Theoretical study on stochastic effects in chemically amplified resist process for extreme ultraviolet lithography

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Outline

- Background / Purpose of this work
- Advanced resist characterization
  - Stochastic defect generation and LER
  - Summary
- Material design for 16 and 11 nm node
  - What is the problem?
  - Basic strategy
  - Effect of molecular weight
  - Effect of protection ratio
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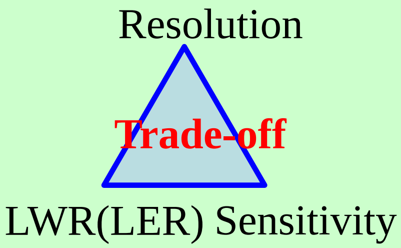
Background



Resolution

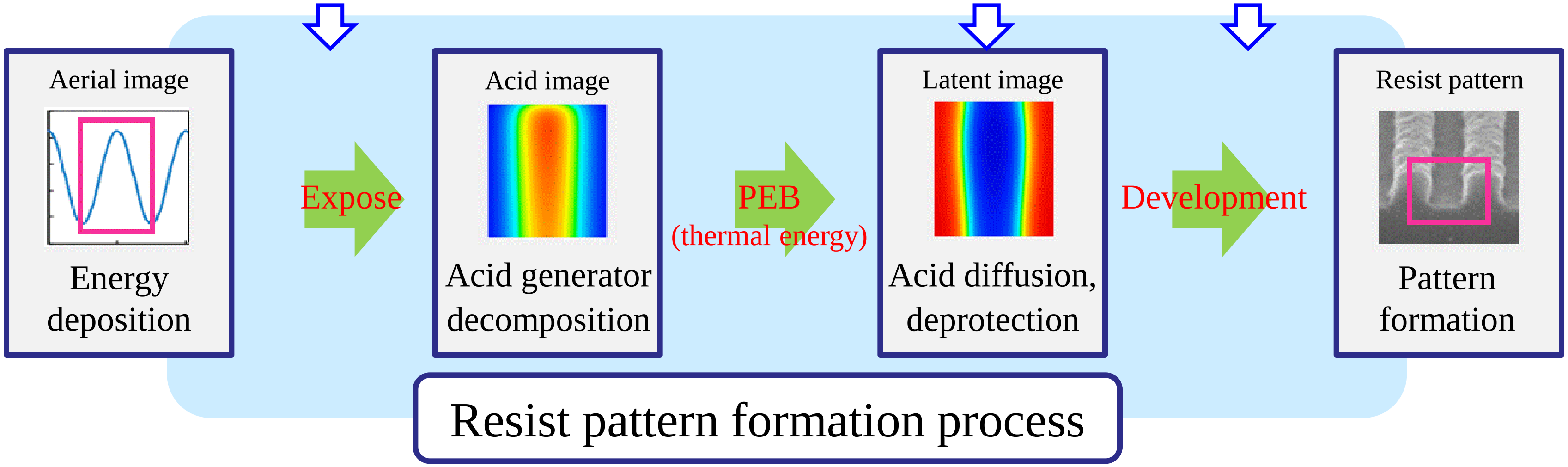
Trade-off

LWR(LER) Sensitivity

Trade-off relationship

Resist RLS trade-off will remain an issue in future <11nm nodes.

Establishment of scientific foundation and technology for resist evaluation



Interaction:
Photon / electron and matter

Chemical reaction:
Solubility change

Molecule
Dissolution

Aerial image
Energy deposition

Expose

Acid image
Acid generator decomposition

PEB
(thermal energy)

Latent image
Acid diffusion, deprotection

Development

Resist pattern
Pattern formation

Resist pattern formation process

Purpose of this work

Need for scientific foundation and technology for resist evaluation:

- Establish resist characterization technology
- Obtain material design pointers for 16 and 11 nm node

⇩

- Deeper understanding of fundamental resist characteristics.
- Feedback to EUV resist material and process development.

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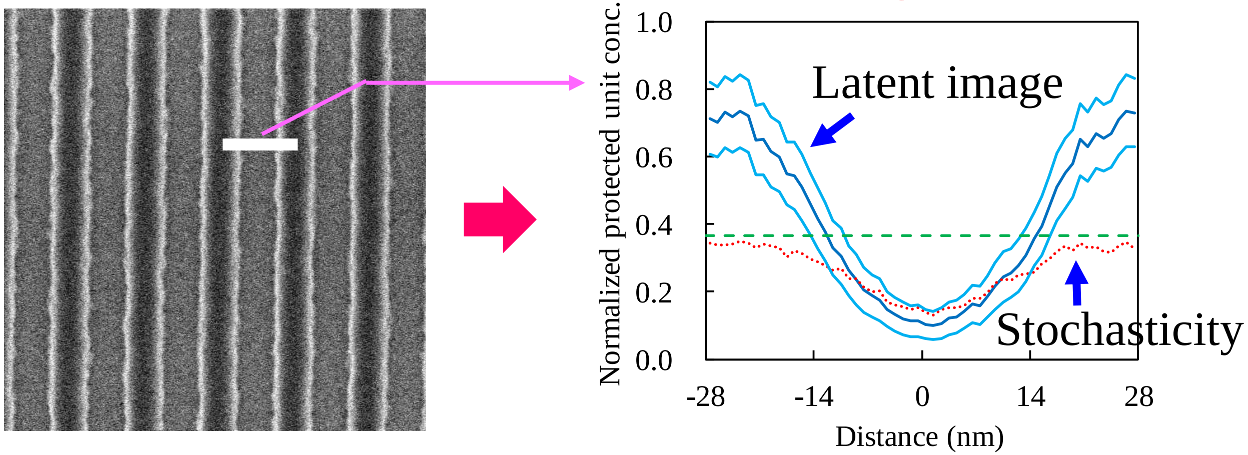
Resist characterization

Reconstruction of chemical image



Conventional characterization

SEM image

Resolution
Line edge roughness
Sensitivity
Exposure latitude

Information

Inadequate for material design for 11 nm node

+

Advanced characterization

Latent image & stochasticity

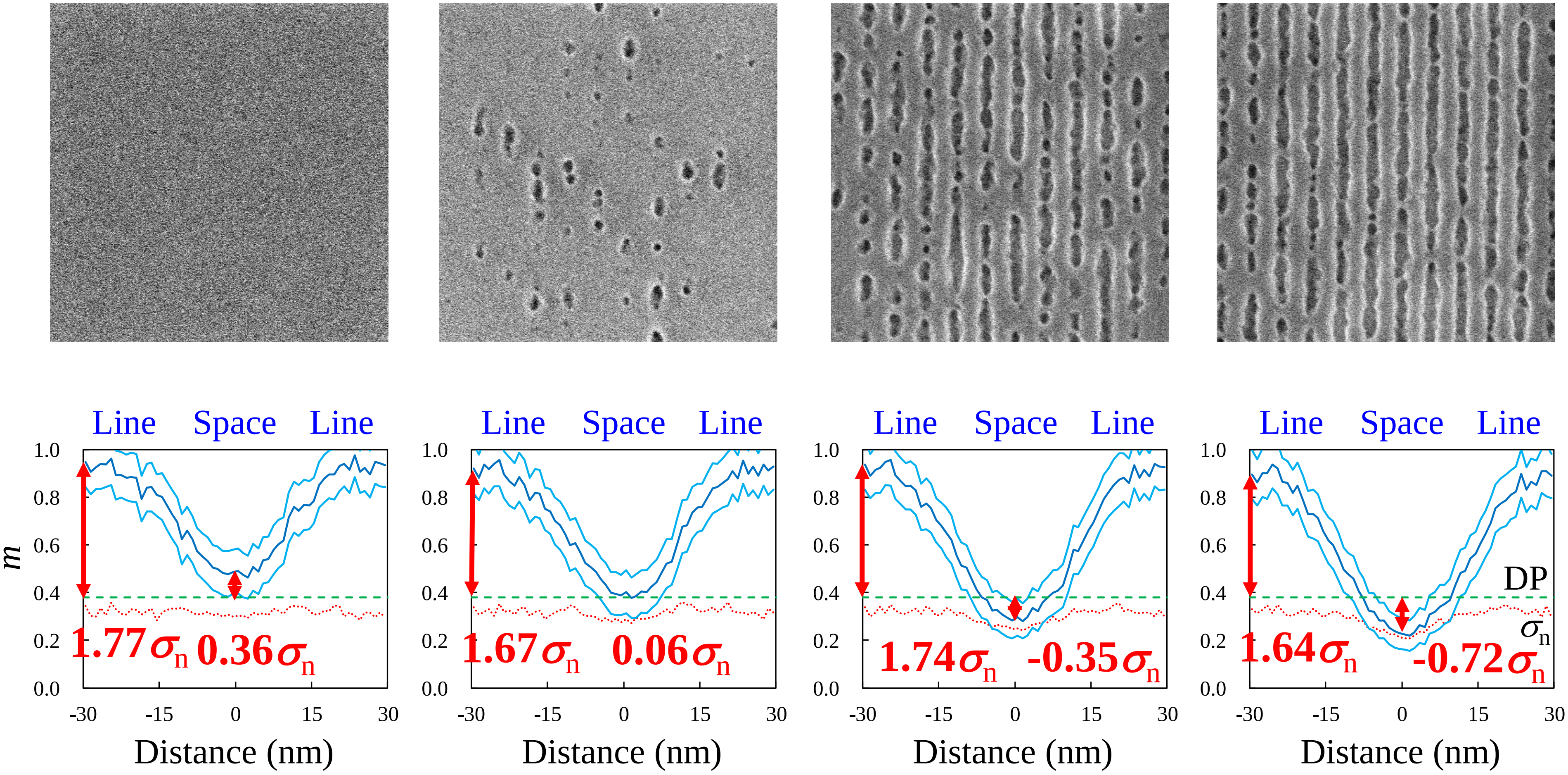
Absorption coefficient
Quantum efficiency
Effective reaction radius
Dissolution point
Dissolution efficiency

Information

Extraction of chemical information from SEM images is essential to efficient resist development.

New resist characterization technology (2012)
& Material design for 16 and 11 nm node (2013)

Relationship between stochastic effects and protected unit fluctuation



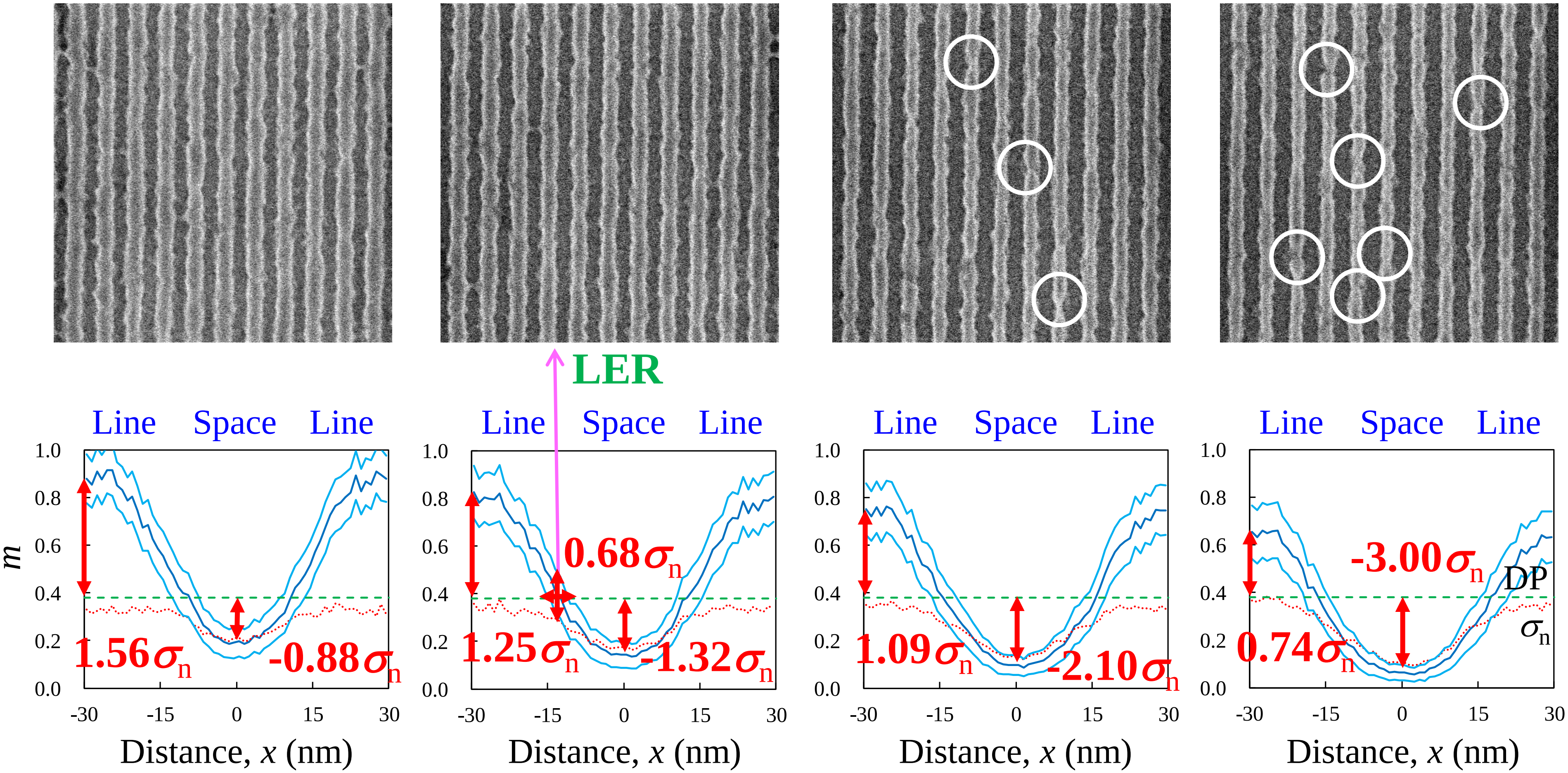
10 mJ cm^{-2} **11 mJ cm^{-2}** **12 mJ cm^{-2}** **13 mJ cm^{-2}**

No image **Space started to appear.** **Bridges**

m is the normalized protected unit concentration.

σ_n is the normalized standard deviation of the number of protected units connected to a polymer molecule.

Relationship between stochastic effects and protected unit fluctuation



14 mJ cm^{-2}

15 mJ cm^{-2}

16 mJ cm^{-2}

17 mJ cm^{-2}

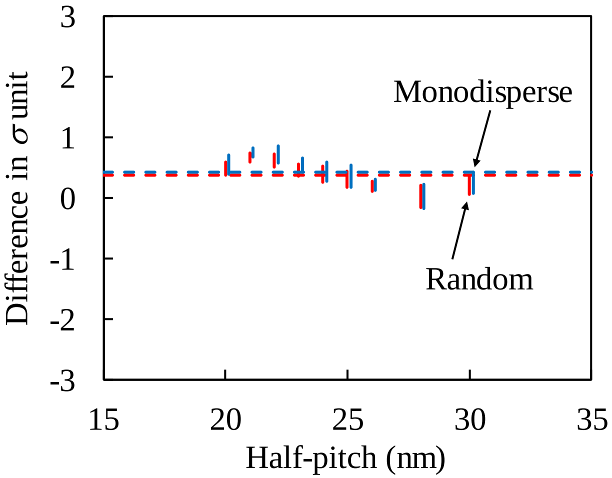
$$LER = \frac{0.68\sigma_n}{dm/dx}$$

Pinching started to appear.

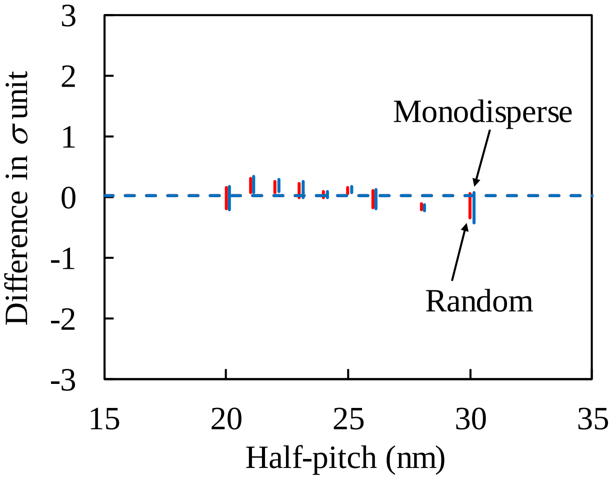
Bridges were eliminated.

Relationship between protected unit fluctuation and pattern defects

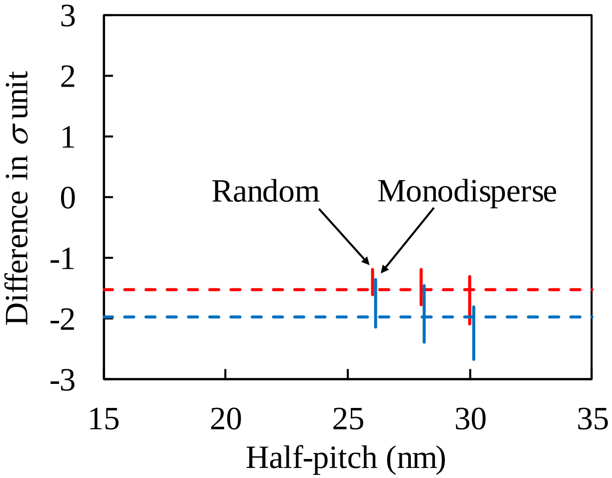
Space



Start of dissociation

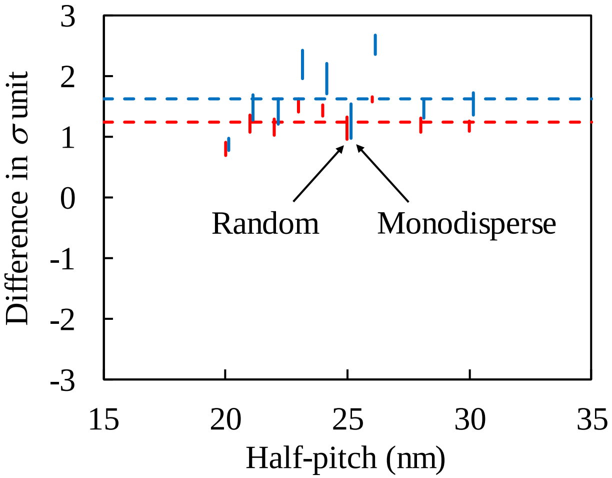


Half open

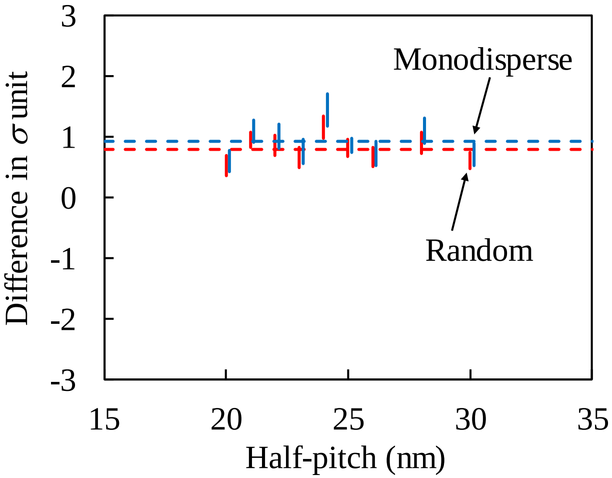


Elimination of bridge

Line



Start of pinching



Start of disconnection

Definition of
“Difference in σ unit”

$$(m\text{-}m_{\mathrm{DP}})/\sigma_{\mathrm{n}}$$

Difference between protected unit concentration and dissolution point

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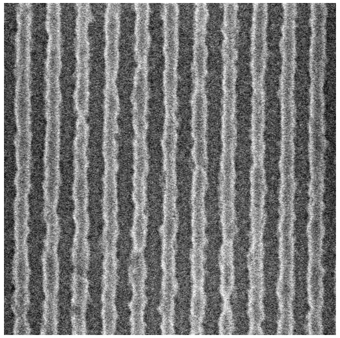
Advanced Resist Characterization



EIDEC
Standard
Resist

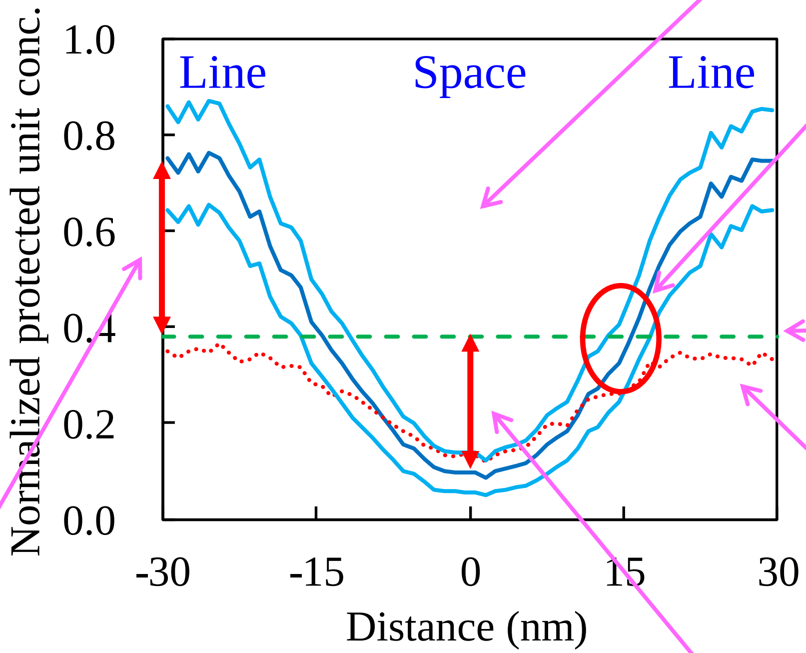
Latent image was successfully reconstructed from SEM image using a Monte Carlo simulation.

Chemical information was also obtained.

The acid diffusion length was approximately 10 nm in the high resolution region.

±0.31-±0.37 σ_n fluctuation of protected units contributed to LER formation.

$$LER = \frac{0.68\sigma_n}{dm/dx}$$



The resolution dependence of dissolution point was estimated.

σ_n

The fluctuation of protected unit was estimated.

To eliminate pinching within 6.1 μm length, 1.2-1.6σ_n difference is required.

To eliminate bridges within 6.8 μm length, 1.5-2.0σ_n difference is required.

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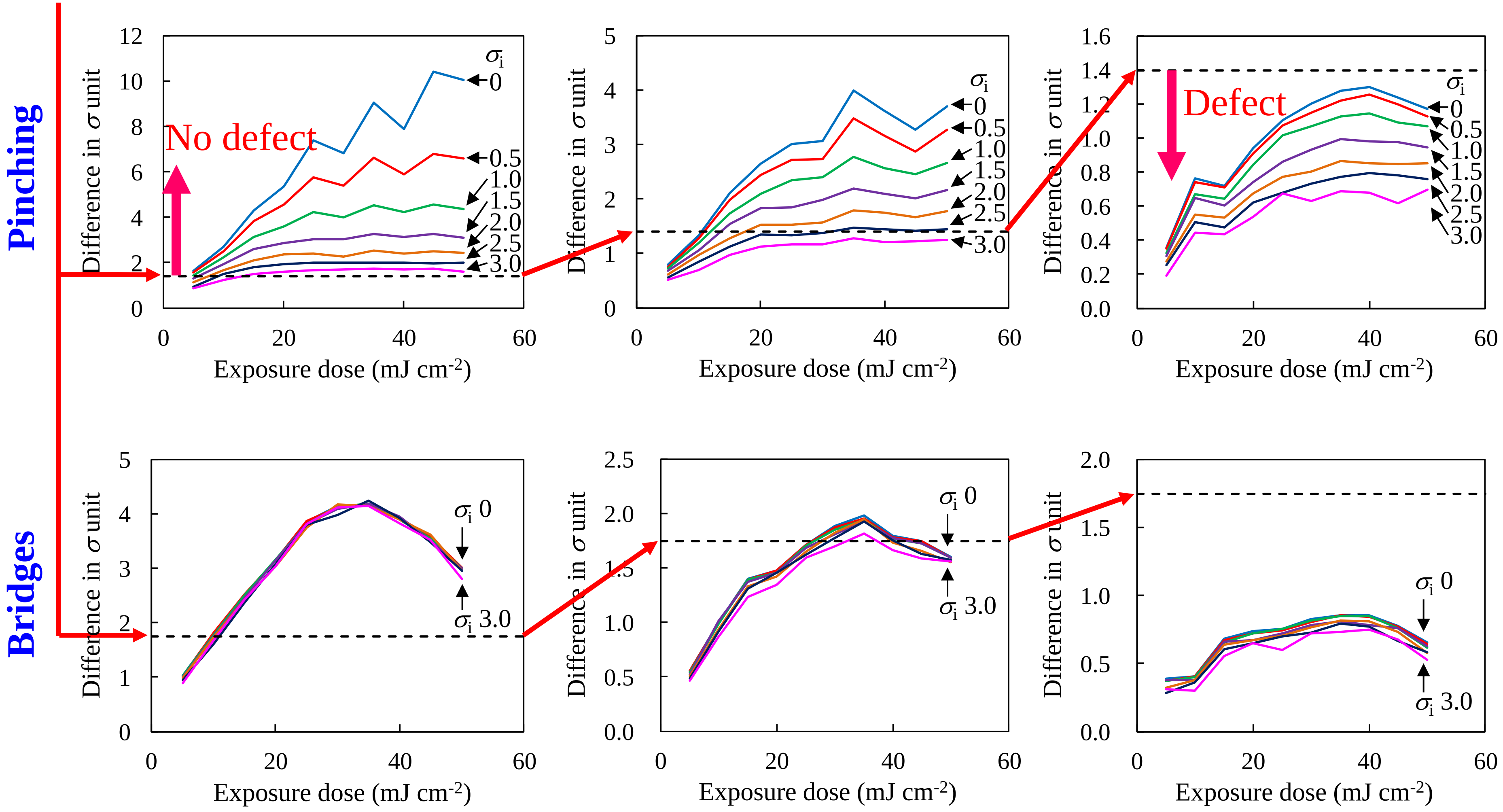
Half pitch dependence of stochastic defect generation

Threshold for the elimination of stochastic defect generation in “a SEM image”



22 nm HP

16 nm HP

11 nm HP

Probability for stochastic defect generation rapidly increased with the reduction of half-pitch.

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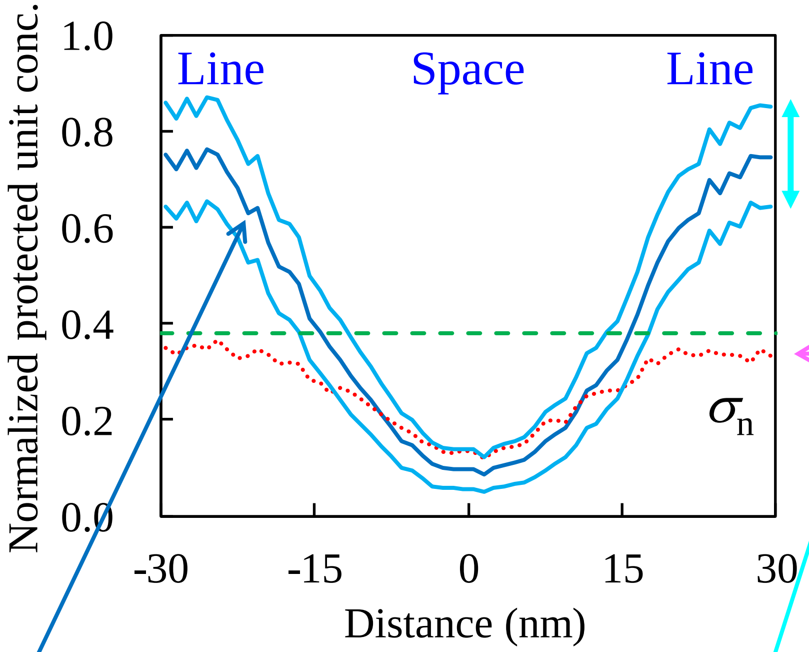
Basic strategy of material design for 11 nm node

The suppression of stochastic effects (LER and stochastic defect generation) is an urgent task for the realization of 11 nm fabrication.



Decrease of dissolution factor

Decrease of protected unit fluctuation

Increase of chemical contrast

$$LER = \frac{0.68\sigma_n}{dm/dx}$$

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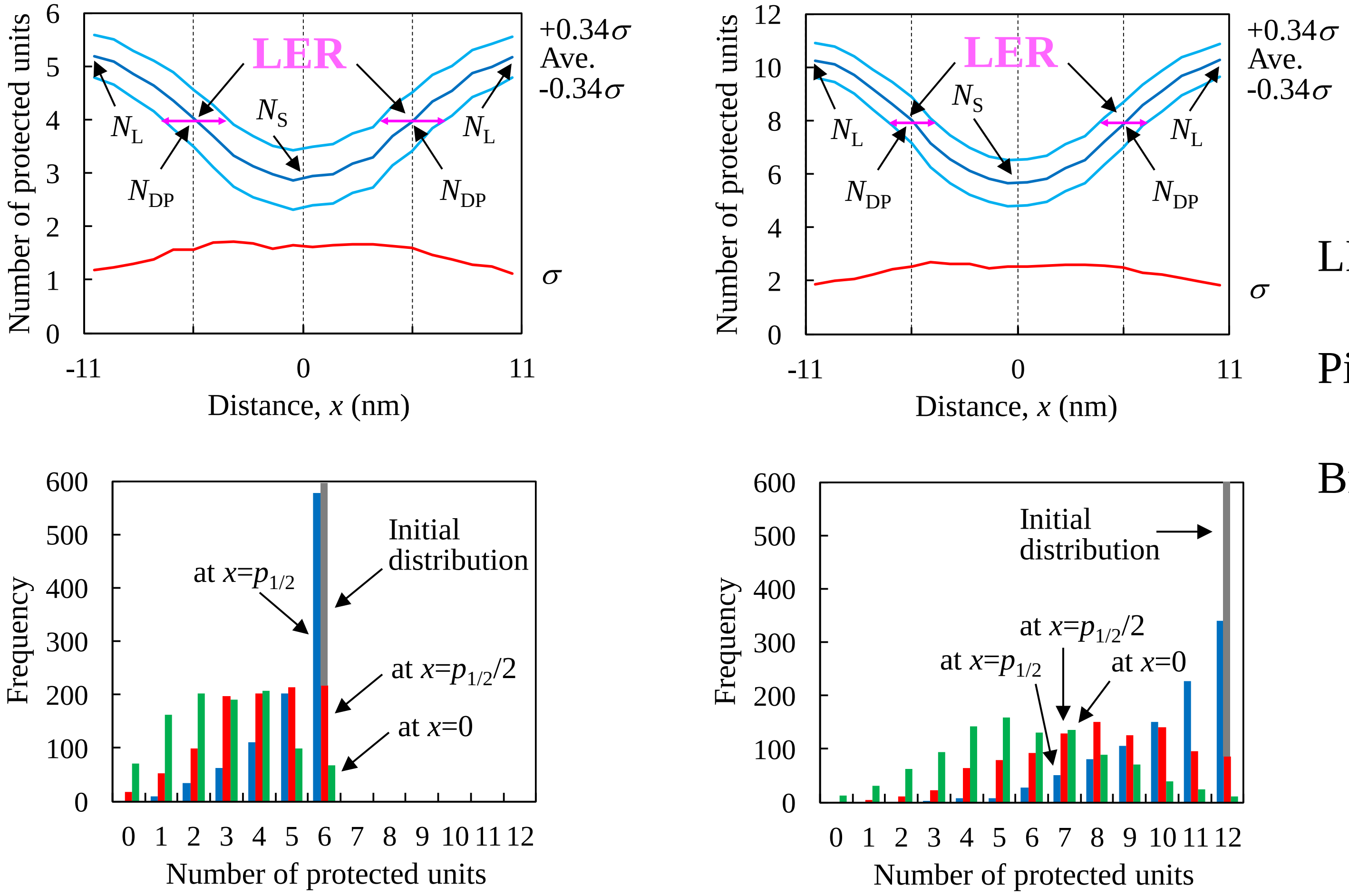
Effect of molecular weight



Mw 2400

Mw 4800

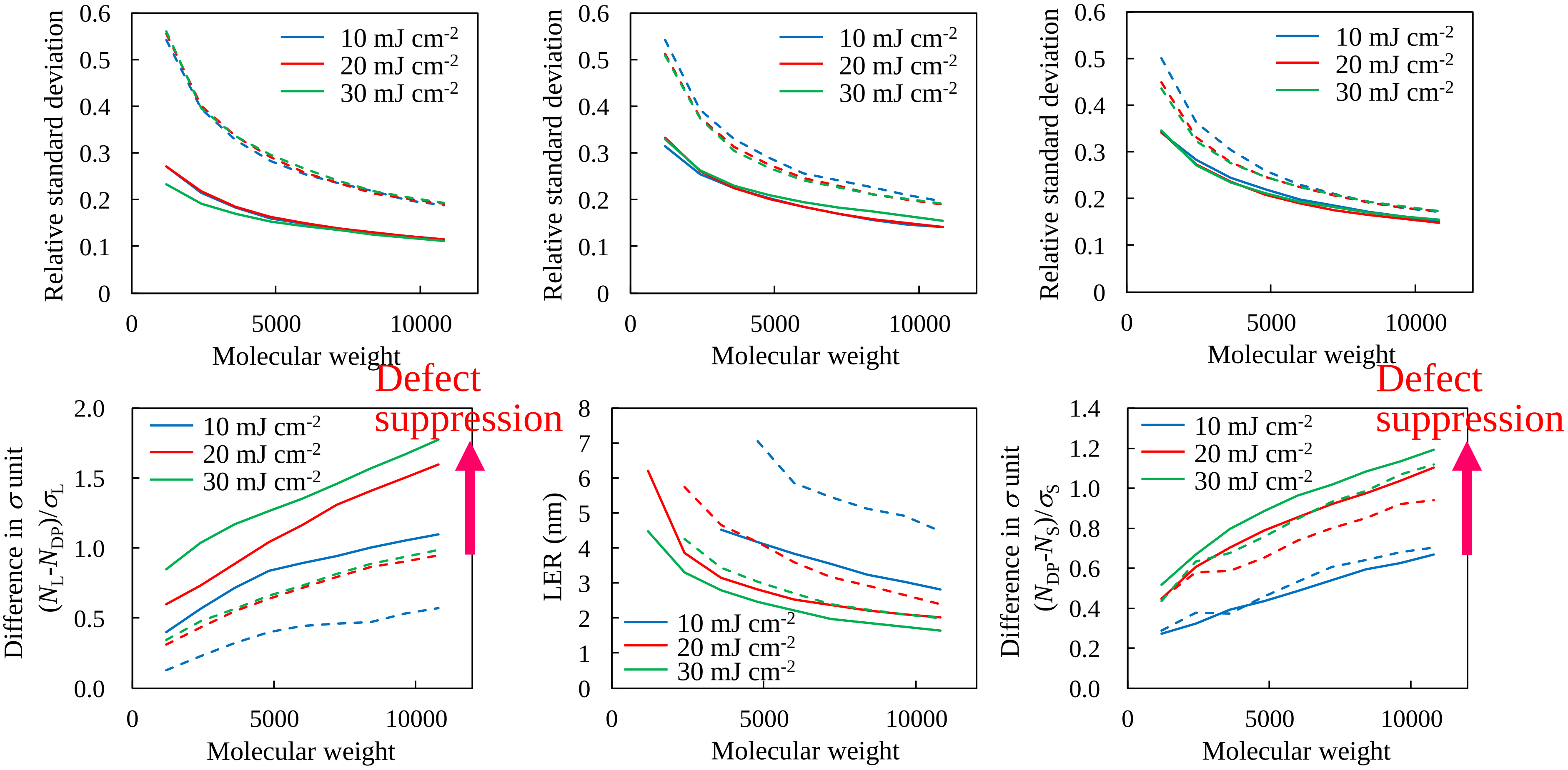
LER
Shift of latent image

Pinching
$(N_L\text{-}N_{DP})/\sigma_L$

Bridge
$(N_{DP}\text{-}N_S)/\sigma_S$

Fig. Latent images of 11 nm line-and-space pattern and standard deviation of the number of protected units connected to a polymer molecule and histograms of the number of protected units at $x=\pm p_{1/2}$, $\pm p_{1/2}/2$, and 0. The protection ratio was 30%. N_L, N_S, and N_{DP} represent the average number of protected units connected to a polymer molecule at $x=\pm p_{1/2}$, 0, and $\pm p_{1/2}/2$, respectively. The exposure dose was 30 mJ cm^{-2}.

Relationship between molecular weight and stochastic effects



at center resist lines

Pinching

at boundaries

LER

at center of spaces

Bridges

The increase of molecular weight is effective for the suppression of stochastic effects.

- The increase of minimum dissolution unit
- The increase of the probability for the polymer aggregation

$$LER = \frac{0.68\sigma_n}{dm/dx}$$

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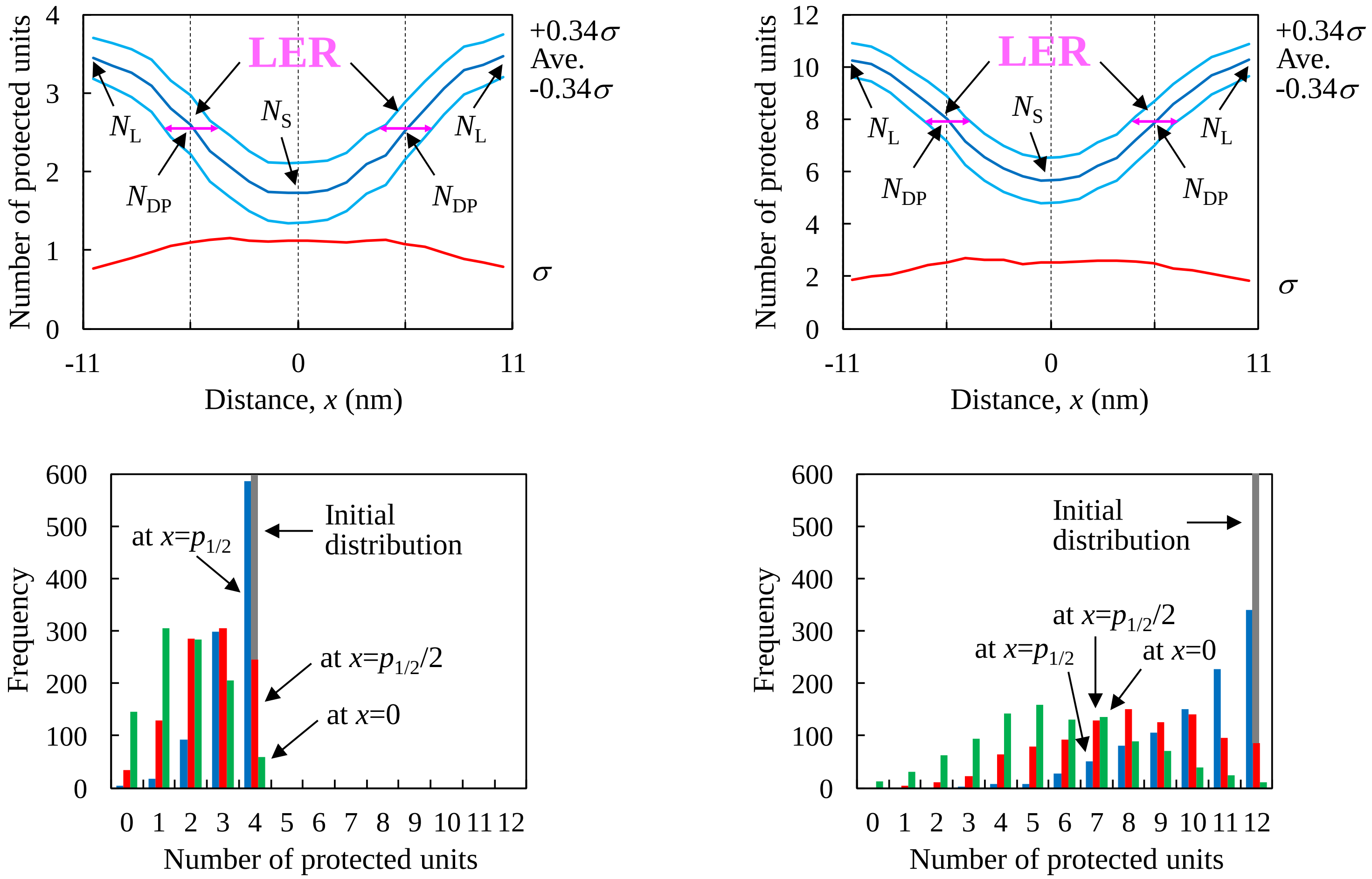
Effect of protection ratio

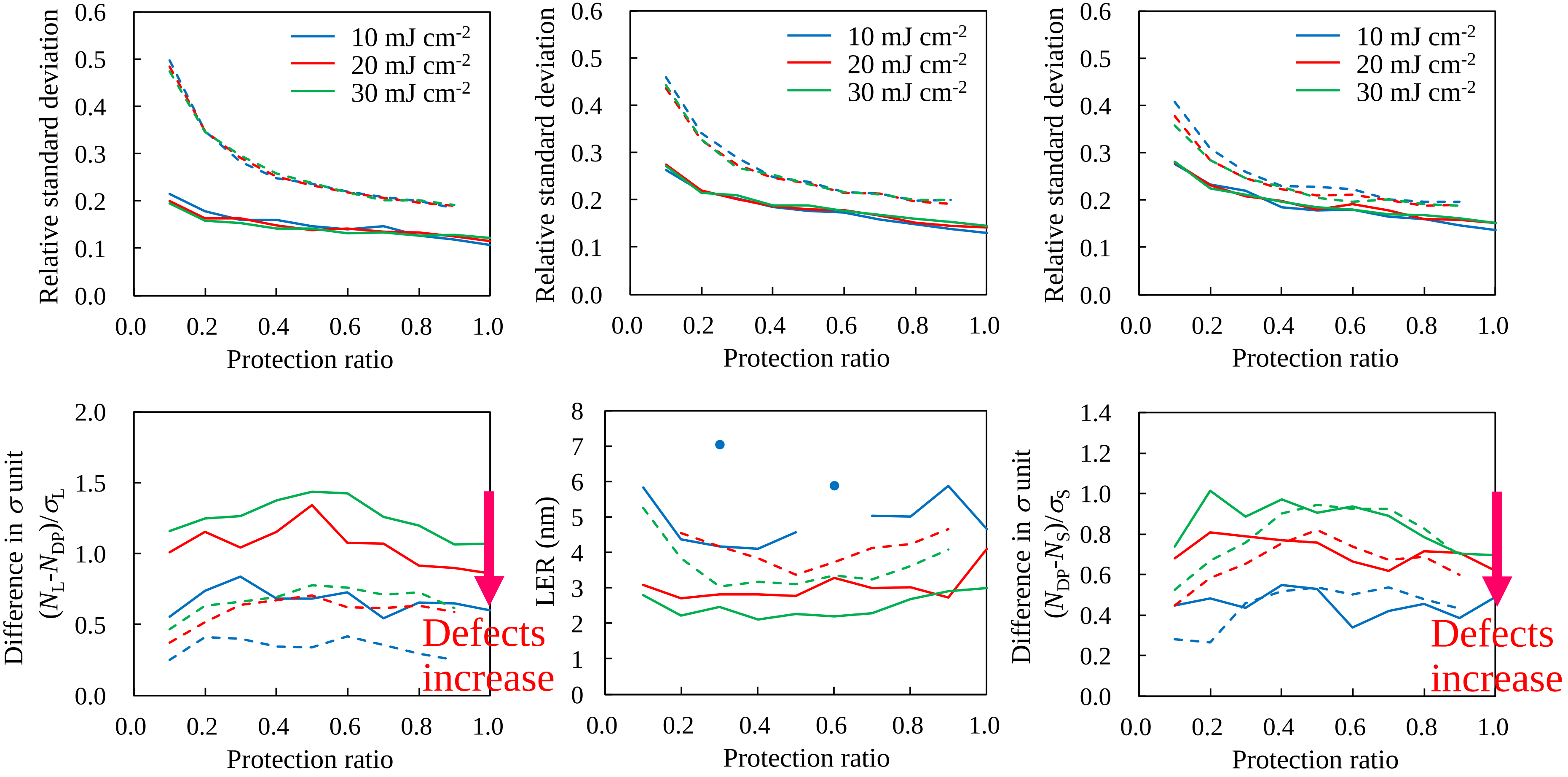


Protection ratio 10%

Protection ratio 30%

Fig. Latent image of 11 nm line-and-space pattern and standard deviation of the number of protected units connected to a polymer molecule and histograms of the number of protected units at $x=\pm p_{1/2}$, $\pm p_{1/2}/2$, and 0. The molecular weight was **4800**. The exposure dose was 30 mJ cm^{-2}.

Relationship between protection ratio and stochastic effects



at center of resist lines

Pinching

at boundaries

LER

at center of spaces

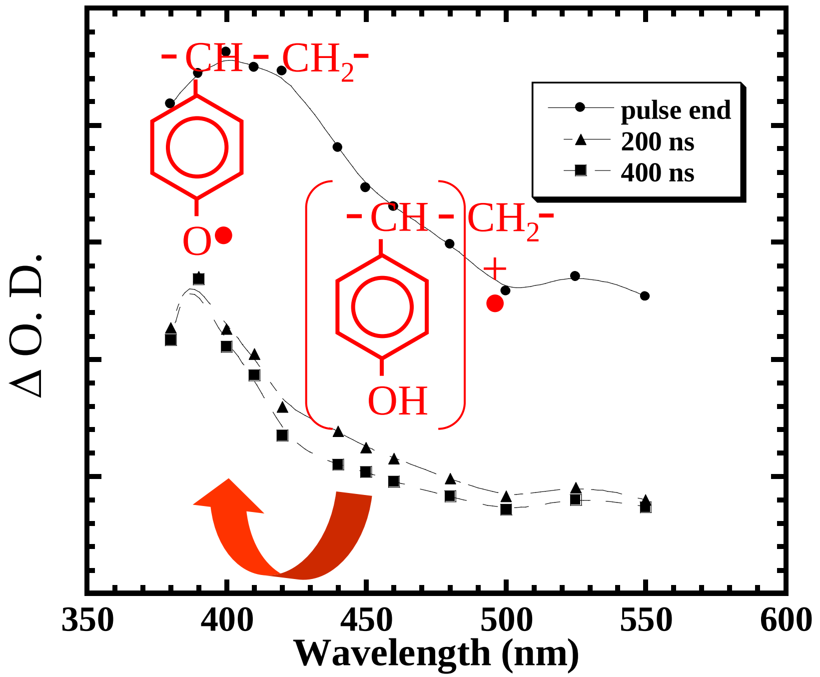
Bridges

The relative standard deviation was decreased with the increase of protection ratio.

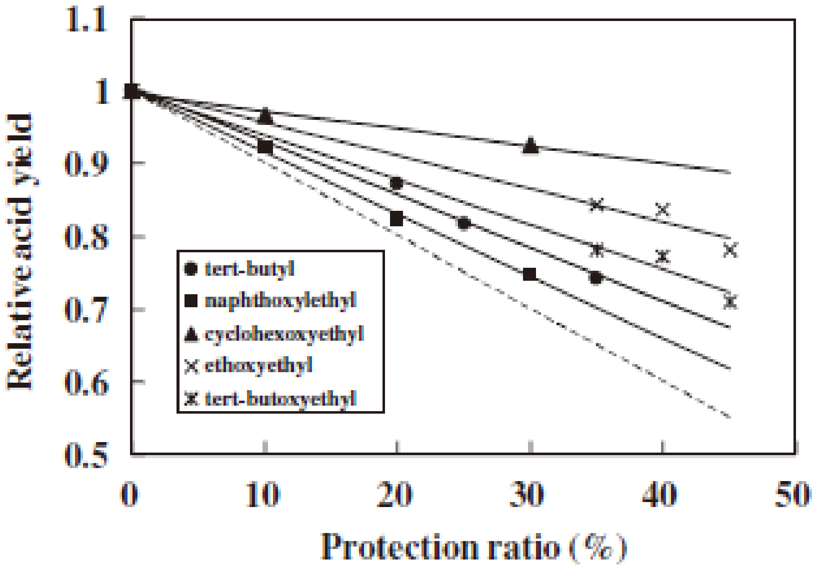
⇕

Optimum protection ratio was 40-60% in terms of the suppression of stochastic effect.
Why was the stochastic effects increased at the high protection ratio region?

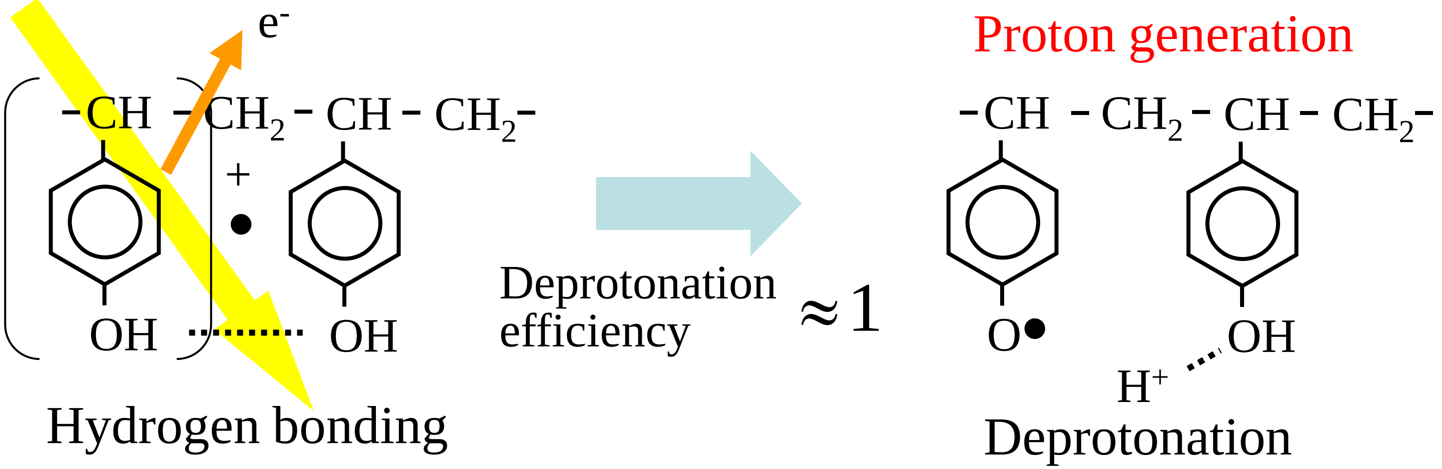
Decrease of quantum efficiency due to protection of proton source



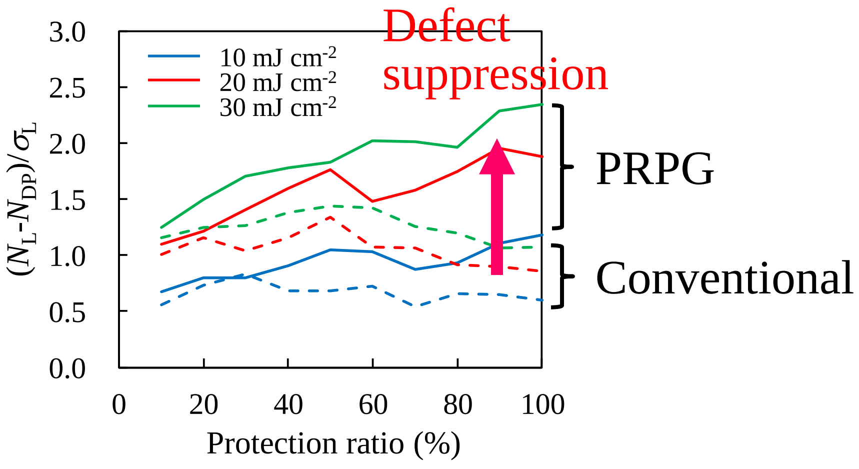
Transient absorption spectra of PHS radical cation and phenoxyl radical



Relationship between acid yield and protection ratio

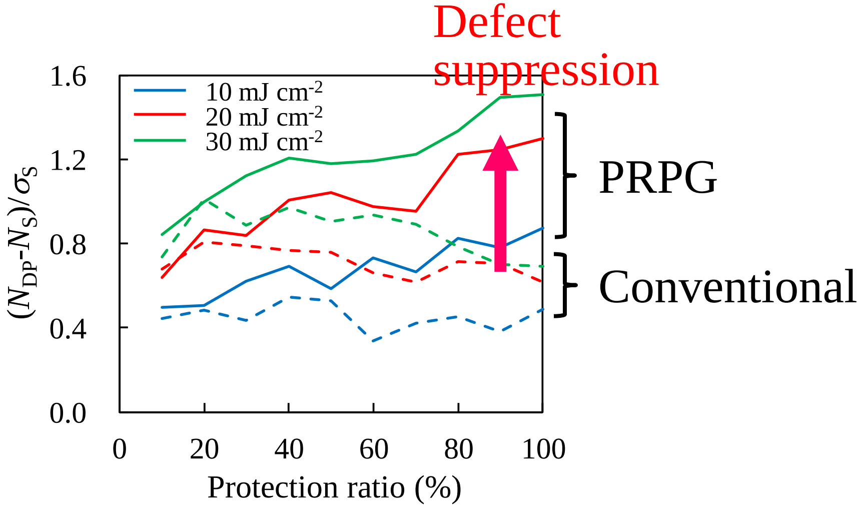


Proton release protecting group (PRPG)



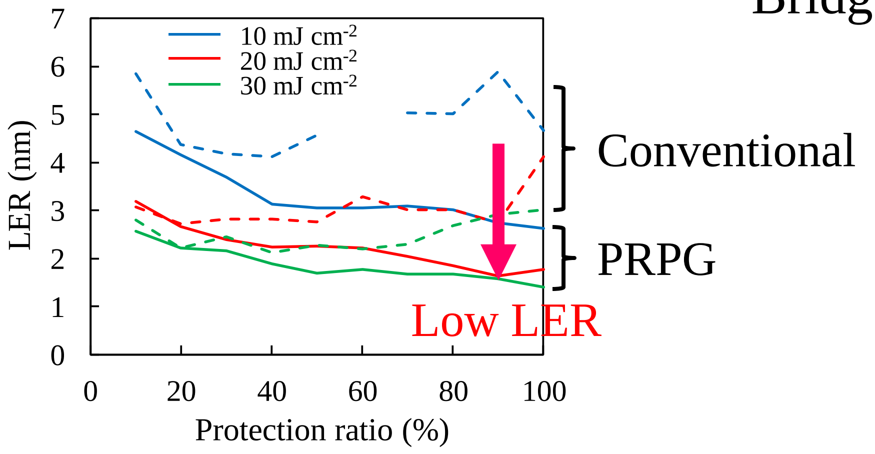
at center of resist lines

Pinching



at center of spaces

Bridges



at boundaries

LER

For the suppression of LER and the stochastic defect,
it is essential to increase the protection ratio without decreasing the quantum efficiency.

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Summary - Material design for 16 and 11 nm node -

①How many photons can be absorbed?

Absorption coefficient: ~4 /µm

②How many acids can be generated by a single photon?

Quantum efficiency: 2-3

③How many dissolution inhibitor (protecting group) can be removed by a single acid during the diffusion of unit length?

Effective reaction radius
- Activation energy for deprotection
- Activation energy for acid diffusion
  - Low-diffusion anion → Anion-bound resist
  - High T_g polymer

④How smoothly are the polymers dissolved in developer?

Relationship between LER and chemical gradient, f_{LER}
- Molecular size, protection ratio, dispersion
- Development, rinse

Resist design

$$LER = \frac{0.68\sigma_n}{dm/dx} \leftarrow ①, ②, ③$$

	DUV, VUV	EUV
AG	①, ②, ③	②, ③
Polymer	③, ④	①, ②, ③, ④

Advanced resist characterization is useful for evaluating these factors.

Acknowledgement

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