3D measurement SEM for EUV mask pattern quality assurance based on lithography simulation

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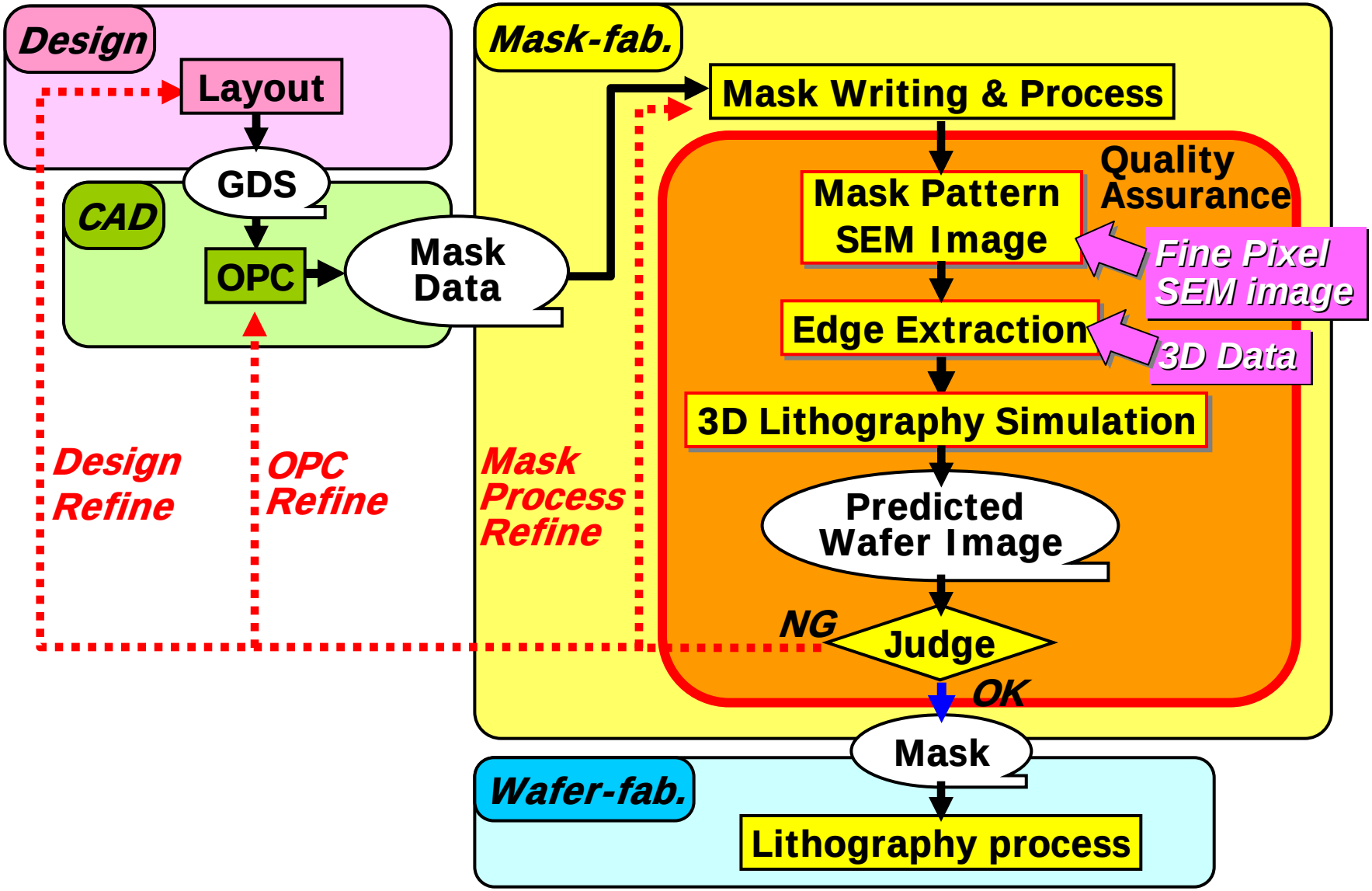
Outline

- Introduction
- 3D measurement SEM
- Experiment
- Conclusions

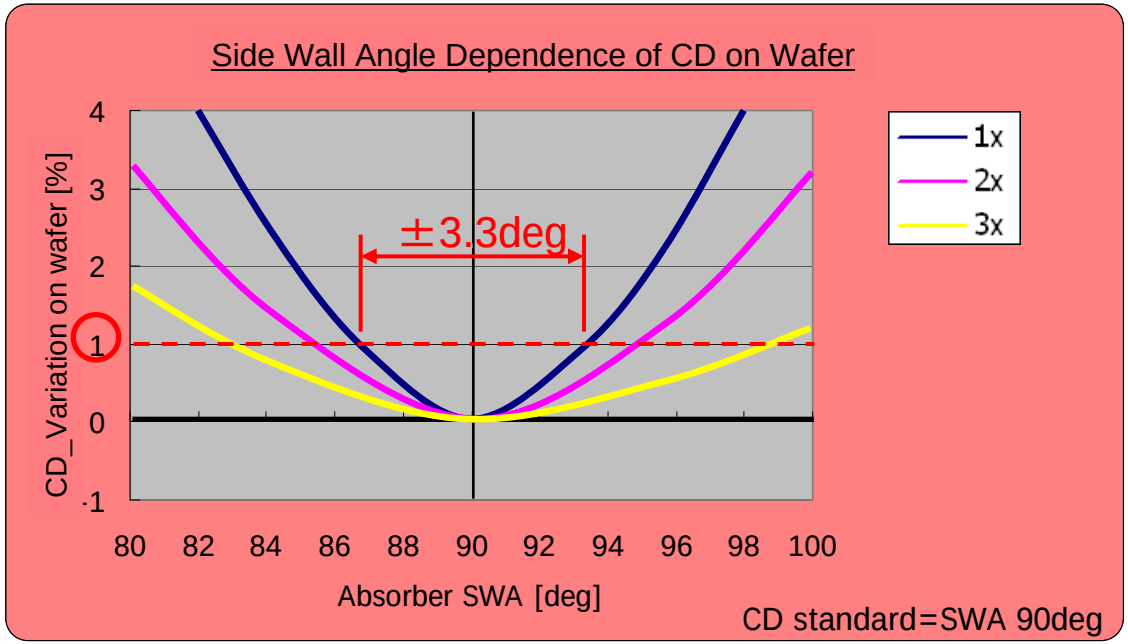
Introduction

- In our previous study, we proposed a lithography simulation based on edge extraction from a fine pixel SEM image of an actual photomask as a quality assurance of mask pattern having a complicated two-dimensional (2D) pattern such as so-called Hotspot.
- In EUV lithography that exposure light is diagonally incident on a mask pattern, the quality assurance of mask requires high accurate three-dimensional (3D) data of mask pattern including the side wall angle.
- In this presentation, we report the measurement accuracy of 3D shape of EUV mask pattern required for the quality assurance. And we report the effectiveness for the quality assurance through some simulation.

Mask Pattern Quality Assurance System



Requirement for Side Wall Angle Management



Requirement for side wall angle management in 1x generation, when CD error budget for side wall angle was assumed ΔCD 1% on wafer

ΔSWA＜±3.3deg

Error budget=10%

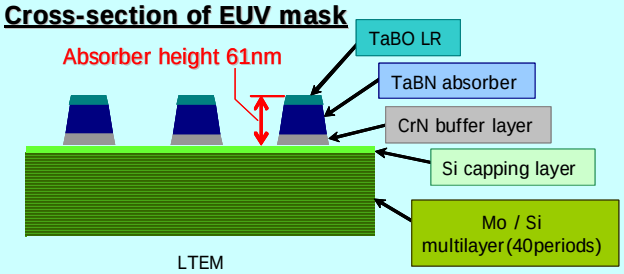
Required measurement accuracy ＜ ±0.3deg

- Simulation Conditions -

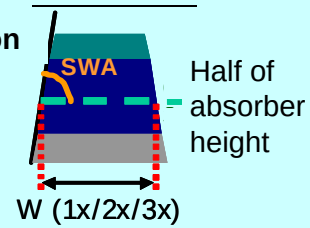
Pattern variation ; 1:1 L/S
hp 1x,2x,3x
Vertical, Horizontal
SWA(Side Wall Angle) : 80~100°

Parameters; λ : 13.5nm
NA : 0.32
Defocus : 0 μm
Flare : 0%
⊿L : 0nm, 10nm

Cross-section of EUV mask



CD Definition

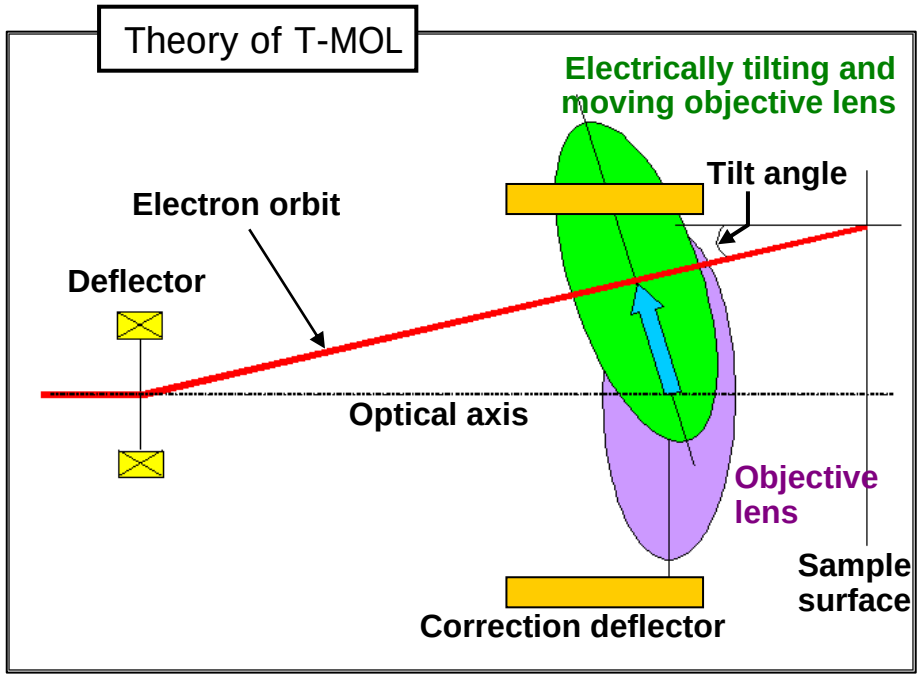


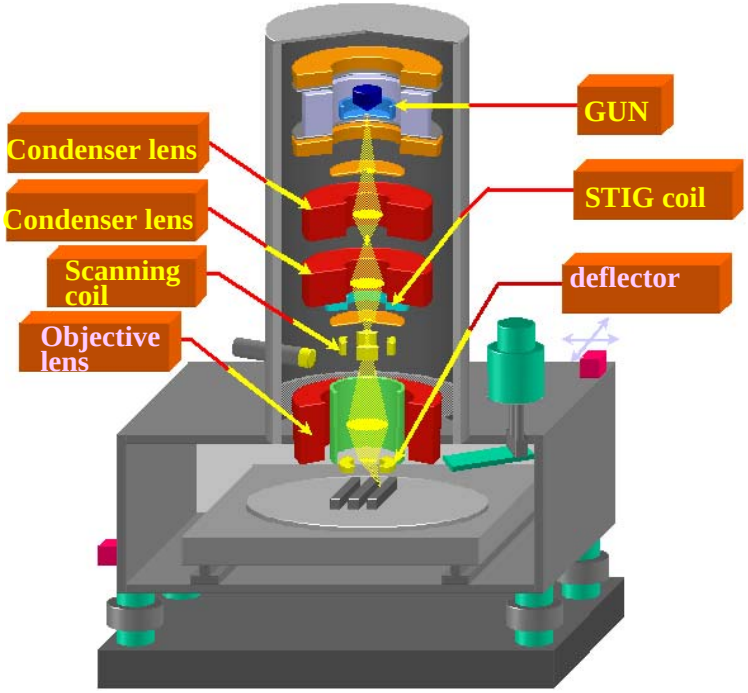
T-MOL (Tilting and Moving Objective Lens)

Side wall angle measurement and 3D data generation are performed using tilted SEM image by T-MOL

Theory of T-MOL :

- We superimpose correction field on Objective lens field.
- The correction field electrically tilts and moves the axis of Objective lens.
- If tilted beam coincides with the tiled and moved axis of Objective lens, then aberration of tilted beam will be minimum.





Method of Side Wall Angle Measurement

Side wall angle is measured with the white band width of the 5 degrees tilted image.

$$\mathbf{W}\phi = \mathbf{B}\cos\phi \quad ---①$$

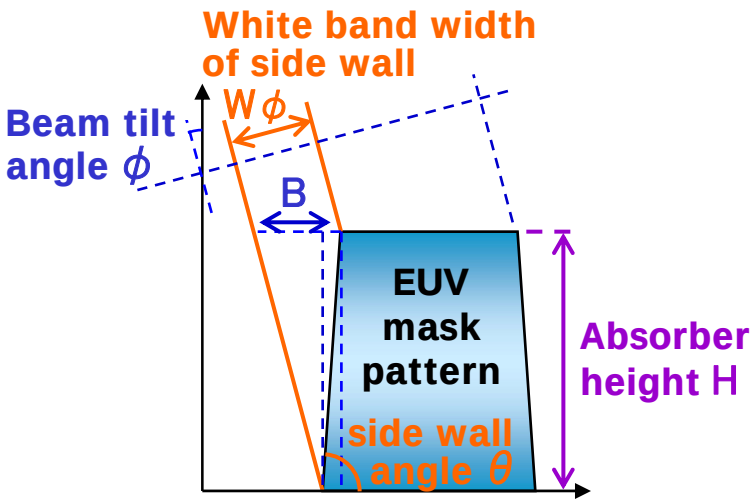
$$\mathbf{B} = \mathbf{H}\tan\phi + \mathbf{H} / \tan\theta \quad ---②$$

from ①, ②

$$\mathbf{W}\phi = \mathbf{H}(\cos\phi / \tan\theta + \sin\phi)$$

$$\tan\theta = \cos\phi / (\mathbf{W}\phi / \mathbf{H} - \sin\phi)$$

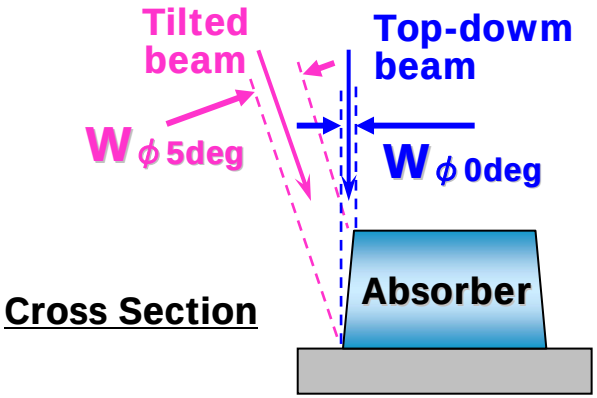
θ is calculated from measurements $\mathbf{W}\phi$ as $\mathbf{H}$ is known quantity



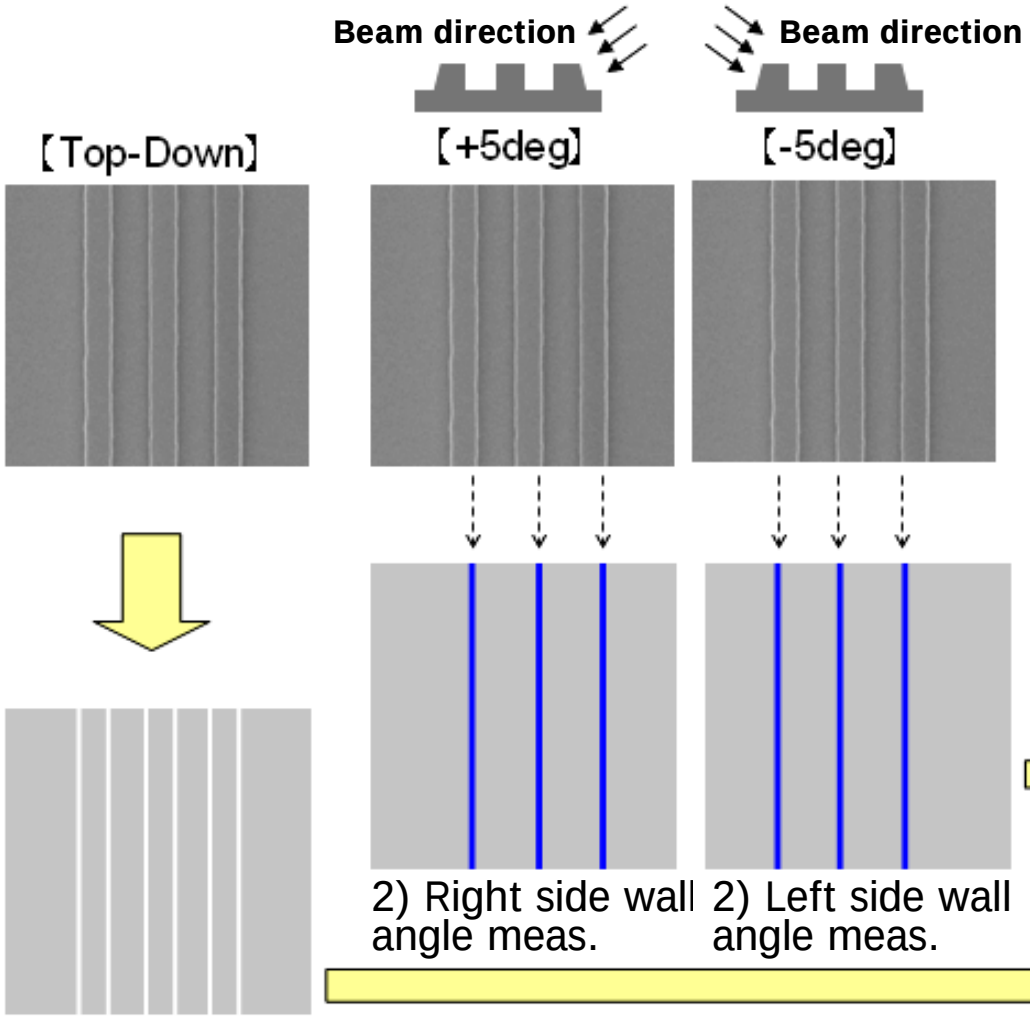
Advantage of Tilting Measurement

$$\mathbf{W}_{\phi\,5deg} = \mathbf{W}_{\phi\,0deg} \times 3.5$$

It is equivalent to the effect that pixel size (beam diameter) is reduced to 1/3.5.



3D Data Generation for Litho-Simulation

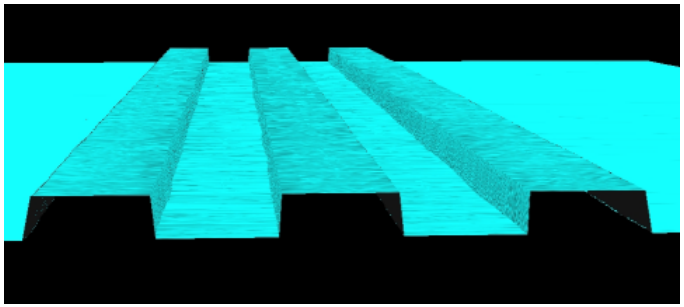


1) Pattern edge extraction from top-down SEM image

2) Each side wall measurement from each tilted SEM image

3) 3D data generation by adding data 2) to data 1)

* Two more tilted SEM images for a horizontal pattern are usually used.



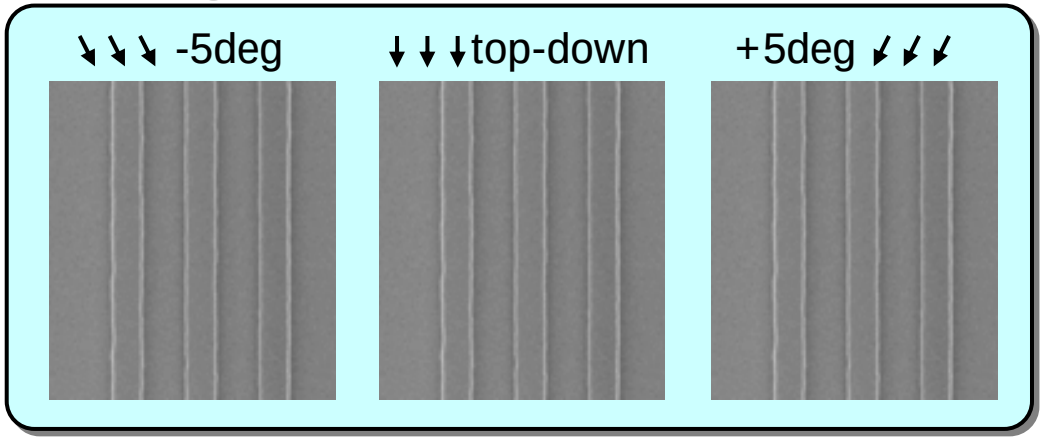
3) 3D data generation

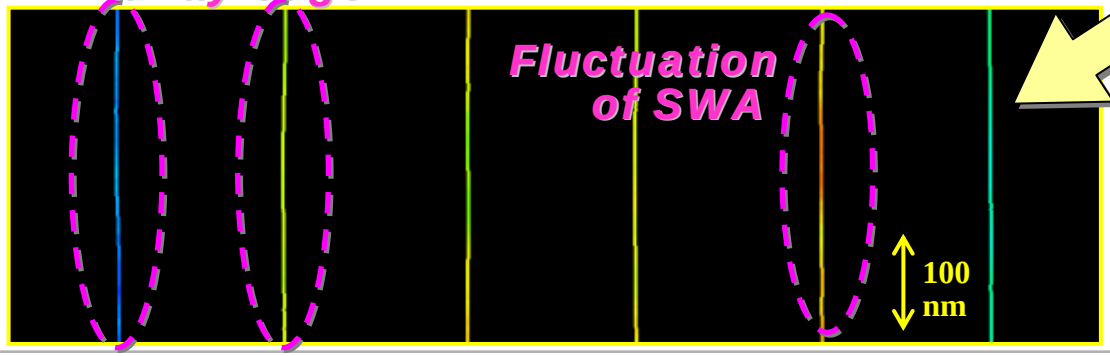
Large image size ; 4x4um on mask
Fine pixel size ; 1nm

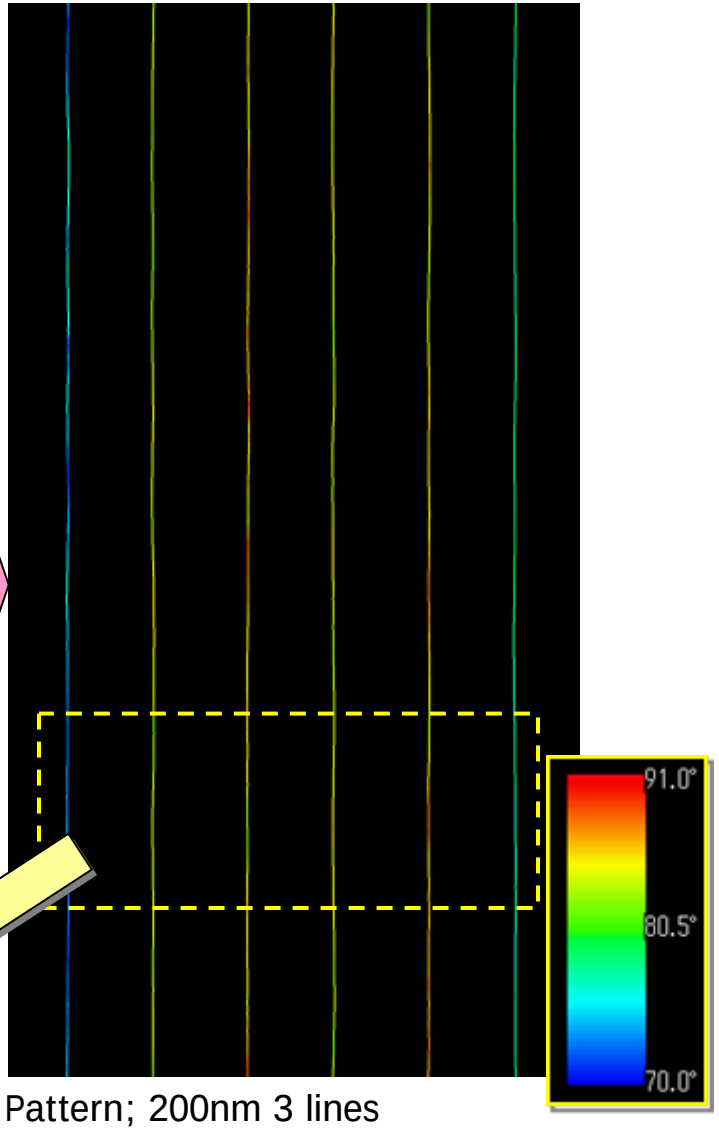
Other Application
- Side Wall Angle Map -

This application provides side wall angle average distribution of arbitrary interval.

SEM images







Pattern; 200nm 3 lines
Map Resolution; 1nm
Average range of each pixel; +/- 100 lines

Experiments

1. Verification of side wall angle measurement

We evaluated the accuracy of the side wall angle by T-MOL tilted SEM image by the comparison with TEM cross-section measurement.

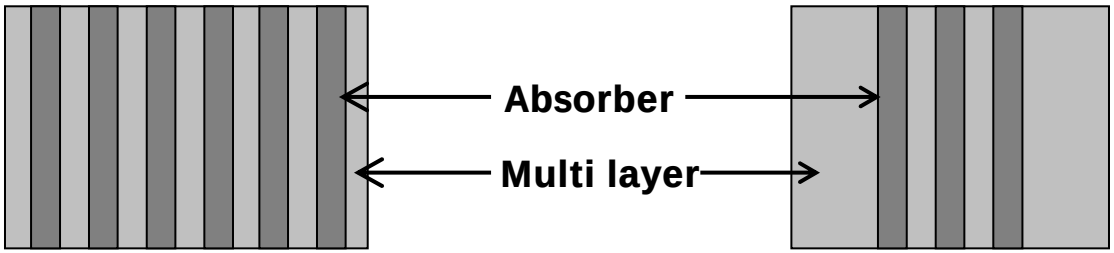
2. Verification of 3D data

We evaluated the accuracy of 3D data of EUV mask pattern including the side wall angle and edge position.

Pattern variation

<1> 1:1 Line and Space ;
80nm, 100nm, 200nm

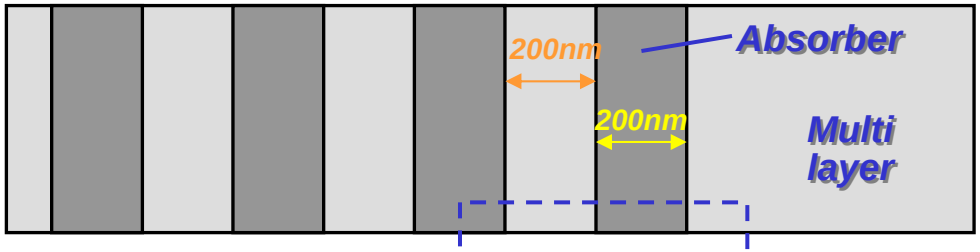
<2> 1:1 3 lines ;
200nm



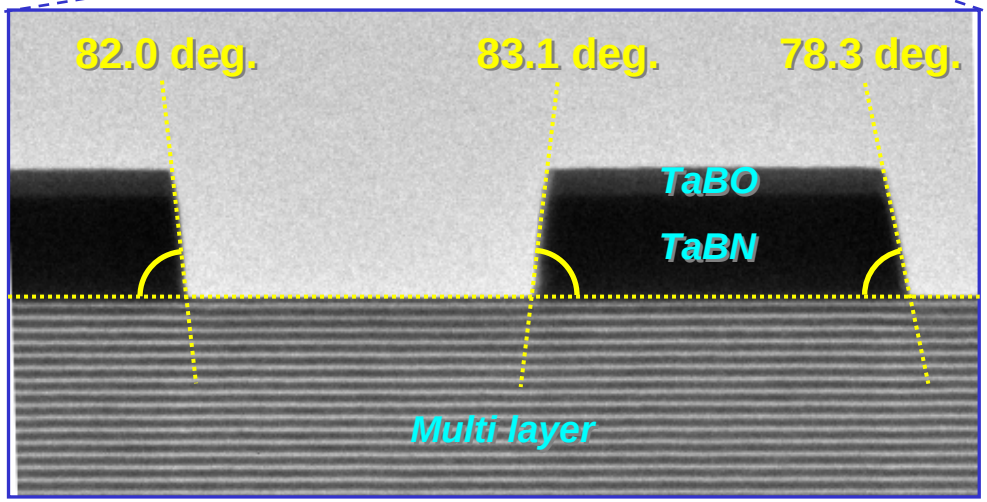
1. Verification of side wall angle measurement

We performed 3D shape measurement for evaluation by cross-sectional measurement of TEM.

Example ; 1:1 200nm Line and Space

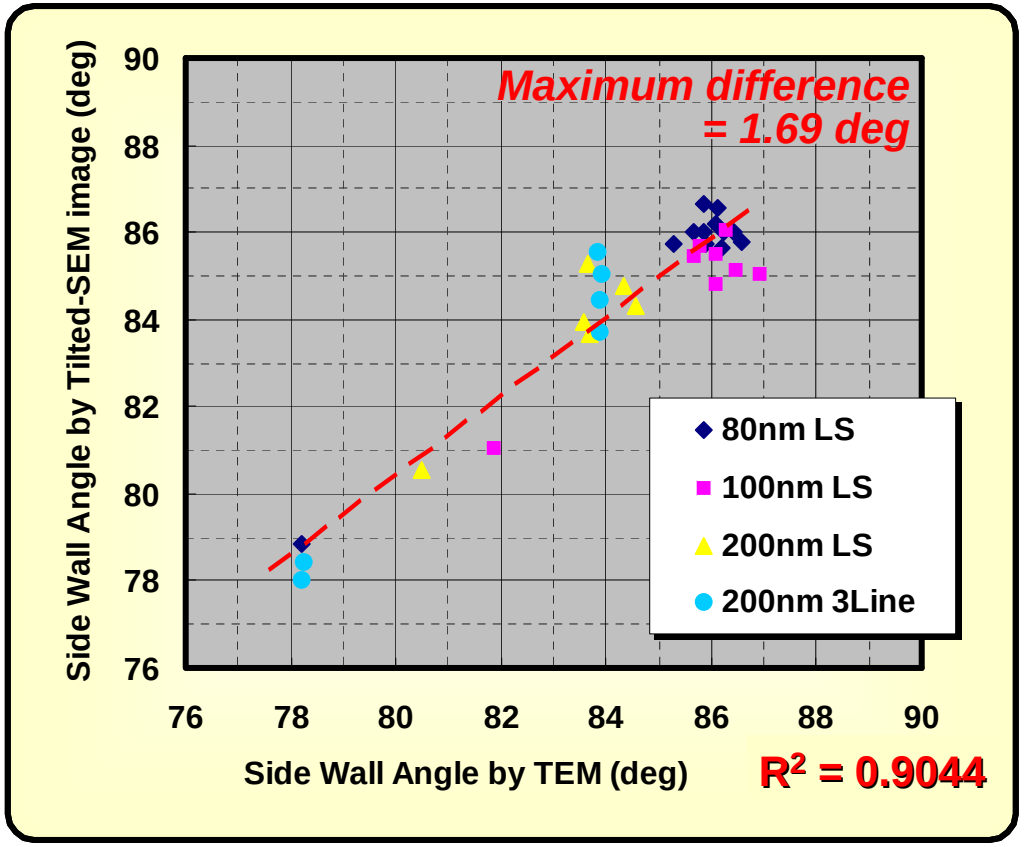


TEM Image

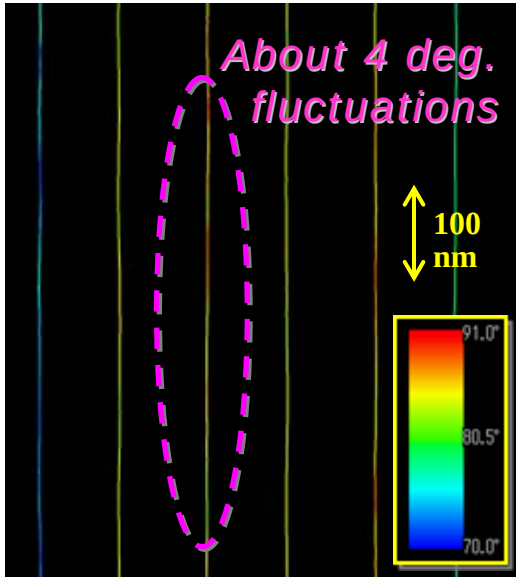


1. Verification of side wall angle measurement

- Correlation with Cross-sectional Measurement by TEM -



Side wall angle map by 3D measurement



TEM result is point data about 100nm sections.

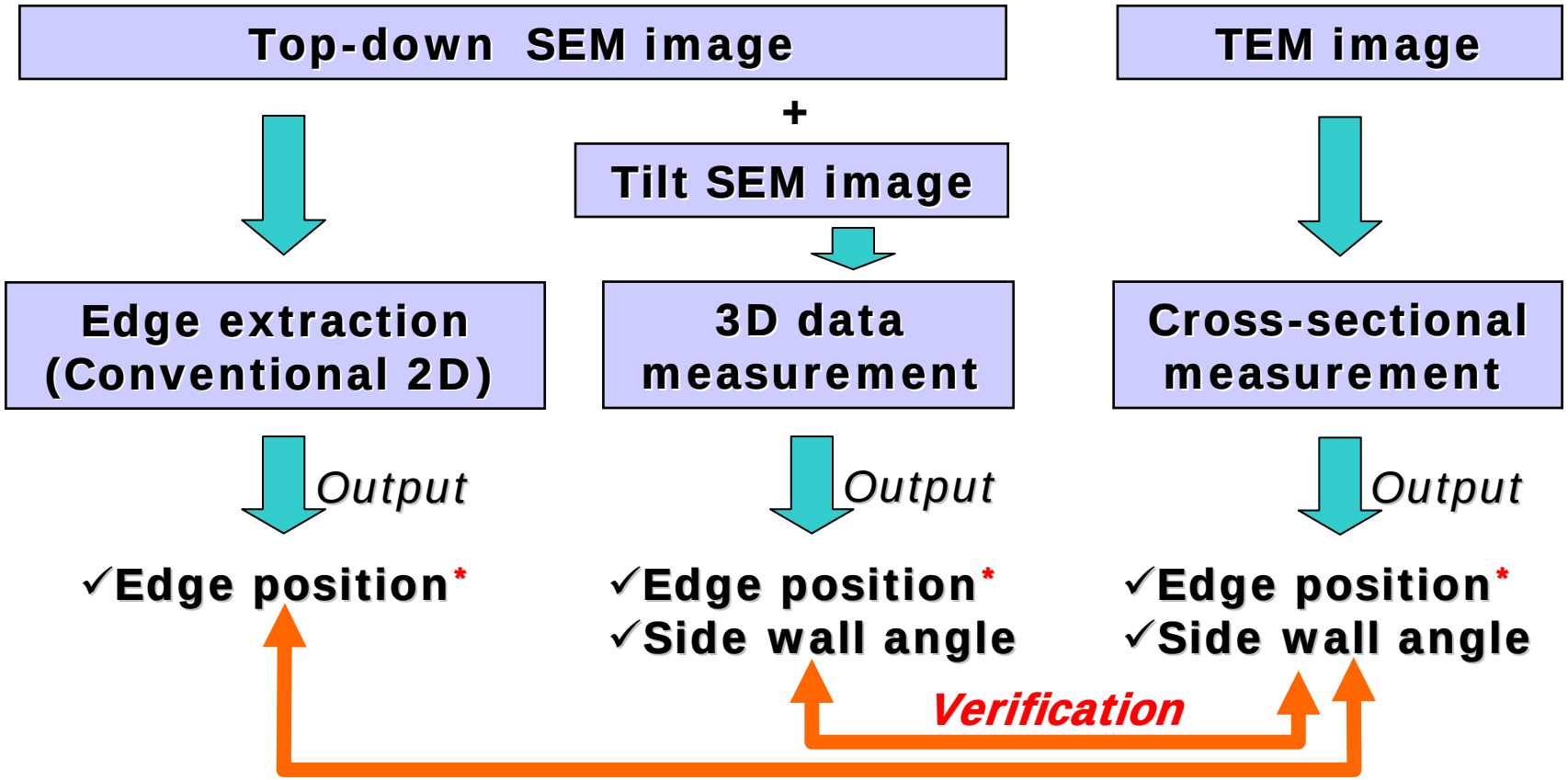
Tilted SEM result is average of 2um section.

✓ *Because the sections of two data are different, this result will include fluctuation of side wall angle.*

✓ *Good correlation was confirmed.*

2. Verification of 3D data

We compared data of our 3D measurement and conventional 2D with cross-sectional measurement of TEM about 200nm 3-line.



* All edge positions are defined at half of absorber height.

2. Verification of 3D data

SEM Image (Top-down)

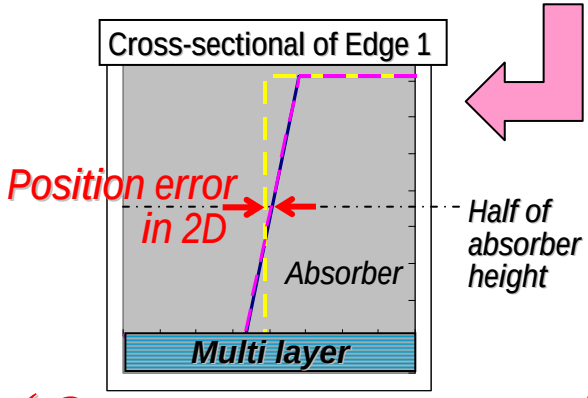
Reference data (TEM)

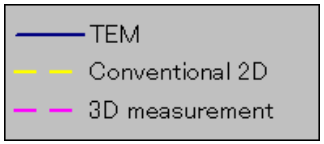
Method	Edge No.	1	2	3	4	5	6
Cross-sectional measurement by TEM	Edge position (nm)	-499.13	-299.10	-101.17	98.86	301.40	499.33
	Side Wall Angle (deg)	78.23	83.87	83.82	83.87	83.90	78.19

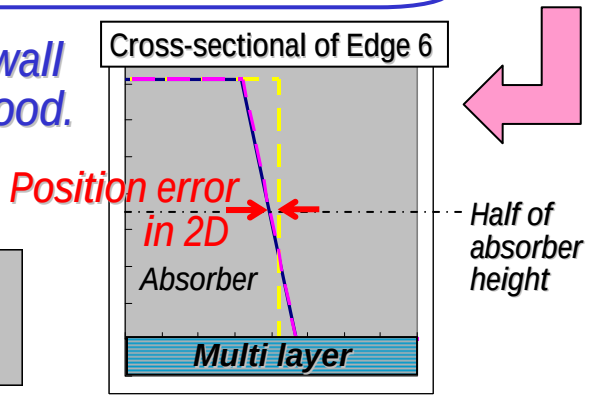
Difference with TEM

Method	Edge No.	1	2	3	4	5	6
Conventional 2D	Edge position (nm)	⊿1.87	⊿0.16	⊿0.47	⊿0.17	⊿0.47	⊿2.25
3D measurement	Edge position (nm)	⊿0.48	⊿0.15	⊿0.29	⊿0.27	⊿0.68	⊿0.49
	Side Wall Angle (deg)	⊿0.21	⊿1.18	⊿0.63	⊿1.7	⊿0.18	⊿0.26

In edge of stable side wall angle, all results are good.





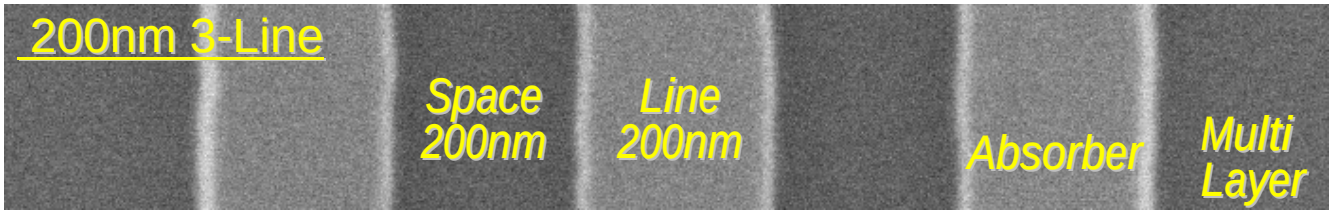


✓ *Our measurement method can achieve high accuracy 3D data.*

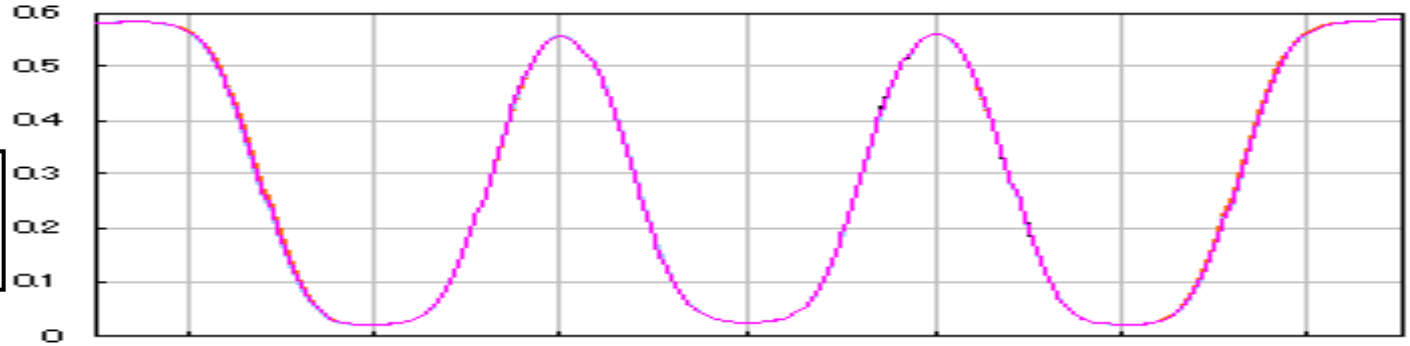
✓ *In conventional 2D data from top-down SEM image, the change of side wall angle deviates the edge position.*

2. Verification of 3D data

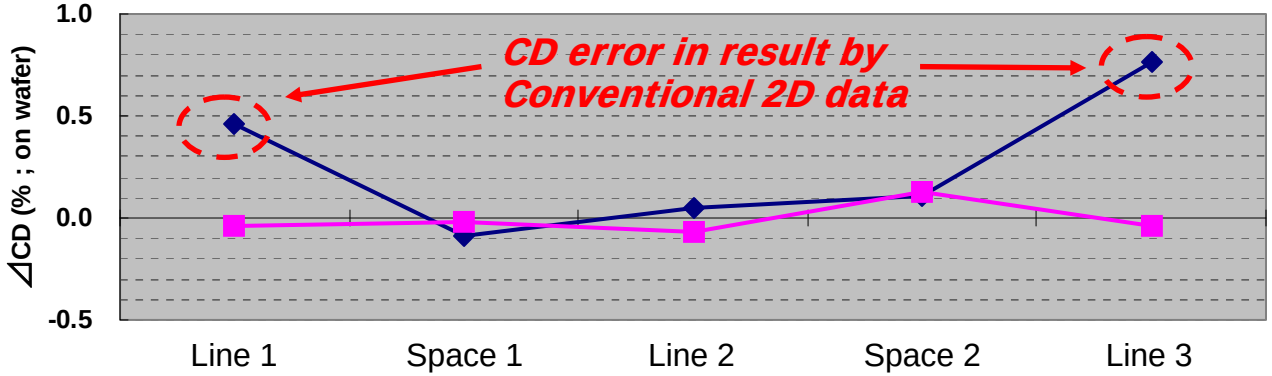
SEM Image (Top-down)



Aerial image by simulation



CD variation with the simulation result by TEM data



✓ *This influence will be more conspicuous in narrow pattern.*

✓ *High accuracy prediction by simulation is achieved by high accuracy 3D data.*

Conclusions

- We developed the side wall angle measurement method with tilted SEM image by T-MOL.
- The verification of side wall angle between our 3D measurement and TEM showed good correlation.

The combination of side wall angle measurement by T-MOL and fine pixel SEM image satisfies required data for EUV mask pattern quality assurance based on lithography simulation.

Future Works

- We will analyze the error factor of the comparison between TEM and our 3D measurement for more reliable measurement accuracy evaluation.
- We will continue the evaluation with actual device patterns.

Acknowledgments

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