Improving SRAF margin and imaging performance by using PSM in EUVL

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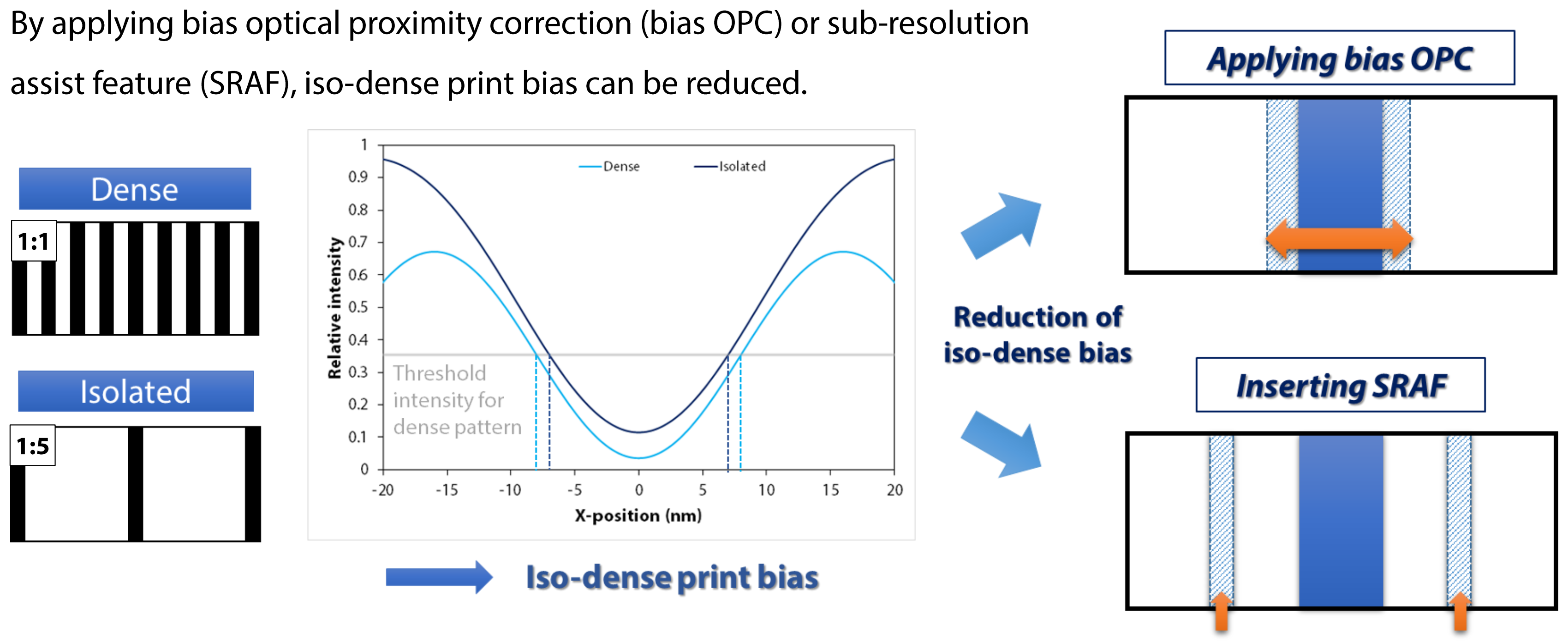
INTRODUCTION

❑ Iso-dense print bias in photo-lithography

- Diffraction amplitude and angle are changed as a size and position of nearby pattern.
  - ➢ Iso-dense print bias, the difference in printed linewidth between dense and isolated line, is occurred
- By applying bias optical proximity correction (bias OPC) or sub-resolution assist feature (SRAF), iso-dense print bias can be reduced.



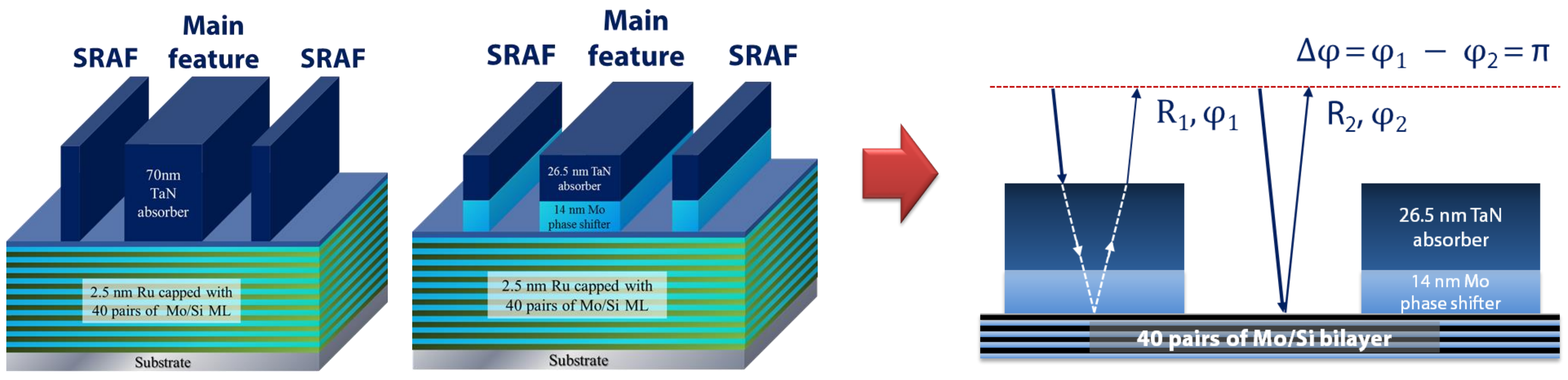
<Iso-dense print bias for same exposure condition>

❑ SRAF for extreme ultraviolet lithography (EUV lithography)

- Iso-dense print bias can be reduced to apply assist feature at both sides of main feature.
- Applying SRAF, process window of isolated pattern can be wider than the case of bias OPC
  - ➢ Common depth of focus (DOF) between dense and isolated pattern is increased
- SRAF is considered to be applied for EUV lithography for printing 7 nm node with k_1 value around 0.4

EXPERIMENT

❑ Proposal of attenuated phase shift mask (PSM) with 6% reflectivity



<Schematic of binary intensity mask (BIM) (left) and attenuated phase shift mask (PSM) (right)>

- PSM purposely induces 180° phase shift between bright and dark region, where dark region has a limited reflectivity.
- Since PSM suggested in the study has 6% reflectivity at dark region, EUV absorption at SRAF region is relatively weak compared to binary intensity mask.
  - ➢ **PSM is expected to allow a larger size window of SRAF**

❑ Simulation condition

Parameters	Value
Numerical aperture	0.33
Chief ray angle	6º
Demagnification	4X
Source shape	Dipole illumination
Center sigma / pole radius	0.65 / 0.3

<Simulation condition for 16 nm hp L/S pattern>

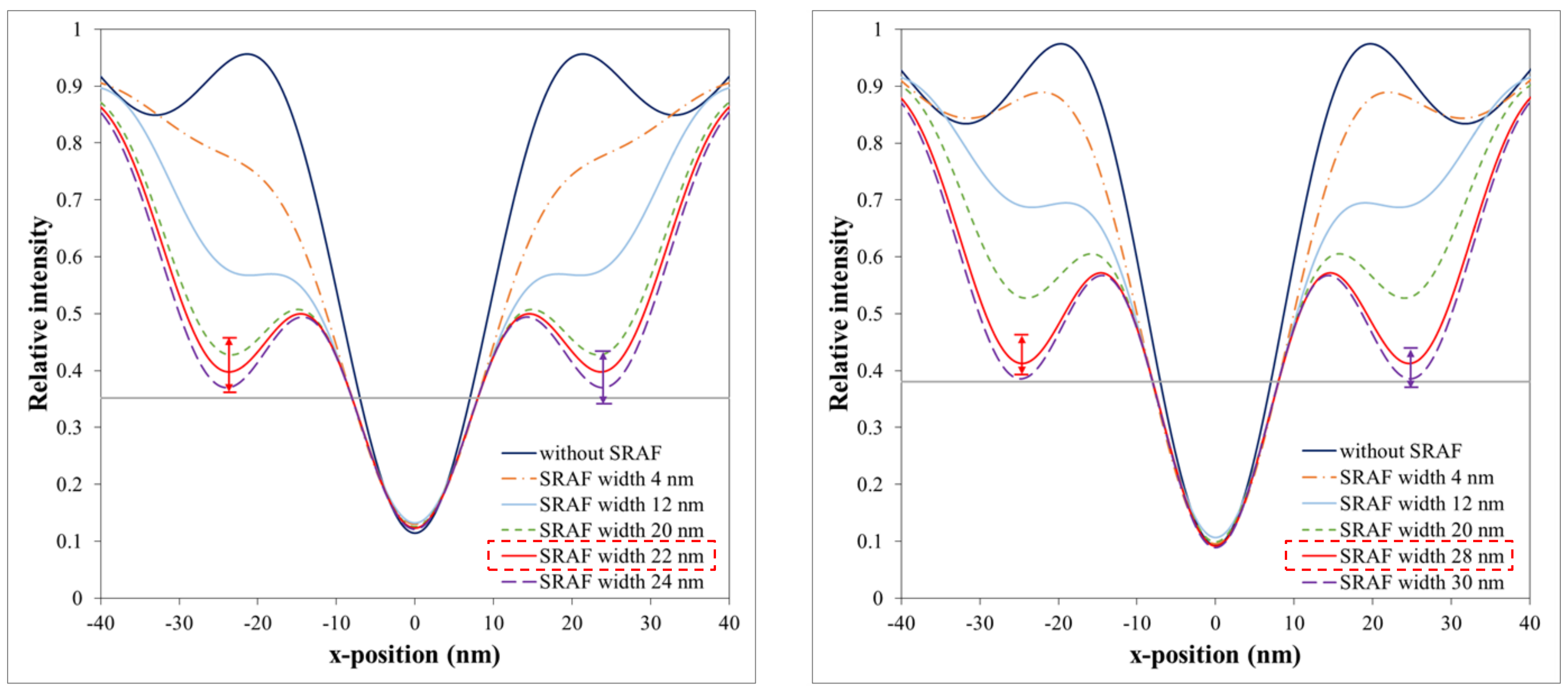
Material	Refractive index (n)	Extinction coefficient (k)
TaN	0.9260	0.0436
Mo	0.9238	0.0064
Si	0.9991	0.0013
Ru	0.8864	0.0171

<Complex refractive index of materials at 13.5 nm> (from CXRO database)

- Aerial image and developed resist simulation were performed by PROLITH X5.1 of KLA-Tencor

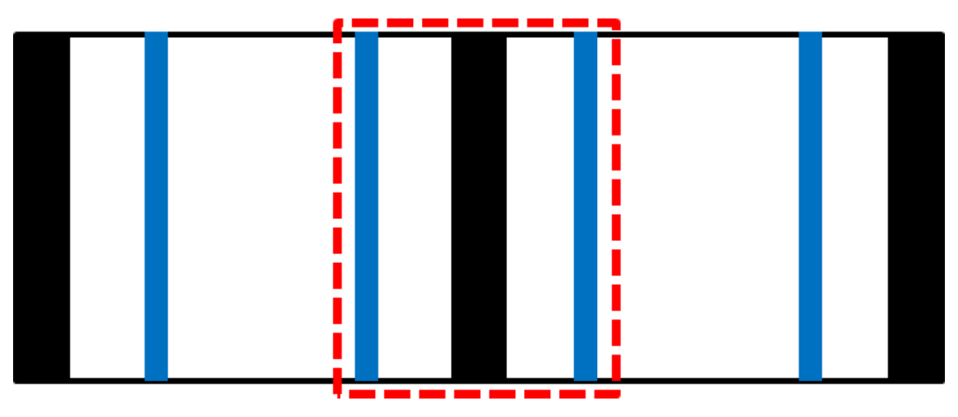
RESULTS & DISCUSSION (Aerial image simulation)

❑ Prediction of SRAF printability through aerial image simulation



<Aerial image of BIM (left) and PSM (right) depending on SRAF width for isolated patterns>

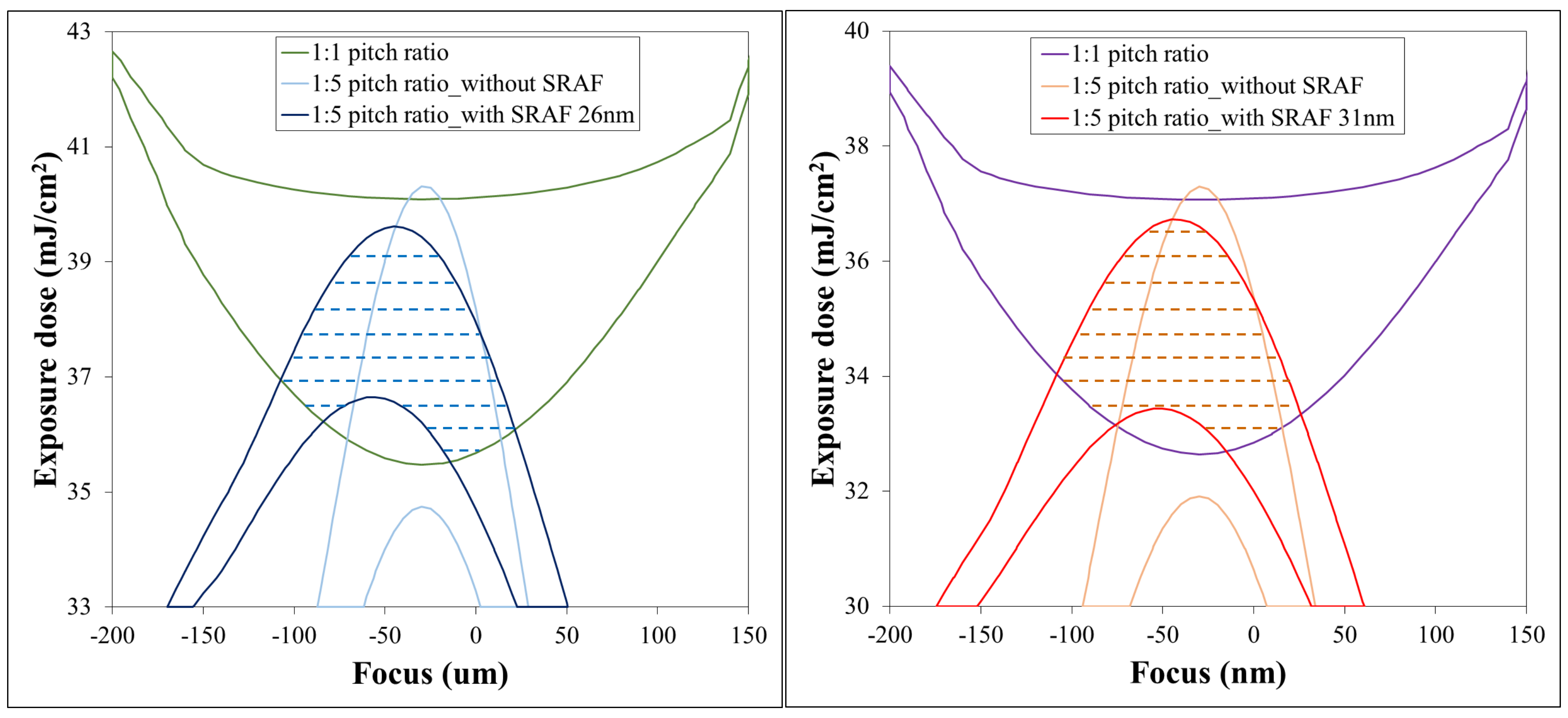
- In the aerial image, maximum non-printing SRAF width for PSM was 28 nm, increasing 30% compared to BIM.
  - ➢ The maximum non-printing SRAF width was determined considering ± 50 nm defocus.
  - ➢ **Due to 6% reflectivity at the SRAF region, the limit of non-printing SRAF width could be extended.**



<Simulation region of isolated pattern with SRAF>

RESULTS & DISCUSSION (Developed resist simulation)

❑ Comparison of process margin through process window simulation



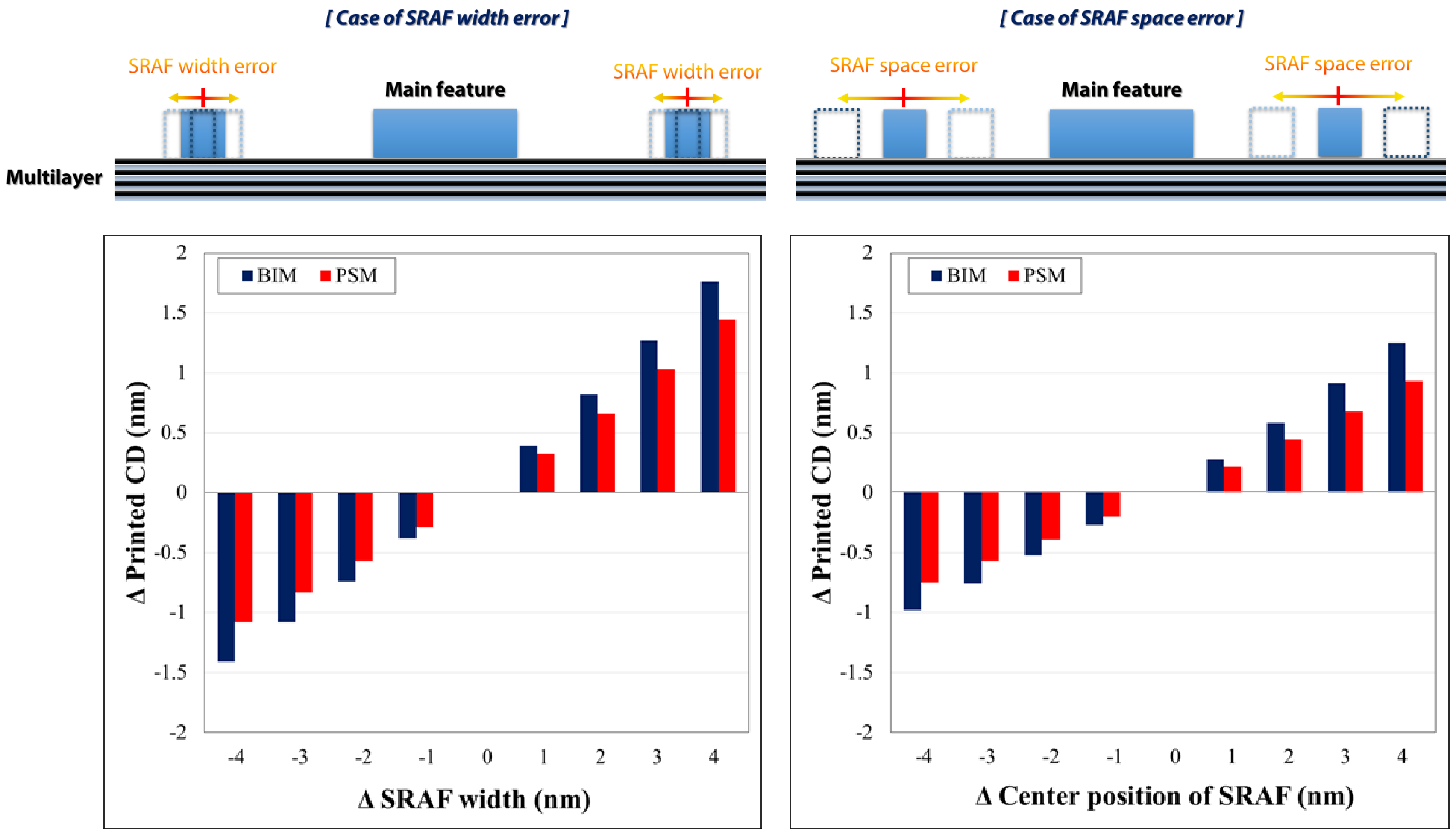
<Comparison of process window for BIM (left) and PSM (right)>

- Process window simulation was performed applying maximum SRAF width at resist profile.
- Process window overlapped region between dense and isolated pattern with SRAF was enlarged for PSM
- Common DOF @ 6% exposure latitude (EL) was also become wider using PSM

Comparison of DOF @ 6% EL

	BIM	PSM
Bias OPC	84 nm	92 nm
With SRAF	90 nm	109 nm

❑ Printed CD error depending on SRAF width and position error

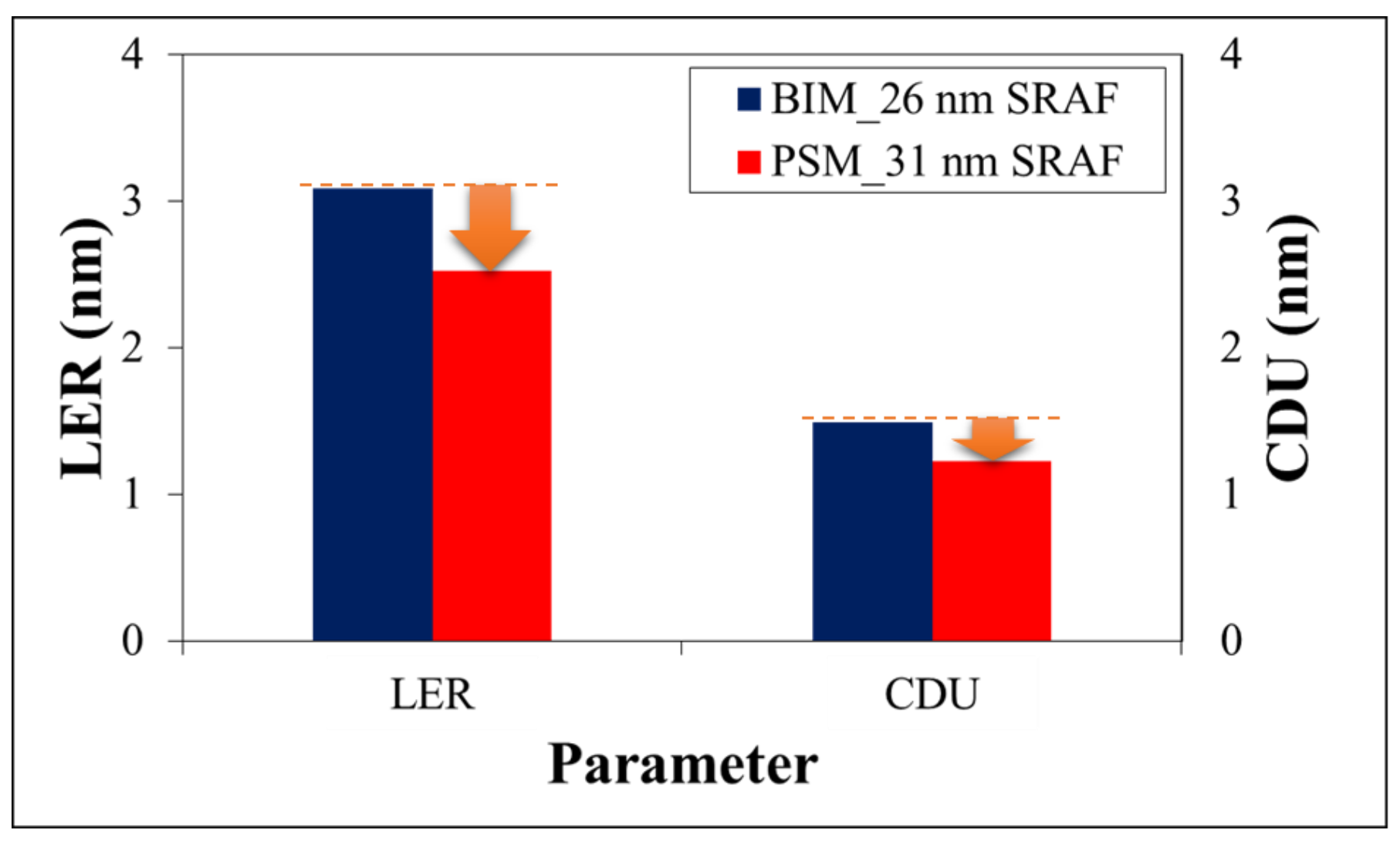


Scale : Δ Prited CD @ wafer, Δ SRAF width @ mask, Δ Center position of SRAF @ mask

<Printed CD error depending on SRAF width variation (left) and variation of SRAF center position (right)>

- When EUV mask is fabricated, SRAF width and position can be moved from originally intended SRAF.
- Printed CD error due to variation of SRAF width and center position was mitigated by applying PSM.
  - ➢ Variation of printed CD due to SRAF width and position error was mitigated 23.4%, 25.6%, respectively.
  - ➢ **Using PSM, process margin for fabricating mask was expected to be enhanced.**

❑ Stochastic simulation results



* *EUV generic resist model*

Comparison of LER and CDU between BIM and PSM

	BIM	PSM
CD uniformity (3σ, nm)	1.49	1.23
Line edge roughness (3σ, nm)	3.09	2.53

<Comparison of stochastic characteristics between BIM and PSM>

- Stochastic imaging performance of PSM with SRAF was improved comparing to BIM
  - ➢ Improvement of LER and CDU due to alleviation of photon shot noise effect

CONCLUSION

❑ Through aerial image simulation,

- Applying SRAF in PSM increased maximum non-printing SRAF width by reduction of EUV absorption at SRAF region as SRAF insertion – enhance SRAF width margin

❑ Through developed resist simulation,

- Since the dose-to-size decreased by applying PSM, throughput could be increased compared to BIM.
- Also, DOF increased 18.5% due to increased maximum non-printing SRAF width.
- Since the high diffraction order efficiency increased, the printed CD error depending on SRAF width variation or center position decreased – Improved process margin for fabricating the EUV mask with SRAF