EUVL Activities in South Korea

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1 *Who are interested in EUVL ?*

Device manufacturer and material supplier

-Samsung : DRAM, Logic, High-end Foundry

-SK hynix: DRAM

-Kumho Petrochemical: Photoresist

Academia and Research Institute

-Hanyang Univ.: strongest activities on Mask/Pellicle/Cleaning/Process Simulation

-SKKU, Inha Univ., KAIST etc.

Tool maker

-Some small/med. size companies (e.g. FST, Auros tech…) are developing EUV-related tools and EUV pellicles in collaboration with customers and academia

1 EUVL insertion scenario

Samsung

Plan to insert EUVL for 1X nm node DRAM in 2016

- Discussion with ASML for EUVL mass production

Coherent scattering microscopy (CSM) was installed for mask inspection

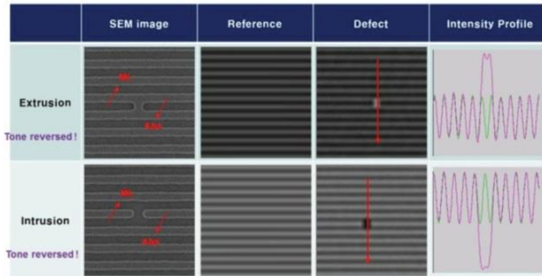
- Using Zone plate for precise focus and accurate inspection

SK hynix

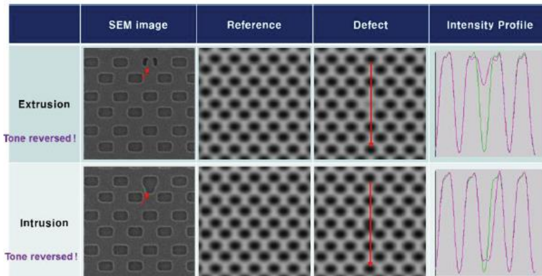
Plan to insert EUVL for 2Z or 1X nm node DRAM in 2015 ~ 2017

- The power of EUV source for mass production is a critical issue

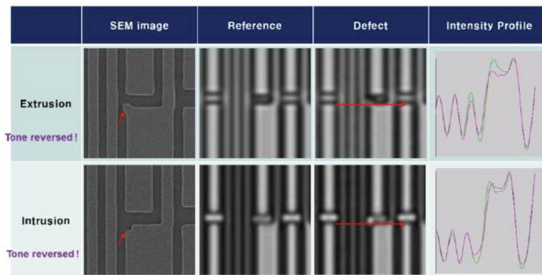
2 Samsung (EUV mask inspection for sub-20nm device)



Inspection image with bridge(extrusion) and cut(intrusion) defect in 1:1 L/S of 2Xnm HP node



Inspection image with extrusion and intrusion defect in dense CNT of 2Xnm HP



Inspection image with extrusion and intrusion defect in isolated pattern of 2Xnm HP

2Xnm HP L/S		1	2	3	4	5	6	7	8	9	10	11	12
Extrusion	Printability								54nm	45.3mn	34.2nm	27.4nm	
	Die to Die	100%	100%	100%	100%	100%	100%	100%	100%	100%	72%	16%	
	Die to DB	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	40%	
Intrusion	Printability								49.8nm	39.2nm	34.1nm	22.6nm	
	Die to Die	100%	100%	100%	100%	100%	100%	100%	100%	100%	92%		
	Die to DB	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	44%	

2Xnm HP CNT		1	2	3	4	5	6	7	8	9	10	11	12
Extrusion	Printability								54.1nm	42.4nm	38.3nm	36.9nm	25.2nm
	Die to Die	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	36%	
	Die to DB	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	36%
Intrusion	Printability								51.1nm	43.2nm	32.1nm	23.6nm	18.4nm
	Die to Die	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
	Die to DB	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	

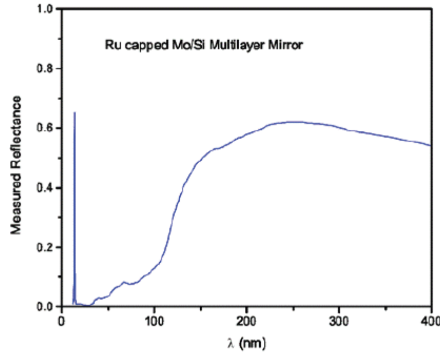
2Xnm HP Iso. Pattern		1	2	3	4	5	6	7	8	9	10	11	12
Extrusion	Printability								44.8nm	43.2nm	40.8nm	37.1nm	
	Die to Die	100%	100%	100%	100%	100%	100%	100%	96%	92%	92%	80%	
	Die to DB	100%	100%	100%	100%	100%	100%	100%	100%	100%	96%	80%	
Intrusion	Printability								49.6nm	44nm	38.4nm	34.6nm	
	Die to Die	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	60%	
	Die to DB	100%	100%	100%	100%	100%	100%	100%	100%	16%			

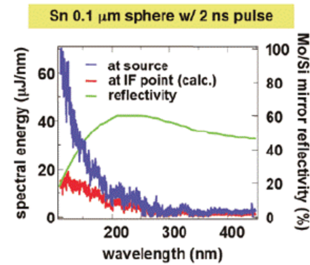
Sensitivity		L/S	CNT	Iso. Pattern
Extrusion	Die to Die	Bad	Bad	Good
	Die to DB	Good	Bad	Good
Intrusion	Die to Die	Good	Good	Good
	Die to DB	Good	Good	Bad
Tone reversal		Reversed	Reversed	Reversed
Readiness		OK	Insufficient	OK

Die-to-DB inspection has slightly better detectability than Die-to-Die. Unlike general optical mask inspection, specific optimal inspection condition exists at a given set of illumination condition, pattern size, and blank type for EUV's

2

Samsung (DUV OoB suppression techniques)

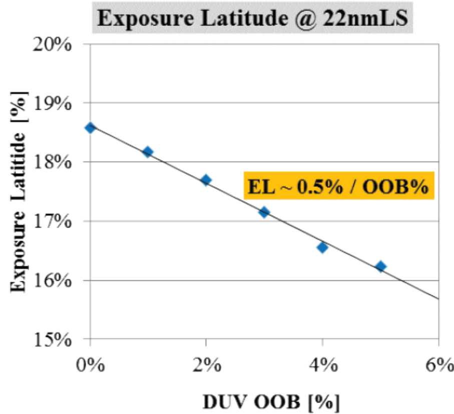


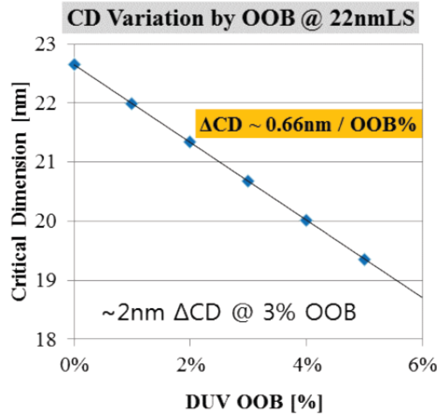


Energy of OoB emission, in the range of 100 - 400 nm, is 2.78 mJ@source, corresponding to 1.14 mJ@IF or 22.1 % of 13.5-nm

Reflectivity of EUV multilayer and OOB

	Method	Pros.	Cons.
System	- DUV Membrane Filter - Optics grating	- Full field shielding of OoB	- EUV photon Loss
Material	- OoB absorbing material (Top Coat)	- Full field shielding of OoB - Resist outgas suppression	- EUV Photon Loss - Extra processing time/cost
Mask	- ML etched BB	- BB field OOB and EUV flare suppression	- Mask Registration - Extra mask processing time/cost





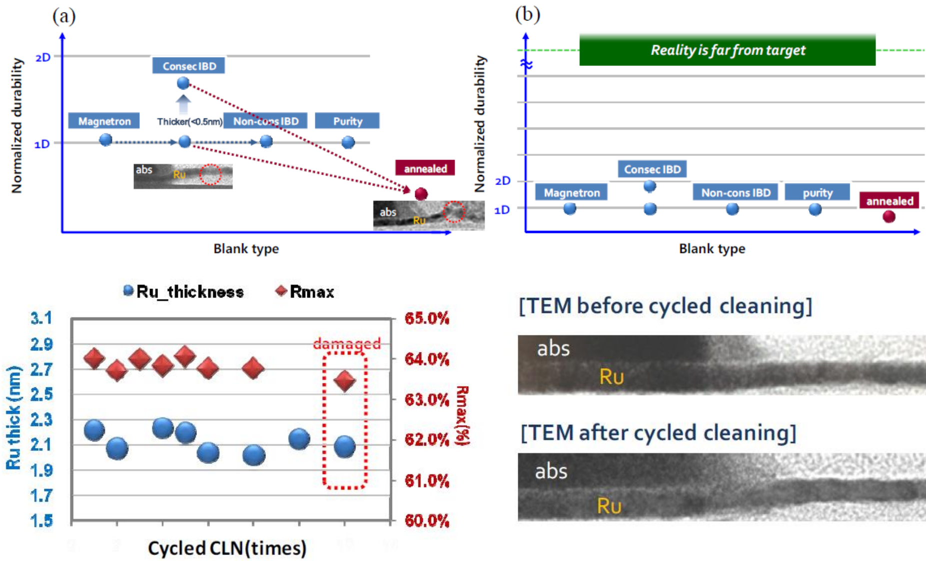
Simulation results of EL & CDU related to DUV OOB

NXE3300 results @ NXE3100 hybrid Source

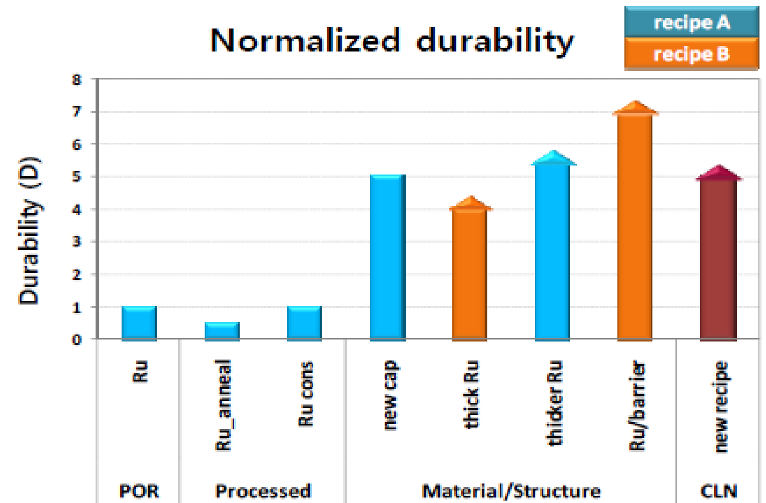
Reference	1x BB	3x BB	1x REMA	3x REMA
3300 (25.5nm)	~2.5nm	Collapse	<0.5nm	~ 1nm
3100 (25.5nm)	~1.5nm	Collapse	<0.2nm	<0.5nm

DUV OOB in EUV system is big roadblock and it should be cleared to implement EUV lithography technology for mass production. New experiment method to verify NXE3100 and NXE3300 REMA OOB effect was mentioned and analyzed each effect.

2 Samsung (Durability of EUV masks)



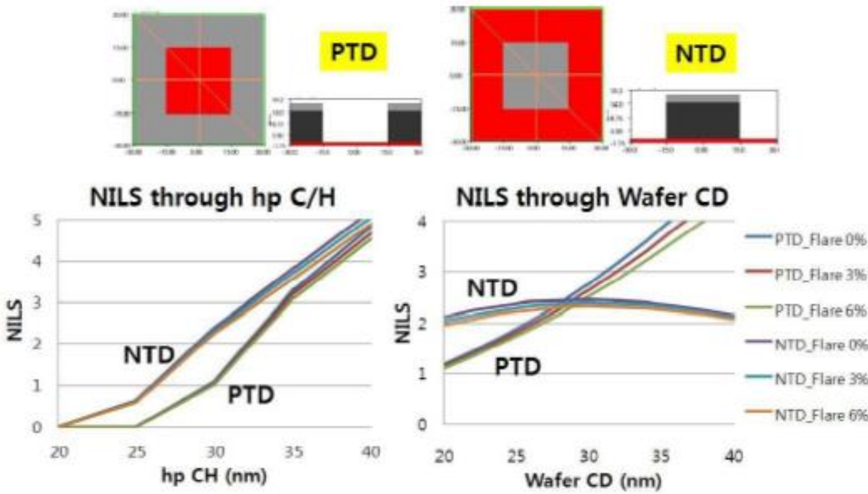
Check list	POR	New Capping	Thick Ru	Ru /w barrier
Durability /w IUV CLN	1D	5D	5.5D	7D
Thickness loss	<0.3nm/1D	<0.1nm/1D	<0.15nm/1D	0.03nm/1D
TEM analysis	damaged	Bad adhesion bt. Abs and capping	OK	OK
Etch stopper	OK	OK	OK	OK
Repair-ability	OK	Repair margin is reduced by 50%	OK	OK
Abs. blank inspection	~XX @100nm	~X @100nm	~XX @100nm	Use etch chamber w/o defect control
Defect issue	OK	Need to check	Need to check	Need to check



	Durability	SEM(BF C.CLN)	SEM(AFT C.CLN)	TEM(AFT C.CLN)
New material	5D	ini	5D	5D abs oxide Ru-alloy
Barrier below Ru	>7D	ini	7D	7D abs Ru
Thicker Ru	>5.5D	ini	5.5D	5.5D abs Ru

Ru damage mechanism regarding IUV cleaning is verified by evaluating capping with various conditions. In the beginning of Ru damage procedure, oxygen is absorbed into Ru under the UV radiation increases, resulting in the formation of SiO2 layer. Then, the SiO2 beneath Ru causes Ru film stress causing volume expansion and weak adhesion. Finally, the peeling is occurred by physical force like mega-sonic.

SK hynix (patterning performance of PTD and NTD)



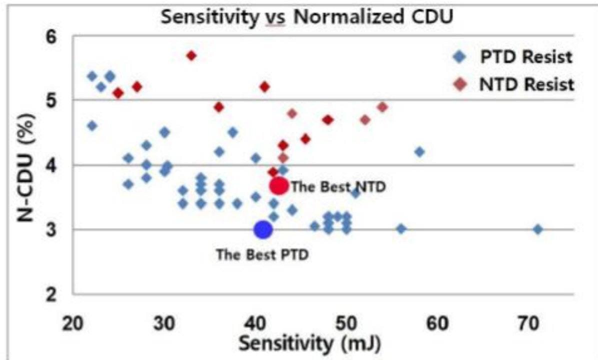
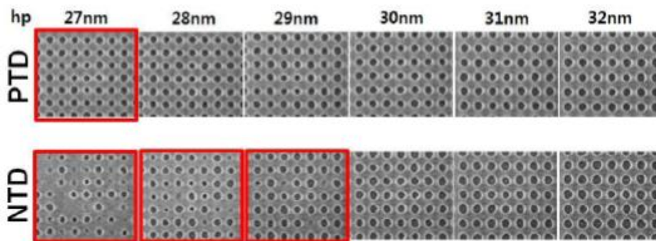
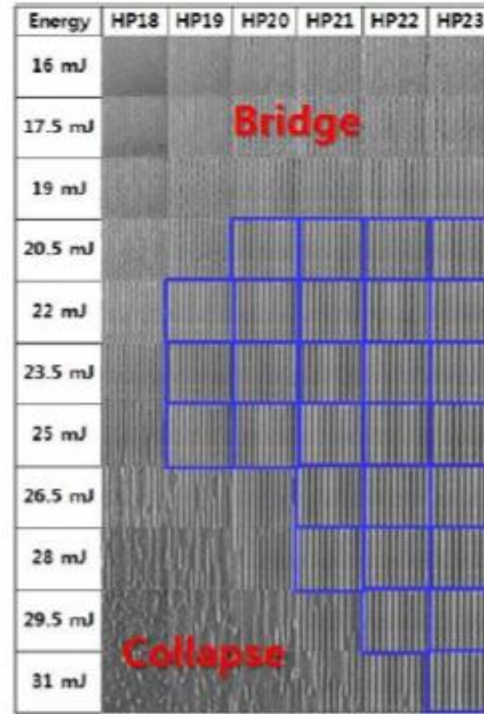
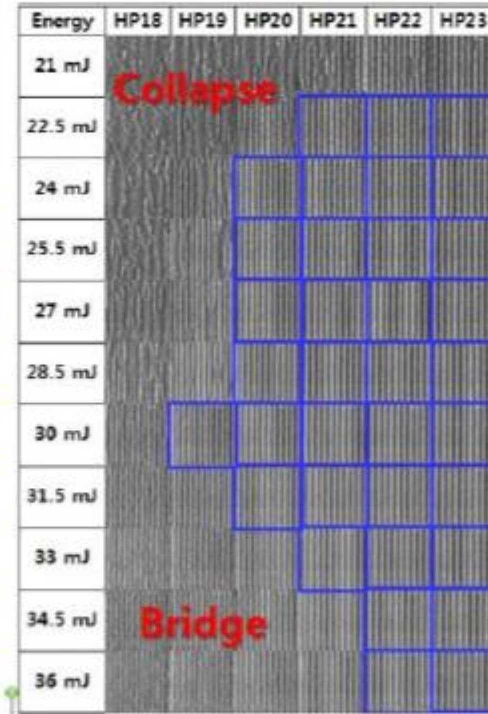


Table. 3 Resolution limit for contact hole between EUV PTD and EUV NTD





EUV PTD



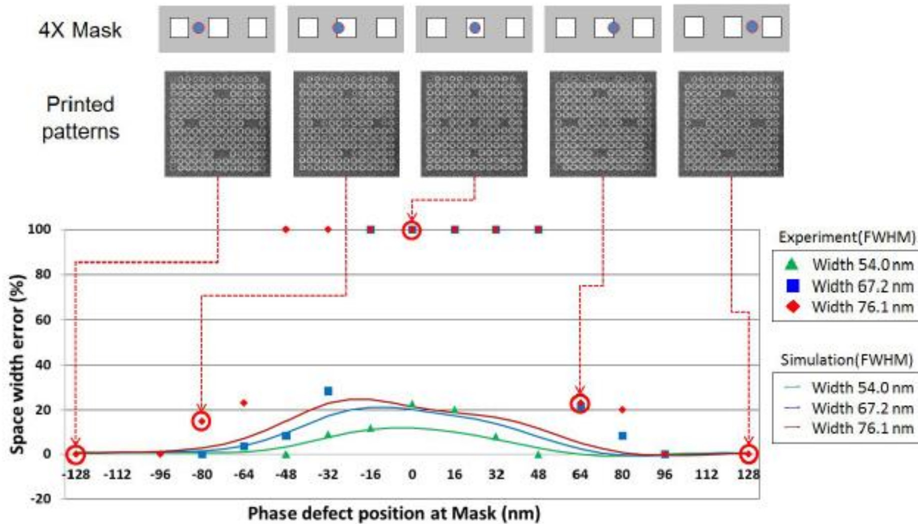
EUV NTD

DRAM has shrunk to 1Xnm in R&D area and at the same time patterning technology has become one of the major challenges, but cost of DPT/SADP and EUV source power issues are pushing development of high sensitive resist and related process. The major motivation of EUV NTD is higher image contrast and swelling free property compared to EUV PTD. Currently same resolution limit and wider process window was demonstrated on EUV NTD L/S but overall performance of EUV NTD contact hole is still behind EUV PTD.

SK hynix (phase defect effect analysis)

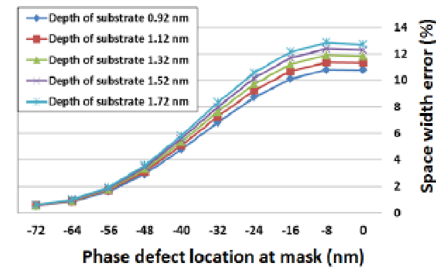
Resist patterns (Phase defect) / Mask	Lx ~ -hp	Lx ~ -hp/2	Lx ~ 0	Lx ~ hp/2	Lx ~ hp
ML surface W=54 nm D=0.96 nm					
ML surface W=67.2 nm D=1.45 nm					
ML surface W=76.1 nm D=1.70 nm					

Wafer SEM image of 32 nm CH patterns printed from a test mask for various location Lx of the pit phase defects with three different sizes

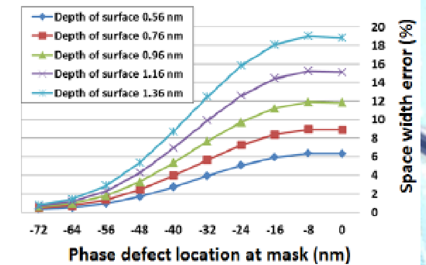


Measured space error of 32nm CH patterns

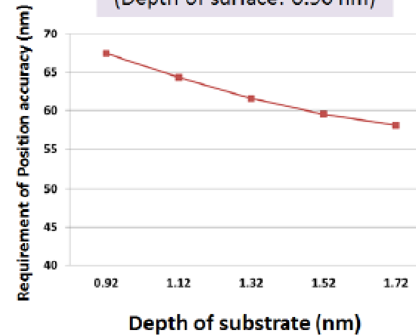
Depth of substrate : variable
(Depth of surface: 0.96 nm)



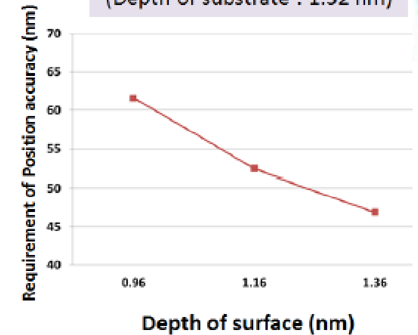
Depth of surface : variable
(Depth of substrate : 1.32 nm)



Depth of substrate : variable
(Depth of surface: 0.96 nm)



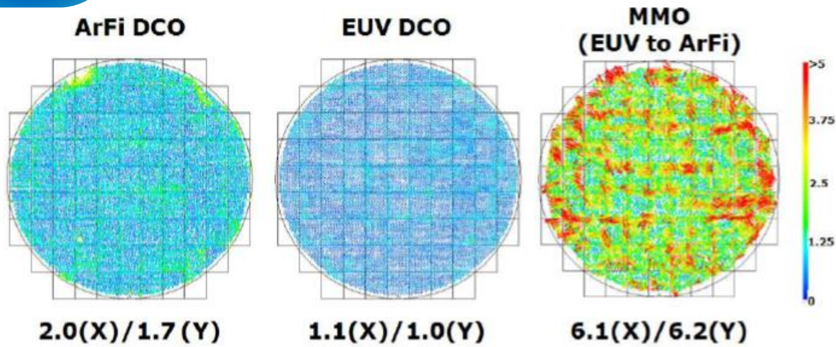
Depth of surface : variable
(Depth of substrate : 1.32 nm)

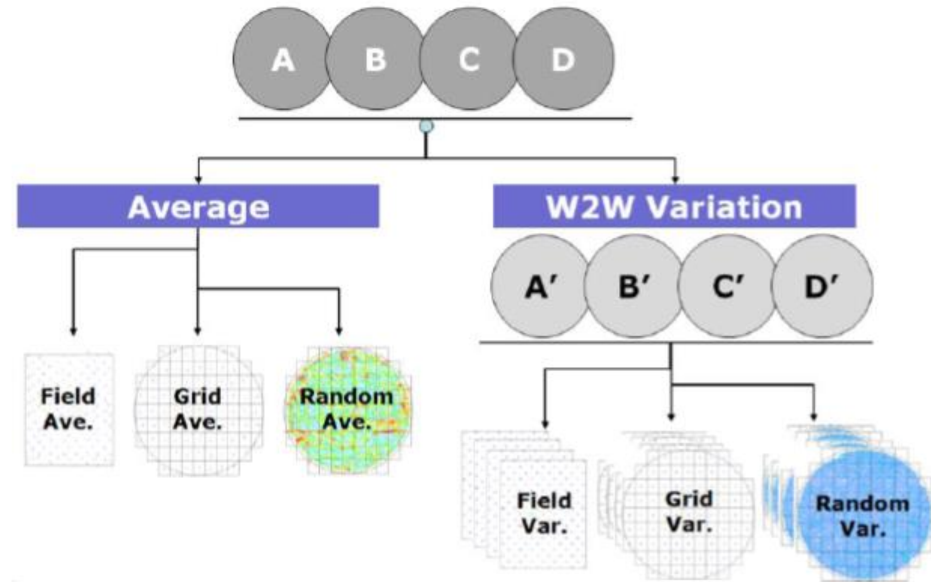


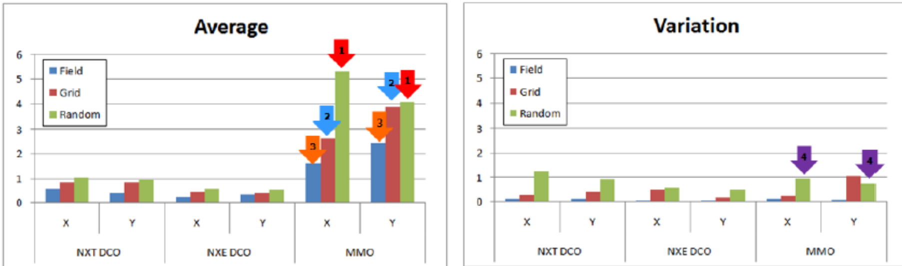
Analysis of phase defect effect on CH

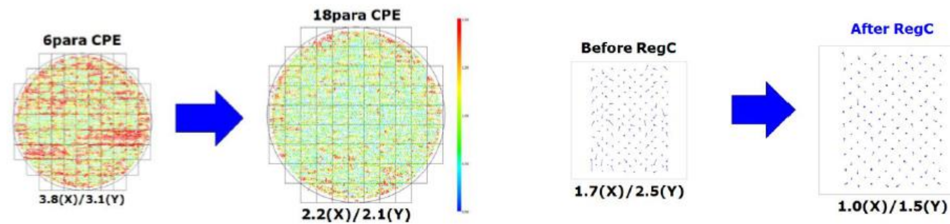
Clear defect size dependence and location dependence on CD errors were verified and the effectiveness of the phase defect mitigation by covering the defect with absorber patterns was experimentally confirmed and it was verified that the requirement of position accuracy for blank defect mitigation was related not only width but also depth.

2 SK hynix (EUV overlay strategy for improving MMO)







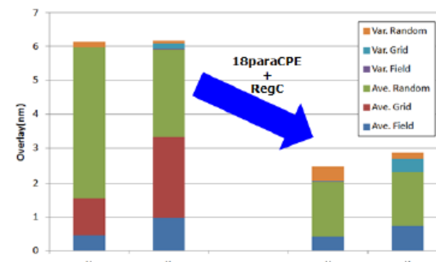


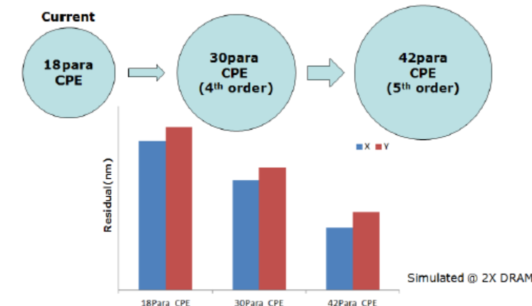
(a) Overlay error after 18para CPE™

(b) Overlay error after RegC™

MMO performance is analyzed by breaking down of overlay results into average & W2W variation terms in the aspects of field, grid and random error.

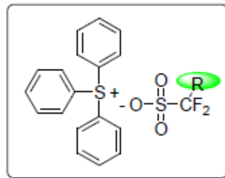
Rank	Terms		Root cause	Solution
#1	Average	Random	Mix-match	More precise tool matching 18para CPE
#2		Grid		CPE
#3		Field		RegC
#4	Variation	Random	ArFi machine	ArFi Machine Improvement





2 Kumho Petrochemical (acid amplifier in EUV PR)

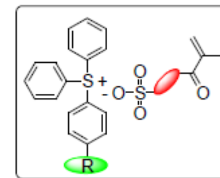
Table 1: Diffusion length(Ld) and coefficient(D) of blending type PAG



R	CF_3	$(CF_2)_3CF_3$	$(CF_2)_7CF_3$	A-cyclo hexyl	A-Adaman tane
Ld(nm)	155	79	48	88	59
D	200	52	19	64	29

* SOB, PEB : 110°C/60sec * Development time : 40sec

Table 2: Diffusion length(Ld) and coefficient(D) of Polymer bound PAG

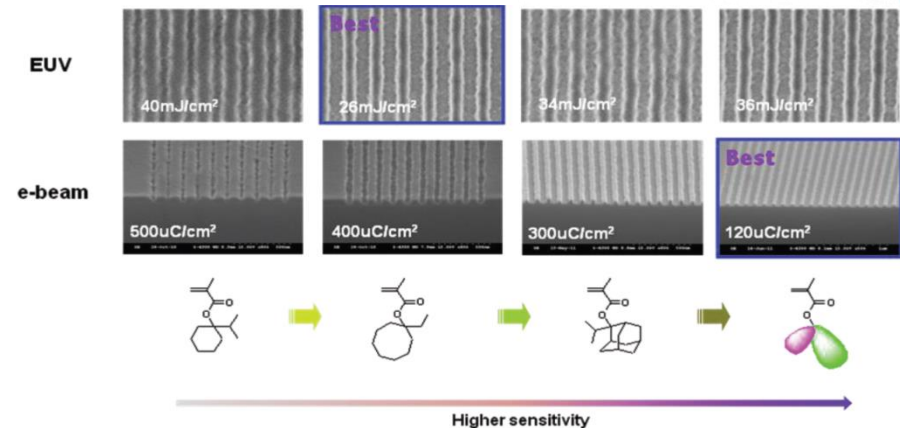


R	CH_3	t-Bu	cyclohexyl	long chain (C# >10)
Ld(nm)	18	17	23	5
D	2.6	2.4	4.3	0.2

* SOB, PEB : 110°C/60sec * Development time : 40sec

PAG	Resol.	Eop	CD-SEM image	Remark
Blending type	40nm	13.3mJ		Severe bridge
PBP	40nm	28.2mJ		

The sensitivity comparison between blending type PAG and PBP in EUV light condition



The sensitivity comparison between EUV light and e-beam with acid labile group variation

LWR is related to acid diffusion of the photoacid generator
PBP type resist is decided as polymer platform because PBP type resist shows shorter acid diffusion length than blending type resist
Acid amplifier, highly sensitive acid labile group in polymer and sensitizer are used for methods to improve sensitivity and LWR

2 Kumho Petrochemical (EUV PR development)

Solvent / Performance	PGMEA	Ethyl lactate (EL)	PGMEA/PGME 7/3	PGMEA/EL 7/3
Boiling point (℃)	145	154	145/118	145/154
Film thickness after soft bake	588	617	591	612
Estimated Eop (mJ/cm^2)	71.5	> 110	91	> 110
Top down SEM image				
Resolution	33nm	17nm	30.5nm	19nm
Dose	71.5mJ	74.8mJ	74.8mJ	71.5mJ

The effect of resist solvent

SOB/PEB (100℃/90℃, 60sec), film thickness (60nm/1500rpm)
33nm hp C/H @ BMET (0.30 NA, Quad)

	Resist A	Resist B	Resist C	Resist D	Resist E
polymer concept	Reference	Mw + 4000	Mw - 3000	B + C	Low Pd polymer
Estimated Eop (mJ/cm^2)	72.3	71.9	60.2	69.5	70.8
Top down SEM image					
Resolution	31.5nm	32.5nm	28.8nm	31.9nm	31.6nm
Dose	71.5mJ	71.5mJ	58.3mJ	68.2mJ	68.2mJ

The effect of Polymer properties

SOB/PEB (100℃/90℃, 60sec), film thickness (60nm/1500rpm)
33nm hp C/H @ BMET (0.30 NA, Quad)

Resolution	32nm	30nm	29nm	28nm
low Ea monomer monomer-1 : high Ea monomer monomer-2				
low Ea monomer monomer-1 : high Ea monomer monomer-1				
low Ea monomer monomer-1 : high Ea monomer monomer-1				

Methacrylate vs acrylate

SOB/PEB (100℃/90℃, 60sec), film thickness (60nm/1500rpm)
30nm hp C/H @ AMET (0.30 NA, Quad)

	Resist A	Resist E	Resist F
PG A : B : C Feed ratio	2 : 3 : 5	1 : 4 : 5	0 : 5 : 5
Top down SEM image			
Resolution	32nm	32nm	32nm
Sensitivity	47mJ	38mJ	36mJ
CDU			

Variation of PG ratio

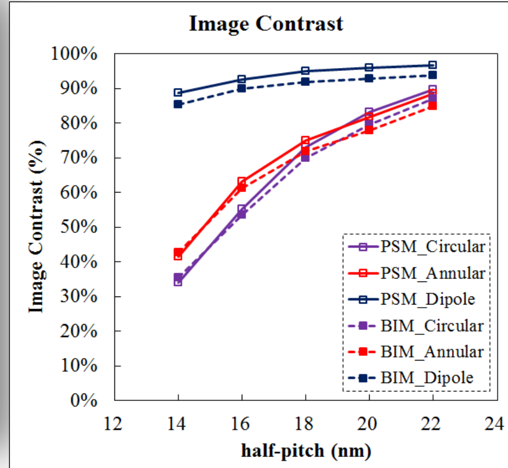
SOB/PEB (100℃/90℃, 60sec), film thickness (60nm/1500rpm)
32nm hp C/H @ AMET (0.30 NA, Quad)

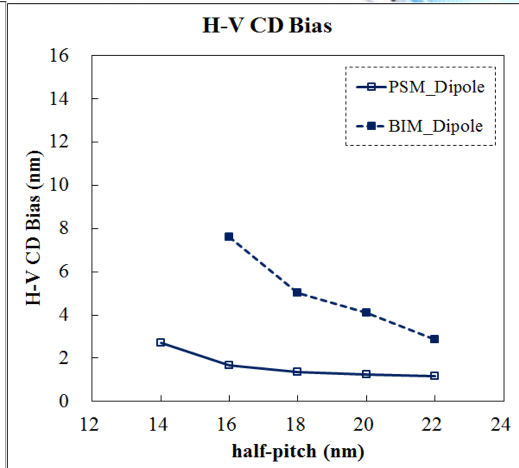
They were considered on polymer blending PAG resist by varying polymer Mw, Pd and PG feed ratio. Polymer for EUV C/H resist requires Mw above certain levels to keep the mechanical strength and low Pd to improve CDU. Moreover, EUV C/H resist were designed by introducing the combination system of high / low Ea PG and of methacrylate / acrylate to overcome RLS tradeoff.

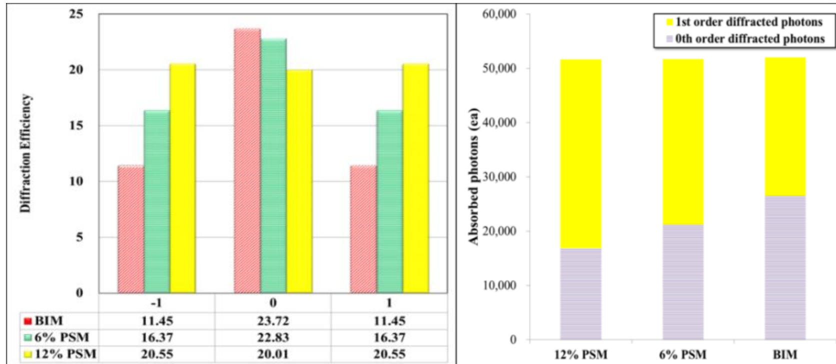
3 Hayang University (Stochastic simulation of PSM)

	12% PSM	6% PSM	BIM
Mask			
Absorber stack	16.5nm TaN / 24nm Mo	26.5nm TaN / 14nm Mo	70nm TaN
Reflectivity	12.66%	5.85%	0.18%
Phase difference	178˚	180˚	79˚

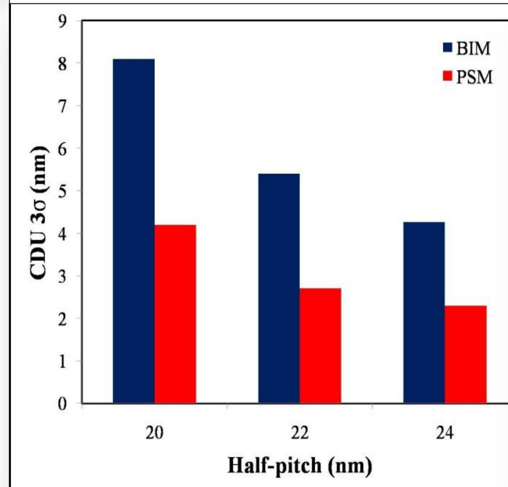
EUVL mask structure research : PSM

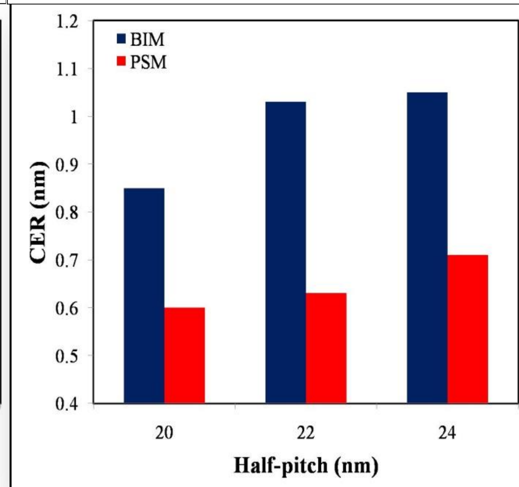






Optical performances of PSM

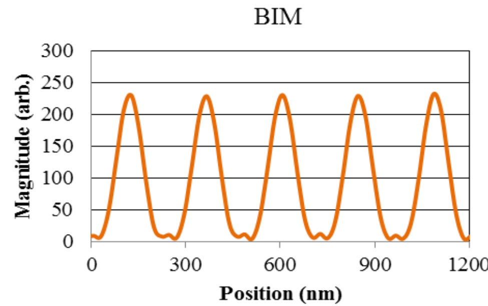


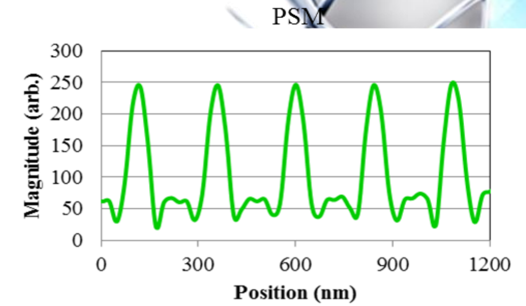


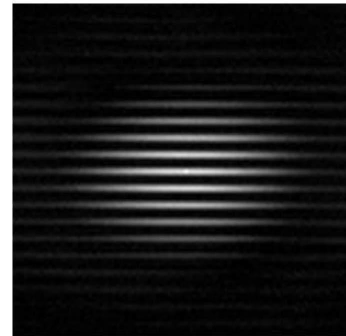
Improved H-V CD Bias, CDU, LER and LWR of the PSM

Hayang University (Mask Inspection with CSM)

Coherent Scattering Microscopy







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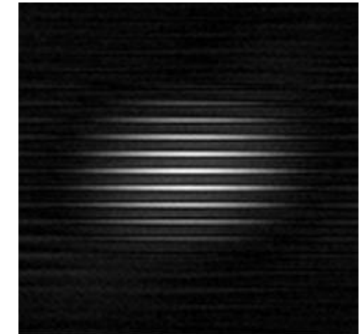
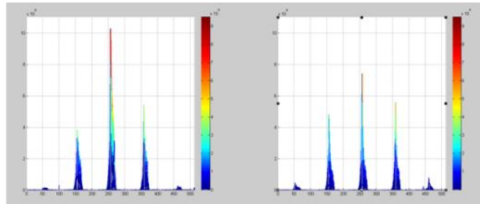
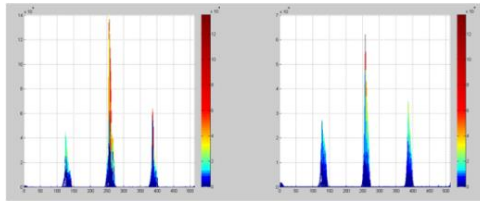


PSM

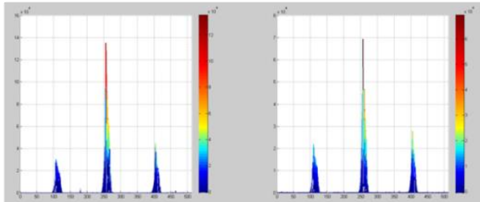
128nm L/S HP



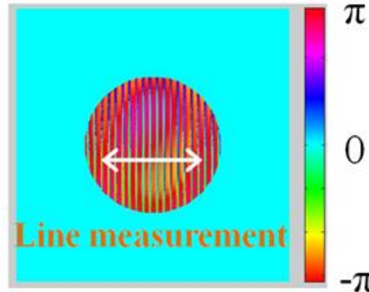
100nm L/S HP



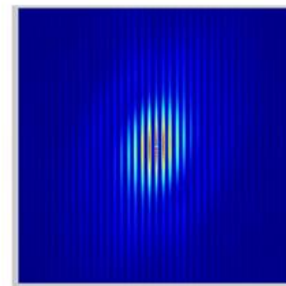
88nm L/S HP



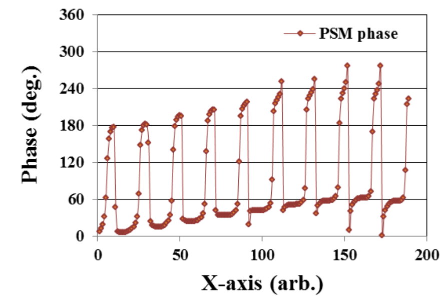
BIM PSM



Phase map



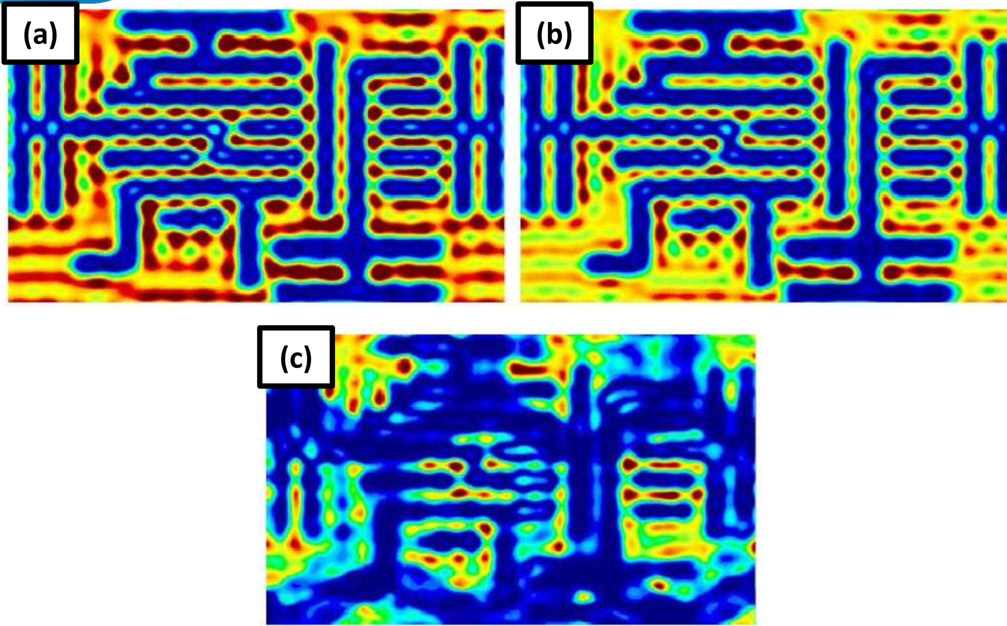
Magnitude map



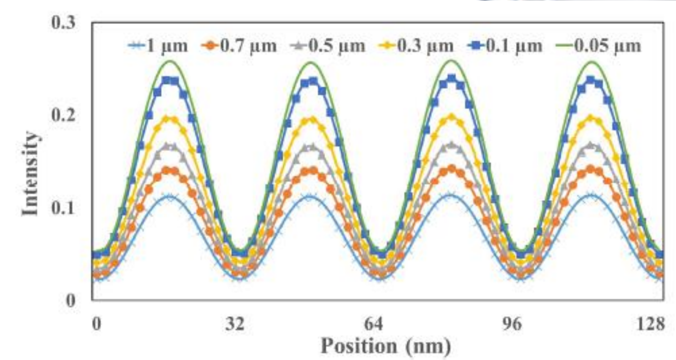
Phase profile

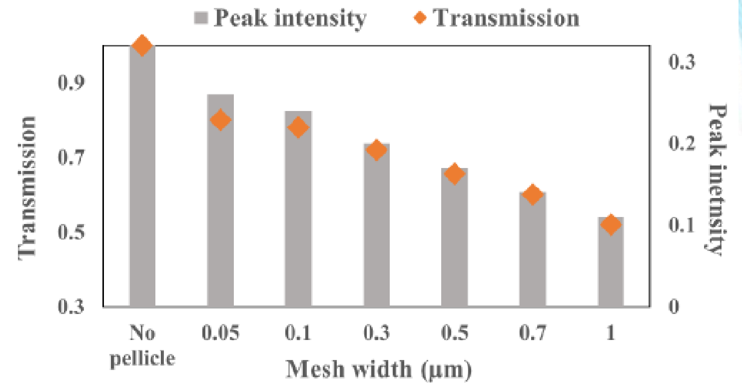
Inspection of fabricated EUV masks; binary intensity mask (BIM) and phase shift mask (PSM)

3 Hayang University (EUV pellicle simulation)

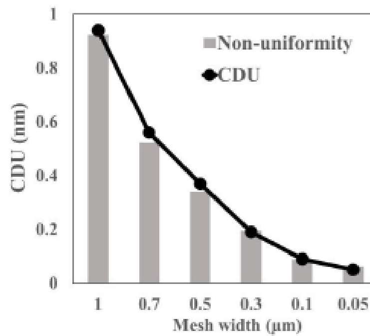


Aerial images of 20nm line width with pellicle structures ; (a) non-pellicled (b) mesh-less 50nm Si film (c) 50nm Si film with 1.2 μm pitch, 100 nm mesh width and 1 μm height mesh support

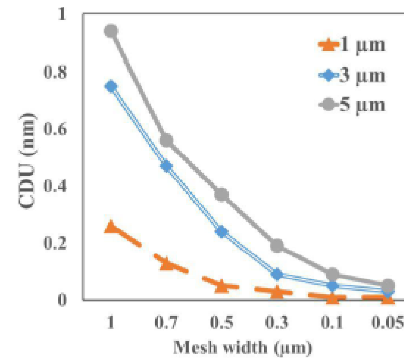




Intensity variation with various mesh widths



Mesh width (μm)	CDU (nm)	Non-uniformity
1	0.94	1.66
0.7	0.56	0.94
0.5	0.37	0.61
0.3	0.19	0.35
0.1	**0.09**	**0.16**
0.05	**0.05**	**0.11**

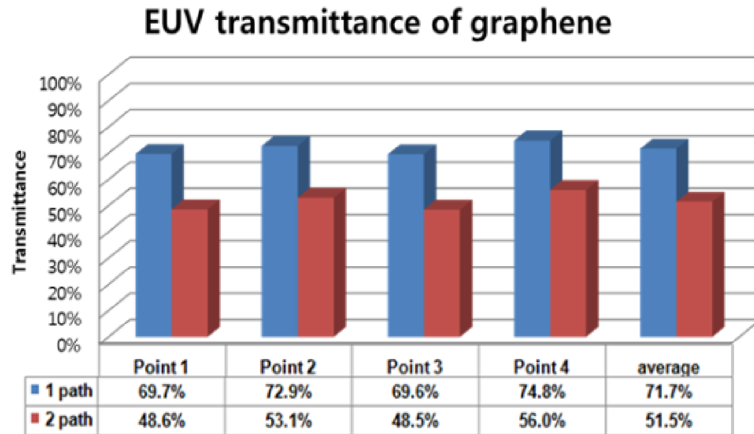


CDU (nm)			
Mesh width (μm)	Height (μm)		
	5	3	1
1	0.94	0.75	0.26
0.7	0.56	0.47	0.13
0.5	0.37	0.24	**0.05**
0.3	0.19	**0.09**	**0.03**
0.1	**0.09**	**0.05**	**0.02**
0.05	**0.05**	**0.03**	**0.01**

CDU variation caused by mesh width change and intensity difference

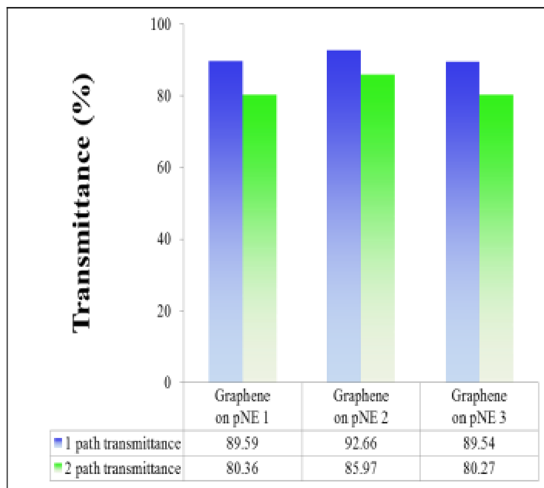
3 Hayang University (EUV pellicle fabrication)

Si with mechnically strong material (toughness, yield strength..)



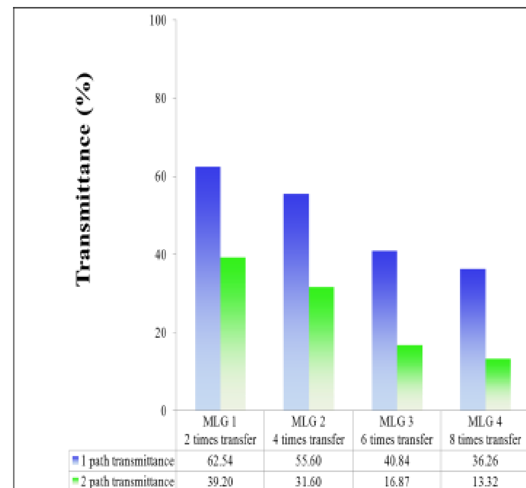
	Point 1	Point 2	Point 3	Point 4	average
1 path	69.7%	72.9%	69.6%	74.8%	71.7%
2 path	48.6%	53.1%	48.5%	56.0%	51.5%

Absorbance of graphene
- 0.2% / monolayer at EUV
- 2.3% / monolayer at visible



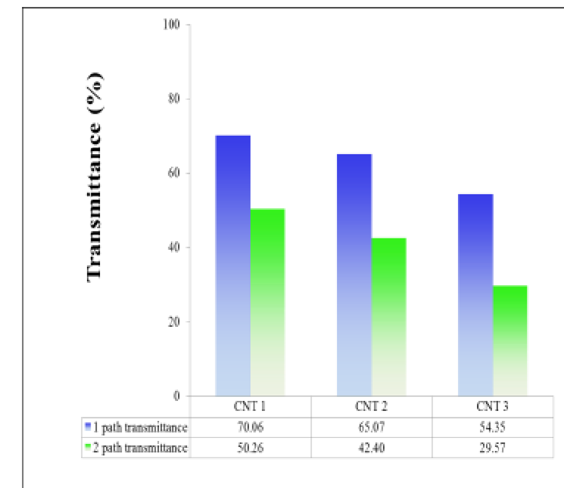
	Graphene on pNE 1	Graphene on pNE 2	Graphene on pNE 3
1 path transmittance	89.59	92.66	89.54
2 path transmittance	80.36	85.97	80.27

<monolayer graphene + pNE>



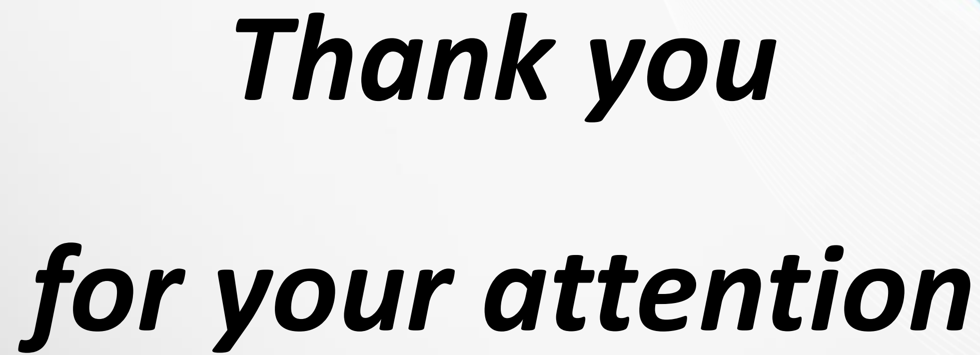
	MLG 1 2 times transfer	MLG 2 4 times transfer	MLG 3 6 times transfer	MLG 4 8 times transfer
1 path transmittance	62.54	55.60	40.84	36.26
2 path transmittance	39.20	31.60	16.87	13.32

<multilayer graphene>



	CNT 1	CNT 2	CNT 3
1 path transmittance	70.06	65.07	54.35
2 path transmittance	50.26	42.40	29.57

<carbon nanotube>


Thank you
for your attention