Impact of mask absorber properties on printability in EUV lithography

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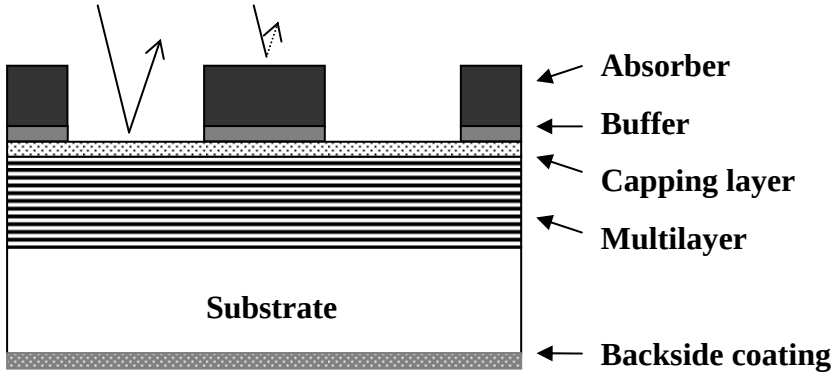
* SFET: Small Field Exposure Tool

Requirements for EUVL Mask and Motivation



Motivation:
Propose optimum absorber structure from the viewpoint of lithographic requirements

(Although EUVL mask requires less aggressive OPC than current photomask, it is considered necessary to introduce correction for shadowing effect.)

- ✓ **Requirements from chip vendor**
  - **High lithographic performance**
    - **High image contrast at wavelength**
    - **Low shadowing effect due to reflective mask and oblique illumination**
    - **Low thermal expansion material substrate**
    - **High flatness control**
    - **High durability against EUV light exposure**

  etc.
- ✓ **Requirements from mask vendor**
  - **High performance of mask processing (writing, etching, cleaning, etc.)**
  - **High performance of defect inspection & repair**

  etc.

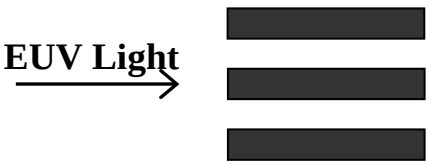
Condition of Aerial Image Simulation

Simulator :	**EM-Suite™ (Panoramic Technology Inc.)**
Exposure Condition :	**NA=0.3(Central Obscuration : 30%), sigma (inner /outer)=0.3/0.7, λ=13.5nm**
Incident Angle :	**6deg**
Magnification :	**1/5**
Pattern :	**45nm L/S, 32nm L/S, 22nm L/S; Parallel to EUV light projection (Horizontal) & Perpendicular to EUV light projection (Vertical)**
Blanks Structure :	**Absorber w/ or w/o Buffer / Si cap (11nm) / (Mo: 2.8nm / Si: 4.2nm) 40pairs M.L. / Qz substrate**
Others:	**No aberration, No flare, No resist model**

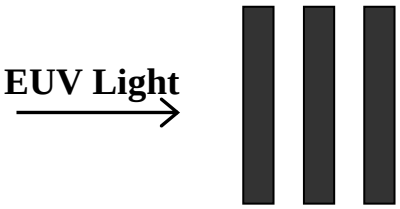
SFET exposure condition

Definition of Mask Pattern Orientation

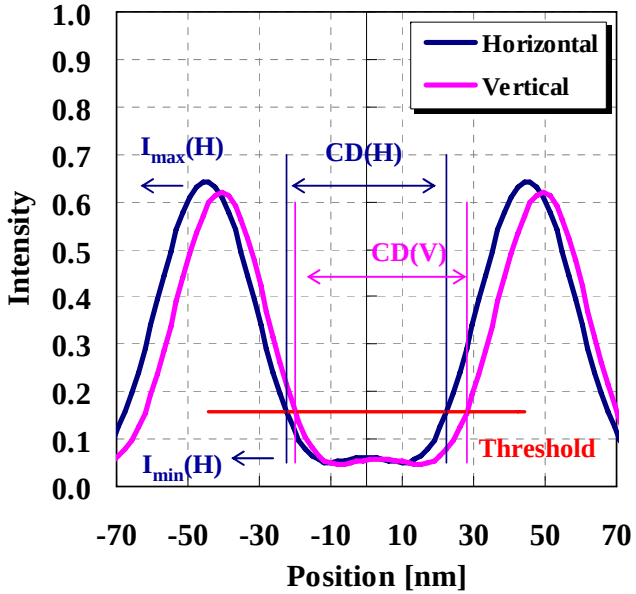
Horizontal (Parallel)



Vertical (Perpendicular)



Definition of Contrast and Printed CD



Contrast =
$(I_{max} - I_{min}) / (I_{max} + I_{min})$

Refractive Index and Reflectivity of Typical EUVL Mask Blanks Material

Blanks structure

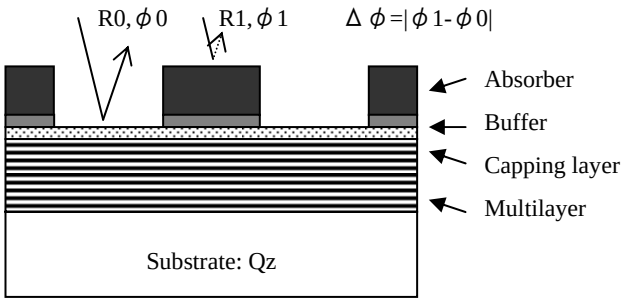
Absorber: Cr, Ge, Ta, TaN, Ta2O5

Buffer: -

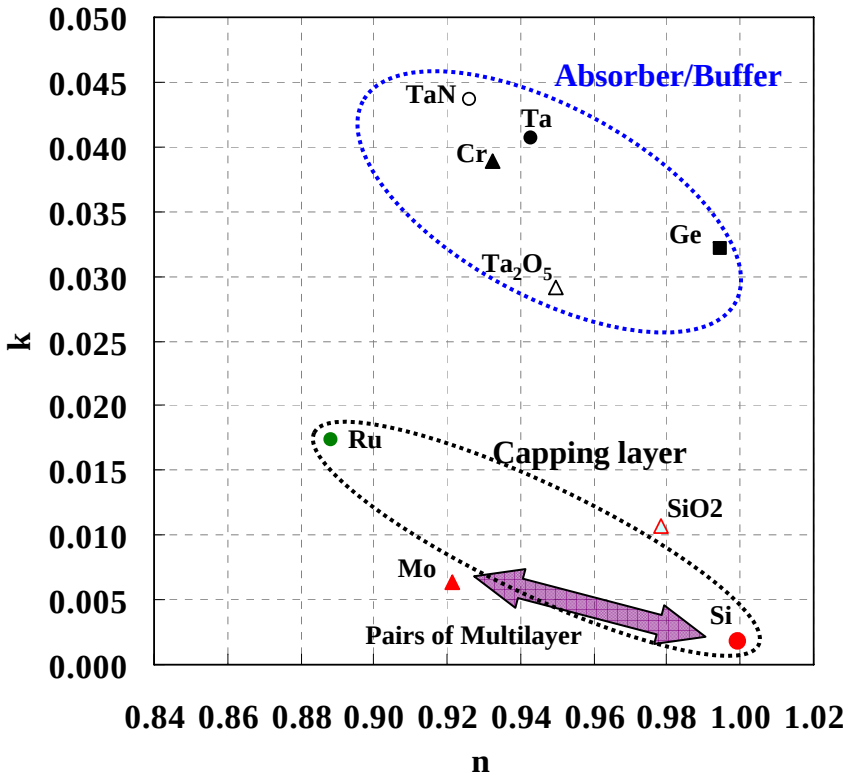
Capping layer: Si (11nm)

Multi layer: 40 pairs of Mo/Si (2.8nm/4.2nm)

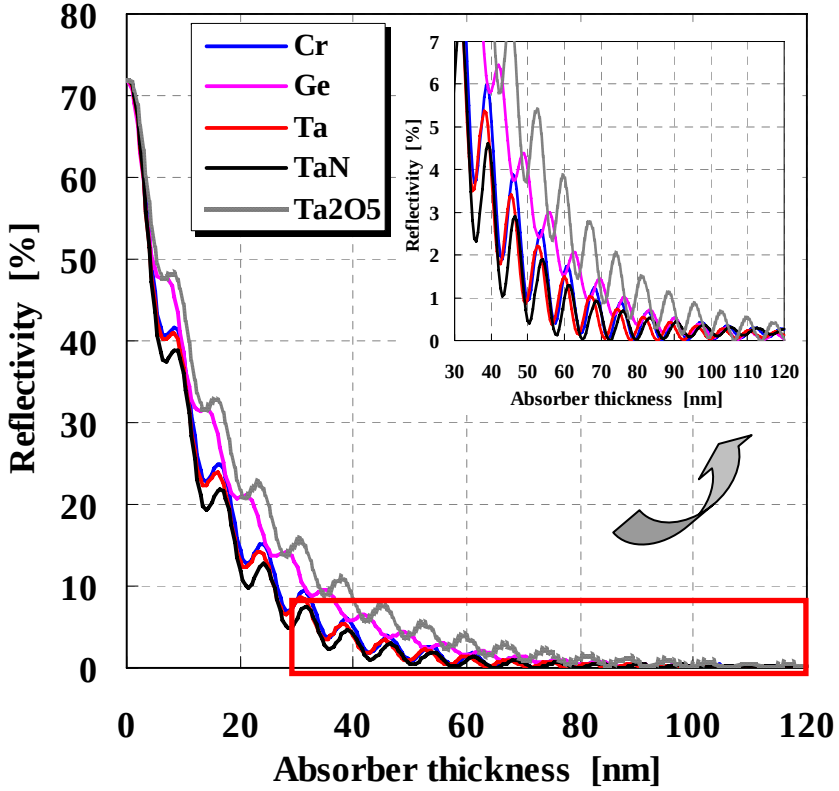
n, k value http://www.cxro.lbl.gov/optical_constants/



Refractive index @ 13.5nm wavelength



Reflectivity Dependence on Absorber thickness



Phase Difference and Contrast of Typical Absorber

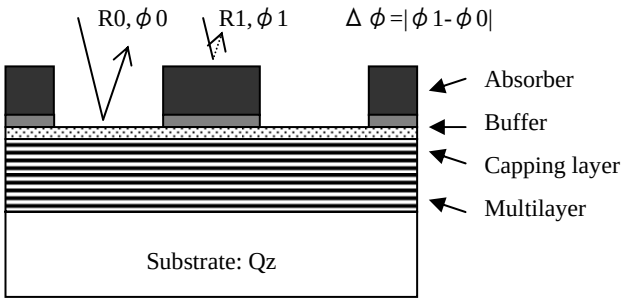
Blanks structure

Absorber: Cr, Ge, Ta, TaN, Ta2O5

Buffer: -

Capping layer: Si (11nm)

Multi layer: 40 pairs of Mo/Si (2.8nm/4.2nm)



Phase Differnece

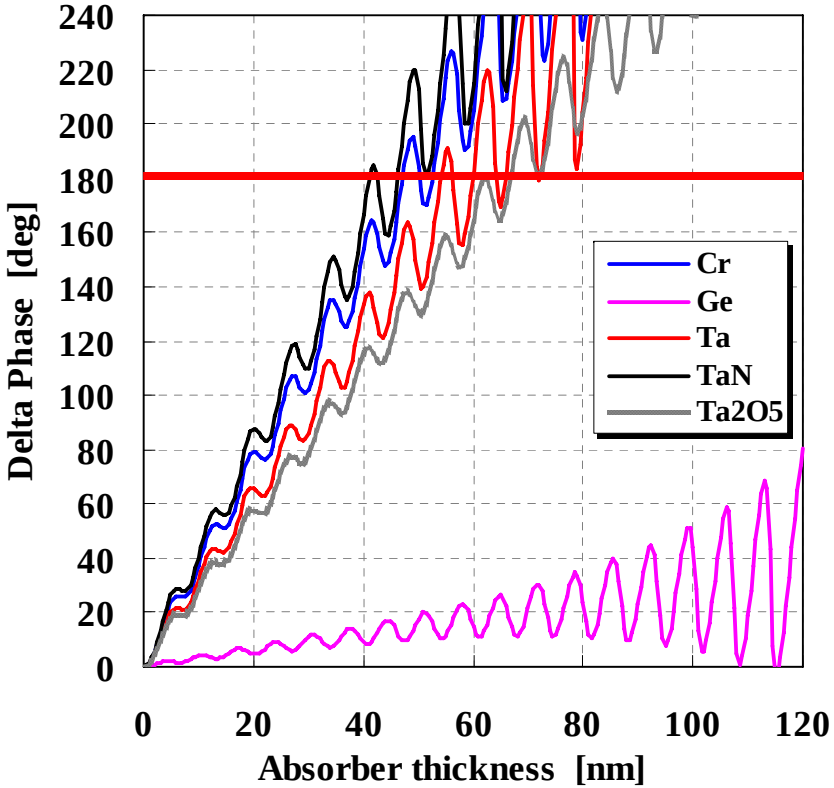
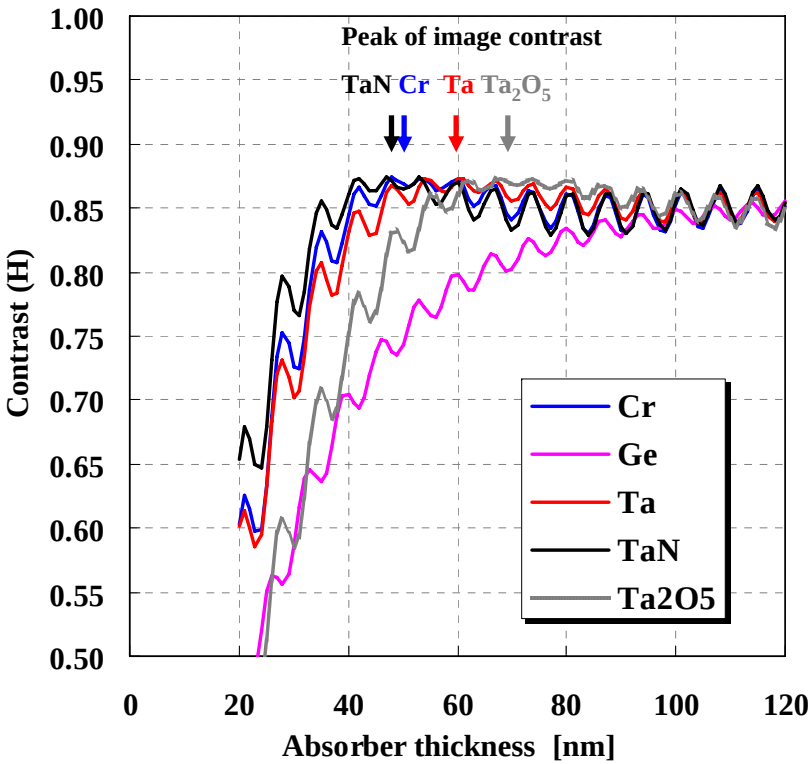


Image Contrast (45nm L/S)

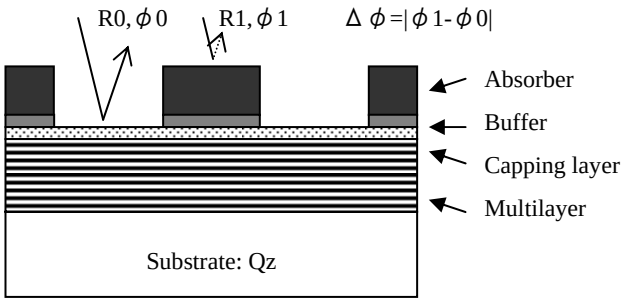


Absorber thickness which gives peak contrast is located near 180deg phase difference.

Phase Difference and Contrast of LR-TaBN Absorber, CrN Buffer

Blanks structure

Absorber:	**LR-TaBN**
Buffer:	**CrN (10nm)**
Capping layer:	**Si (11nm)**
Multi layer:	**40 pairs of Mo/Si (2.8nm/4.2nm)**



Phase Difference

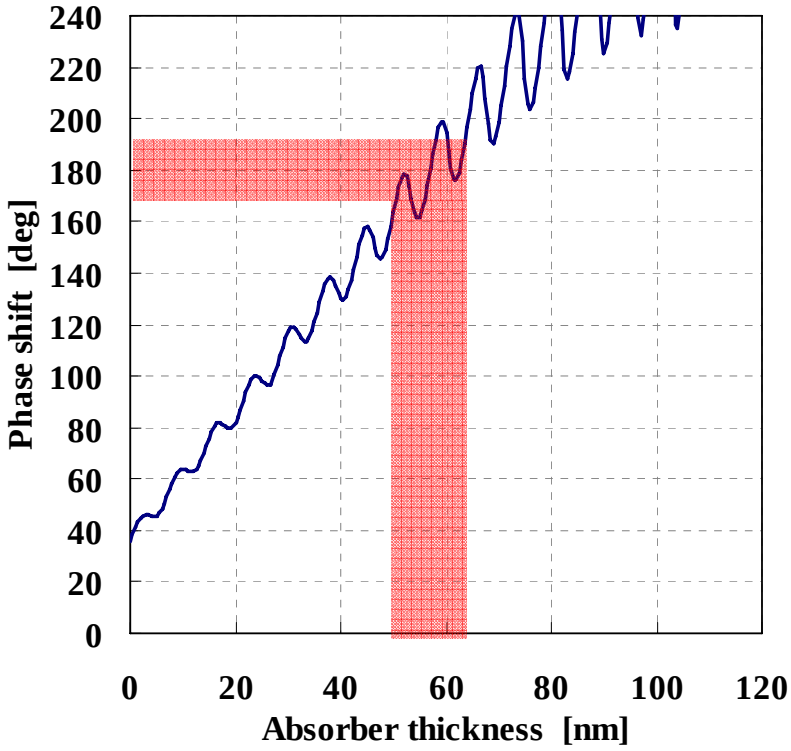
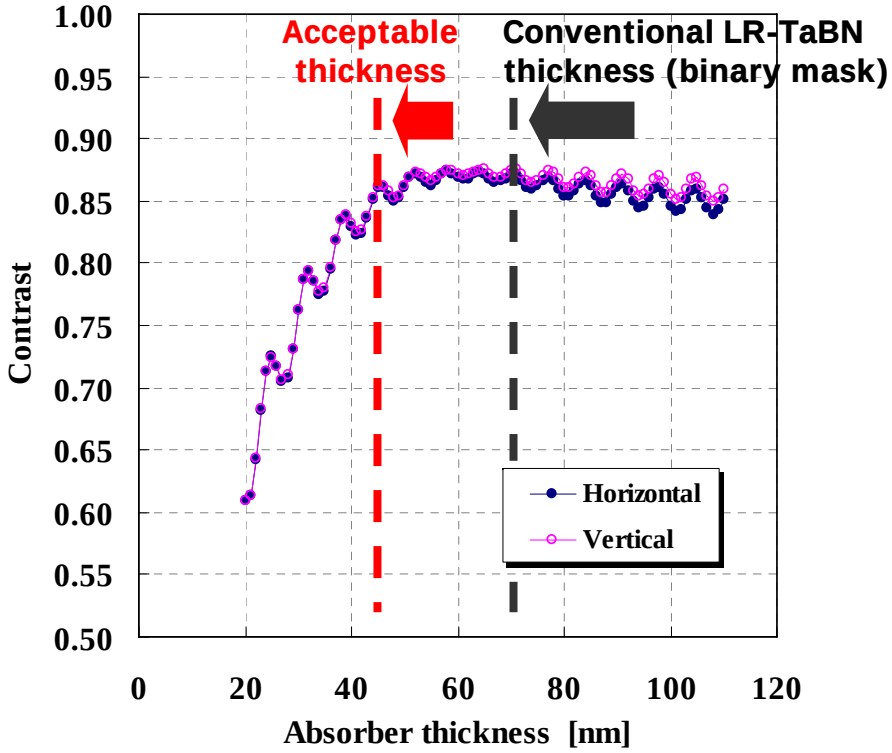
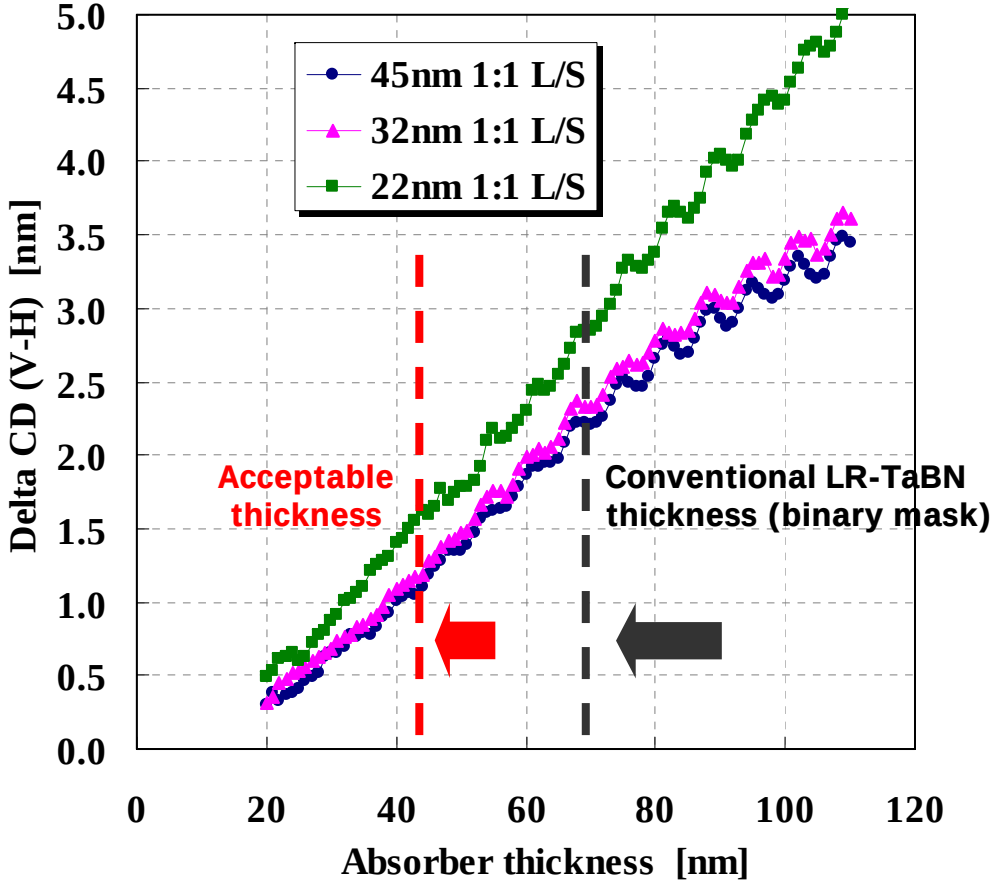


Image Contrast (45nm L/S)



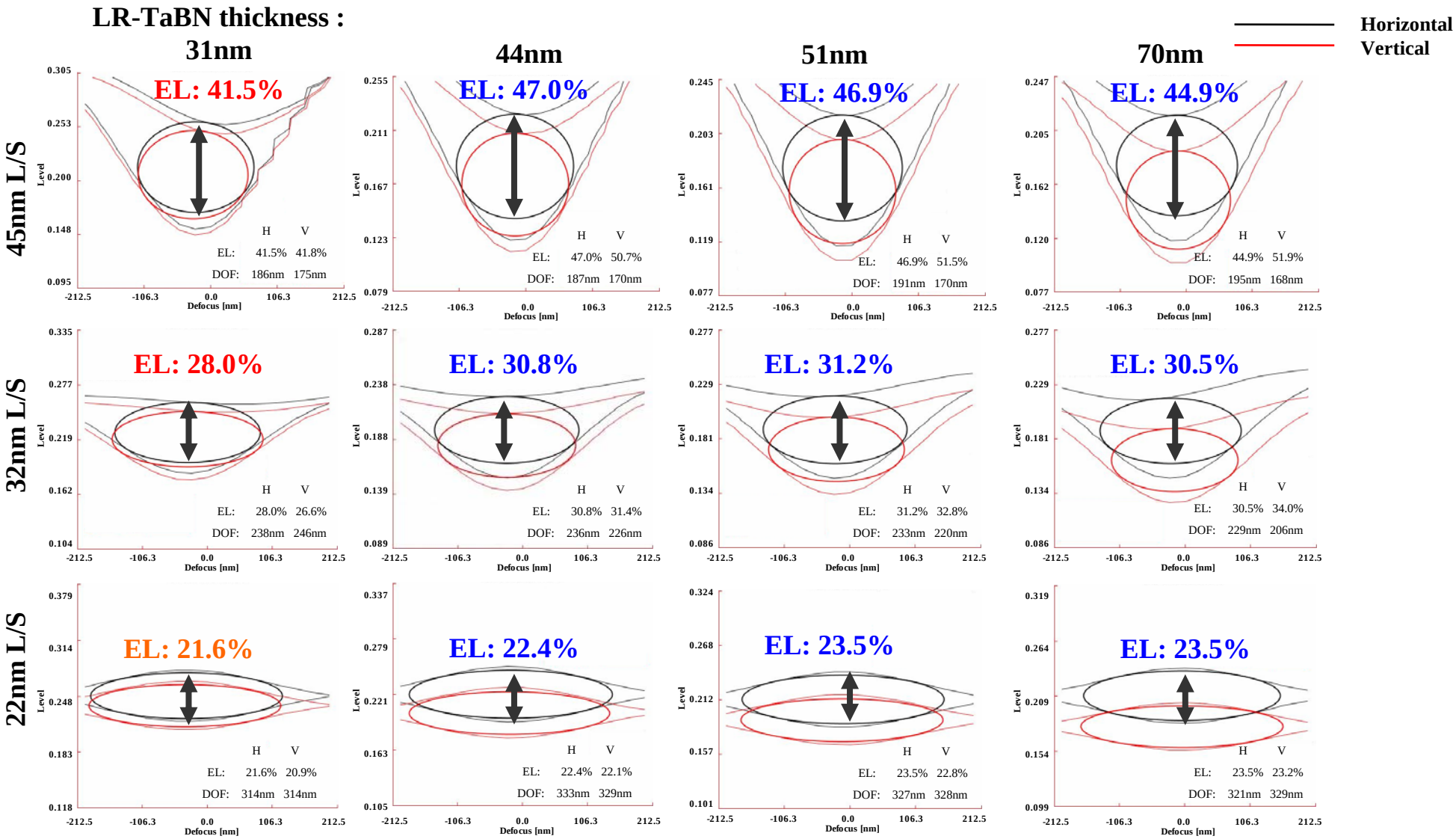
44nm LR-TaBN thickness mask has an acceptable image contrast.

CD difference between vertical and horizontal pattern



As LR-TaBN absorber thickness gets reduced, printed CD difference between horizontal and vertical pattern is further reduced.

Process Window (ED-Window: +/-10% CD tolerance)



- ✓ **By thinning LR-TaBN absorber, process window's overlapping area gets larger.**
- ✓ **LR-TaBN mask of 44nm absorber thickness has no less exposure latitude (E.L.) than that of 70nm absorber thickness. E.L. of 31nm absorber thickness mask begins to get worse.**

Blanks, Masks and SFET Exposure Condition

Blanks for EUV Reflectivity Measurement (6 plates)

Blanks structure :	LR-TaBN / CrN buffer(10nm) / Si cap (11nm) / M.L. (Mo/Si) 40pairs / Qz substrate
LR-TaBN thickness variation :	32nm, 42nm, 44nm, 46nm, 60nm, 70nm
Reflectivity Measurement :	LPR1016-FS1515 (EUV Technology)

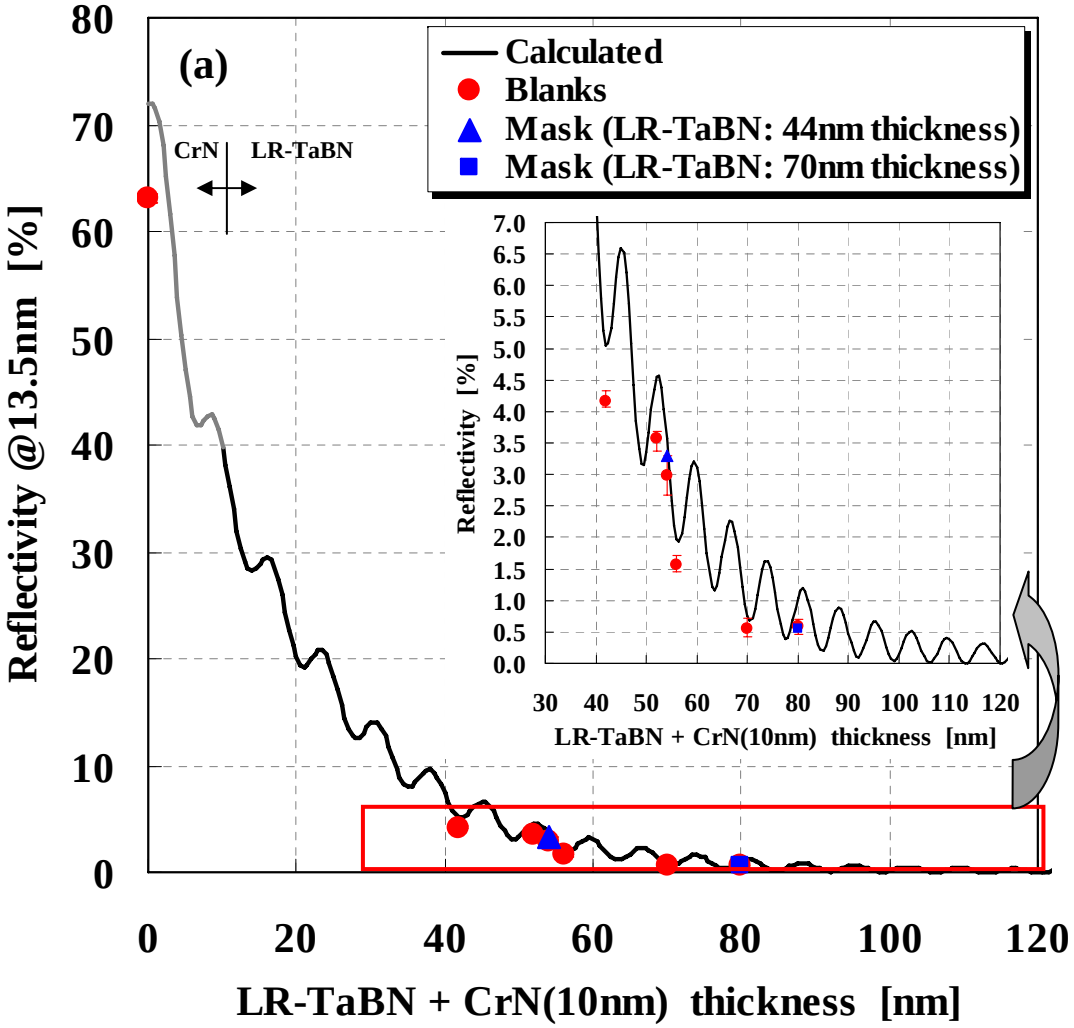
Masks for SFET Exposure (2 plates)

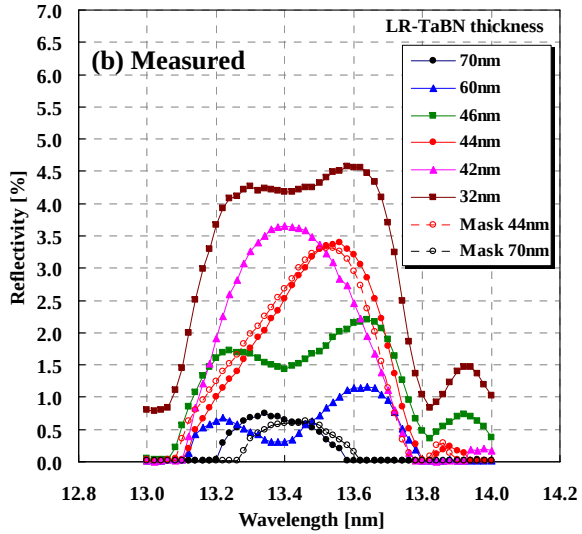
Thin absorber type :	44nm LR-TaBN thickness
Reference :	70nm LR-TaBN thickness

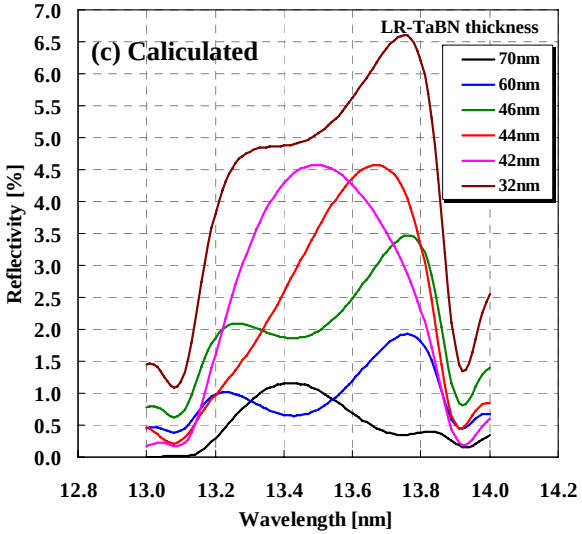
SFET Exposure Condition and Resist CD Evaluation

Exposure condition:	NA=0.3 (central obscuration: 30%), sigma (inner/outer)=0.3/0.7, Incident angle=6deg, Magnification=1/5
Resist :	MET-2D (Rohm & Haas) 125nm thickness
Resist CD evaluation:	S9380II (HITACHI High-Technologies)

EUV Reflectivity of LR-TaBN Blanks







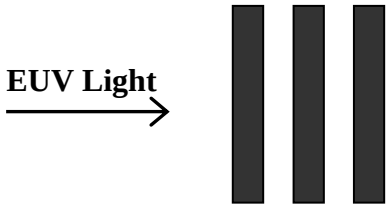
Measured reflectivity of absorber blanks/mask is in fairly good agreement with calculated reflectivity.

Small difference between measured and calculated reflectivity is observed because mulilayer model in this calculation is simple Mo/Si 40 pairs.

Mask CD for SFET Exposure (225nm 1:1 L/S (5x))

Horizontal (Parallel)

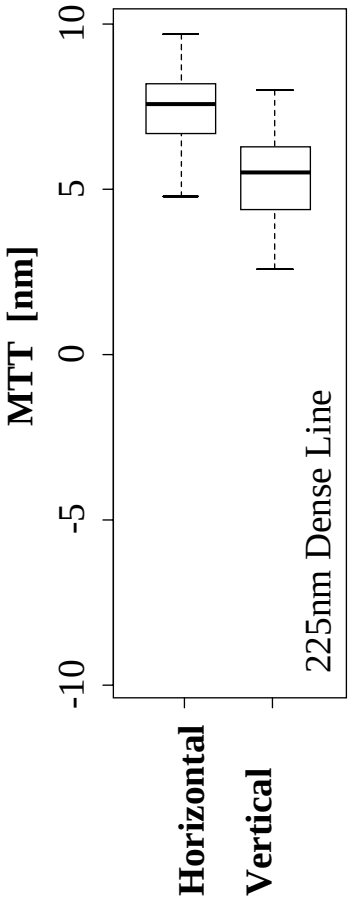
Vertical (Perpendicular)



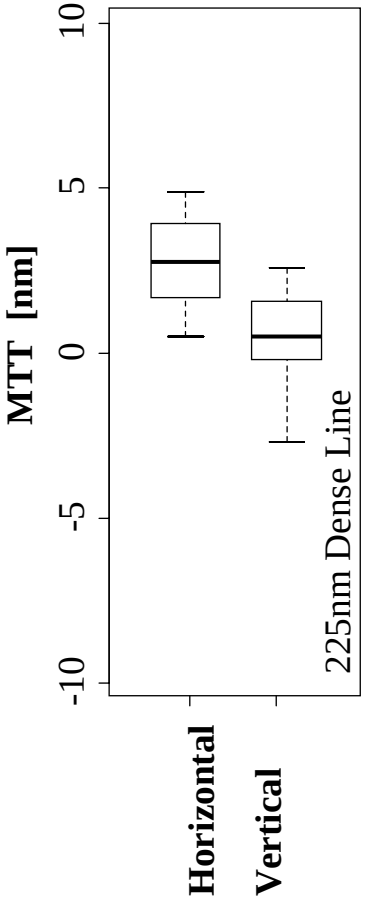
MTT =

Measured Line CD - Target Line CD (5x)

LR-TaBN : 70nm



LR-TaBN : 44nm



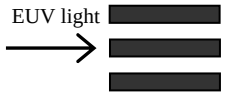
In both masks, the horizontal line CD is larger than the vertical line CD.

ED-Window (70nm thickness LR-TaBN)

Resist: MET-2D (125nm thickness)

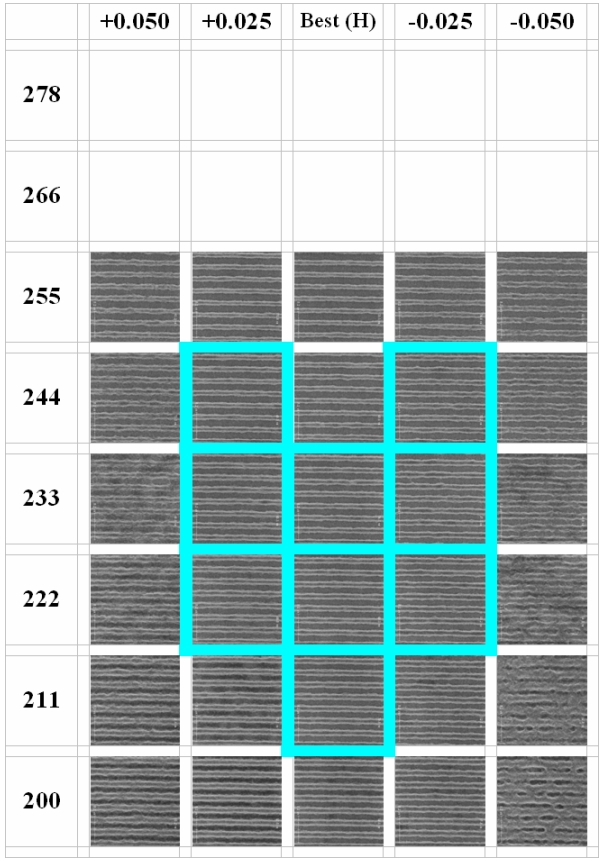
Pattern: 45nm 1:1 L/S

Horizontal (Parallel)



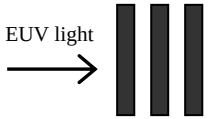
Defocus [um]

Dose [J/m2]



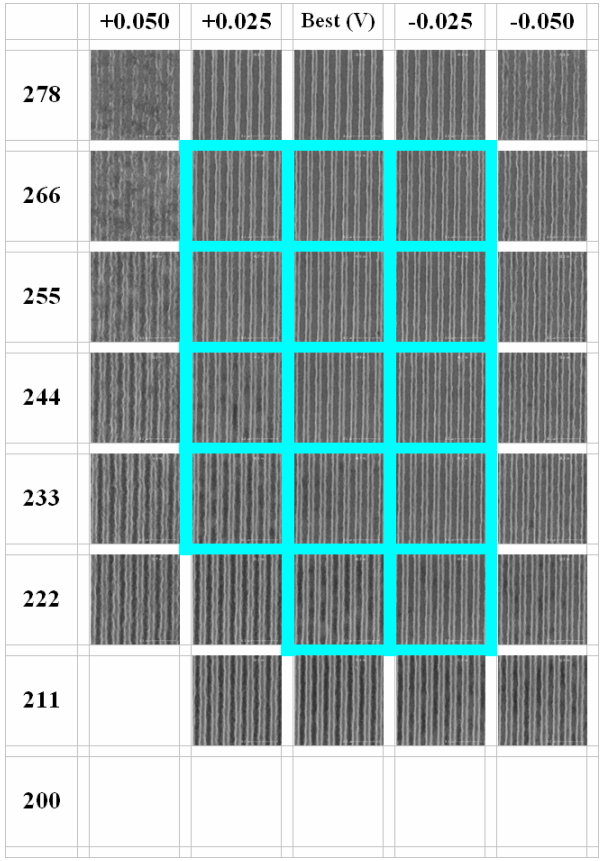
Colored area patterns satisfy the +/- 10% tolerance from the target CD.

Vertical (Perpendicular)



Defocus [um]

Dose [J/m2]



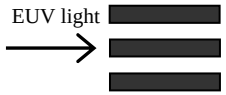
The best dose difference between H and V pattern is about 10%.

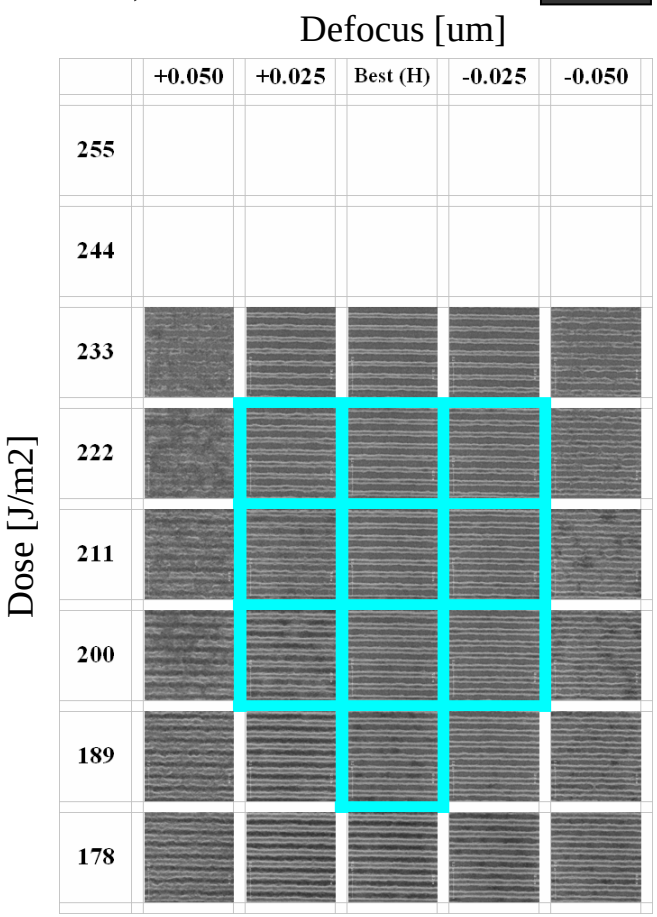
ED-Window (44nm thickness LR-TaBN)

Resist: MET-2D (125nm thickness)

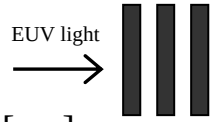
Pattern: 45nm 1:1 L/S

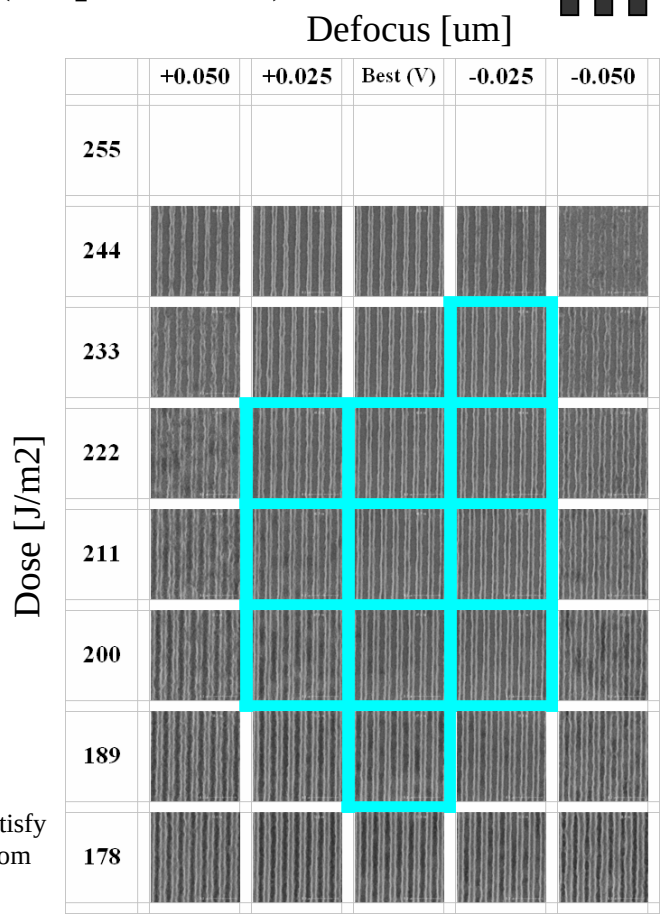
Horizontal (Parallel)





Vertical (Perpendicular)





Colored area patterns satisfy the +/- 10% tolerance from the target CD.

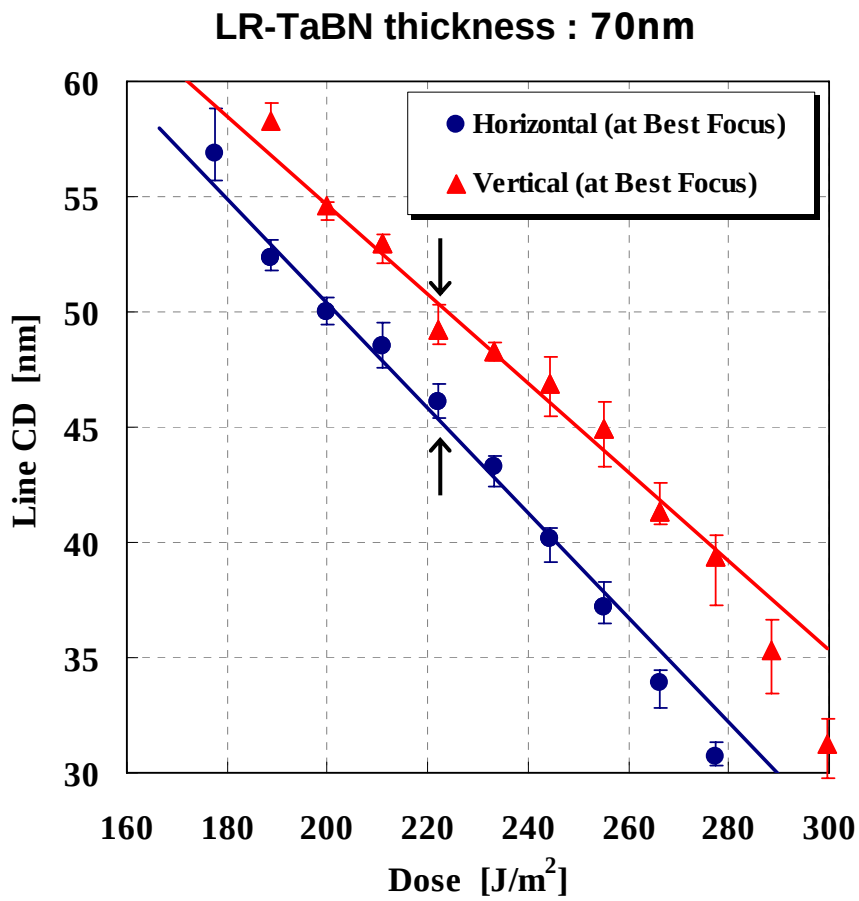
The best dose difference between H and V pattern is less than 5%.

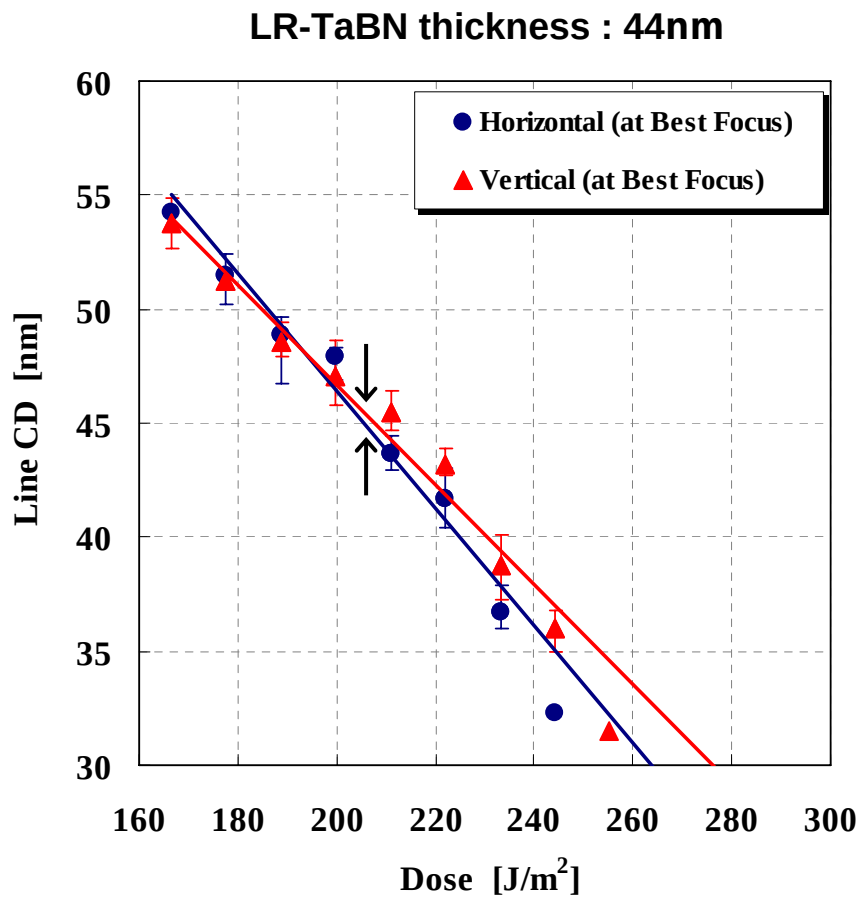
Horizontal pattern's process window size of 44nm and 70nm LR-TaBN mask is almost same.

Line CD Dependence on Dose @ Best Focus

Resist: MET-2D (125nm thickness)

Pattern: 45nm 1:1 L/S



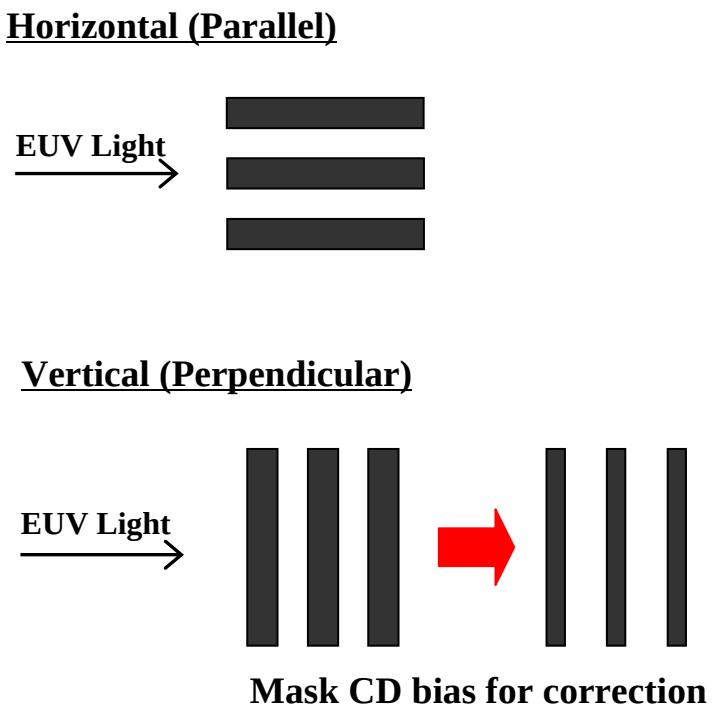


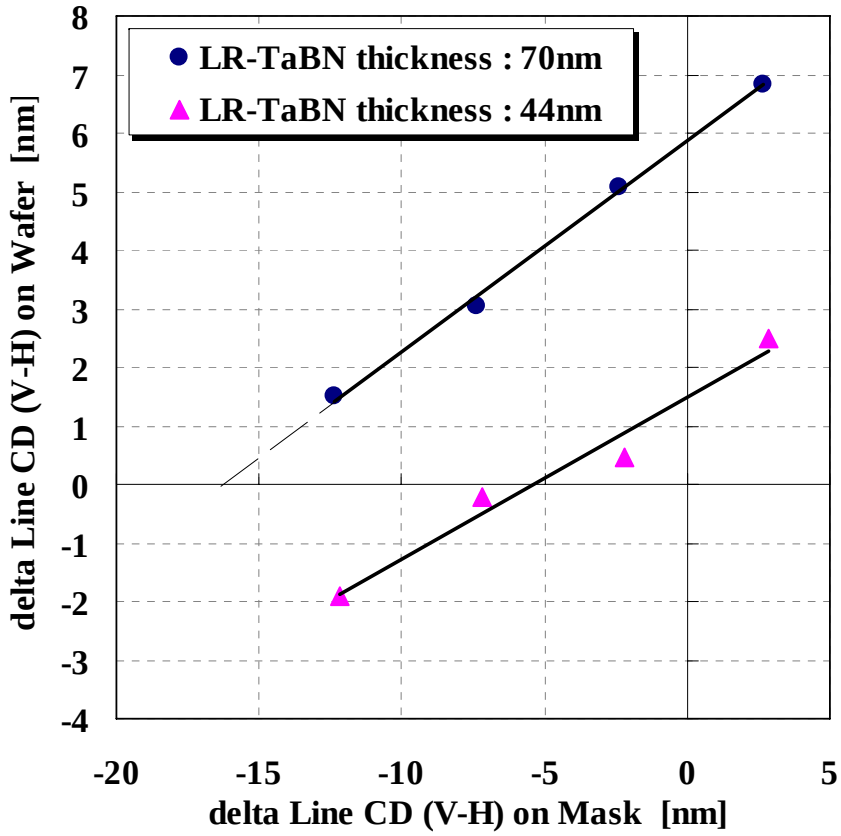
Comparing 44nm LR-TaBN thickness mask to 70nm LR-TaBN thickness mask, printed H-V CD difference was reduced.

Correction of H-V CD Difference with Mask Bias

Resist: MET-2D (125nm thickness)

Pattern: 45nm 1:1 L/S





Optimum mask bias (absolute value) for printed CD difference correction of 44nm LR-TaBN thickness mask is smaller than that of 70nm LR-TaBN thickness mask.

Conclusions

From lithography simulation,

we found that there exists optimum thickness of Ta-based absorber for image contrast with reducing shadowing effect.

From SFET exposure experiment,

we demonstrated that shadowing effect was reduced without loss of printability performance by optimizing LR-TaBN absorber thickness.

No loss of printability performance even by thinning absorber is due to attenuated phase shifting mask effect around the optimized thickness of the absorber.

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