ET-P05

Resolution capability of SFET with slit and dipole illumination

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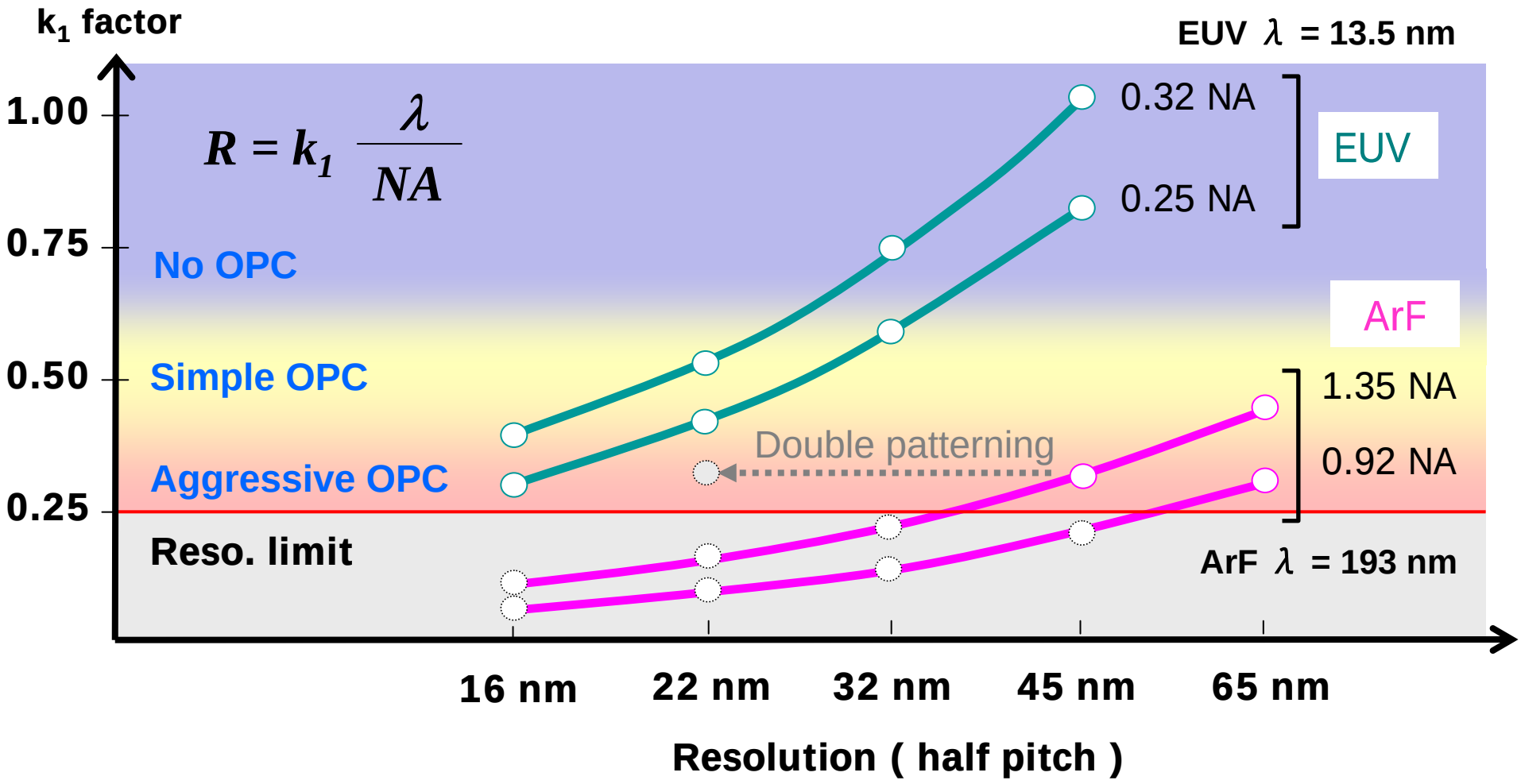
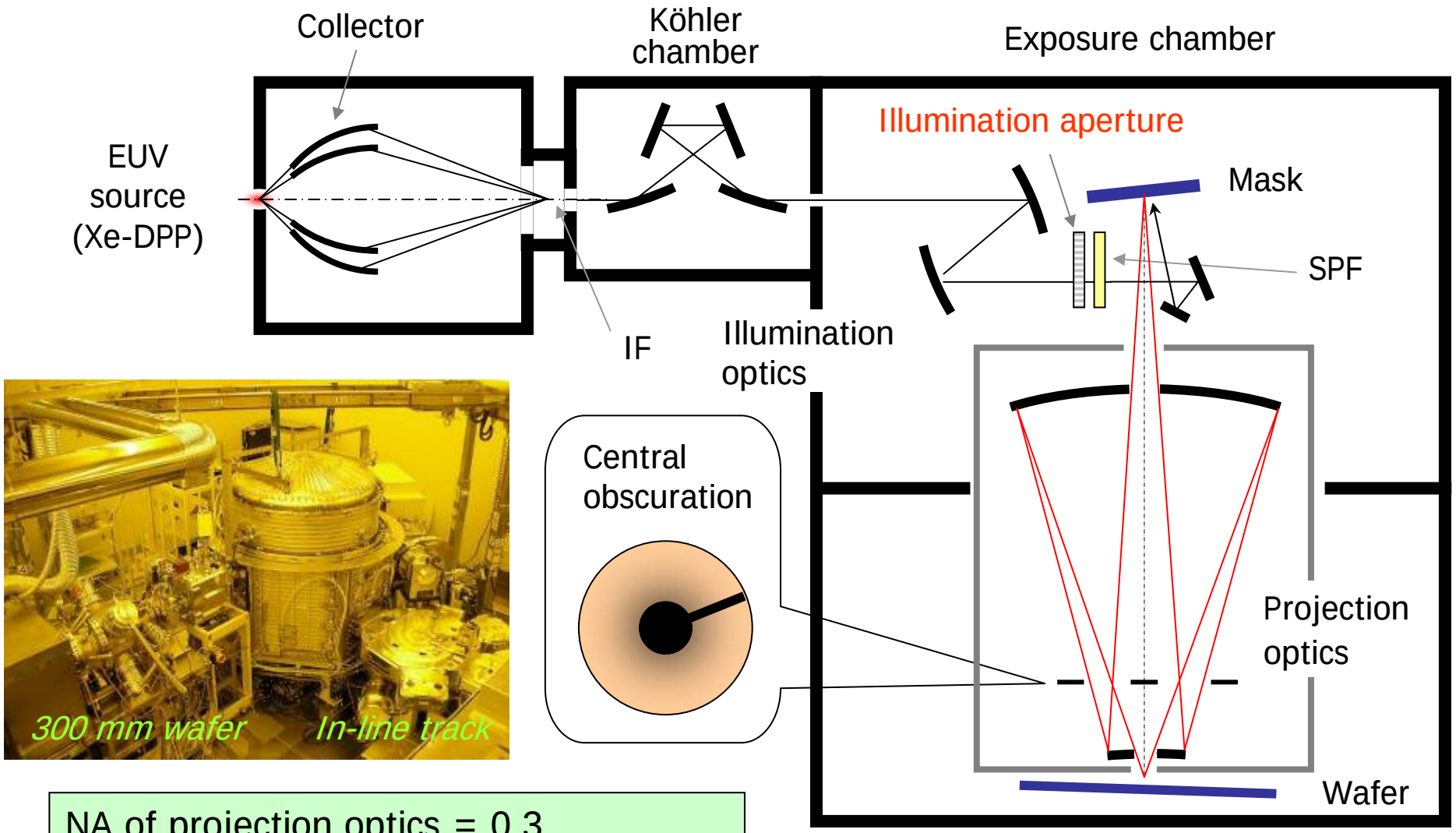
2. Characteristics of SFET
3. Resolution capability of SFET with annular, x-slit, and x-dipole illumination
4. Effect of flare and blur
5. Depth of focus for 16 nm L/S patterns
6. Ultimate resolution of SFET
7. Conclusions

Introduction



For half-pitch (hp) 16 nm node, EUVL should be necessary. In this study, we evaluated the resolution capability of the EUV small-field exposure tool (SFET), and investigated the issues for hp 16 nm node.

Schematic diagram of SFET

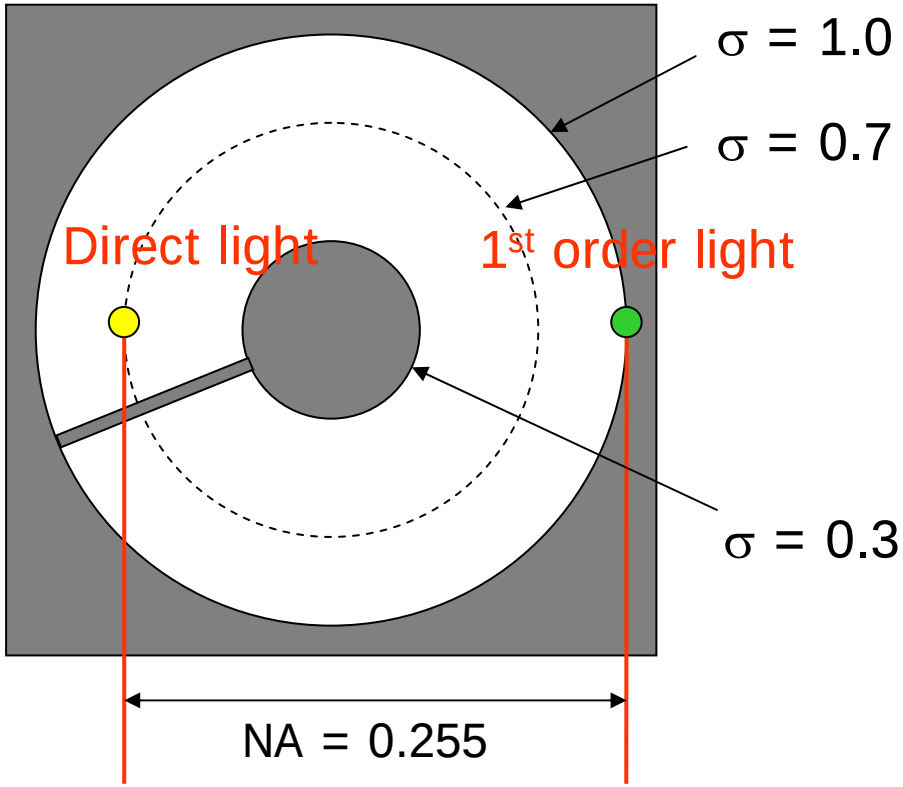


NA of projection optics = 0.3
Maximum σ of illumination optics = 0.7
Central obscuration (r/r_0) = 0.3

DPP: Discharge Produced Plasma
IF: Intermediate Focus
SPF: Spectral Purity Filter

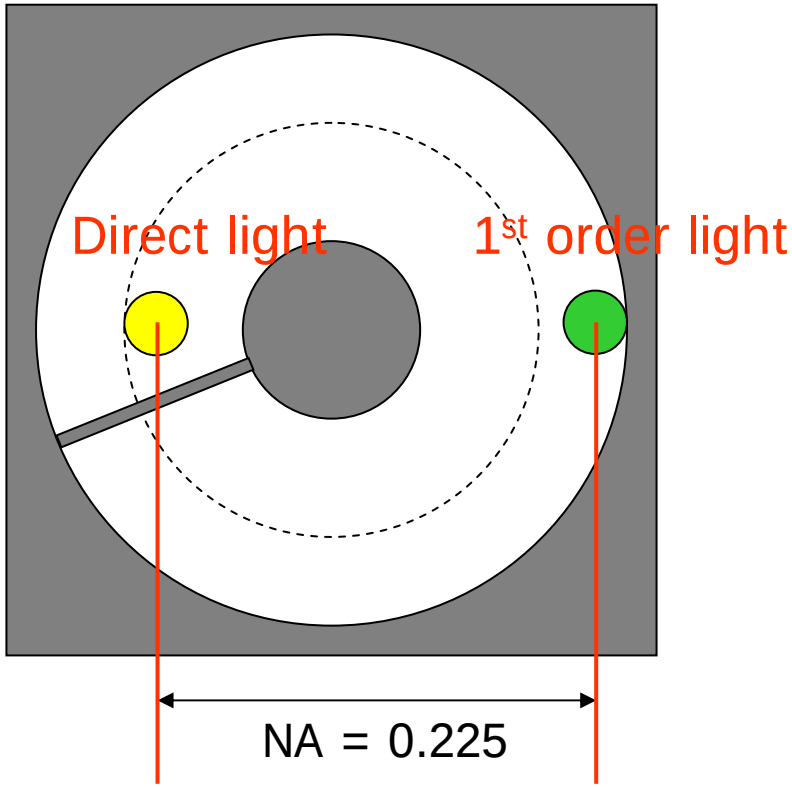
Calculated resolution limit of SFET optics

(1) Monopole illumination (σ≒0)



Effective NA of PO = 0.255
R = 0.25×13.5÷0.255 = 13.24 nm

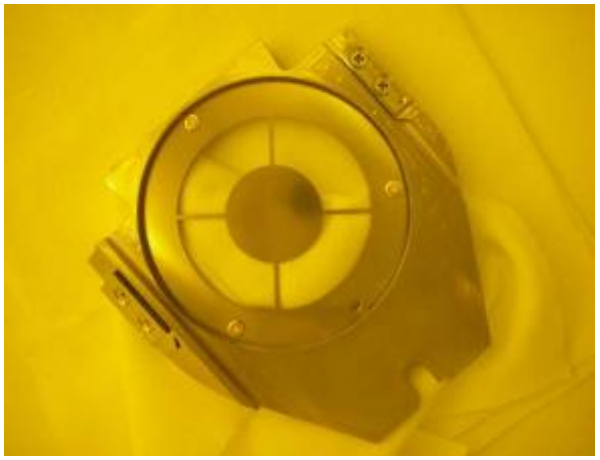
(2) Monopole illumination (σ=0.1)



Effective NA of PO = 0.225
R = 0.25×13.5÷0.225 = 15.0 nm

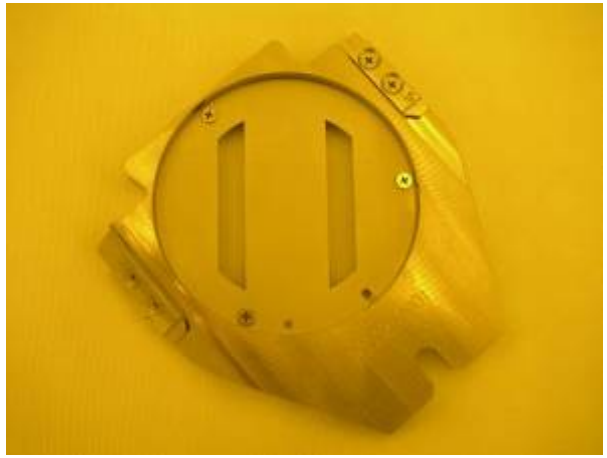
Since the maximum σ is 0.7, effective NA of projection optics is smaller than 0.3. Calculated resolution limit of the SFET is 14-15 nm.

Illumination apertures for SFET



Annular (σ=0.3/0.7)

For > hp 30 nm



X-slit (σ=0.3/0.5)

For hp 2x nm

X-dipole (σ=0.5/0.7)

For hp 1x nm

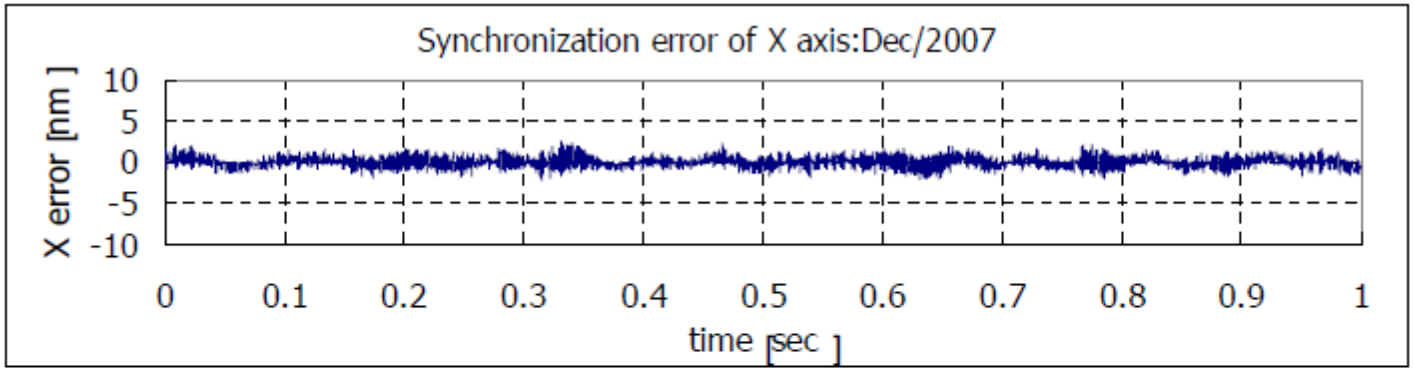
Low resolution ⟷ High resolution

High throughput ⟷ Low throughput

The SFET can use 6 illumination apertures by rotating illumination turret.
We usually use 3 apertures, annular, x-slit, and x-dipole, for L/S patterns.

Stage stability of SFET

N. Nishimura, et. al., SPIE vol.6921, 69211C (2008).



Graph1 Synchronization error between mask and wafer stage in Dec 2007

	X	Y	Z
Average	0.001	0.004	-0.001
Deviation	0.7	0.8	0.4

cf. 1000 data sampled by 0.1msec interval

Table 1 Synchronization error between mask and wafer stage in Dec 2007

Synchronization error between mask and wafer stage is less than 1 nm (σ). The error is little enough to resolve 16 nm L/S patterns.

Experimental and simulation conditions

＜Exposure tool (SFET)＞

WFE：0.76 nm RMS (Annular Zernike 37)
Flare： 11% (Measured with 2 μmϕ PAD)
Incident angle: 6°
Magnification：1/5
Field size: 600 μm X 200 μm
SPF: Zr filter (100 nm thick)

＜Mask＞

Structure：LR-TaBN(51 nm)/CrN(10 nm)/Si(11 nm)/ML(40 pair)/Qz

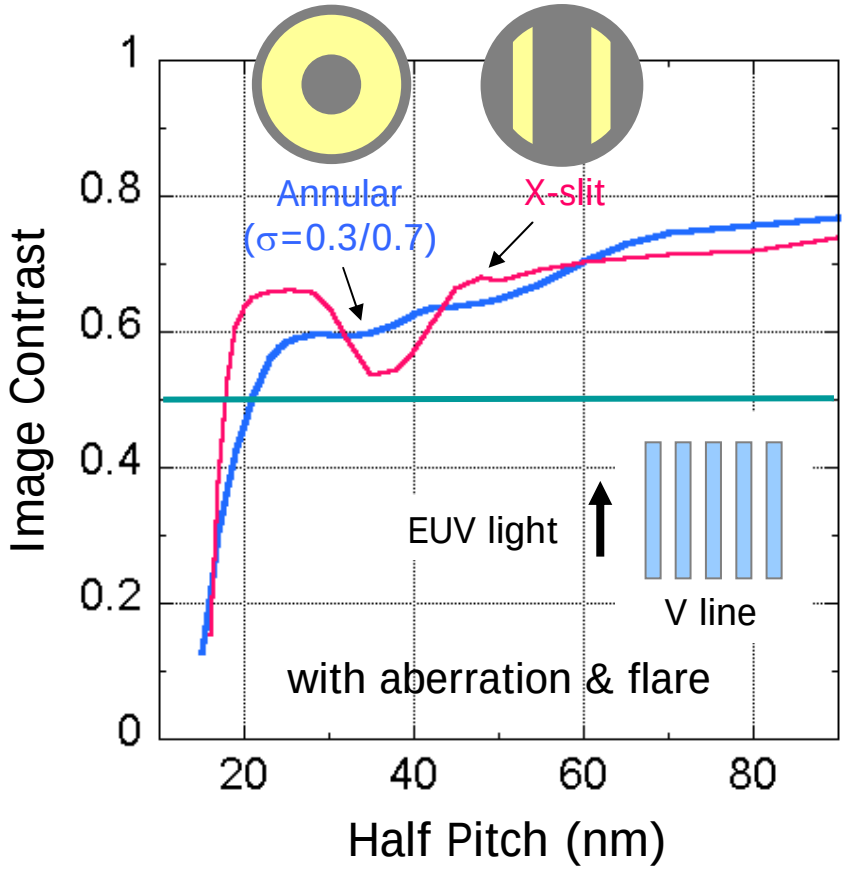
＜Resist＞

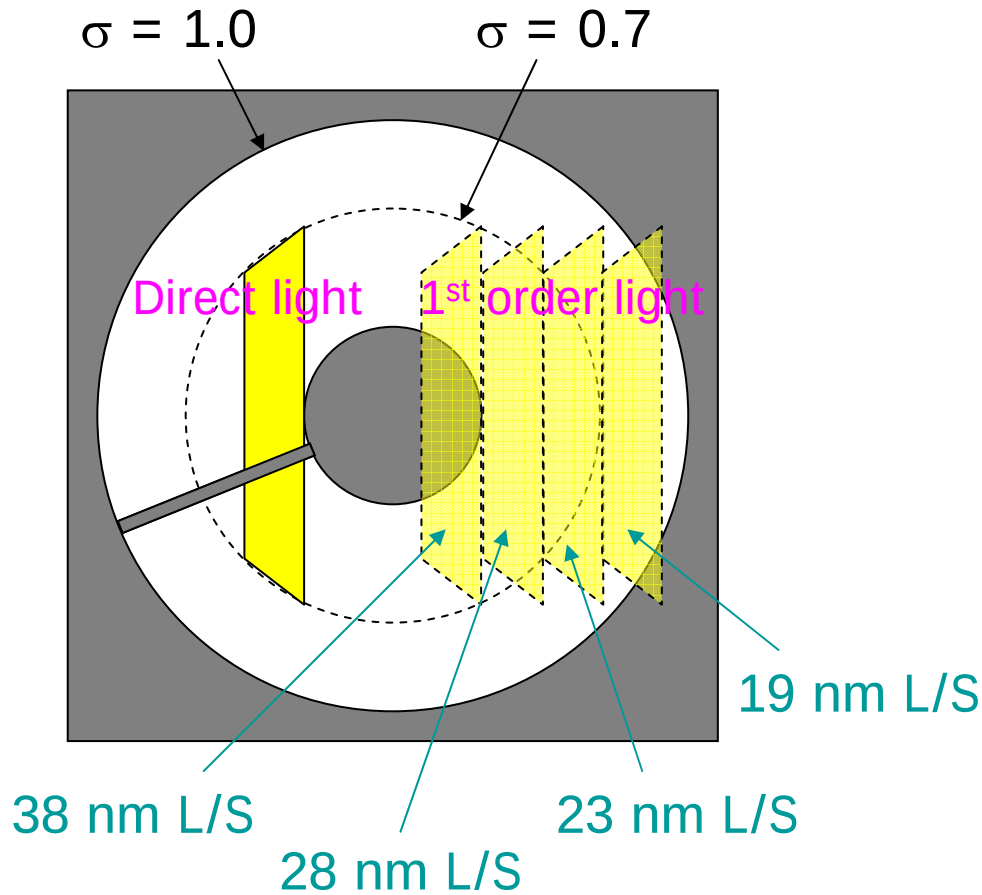
SMR569 (40 nm thick)
Development: TBAH (Tetrabutyl ammonium hydrooxide)

＜Simulator＞

S-Litho. (Synopsys)
Mask structure：2D (Binary)

Image contrast of SFET with x-slit illumination

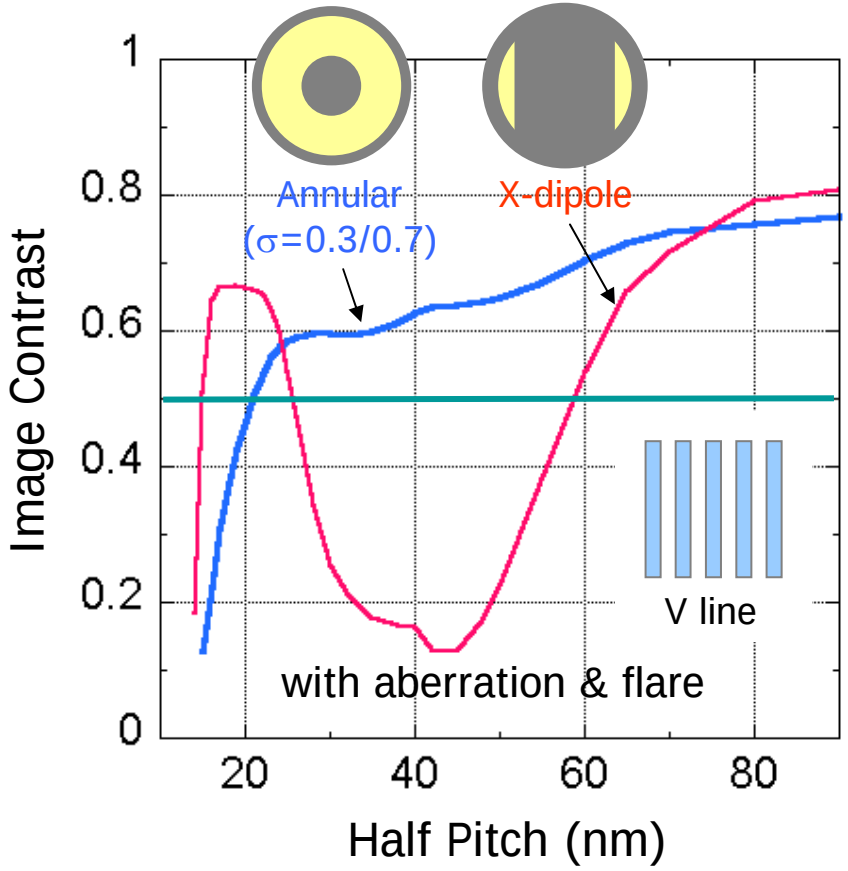


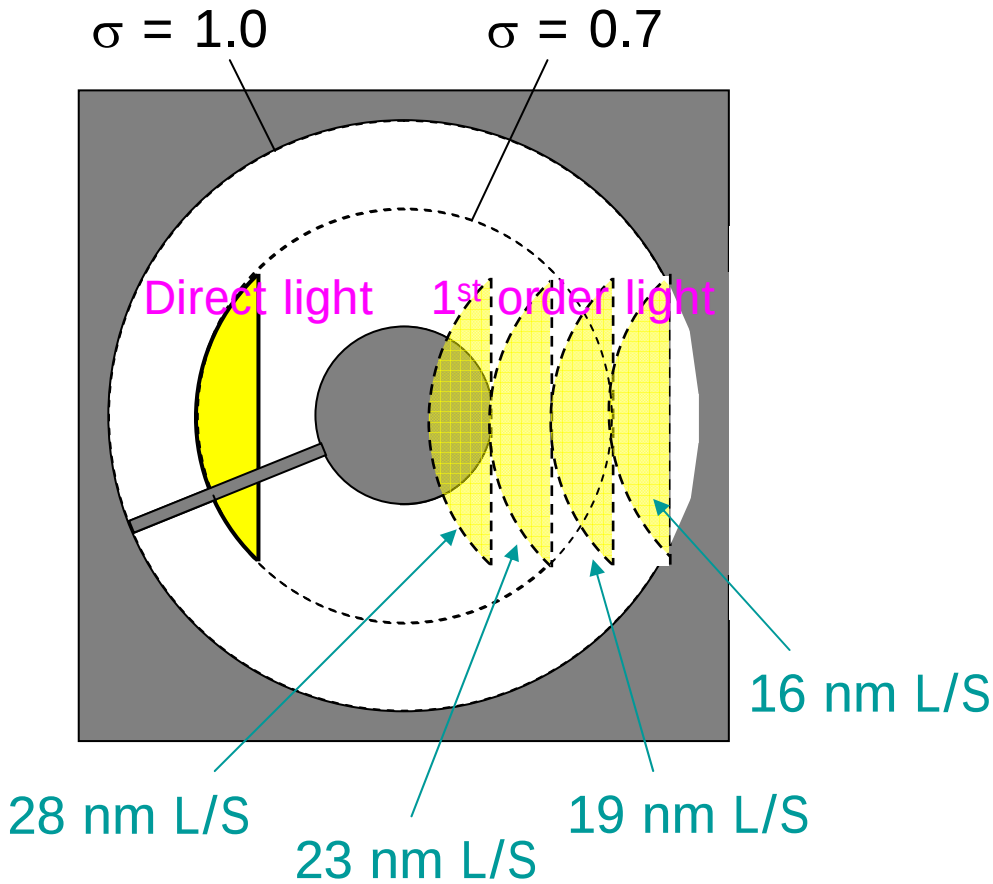


<Simulation conditions> Aberration: 0.76 nm RMS (AZ37) Flare: 11% (Constant)
Pattern density: 100% Mask structure: 2D (Binary)

X-slit illumination provides a high image contrast for pattern sizes of hp 20-30 nm. The contrast is relatively low for pattern sizes of hp 30-45 nm because of the effect of central obscuration.

Image contrast of SFET with x-dipole illumination

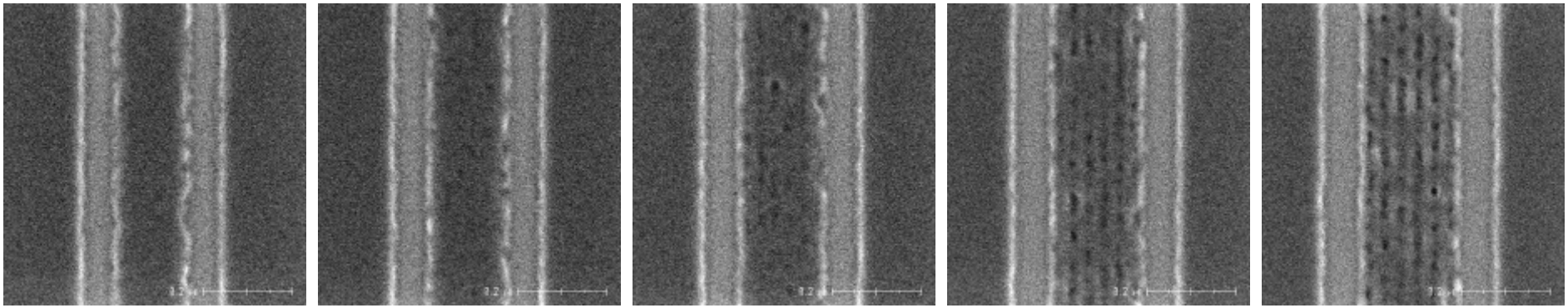




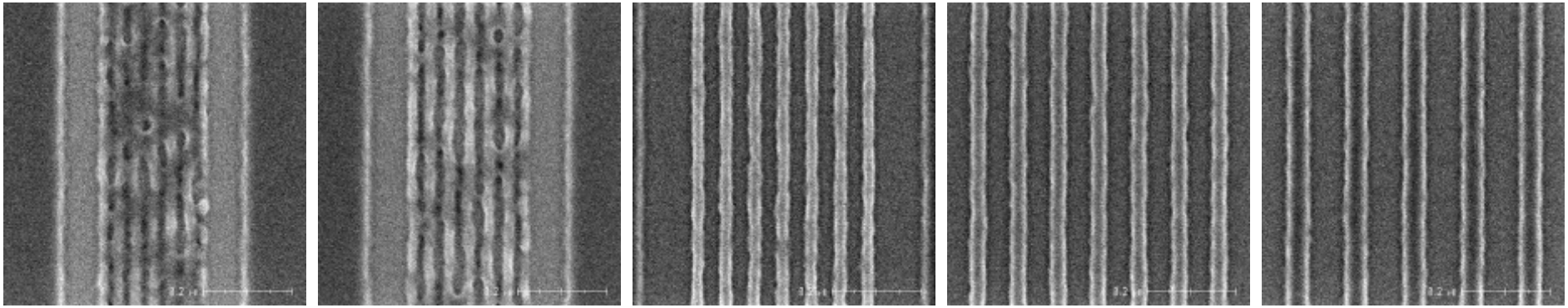
<Simulation conditions> Aberration: 0.76 nm RMS (AZ37) Flare: 11% (Constant)
Pattern density: 100% Mask structure: 2D (Binary)

X-dipole illumination provides a high image contrast for pattern sizes of hp 16-23 nm. The contrast is quite low for pattern sizes of hp 26-55 nm because of the effect of central obscuration.

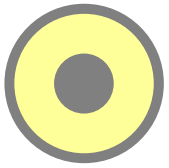
Resolution capability with annular illumination



15 nm L/S | 16 nm L/S | 17 nm L/S | 18 nm L/S | 19 nm L/S



20 nm L/S | 22 nm L/S | 32 nm L/S | 45 nm L/S | 65 nm L/S

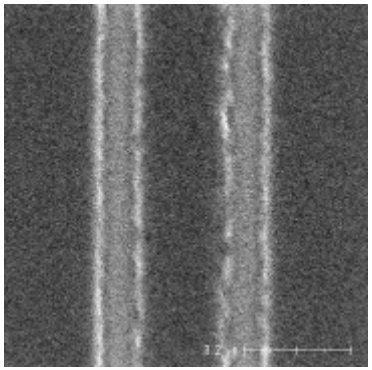


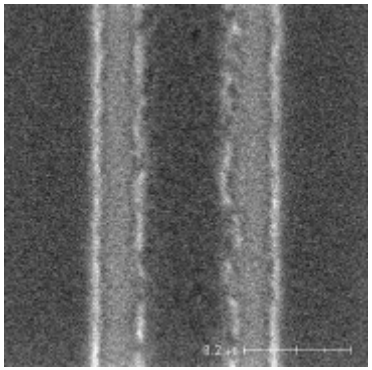
Annular
(σ=0.3/0.7)

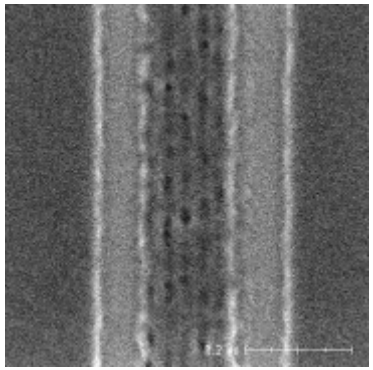
Resist: SMR569 (40 nm^t)
Dev: TBAH
Dose: 12.0 mJ/cm^2
Exp. time: 35sec/shot

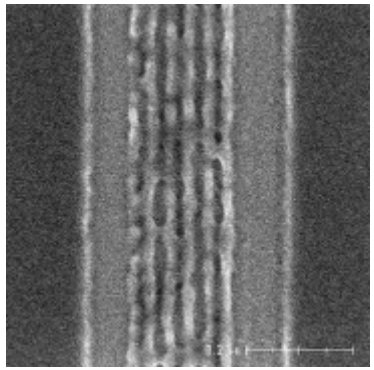
Using annular illumination, pattern shapes are not good for pattern sizes of 22 nm or less.

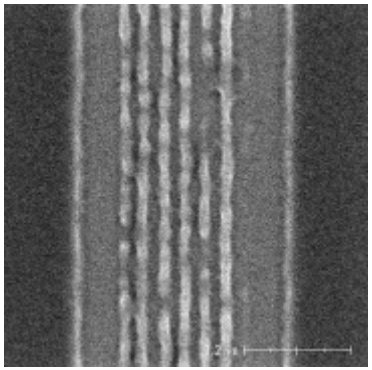
Resolution capability with x-slit illumination

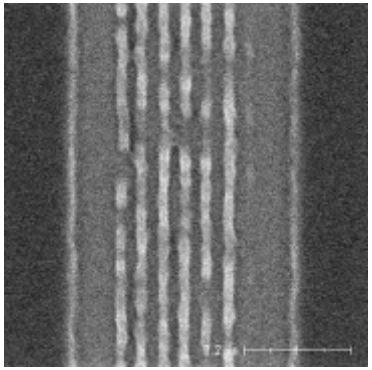

15 nm L/S

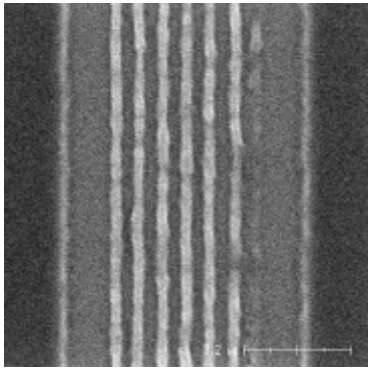

16 nm L/S

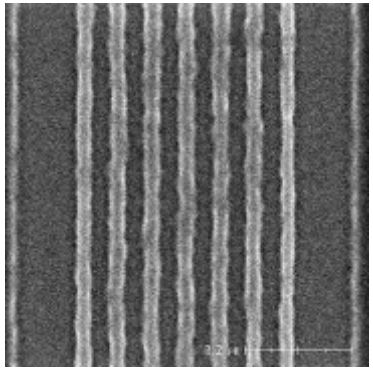

17 nm L/S

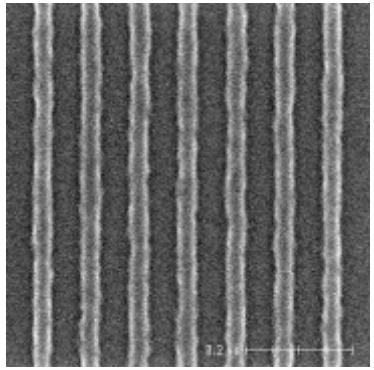

18 nm L/S

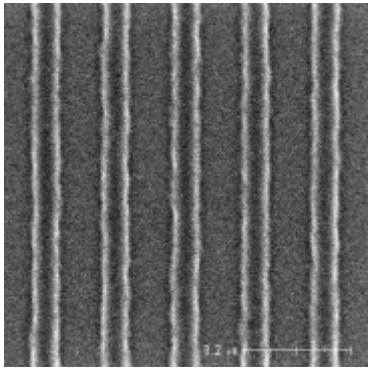

19 nm L/S

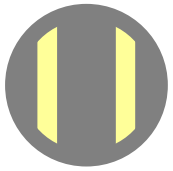

20 nm L/S


22 nm L/S


32 nm L/S


45 nm L/S

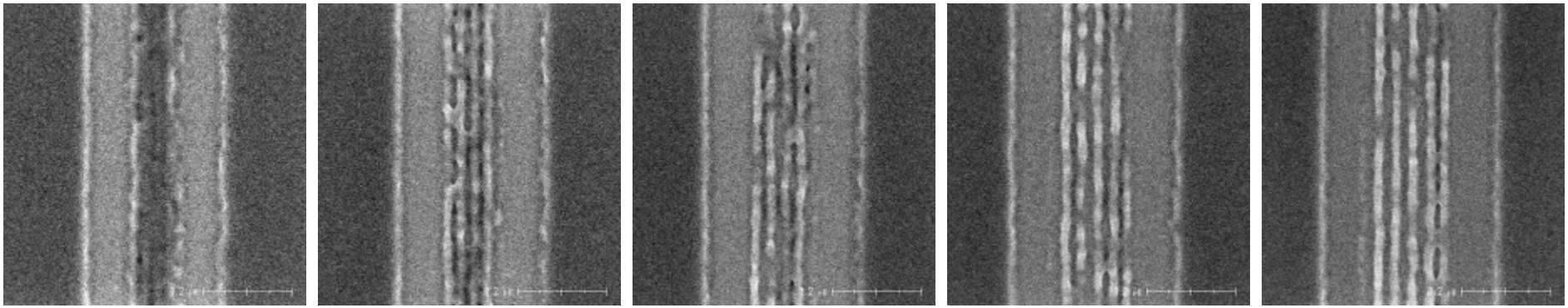

65 nm L/S


X-slit

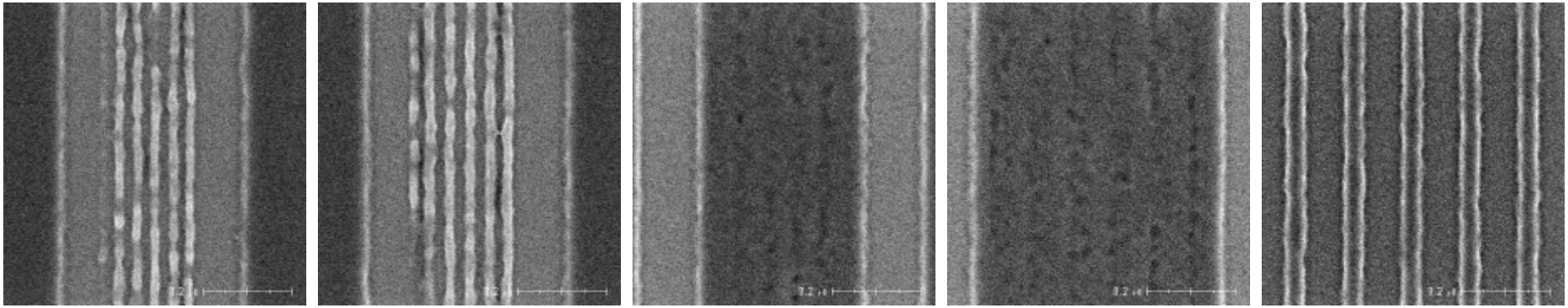
Resist: SMR569 (40 nm^t)
Dev: TBAH
Dose: 12.0 mJ/cm^2
Exp. time: 82sec/shot

Using x-slit illumination, pattern shapes are improved for pattern sizes of 18-30 nm. Resolution limit seems to be 18 nm.

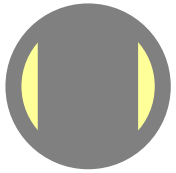
Resolution capability with x-dipole illumination



15 nm L/S | 16 nm L/S | 17 nm L/S | 18 nm L/S | 19 nm L/S



20 nm L/S | 22 nm L/S | 32 nm L/S | 45 nm L/S | 65 nm L/S



X-dipole

Resist: SMR569 (40 nm^t)
Dev: TBAH
Dose: 12.0 mJ/cm^2
Exp. time: 197sec/shot

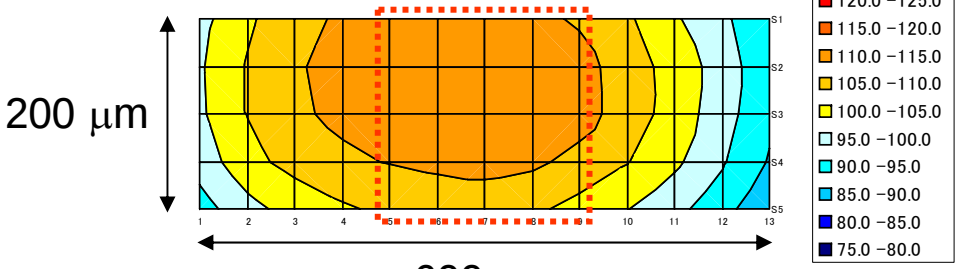
Using x-dipole illumination, modulation was formed even at 16 nm. Patterns were not resolved in pattern sizes of 32-45 nm, which agrees well with the simulation results.

Dose uniformity in exposure field

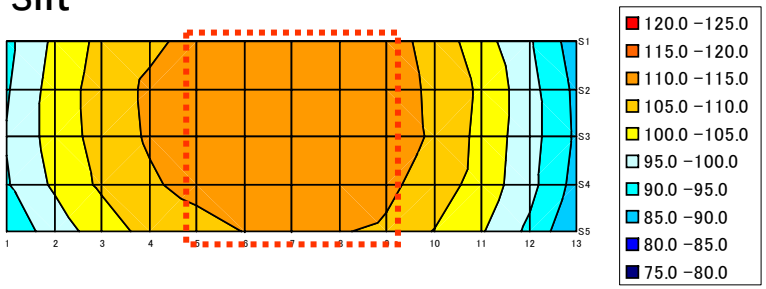
(%)

	Field size: 600 μm × 200 μm	Field size: 200 μm × 200 μm
(1) Annular	±13.9%	±4.9%
(2) X-slit	±14.4%	±2.8%
(3) X-dipole	±10.0%	±2.9%

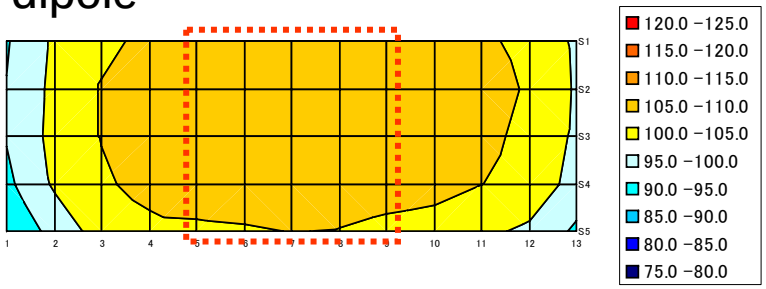
(1) Annular



(2) X-slit

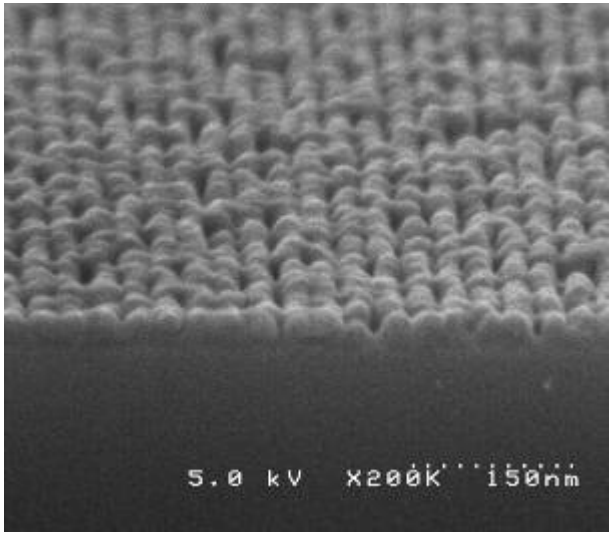


(3) X-dipole

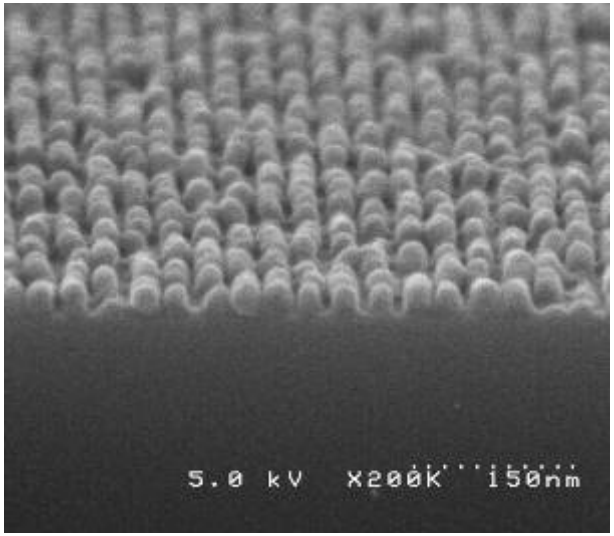


Using x-dipole illumination, dose uniformity is ±10% in the 600 μm × 200 μm field and ±3% in the central 200 μm × 200 μm field.

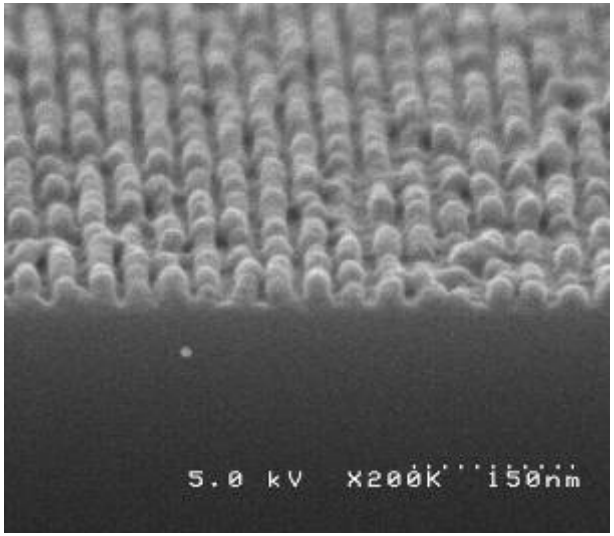
Cross-sectional images of resist patterns



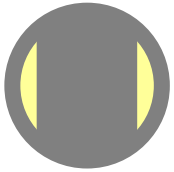
15 nm L/S



16 nm L/S



17 nm L/S

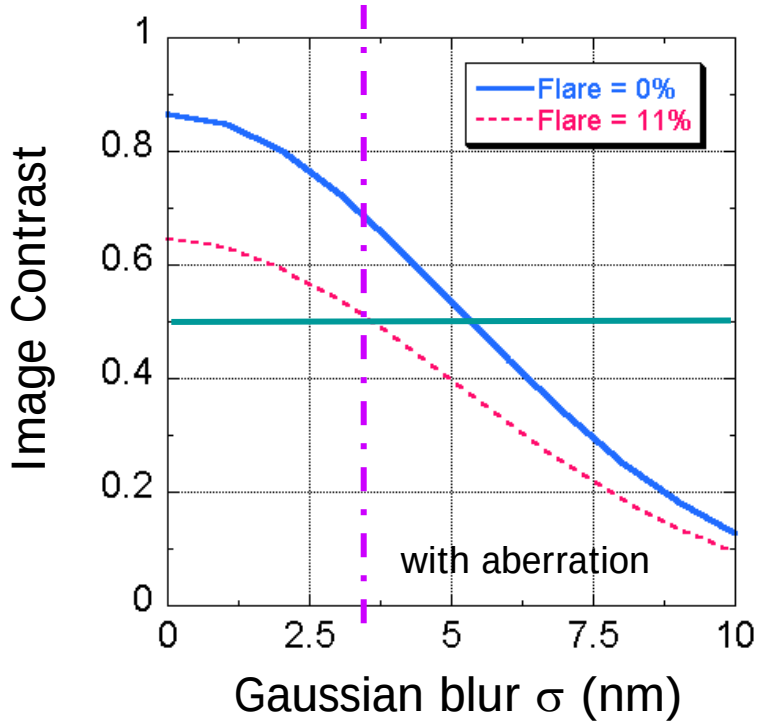


X-dipole

Resist: SMR569 (40 nm^t)
Dev: TBAH

Good uniformity of dose makes it easy to observe cross sections of fine L/S patterns. Clear modulation was formed even at 16 nm L/S patterns.

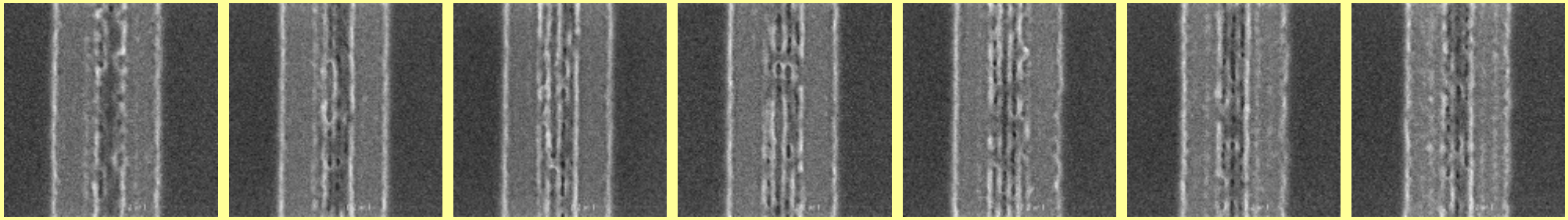
Effects of flare & blur on image contrast of 16 nm L/S



Effect of blur on the image contrast of 16 nm L/S patterns.

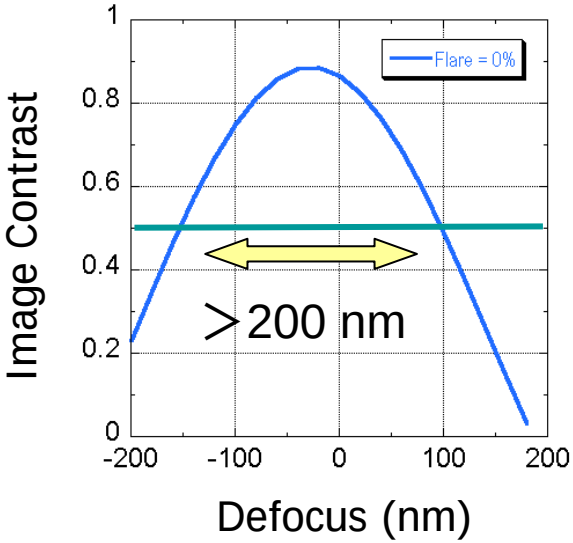
Main causes of the pattern degradation in 16 nm L/S might be the effects of flare and blur. Since the synchronization error between mask and wafer stage is less than 1 nm (σ) in the SFET, the main cause of the blur might be acid diffusion in resist. For hp 16 nm, resist blur should be less than 3.5 nm (σ).

Depth of focus for 16 nm L/S patterns



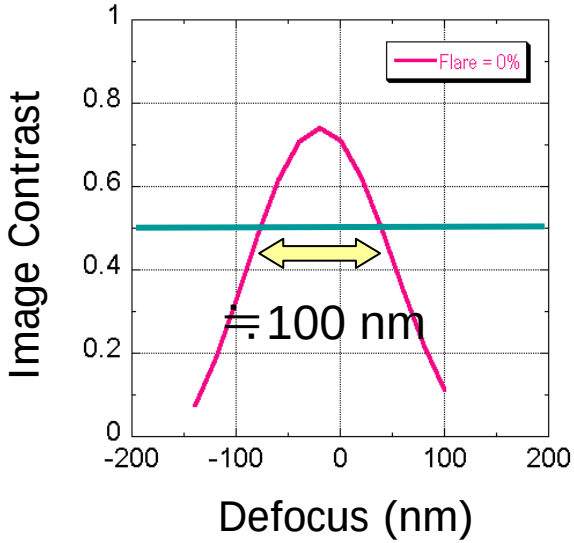
-90 nm | -60 nm | -30 nm | ±0 nm Defocus | +30 nm | +60 nm | +90 nm

＜SFET with x-dipole＞



(1) SFET（NA=0.3）＋ x-dipole

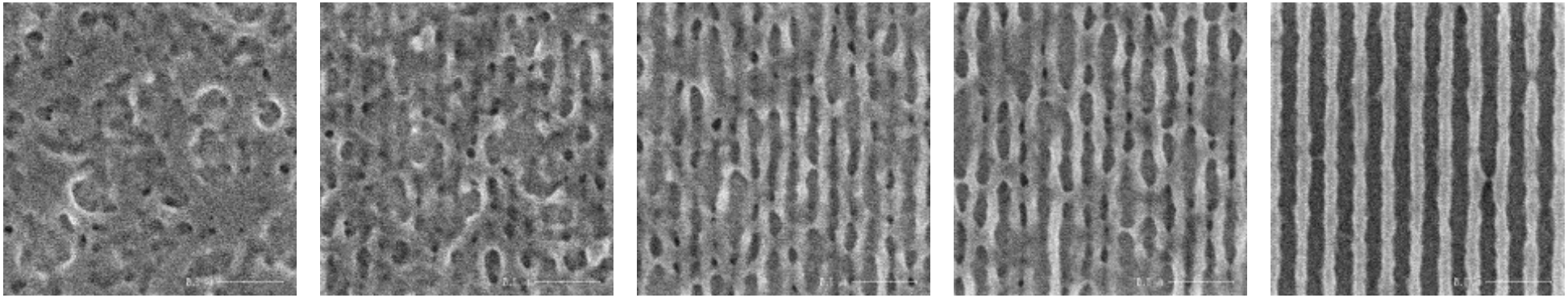
with aberration



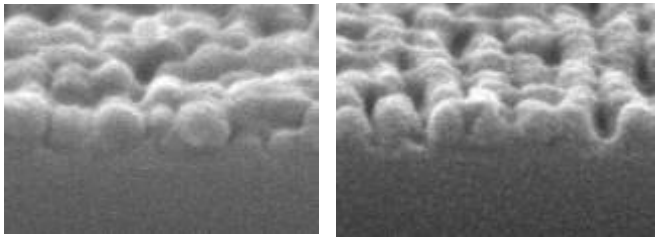
(2) High-NA tool（NA=0.4）＋ annular（σ=0.3/0.7）

DOF for 16 nm L/S might be larger than 200 nm for the SFET with x-dipole.
However, it will be reduced by increasing NA and using annular illumination.

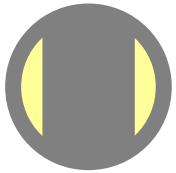
Ultimate resolution of SFET



13 nm L/S | 14 nm L/S | 15 nm L/S | 16 nm L/S | 22 nm L/S

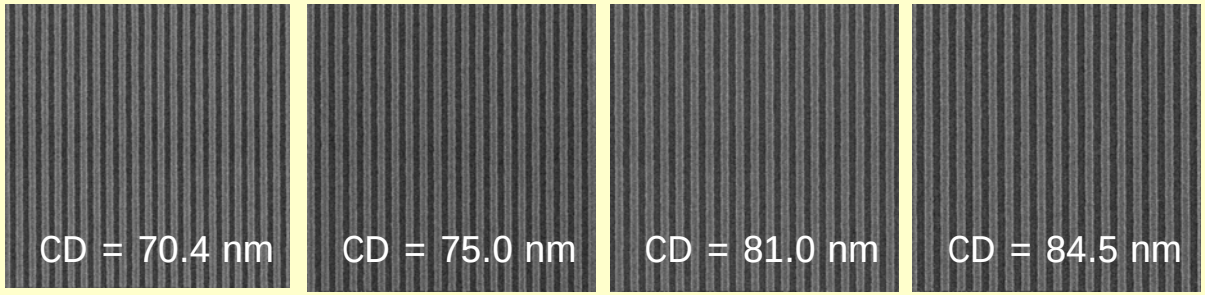


14 nm L/S | 15 nm L/S



X-dipole

Resist: SSR6 (40 nm^t)
Dev: TMAH



65 nm L/S | 70 nm L/S | 75 nm L/S | 80 nm L/S

Mask CD (5X)

Ultimate resolution of the SFET is 14-15 nm, which agrees well with the simulation results.

Conclusions

- We evaluated resolution capability of the SFET and obtained clear modulation of 16 nm L/S using x-dipole illumination. The resolution limit of the SFET seems to be 14-15 nm.
- To obtain better shapes of 16 nm L/S, resist blur should be reduced to less than 3.5 nm (σ).
- Regarding exposure tools, flare and synchronization error between mask and wafer stage might be the main causes of resolution degradation. The synchronization error should be less than 1 nm (σ).
- DOF for 16 nm L/S might to be larger than 200 nm for the SFET with x-dipole illumination. However, it will be reduced by increasing NA and using annular illumination.

Acknowledgements

We would like to thank Canon and EUVA for their support in the use of SFET.

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