Simulation of multilayer defects in EUV masks

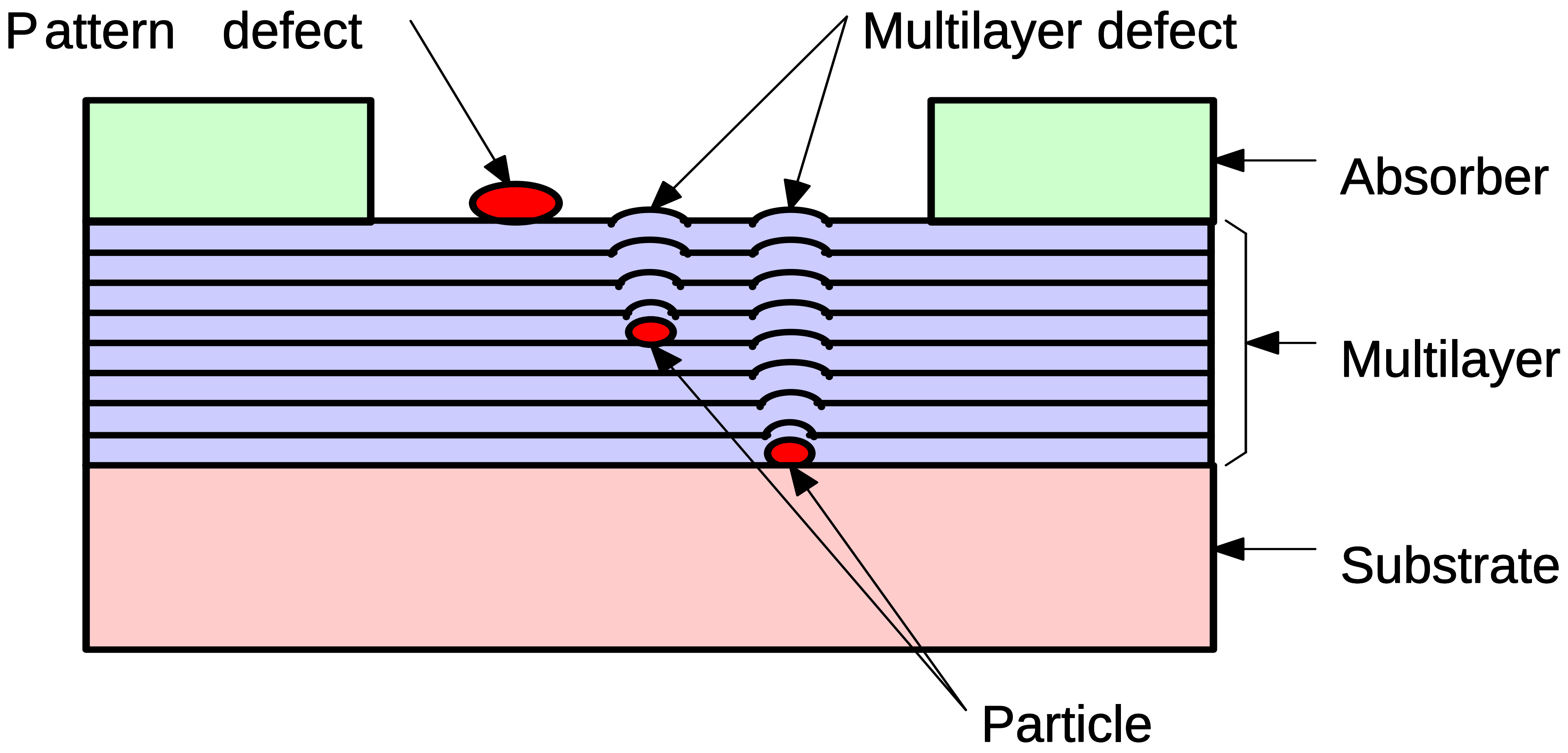
Masaaki Ito, Taro Ogawa, Katsura Otaki,
Iwao Nishiyama and Shinji Okazaki

EUV Lithography Laboratory, ASET

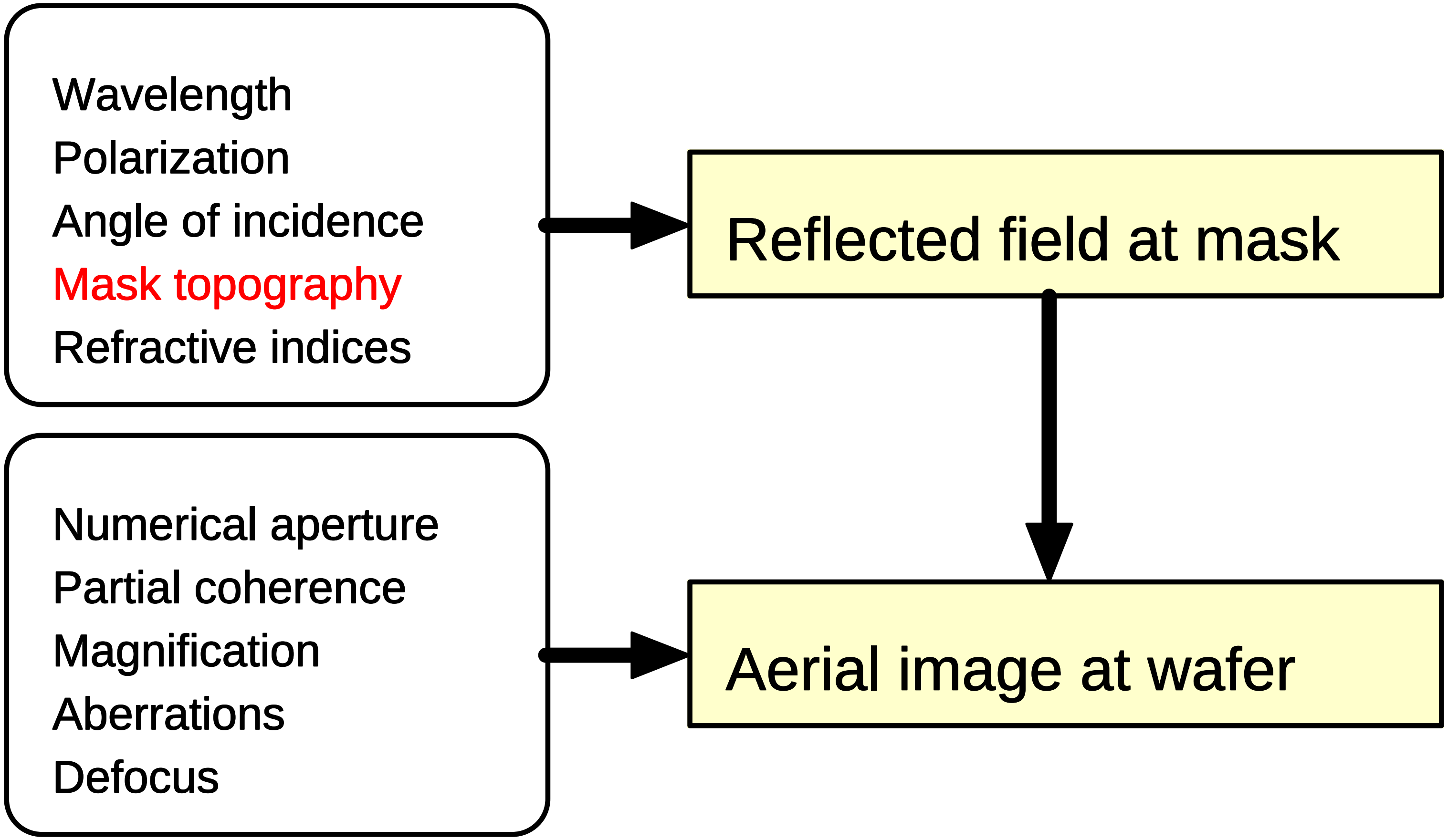
Outline

- Introduction
- Calculation of reflected field
  - Fresnel method
  - Benchmark test
- Printability of point defects
- Summary

Schematic of EUV mask defects



Basic steps in mask defect simulation



Wavelength
Polarization
Angle of incidence
Mask topography
Refractive indices

Reflected field at mask

Numerical aperture
Partial coherence
Magnification
Aberrations
Defocus

Aerial image at wafer

Methods of reflected field calculation

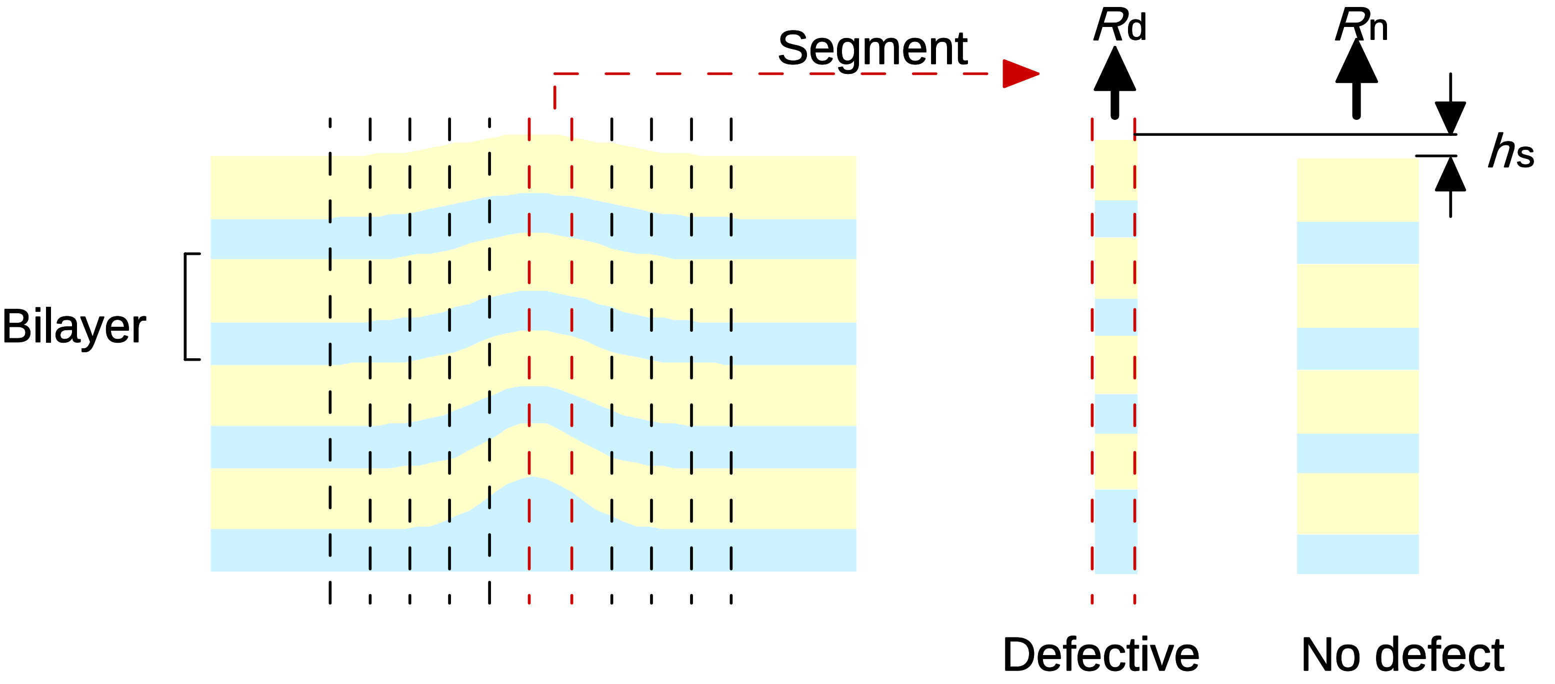
- Electromagnetic (EM) method
  - accurate results
  - massive computing power for 3-D analysis
- Fresnel method
  - approximate results
  - great savings in computing time

We predict critical point defects using Fresnel method.

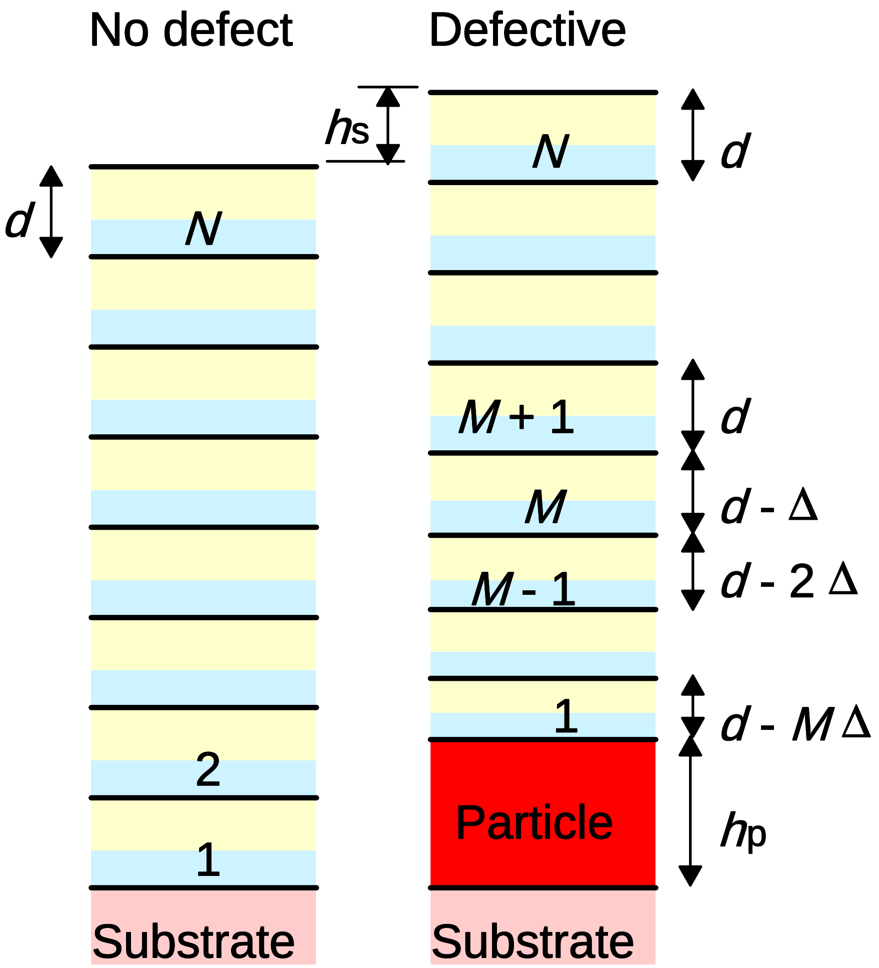
Fresnel method

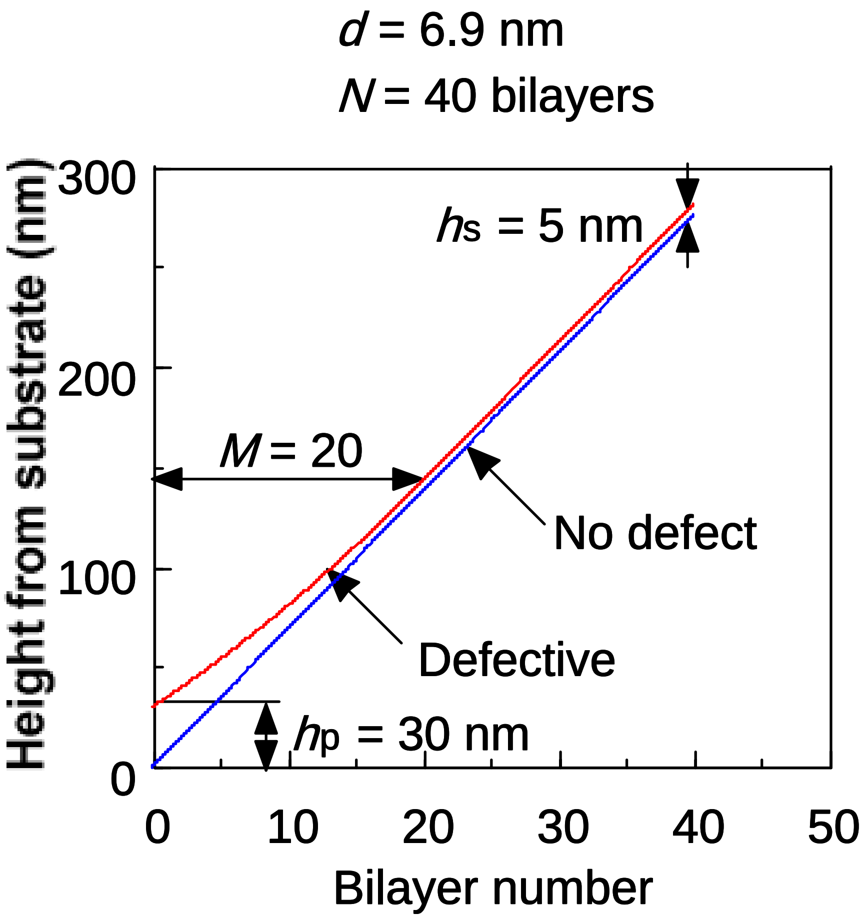
- Assumptions
  - Normal incidence illumination
  - No interaction between segments
  - Parallel layers in each segment

- Calculation using Fresnel formulas
  - Complex reflectance: R_d, R_n
  - Amplitude = $|R_d|$
  - Phase shift = arg R_d - arg R_n + $4\pi h_s / \lambda$



1-D model of multilayer smoothing



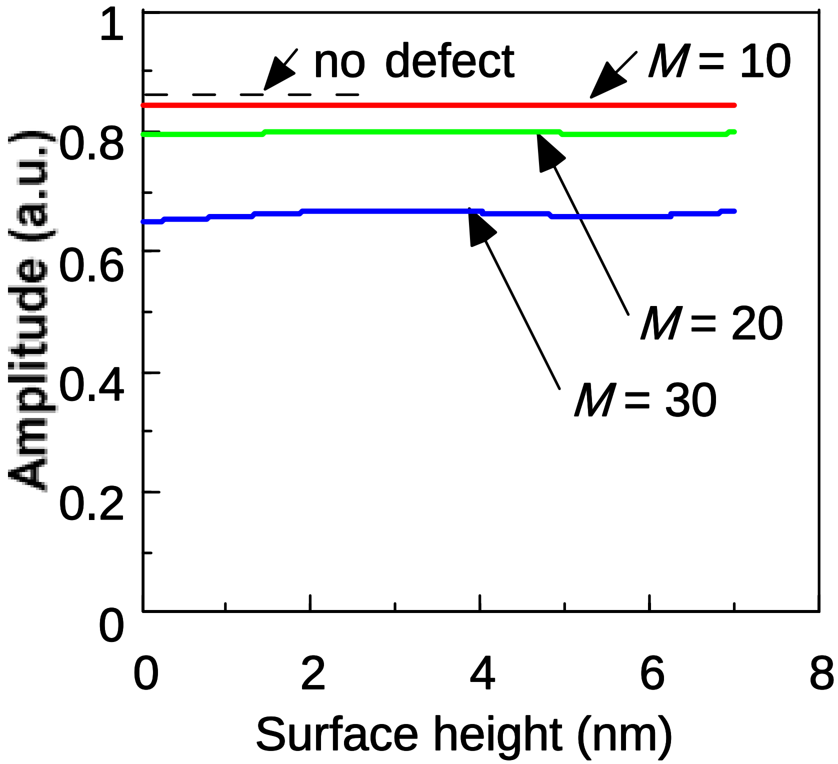


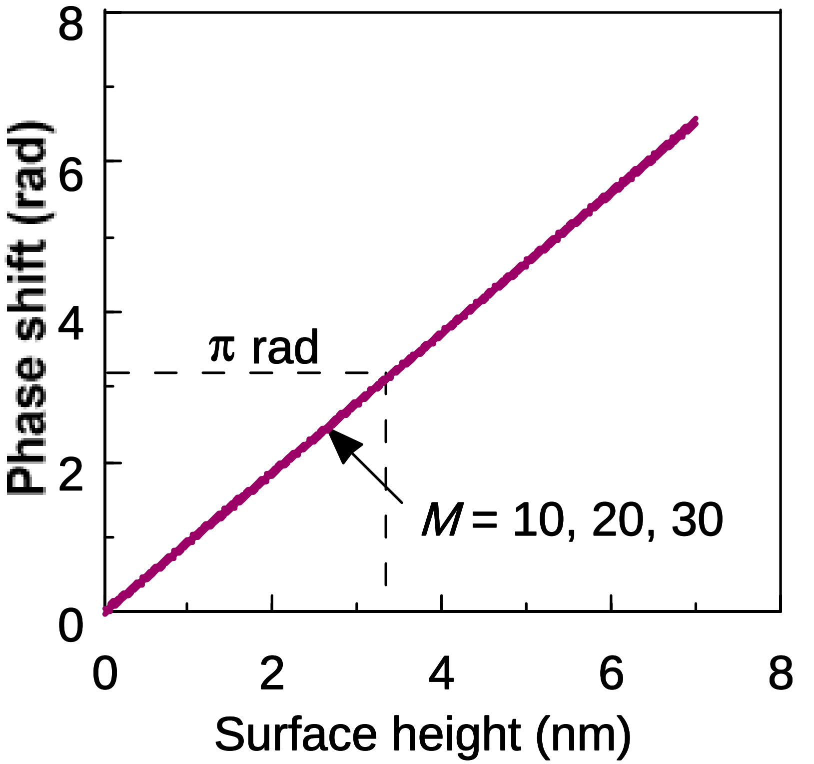
Reflected field vs. surface height

Wavelength: 13.5 nm

Mo/Si multilayer: d = 6.9 nm, N = 40 bilayers

Particle height: 30 nm

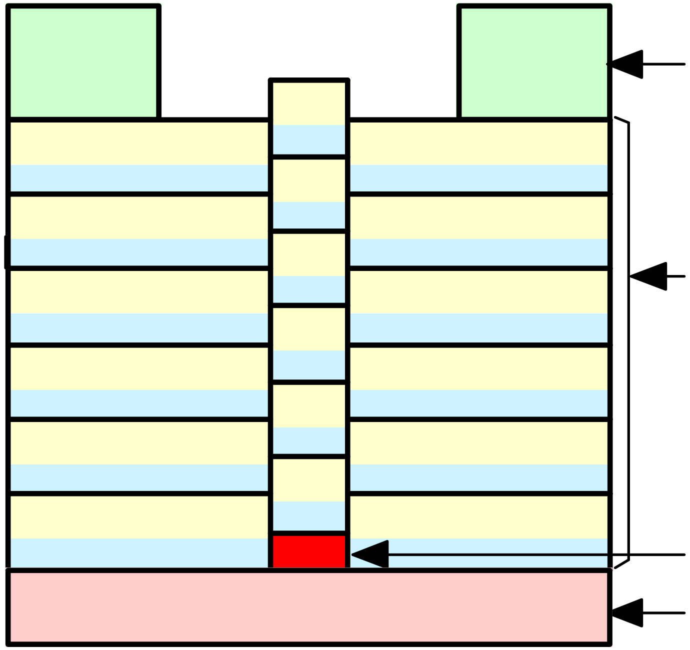




2-D mask model for benchmark test

4x mask pattern: isolated 280-nm space

Defect topography: rectangular-shaped, normal thickness



Ta absorber

Mo/Si multilayer
d = 6.9 nm
N = 40 bilayers

Particle

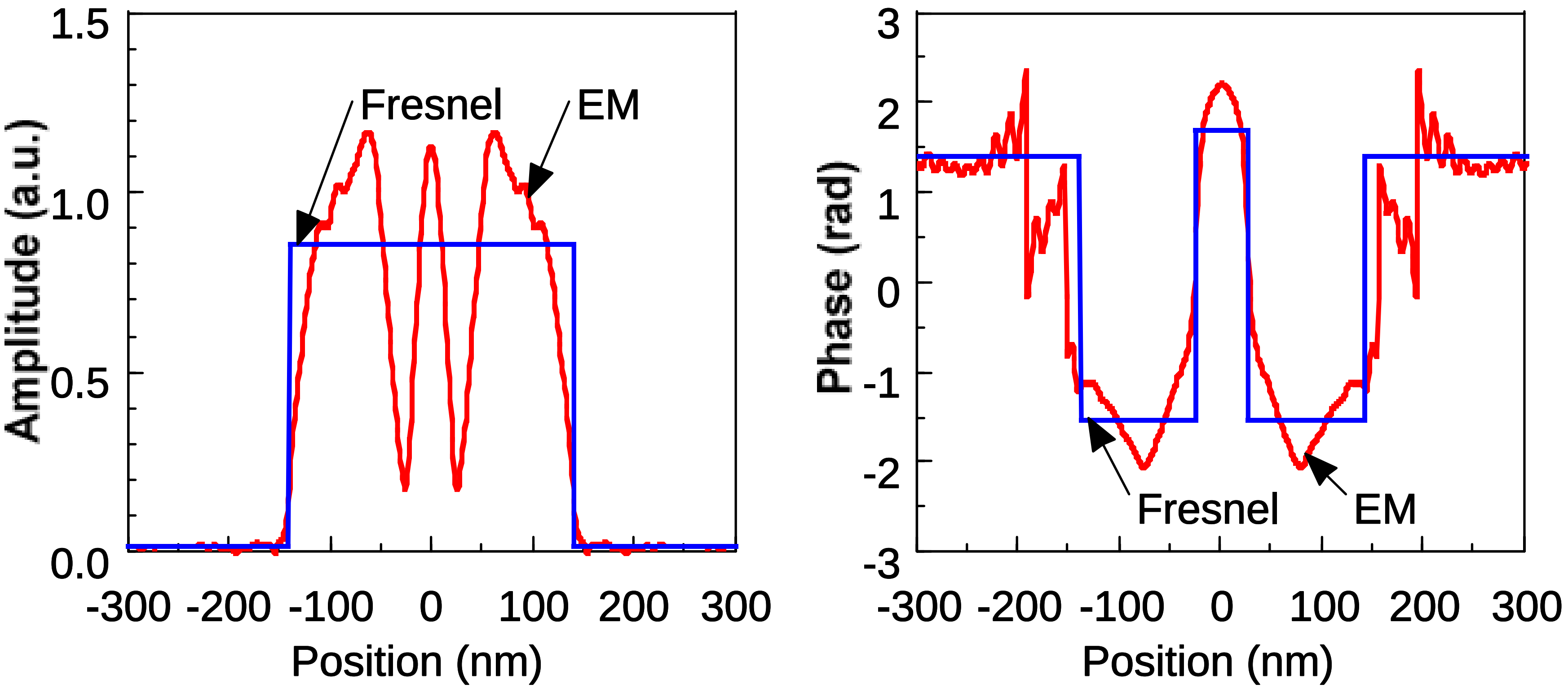
Substrate

Wavelength: 13.5 nm
Incidence angle: 0 deg
NA: 0.1
Partial coherence: 0.6
Magnification: 4x
Aberrations: none
Defocus: none

Reflected field at defective mask

Incident field amplitude: 1

Defect size: 50 nm wide, 3.5 nm high



Aerial image at wafer

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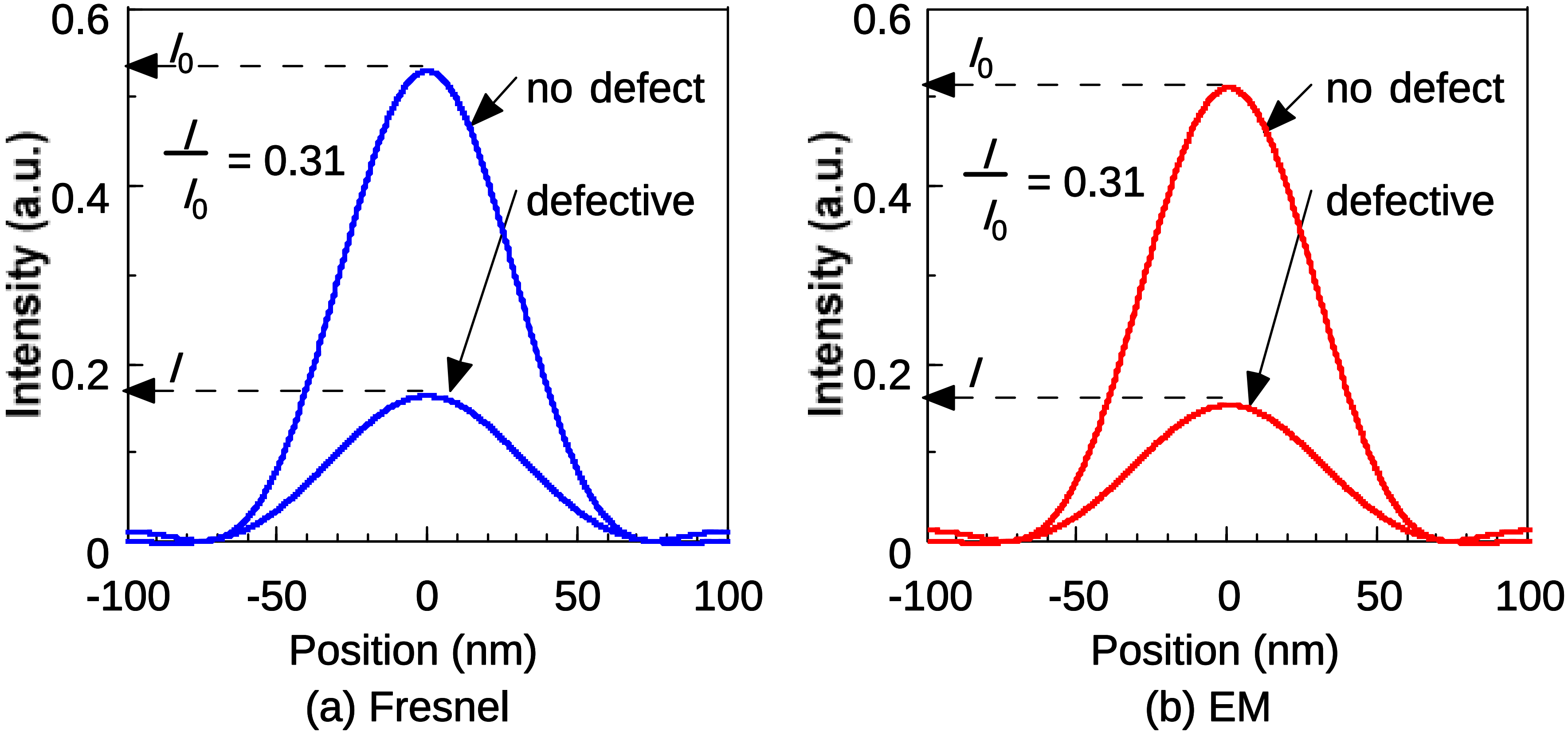
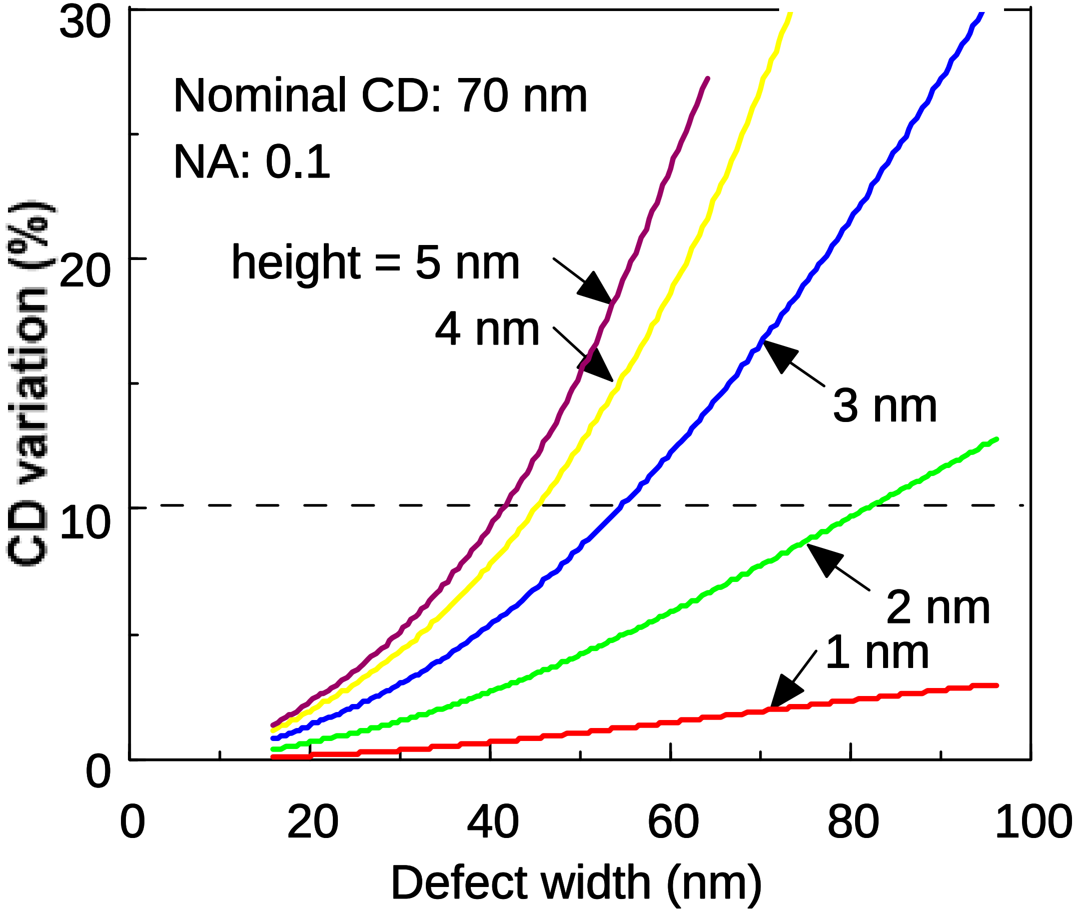
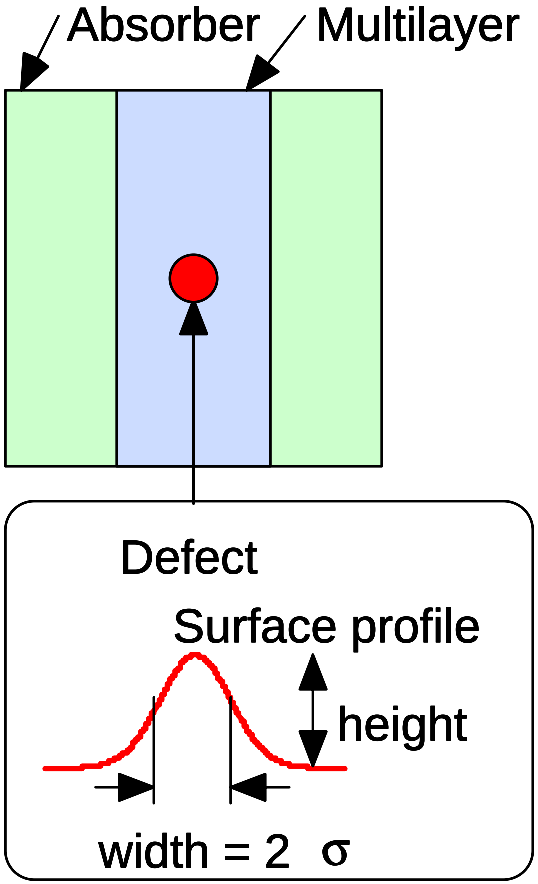


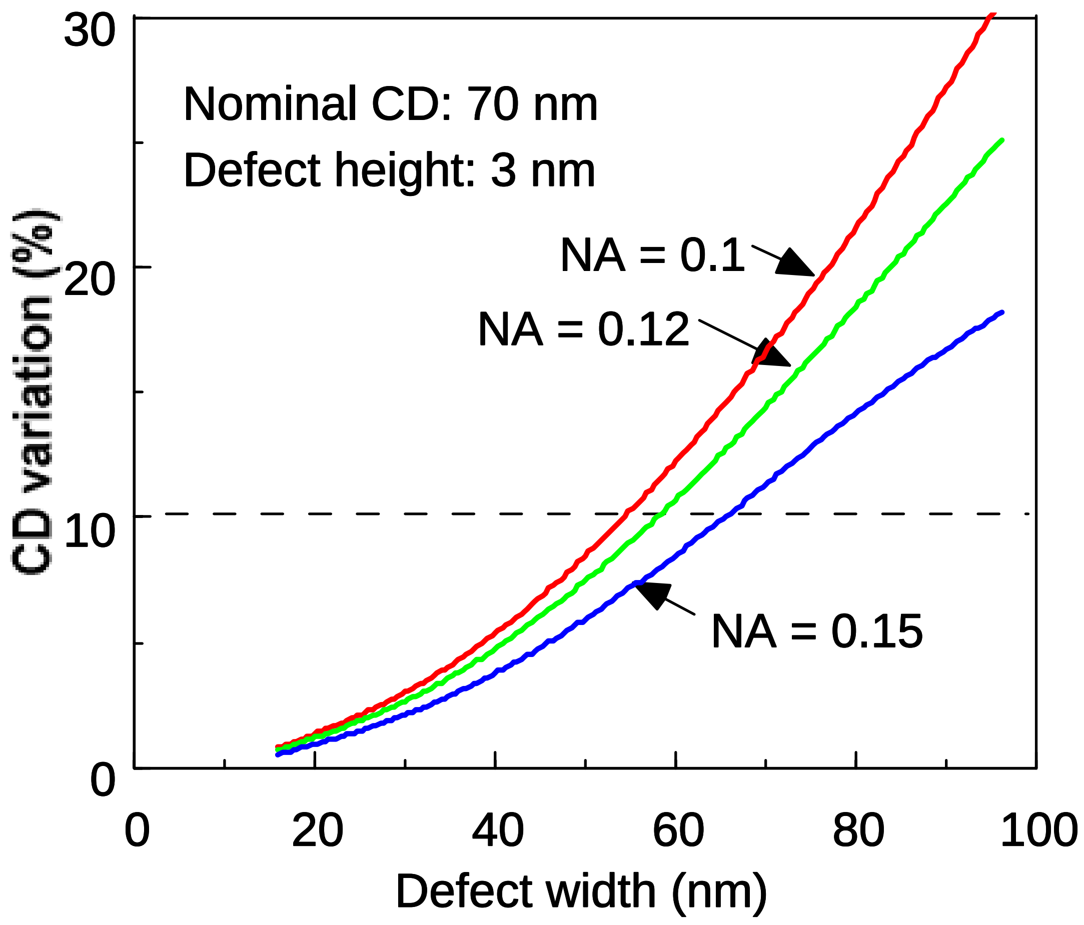
(a) Fresnel (b) EM

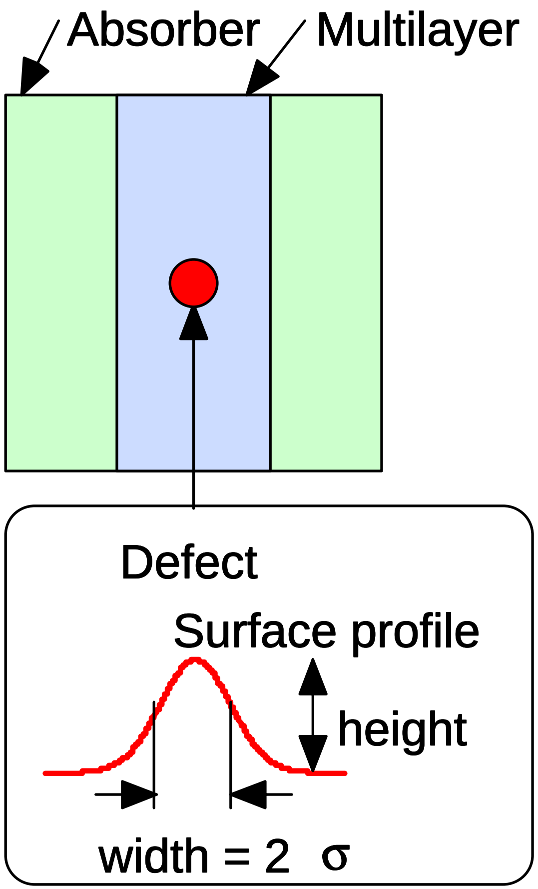
Printability of Gaussian-shaped defect





Effect of NA on defect printability





Summary

- A Fresnel method can be used to calculate the reflected field from a multilayer defect.
- A multilayer smoothing model indicates that the phase shift depends only on the profile of upper layers.
- A Gaussian-shaped defect with a height of 2 nm or a width of 40 nm can cause 10% CD variation for isolated 70-nm space.
- Defects become less printable as NA increases.

Acknowledgement

This work was performed as a MITI project

under the contract with NEDO.