Simplified Model for Spectrum Simulation of Multilayer with Buried Defect in EUV Lithography

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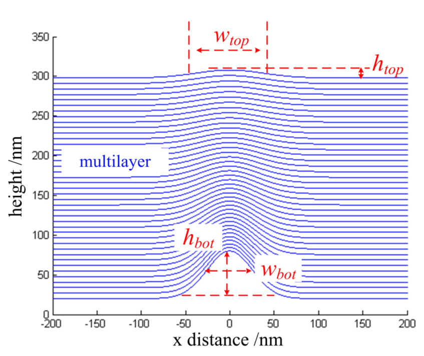
Introduction

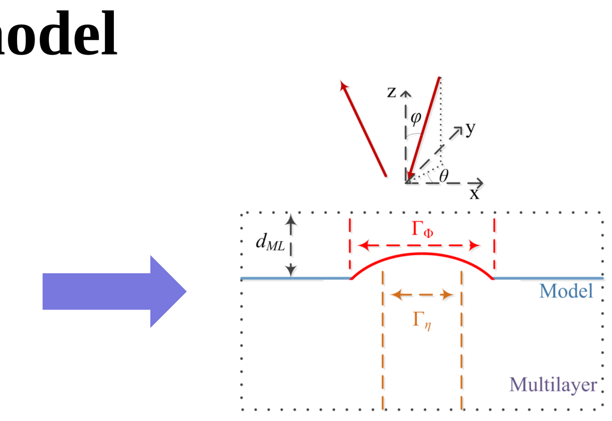
A simplified model is developed for spectrum simulation of multilayer with buried defect in EUV lithography. An analytical expression of spectrum is deduced. This model is developed based on the smoothing based multilayer. In this model, the multilayer is treated as a mirror, and the defect is treated as phase perturbation and amplitude attenuation of reflection coefficient. The phase perturbation depends on surface defect size of the defective multilayer and the amplitude attenuation depends on substrate defect size. This approximate method for the spectrum simulation of the multilayer with buried defect is as fast as the advanced single surface approximation model, while it is more accurate.

Theoretical Model

1. Simplified model



Multilayer structure



the simplified model

Suppose $\Delta = (h_{top}, w_{top}; h_{bot}, w_{bot})$, the spectrum of the multilayer with buried defect is presented as follow,

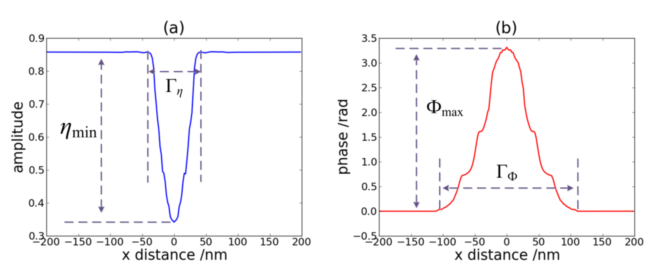
$$G(\alpha_m) = e^{-j\frac{2\pi}{\lambda}\cdot d_{ML}\sqrt{1-\alpha_m^2-\beta_{in}^2}} \int_{-1/2}^{1/2} \eta(x,\Delta) e^{j\Phi(x,\Delta)} \cdot r_{ML} e^{-j\frac{2\pi}{\lambda}\cdot d_{ML}\sqrt{1-\alpha_{in}^2-\beta_{in}^2}} \cdot e^{-j\frac{2\pi}{\lambda}\cdot\alpha_m x} dx$$

$\eta(x, \Delta)$ is amplitude attenuation factor， $\Phi(x, \Delta)$ is phase perturbation.

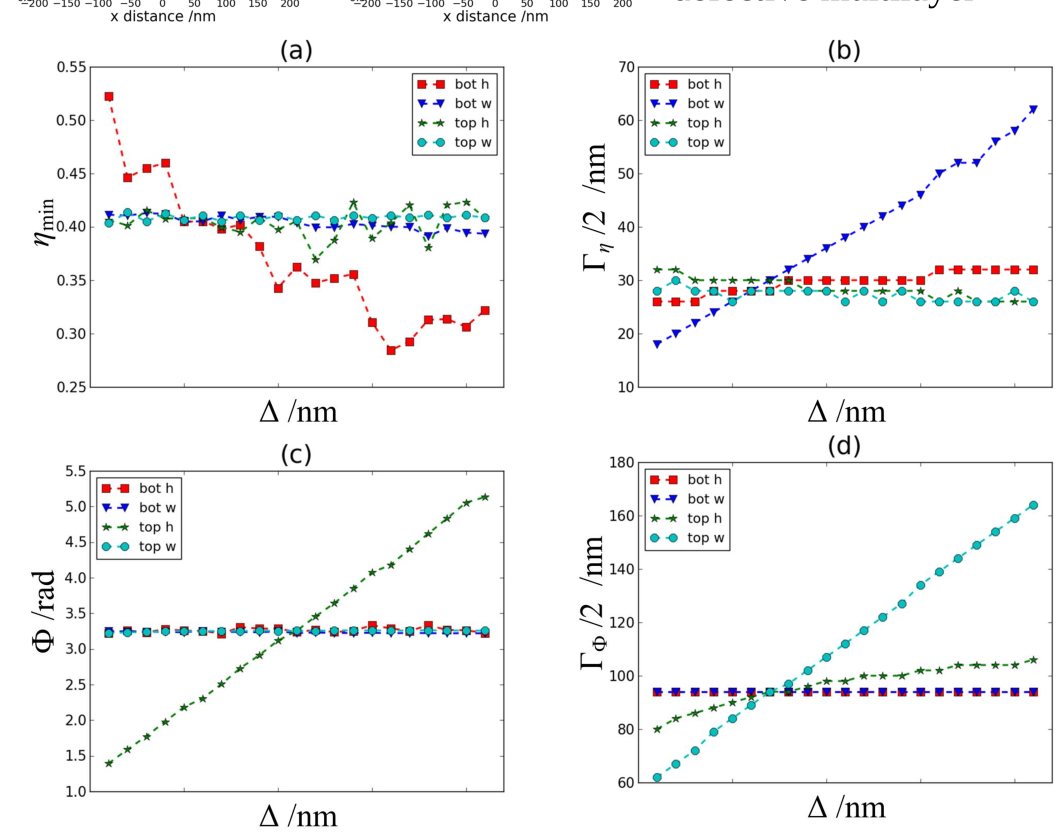
$$\eta(x,\Delta) = \begin{cases} f_\eta(x,\Delta) & x \in \Gamma_\eta / p \\ 1 & x \in others \end{cases}$$

$$\Phi(x,\Delta) = \begin{cases} \frac{2\pi}{\lambda}\cdot h_\Phi(x,\Delta)(\sqrt{1-\alpha_{in}^2-\beta_{in}^2}+\sqrt{1-\alpha_m^2-\beta_{in}^2}) & x \in \Gamma_\Phi / p \\ 0 & x \in others \end{cases}$$

2. Parameters of simplified model



definition of parameters: (a) the amplitude and (b) the phase of reflection on different positions of defective multilayer

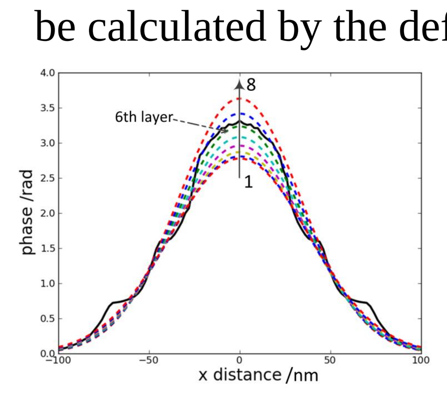


The parameters versus defect size.

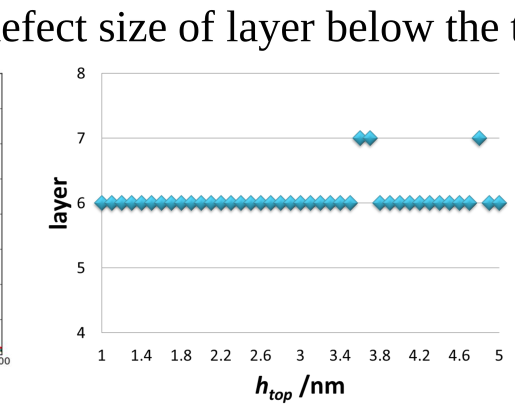
In each simulation, only 1 variable of Δ is variable and other 3 variables are constant. Variable range: h_{bot} (20, 60) nm, w_{bot} (20, 60) nm, h_{top} (1, 5) nm, w_{top} (60, 160) nm; constant values: $h_{bot} = w_{bot}$ =30 nm, h_{top} = 3 nm, w_{top} = 90 nm.

2.1 phase perturbation

The parameters of phase perturbation are dependent on the defect size of multilayer surface. For the smoothing model, the phase perturbation can be calculated by the defect size of layer below the top surface.



The fitting layer for the phase perturbation

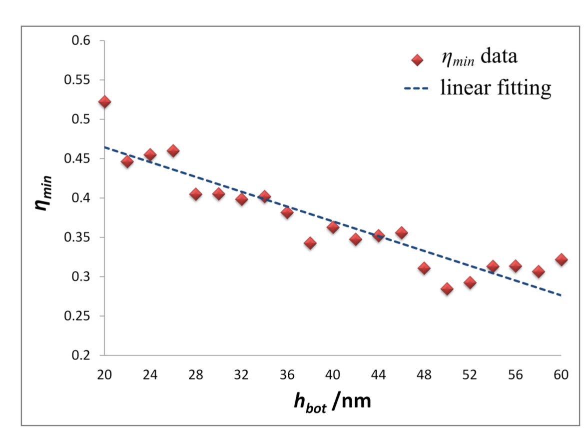


The preferable layer

the results of simulation show that, the preferable layer is the 6[th] layer below the top surface.

2.2 amplitude attenuation

The parameters of amplitude attenuation are dependent on the defect size of the substrate.



The amplitude attenuation $f_\eta(x, \Delta)$ is fitted by a quadratic polynomial, as follows:

$$f_\eta(x,\Delta) = \frac{1-\eta_{min}}{(w_{bot}/p)^2}x^2 + \eta_{min}, \quad x \in (-w_{bot}/p, w_{bot}/p)$$

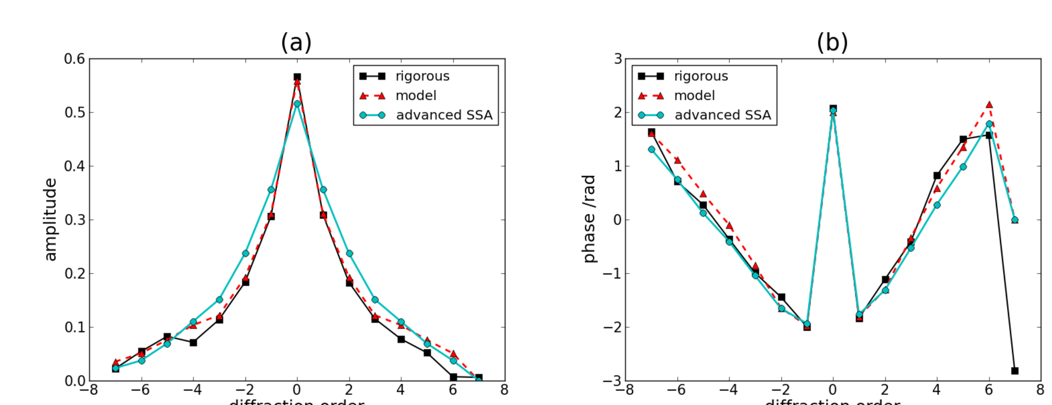
where η_{min} is the minimum reflection of defective multilayer:

$$\eta_{min} = -0.0047 \cdot h_{bot} + 0.5585$$

Simulation

Simulation parameters

Multilayer	Multilayer	40 Bilayers of Mo/Si: 4.17/2.78 nm, *Pitch*=100 nm at Wafer Scale
	Defect	Gaussian Defect at Mask Scale
Optics	Illumination	λ=13.5 nm, Incidence Angle φ=6 º, Azimuth Angle θ=0 º, Traditional Source, TE Polarized, σ=0.5
	Projection	4×Reduction, *NA*=0.35

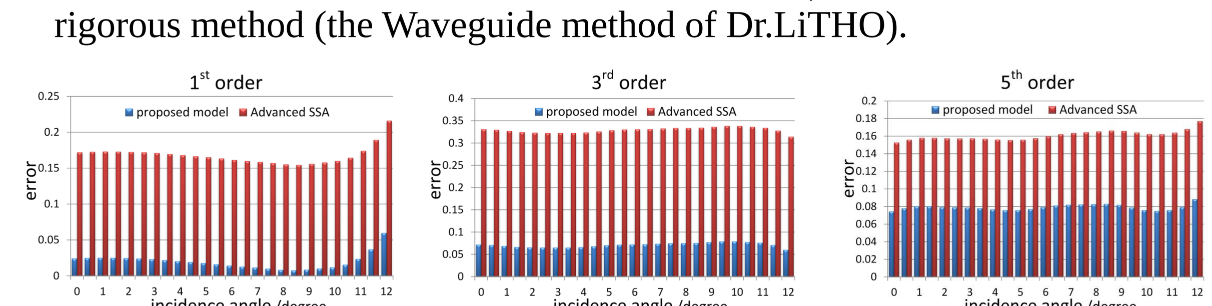


The spectrum of defective multilayer. (a) magnitude and (b) phase of diffraction orders simulated by Waveguide method of Dr.LiTHO, the proposed model and Advanced SSA method. (h_{top}=3 nm, w_{top}=90 nm, h_{bot}=30 nm, w_{bot}=30 nm)

The errors of magnitude of the diffraction orders are defined as

$$error = \frac{|A_m(n) - A_r(n)|}{A_r(n)} \times 100\%$$

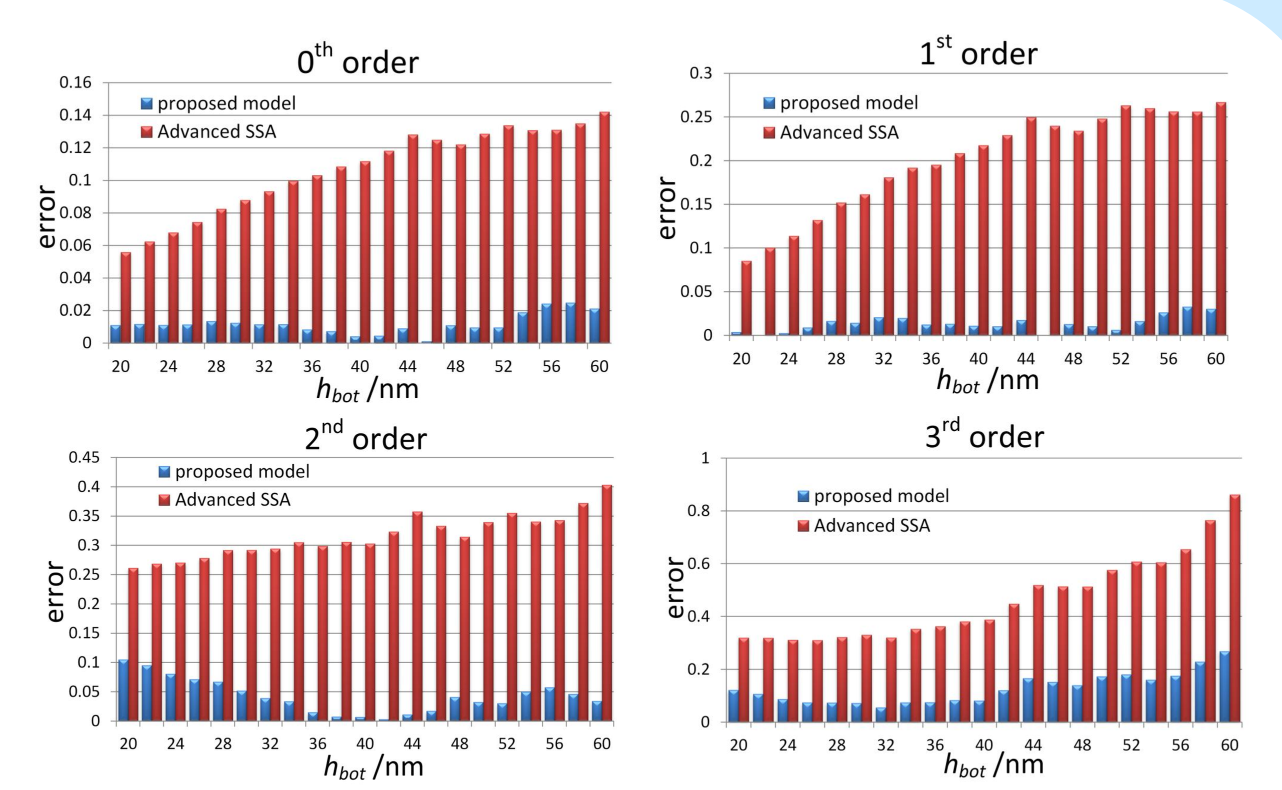
where $A_m(n)$ is the magnitude of the diffraction orders calculated by the proposed model or Advanced SSA method, and $A_r(n)$ is calculated by rigorous method (the Waveguide method of Dr.LiTHO).



The errors of the diffraction orders' magnitude for different incidence angles (h_{top}=3 nm, w_{top}=90 nm, h_{bot}=30 nm, w_{bot}=30 nm)

The proposed model for spectrum of defective multilayer is more accurate than the Advanced SSA method for different incidence angles.

- The errors of the proposed model are much 50% smaller than the errors of Advanced SSA method.
- The errors of the proposed model have little fluctuation, which is the same as that of the Advanced SSA method.



The errors of the diffraction orders' magnitude for different defect size of the substrate. (incidence angle = 6 º, h_{top}=3 nm, w_{top}=90 nm, $h_{bot} = w_{bot}$)

For spectrum simulation of the defective multilayer, The proposed model is more accurate than the Advanced SSA method for different substrate defect size.

Conclusions

- A simplified model for spectrum simulation of multilayer with buried defect in EUV lithography has been proposed. the proposed model is more accurate than the Advanced SSA method.
  - ✓ The defect has been treated as phase perturbation and amplitude attenuation of reflection coefficient.
  - ✓ An analytical expression of spectrum of defective multilayer has been deduced.

Future Work

- The fast method of defect mitigation will be developed based on this simplified model.
- Derivation of the analytical expression of the defect compensation will be performed based on the analytical expression of spectrum of defective multilayer.

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