Improved Stochastic Imaging Properties in Contact Hole Pattern by using PSM for EUVL

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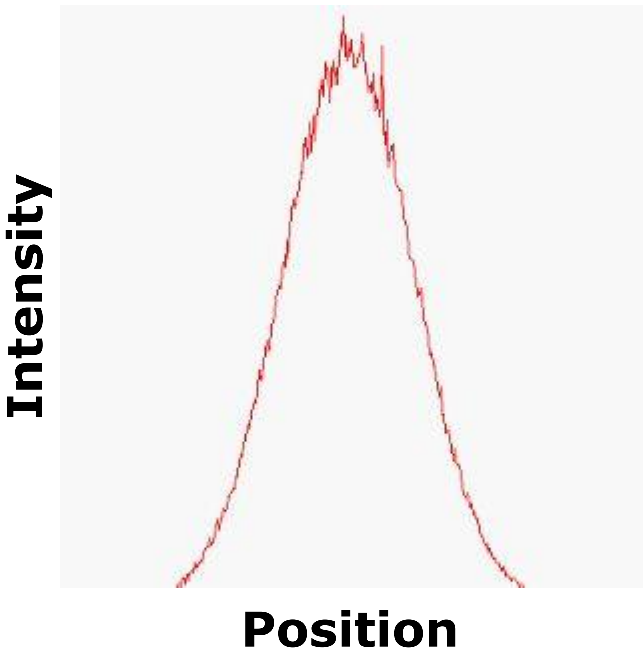
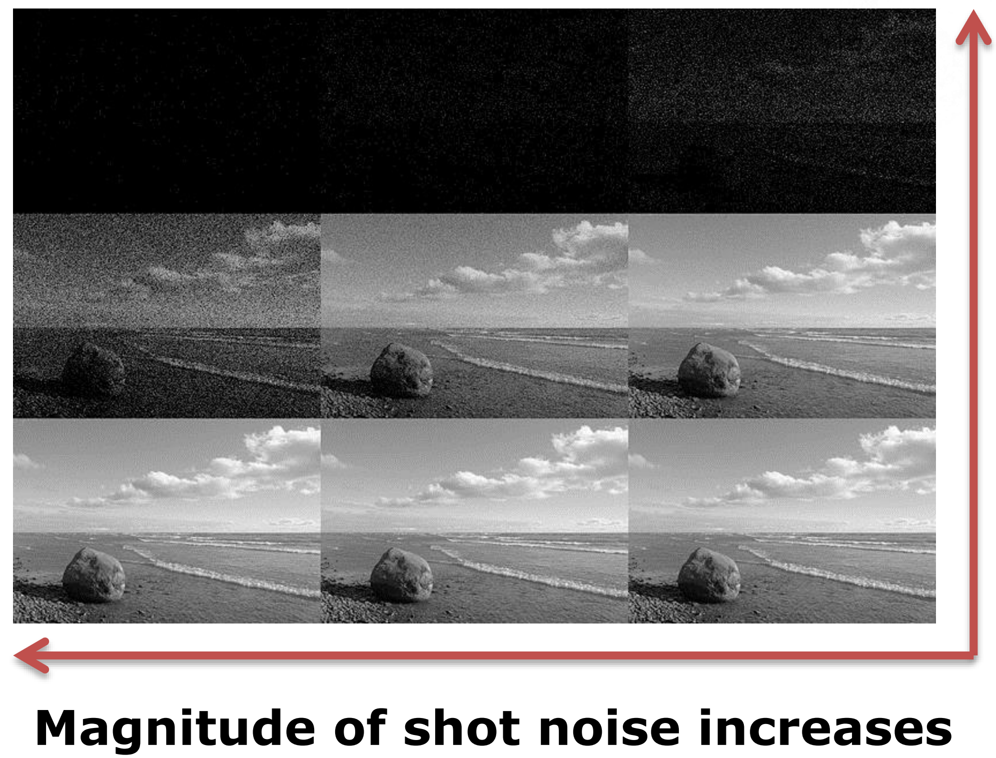
Contents

- Photon shot noise effect in EUVL
  - Degrades stochastic imaging performance
- Suggestion of a thin attenuated PSM
- Comparing PSM with conventional BIM
  - Photon latent image simulation results
  - Aerial image simulation results
  - Stochastic imaging performance simulation results
- Conclusion

Photon shot noise effect

- Fluctuations of the number of photons detected due to their occurrence independent on each other





Photon shot noise effect in EUVL

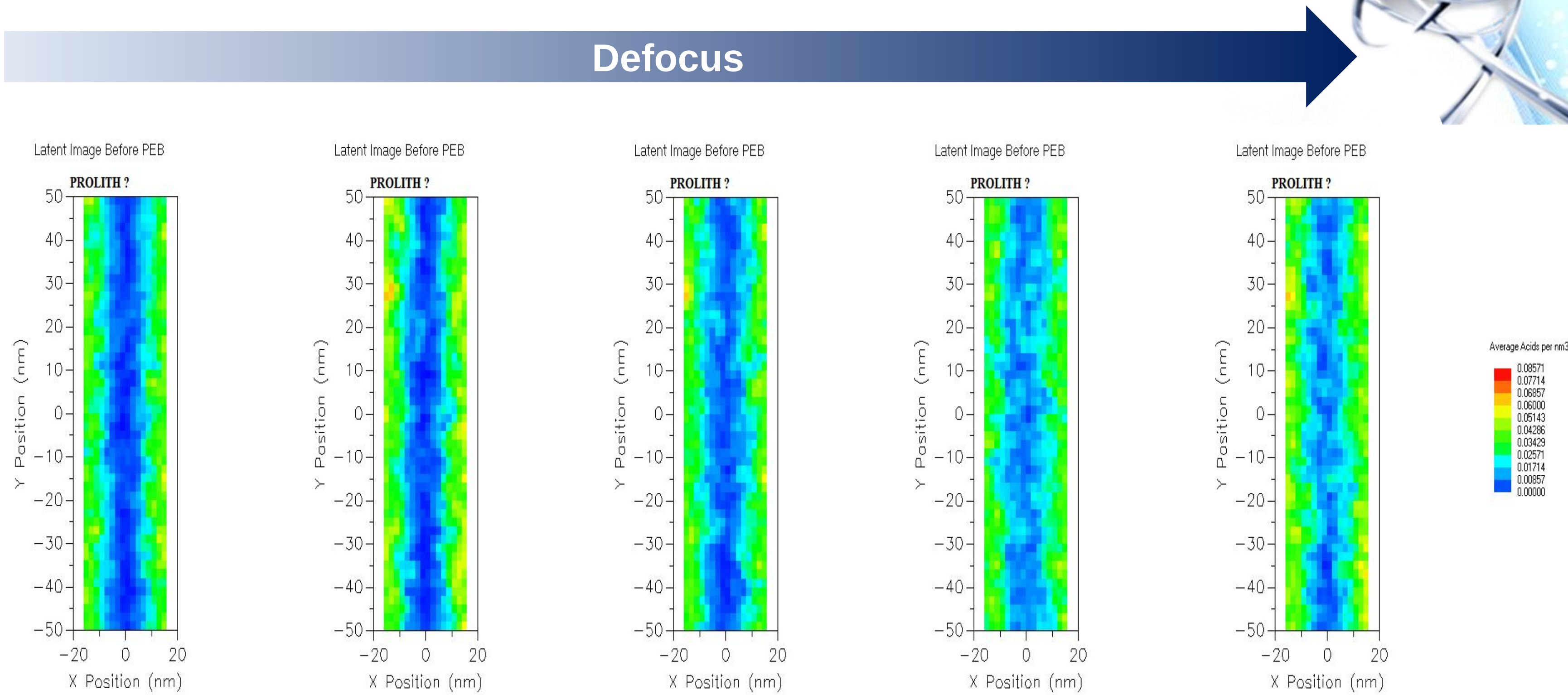
- Statistical fluctuations between photon and photoresist
  - Exposure dose – number of quanta
- Photon energy and dose
  - Small number of quanta for shorter wavelength – Large shot noise

$$E = h\nu = \frac{hc}{\lambda} \rightarrow \mathrm{Dose} = \mathrm{N_{photon}E} = \boxed{\mathrm{N_{Photon}}\frac{hc}{\lambda}}$$

Light source	Energy (eV)	Wavelength
ArF	6.4	193 nm
EUV	92	13.5 nm
E-beam	50,000	5.5 pm

※ *Timothy A. Brunner, JVST B Vol. 21, 2632 (2003)*
Burn J. Lin, SPIE Vol. 7520, 752004 (2009)

Photon shot noise effect in EUVL

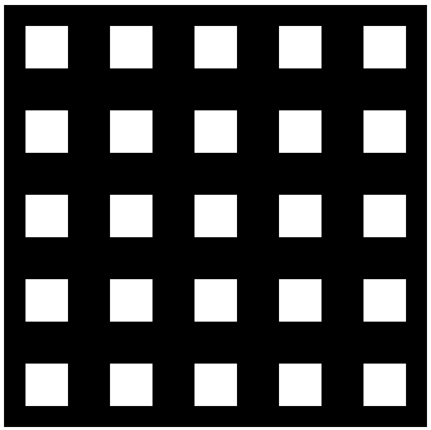


◆ Shot noise effect in defocus

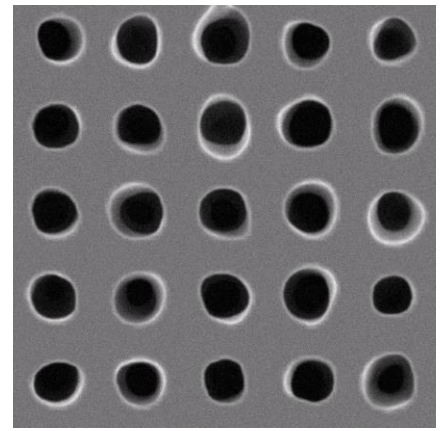
Reduction of photon numbers concentrated on the edge of pattern, causes increase of PSN effect at the edge of the pattern

Photon shot noise effect in EUVL

- PSN effect deteriorates CER and CDU in contact hole pattern



Mask



Resist

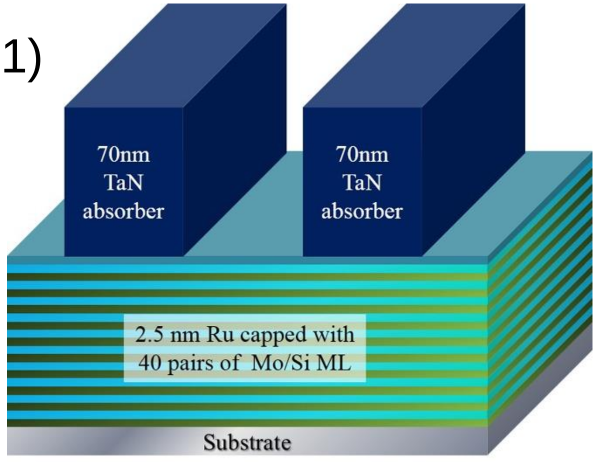
$$CDU\ (3\sigma) \propto \left(\frac{6}{ILS}\right)\left(\frac{1}{\sqrt{N}}\right)$$

- N = absorbed photons in exposed area
- Increasing # of photons by increasing exposure dose, improves CDU

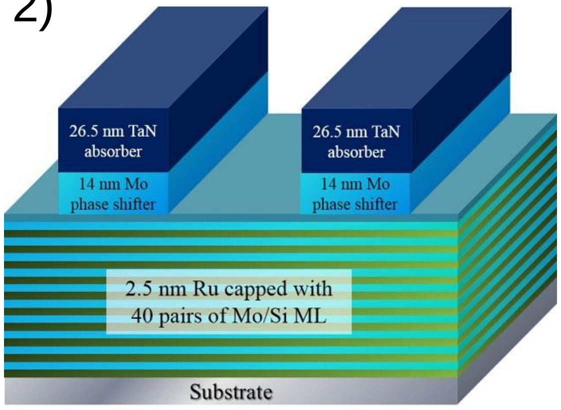
※ *Zhih-Yu Pan, SPIE Vol. 6924, 69241K (2008)*

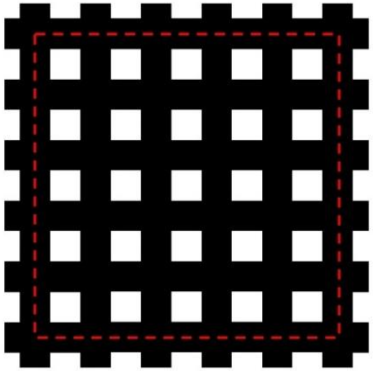
Simulation condition

1)



2)



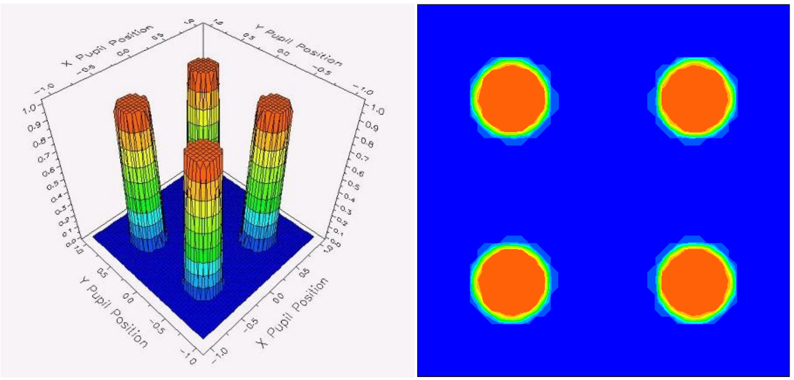


1) BIM = 70 nm TaN absorber layer

2) Attenuated PSM = 26.5 nm TaN absorber layer, 14 nm Mo phase shift layer

- <u>20, 22, 24 nm 1:1 dense C/H pattern</u>

Simulation condition



NA	0.33
Center sigma	0.7
Pole radius	0.2
AOI	6°
Demagnification	4X

Modeling of illumination condition

Simulator	PROLITH X4 (KLA-Tencor)
Resist	[Adv. CA] EUV generic resist model (offered by KLA-Tencor)

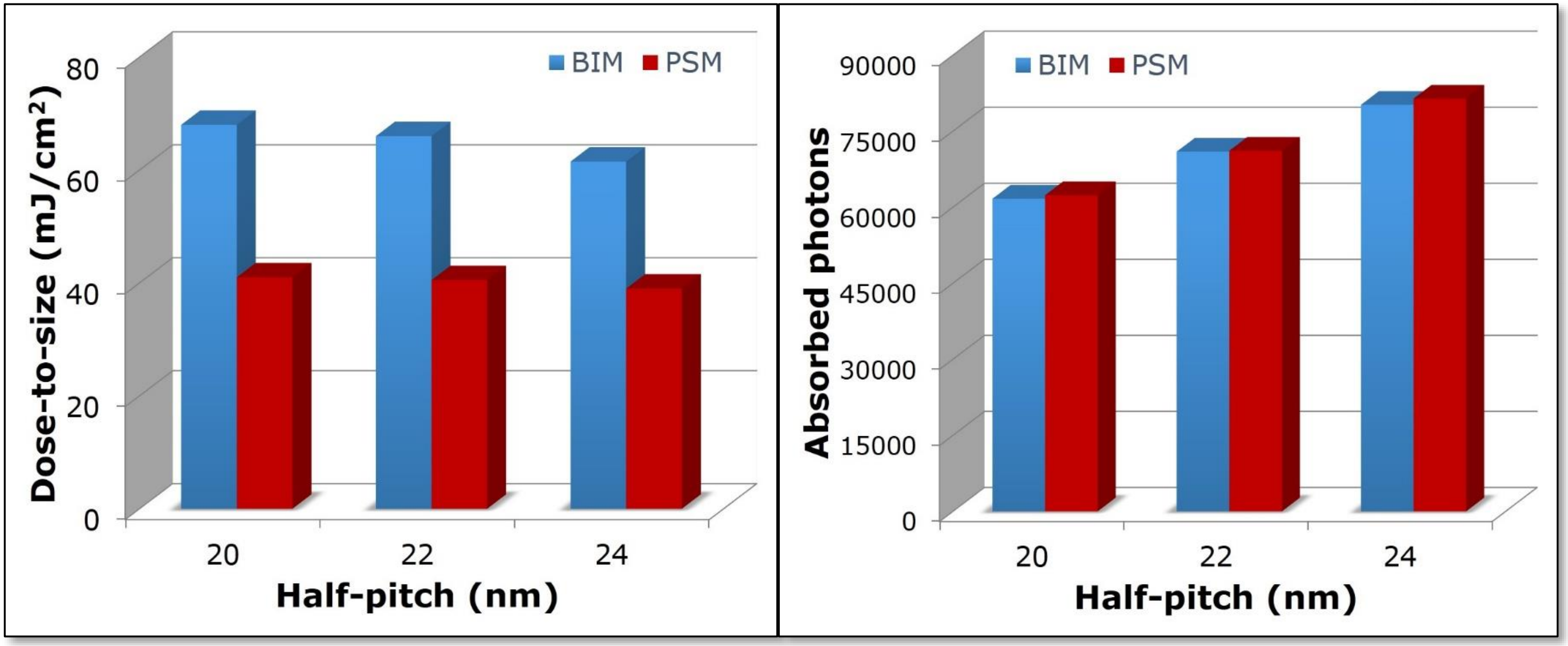
Simulator & Resist model

Material	n	k
TaN	0.9260	0.0436
Si	0.9990	0.0018
Mo	0.9238	0.0064
Ru	0.8864	0.0171

Optical constants of materials at 13.5 nm

<Refractive index (n) = 1-δ+iβ>

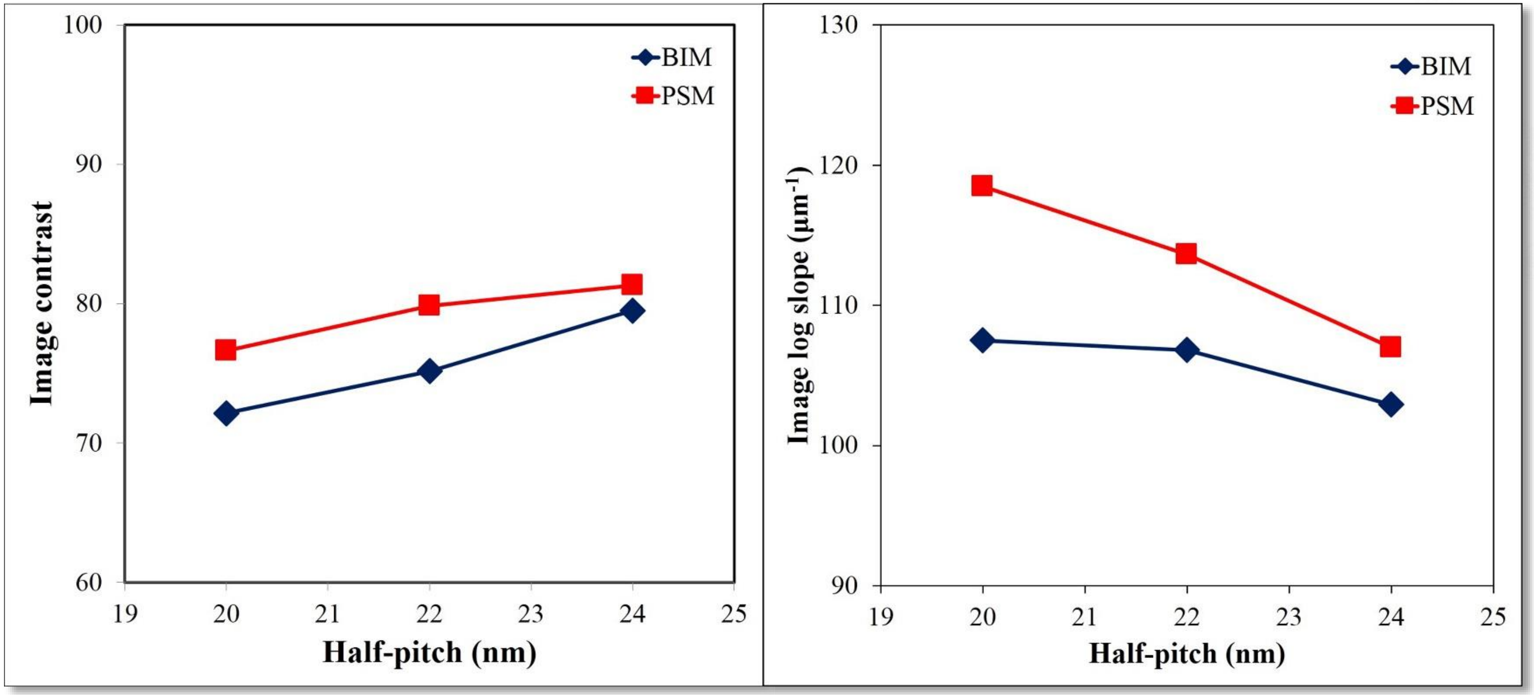
Simulation results



◆ Photon latent image simulation results

Decrease in dose-to-size by using PSM for smaller patterns

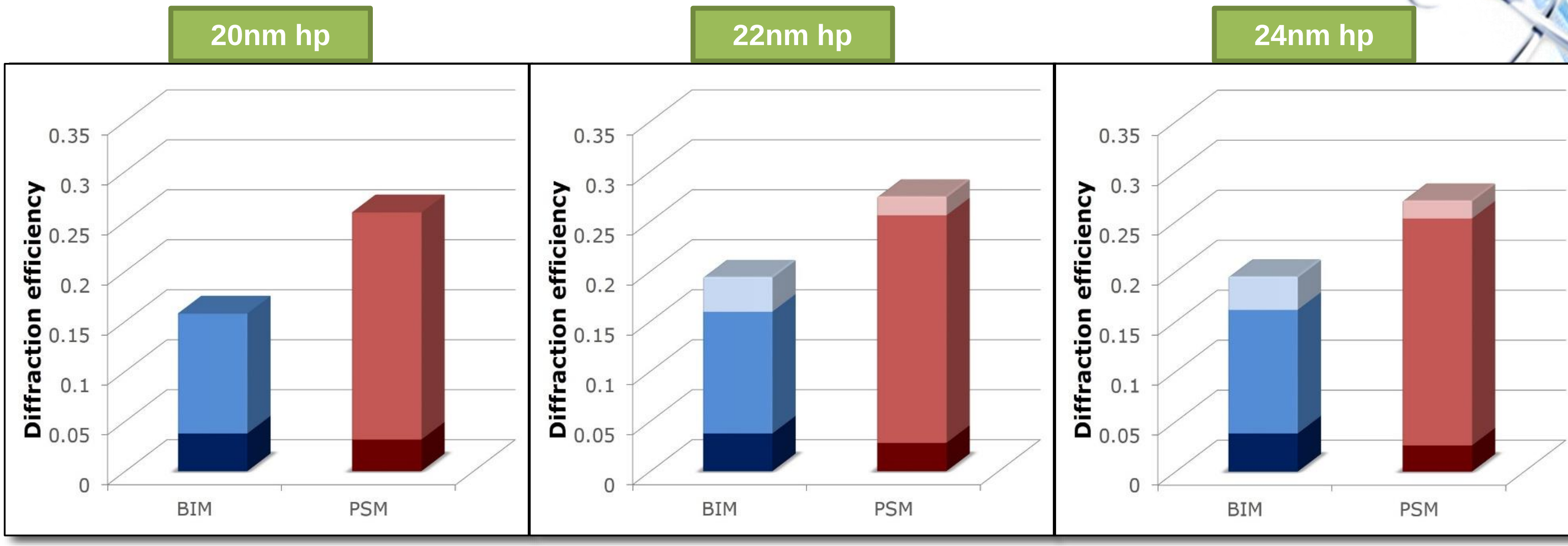
Simulation results



- Aerial image simulation results

  Improvement in image contrast and ILS by using PSM

Simulation results



■/■/■ = 0th/1st/2nd order diffraction with BIM ■/■/■ = 0th/1st/2nd order diffraction with PSM

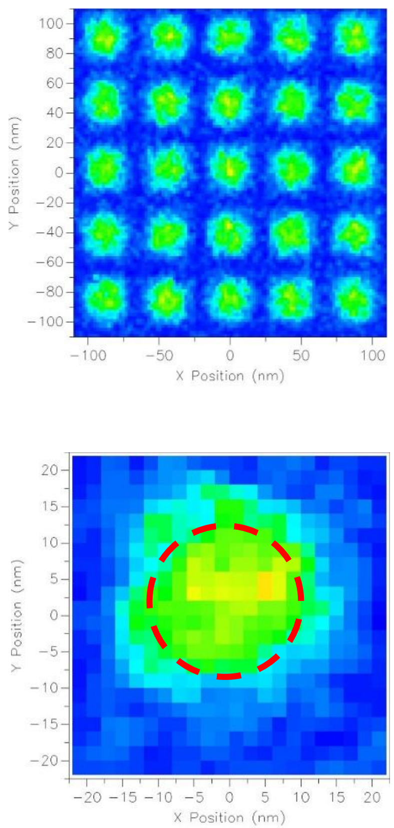
◆ Simulation results of diffraction efficiencies

Diffraction efficiencies (±1st order, ±2nd order, …) of PSM were much higher

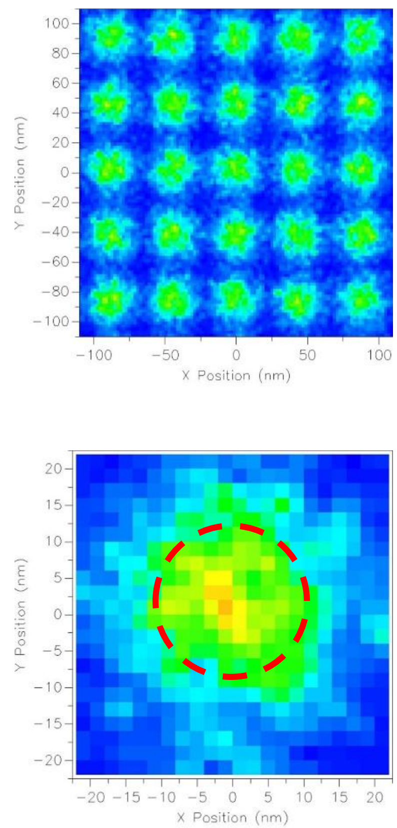
Contains information of pattern image

Simulation results

PSM

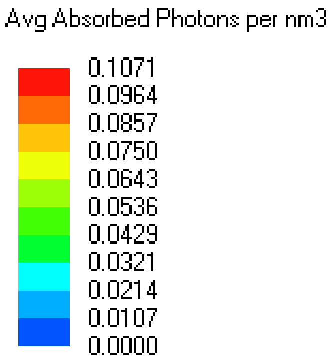


BIM

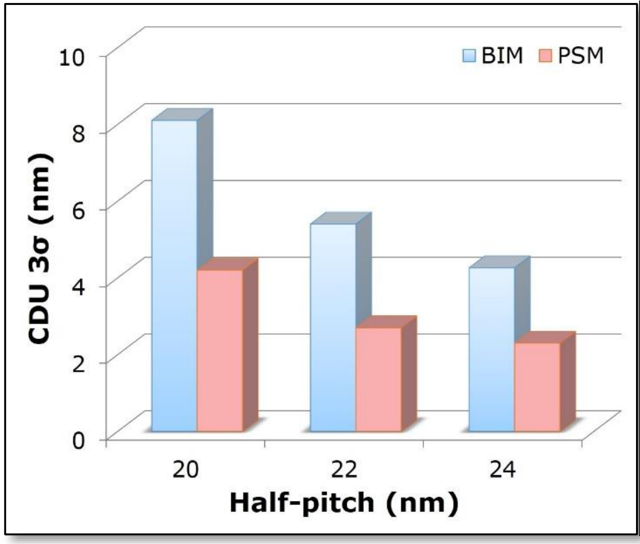


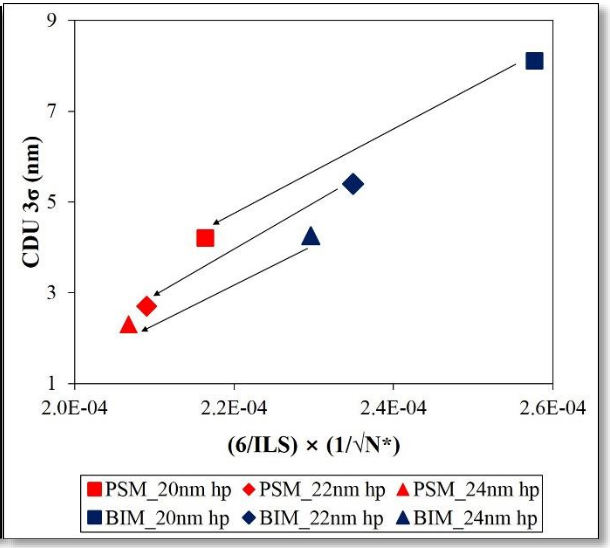
- Distinct difference in the distributions of absorbed photons

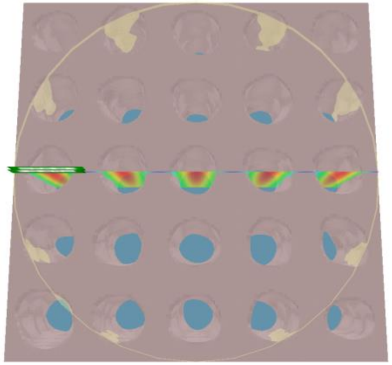
➢ <u>Less diffusion at the edge of the patterns by using PSM</u>



Simulation results





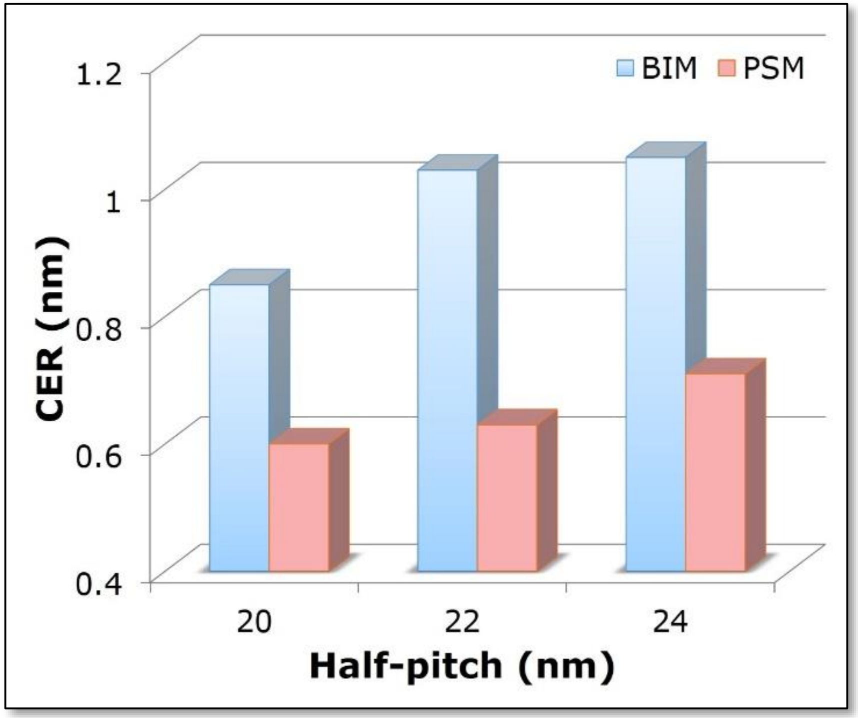


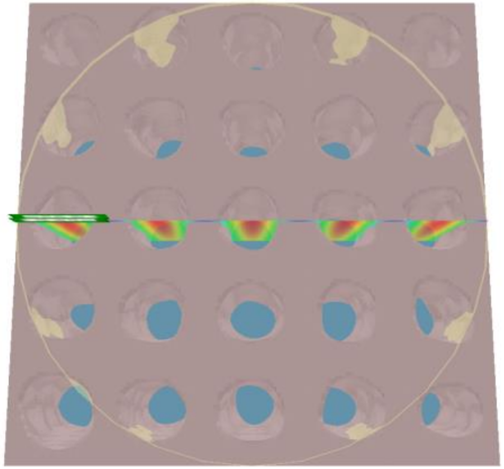
◆ Stochastic imaging performance simulation results

Improvement in CDU by adopting PSM

- CDU – 48%, 50%, 46% improvement @ 20, 22, 24 nm hp
- **CDU ∝ (6/ILS) × (1/√N*)**, N* = **diffracted photons** absorbed in exposed area

Simulation results

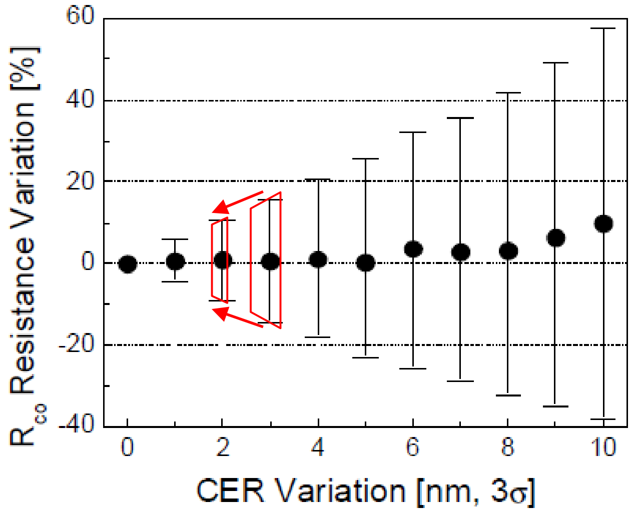




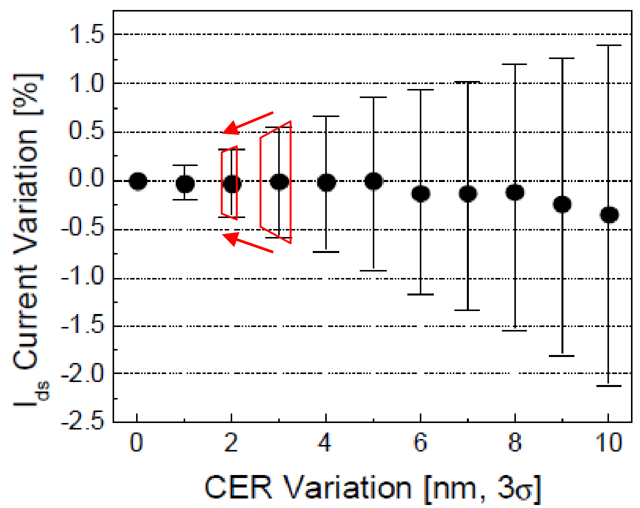
◆ Improvement in CER by adopting PSM

- CER – 29%, 42%, 37% improvement @ 20, 22, 24 nm hp

Simulation results



(a) Variation of the S/D Contact resistance



(b) Variation of the device saturation current

※Yongchan Ban, SPIE Vol. 7641, 76410D (2010)

- If the CER decreases 30% (3 nm → 2.1 nm [3σ]) for 32nm contact hole
  - Contact resistance variation: ±16% → ±8%
  - Saturation current variation: ±0.63% → ±0.26%
- CER reductions by using PSM = 29%, 42%, 37% for 20, 22, 24 nm contact holes
  - ➢ **Reduction of the resistance and current variation will be much larger**

Conclusion

- In order to alleviate PSN effect in C/H pattern, we suggested **attenuated phase-shift mask concept.**

- By using PSM
  - Dose-to-size were reduced
  - Image contrast & ILS of aerial image were increased
  - CDU & CER were improved

  comparing with a conventional BIM

- **PSN effect was effectiviely mitigated with the PSM** resulting in the improvement of stochastic imaging properties and consequently increasing the device performance of contact resistance and saturation current.

Thank you!