Fidelity of rectangular patterns printed with 0.3-NA MET optics

○Yuusuke Tanaka, Yukiko Kikuchi,
DooHoon Goo, and Iwao Nishiyama

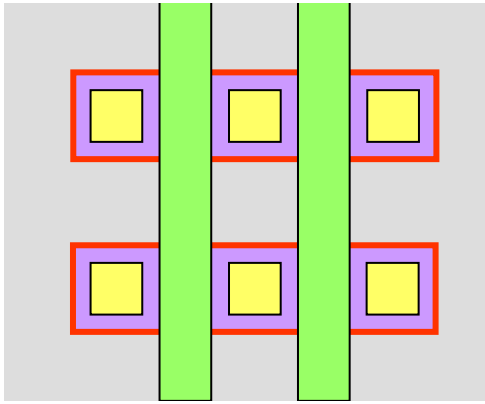
ASET EUV Process Technology Research Laboratory

E-mail: y-tanaka@aset-euv.jp

Background & Purpose

＜Background＞

- Rectangular patterns are necessary for the isolation layer and other layers of the ULSI fabrication process.
- In optical lithography, fine rectangular patterns tend to deform. This requires complex correction for mask patterns.



＜Purpose of this research＞

- To evaluate the pattern fidelity of the rectangular patterns printed with EUV lithography.
- To investigate the cause of the pattern deformation if the fidelity was not good.

Experimental Conditions

＜Mask＞

Reflective mask fabricated by DNP & ASET（5x, 6025）

＜Resist＞

MET-1K (120 nm^{t}) （Positive-tone CA resist developed by Rohm & Haas）

- SB/PEB: 130°C 60s / 120°C 90s (Standard condition)
- Development: TMAH 45s

＜Exposure Tool＞

Berkeley MET（Micro Exposure Tool）

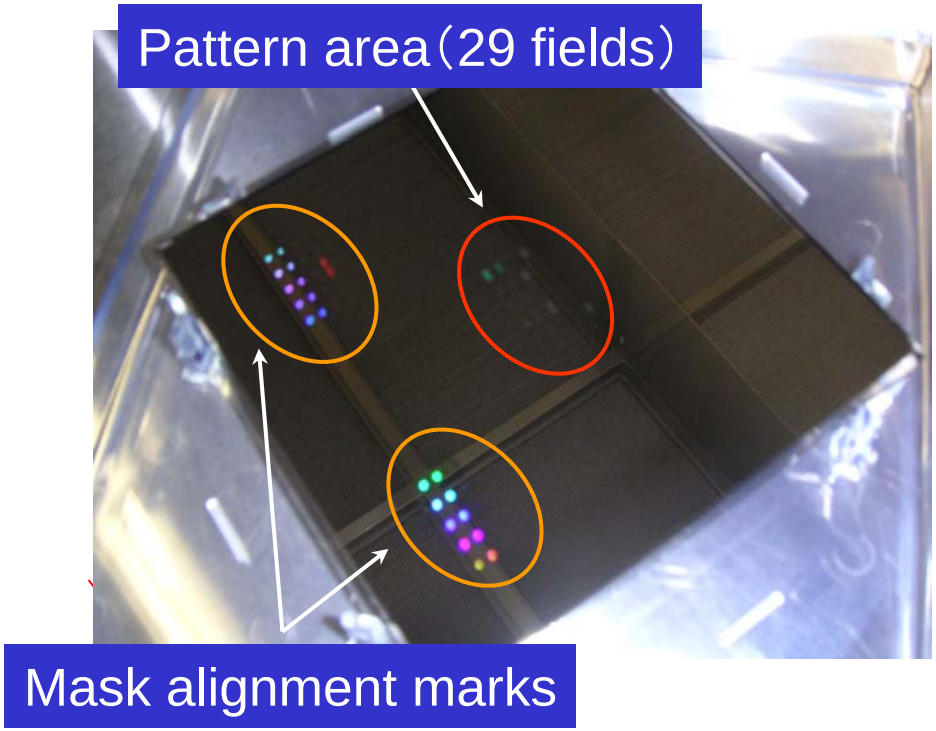
- Light source: Synchrotron（ALS）
- Illumination: Annular (σ=0.3-0.8)
- Focus step: 50 nm (Standard condition)

＜Simulator＞

SOLID-EUV（Sigma-C）

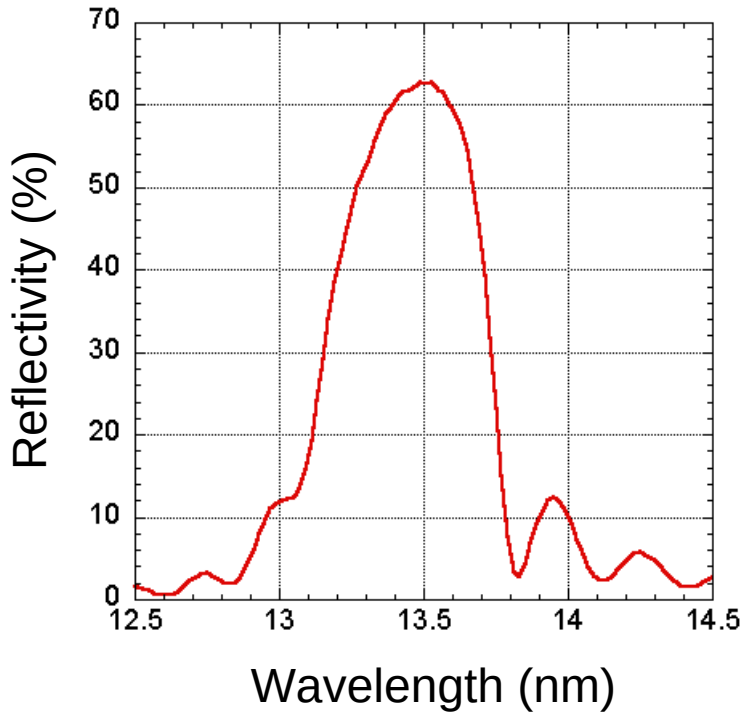
- Mask structure: 2D mask

EUVL mask for Berkeley MET



(a) Bird's-eye view of the mask

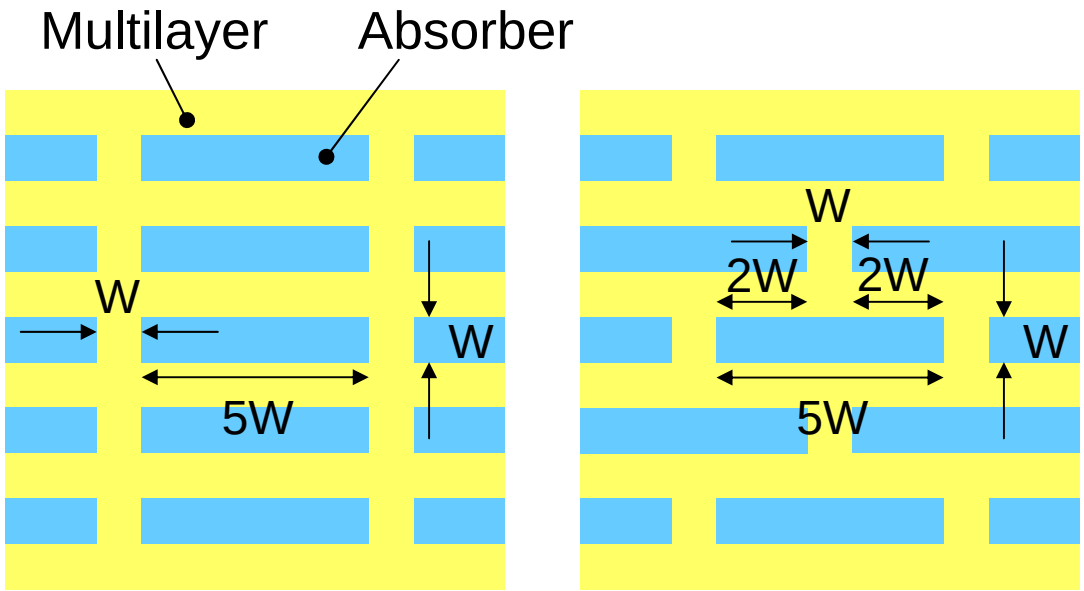
TaGeN(65nm)/Cr(10nm)/ML(40pairs)/Quarz



(b) EUV reflectivity

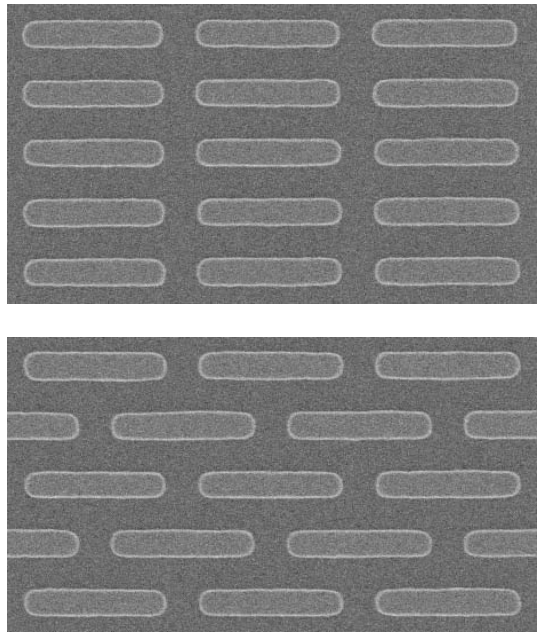
Peak reflectivity: 62.8%
Centroid wavelength: 13.44 nm

Shapes of the Mask Patterns



Rectangular pattern A　Rectangular pattern B

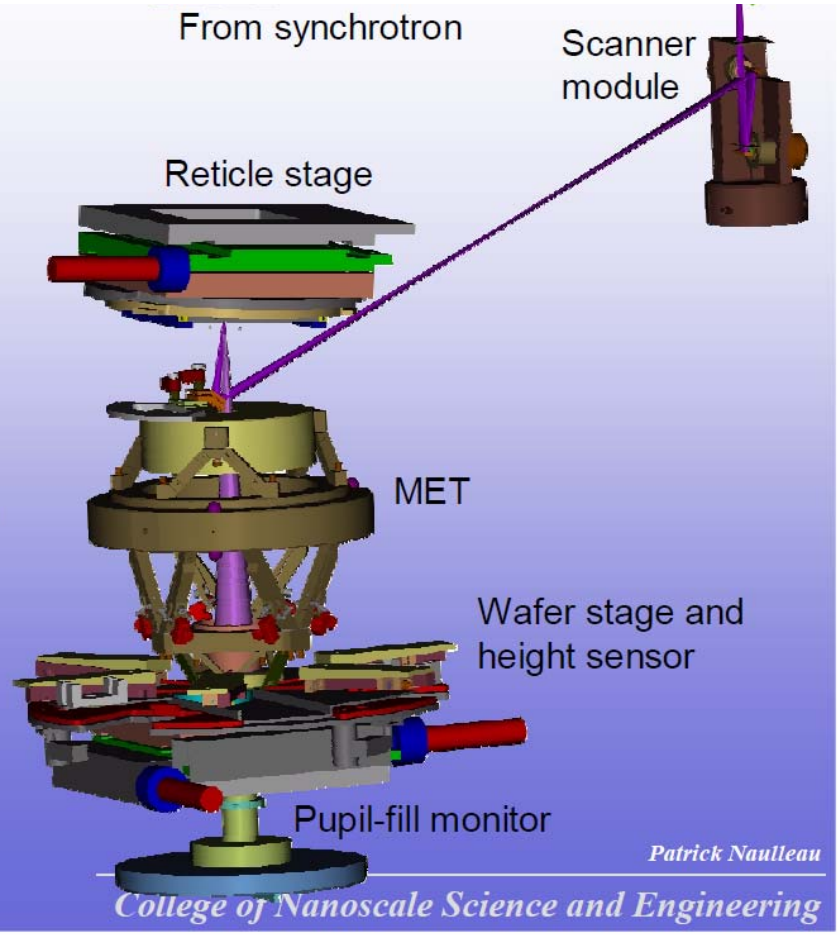
W（hp：half pitch）=
45, 50, 60, 70, 80, 90 nm（on wafer）



Examples of mask pattern shape（hp 45 nm）

Berkeley MET

- Based on MET optic
- Magnification = 5x, NA = 0.3
- Rayleigh resolution = 27 nm
- Field size = 200x600 μm
- Programmable coherence illuminator for low k_1
- Reticle and wafer load-lock and manual transfer systems
- Wafer-height sensor
- nm-resolution wafer-height sensor and focus actuation
- Pupil-fill monitor



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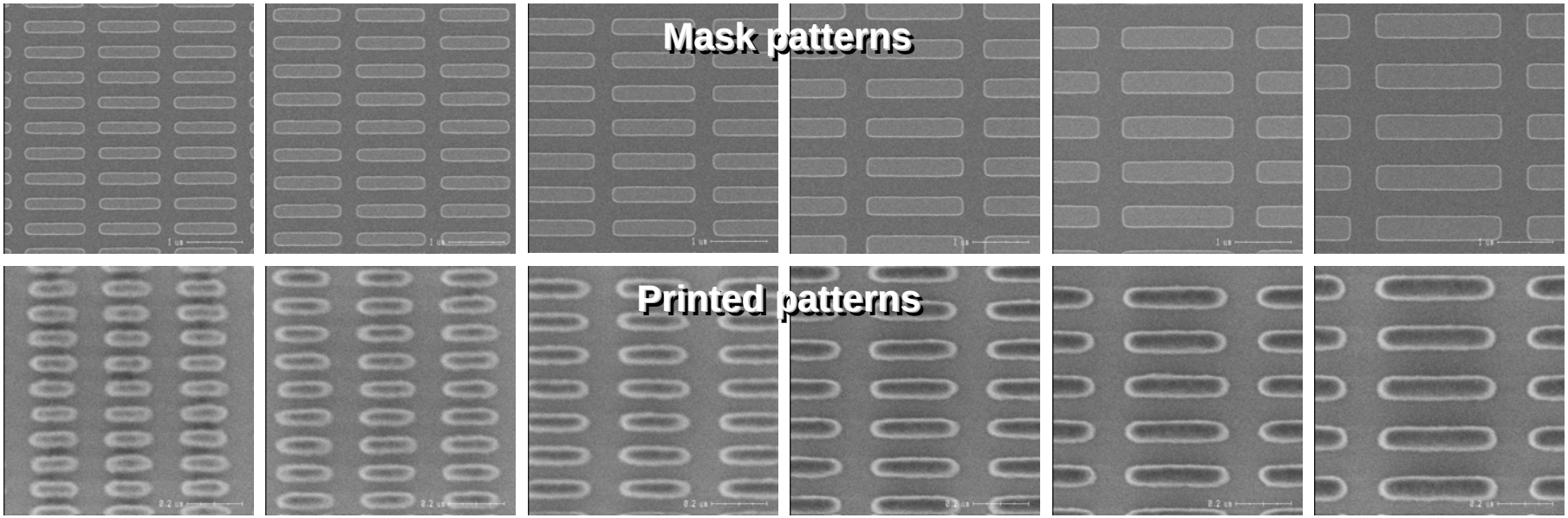
Patrick Naulleau

College of Nanoscale Science and Engineering

Fidelity of Rectangular Pattern A



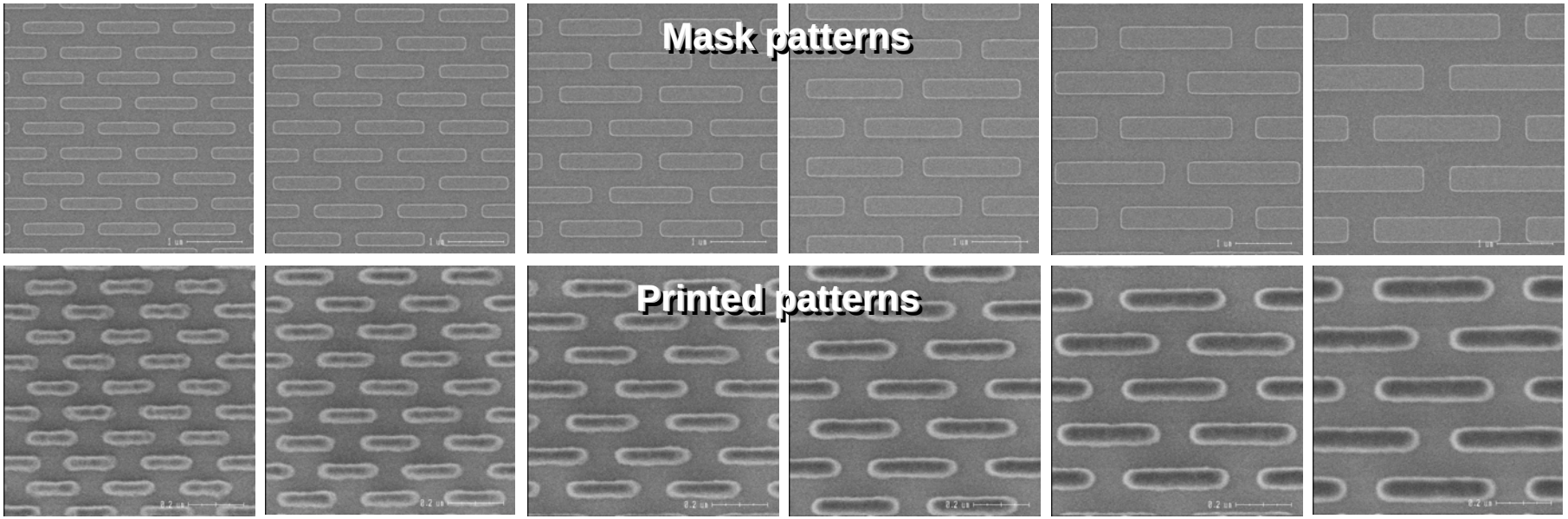
hp 45 nm | hp 50 nm | hp 60 nm | hp 70 nm | hp 80 nm | hp 90 nm

Half pitch（on wafer）

Illumination: Annular（σ= 0.3-0.8）　Resist: MET-1K (120 nm^{t} , PEB:120°C 90s)

Shortening was observed in the lengthwise direction.
The shortening increased with the pattern size reduction.

Fidelity of Rectangular Pattern B



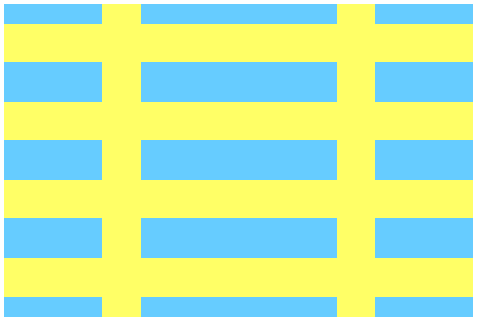
hp 45 nm | hp 50 nm | hp 60 nm | hp 70 nm | hp 80 nm | hp 90 nm

Half pitch（on wafer）

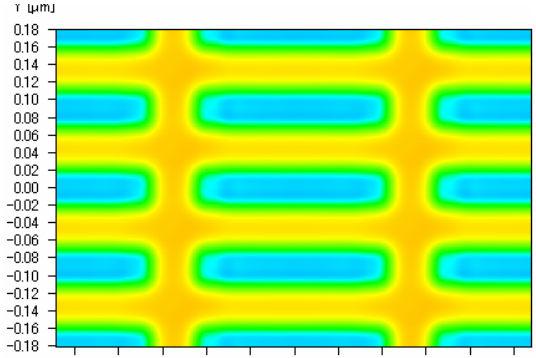
Illumination: Annular（σ= 0.3-0.8）　Resist: MET-1K (120 nm^{t} , PEB:120°C 90s)

Shortening was also observed in the lengthwise direction.
It is difficult to prevent shortening only by layout optimization.

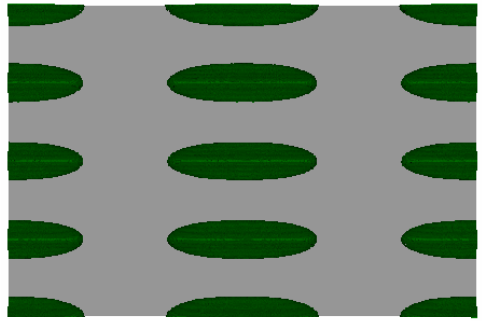
Simulation results of hp 45-nm pattern A



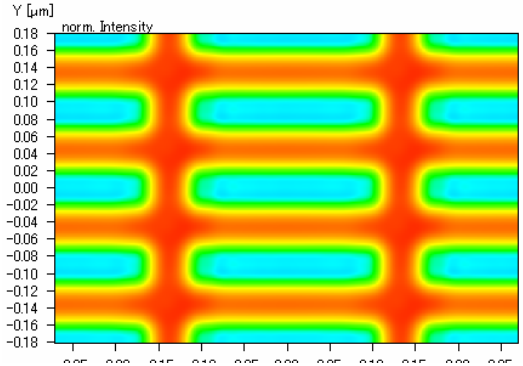
（1）Mask shapes



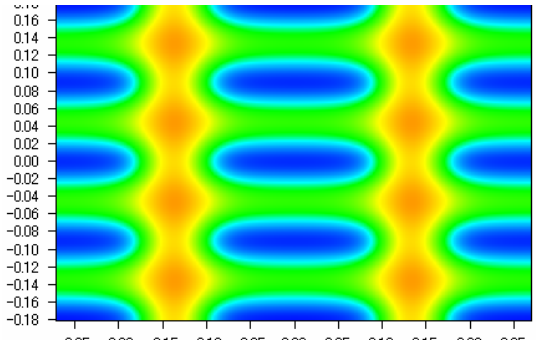
（3）Acid concentration after exposure



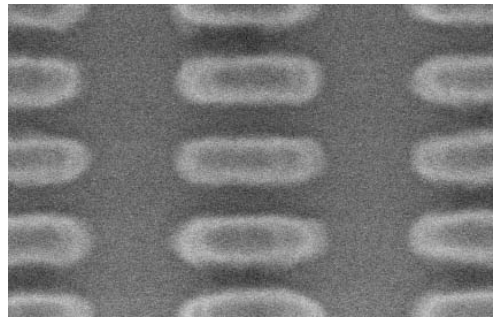
（5）Calculated resist pattern shape



（2）Aerial image
（WFE=0.7nmRMS,Flare=10%）



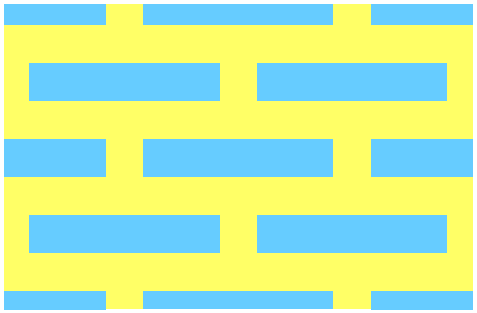
（4）Acid concentration after PEB
（Diffusion length of acid=20 nm）



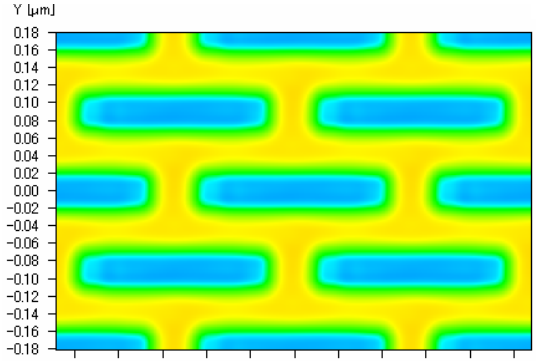
（6）Printed resist pattern shape

Calculated aerial image was almost good. The cause of the shortening might be the acid diffusion in the PEB process.

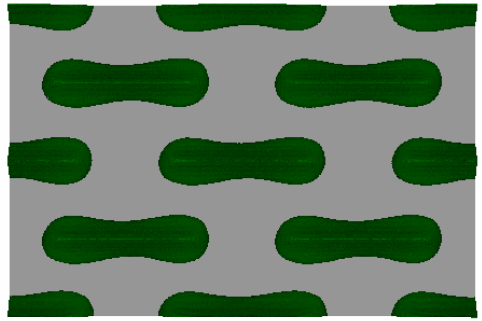
Simulation results of hp 45-nm pattern B



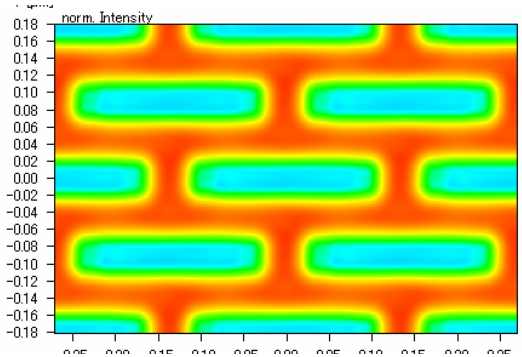
（1）Mask shapes



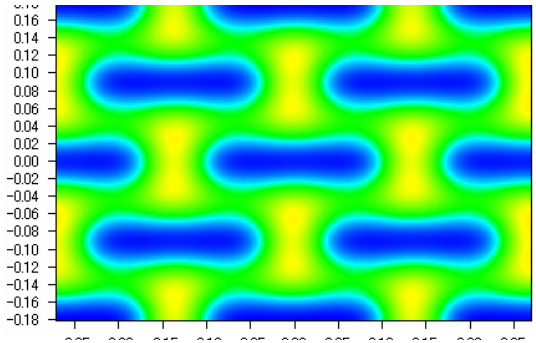
（3）Acid concentration after exposure



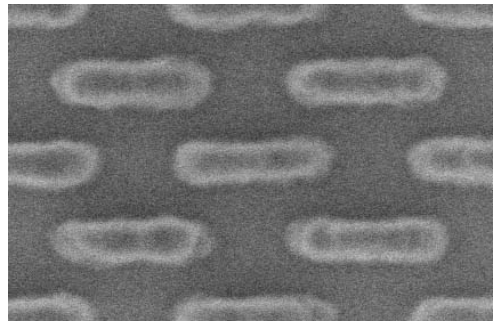
（5）Calculated resist pattern shape



（2）Aerial image
（WFE=0.7nmRMS,Flare=10%）



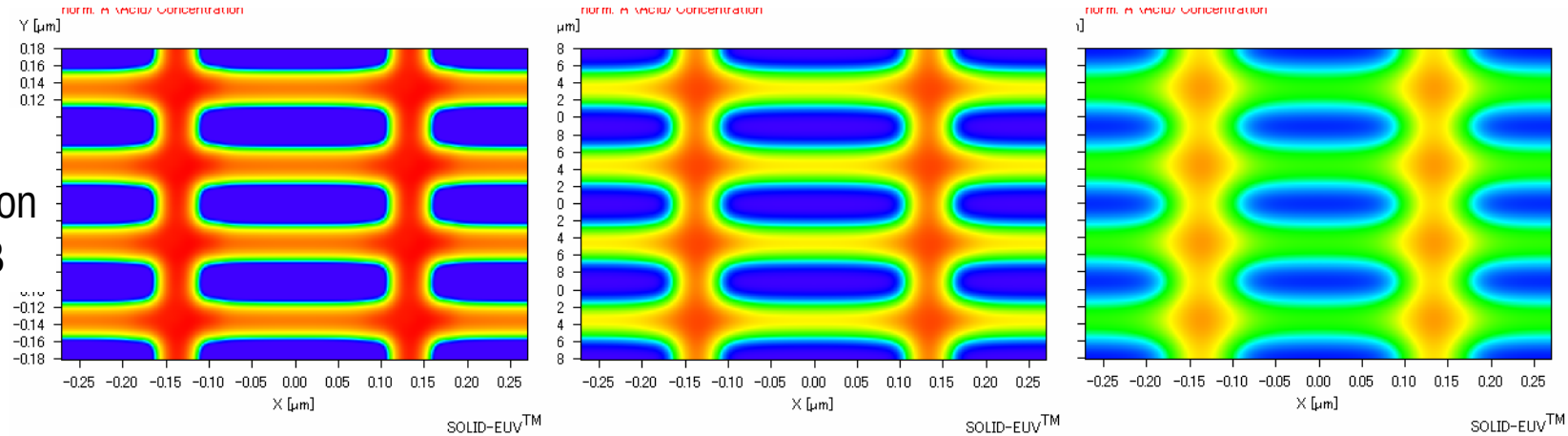
（4）Acid concentration after PEB
（Diffusion length of acid=20 nm）



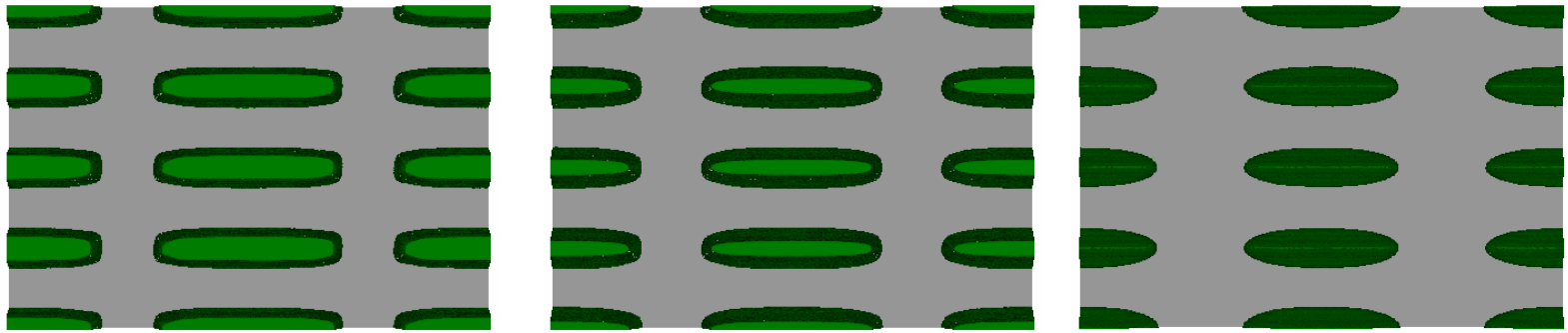
（6）Printed resist pattern shape

Effect of acid diffusion on the shape of hp 45-nm pattern A

Acid concentration after PEB



Calculated resist pattern shape

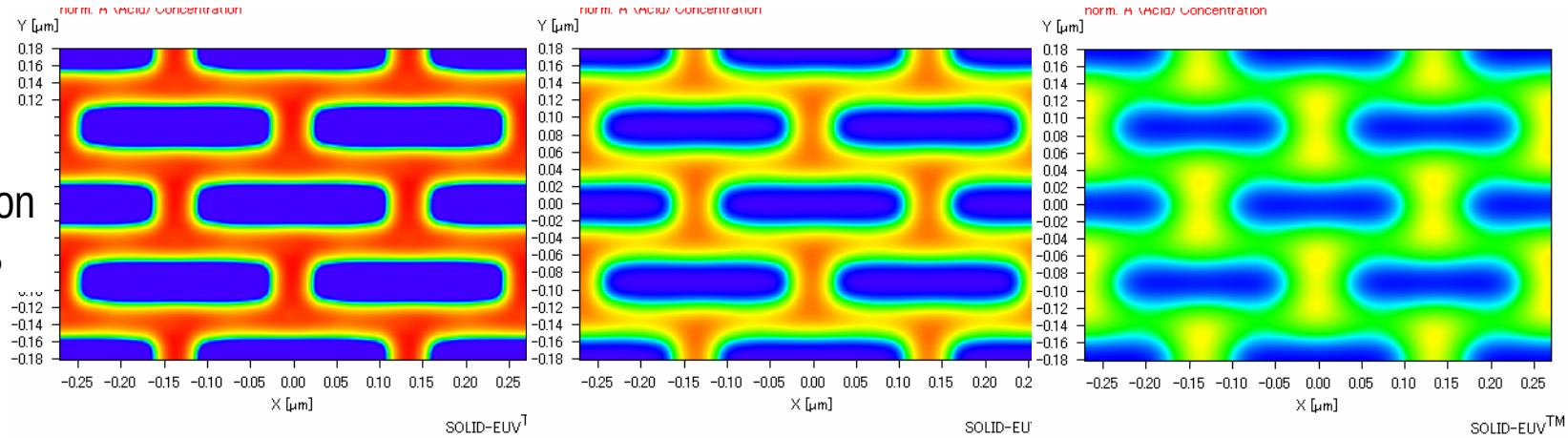


(1) Diffusion length : 1 nm (2) Diffusion length : 10 nm (3) Diffusion length : 20 nm

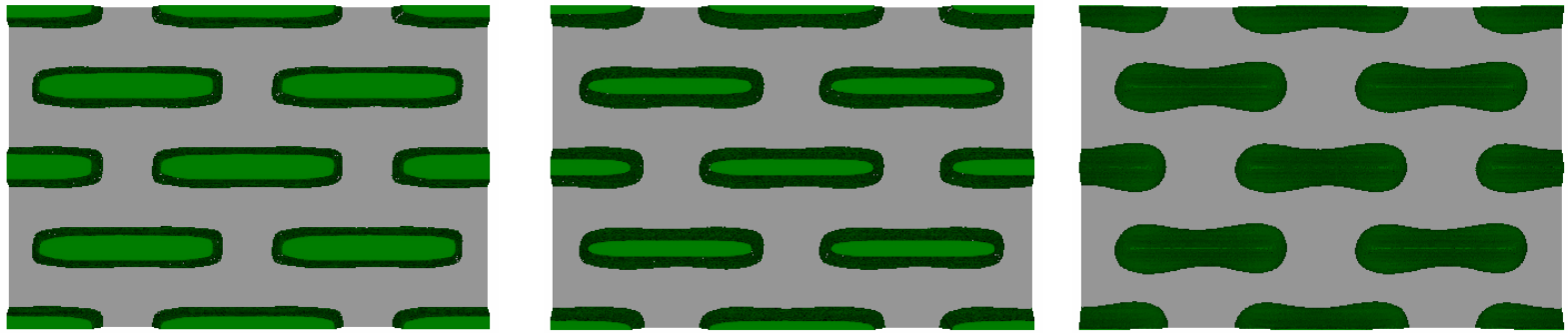
The simulation results indicate that the shortening increased with the diffusion length of acid.

Effect of acid diffusion on the shape of hp 45-nm pattern B

Acid concentration after PEB

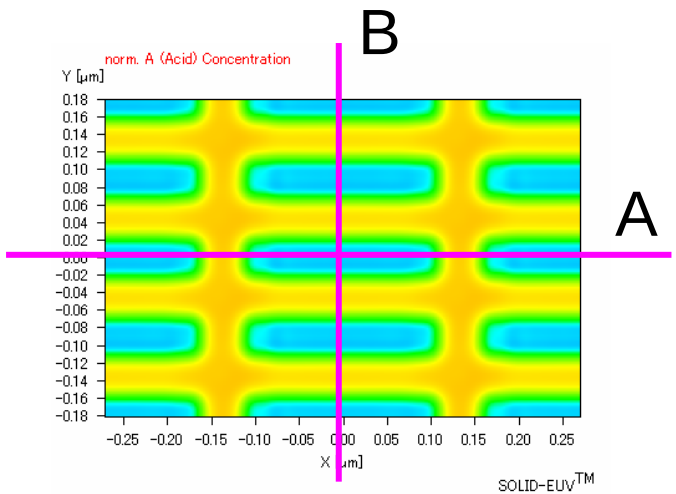


Calculated resist pattern shape

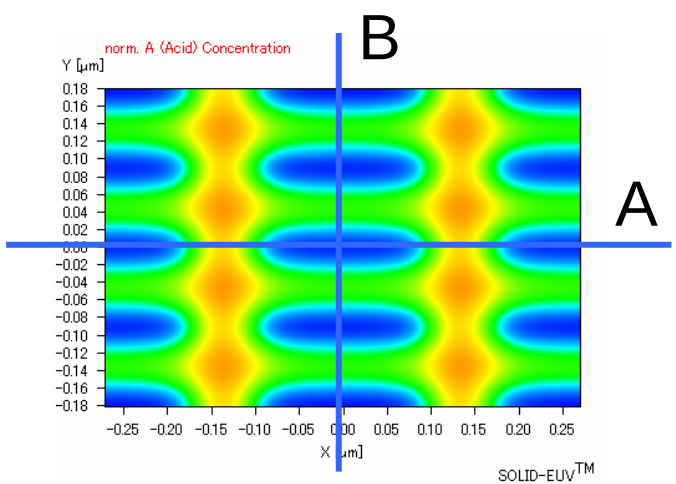


（1）Diffusion length：1 nm　（2）Diffusion length：10 nm　（3）Diffusion length：20 nm

Acid concentration profiles after exposure and after PEB

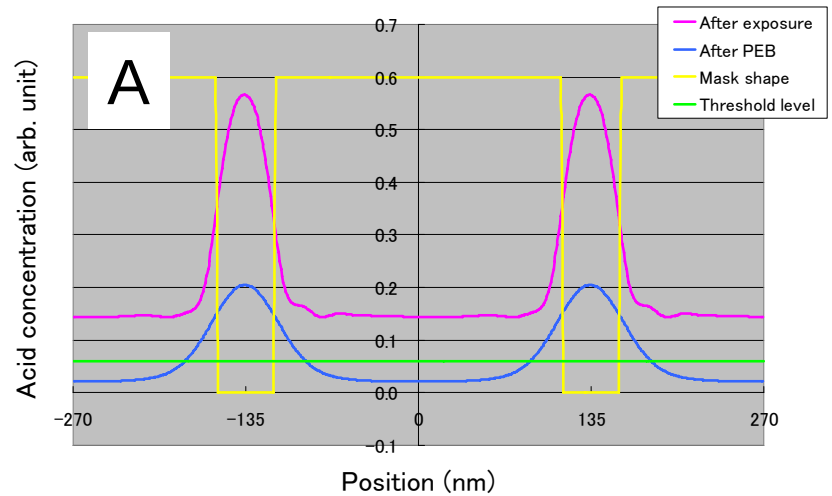


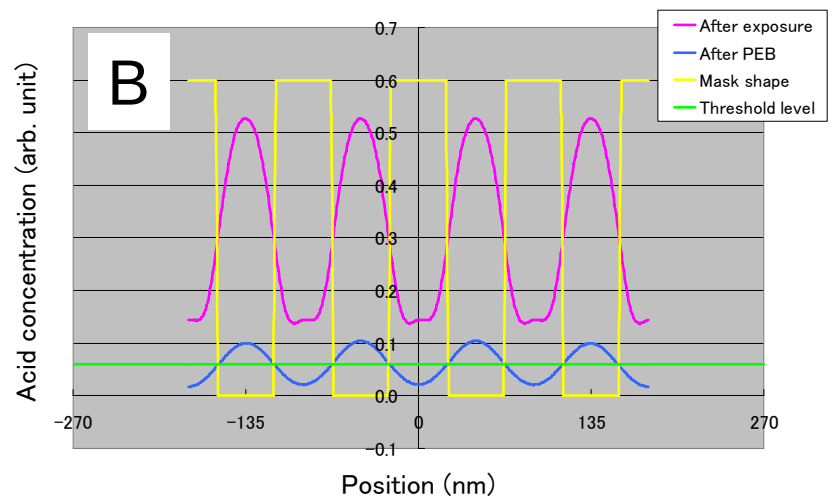
(1) After exposure



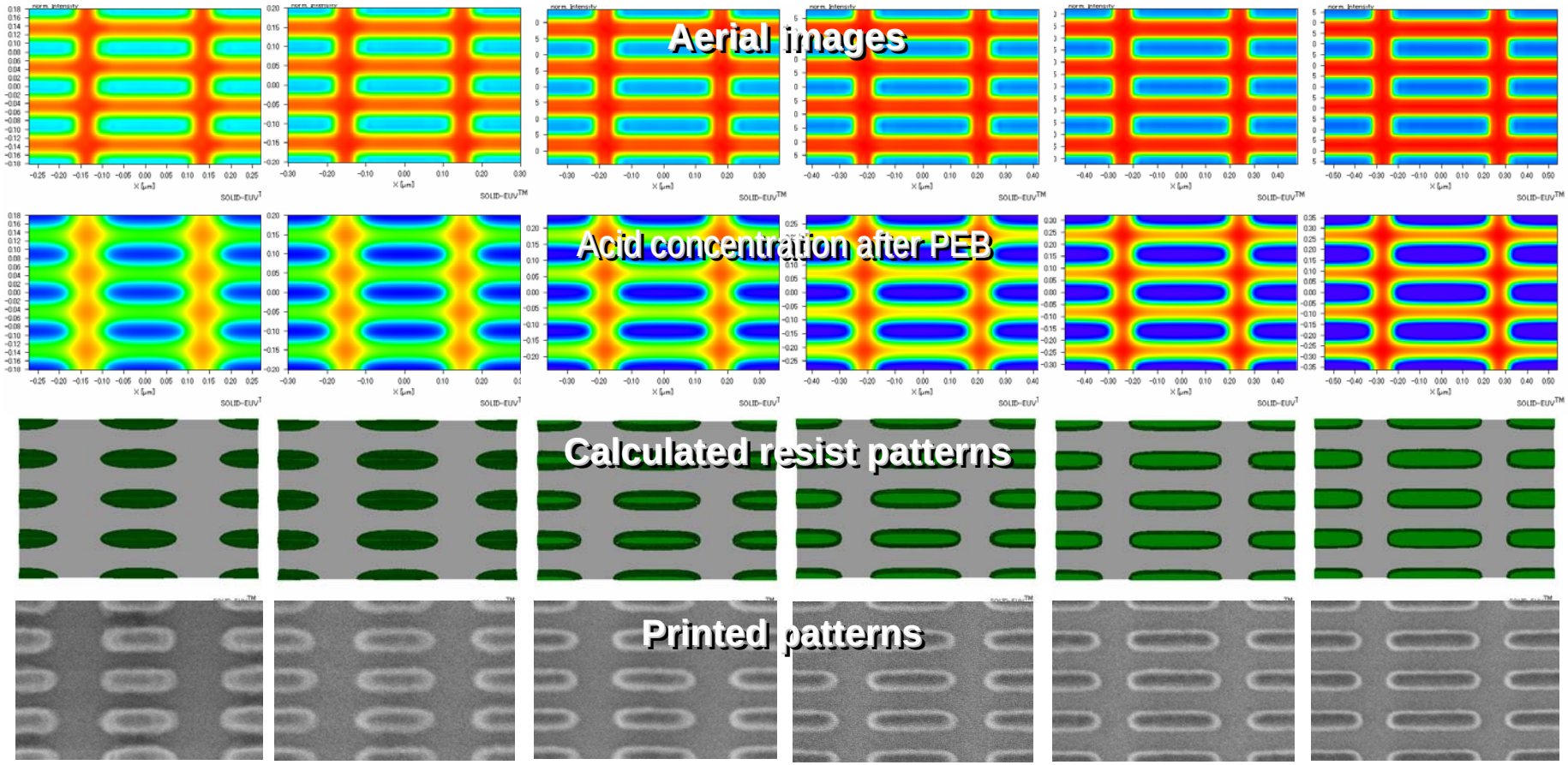
(2) After PEB

hp 45-nm pattern A





Simulation results of various sizes of pattern A

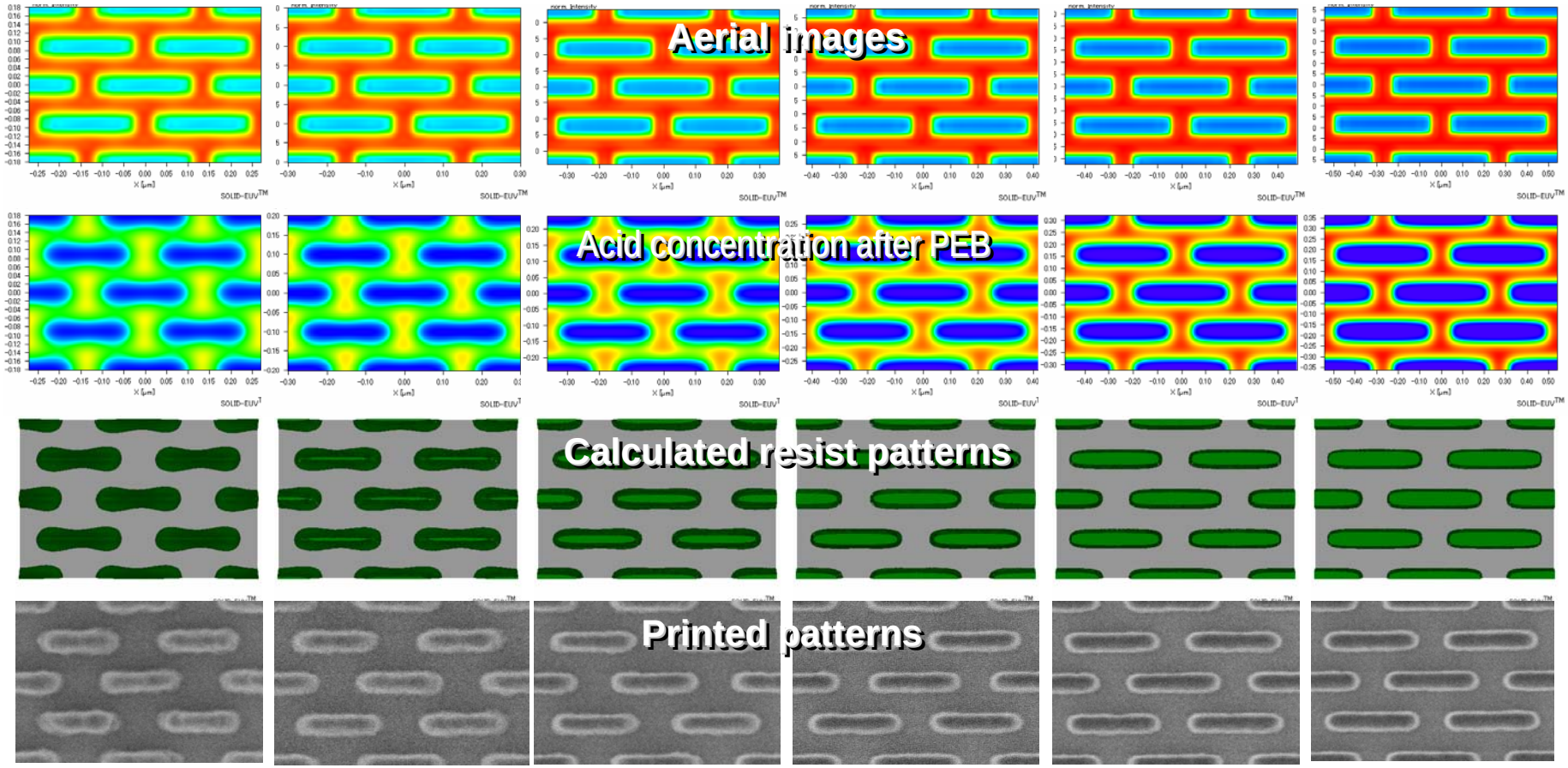


hp 45 nm | hp 50 nm | hp 60 nm | hp 70 nm | hp 80 nm | hp 90 nm

◆Simulation conditions◆ Aberration : 0.7nmRMS, Flare : 10%, Diffusion length of acid : 20nm

Calculated shapes of resist patterns agreed well with the experimental results for various sizes of pattern A.

Simulation results of various sizes of pattern B

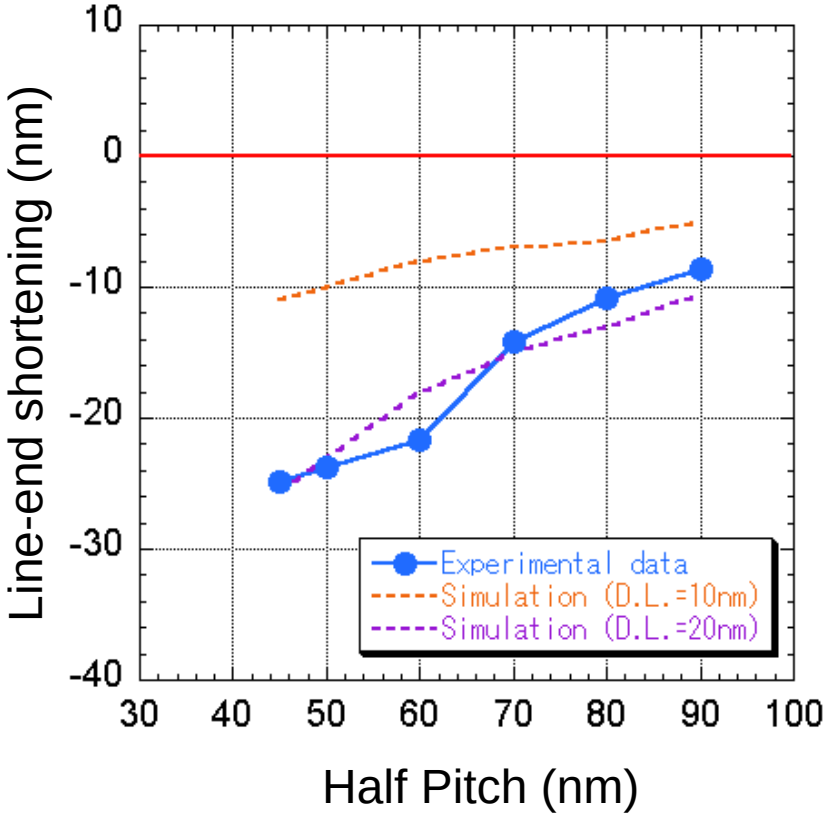


hp 45 nm | hp 50 nm | hp 60 nm | hp 70 nm | hp 80 nm | hp 90 nm

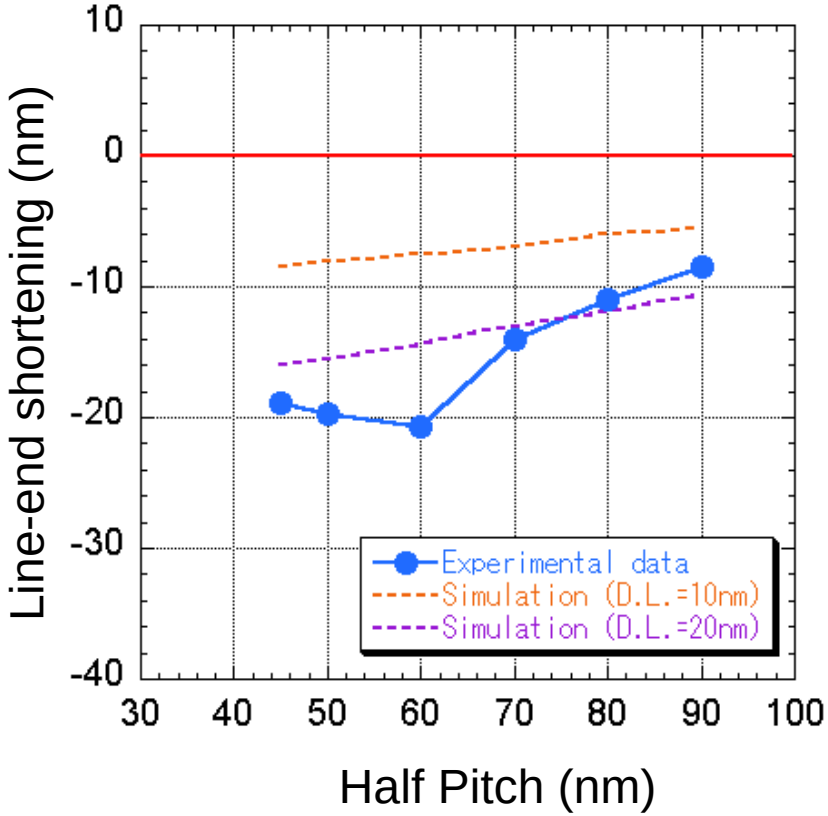
◆Simulation conditions◆ Aberration : 0.7nmRMS, Flare : 10%, Diffusion length of acid : 20nm

Calculated shapes of resist patterns also agreed well with the experimental results for pattern B.

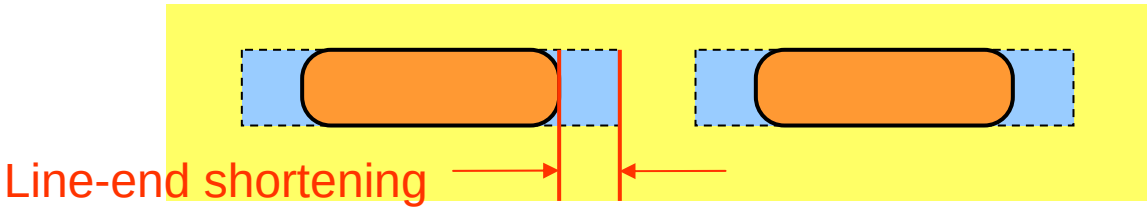
Line-end shortening for various sizes of patterns



（a）Rectangular pattern A

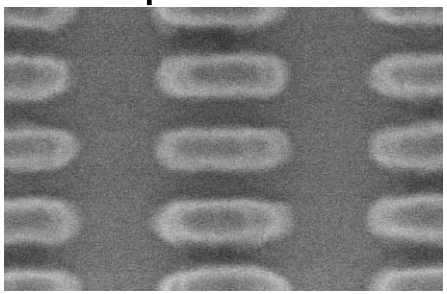
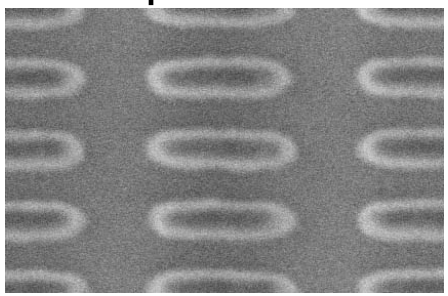
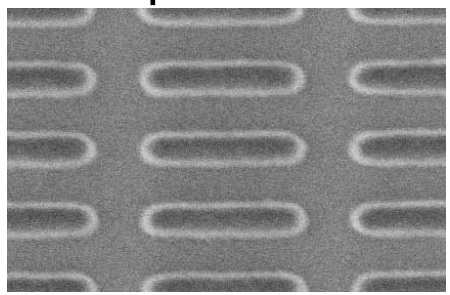
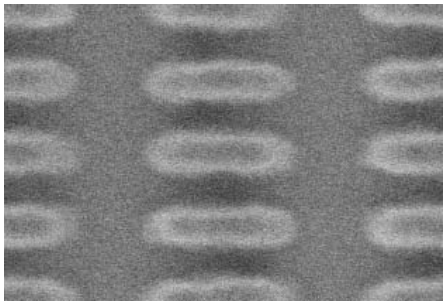
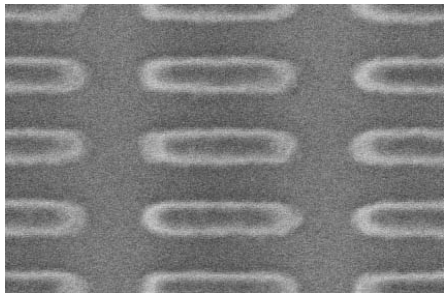
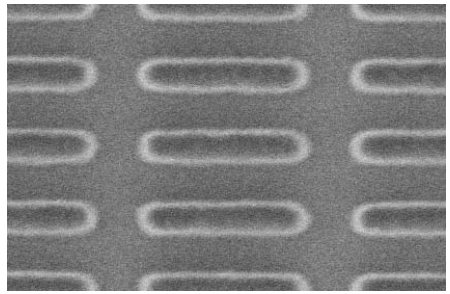
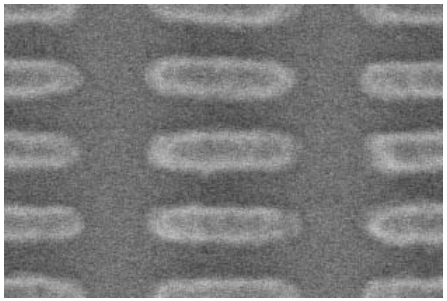
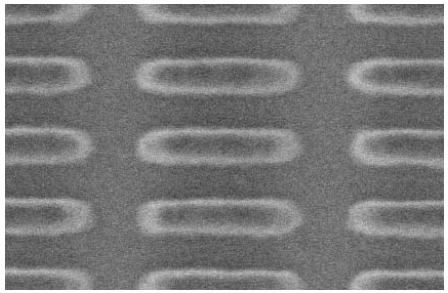
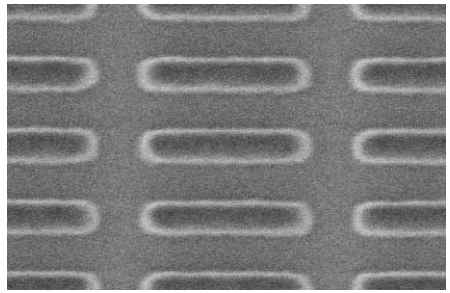


（b）Rectangular pattern B



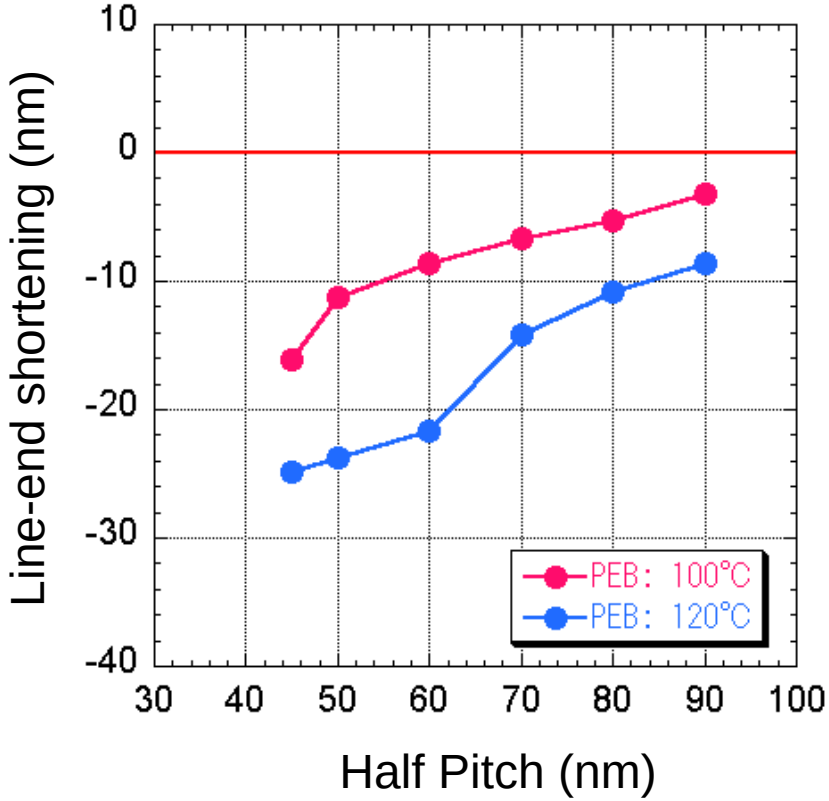
※D.L. = Diffusion length of acid

Effect of PEB temperature on pattern fidelity

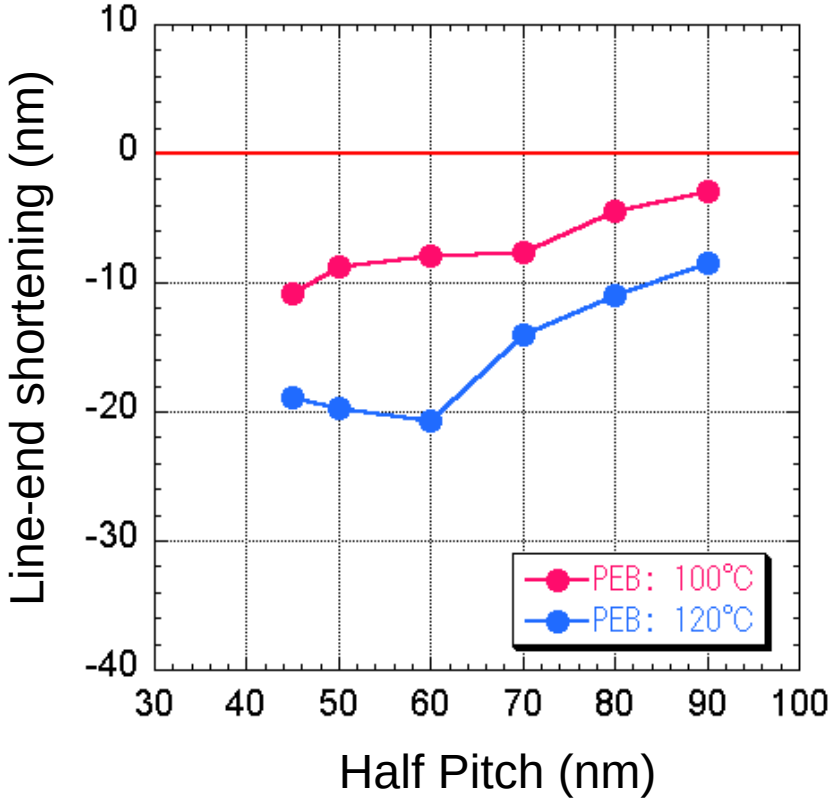
PEB	hp 45 nm	hp 60 nm	hp 90 nm	Sensitivity
120˚C 90s				23mJ/cm^2
110˚C 90s				33mJ/cm^2
100˚C 90s				33mJ/cm^2

Pattern fidelity was improved by lowering PEB temperature.
This should be due to the shorter diffusion length of acid.

Effect of PEB temperature on line-end shortening



（a）Rectangular pattern A



（b）Rectangular pattern B

Line-end shortening decreased by lowering PEB temperature.

Conclusions

- The pattern fidelity of hp 90-nm rectangular patterns printed with EUV lithography was fairly good. However, hp 45-nm patterns exhibited considerable shortening in the lengthwise direction.
- When a diffusion length of 20 nm was used for acid diffusion, the calculated resist pattern shapes agreed well with the experimental results for various sizes.
- Pattern fidelity was improved by lowering PEB temperature. This should be due to the shorter diffusion length of acid.
- Diffusion length of acid should be reduced with the pattern size reduction.

Acknowledgements

We would like to thank International SEMATECH for giving us an opportunity to use MET.

We also would like to thank CXRO group in Lawrence Berkeley National Lab. for their support for the printing experiments using MET.

EUVL mask was fabricated by Dai Nippon Printing Co. Ltd.

MET-1K resist was supplied by Rohm & Haas.

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