[DI-P04]

Evaluation of EUVL mask pattern defect inspection using 199nm inspection optics

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Semiconductor Leading Edge Technologies, Inc.

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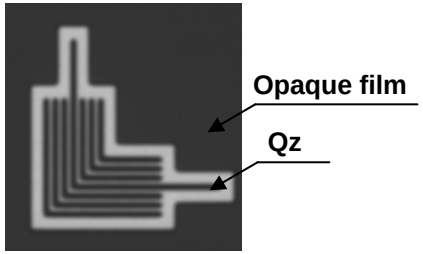
Introduction

Technological Issues of EUVL Mask Pattern Inspection

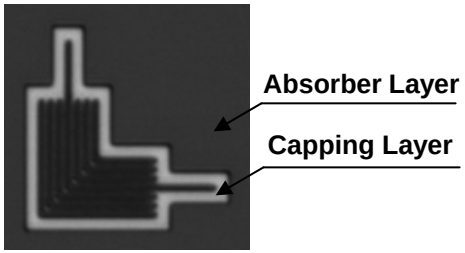
- Only reflected light images are available.
- The device pattern sizes are smaller than that for current optical lithography.

➡ For hp32nm technology era and beyond, improving the contrast of inspection images are necessary.

ArF-HT mask



EUV mask with 70nmt of abs. stack



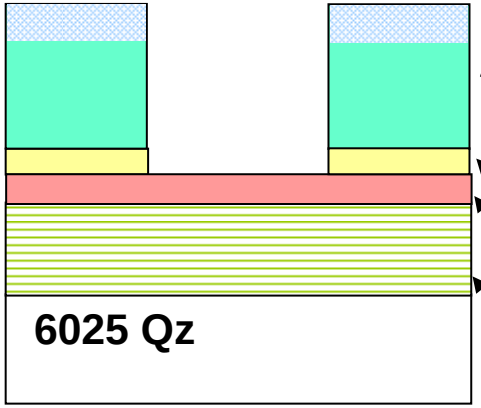
The key words to improve the inspection image contrast are:

- Inspection optics;
  Adopting higher NA and shorter wavelength etc.
- Mask structures;
  Optimizing the contrast value and <u>the absorber thickness</u> etc.

In this work, we evaluated the influence of absorber thickness on inspection image contrast and its capability for defect inspection with using wavelength of 199-nm inspection optics.

Sample mask structure

- **Sample structure (Hoya blanks)**



Absorber Layer ; LR*- TaBN Absorber

> For image contrast test
70, 60 and 44nm

> For inspection sensitivity test
70 and 44nm

Buffer Layer ; CrN 10 nm

Capping Layer ; Si 11 nm

Reflective Layer ; Mo / Si 40 pairs

***LR; Low Reflectivity**

Test pattern/ Image contrast evaluation

- **Design of test mask**

Absorber Thickness; 70, 60 and 44nm

Base Pattern; 1:1 L/S, hp128, 180nm

CD Errors / L/S-space CD

Thickness of absorber layer/nm	hp128nm Space CD error/nm	hp180nm Space CD error/nm
70	2.7	2.1
60	-0.4	-1.5
44	0.8	0.2

Measured by SEM ; LWM9000SEM (Vistec Semiconductor Systems)

- **Mask CDs are well targeted.**

Test pattern and Inspection condition

- **Design of Programmed Defect mask**

Absorber Thickness;	70, 44nm
Base Pattern;	1:1 L/S, hp128, 180nm
Defect Type;	Opaque Extension, Clear Extension
Defect Size;	16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 44, 48, 52
	56, 60, 64, 68, 72, 78, 84, 90, 96, 102, 110, 120, 130, 180

- **Inspection condition**

Image Pixel Size;	50nm
Mode;	Die to Die, 5runs

Defect size measurement

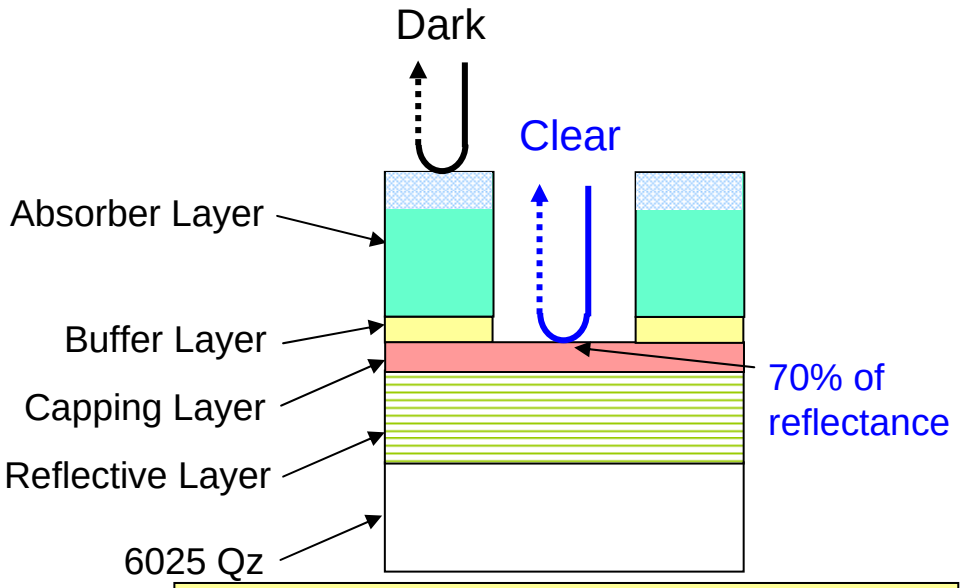
Measured defect size = Square root of area / nm

Why did Selete choose 44nm?
Refer to following presentation.
[MA-P09]
"Impact of mask absorber properties on printability in EUV lithography"

Image contrast / Comparison of mask structures

EUVL mask Reflected image

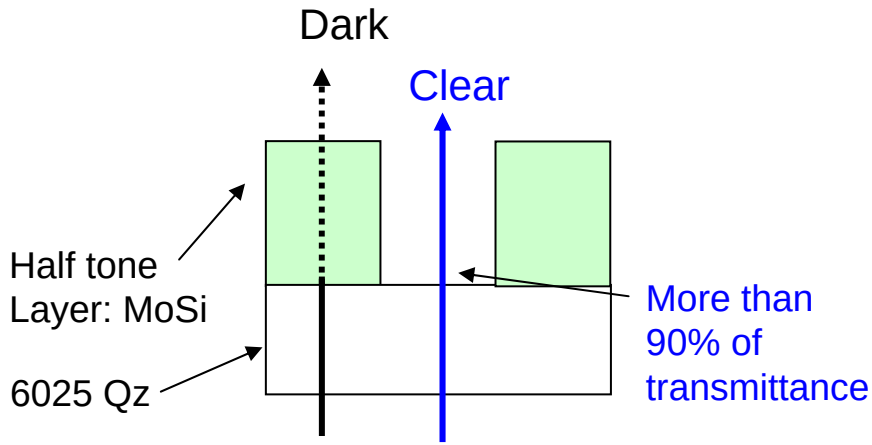
Low-contrast image



The inspection light should travel back and forth between the surface and bottom of absorber layer. (Round trip)

ArF-HT mask Transmitted image

High-contrast image!



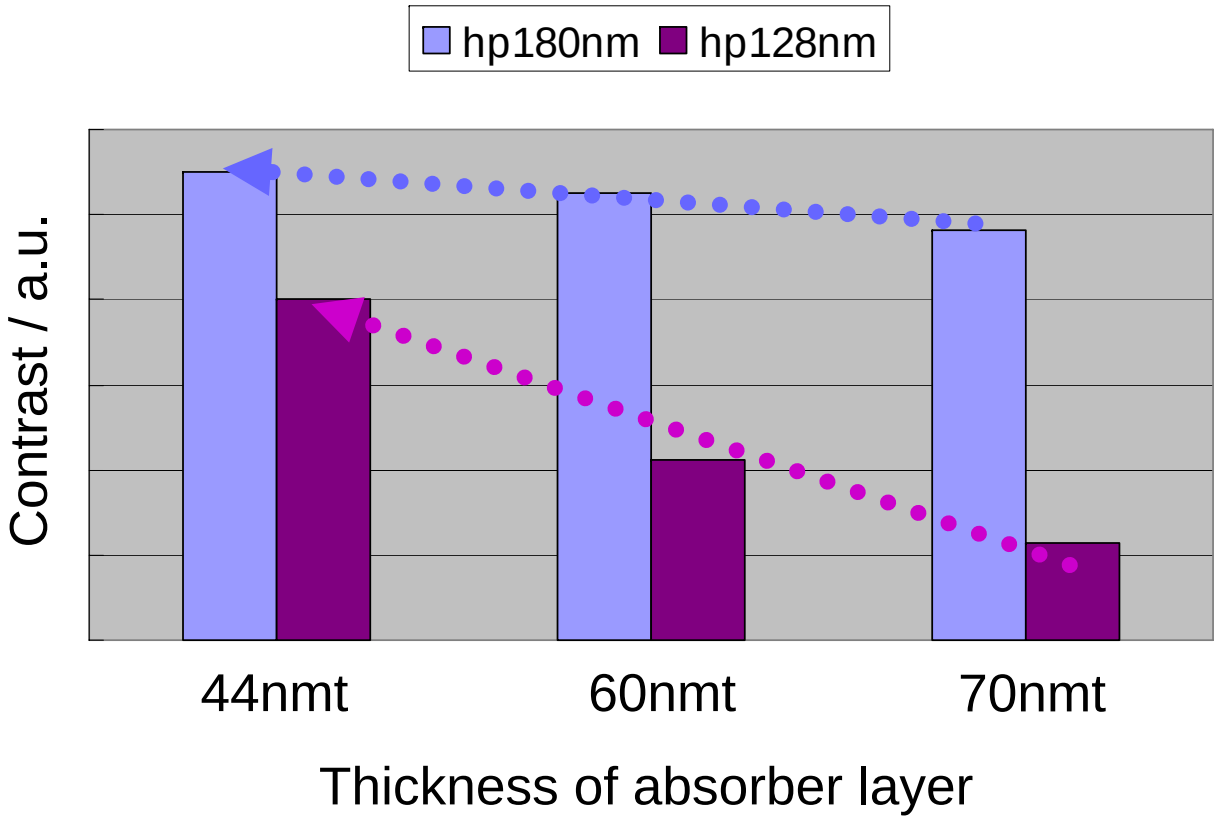
The inspection light travels through the Qz substrate and the aperture of half tone layer. (One-way)

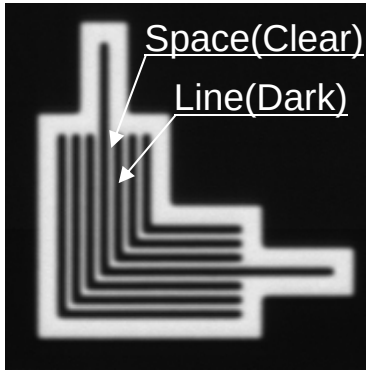
The optical property of ArF-HT masks itself are optimized for exposure condition of wafer printout. The wavelengths of these lights are almost same.

- **Conventional 70nm absorber layer thickness is equivalent to 160nm(*) of light travel distance.**
  (*)160nm=2x(70nmt+10nmt)

➡ **Reducing the thickness of absorber layer is effective way to improve the image contrast of mask patterns.**
However, we should keep the thickness within the limits of wafer printout available thickness.

Image contrast / hp180 and 128nm 1:1 L/S



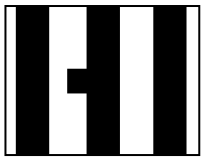


$$\text{Contrast} = \frac{(\text{Clear})-(\text{Dark})}{(\text{Clear})+(\text{Dark})}$$

- **The image contrasts were improved with reducing the thickness of absorber layer.**
- **Thinning the absorber layer from 70nm to 44nm:**
  - **> It was effective for the image contrast of hp128nm L/S pattern.**
  - **> It was not so effective for hp180nm L/S pattern. Because the pattern size was large enough to reflect the DUV light from reflective layer.**

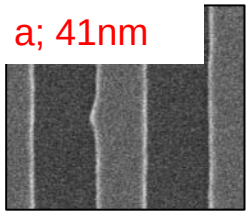
Inspection Sensitivity/hp180nm, Opaque Extension

Opaque Extension

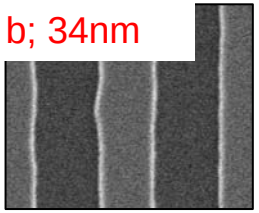


a; 70nm thickness		b; 44nm thickness	
Size/nm	Yield	Size/nm	Yield
29		24	
30		29	
37		34	
38		36	
39		39	
41		42	
45		45	
46		52	
49		53	
56		55	

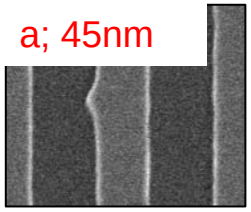
a; 41nm



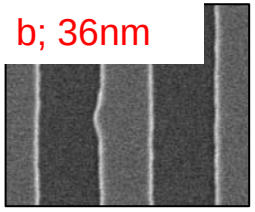
b; 34nm



a; 45nm



b; 36nm

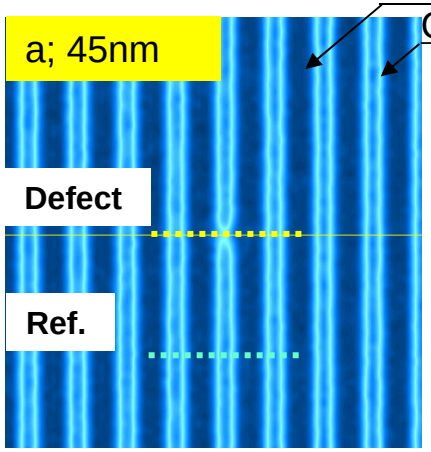


70nm thickness

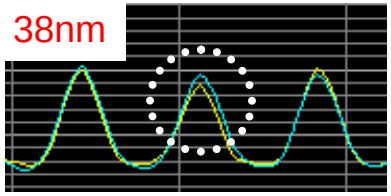
Absorber

Cap. Layer

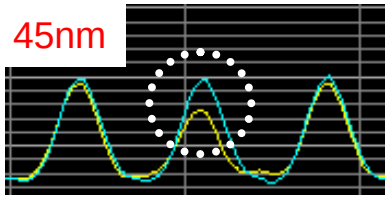
a; 45nm



38nm

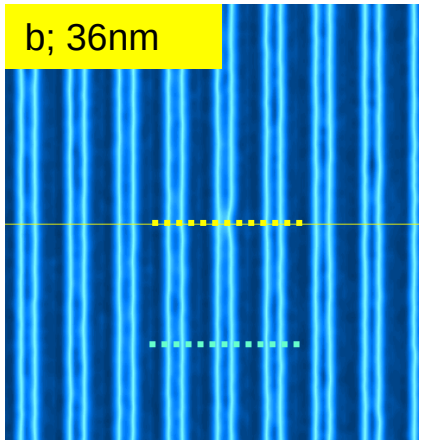


45nm



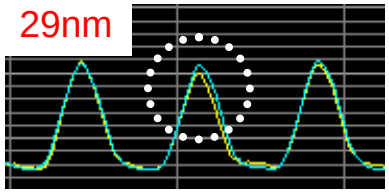
44nm thickness

b; 36nm

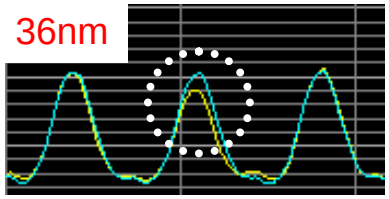


29nm

2)*



36nm



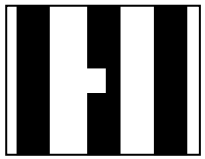
1)*

1)* Compared with almost same defect size, 44nm-thick type mask caused larger intensity variation.
2)* To improve the intensity changes, higher image contrast is needed.
The key items are:
> Improving and devising the inspection optics.
> Optimizing the reflectivity and structures of mask blanks.

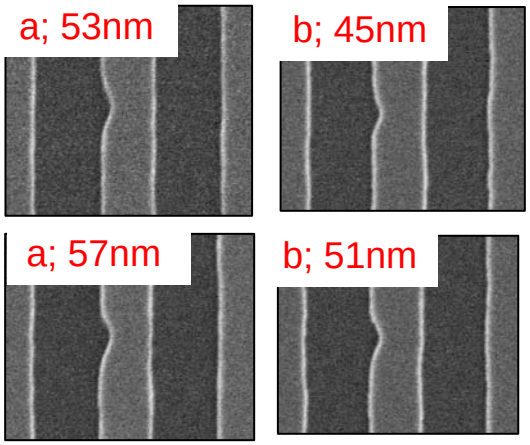
- **By applying 44nm of the absorber layer thickness, the sensitivity meets the ITRS roadmap specifications.**

Inspection Sensitivity/hp180nm, Clear Extension

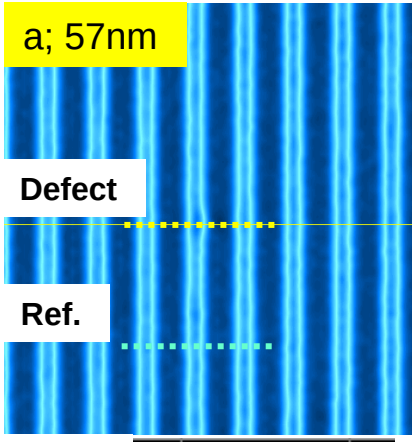
Clear Extension

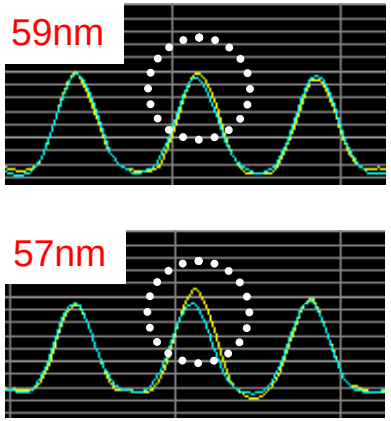


a; 70nm thickness		b; 44nm thickness	
Size/nm	Yield	Size/nm	Yield
36		31	
45		39	
59		45	
53		51	
57		58	
59		61	
75		71	
76		74	
81		80	
91		88	

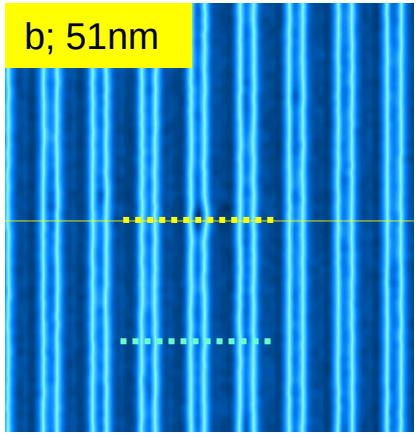


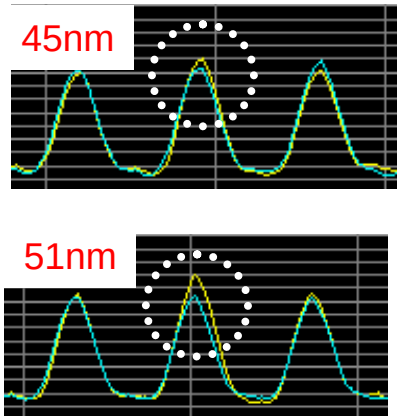
70nm thickness





44nm thickness





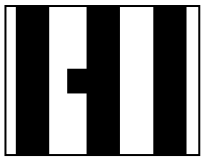
2)*

1)*

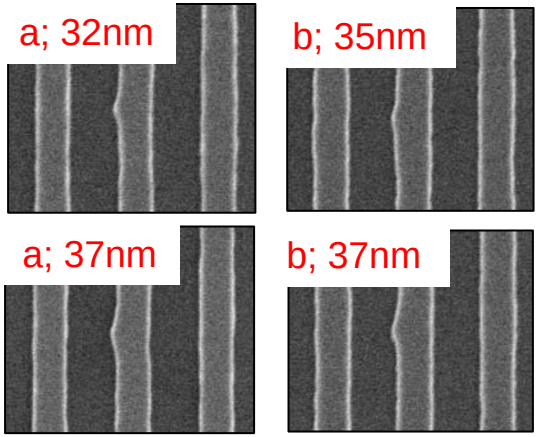
- **The effect of thinning the absorber layer was significant.**
- **The sensitivity performances for clear defects were lower than that of opaque extension defects. -> We need to re-balance the detection balance tuning.**

Inspection Sensitivity/hp128nm, Opaque Extension

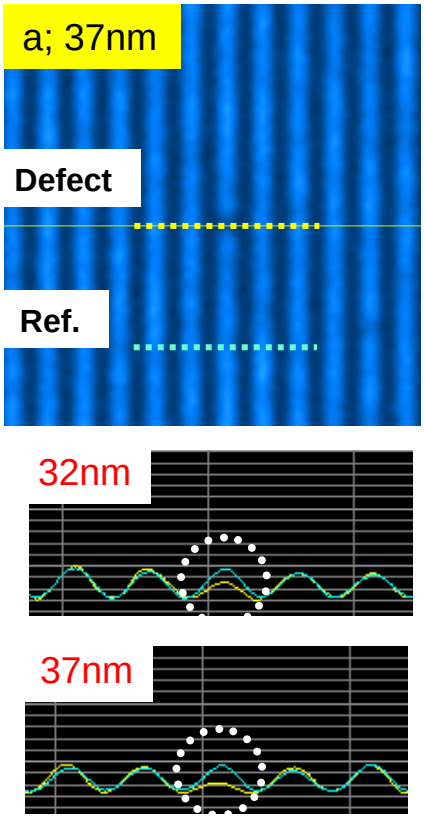
Opaque Extension



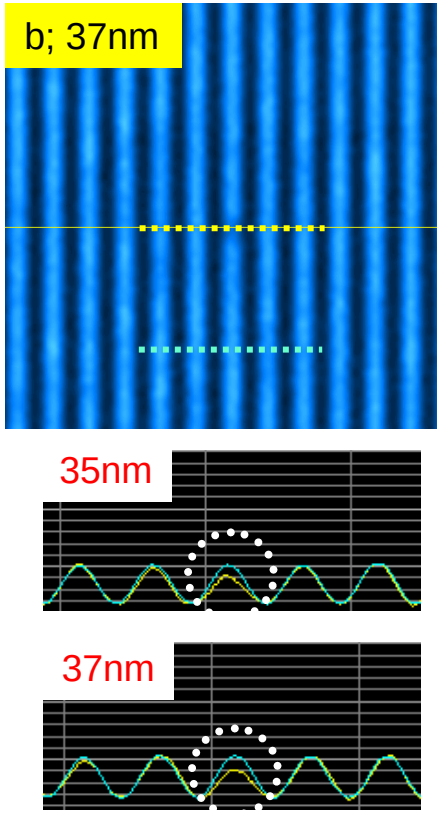
a; 70nm thickness		b; 44nm thickness	
Size/nm	Yield	Size/nm	Yield
28		29	
30		30	
32		35	
37		37	
38		38	
39		42	
42		43	
43		44	
44		46	
48		51	



70nm thickness



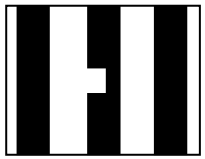
44nm thickness



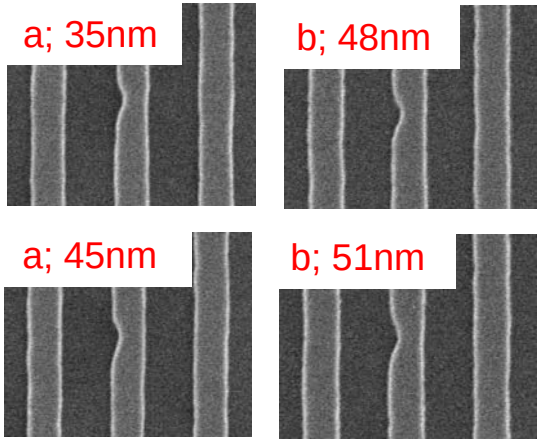
- **The effect of thinning the absorber layer on the sensitivity was not observed.**
- **In the case of 70nm thickness, it's hard to improve inspection algorithm to increase sensitivity, because the S/N ratio of intensity profiles are poor.**

Inspection Sensitivity/hp128nm, Clear Extension

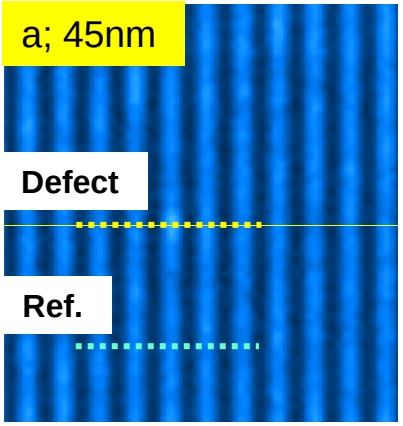
Clear Extension

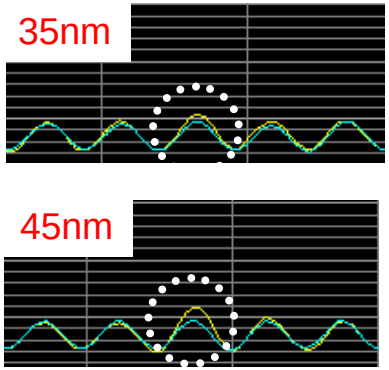


a; 70nm thickness		b; 44nm thickness	
Size/nm	Yield	Size/nm	Yield
32		33	
35		35	
45		48	
50		51	
56		58	
63		61	
65		75	
75		79	
82		82	
84		85	

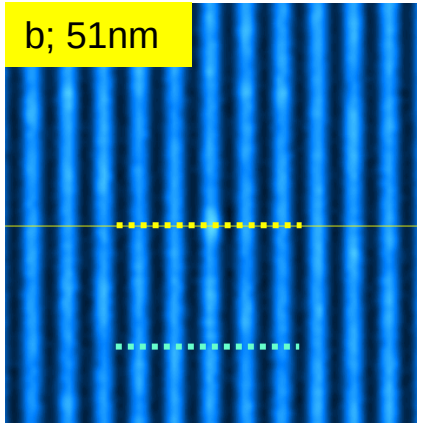


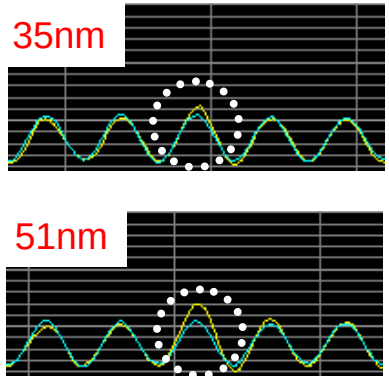
70nm thickness





44nm thickness





- **The effect of thinning the absorber layer was not significant.**
- **The sensitivity performance for clear defects were lower than that of edge extension defects. -> We need to re-balance the detection balance tuning.**

Summary

- We made a study on the impact of the absorber layer thickness, within the limitation of EUV lithography available region, on pattern image contrast captured by 199-nm inspection optics.
  Reducing the absorber layer thickness was effective in improving the image contrasts. We could get excellent image contrast of hp128nm L/S pattern by applying a 44nm absorber layer thickness.

- With the application of the 44nm absorber layer thickness, the inspection system could detect 36nm size opaque extension in hp180nm L/S pattern.
  The inspection sensitivity met the ITRS roadmap.
  Moreover, the inspection system could detect 37nm size of opaque extension in hp128nm L/S pattern.

- The clear extension defects tended to cause smaller intensity profile variation compared to those of the opaque extension defects.
  To improve the inspection sensitivity, the key items are:
  > Improving and devising the inspection optics.
  > Optimizing the reflectivity and structures of mask blanks.

Future Works

- Optimization of the defect inspection algorithm.
  Rebalancing the inspection sensitivity for opaque and clear defects.
- Optimization of the mask structure for 199nm inspection optics.
- Application to hp 2X nm node EUVL mask and beyond.
- Definition of the defect size to be detected by inspection tool.
  Estimation of the defect printability by EUVL tool and simulation.

Acknowledgement

• This work was supported by New Energy and Industrial Technology Development Organization (NEDO).

• We would like to thank
-T. Takikawa, T. Abe, T. Adachi and H. Akizuki of Dai Nippon Printing Co., Ltd for their mask fabrication support.
- Y. Tsuji and M. Hirono of Advanced Mask Inspection Technology Inc. for their technical support.