Asymmetry in mask pattern correction for binary and attenuated phase shift masks by off-axis incident light

Minoru Sugawara, Iwao Nishiyama

Association of Super-Advanced Electronic Technologies (ASET)
EUV Process Technology Research Laboratory

Mikio Takai

Osaka University
Research Center for Materials Science at Extreme Conditions

Contents

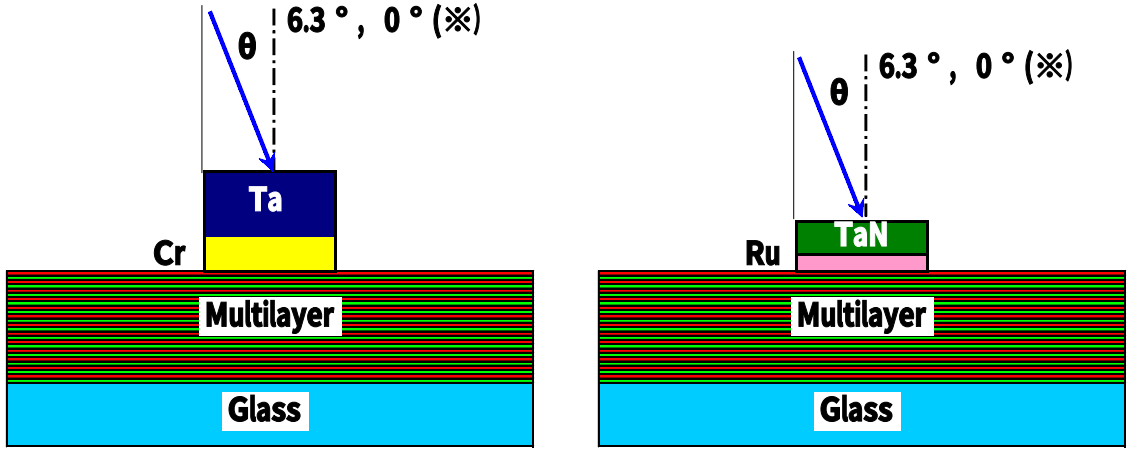
EUVL ASET

1. Mask pattern correction to the pattern edge for a 2-D model pattern with a 22-nm-wide line for the process factor k_1 0.41 at NA 0.25.
   - Binary masks
   - Attenuated phase shift mask

2. Evaluation of asymmetry of
   - Positions of pattern edges
   - Mask error enhancement factor (MEEF)
   - Pattern edge contrast by NILS.

3. Evaluation of CD-focus and NILS-focus

Simulation conditions



(a) Binary mask (b) Attenuated PSM

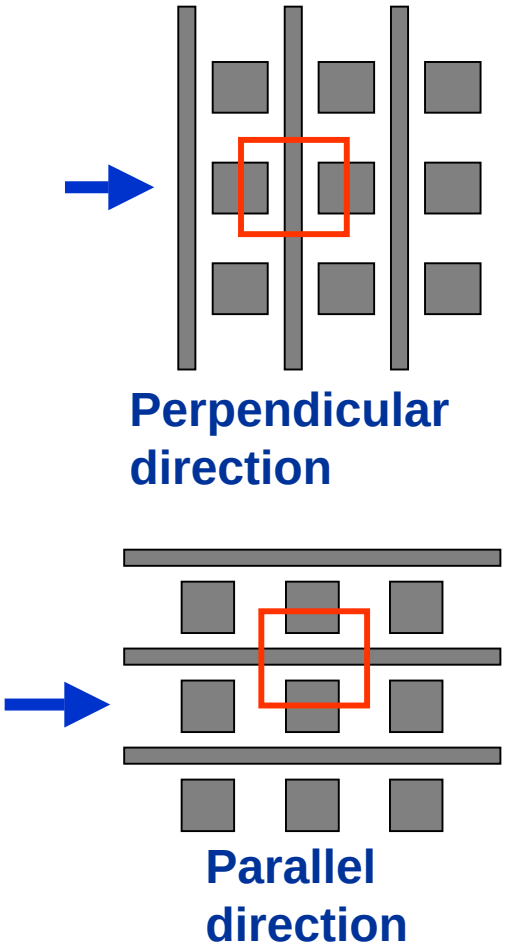
Configurations of mask structure

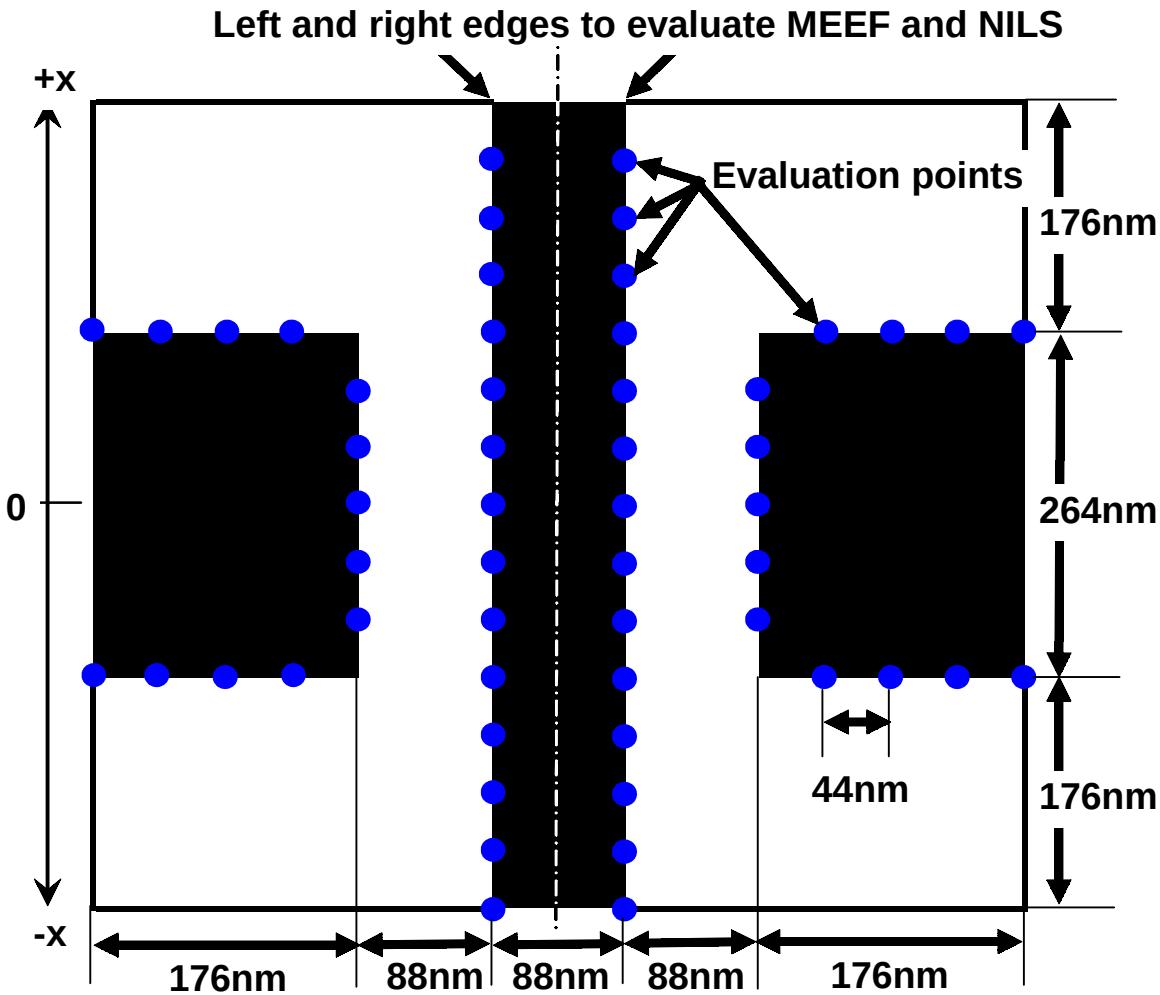
	Binary masks		Att-PSM
	Thin configuration	Thick configuration	
Upper layer	Ta 34 nm	Ta 78 nm	TaN 29 nm
Bottom layer	Cr 30 nm	Cr 30 nm	Ru 16 nm
Reflectance at 6°	0.37%	0.11%	7.05% (Att. Ref. 9.6%)

Optical conditions

	Binary masks	Att-PSM
NA	0.25	0.25
σ	0.80	Outer 0.75/Inner 0.37
Incident angle	6.3°	6.3°

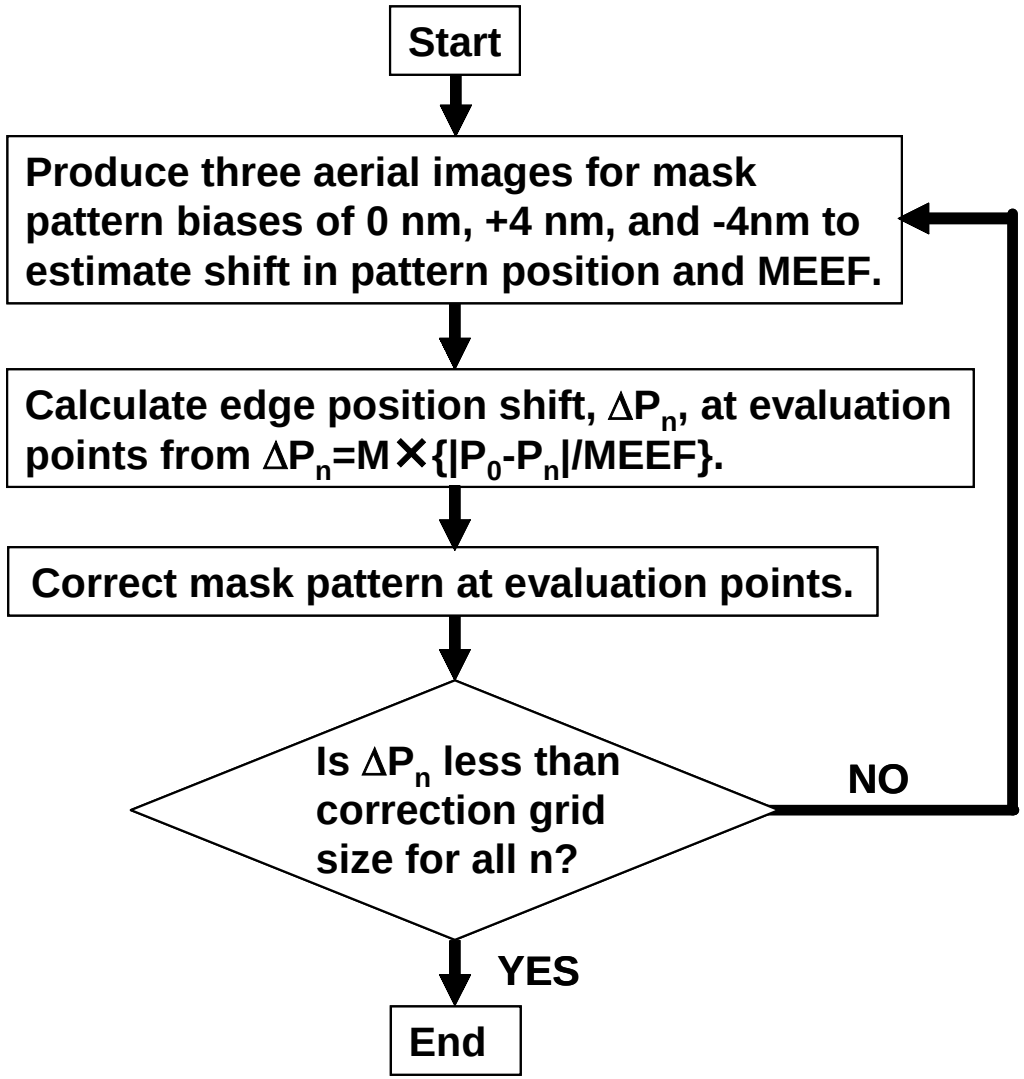
Model pattern for mask pattern correction



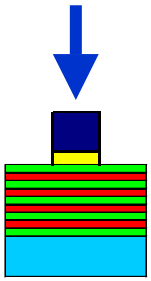


A model pattern on 4x mask. Correction grid size is 1.0 nm.

Flow chart of mask pattern correction



Corrected mask pattern for normal incidence



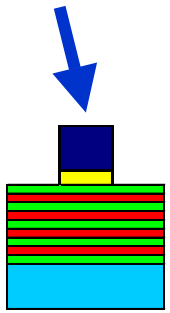
(a) Binary mask
Ta 34nm/Cr 30nm
NA: 0.25, σ: 0.80

(b) Binary mask
Ta 78nm/Cr 30nm
NA: 0.25, σ: 0.80

(c) Att-PSM
TaN 29nm/Ru 16nm
NA: 0.25, σ: 0.75/0.37

Equivalent OPCed masks are provided at k_1=0.41 for binary masks and att-PSM, when normal incidence is assumed.

Corrected mask pattern for off-axis incidence



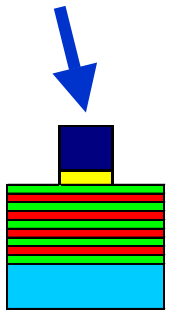
(a) Binary mask
Ta 34nm/Cr 30nm
NA: 0.25, σ: 0.80

(b) Binary mask
Ta 78nm/Cr 30nm
NA: 0.25, σ: 0.80

(c) Att-PSM
TaN 29nm/Ru 16nm
NA: 0.25, σ: 0.75/0.37

The widths of line patterns are smaller for off-axis incidence than for normal incidence as a result of compensation for the energy loss. Equivalent mask pattern correction are also provided for off-axis incidence.

Aerial image by corrected masks for off-axis incident light



(a) Binary mask
Ta 34nm/Cr 30nm
NA: 0.25, σ: 0.80

(b) Binary mask
Ta 78nm/Cr 30nm
NA: 0.25, σ: 0.80

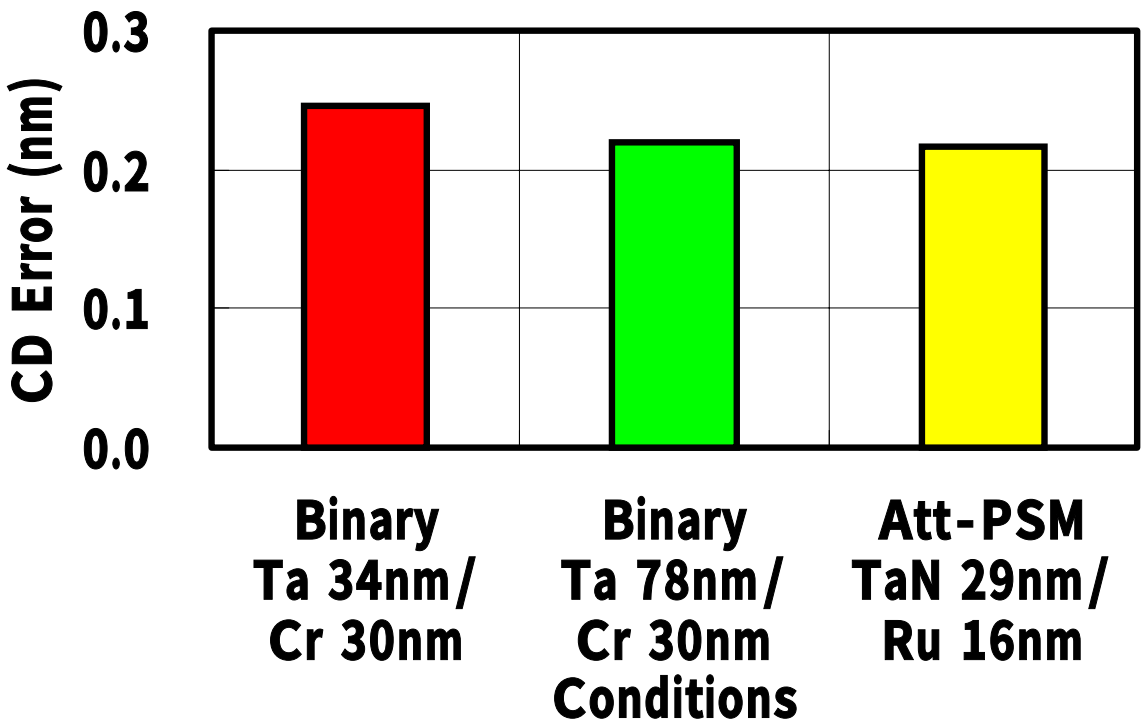
(c) Att-PSM
TaN 29nm/Ru 16nm
NA: 0.25, σ: 0.75/0.37

Mask pattern correction provides feasible pattern fidelity for binary masks and att-PSM.

CD error after mask pattern correction

$$CD_{error} = \sqrt{\left\{\sum_{1}^{n}(CD_0 - CD_n)\right\}^2 / n}$$

***CD_0*: Designed CD of 22.0 nm**
***CD_n*: CD after mask pattern correction**



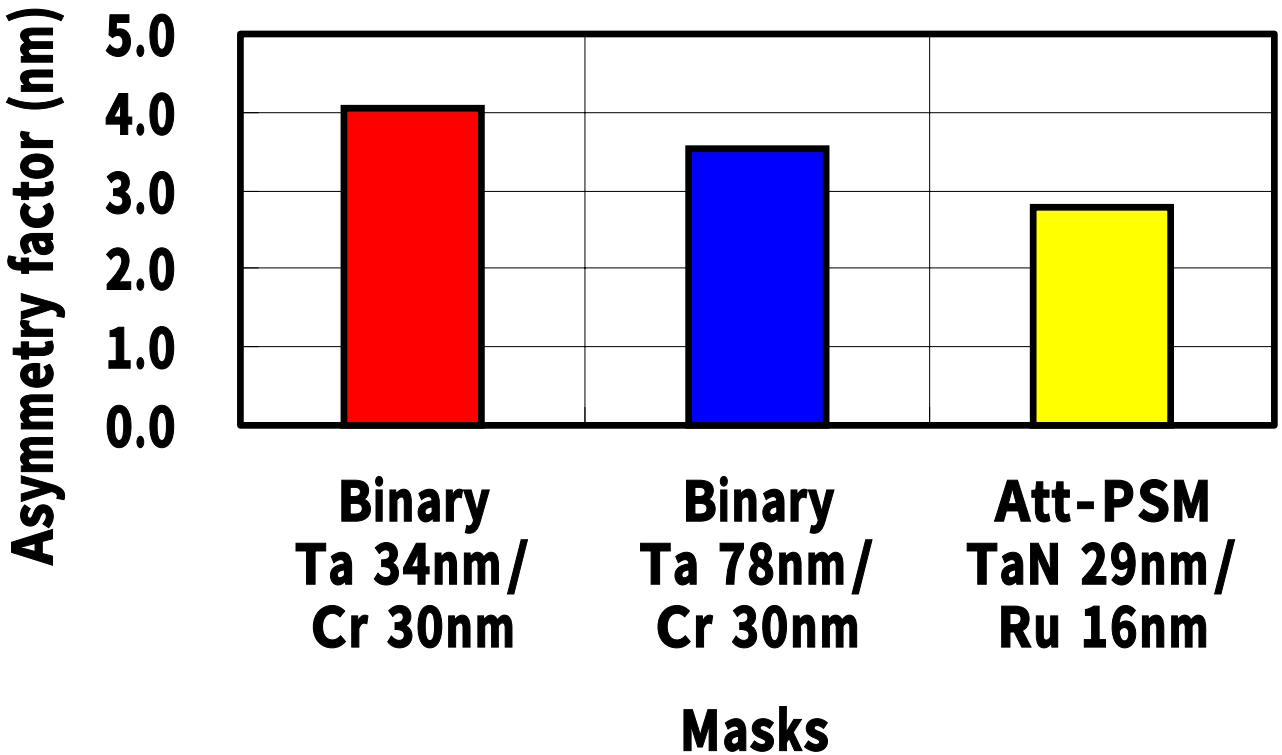
Equivalent CD error are provided for binary masks and att-PSMs.

Asymmetry of mask pattern position

EUVL ASET

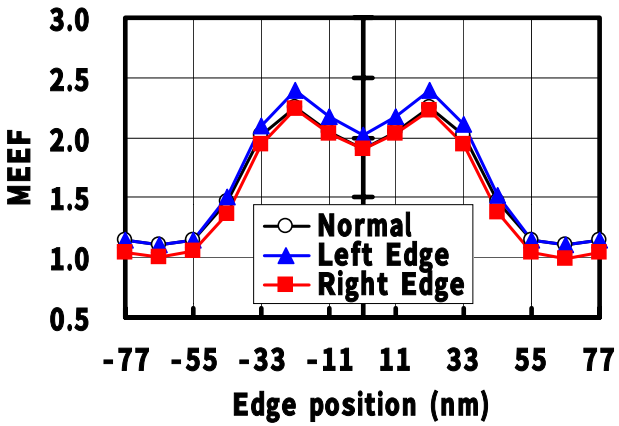
$$Assymetry = \left\{ \sum_{1}^{n} | (P_{nL} - P_{nR}) | \right\} / n$$

P_{nL}: Positions of the left edges
P_{nR}: Positions of the right edges against the center line in the designed mask feature.

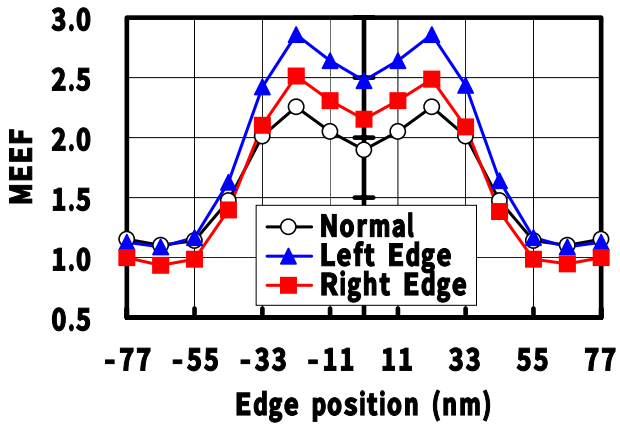


Equivalent asymmetries are provided for binary masks and att-PSMs.

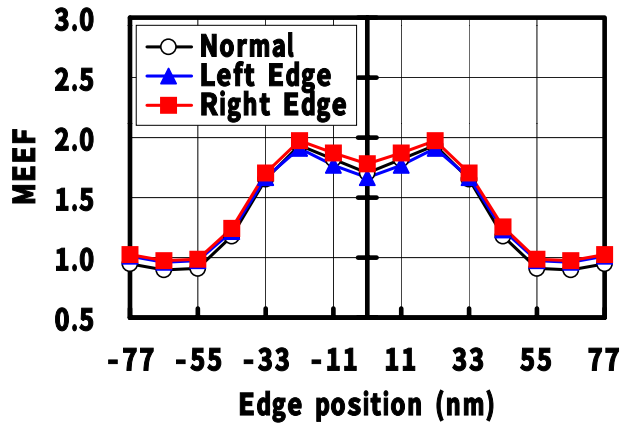
Asymmetry of MEEF



(a) Binary mask
Ta 34nm/Cr 30nm
NA: 0.25, σ: 0.80



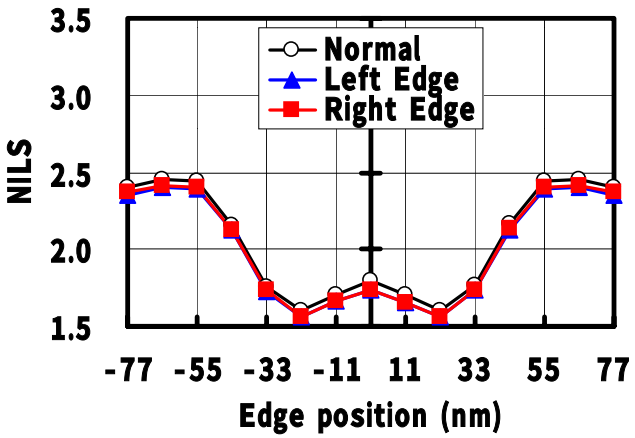
(b) Binary mask
Ta 78nm/Cr 30nm
NA: 0.25, σ: 0.80



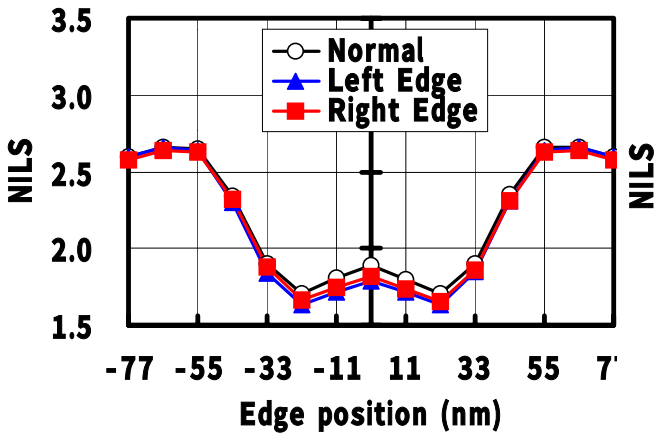
(c) Att-PSM
TaN 29nm/Ru 16nm
NA: 0.25, σ: 0.75/0.37

- Asymmetry in the MEEF depends on the thicknesses for binary masks.
- Att-PSM provides symmetry of MEEF and smaller MEEF than binary masks.

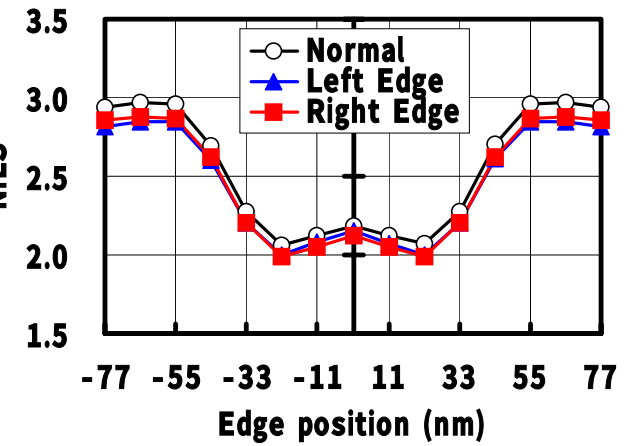
Asymmetry of NILS



(a) Binary mask
Ta 34nm/Cr 30nm
NA: 0.25, σ: 0.80



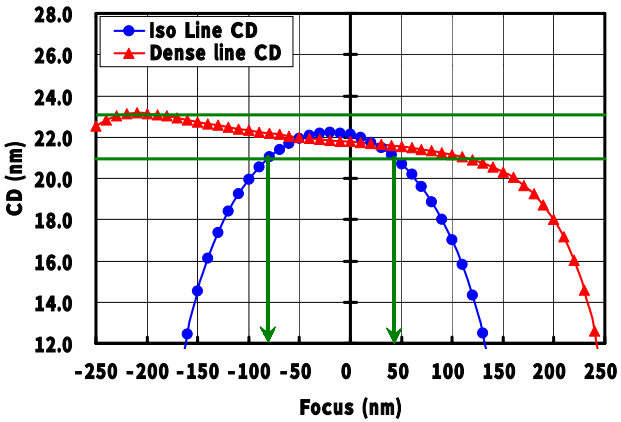
(b) Binary mask
Ta 78nm/Cr 30nm
NA: 0.25, σ: 0.80



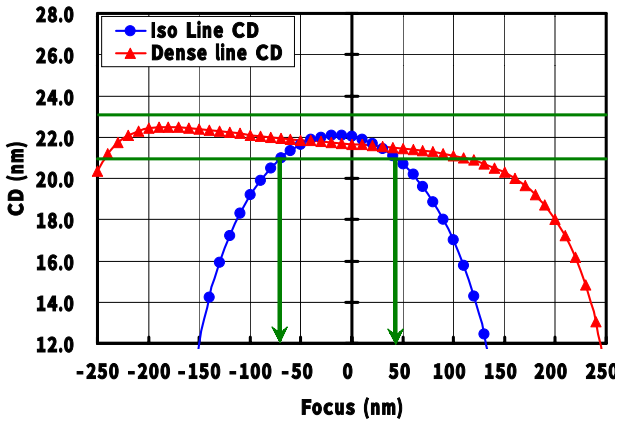
(c) Att-PSM
TaN 29nm/Ru 16nm
NA: 0.25, σ: 0.75/0.37

Symmetry NILS is provided for binary masks and att-PSM.

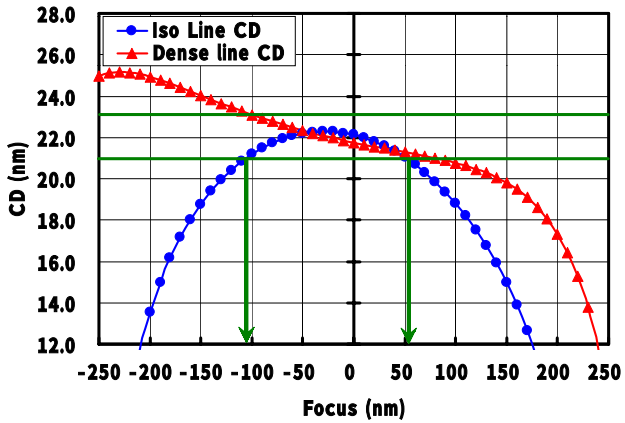
CD-focus curves



(a) Binary mask
Ta 34 nm/Cr 30 nm
NA: 0.25, σ: 0.80



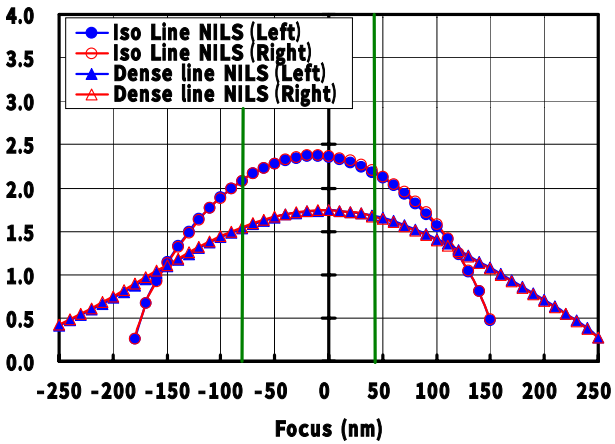
(b) Binary mask
Ta 78 nm/Cr 30 nm
NA: 0.25, σ: 0.80



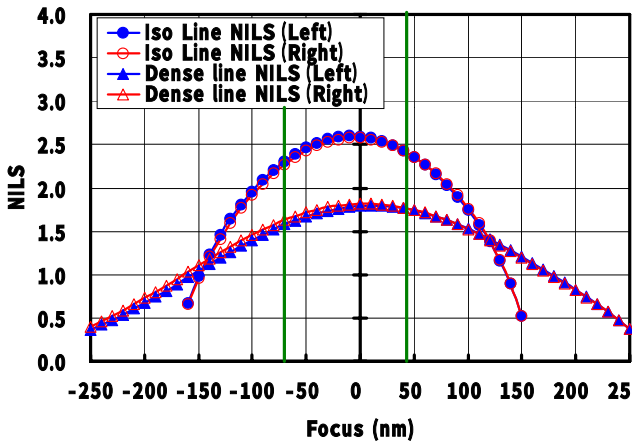
(c) Att-PSM
TaN 29 nm/Ru 16 nm
NA: 0.25, σ: 0.75/0.37

DOF by NILS for Ta 34 nm/Cr 30 nm is slightly larger than that for Ta 78 nm/Cr 30nm in binary masks.
DOF by NILS for isolated feature is increased by att-PSM.
Common DOF between iso-dense features is enlarged by att-PSM.

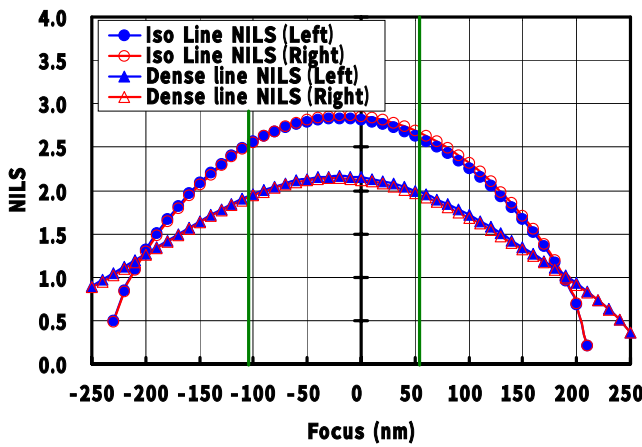
NILS-focus curves



(a) Binary mask
Ta 34nm/Cr 30nm
NA: 0.25, σ: 0.80



(b) Binary mask
Ta 78nm/Cr 30nm
NA: 0.25, σ: 0.80



(c) Att-PSM
TaN 29nm/Ru 16nm
NA: 0.25, σ: 0.75/0.37

NILS increases for isolated and dense features, when att-PSM is used.

Conclusions

EUVL ASET

- A feasible pattern fidelity was achieved after mask pattern correction for a 22-nm-wide model pattern.
- Mask pattern feature after correction was equivalent between binary and attenuated phase shift masks.
- Symmetry in the MEEF for left and right pattern edges was provided by the thin configuration of Ta 34 nm/Cr 30 nm and att-PSM of TaN 29 nm/Ru 16 nm.
- Symmetry of NILS was provided for binary masks and att–PSM at NA 0.25.
- Att-PSM increased DOF of isolated features in the model pattern and provided larger NILS than binary masks.
  Att-PSM is an effective candidate for 22-nm-wide patterns.

Acknowledgement

This work was performed under the management of ASET in a METI R&D program supported by NEDO.