction with the sample, use information to reconstruct the structures under test.

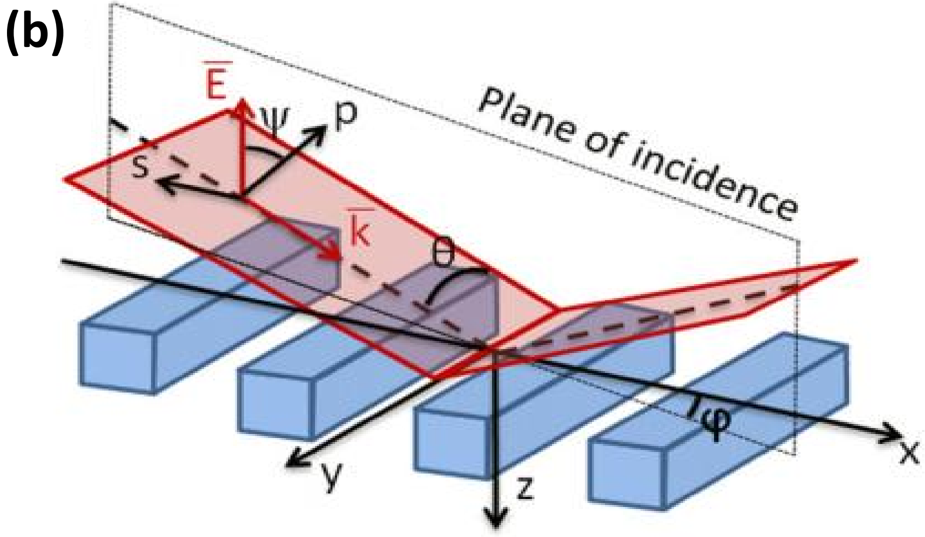
1. Properties of light, that can be measured with scatterometric methods are:

- Radiant power (diffr. efficiency h, amplitude)
  (type: pol. reflectometer, class. scatterometer)
- Direction of propagation
  (type: diffractometer)
- State of polarisation
  (type: ellipsometer, Mueller matrix)
- Phase information
  (type: interferometric scatterometer)

2. Classification after independent measurement variable:

a). spectroscopic b). angular





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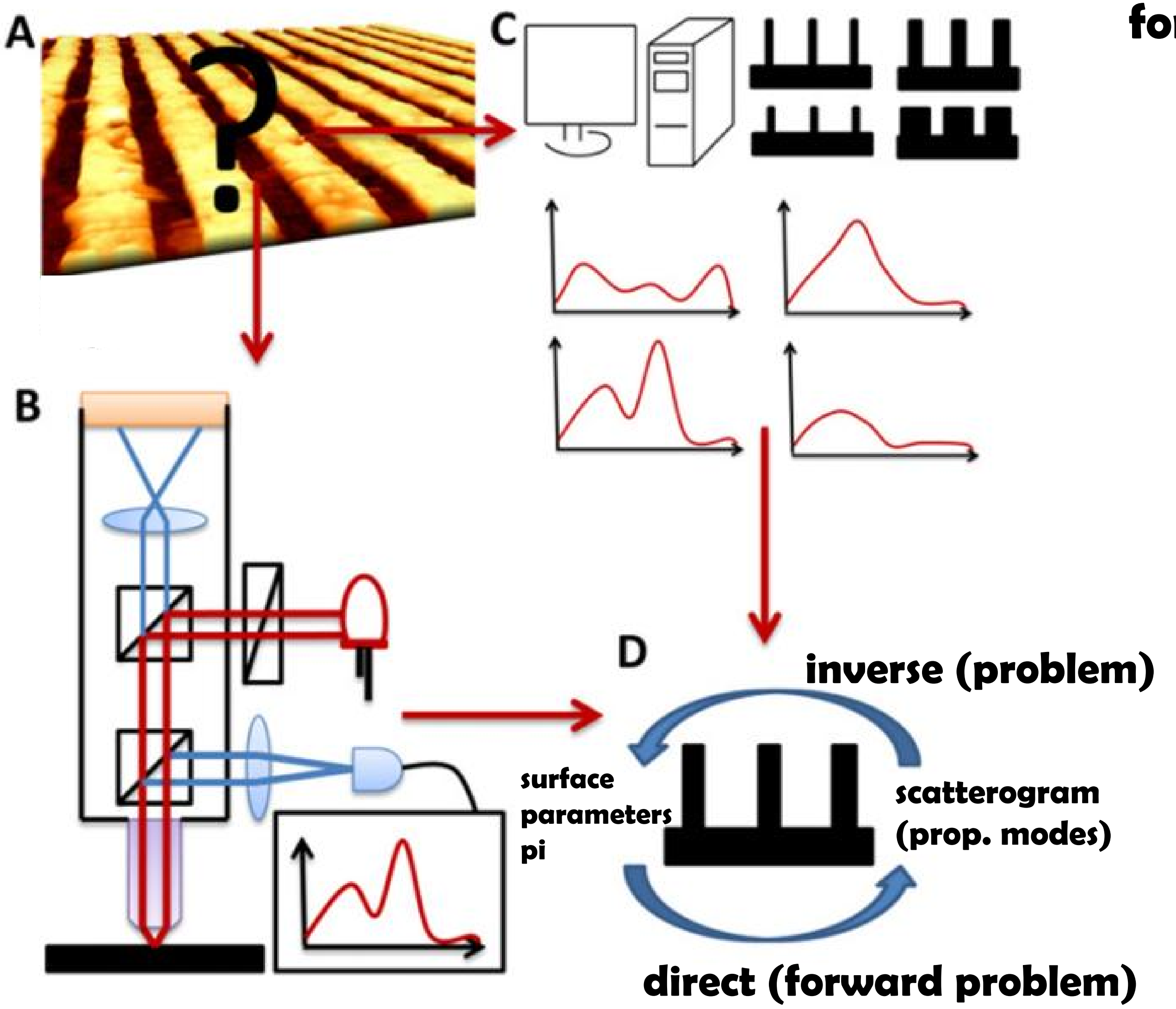
Current commercial OCD tools

OCD: A Model-Based Optical Metrology



forward problem:

Rigorous Calculation of Diffracted E- and H-fields by Numerical Solution of Maxwell's equations:

- Rigorous Coupled-Wave Analysis (RCWA)
- The Finite-Difference Time- Domain Method (FDTD)
- Finite Element Method(FEM)
- waveguide,...

inverse problem

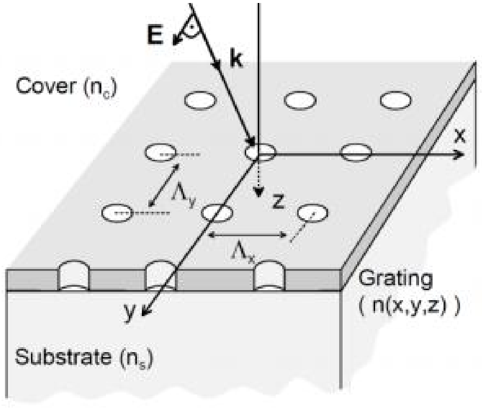
- library approach:
  - ✓ fast, robust, easy to use
  - ☐ long set-up time
  - ☐ large memory resources
- nonlinear optimisation:
  - ✓ more flexible, accurate
  - ☐ significantly slower
  - ☐ large computational resources

OCD Challenges in Advanced Technology Nodes

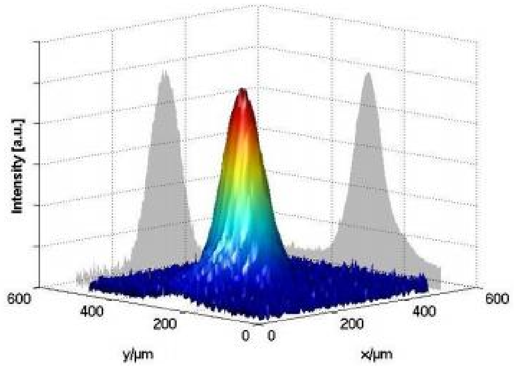
- Size shrinkage challenges for optical methods:
  - Sensitivity
  - Accuracy

  ⇒ size ~ wavelength/100
- Increasing complexity
  - increasing parameter correlations
  - ambiguity issues
  - computations costs (time and memory issues)
- Numerical Approximations:
  - periodic extension
  - computational volume and discretisation
- Infinite Interaction Area
  - finite spot size of illuminating beam
  - finite target grating size
- Neglection of Local Parameter Variations
  - CDU & stiching
  - stochastic parameters: depolarisation & diffuse scattering
  - surface roughness, LER & LWR
- Geometrical Structure Model
  - not just binary or trapezoidal
  - corner roundling

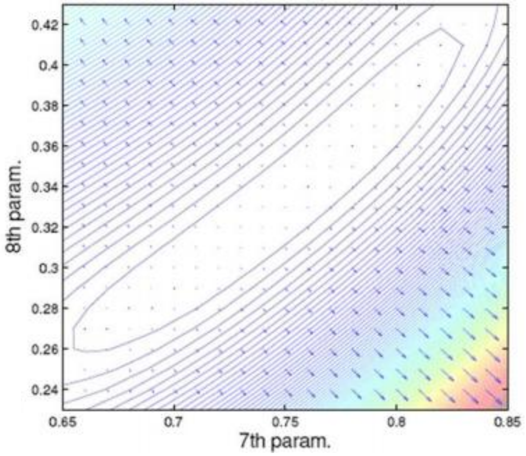
(a)



(b)



(c)



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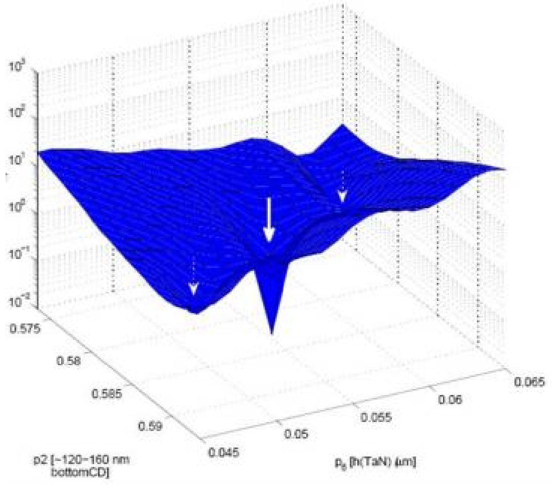
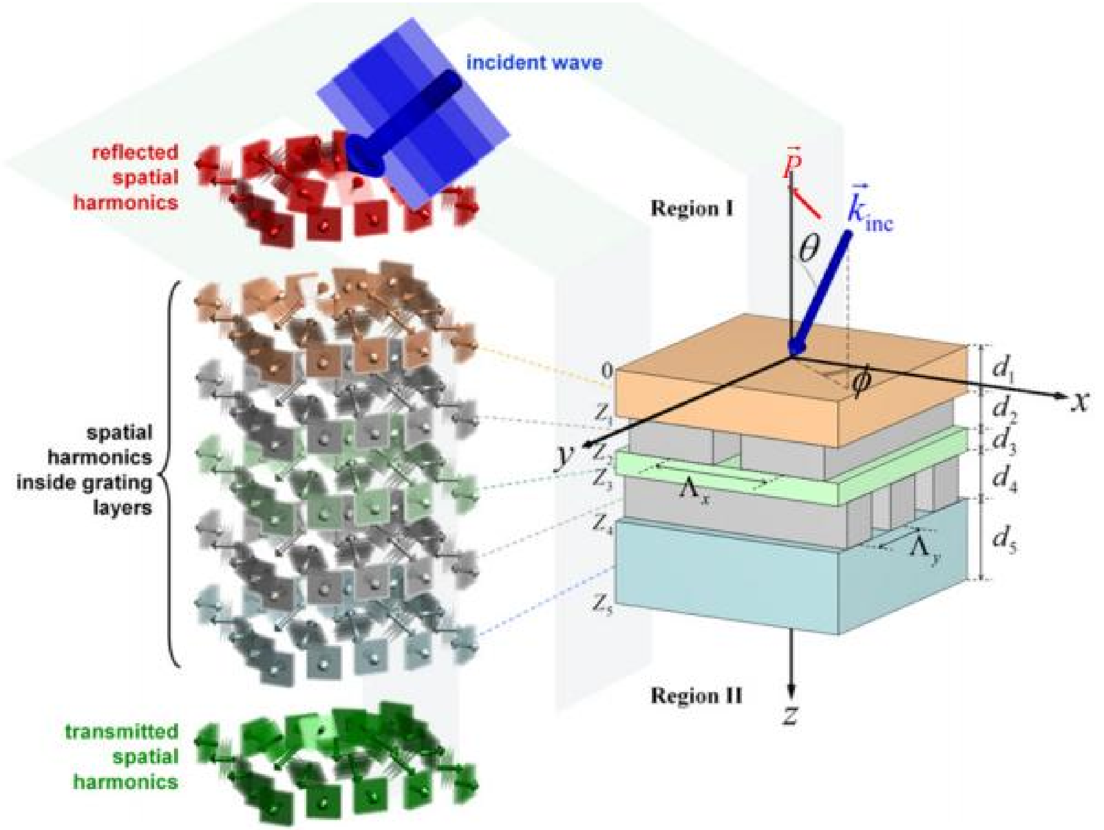


Modeling: Rigorous Coupled-Wave Analysis (RCWA)


Dr. M. G.“Jim” Moharam


Dr. Thomas K. Gaylord


Dr Li Lifeng



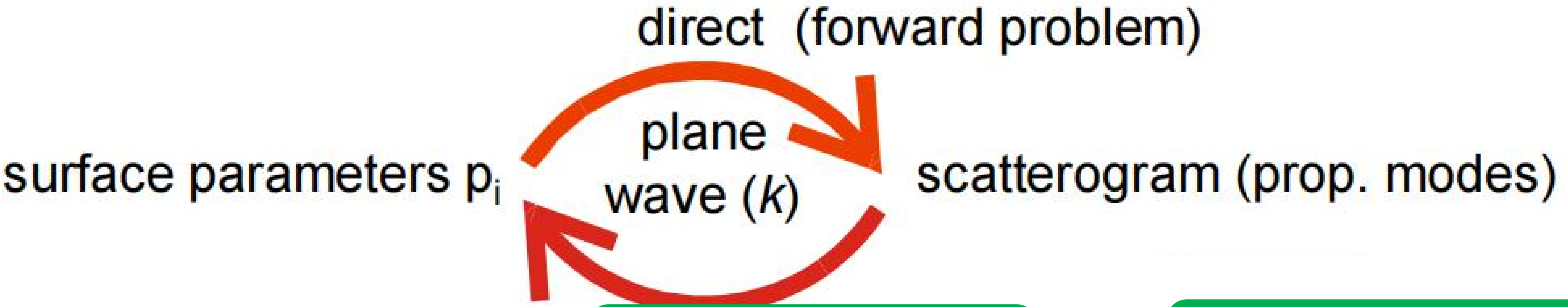
- ✓ In 1980s, RCWA is developed by Dr.Moharam and Dr.Gaylord
- ✓ In 1990s, Dr.Li promoted the S-matrix and R-matrix algorithms in grating numerical calculations

Alternate Names for this Method:

- Rigorous Coupled-Wave Analysis
- Fourier Modal Method
- Transfer Matrix Method with a Plane Wave Basis

The Necessity to Build Up Standard Structures Libraries

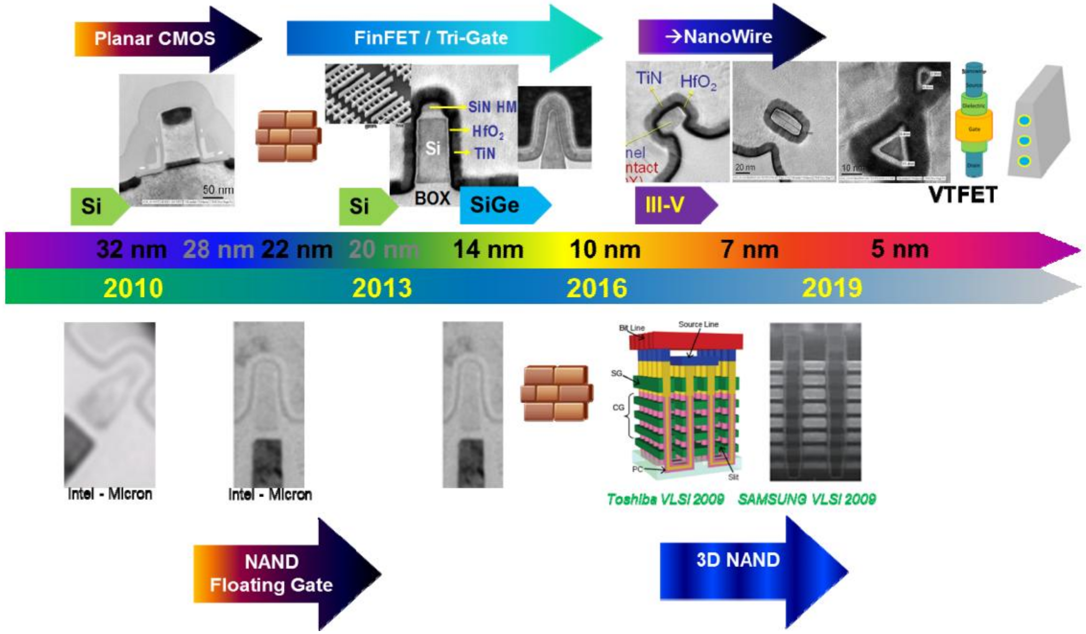
1.



inverse (problem) ⇨ library approach

2.Factory Calibration, Equipment Inspection and Maintenance

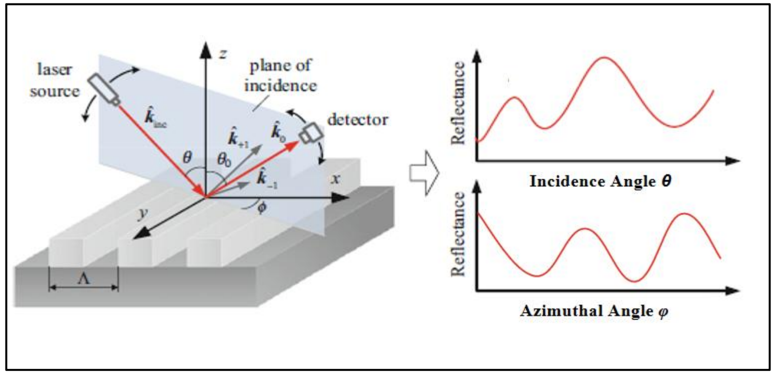
3.Improving Detection Limit in Advanced Technology Nodes

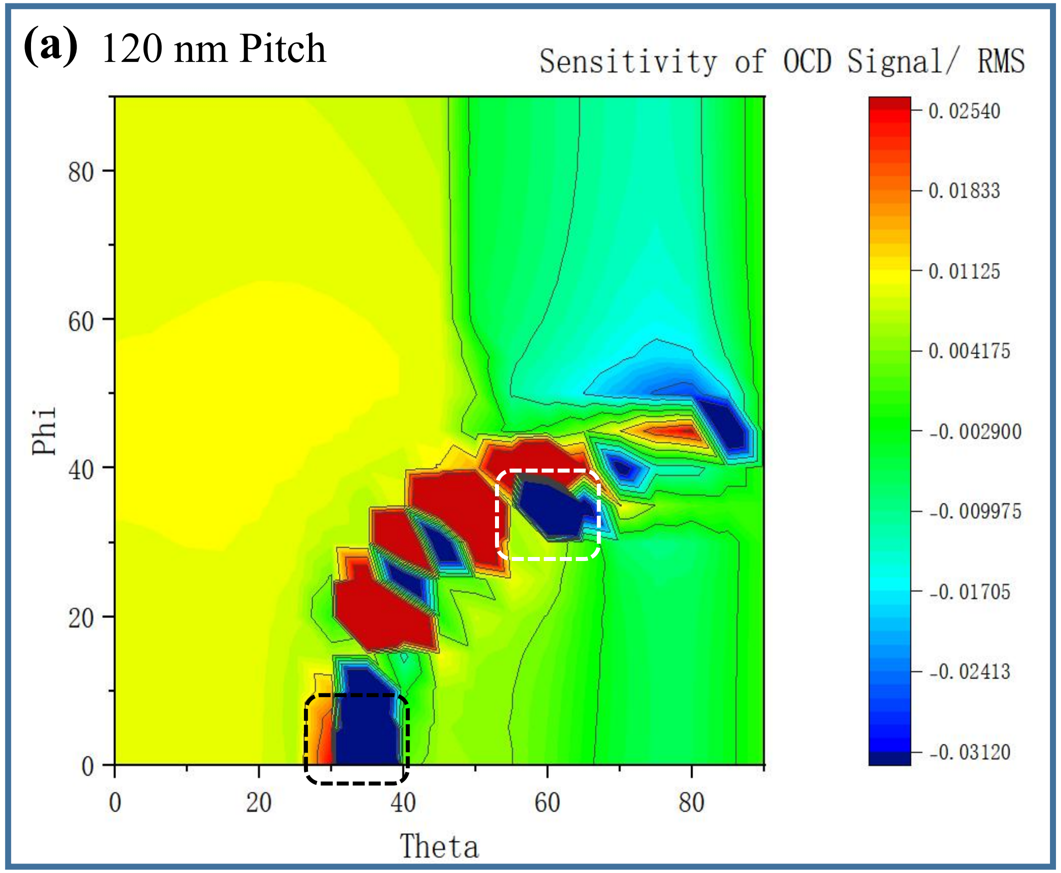


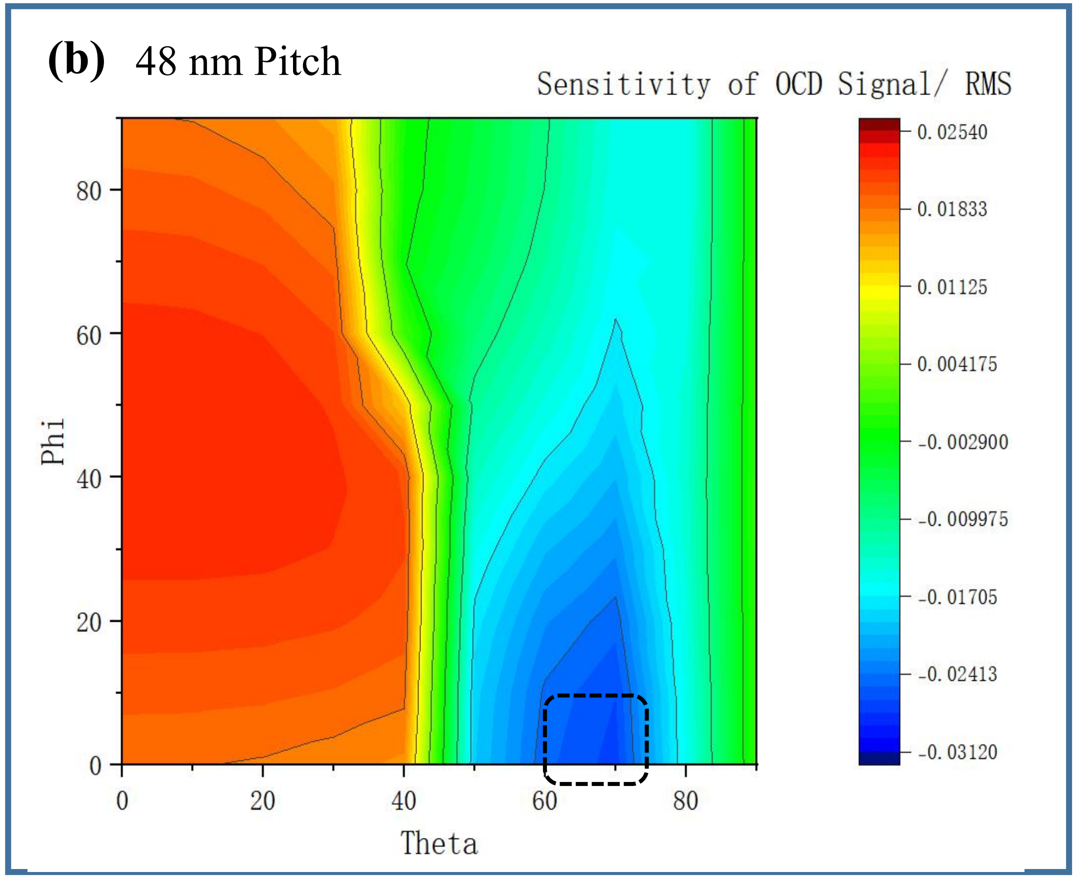
Angular Comparison of SiO_2 Optical Gratings Standard Structures for 28/3 nm Nodes

At 28 nm nodes FEOL gate process, min. pitch is 118 nm and min. CD is 55 nm with single expose. For convenience, we use 120 nm pitch optical gratings with 60 nm line-width to build standard structures.

At 3 nm nodes FEOL gate process, min. pitch is 48 nm and min. CD is 24 nm with SADP technique.

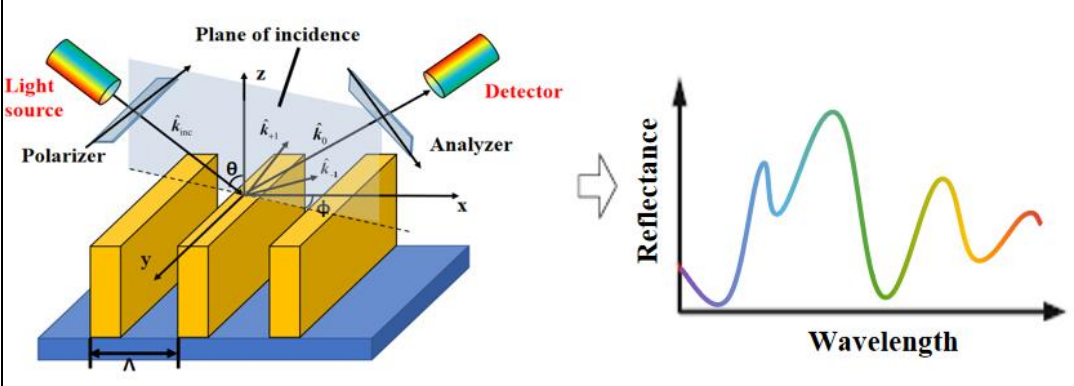




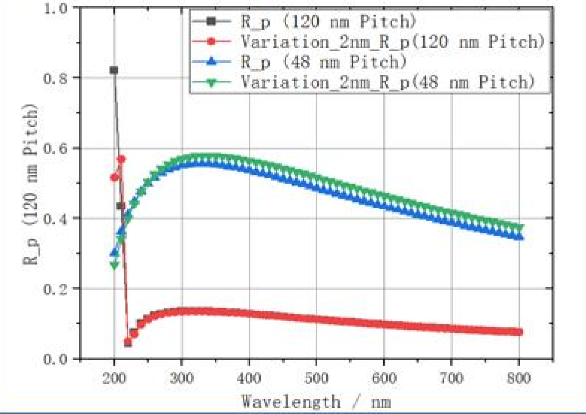


Spectroscopic OCD Comparison of Typical Materials (SiO_2, Si_3N_4, TiN and HfO_2) for 28/3 nm Nodes

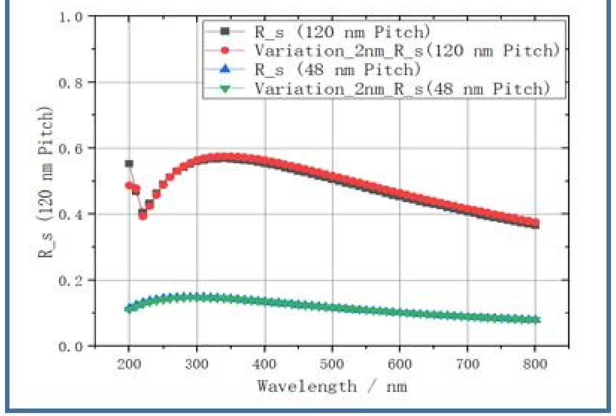
The reflectance is in the form of R_p and R_s, which represent Fresnel reflection coefficients of p-polarized and s-polarized light respectively.



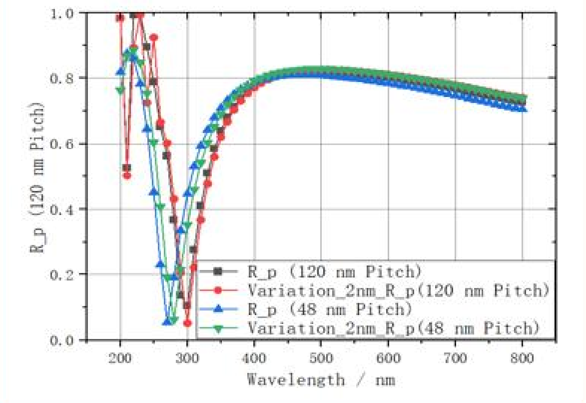
(a) SiO_2 Optical Gratings



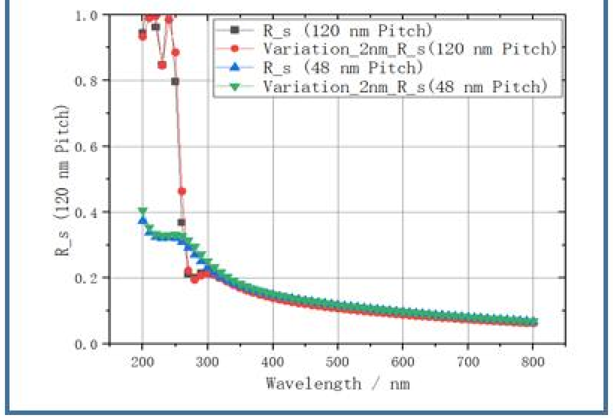
(b) SiO_2 Optical Gratings



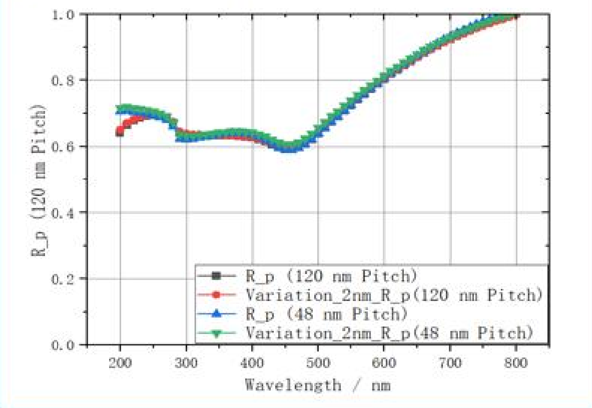
(c) Si_3N_4 Optical Gratings



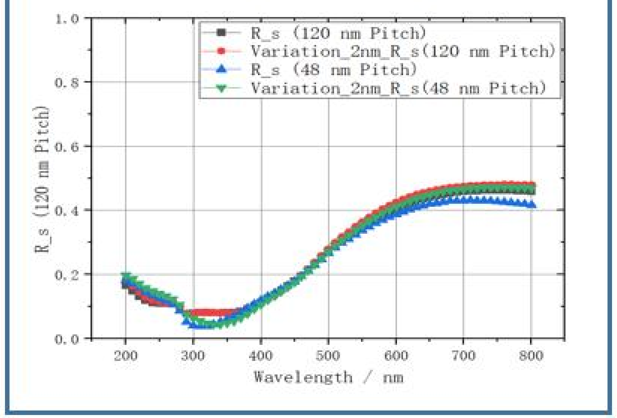
(d) Si_3N_4 Optical Gratings



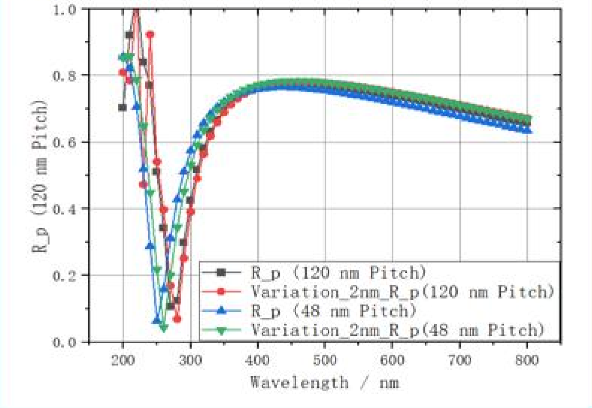
(e) TiN Optical Gratings



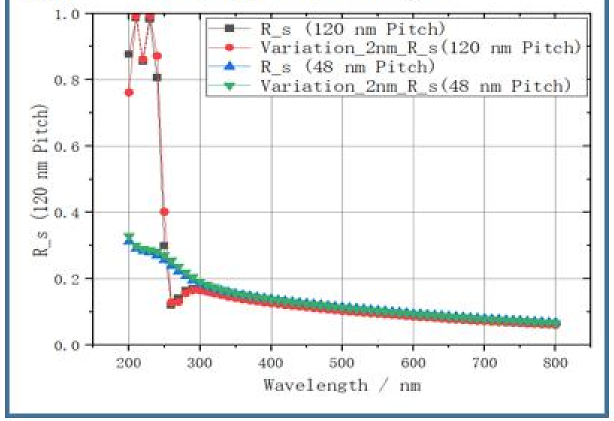
(f) TiN Optical Gratings



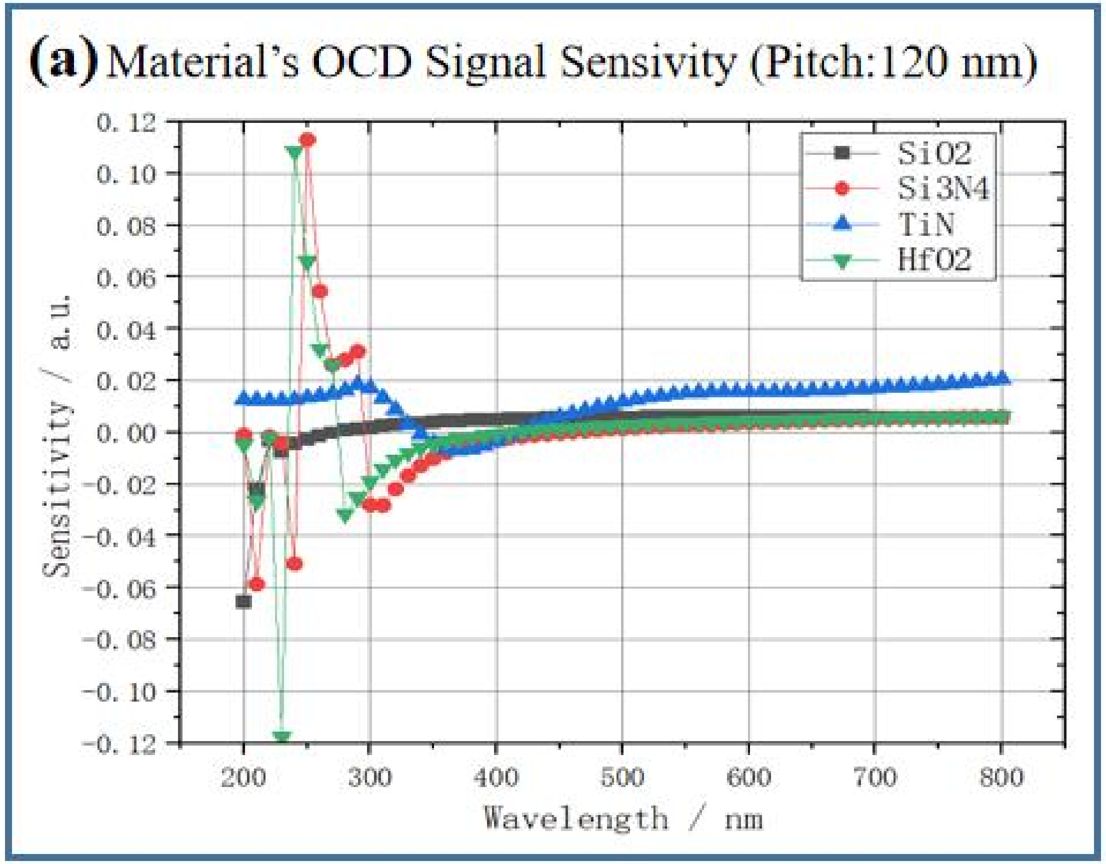
(g) HfO_2 Optical Gratings

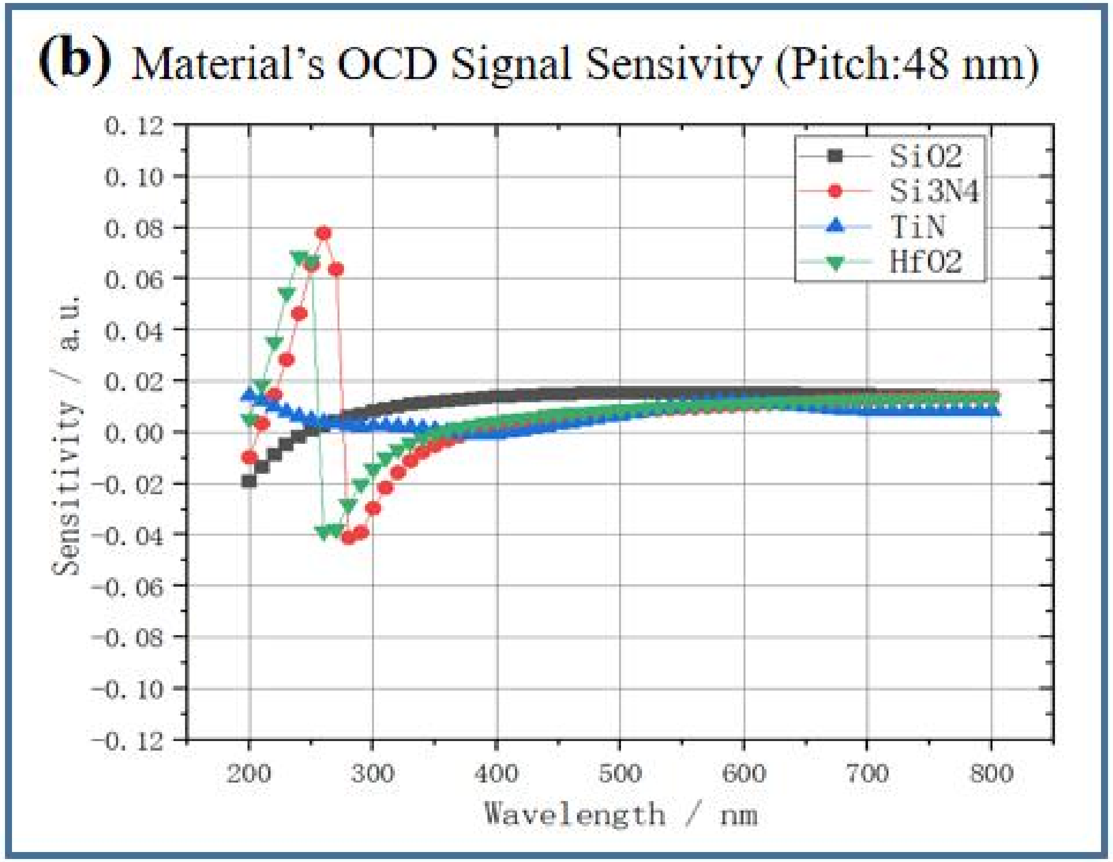


(h) HfO_2 Optical Gratings



Spectroscopic Sensitivity of OCD Signals with 2 nm Linewidth Variation





- **Optical gratings made by Si_3N_4 and HfO_2 has significantly higher OCD signal response sensitivity comparing to those made by SiO_2 and TiN.**
- **Optical gratings with 48 nm pitch has a lower sensitivity than gratings with 120 nm pitch.**
- **To improve the detection limit, it is neccessary to further extend to deeper ultra-violet range.**

Summary and Conclusion

- Model accuracy and precision are dependent on well-developed standard structures’ library signatures, the quality of measurement and fittings of the unknown signature.
- The standard optical gratings with line-space structures are simulated at advanced nodes. By tuning detection parameters, such as angle-of-incidence, illumination wavelength, or polarization, both of the angular and spectroscopic results of OCD signals are obtained, and the comparison of the signal sensitivity of different materials is realized.
- With this study, the OCD model of standard structures is acheived to understand the mechanism of optical scattering signal response, which can be helpful to detect and measure structures in the advanced technology nodes.
- As future work, we will study the sensitivity of the fit to the individual parameter dimension, and will investigate the angle resolved focused beam scatterometry with high NA to measure more complex structures.

THANKS