EUVL Activities in South Korea

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1 *Who are working on EUVL ?*

Device manufacturer and material supplier

-Samsung : DRAM, Logic, High-end Foundry

-SK hynix: DRAM

-Kumho Petrochemical: Photoresist

Academia and Research Institute

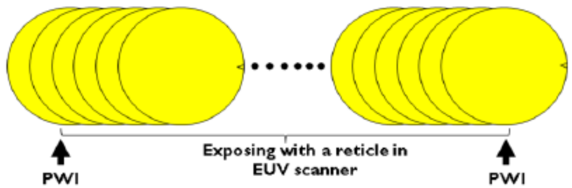
-Hanyang Univ.: EUV mask, Mask Cleaning, EUV Microscope, EUV pellicles*

***** National Nanofab Facility will join the EUV pellicle program***

Tool /component maker

-FST and Auros technology are developing EUV sources for inspection and pellicles in collaboration with customers and academia

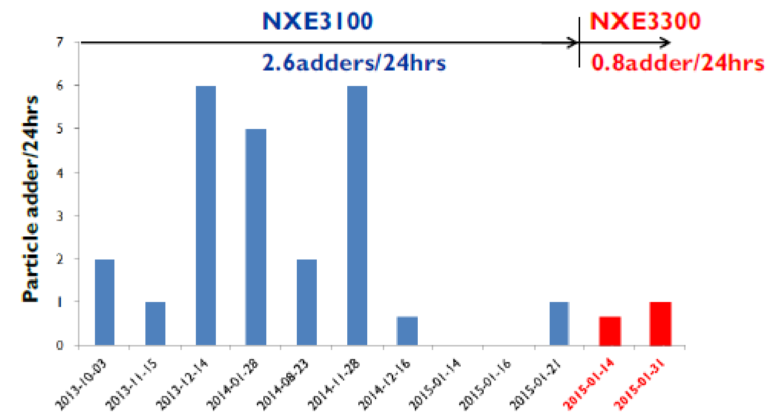
SK hynix (EUV mask particle adders during scanner exposure)



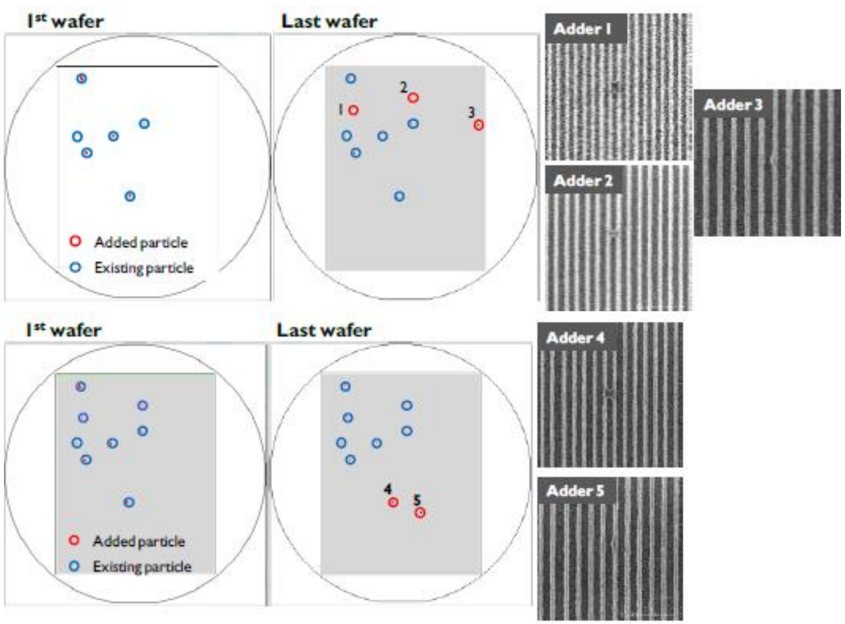
NXE3100	
Pattern on a mask	32nm LS
Mask field size	24.5 x 26.1 mm
Illumination setting	0.25NA conventional
Adder detect	PWI(+PMI)

NXE3300	
Pattern on a mask	22nm LS
Mask field size	26 x 33 mm
Illumination setting	0.33NA dipole_X 90
Adder detect	PWI

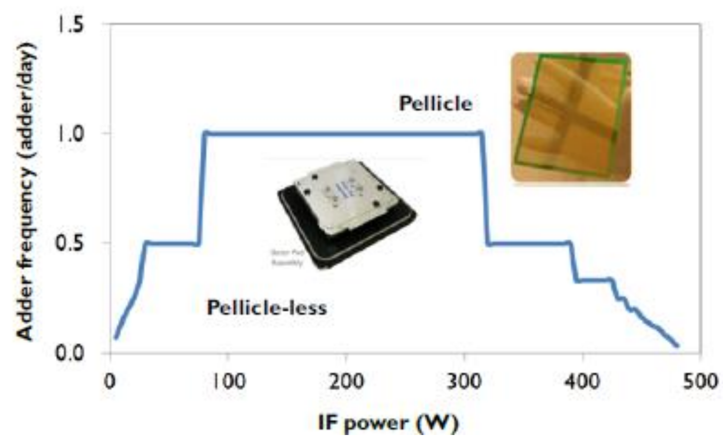
Scanner cleanliness monitoring method and test description



Particle adders decreased due to the improved mask protection functions of NXE 3300



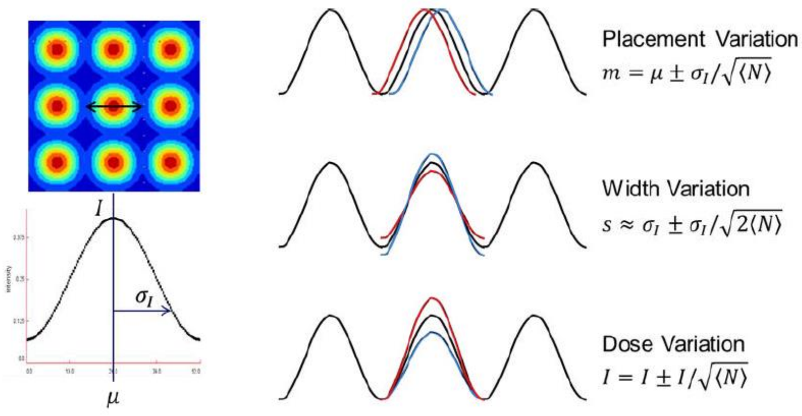
Particle adder map of PrPi (imaged particle per reticle pass) tests with wafer SEM images



Cost parity of pellicle and pellicle-less EUVL

When the scanner power source power is relatively low or higher than 300W using pellicle will be more economical in EUVL. When source power is between 100W and 300W, the boundary of pellicle and pellicle-less EUVL will be 1adder/day.

SK hynix (Study of stochastic noise)



$$\sigma^2_{stochastic} = \sigma^2_{placement} + \sigma^2_{width} + \sigma^2_{dose}$$

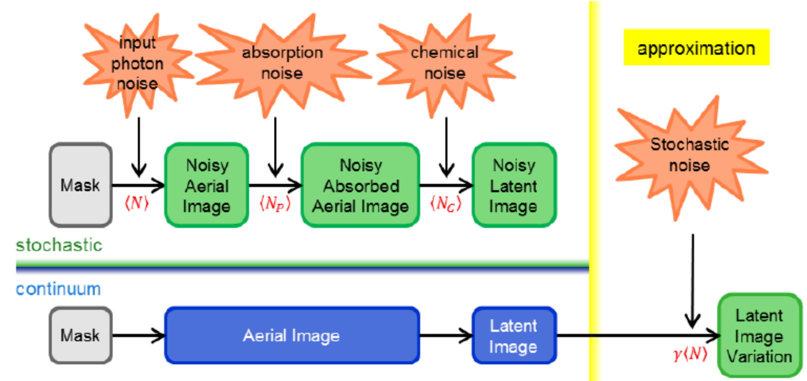
Three kinds of statistical uncertainties in dense contact-hole array during the aerial image formation

$$\sigma^2_{stochastic} = \left(\sigma^2_{placement} + \sigma^2_{width} + \sigma^2_{dose}\right)_{input} + (\cdots)_{absorption} + (\cdots)_{chemical}$$
$$= \left(\sigma^2_{input} + \sigma^2_{absorption} + \sigma^2_{chemical}\right)_{placement} + (\cdots)_{width} + (\cdots)_{dose}$$

Events	Average number of particles	Dose variation impact	Mean	Standard deviation
Input photon noise	$\langle N\rangle$	$1/\sqrt{\langle N\rangle}$	$m_I = \mu \pm \sigma_I/\sqrt{\langle N\rangle}$	$s_I \approx \sigma_I \pm \sigma_I/\sqrt{2\langle N\rangle}$
absorption noise	$\langle N_P\rangle = a\langle N\rangle$	$1/\sqrt{\langle N_P\rangle}$	$m_P = \mu \pm \sigma_I/\sqrt{\langle N_P\rangle}$	$s_P \approx \sigma_I \pm \sigma_I/\sqrt{2\langle N_P\rangle}$
chemicals noise	$\langle N_C\rangle \equiv b\langle N_P\rangle = ab\langle N\rangle$	$1/\sqrt{\langle N_C\rangle}$	$m_C = \mu \pm \sigma_I/\sqrt{\langle N_C\rangle}$	$s_C \approx \sigma_I \pm \sigma_I/\sqrt{2\langle N_C\rangle}$
total noise	$\gamma\langle N\rangle$	$1/\sqrt{\gamma\langle N\rangle}$	$m = \mu \pm \sigma_I/\sqrt{\gamma\langle N\rangle}$	$s \approx \sigma_I \pm \sigma_I/\sqrt{2\gamma\langle N\rangle} \approx \sigma_I(1 \pm \varepsilon)$

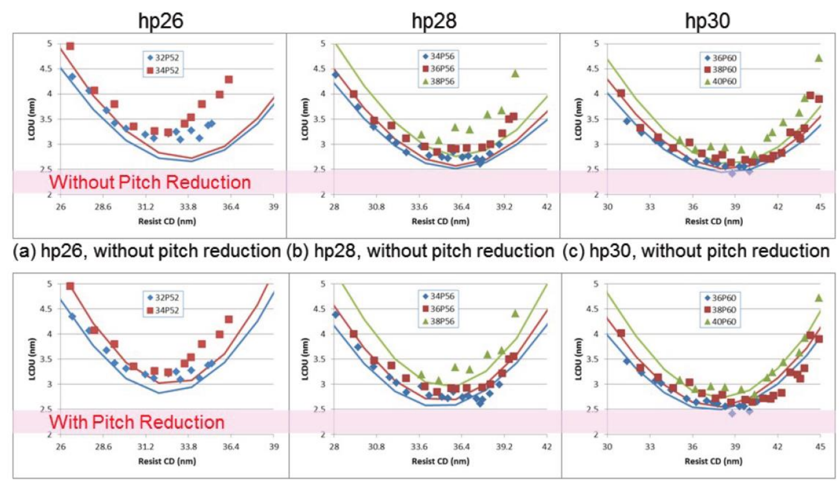
where γ is event efficiency which is defined by $\frac{1}{\gamma} \equiv 1 + \frac{1}{a} + \frac{1}{ab}$ and $\varepsilon \equiv 1/\sqrt{2\gamma\langle N\rangle}$

Three kinds of stochastic events in the lithography process



$$\sigma^2_{stochastic} \approx \left(\frac{2}{bILS}\right)^2 \left[1 + \frac{1}{2}\left(\frac{\partial \ln L'}{\partial \vec{p}} \cdot \vec{\beta}\right)^2\right] \frac{1}{\gamma\langle N\rangle}$$

Three stochastic events can be merged to a total event and assumed to make impact on latent image directly

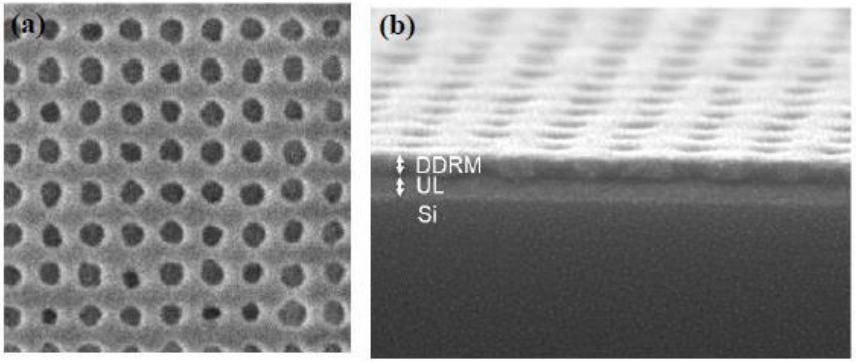


(a) hp26, without pitch reduction (b) hp28, without pitch reduction (c) hp30, without pitch reduction

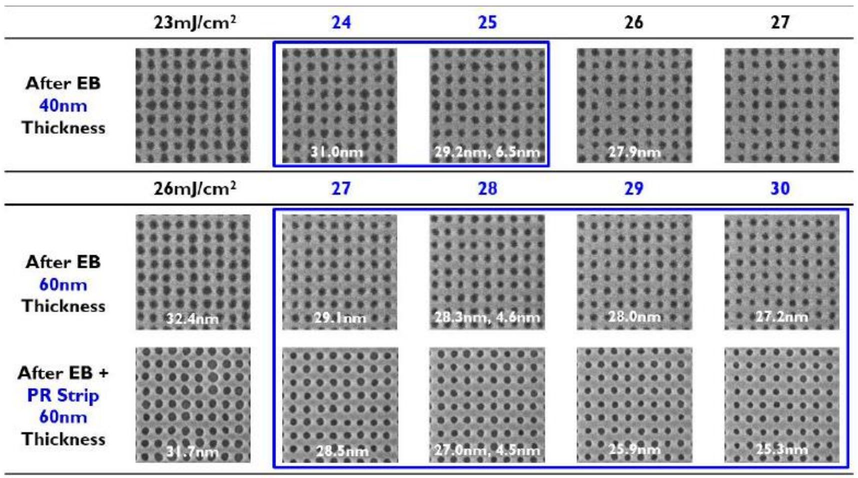
Comparison between experimental LCDU and model prediction

Matching looks good especially in 'with pitch reduction' case due to the placement variation effect

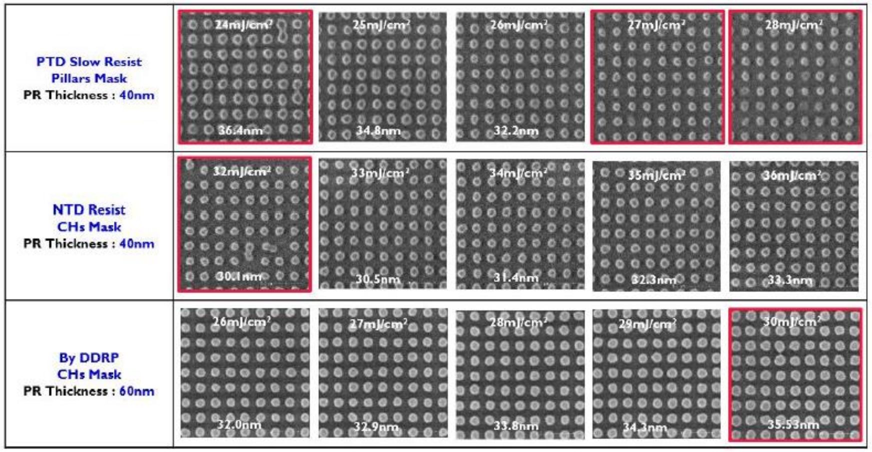
2 SK hynix (Contact holes and pillars patterning)

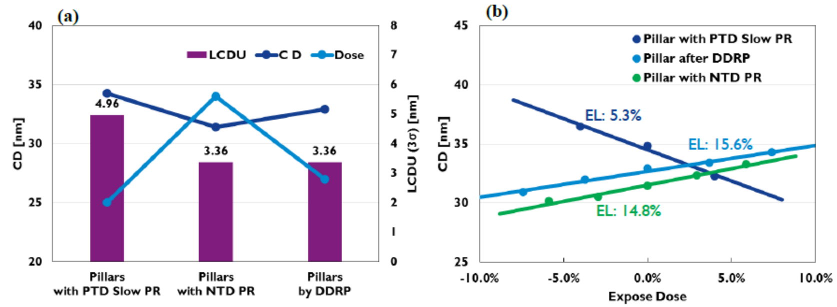


Dry development rinse process (DDRP) was introduced from Nissan Chemicals.



Improvement of process margin and LCDU by optimization of DDRP





Pillars patterning performance improved by NTD resist and DDRP

It is necessary to study further on the high sensitive NTD resist to reduce the DtS and optimize the DDRP and DDRM for better isolated patterning

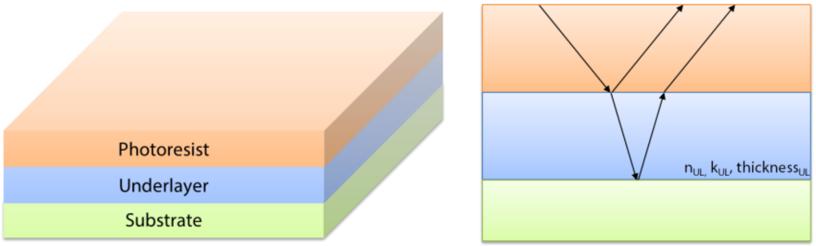
2 Samsung Summary

- ***Actinic inspection***
  - ***EUV Mask Defect Review System (EMDRS) developed for mask inspection and compensation repair (using Zone plate for precise focus and accurate inspection)***
  - ***Collaborated with Hanyang Univ. for EUV Coherent Scattering Microscopy (CSM)***

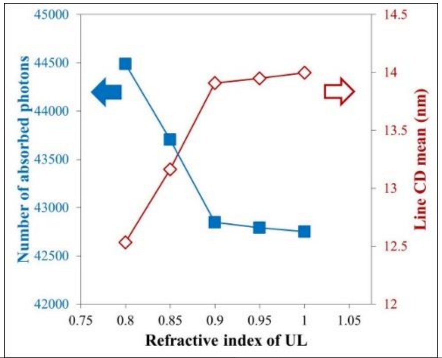
- ***EUV pellicle***
  - ***Si based material and structure is on research for high transmittance (>90%) EUV pellicle***
  - ***Studying of thermal stability of EUV pellicle***

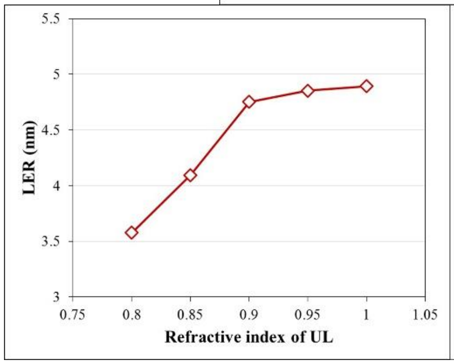
    - pSi pellicle membrane may not stable above 200W of EUV source power

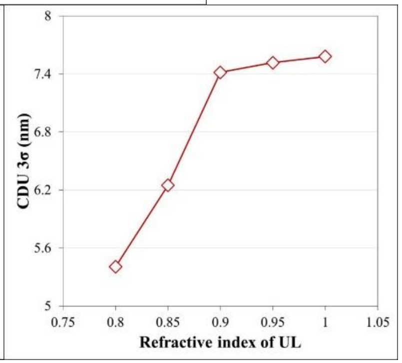
Hanyang University (EUV Underlayer)



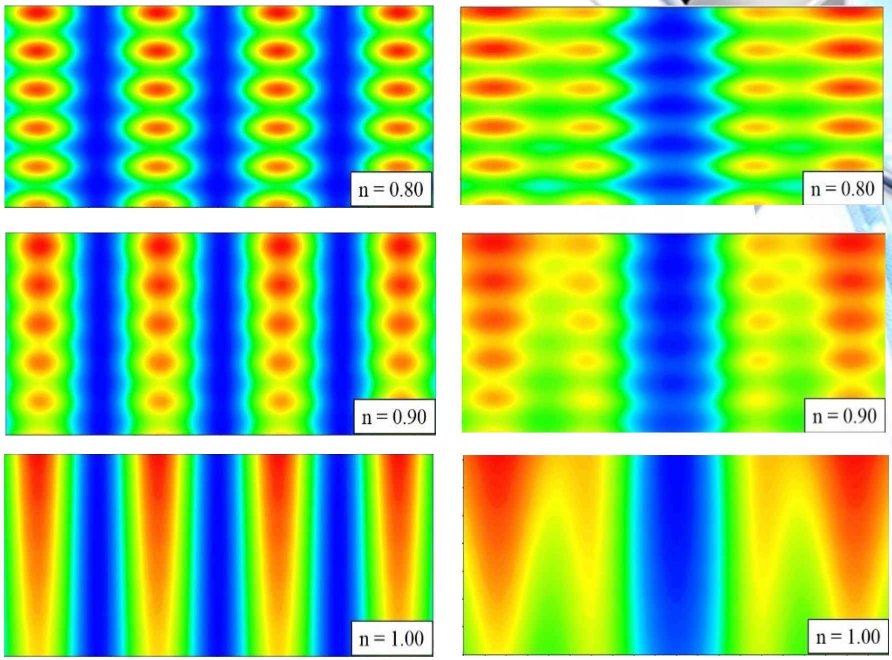
Schematic image of photoresist and underlayer







Smaller refractive index of the UL increases the number of absorbed photons in PR, resulting in LER decrease due to mitigation of photon shot noise effect



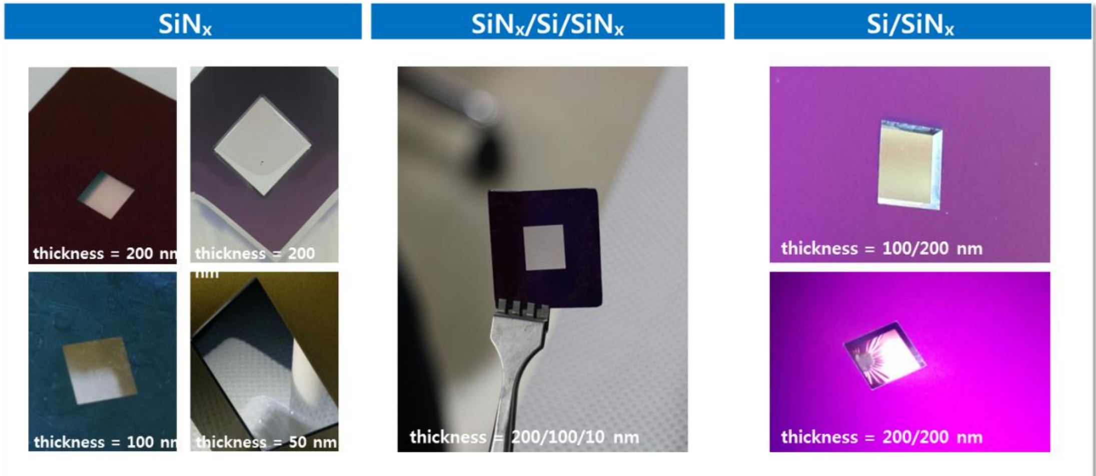
Serious standing wave effect with low refractive index of UL, and this effect varies with pattern pitch ratio (below)

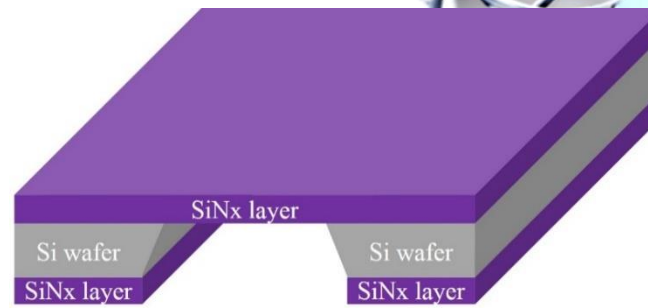
Refractive index of UL	1:1 pitch ratio	1:5 pitch ratio
0.80	5 nm	10.7 nm
0.85	4.4 nm	9.4 nm
0.90	2.2 nm	4.0 nm
0.95	1.3 nm	2.2 nm
1.00	0.0 nm	0.0 nm

Difference in line CD between the underexposed area and overexposed area at the light intensity in resist image

3 Hanyang University (Fabrication of EUV pellicle)

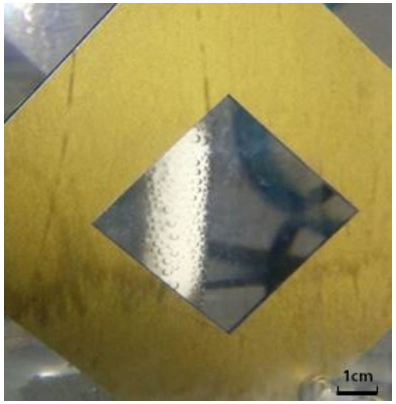
◆ *Diversification of pellicle membrane structure*





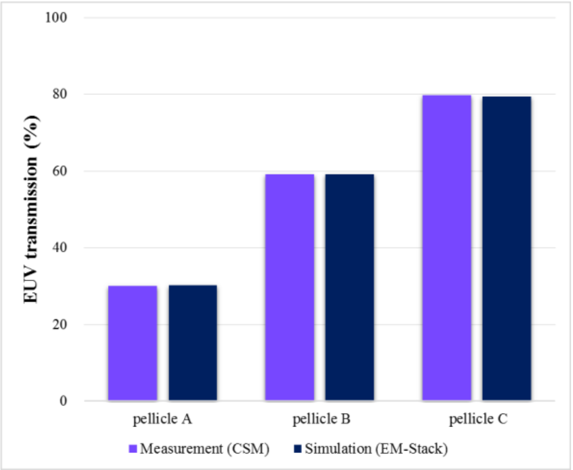
	Measurement (CSM)	*Simulation (EM-Suite)**
Pellicle A (175 nm)	*30.0%*	*30.3%*
Pellicle B (93 nm)	*59.2%*	*59.2%*
Pellicle C (43 nm)	*79.7%*	*79.4%*

◆ *Process set-up for pellicle test vehicle (various materials accepted)*



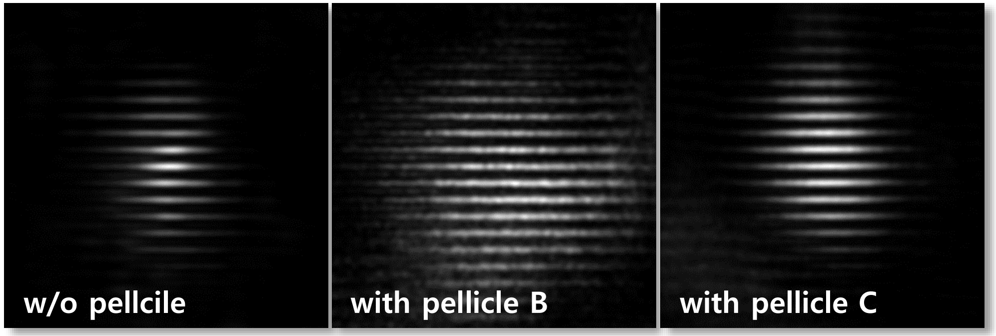
40mm X 40mm pellicle process stabilized

Transmittance of fabricated EUV pellicle



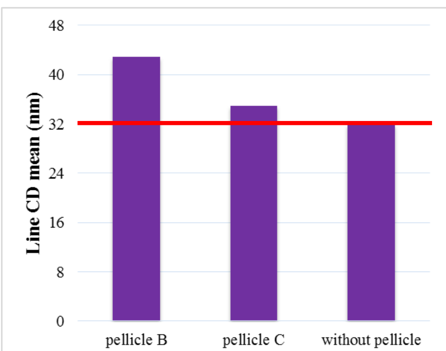
3 Hanyang University (Optical effect of EUV pellicle)

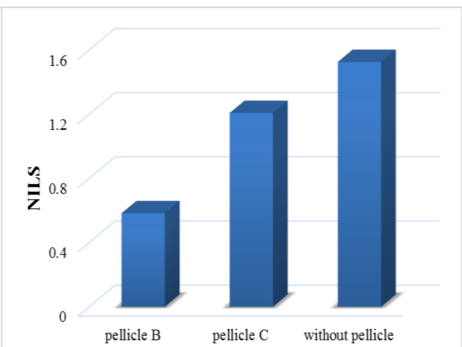
- ◆ *Result of aerial image reconstruction by CSM (32 nm hp L/S pattern)*

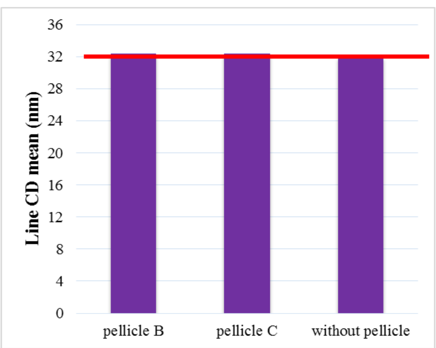


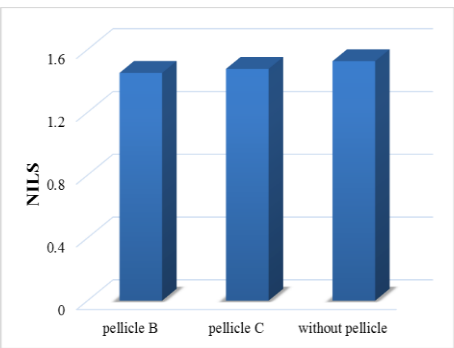
As the transmittance decreases, darker aerial images are obtained resulting in larger CD and smaller NILS at fixed threshold (CSM image)

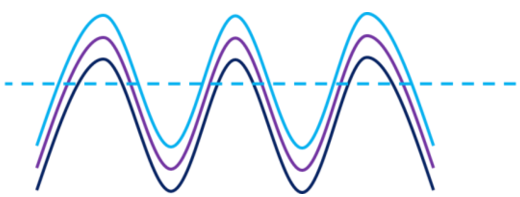
	Fixed threshold		Relative threshold	
	CD (nm)	NILS	CD (nm)	NILS
Pellicle B (59% transmission)	42.9	0.583	32.4	1.451
Pellicle C (80% transmission)	34.9	1.208	32.4	1.477
Without pellicle	31.9	1.526	31.9	1.526



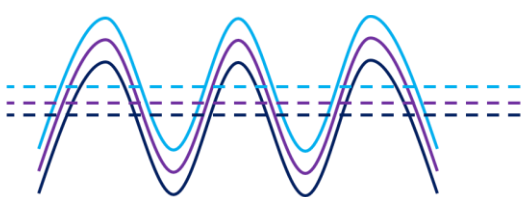






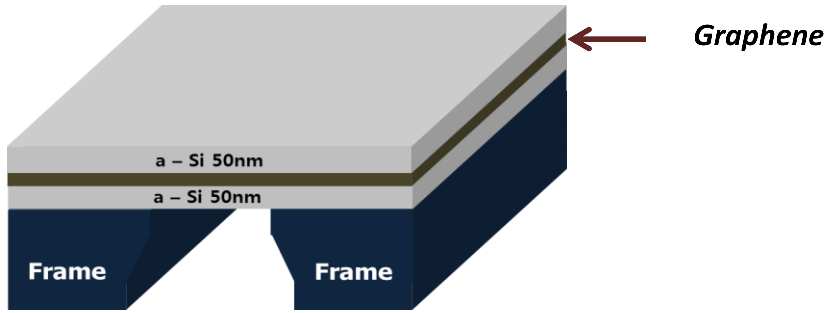


<Fixed Intensity threshold of aerial image : fixed exposure time >

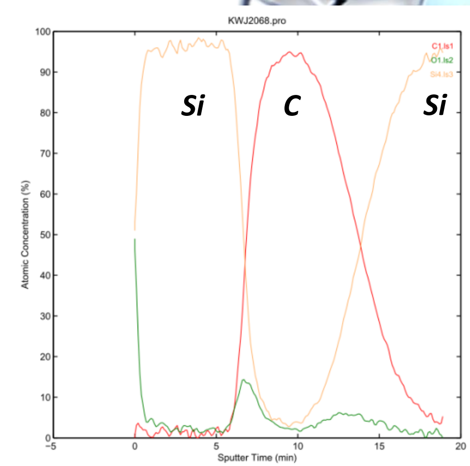


< Relative Intensity threshold of aerial image : exposure time variation >

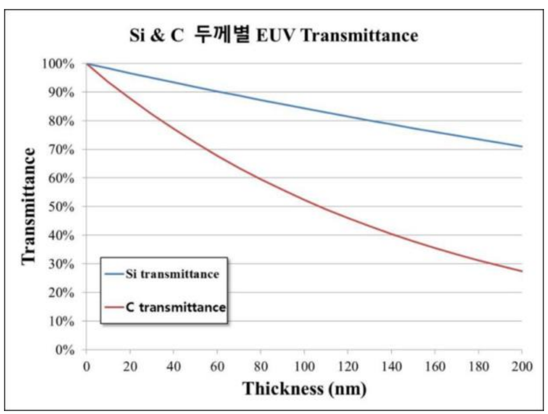
Hanyang University (Graphene composite pellicle)



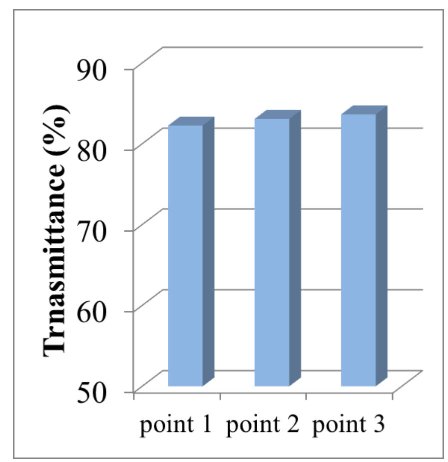
a-Si/graphene/a-Si membrane (100nm)



XPS data



According to simulation and experiment, graphene absorbs ~0.2% of EUV per layer. (10 layers graphene transmittance ~ 98%)

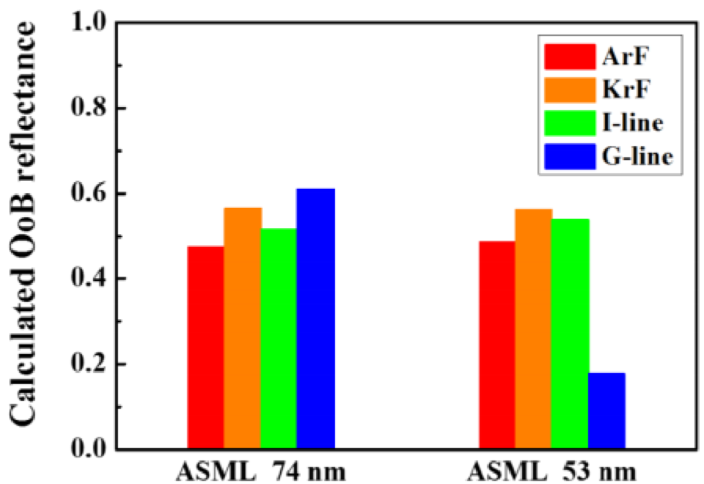


Uniformity of a-Si(43nm)/graphene 10 layers/a-Si(43nm)

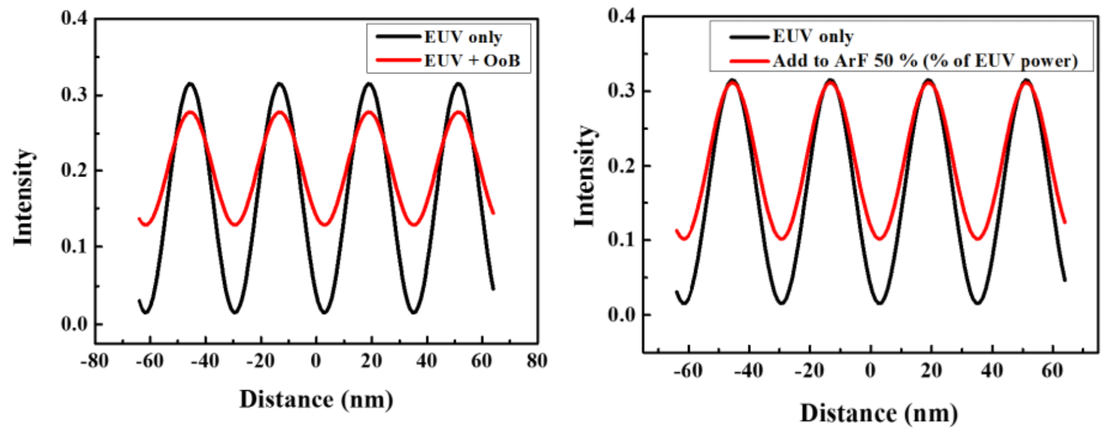
Hanyang University (OoB reduction with EUV pellicle)

Wavelength		Intensity ratio (relative to EUV)	
		@ IF	@ Pellicle
In-Band	EUV (13.5 nm)	100 %	
Out-of-Band	ArF (193 nm)	~ 47	~ 33
	KrF (248 nm)	~ 33	~ 30
	I-line (365 nm)	~ 5	~ 3
	G-line (436 nm)	~ 5	~ 1

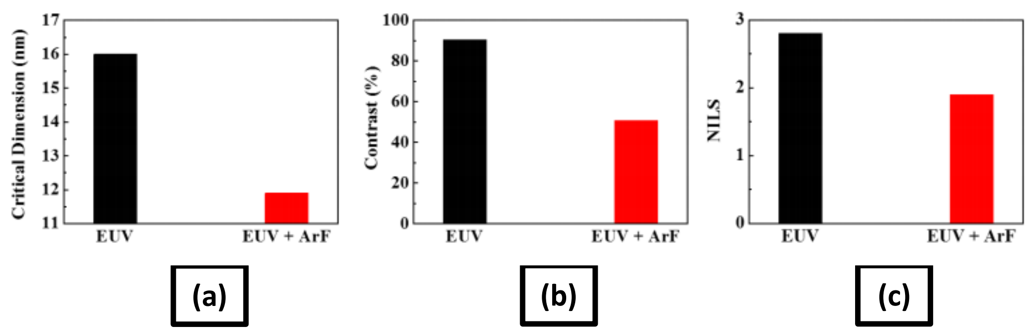
Calculated intensity ratio of in-band and out-of-band



Reduced ratio of OoB radiation reflectance for ASML EUV pellicles (SiN/poly-Si/SiN) compared to that without a pellicle



Aerial image deformation by OoB radiation and with ASML EUV pellicle



(a) Image CD error and (b) Contrast decrease, and (c) NILS decrease

4 New Project (Submitted)

Target

- *Providing platform technologies for EUV pellicle development*

Project team

- *Project leader: Hanyang Univ.*
- *National Nano Fab Center, KAIST, SKKU, CPRI*

Scope of research

- *Full-scale membrane process*
- *EUV pellicle evaluation technologies*
- *New pellicle materials for high-power EUV source*

Collaborations are welcomed !!

Thank you