Assessment and extendibility of chemically amplified resists for extreme ultraviolet lithography

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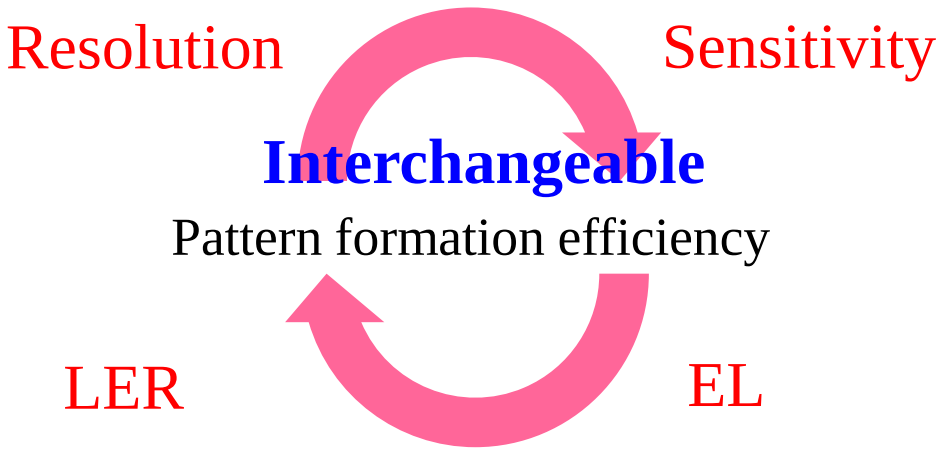
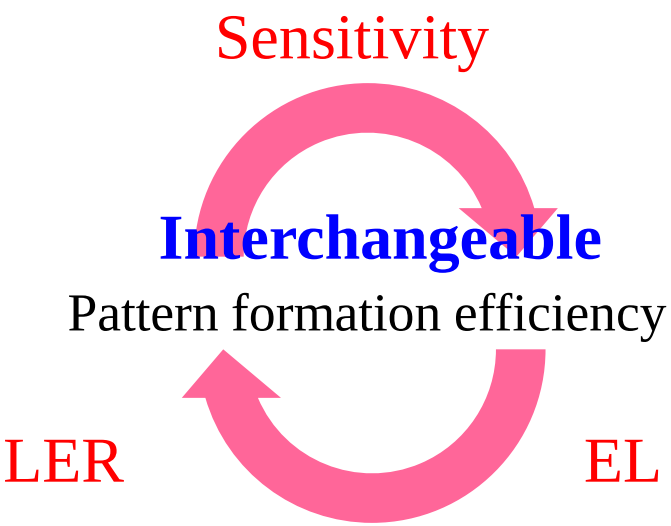
Resolution, LER, Sensitivity, Exposure latitude



To fully extract the resist potential, users must carefully consider the allocation of pattern formation efficiency.

Actually, there is no room for the negotiation on resolution.

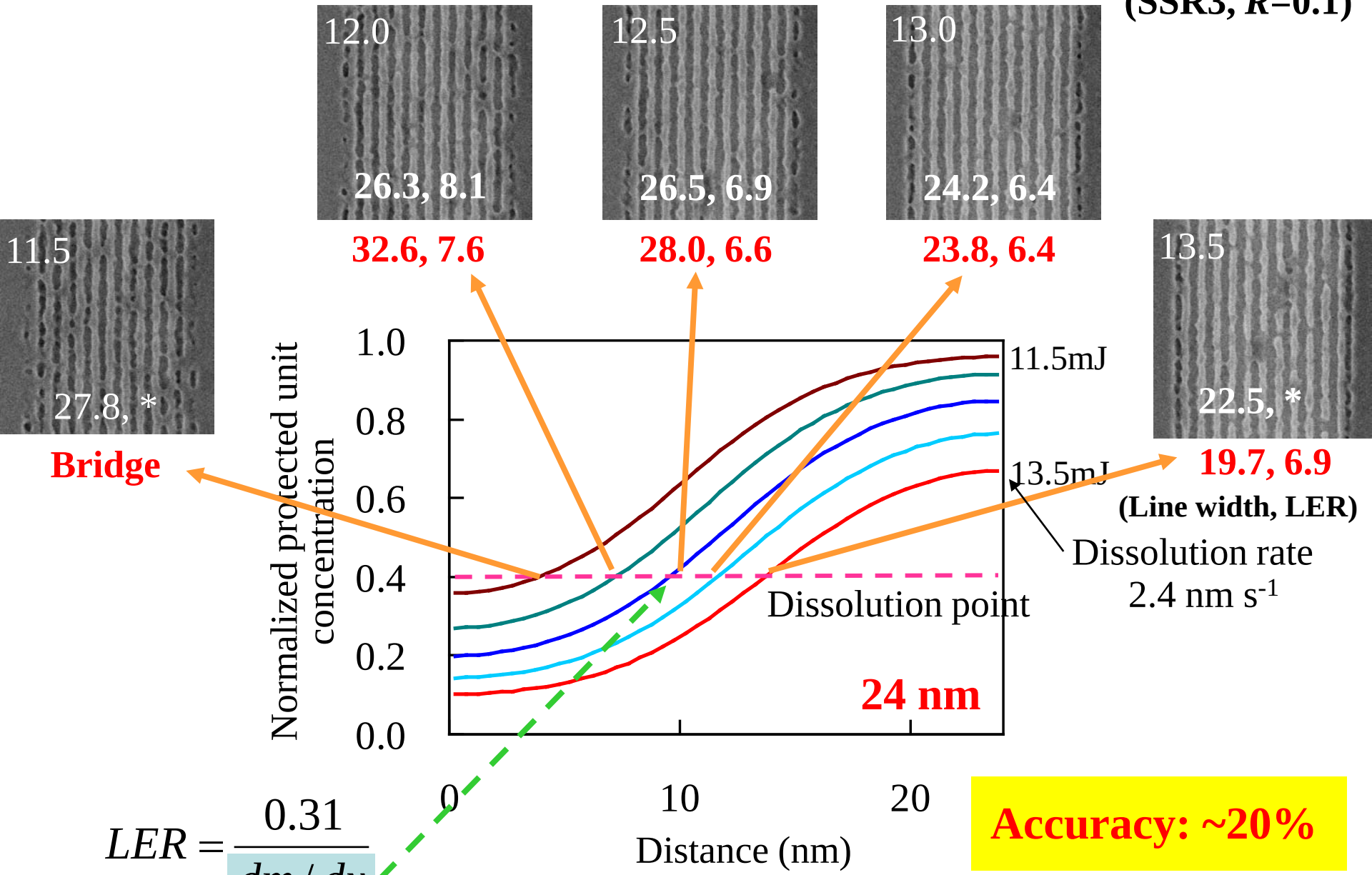
The balance among sensitivity, LER, and EL is important for the enhancement of productivity.



The extraction of basic parameters related to pattern formation efficiency is essential for resist assessment.

Reconstruction of latent images from does-pitch matrices of line width and LER

(SSR3, *R*=0.1)



$$LER = \frac{0.31}{dm/dx}$$

Chemical gradient

EUV Symp. 2009

Objective

1. To enhance the accuracy of parameter extraction from ~20% to <10%

The incorporation of a simple model for acid-base equilibrium

Dose correction using

$$Dose' = \frac{1}{\beta}\left[1 - \exp\left(-Dose \times \beta\right)\right]$$

Dose-pitch matrix → Dose-pitch matrix with cross sectional SEM image

2. To evaluate the resist performance upon exposure using a high NA tool.

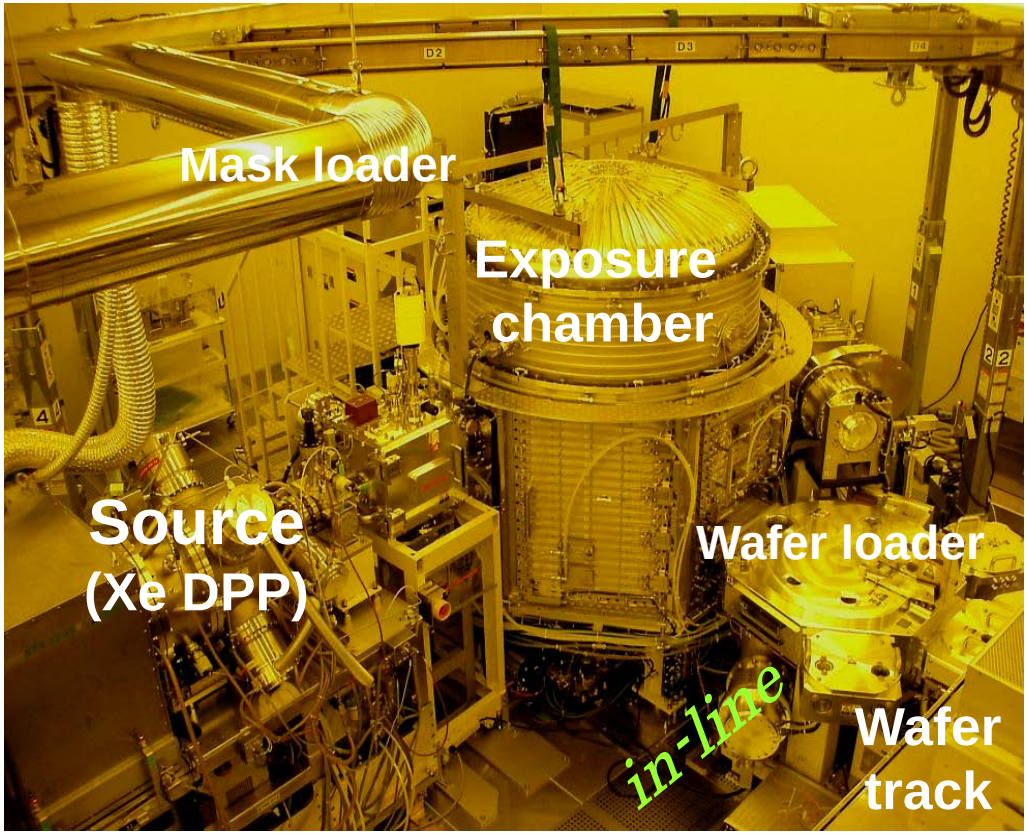
NA 0.35 with conventional illumination ($\sigma = 0.8$)

3. To discuss the extendibility of chemically amplified resists.

Resist requirement for 16 nm node

Experimental condition

Small Field Exposure Tool : SFET



Items	Target Specifications
NA	0.3
Illumination mode	Annular(0.3/0.7), x-slit
Field size	0.2 x 0.6 mm
Magnification	1/5
Wavefront error	＜0.9 nm rms
Flare	＜7%（MSFR）
Source power	0.5W @IF
Wafer size	300 mm

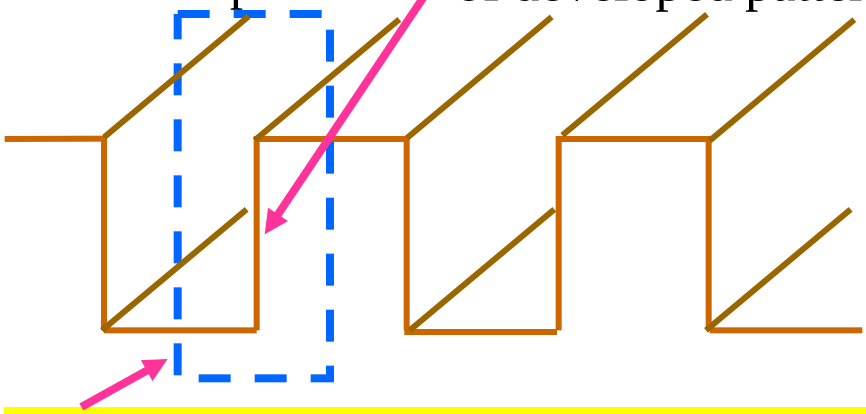
Resist: Selete Standard Resists (SSR4 and SSR5)

Pattern: Line and space (HP: 22-60 nm)

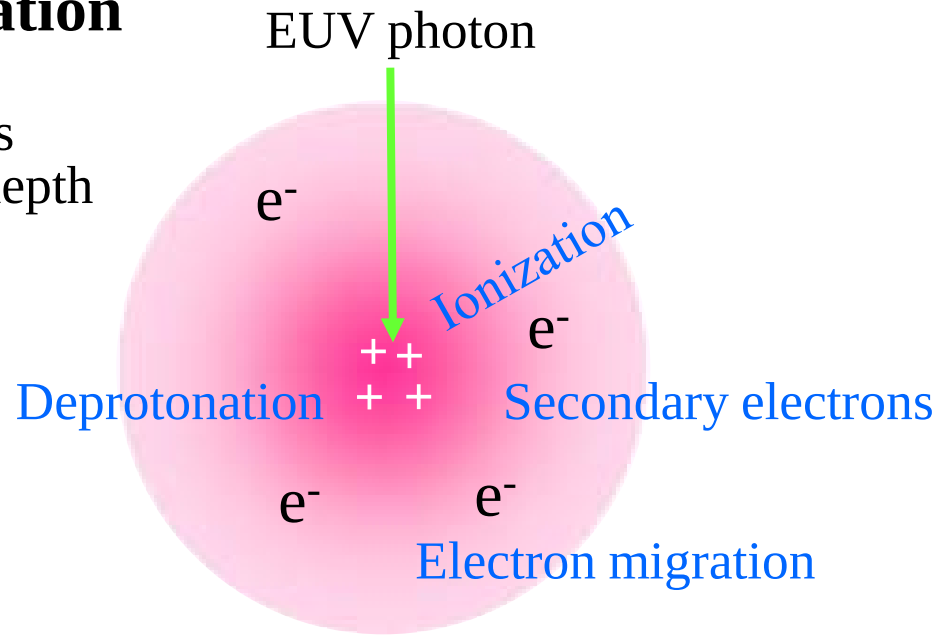
SEM: Hitachi S-9380II

Simulation

Pattern



Chemical gradient was evaluated at the half-depth of developed pattern.

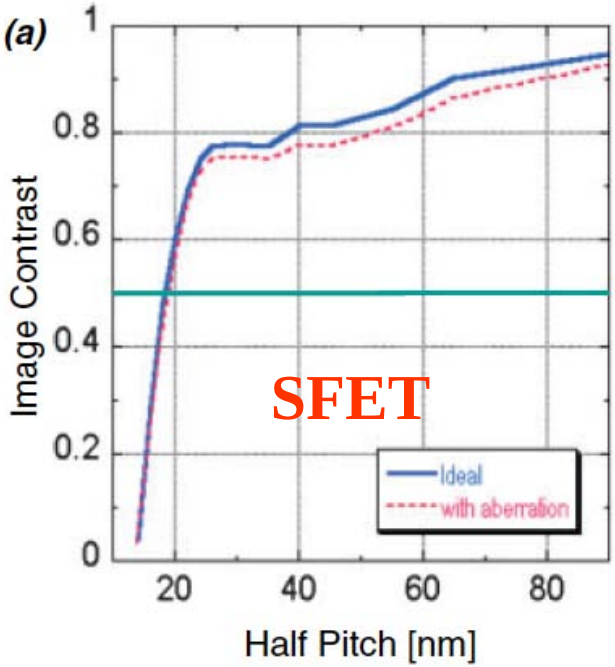


Latent images were calculated on the basis of reaction mechanisms of chemically amplified EUV resists.

Aerial image of incident EUV

$$I(x,y,z) = A\left\{\frac{1}{2}\left[1 + \underbrace{C}_{\text{Contrast}}\cos\left(\frac{\pi x}{p_{1/2}}\right)\right] + \underbrace{F}_{\text{Flare}}\right\}\exp(-\alpha|z|)$$

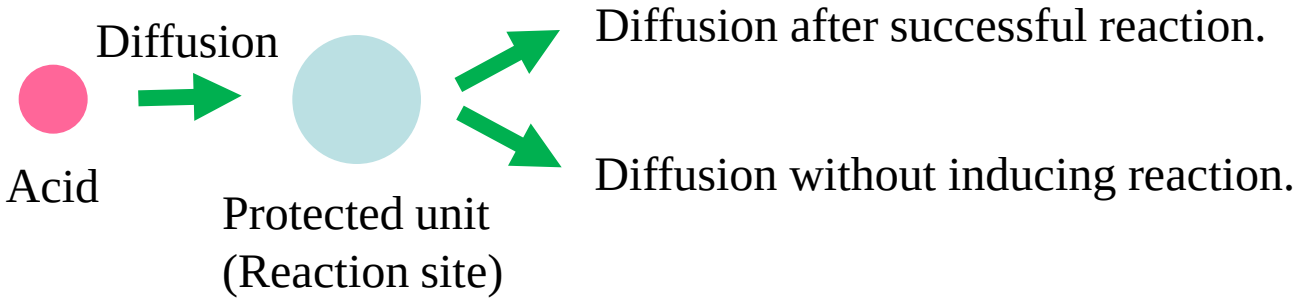
K. Tawarayama et al. Jpn. J. Appl. Phys. **47** (2008) 4866.



Fitting parameter

Effective reaction radius for deprotection, R_{eff}

The efficiency of chemical reaction per unit diffusion length



Dissolution point

The amount of chemical reactions required for the dissolution of resist polymer

Quencher concentration

The number of acids participating in chemical reaction

*Quantum efficiency of acids

Acid diffusion constant

Activation energy for acid diffusion

Acid-base equilibrium

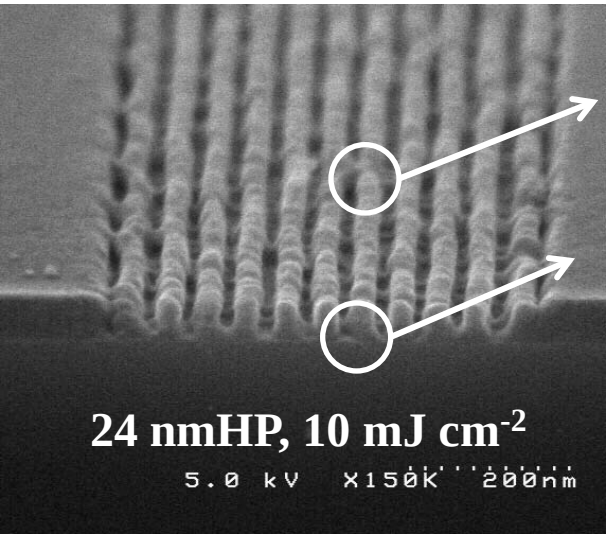
Exposure latitude, sensitivity

Representative patterning results

SSR4

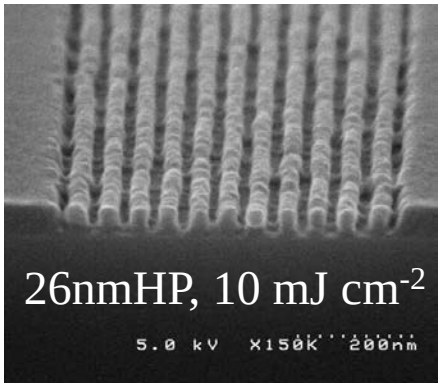
Changing HP

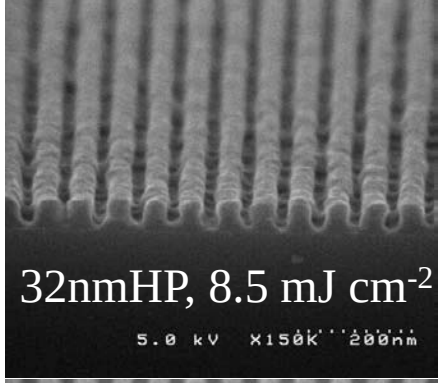
Changing dose

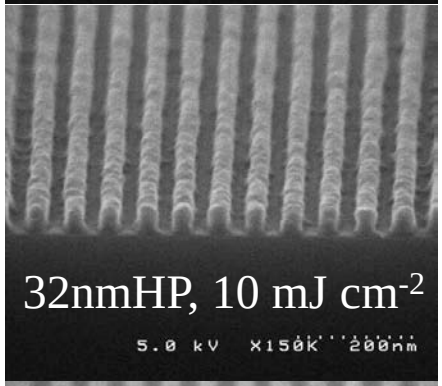


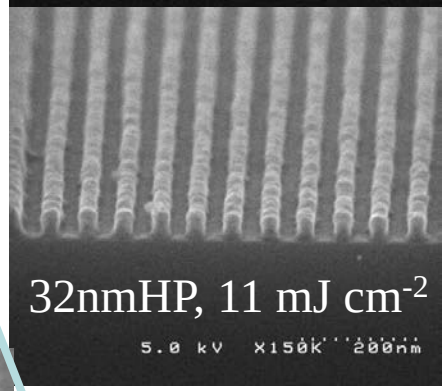
Line width, LER
(Top down)

Thickness
(0 degree)

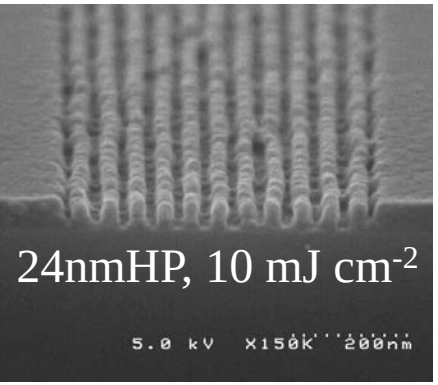


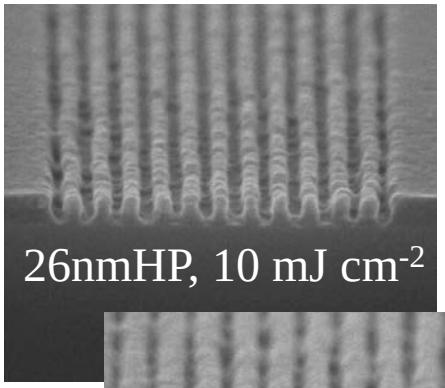


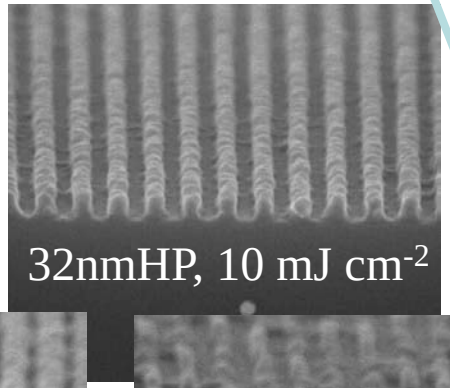


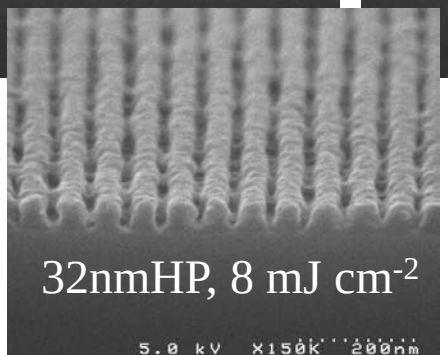


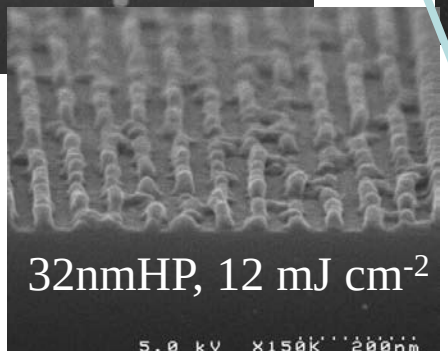
SSR5

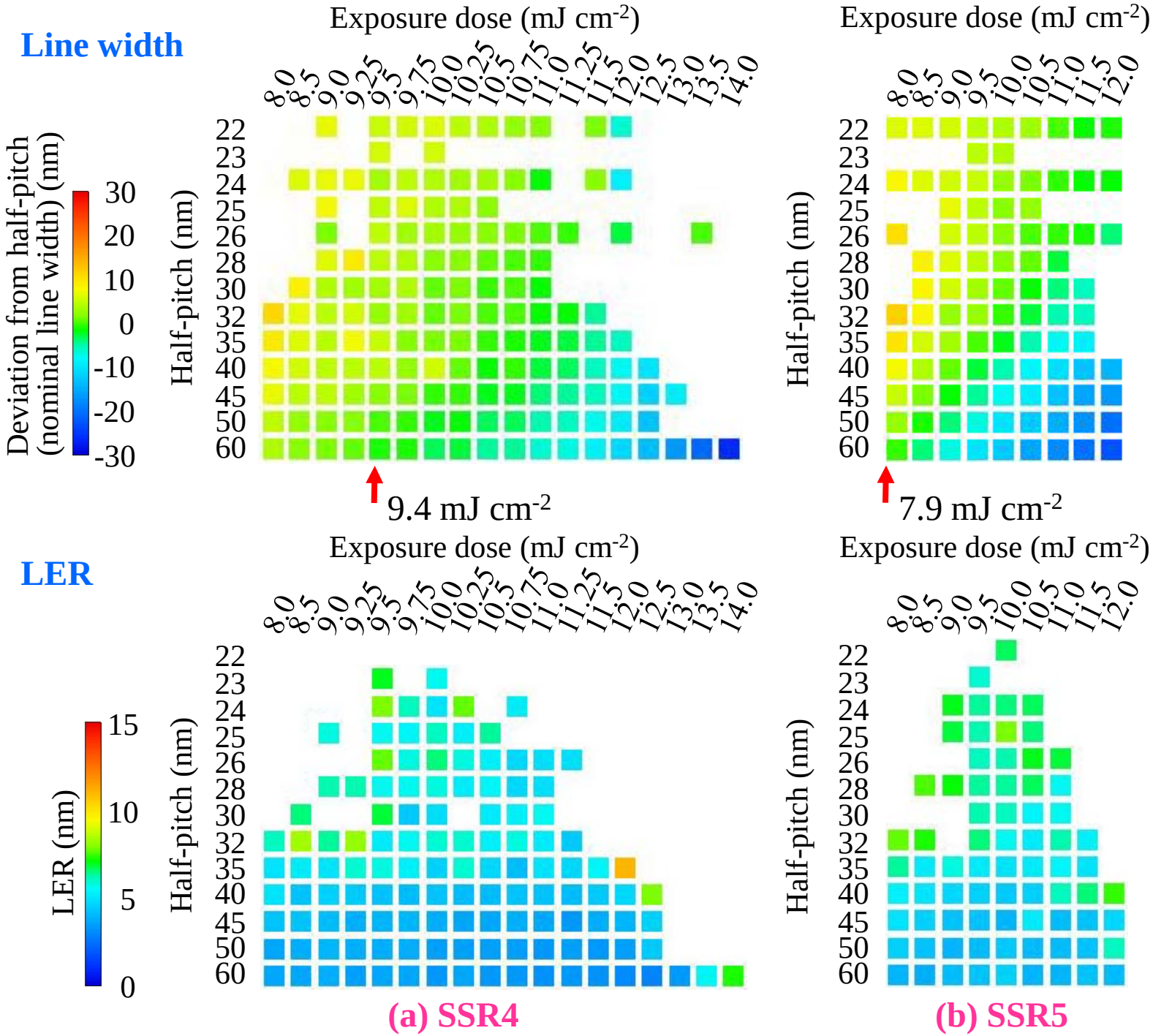


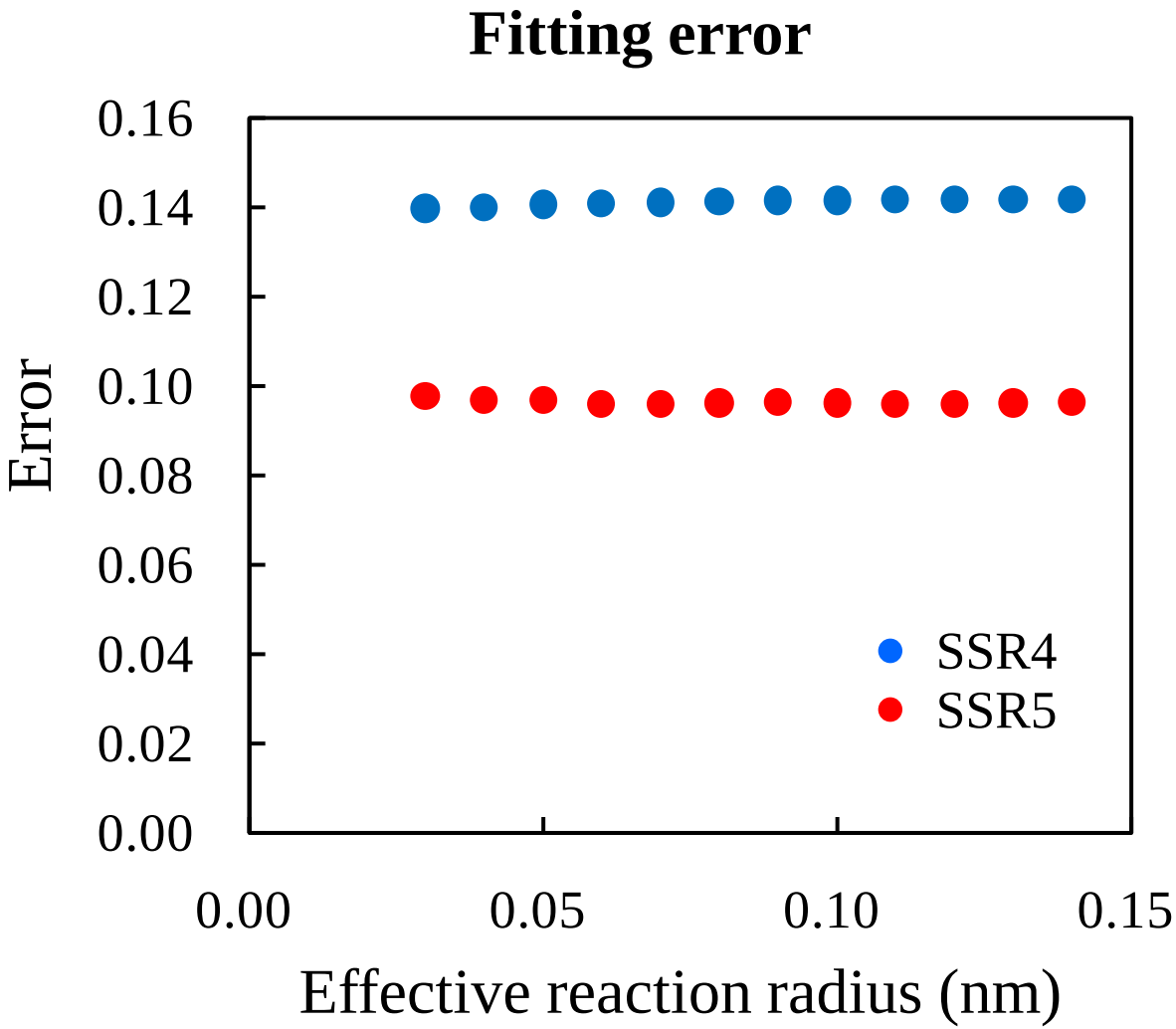








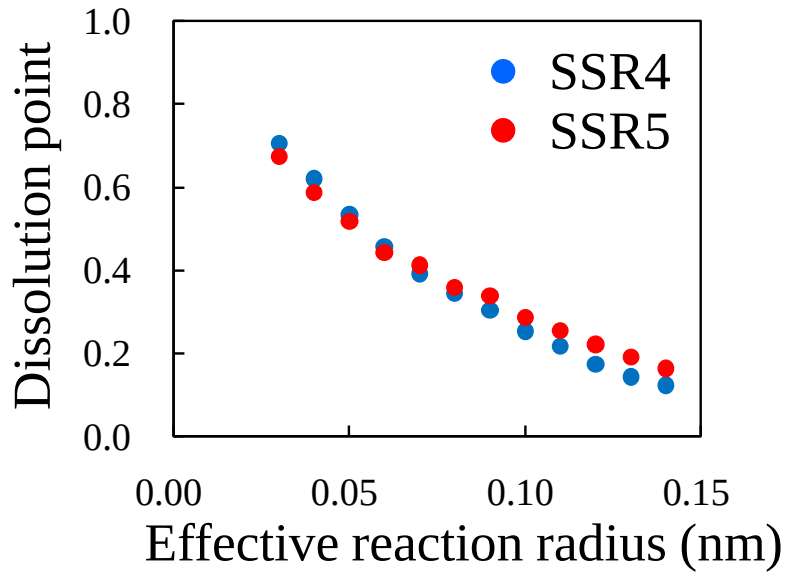

Line width
Exposure dose (mJ cm-2)
8.0 8.5 9.0 9.25 9.5 9.75 10.0 10.25 10.5 10.75 11.0 11.25 11.5 12.0 12.5 13.0 13.5 14.0
Deviation from half-pitch (nominal line width) (nm)
30 20 10 0 -10 -20 -30
Half-pitch (nm)
22 23 24 25 26 28 30 32 35 40 45 50 60
9.4 mJ cm-2
Exposure dose (mJ cm-2)
8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0
Half-pitch (nm)
22 23 24 25 26 28 30 32 35 40 45 50 60
7.9 mJ cm-2
LER
Exposure dose (mJ cm-2)
8.0 8.5 9.0 9.25 9.5 9.75 10.0 10.25 10.5 10.75 11.0 11.25 11.5 12.0 12.5 13.0 13.5 14.0
LER (nm)
15 10 5 0
Half-pitch (nm)
22 23 24 25 26 28 30 32 35 40 45 50 60
(a) SSR4
Exposure dose (mJ cm-2)
8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0
Half-pitch (nm)
22 23 24 25 26 28 30 32 35 40 45 50 60
(b) SSR5



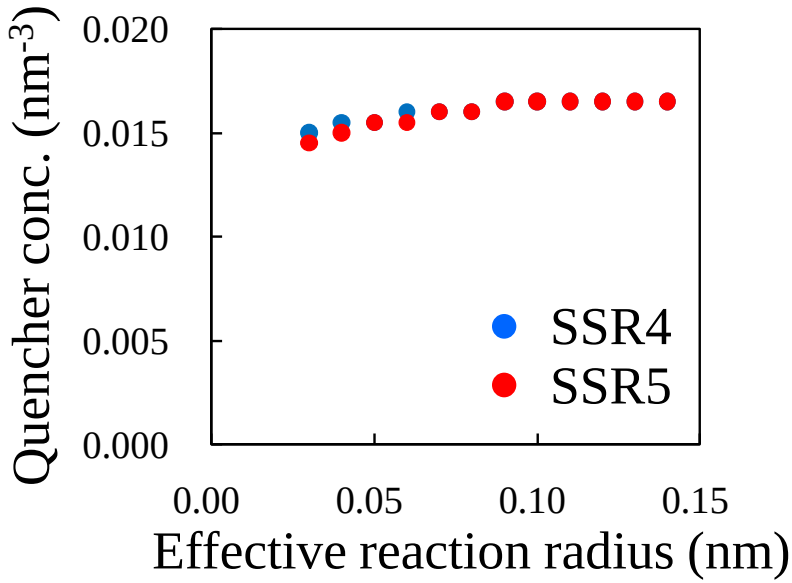
$$error = \sqrt{\sum_i \left[\left(\frac{Width_{\exp,i} - Width_{sim,i}}{Width_{sim,i}} \right)^2 + \left(\frac{LER_{\exp,i} - LER_{sim,i}}{LER_{sim,i}} \right)^2 + \left(\frac{T_{\exp,i} - T_{sim,i}}{T_{sim,i}} \right)^2 \right] / N}$$

T: Thickness of remaining resist, N: Total number of data

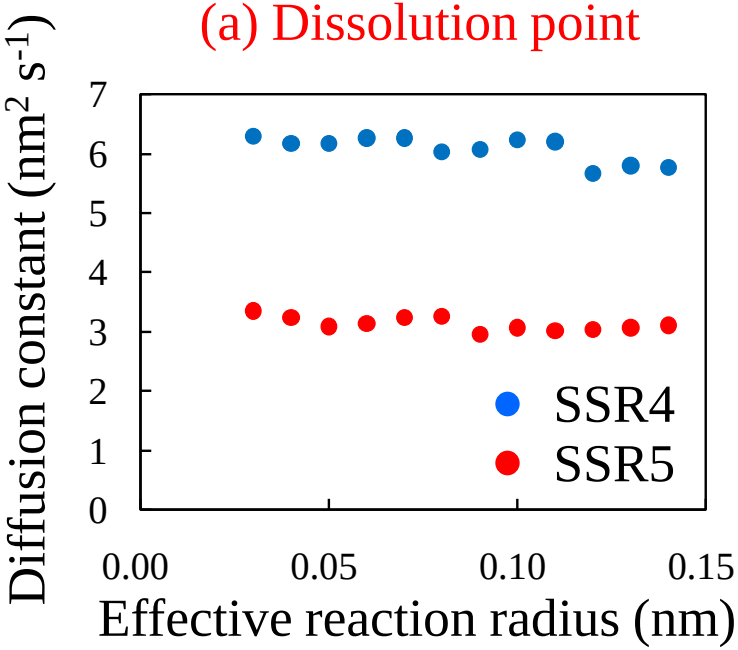
Extracted parameters



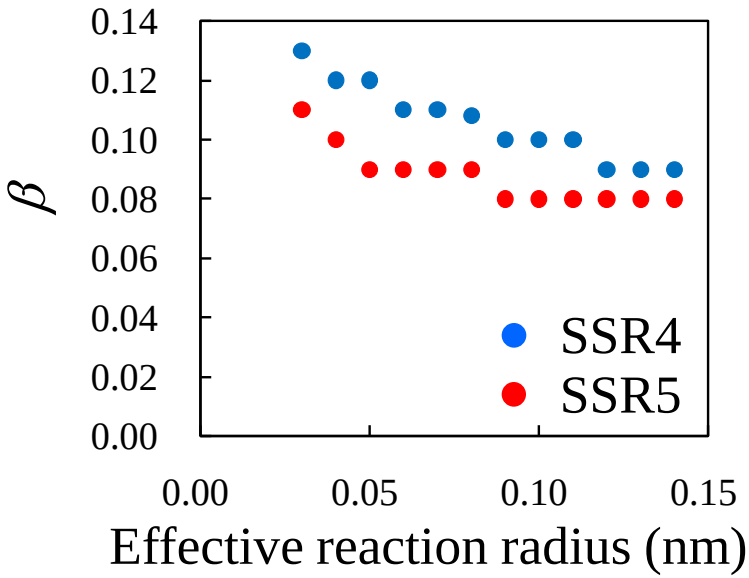
(a) Dissolution point



(b) Quencher concentration

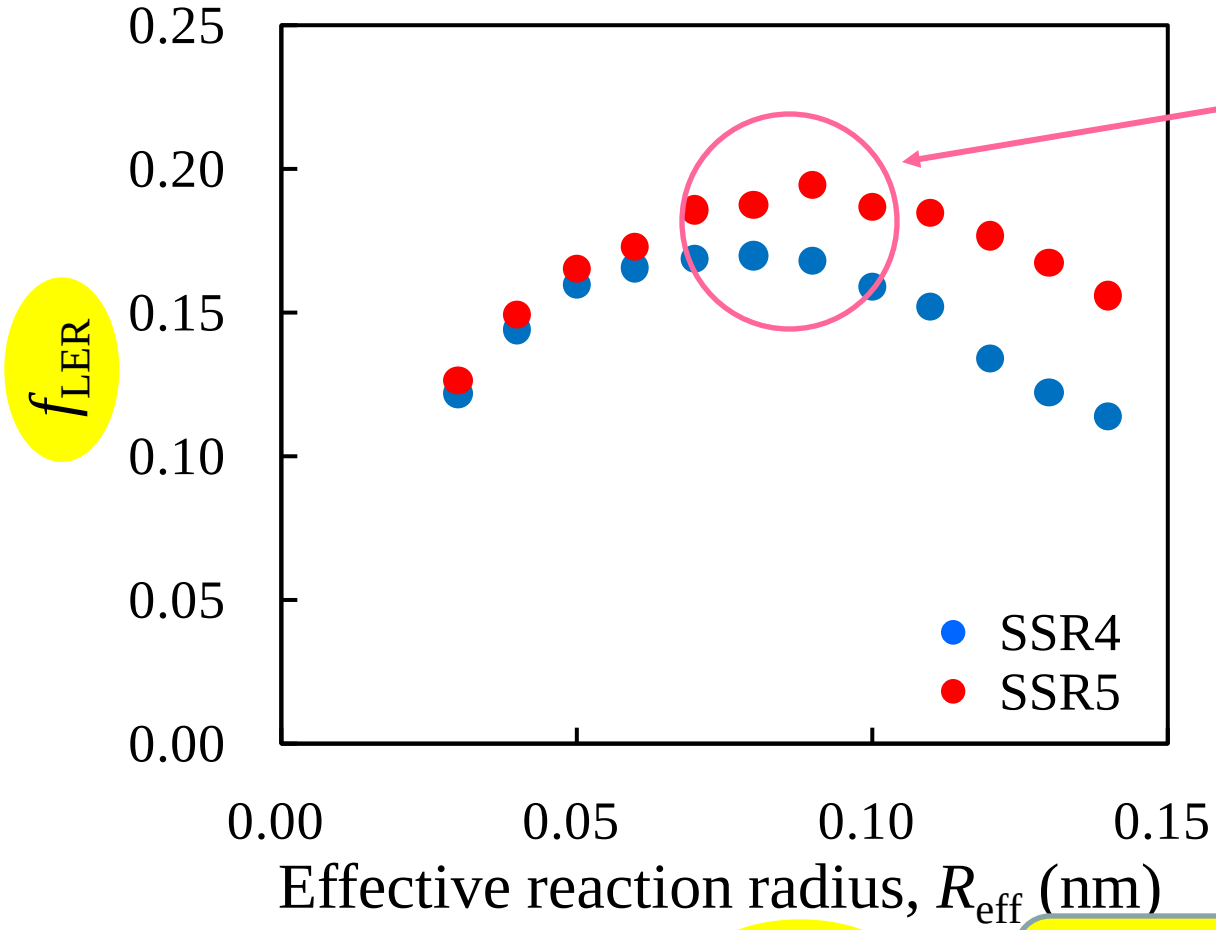


(c) Acid diffusion constant



(d) Acid-base equilibrium

Relationship between chemical gradient and LER



The chemical gradient also has a maximum value here.

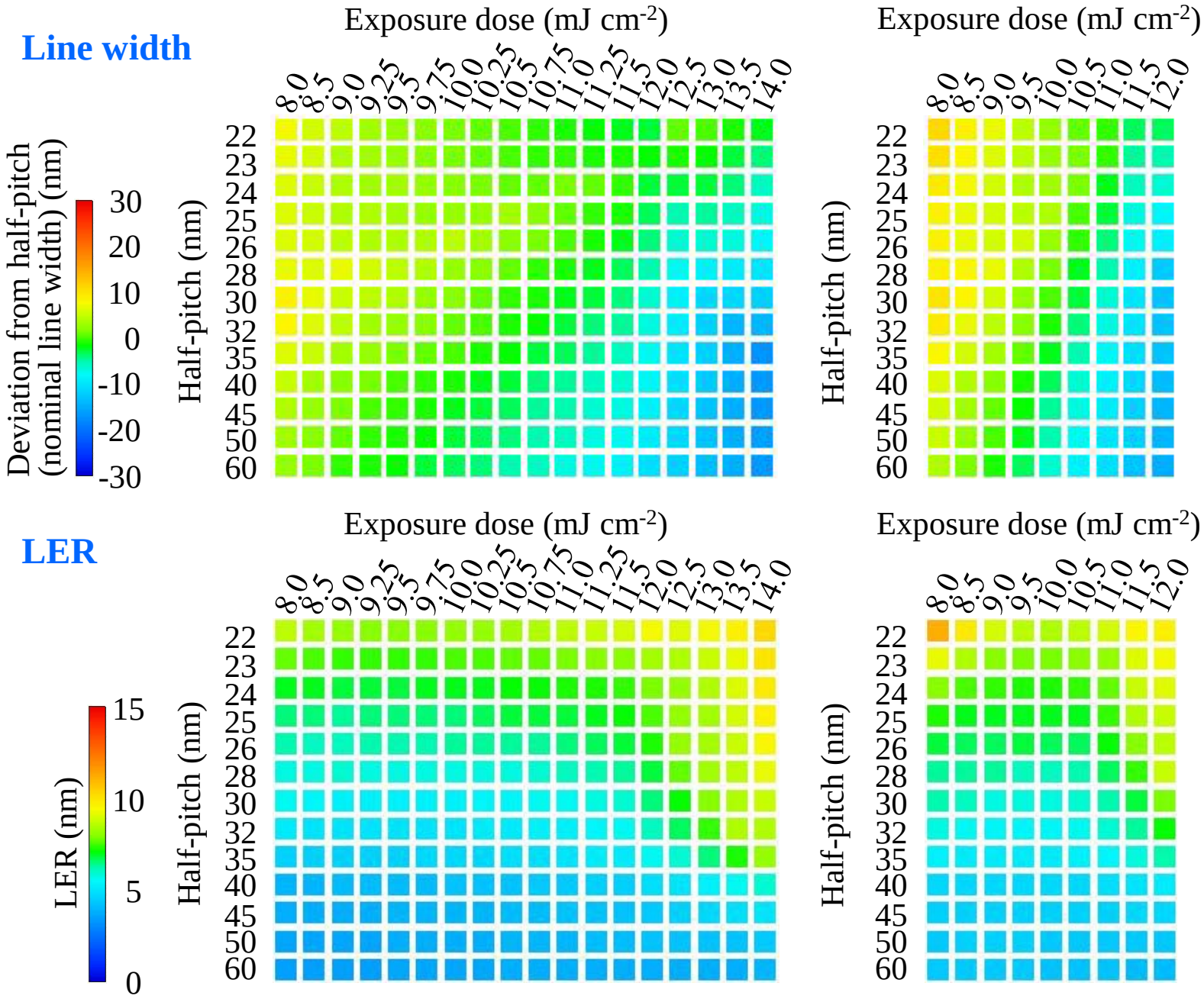
Because LER is inversely proportional to the chemical gradient, the process and material optimizations are equivalent to a task to maximize the chemical gradient.

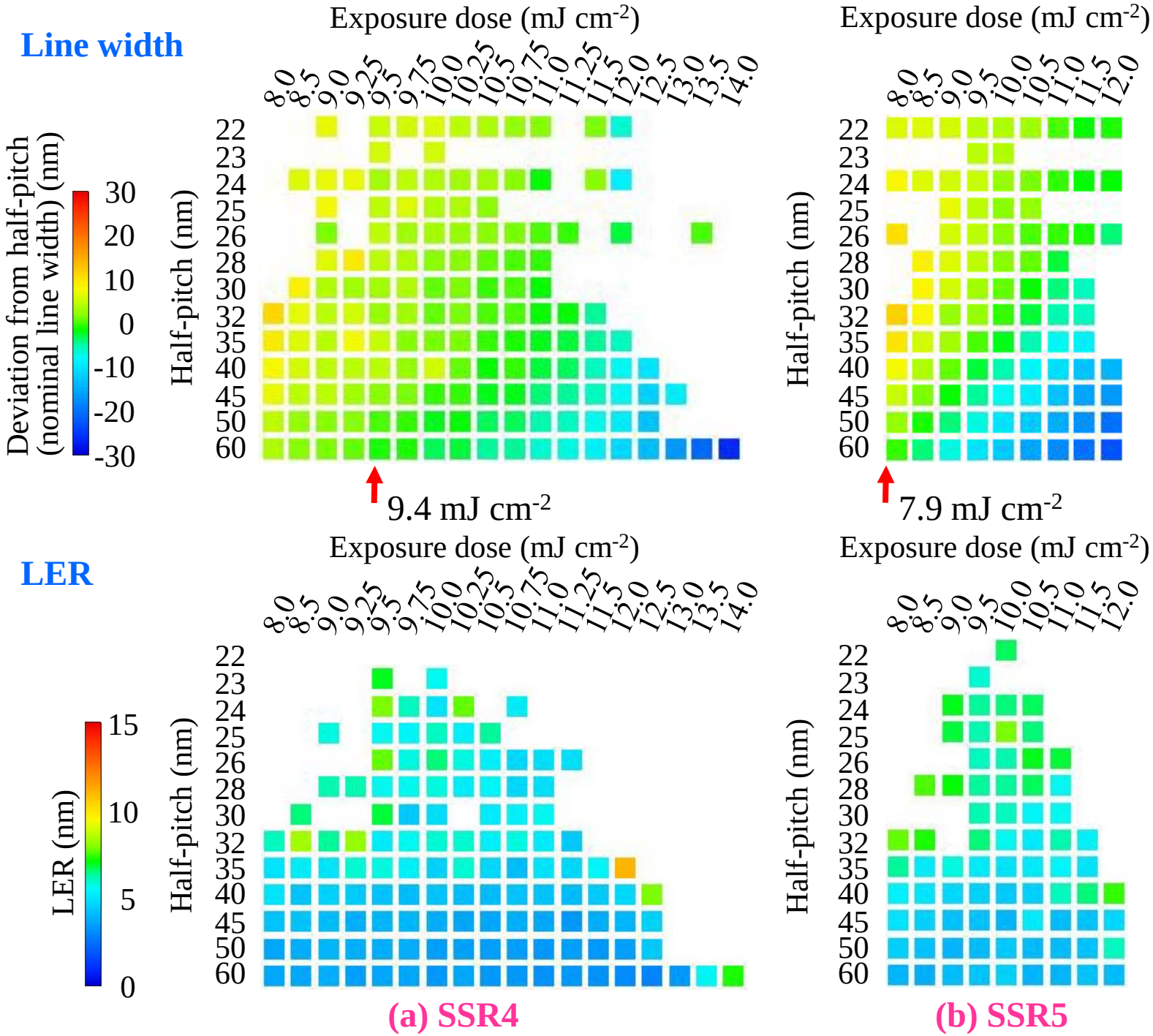
$$LER \approx \frac{f_{LER}}{dm / dx}$$

Determined by material and process factors associated with development and rinse processes.

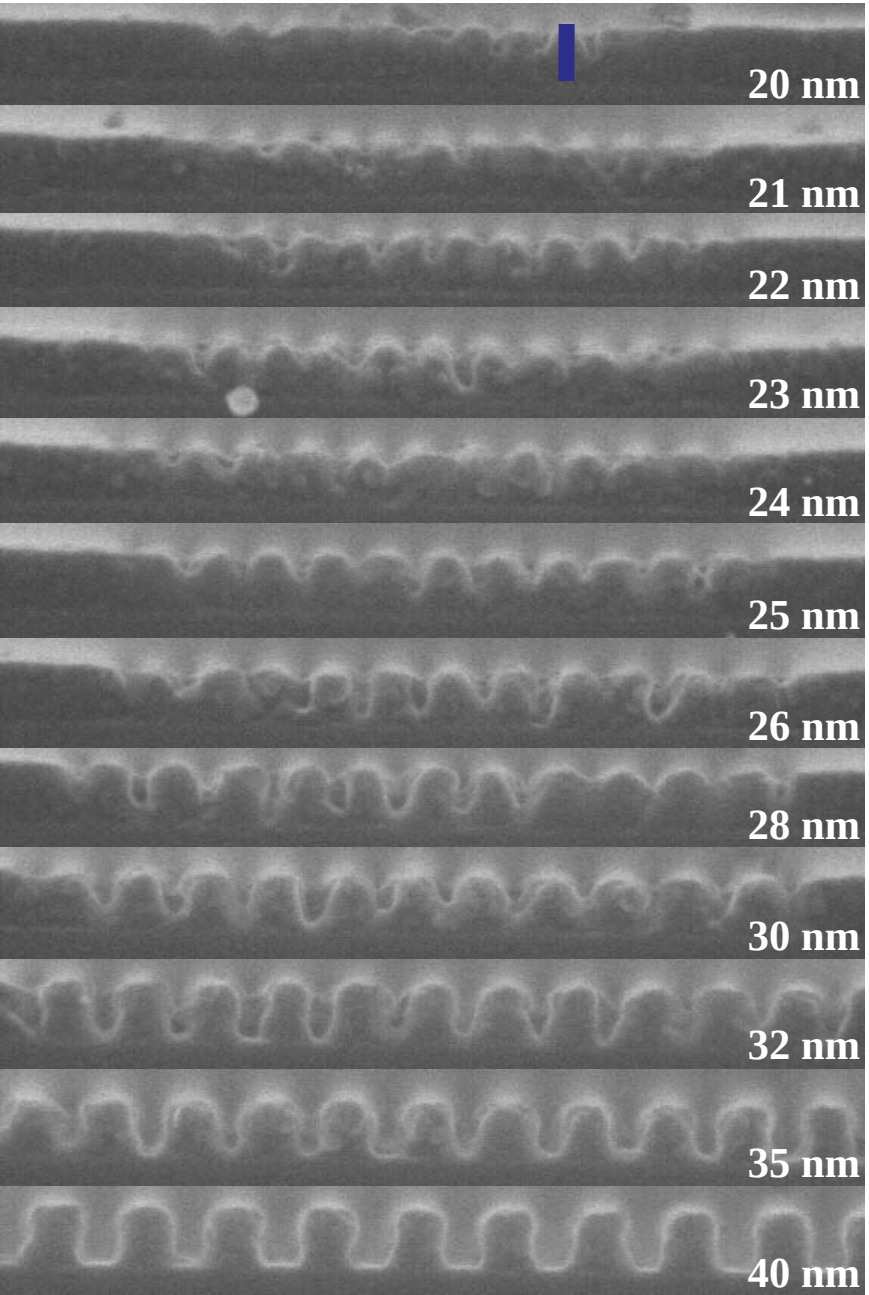
Determined by factors such as the aerial image quality of incident photons, exposure dose, absorption coefficient, the quantum efficiency of acids, and the effective reaction radius of deprotection.

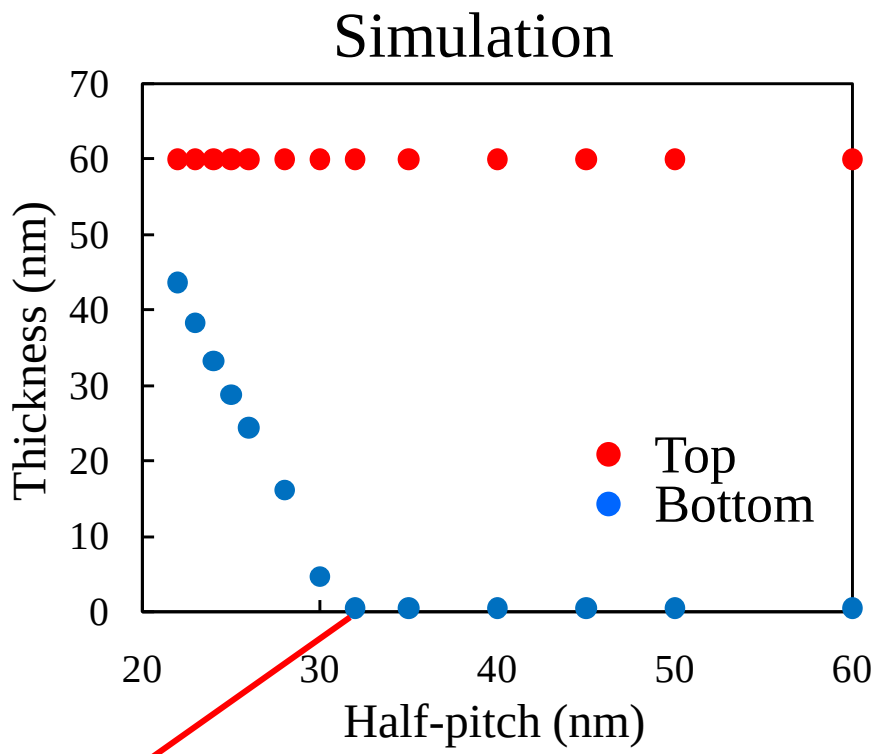
Simulation result

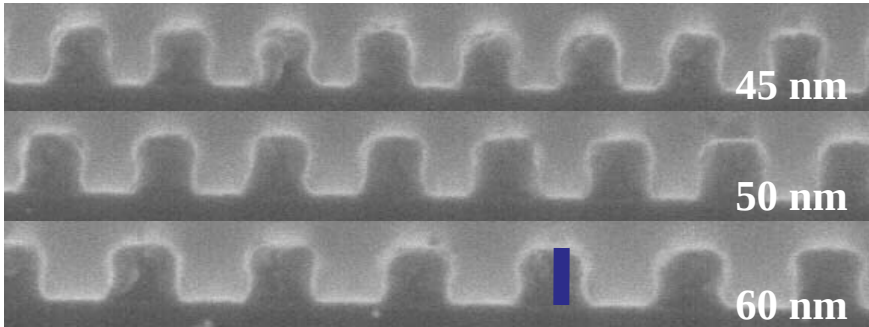



Line width
Exposure dose (mJ cm-2)
8.0 8.5 9.0 9.25 9.5 9.75 10.0 10.25 10.5 10.75 11.0 11.25 11.5 12.0 12.5 13.0 13.5 14.0
Deviation from half-pitch (nominal line width) (nm)
30 20 10 0 -10 -20 -30
Half-pitch (nm)
22 23 24 25 26 28 30 32 35 40 45 50 60
9.4 mJ cm-2
Exposure dose (mJ cm-2)
8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0
Half-pitch (nm)
22 23 24 25 26 28 30 32 35 40 45 50 60
7.9 mJ cm-2
LER
Exposure dose (mJ cm-2)
8.0 8.5 9.0 9.25 9.5 9.75 10.0 10.25 10.5 10.75 11.0 11.25 11.5 12.0 12.5 13.0 13.5 14.0
LER (nm)
15 10 5 0
Half-pitch (nm)
22 23 24 25 26 28 30 32 35 40 45 50 60
(a) SSR4
Exposure dose (mJ cm-2)
8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0
Half-pitch (nm)
22 23 24 25 26 28 30 32 35 40 45 50 60
(b) SSR5

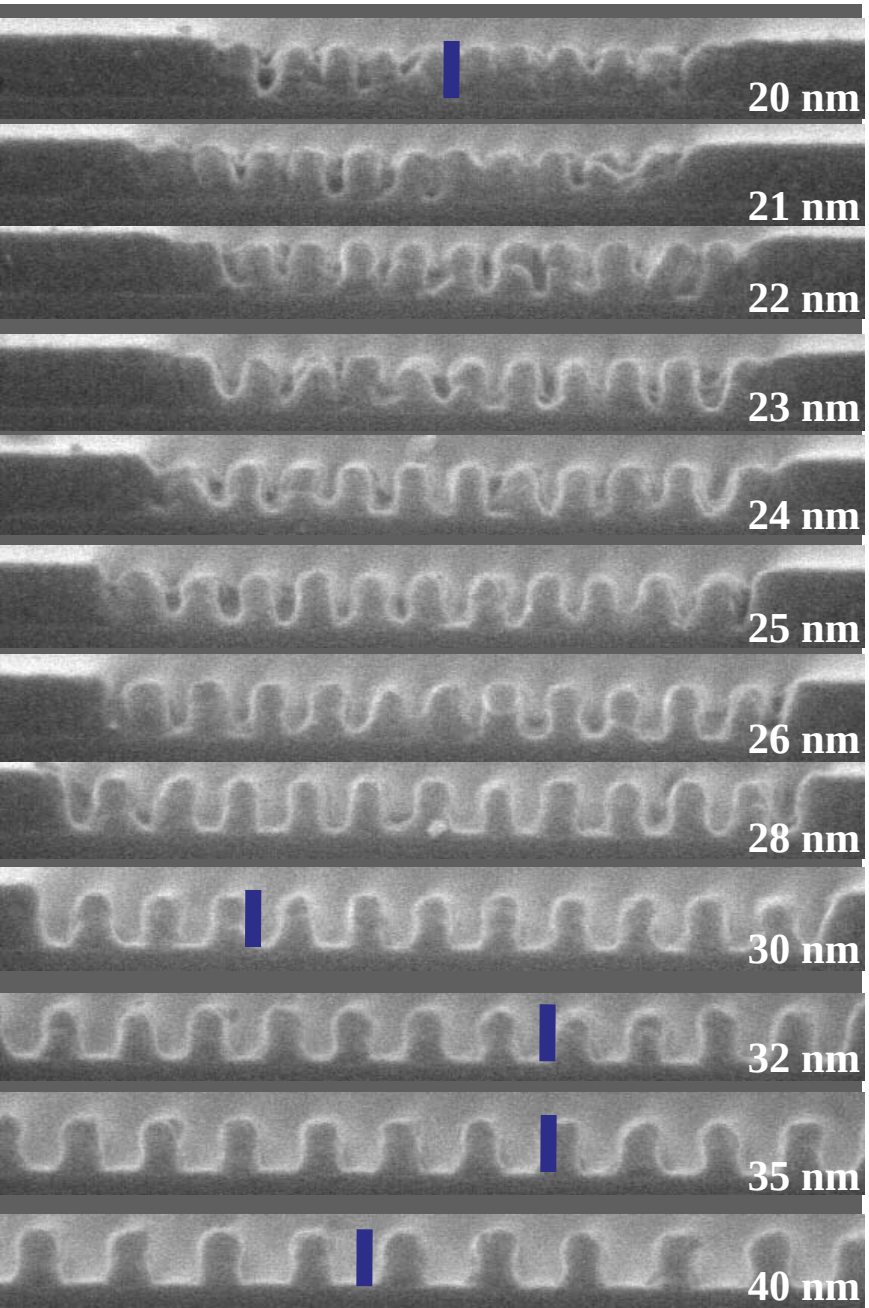
Cross-sectional view of SSR5 at 8 mJ cm^{-2}

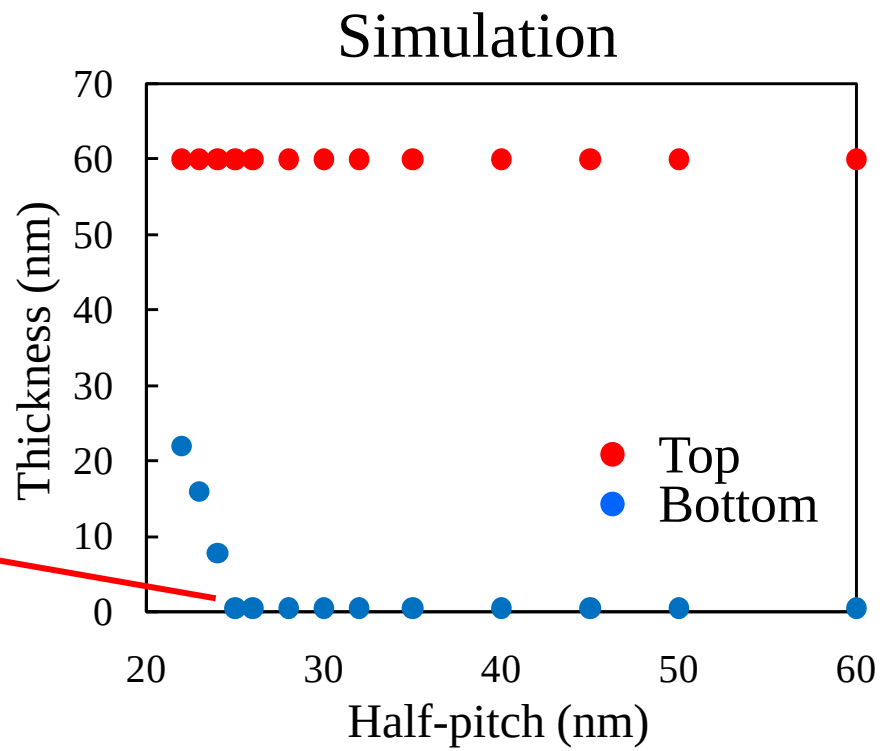


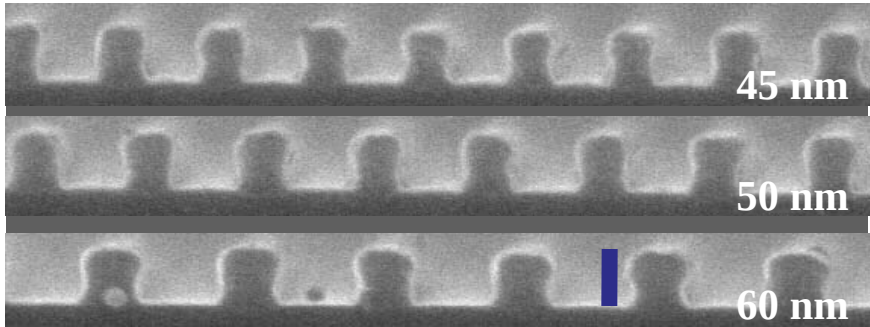




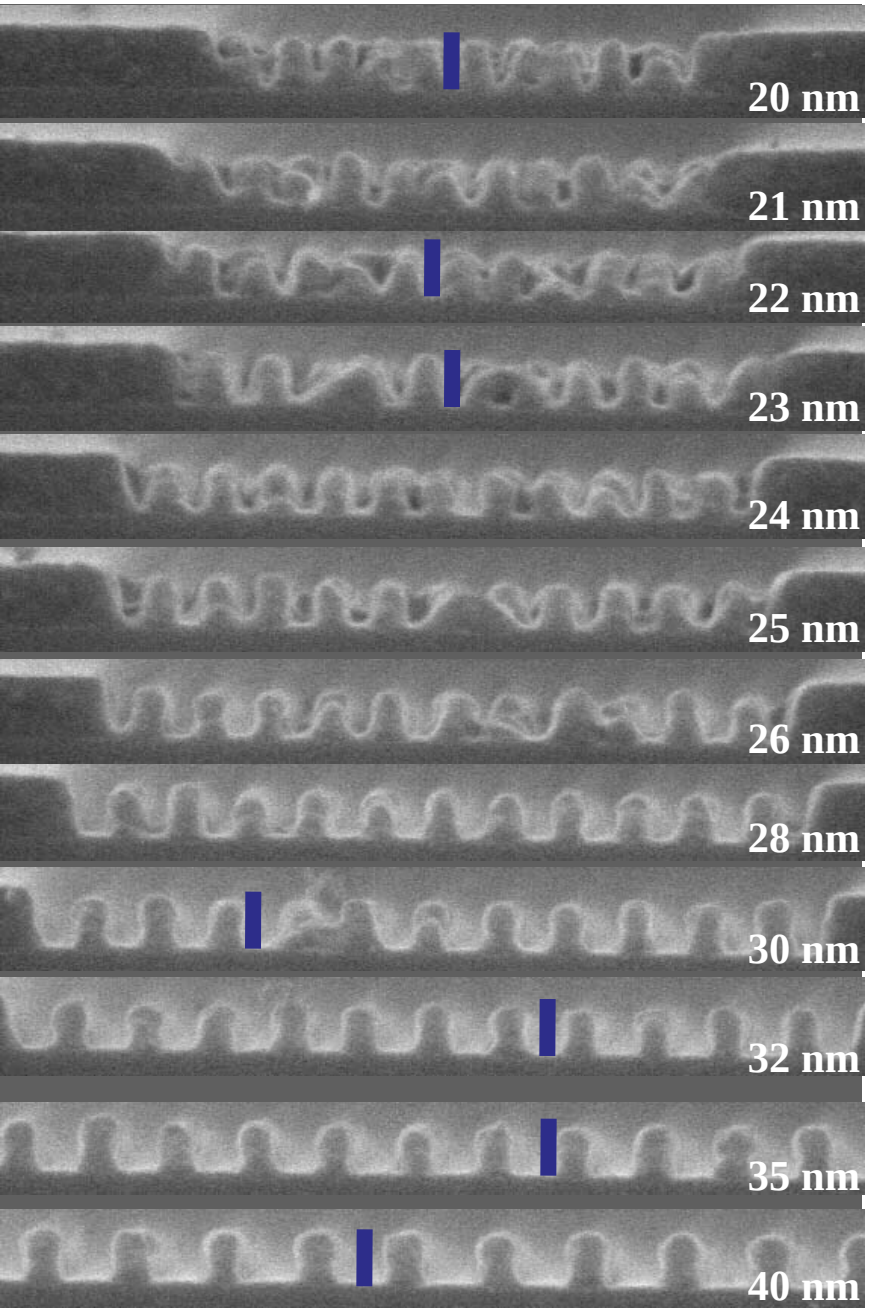
Cross-sectional view of SSR5 at 10 mJ cm^{-2}

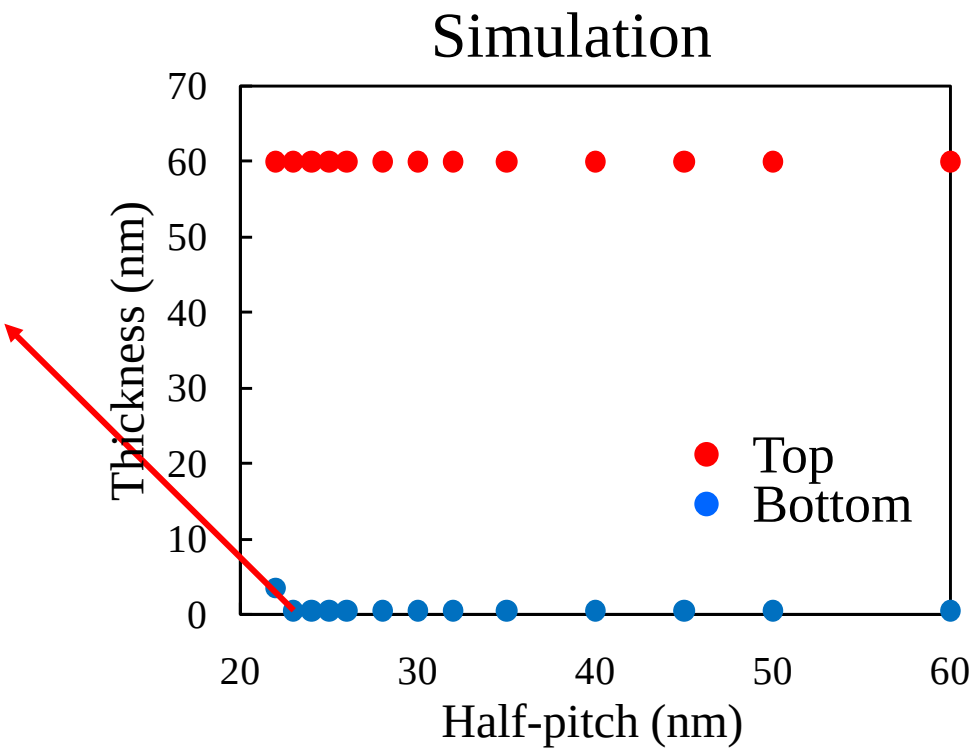


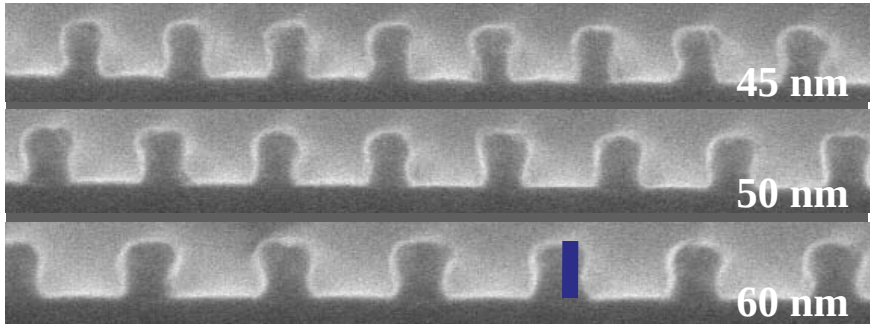




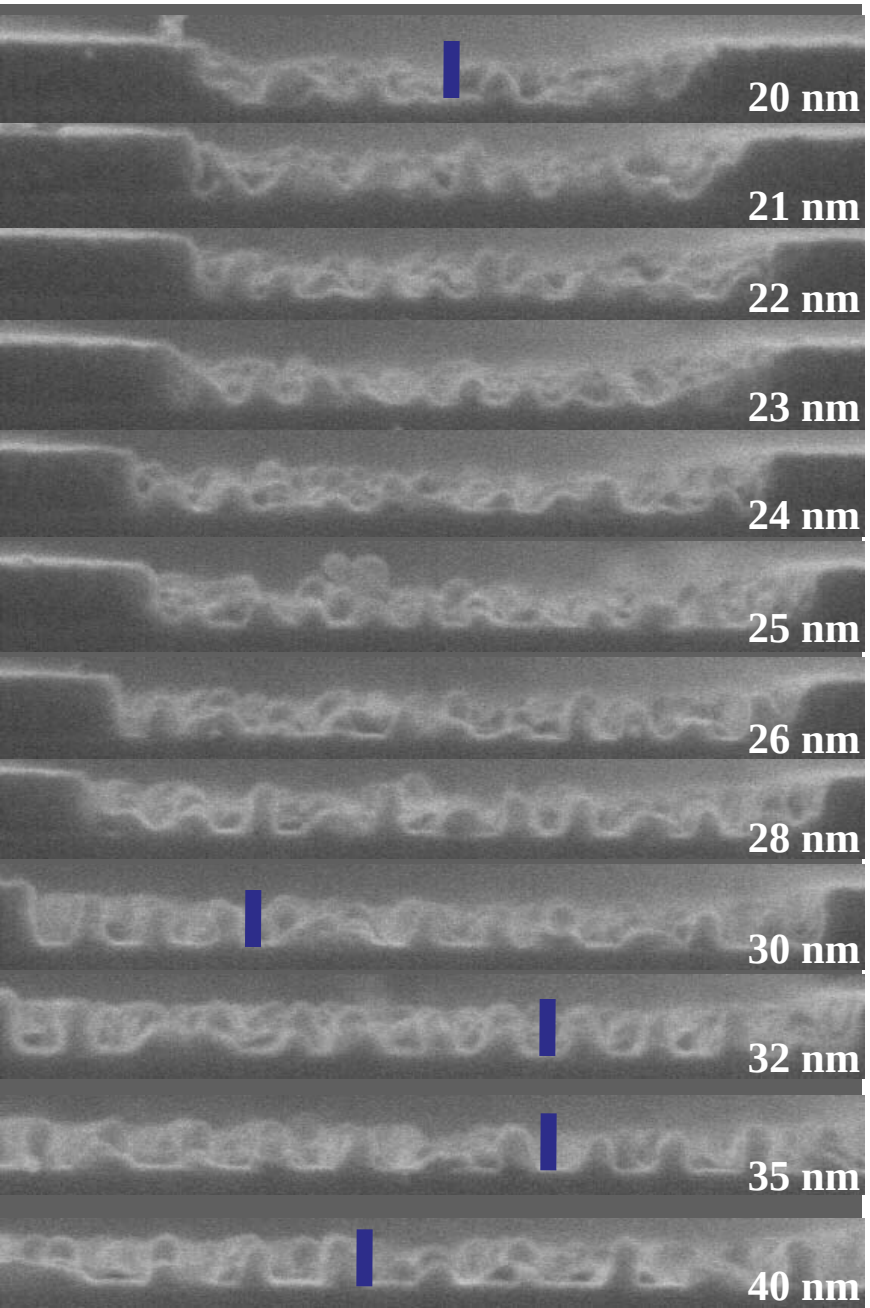
Cross-sectional view of SSR5 at 11 mJ cm^{-2}

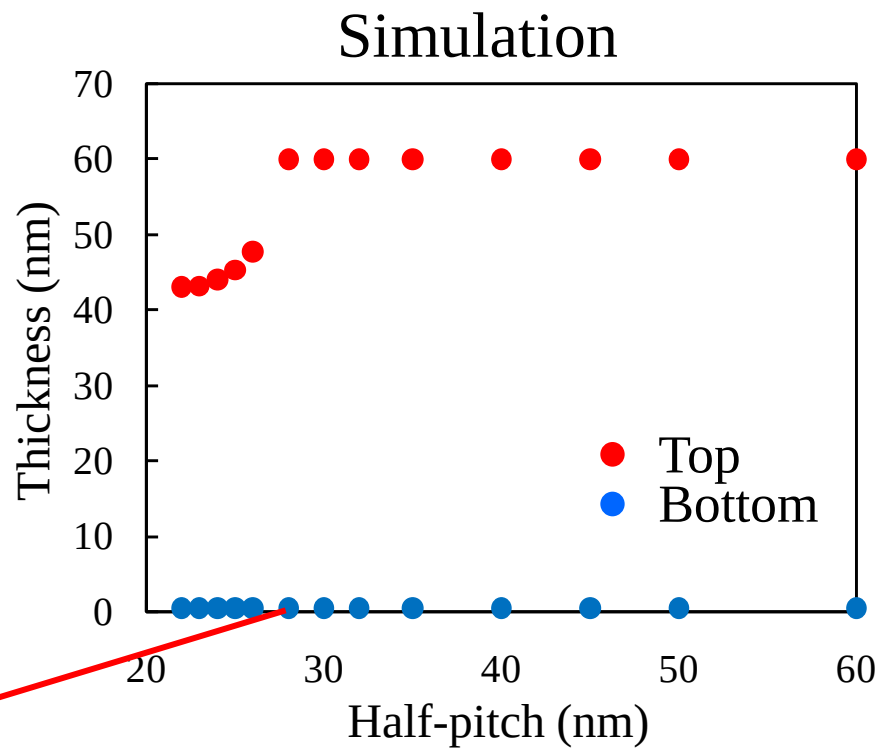


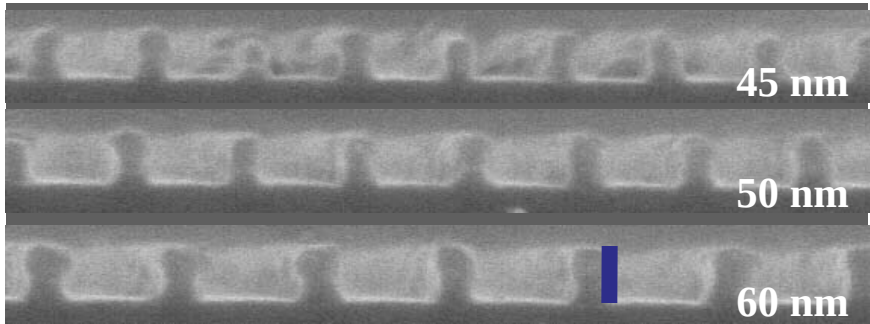




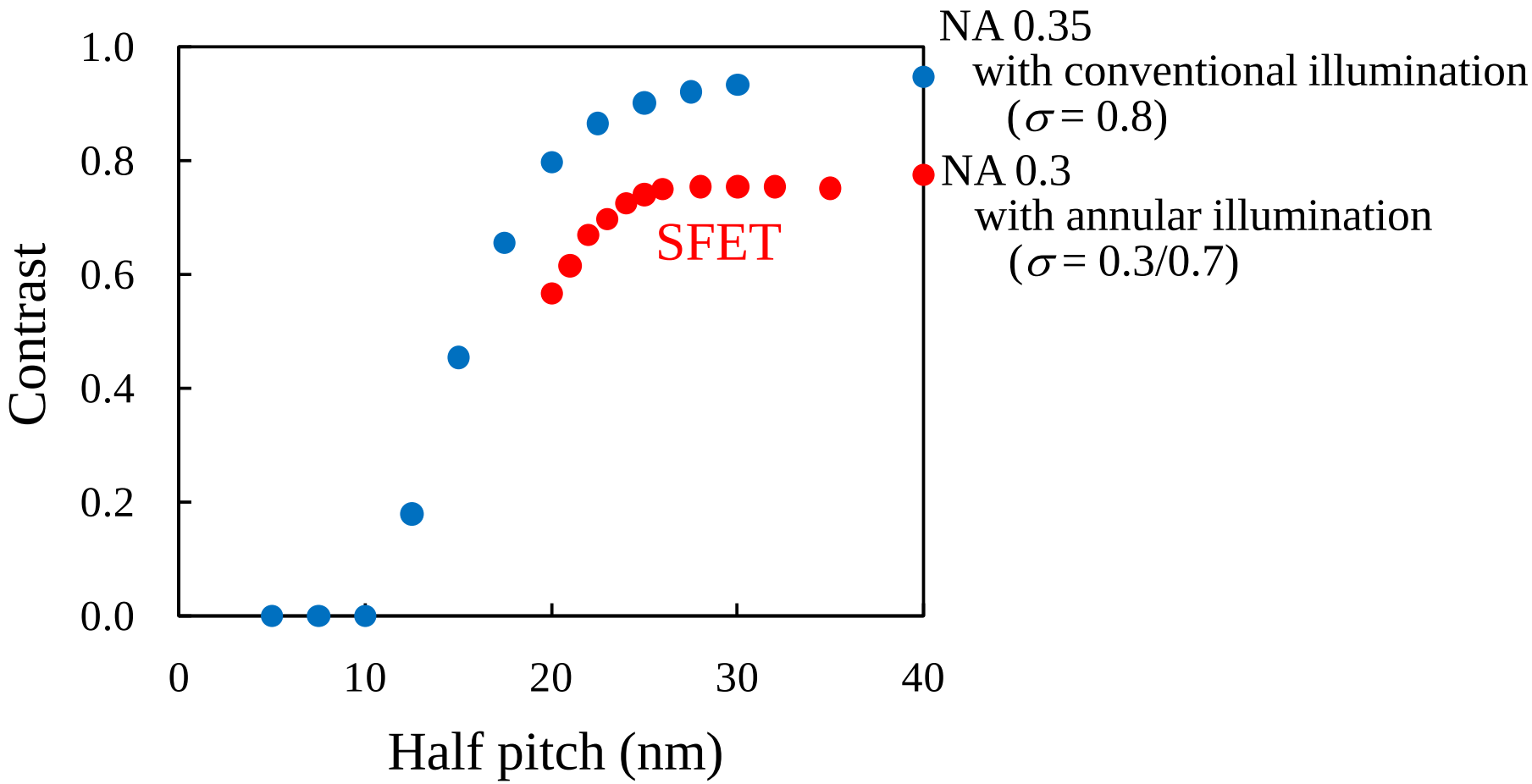
Cross-sectional view of SSR5 at 12 mJ cm^{-2}





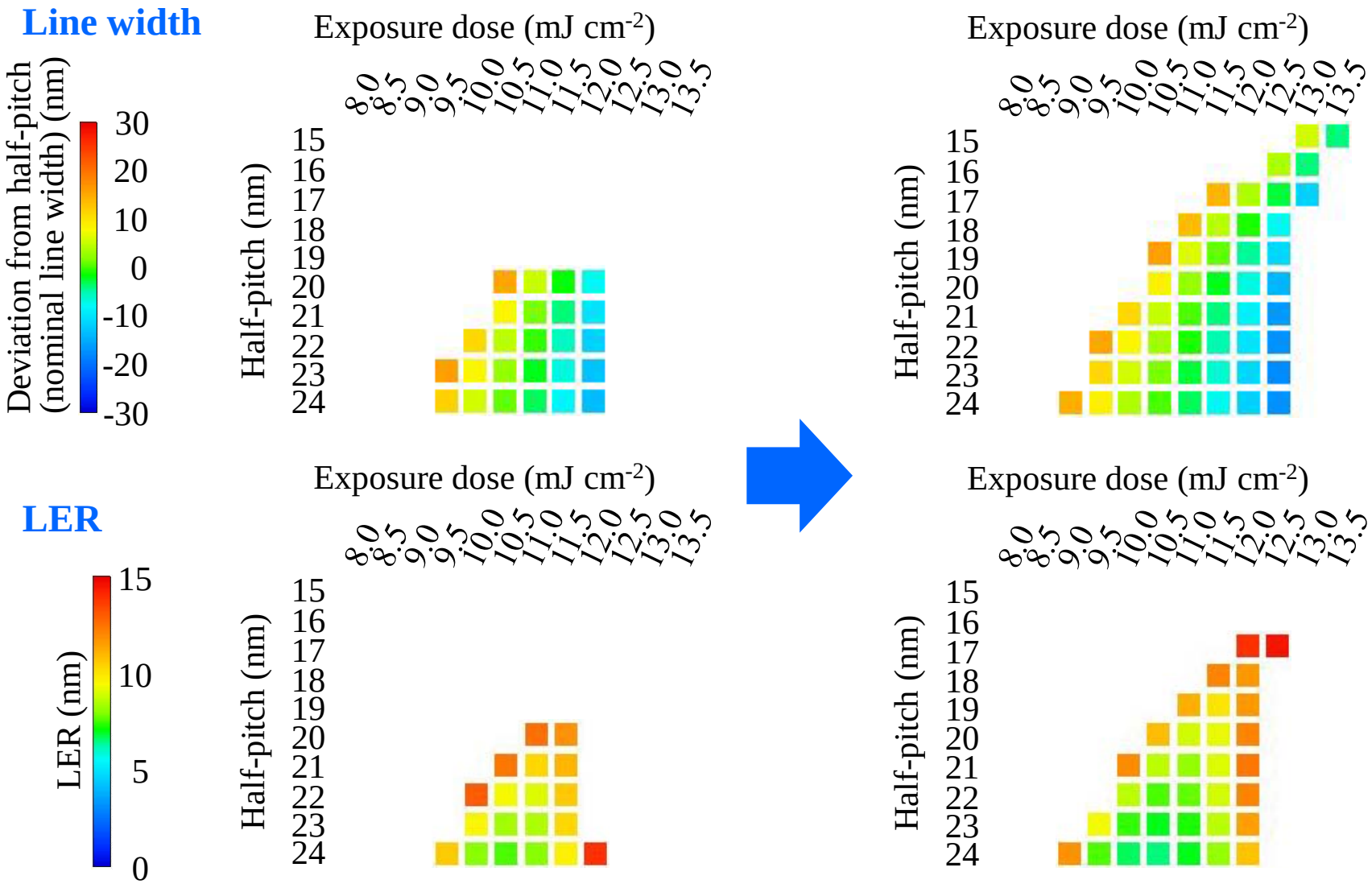


High NA exposure toll



Resist performance upon exposure using a high NA tool.

Resist performance (SSR5) upon exposure using a high NA tool



(a) SFET

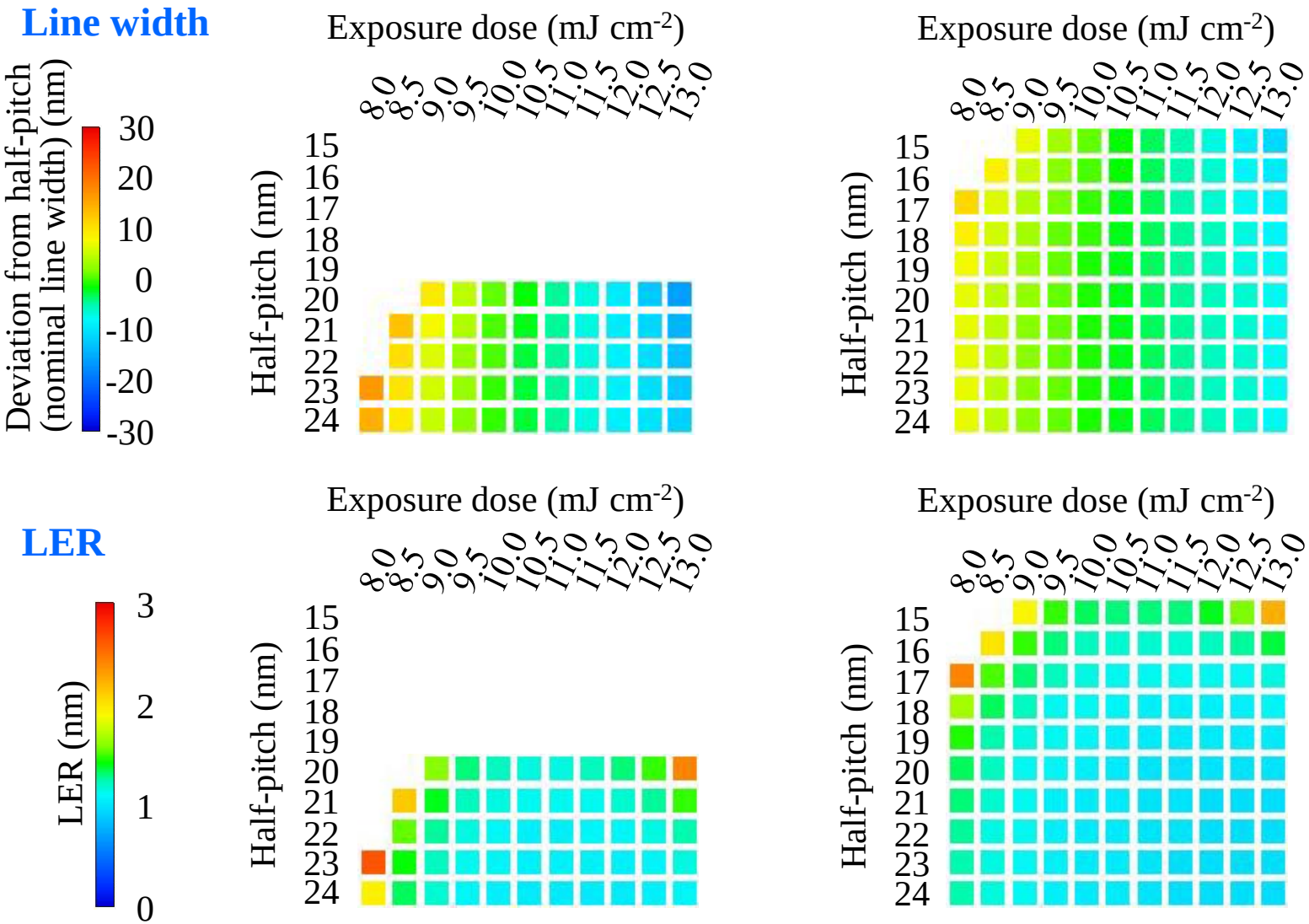
(b) High NA

Extendibility of chemically amplified resist

	Current status	Technical limit	Physical limit
Absorption coefficient (μm^{-1})	**~4**	**10**	**~16** (with ultrathin resist process)
Quantum efficiency	**~2.4**	**4**	**~6**
Effective reaction radius (nm)	**~0.1**	**0.5**	**~0.5** (maybe more)
Dissolution point	Optimized at 10 mJ cm^{-2} and 16 nm HP*		
Quencher concentration	Optimized at 10 mJ cm^{-2} and 16 nm HP*		

**Optimum dissolution point and quencher concentration depend on sensitivity and half-pitch because of RLS trade-off relationship.*

Resist performance at technical limit



(a) SFET

(b) High NA

By increasing pattern formation efficiency, not only LER but also exposure latitude and linearity were significantly improved.

Summary

1. By improving the resist modeling, the accuracy of parameter extraction was successfully reduced from ~20% to <10%.

2. The resist performance of current EUV resists upon exposure to a high NA tool (NA 0.35) was estimated. LER is away from the requirement.

3. Assuming the technical limit of the parameters associated with pattern formation efficiency, the extendibility of chemically amplified resists was examined. The resist requirements for 16 nm are achievable at NA=0.35, but comparable to the technical limit.

Acknowledgement

Dr . Hiroshi Chiba and Dr. Takuro Ono of Nikon Corporation for the calculation of optical images