Focus monitor application to EUV exposure tool using asymmetric diffraction rays by off-axis monopole illumination

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1)
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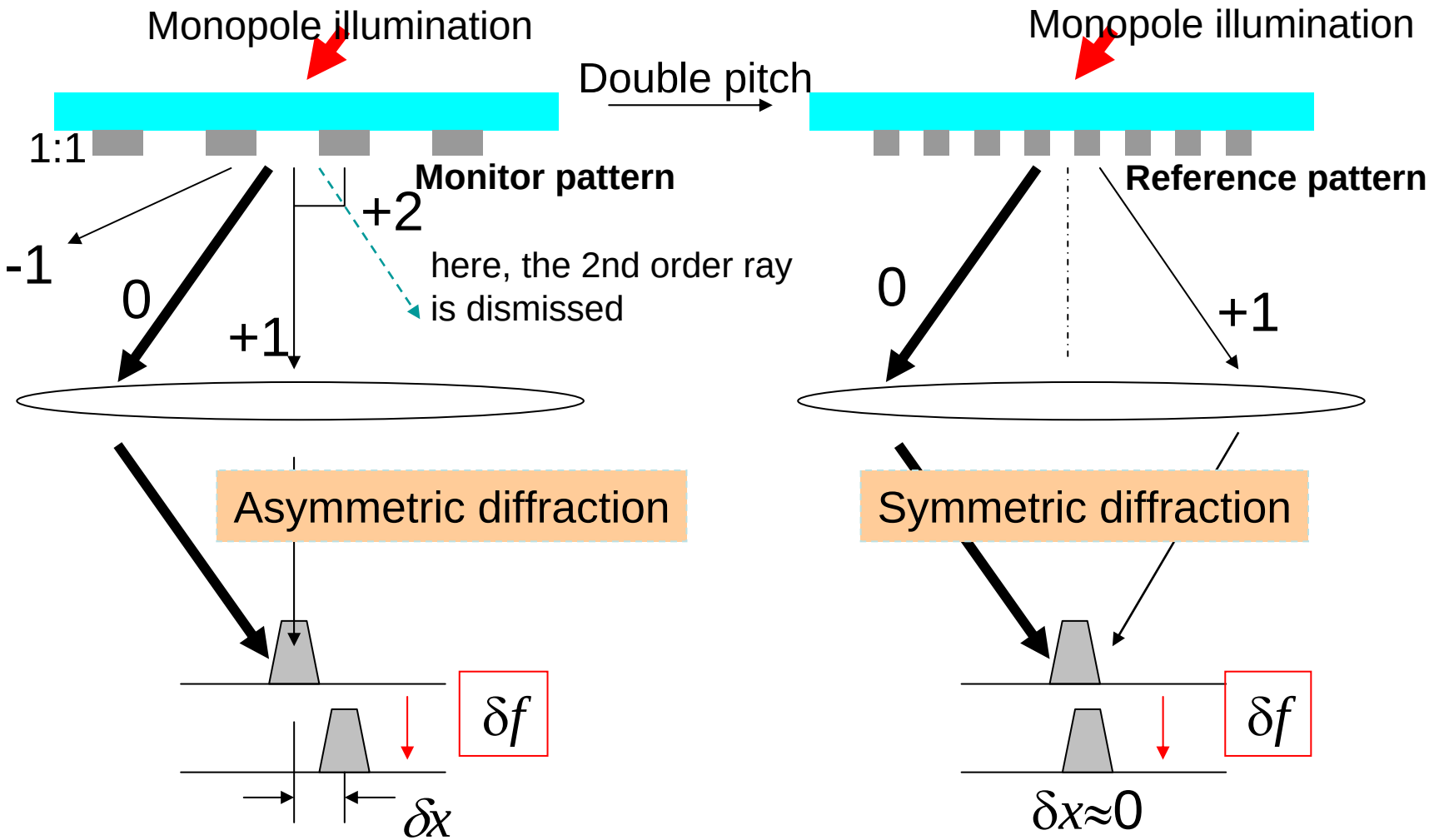
2)

Outline

- Principle of focus monitor
- Experimental condition and simulation on EUV exposure tool
- Measurement result
- Summary

Principle of focus monitor using off-axis illumination



The pattern position is **shifted** at defocus

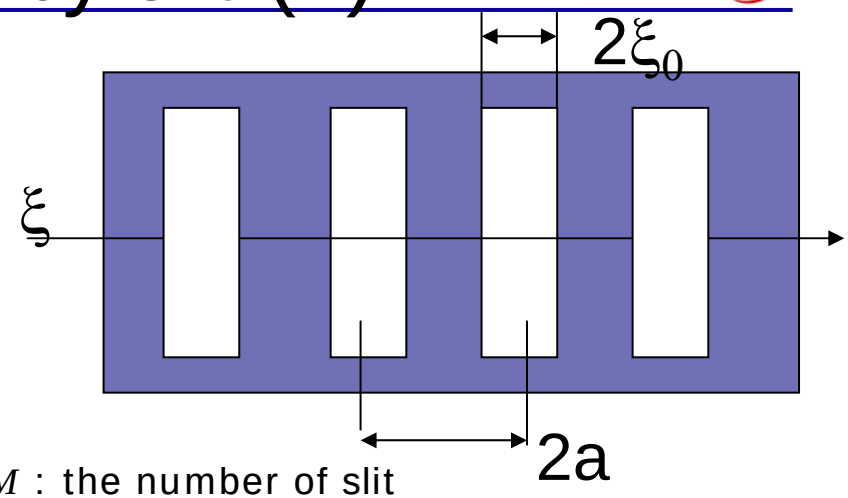
The pattern position is **NOT shifted** at defocus

Measure the transferred position difference between two patterns

Diffraction ray generated by slit (1)

The diffraction ray generated by right figure.

$$I(x) = I_0 \left(\frac{\sin \frac{2\pi\xi_0 x}{\lambda f}}{\frac{2\pi\xi_0 x}{\lambda f}} \right)^2 \left(\frac{\sin \frac{2\pi M a x}{\lambda f}}{M \sin \frac{2\pi a x}{\lambda f}} \right)^2$$



λ: wavelength, f :distance from slit to screen, M : the number of slit

The 1st term ; the diffraction light of the Fraunhofer diffraction generated in one slit. It is zero at the following point:

$$x_m = \frac{m\lambda f}{2\xi_0}$$

The 2nd tem ; the interference pattern of the diffraction rays in the number of M slits. It is local maximal at the following point:

$$x_N = \frac{N\lambda f}{4a}$$

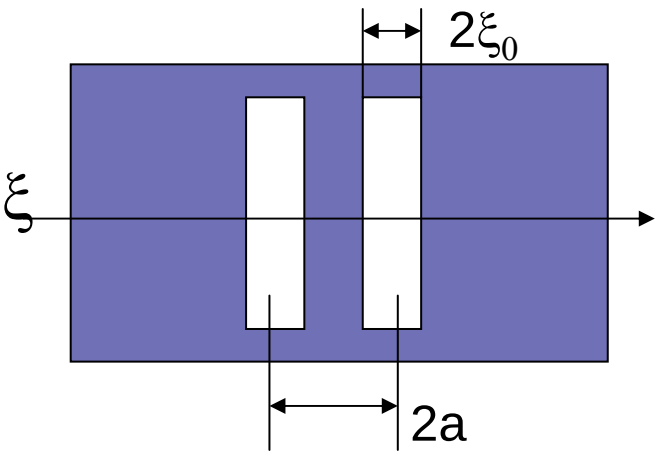
When $x_m = x_N$, $N = m\frac{2a}{\xi_0}$. If $\frac{2a}{\xi_0}$ is integer,

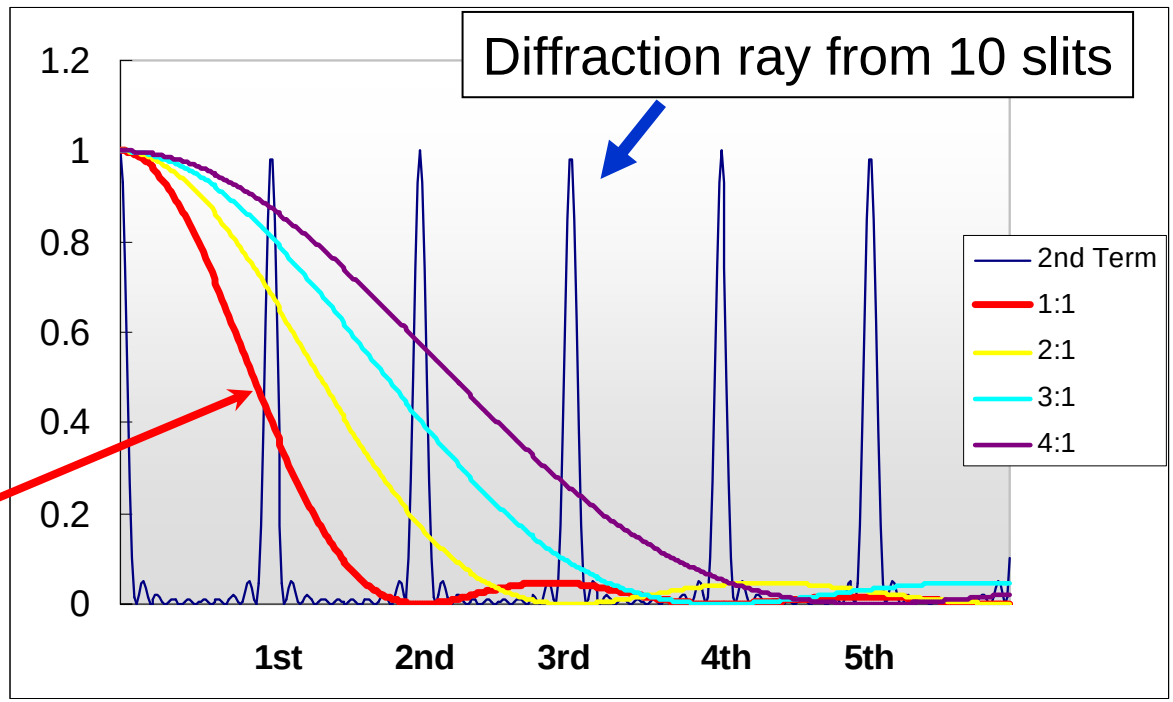
the maximal value of x_N , which is the intensity of N-th order diffraction ray, will be zero.

If a = $2\xi_0$, the 2nd order diffraction ray is disappeared.

Diffraction ray generated by slit (2)

If the ratio of $a:\xi_0$ is varied, any order of diffraction rays can be disappeared.





Diffraction ray from one slit (Distribution difference on the slit width)

The 2nd order diffraction ray is NOT generated at 1:1 L/S.

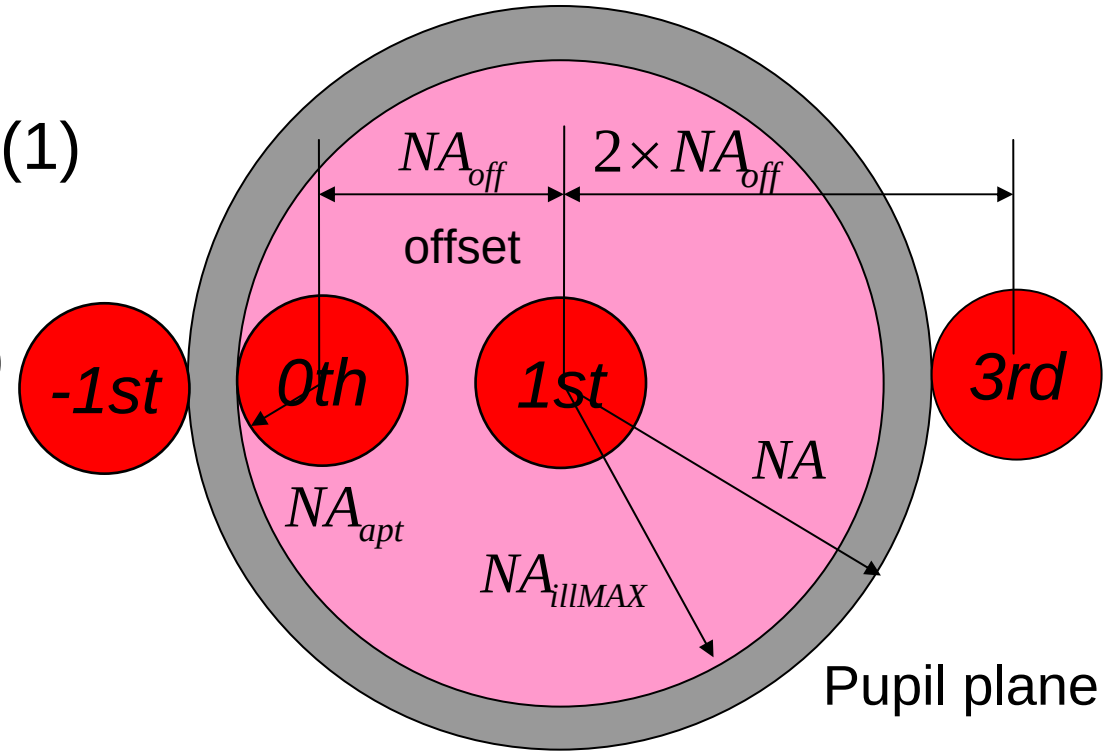
Requirement of monopole illumination

For 0th order,

$$NA_{off} < NA_{illMAX} - NA_{apt} \quad (1)$$

For -1st and 3rd order,

$$2NA_{off} > NA + NA_{apt} \quad (2)$$



From (1) and (2)

$$\frac{1}{2}(NA + NA_{apt}) < NA_{off} < NA_{illMAX} - NA_{apt}$$

Here,

$$\frac{1}{NA_{off}} = \frac{p}{\lambda}$$

Therefore,

$$\frac{2\lambda}{NA + NA_{apt}} > p > \frac{\lambda}{NA_{illMAX} - NA_{apt}} \quad (3)$$

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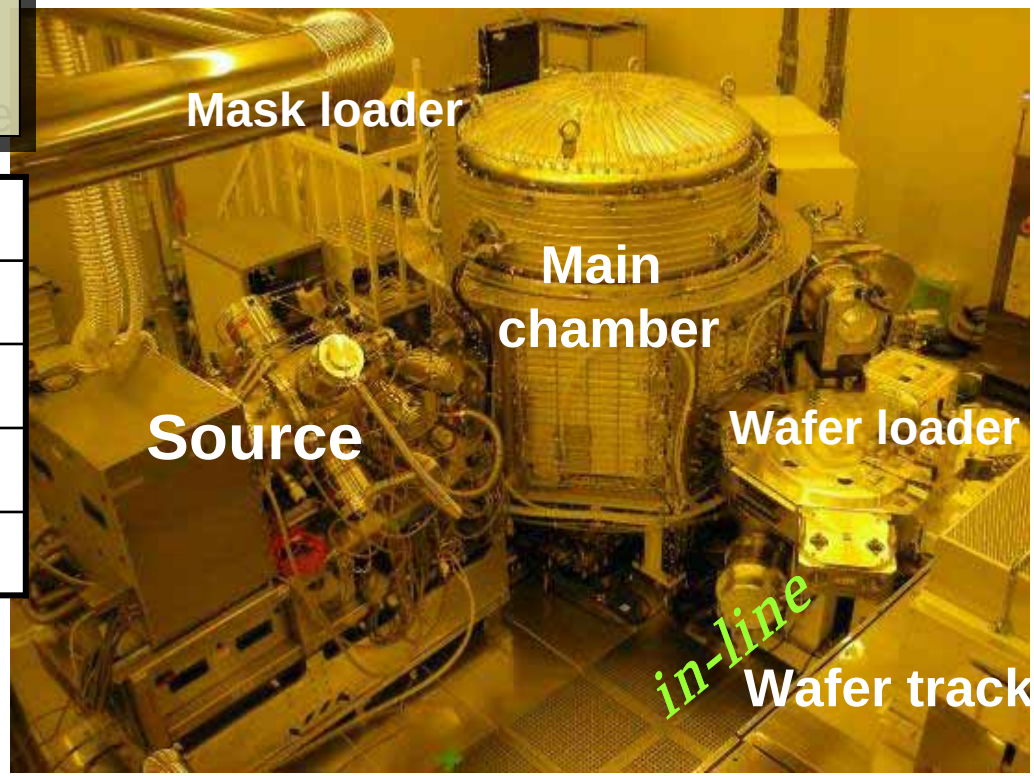
Specifications of **S**mall **F**ield **E**xposure **T**ool (SFET)

Selete

Purposes
- Optimize mask structure
- Develop resist materials
- Evaluate optics & source lifetime

Items	Specification
NA	0.3
Field size	0.2 x 0.6 mm
Magnification	1/5
Source type	Xe GDPP



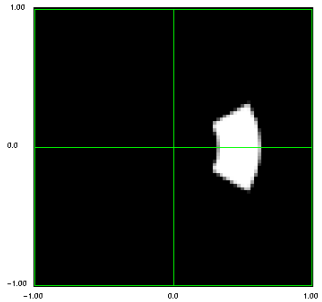
Experimental conditions (NA=0.30, EUV SFET)

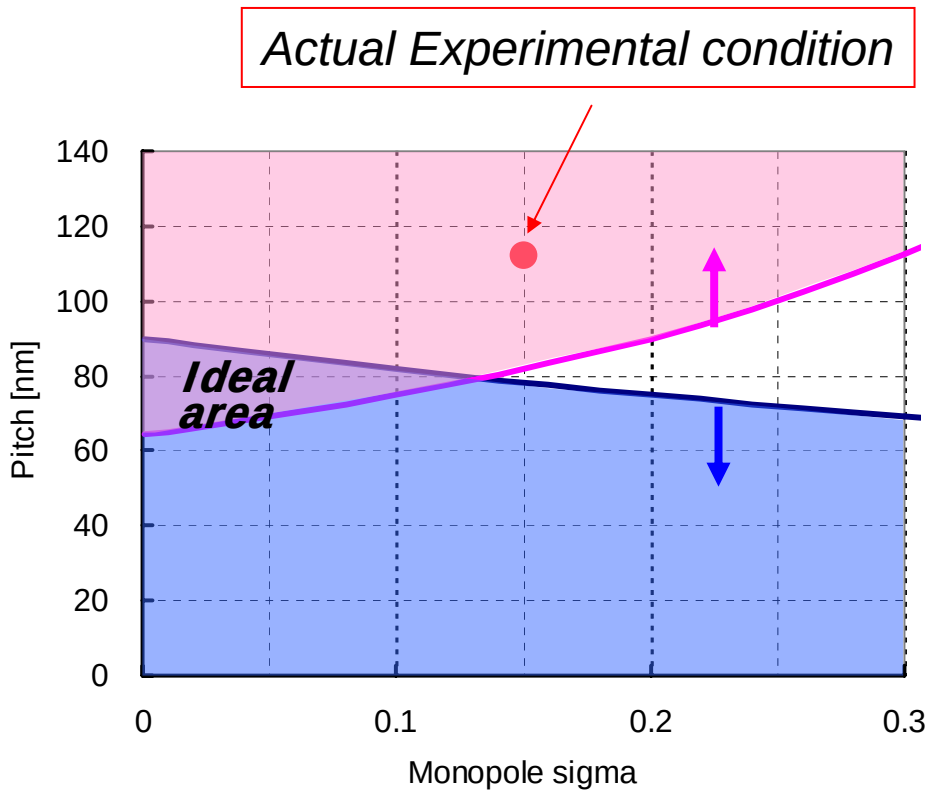
NA=0.30

sigma $_{outer}$=0.63

sigma $_{inner}$=0.33

Open aperture angle 45 degrees





Measurement pattern:

p=112nm (56nmL&S)

Reference pattern:

p=56nm (28nmL&S)

-1st & 3rd ray out of pupil 0th ray into the pupil

$$\frac{2\lambda}{NA + NA_{apt}} > p > \frac{\lambda}{NA_{illMAX} - NA_{apt}}$$

Measurement pattern for EUV

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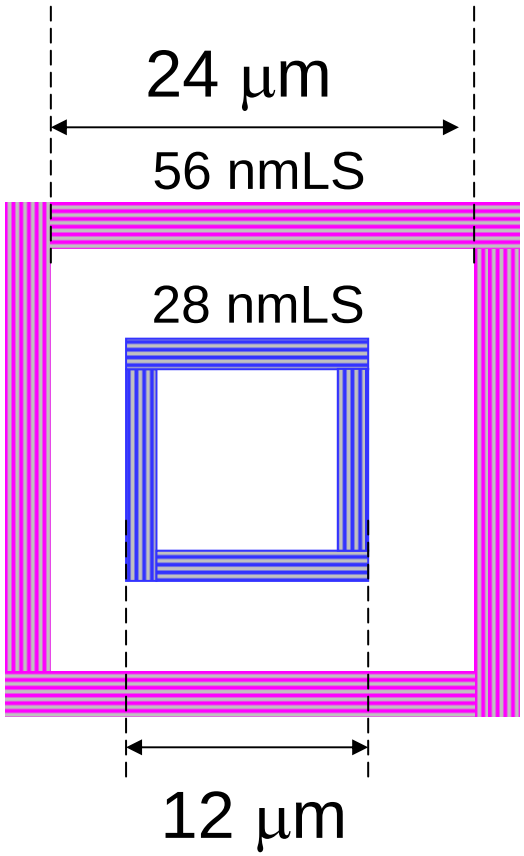
relative shift measurement

The reference pattern and the measurement pattern are **exposed simultaneously**.

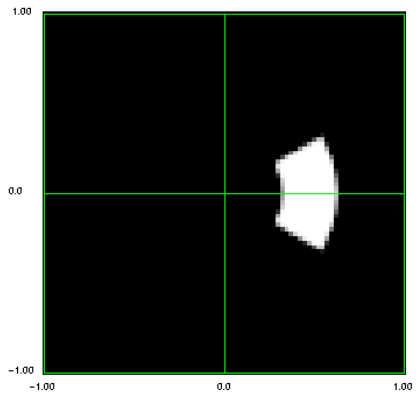
Then bars-in-bars pattern are transferred for focus monitoring.

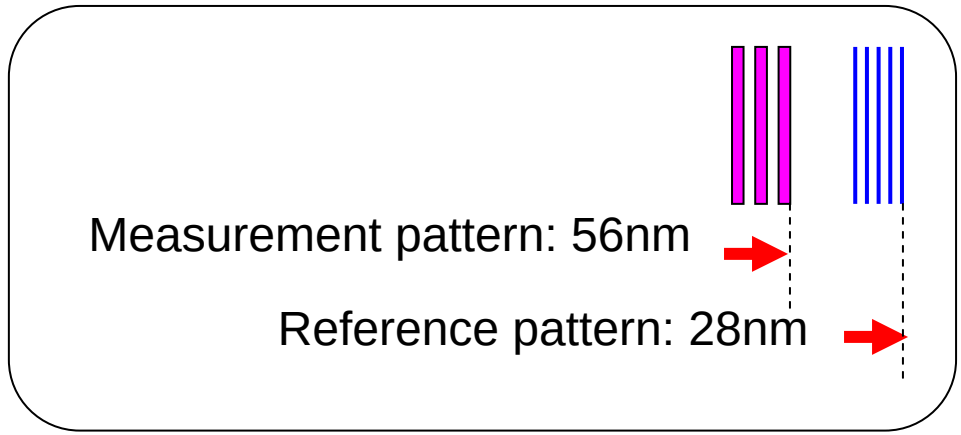


Outer bar: 17 lines
Inner bar: 35 lines

56 nm LS pattern is moved at defocus position.

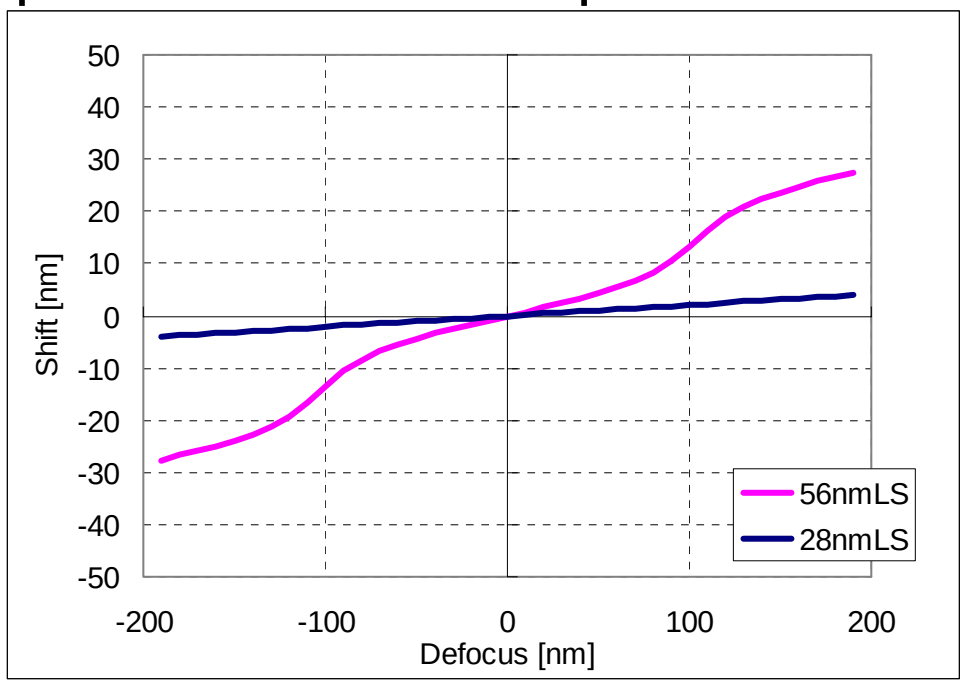
Simulation result -pattern shift-





NA:0.3, Monopole
lambda:13.5nm
Thin mask, w/o aberration,
w/o centre obscuration,
w/ flare
aerial image

pattern shift of L&S pattern



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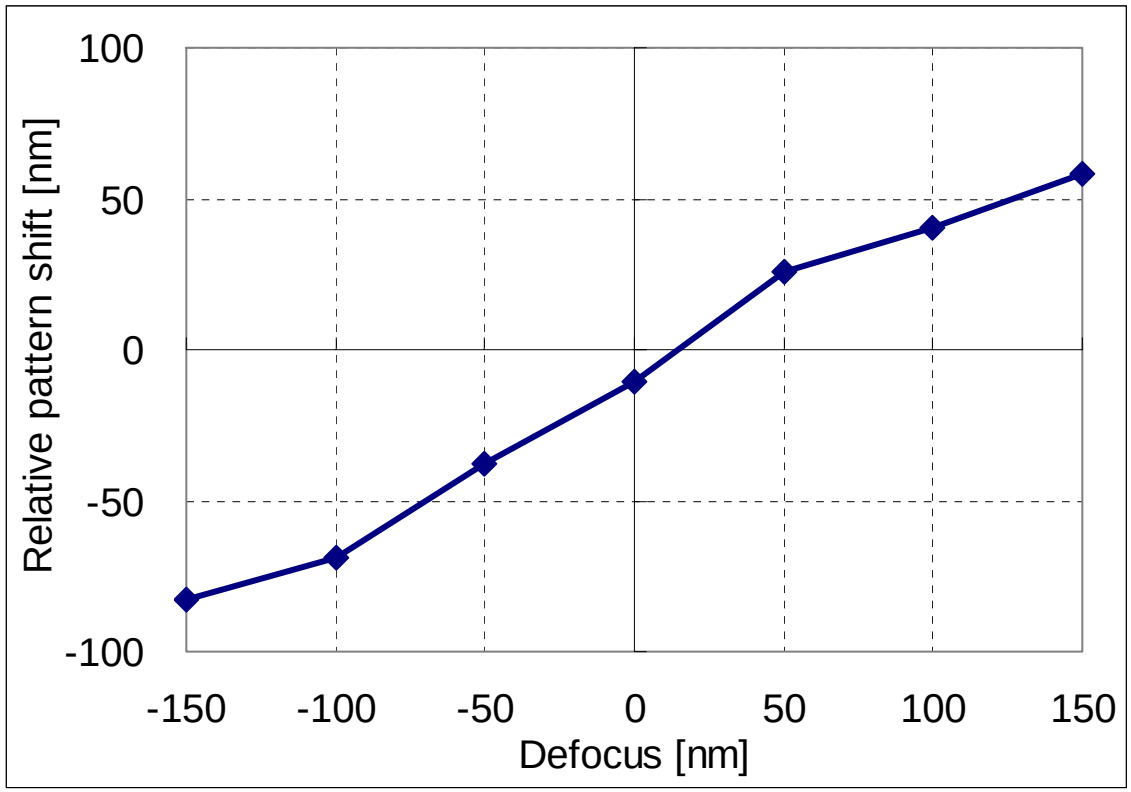
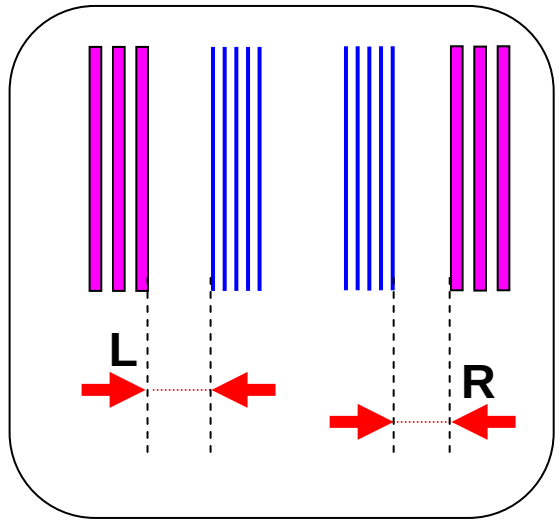
Experimental result on SFET

Relative pattern shift of **(L-R)**





Resist: High sensitivity resist 60nmt
CD-SEM meas.

Focus sensitivity around 60nm / 100nm-Defocus

(Overlay error indicates half of that)

Summary

- We applied focus monitoring method using asymmetric diffraction rays to EUV exposure tool.

- Experimental result shows focus sensitivity for 60nm/100nm-Defocus

- We showed this focus monitoring method is available & useful for EUV tool

Acknowledgements

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

Special Thanks to

TOSHIBA Soichi Inoue

Selete all colleagues

Appendix

Semiconductor Leading Edge Technologies, Inc.

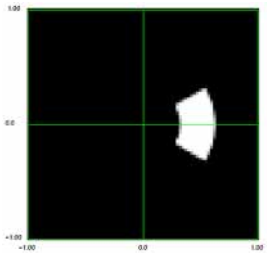
Experimental conditions (NA=0.25, **EUV1**)

NA=0.25

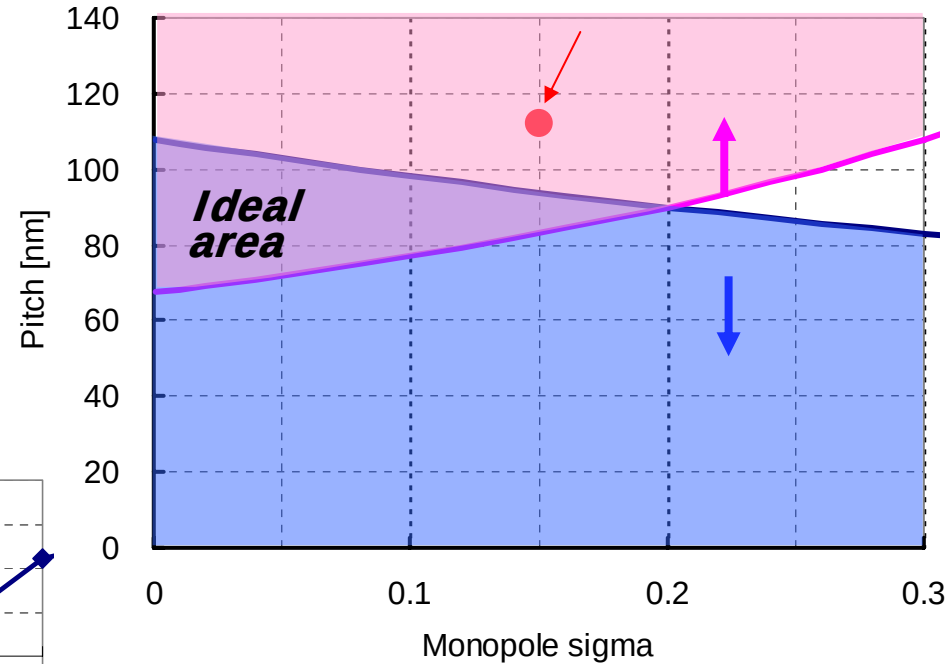
sigma $_{outer}$=0.63

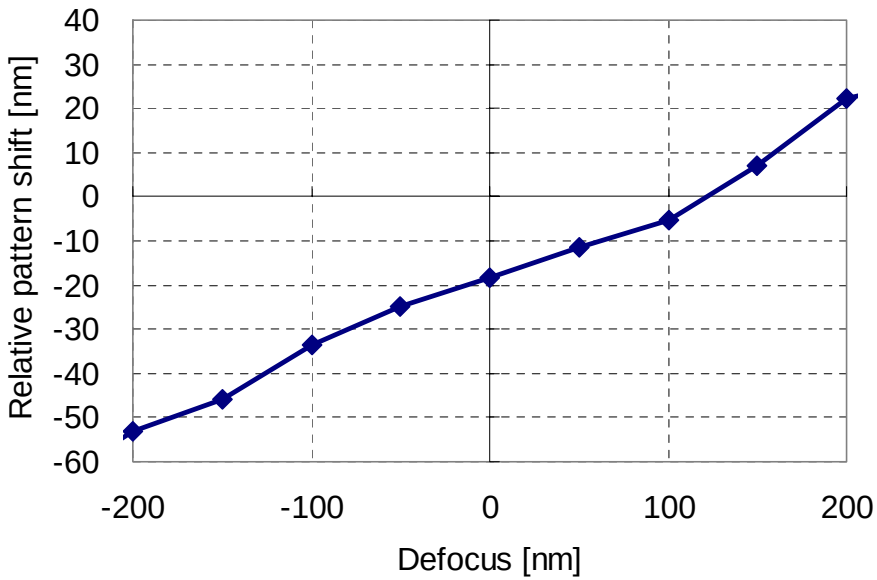
sigma $_{inner}$=0.33

Open aperture angle 45 degrees



Actual Experimental condition





Measurement pattern:

p=112nm (56nmL&S)

Reference pattern:

p=56nm (28nmL&S)

Result : ArF-i case

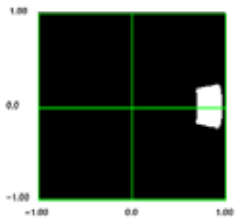
T. Sato, et al.,
Jpn. J. Appl. Phys. 48 (2009) 06FA03

Experimental (NA=1.30, ArF immersion tool)

NA=1.300
σ outer=0.970
σ inner=0.708

Open aperture angle 30 degrees

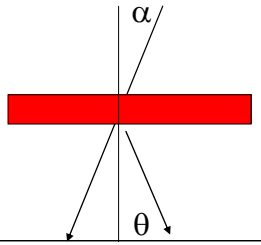
Y-polarization is adopted here.



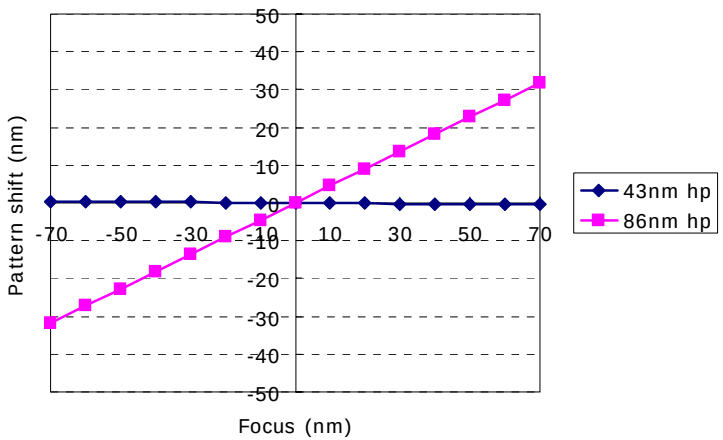
Reference pattern pitch po:
345.346 (on-mask)
86 nm (on-wafer)(= 43 nm LS)

Measured pattern pitch pm:
172 nm (on-wafer) (=86 nm LS)

These pattern features are determined from the optics and diffraction angles.

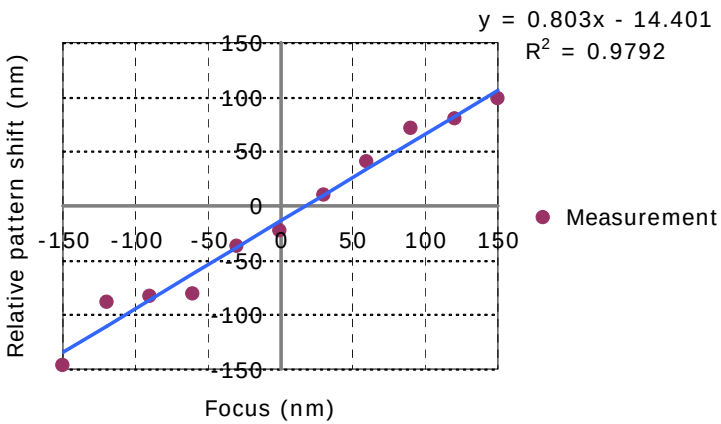


Pattern shift at defocus by optical simulation



The 86 nm pattern is shifted at defocus, but the 43 nm pattern is almost zero shifted.

Measurement result through focus



Measured relative pattern shift between 86 nm LS and 43 nm LS. This was measured by an overlay inspection tool.