EUV mask pattern defect inspection for 32/22nm node

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- Summary

Motivation

In addition to Generic mask requirement, EUVL specific mask requirements are listed on ITRS

- Mask manufacturing remains challenges for the implementation of EUVL into HVM
  - Pattern resolution
  - CD quality
    - Uniformity
    - Linearity
  - Defect quality
    - **Defect inspection** → **This presentation**
    - Defect repair
  - etc.

DNP presented new patterning process results for 3x-2x nm node in last EUVL symposium

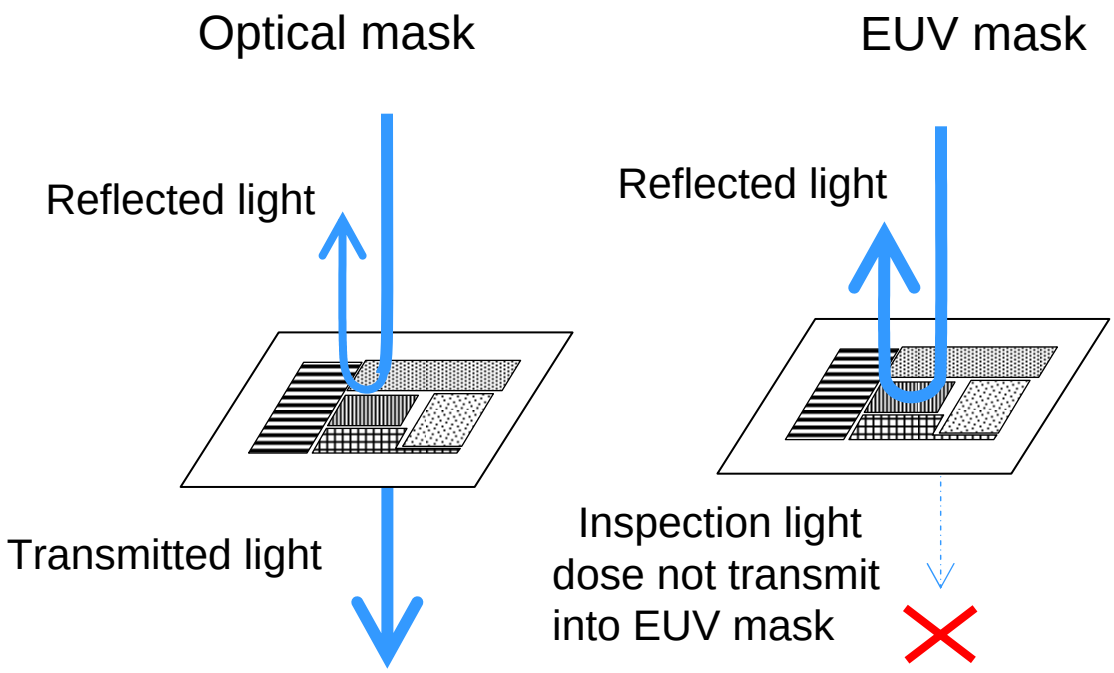
ITRS2007 : EUV mask requirements

Year of Production	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
DRAM ½ pitch (nm) (contacted)	57	50	45	40	36	32	28	25
Flash ½ pitch (nm) (un-contacted poly)	45	40	36	32	28	25	23	20
DRAM/Flash CD control (3 sigma) (nm)	4.7	4.2	3.7	3.3	2.9	2.6	2.3	2.1
MPU/ASIC Metal 1 (M1) ½ pitch (nm)(contacted)	59	52	45	40	36	32	28	25
MPU gate in resist (nm)	38	34	30	27	24	21	19	17
MPU physical gate length (nm)	23	20	18	16	14	13	11	10
Gate CD control (3 sigma) (nm) [A]	2.3	2.1	1.9	1.7	1.5	1.3	1.2	1.0
Overlay	11.3	10.0	9.0	8.0	7.1	6.4	5.7	5.1
Contact after etch (nm)	67	58	51	45	40	36	32	28
Generic Mask Requirements								
Mask magnification [B]	4	4	4	4	4	4	4	4
Mask nominal image size (nm) [C]	151	135	120	107	95	85	76	67
Mask minimum primary feature size [D]	106	94	84	75	67	59	53	47
Image placement (nm, multipoint) [E]	6.8	6.0	5.4	4.8	4.3	3.8	3.4	3.0
CD uniformity (nm, 3 sigma) [F]								
Isolated lines (MPU gates)	3.4	3.0	2.7	2.4	2.1	1.9	1.7	1.5
Dense lines DRAM (half pitch)	6.5	5.8	5.2	4.6	4.1	3.7	3.3	2.9
Contact/vias	6.2	5.6	4.0	3.5	3.1	2.8	2.5	2.2
Linearity (nm) [G]	8.6	7.6	6.8	6.1	5.4	4.8	4.3	3.8
CD mean to target (nm) [H]	4.5	4.0	3.6	3.2	2.9	2.5	2.3	2.0
Defect size (nm) [I]	45	40	36	32	29	25	23	20
Data volume (GB) [J]	413	520	655	825	1040	1310	1651	2080
Mask design grid (nm) [K]	2	2	2	2	2	2	2	2
EUVL-specific Mask Requirements								
Substrate defect size (nm) [L]	38	36	35	33	31	30	28	27
Mean peak reflectivity	65%	66%	66%	66%	67%	67%	67%	67%
Peak reflectivity uniformity (% 3 sigma absolute)	0.69%	0.58%	0.47%	0.42%	0.37%	0.33%	0.29%	0.26%
Reflected centroid wavelength uniformity (nm 3 sigma) [M]	0.08	0.07	0.06	0.05	0.05	0.05	0.04	0.04
Absorber sidewall angle tolerance (± degrees) [P]	1	1	0.75	0.69	0.62	0.5	0.5	0.5
Absorber LER (3 sigma nm) [N]	3.2	2.8	2.5	2.2	2.0	1.8	1.6	1.4
Mask substrate flatness (nm peak-to-valley) [O]	65	57	51	46	41	36	32	29

Manufacturable solutions exist, and are being optimized
Manufacturable solutions are known
Interim solutions are known
Manufacturable solutions are NOT known

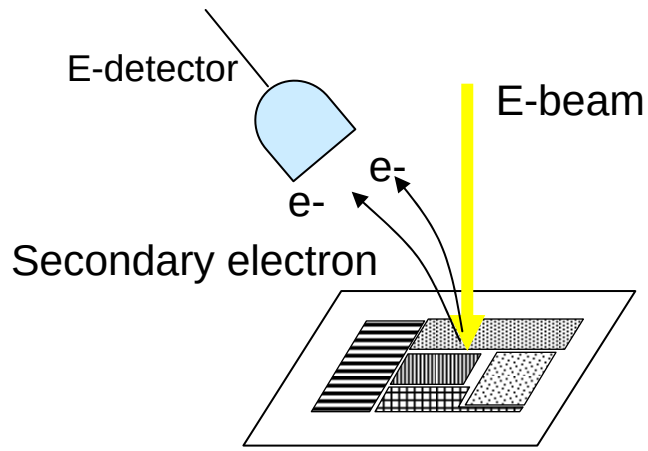
EUV reticle inspection

DUV reticle inspection



- Inspection resolution is limited by light diffraction
- Need AR layer optimized for inspection wave length

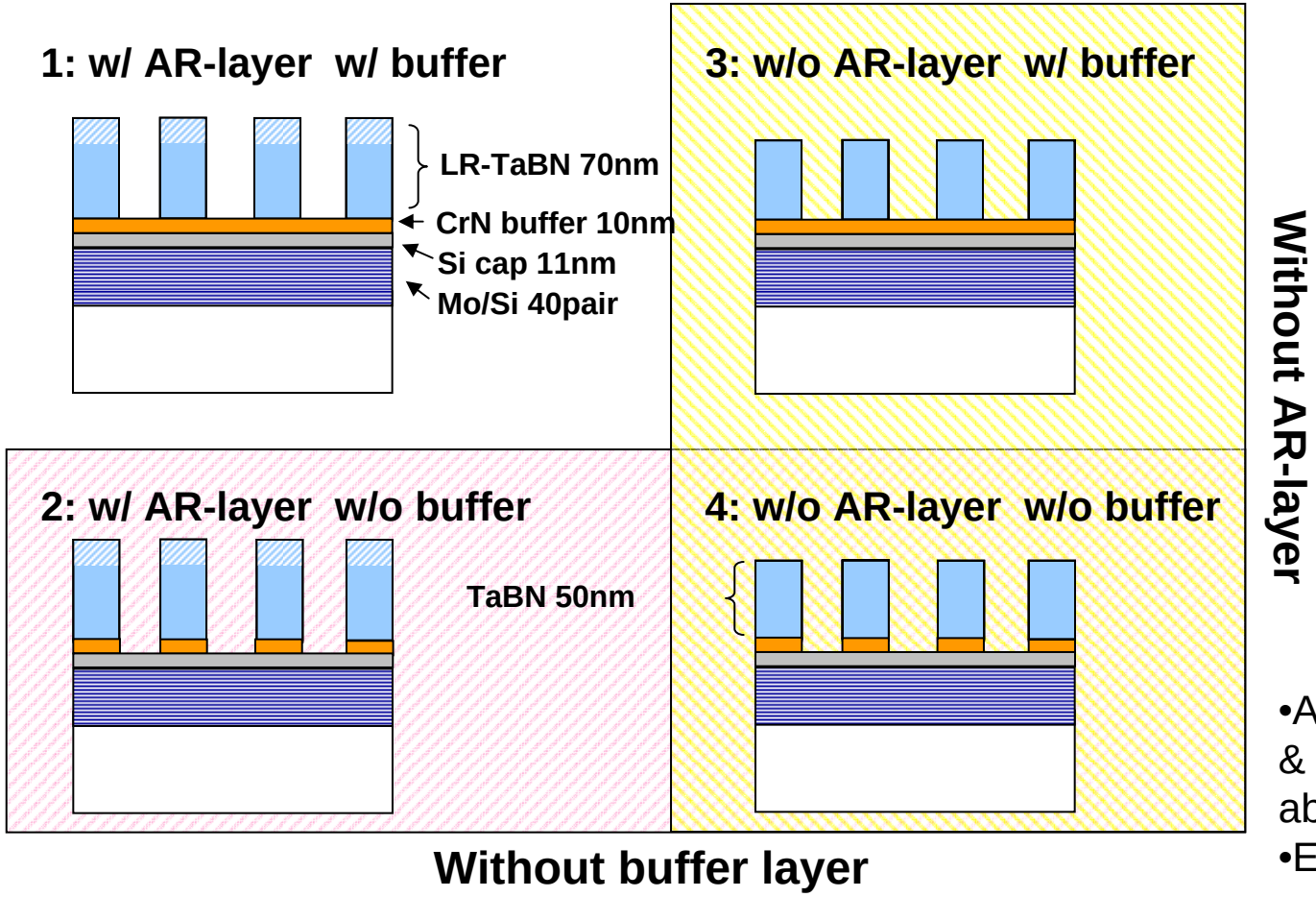
EB reticle inspection



- **Inspection resolution is potentially high due to smaller beam spot size**
- Inspection speed is issue

Evaluation samples

4 different structure of Si capping & CrN buffer samples were prepared



- Anti-reflective layer of No3 & No4 were removed after absorber patterning
- EUV blank supplier: HOYA

Evaluation pattern

Type: Line pattern
Size(4x): 88nm, 108nm, 128nm

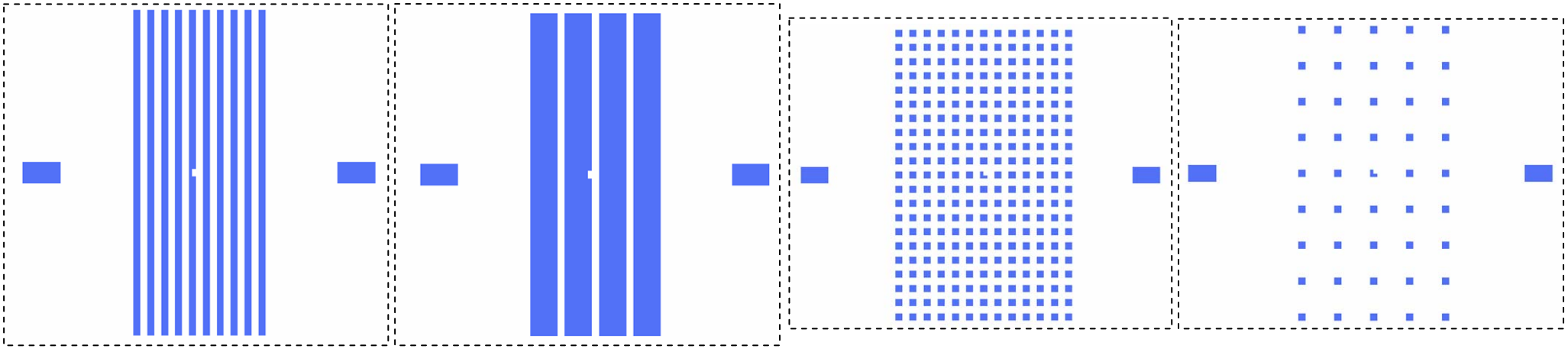
Type: Hole pattern
Size(4x): 128nm, 152nm

Line pattern
L:S = 1:1

Line pattern
L:S = 1:4

Hole pattern
H:S = 1:1

Hole pattern
H:S = 1:4

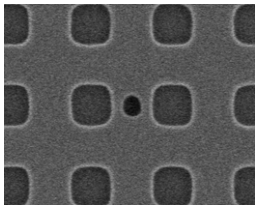


Blue color: etching region
White color: absorber region

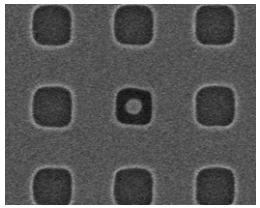
Designed defect category

SEM images of programmed defect
Main pattern size :
- **Hole 152nm HP**
- **Line 128nm HP**

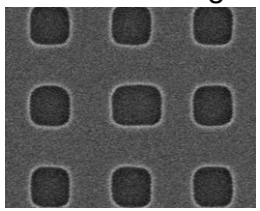
Pin hole



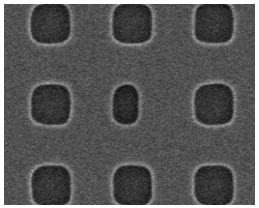
Pin Dot



Miss CD : large



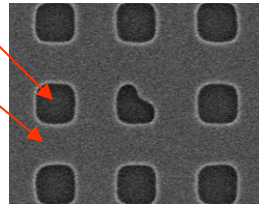
Miss CD : small



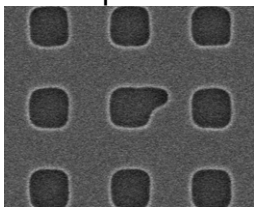
Etching region

Absorber region

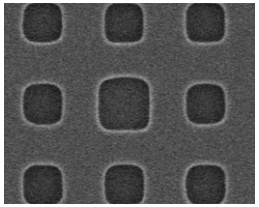
Corner intrusion



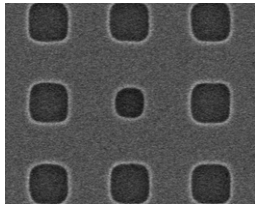
Corner protrusion



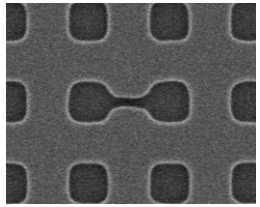
Miss size : Large



Miss size : small



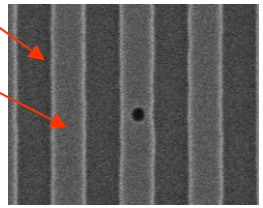
Hole connect



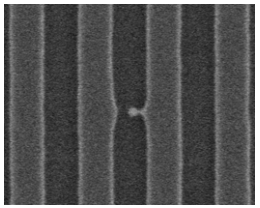
Etching region

Absorber region

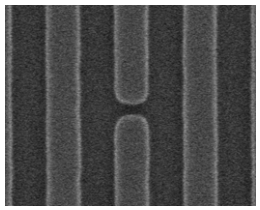
Pin hole



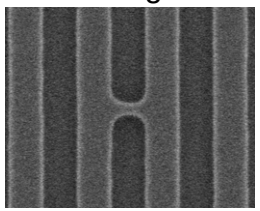
Pin Dot



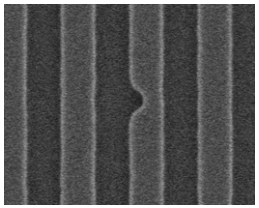
Line cut



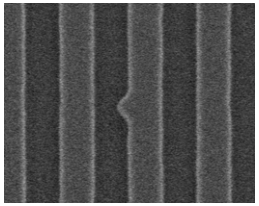
Bridge



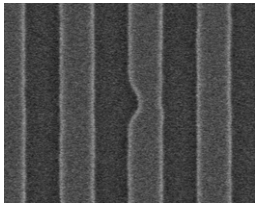
1x1 clear extension



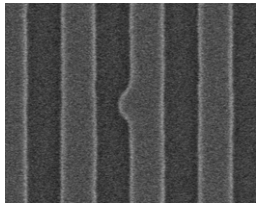
1x1 opaque extension



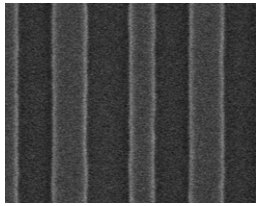
1x2 clear extension



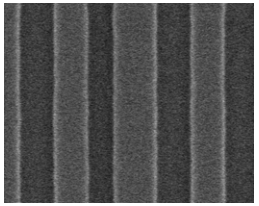
1x2 opaque extension



Line CD error : small



Line CD error : large



- **Defect size was defined as square root of defect area**
- **Line CD error was measured by CD-SEM measurement function**

EB reticle inspection tool

HMI's eXplore™ 5200:

- The 1st Mask EB Inspection (EBI) system
- Inspection resolution :
  - 10nm of leap and scan mode
  - 20nm of continuous scan mode
- CS for EUV mask and higher throughput time

Inspection conditions:

- Pixel size: 20 nm
- Landing energy: 2800 V
- Inspection mode: Die to Die

Sensitivity chart for 88nm L/S (Type 1 structure)

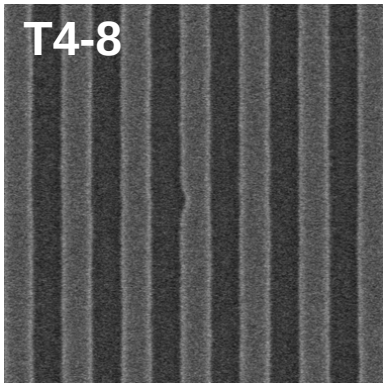
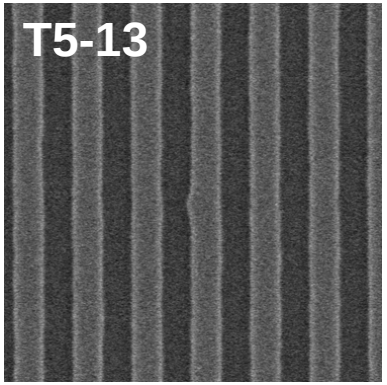
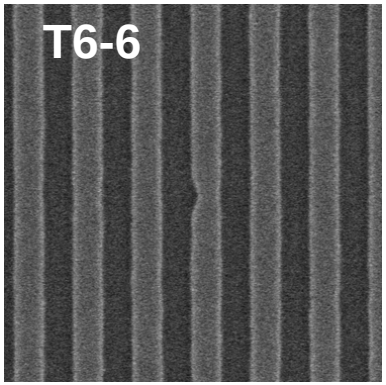
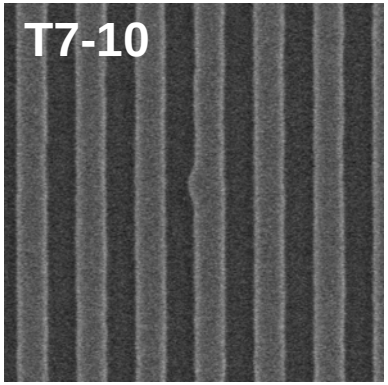
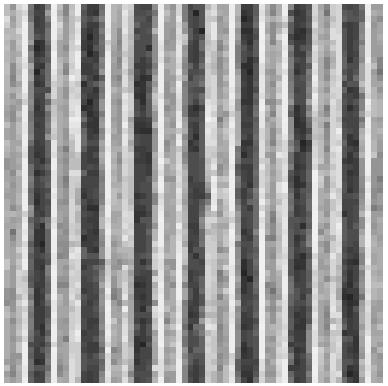
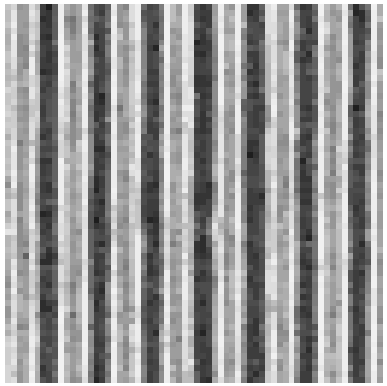
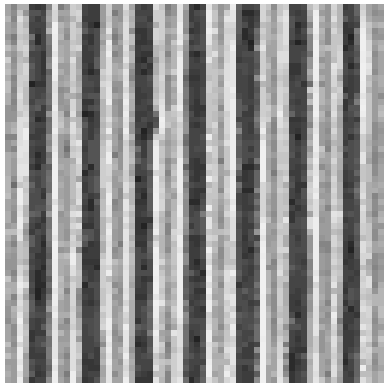
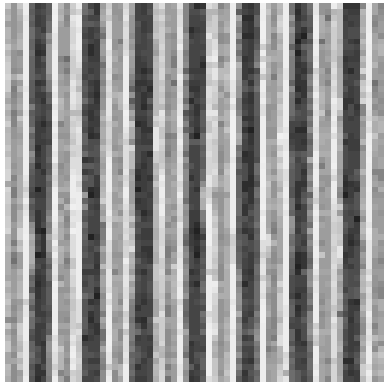
Type	0		1		2		3		4		5		6		7		8		9	
No.	Size		Size		Size		Size		Size		Size		Size		Size		Size		Size	
0																				
1																	2			
2																	4			
3																	6			
4													21				7			
5					13								22				11			
6					31				15				33				11			
7					34				22				39				15		4	
8					44				26				45				16		6	
9					67		26		33				47		20		17		7	
10					71		28		41		17		60		24		19		10	
11					72		38		44		19		63		34		22		12	
12					76		43		48		20		70		39		26		14	
13					78		48		53		25		78		45		26		16	
14	70		21		81		56		62		32		90		50		30		19	
15	73		26		82		59		63		33		96		62		31		19	
16	76		30		84		67		70		33		100		88		34		23	
17	77		59		84		67		80		41		105		100		37		24	
18	80		64		87		70		84		61		107		103		37		28	
19	86		69		90		72		88		68		112		110		93		31	
20	87		73		93		76		91		73		116		116		93		33	
21	91		76		93		76		91		74		117		121		93		36	
22	98		81		93		81		94		78		123		124		93		38	
23	96		81		97		83		95		84		126		128		93		42	
24	99		85		98		87		100		87		126		131		93		42	
25	99		86		100		88		102		88		128		131		93		44	
26	99		88		101		93		102		91		131		134		93		93	
27	102		91		101		91		99		91		133		137		93		93	
28	101		94		102		96		99		95		133		139		93		93	
29	104		96		104		96		106		98		135		142		93		93	
30	104		100		102		100		105		98		139		144		93		93	

No (visible) defect
Not clealy resolved
Break or Bridge

25nm defect size
(ITRS 32nm HP)

Not detected
Detected by EBI

Minimum captured PDs: SEM images and inspection images

	1x1 clear extension Defect size: 26nm	1x1 opaque extension Defect size: 32nm	1x2 clear extension Defect size: 33nm	1x2 opaque extension Defect size: 24nm
SEM Images				
Inspection Images				

Sensitivity chart for 128nm Hole (Type 1 structure)

Type	0		1		2		3		4		5		6		7		8	
No.	Size		Size		Size		Size		Size		Size		Size		Size		Size	
0																		
1													33					
2					26								41					
3					43								60					
4					44								70					
5					54		28						73					
6					58		34		11				79				25	
7					58		37		18				85		27		34	
8					64		45		27		23		97		47		47	
9					67		56		36		29		105		54		55	
10					69		56		37		32		107		64		61	
11			32		74		62		47		36		115		72		87	
12			37		80		67		48		42		120		76		87	
13			34		82		69		52		48		125		81		89	
14			47		86		75		60		47		133		86		95	
15			41		90		75		65		50		139		91		98	
16			51		92		80		67		55		142		96		101	
17	55		125		94		84		68		60		148		101		105	
18	63		115		96		87		73		66		152		102		105	
19	68		125		101		93		80		65		159		106		107	
20	77		125		104		95		84		72		164		110		109	
21	81		125		105		98		87		79		168		125		110	
22	84		125		109		100		90		86		173		125		113	
23	97		125		111		110		93		111		177		125		114	
24	104		125		111		116		98		125		183		125		117	
25	106		125		116		125		102		125		187		125		120	
26	109		125		123		125		108		125		192		125		123	
27	112		125		126		125		115		125		198		125		124	
28	116		125		126		125		119		125		201		125		127	
29	121		125		128		125		123		125		206		125		127	
30	125		125		127		125		128		125		213		125		131	

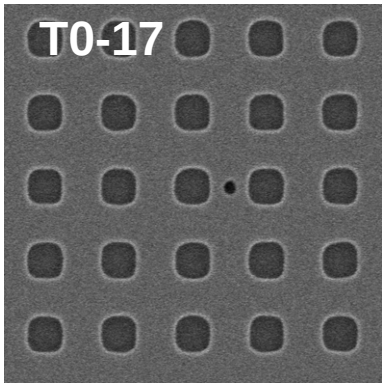
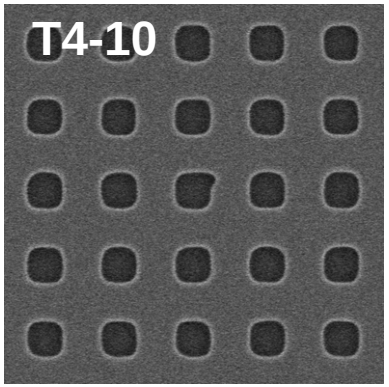
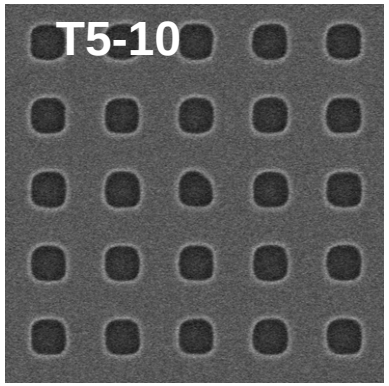
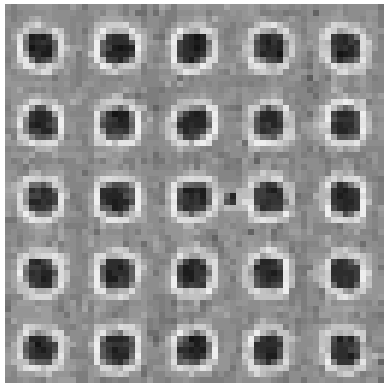
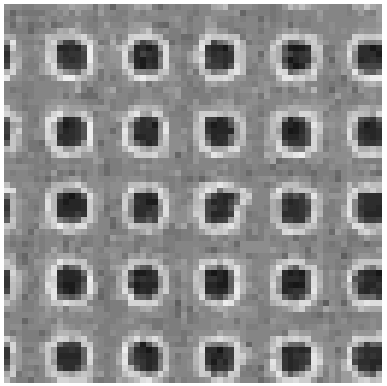
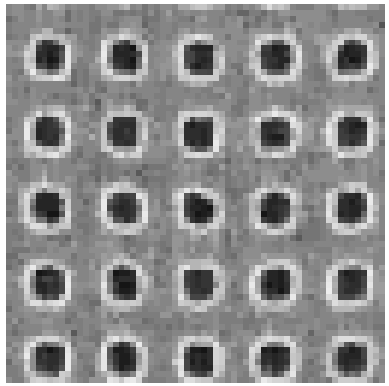
No (visible) defect
Not clealy resolved
Break or Bridge

25nm defect size

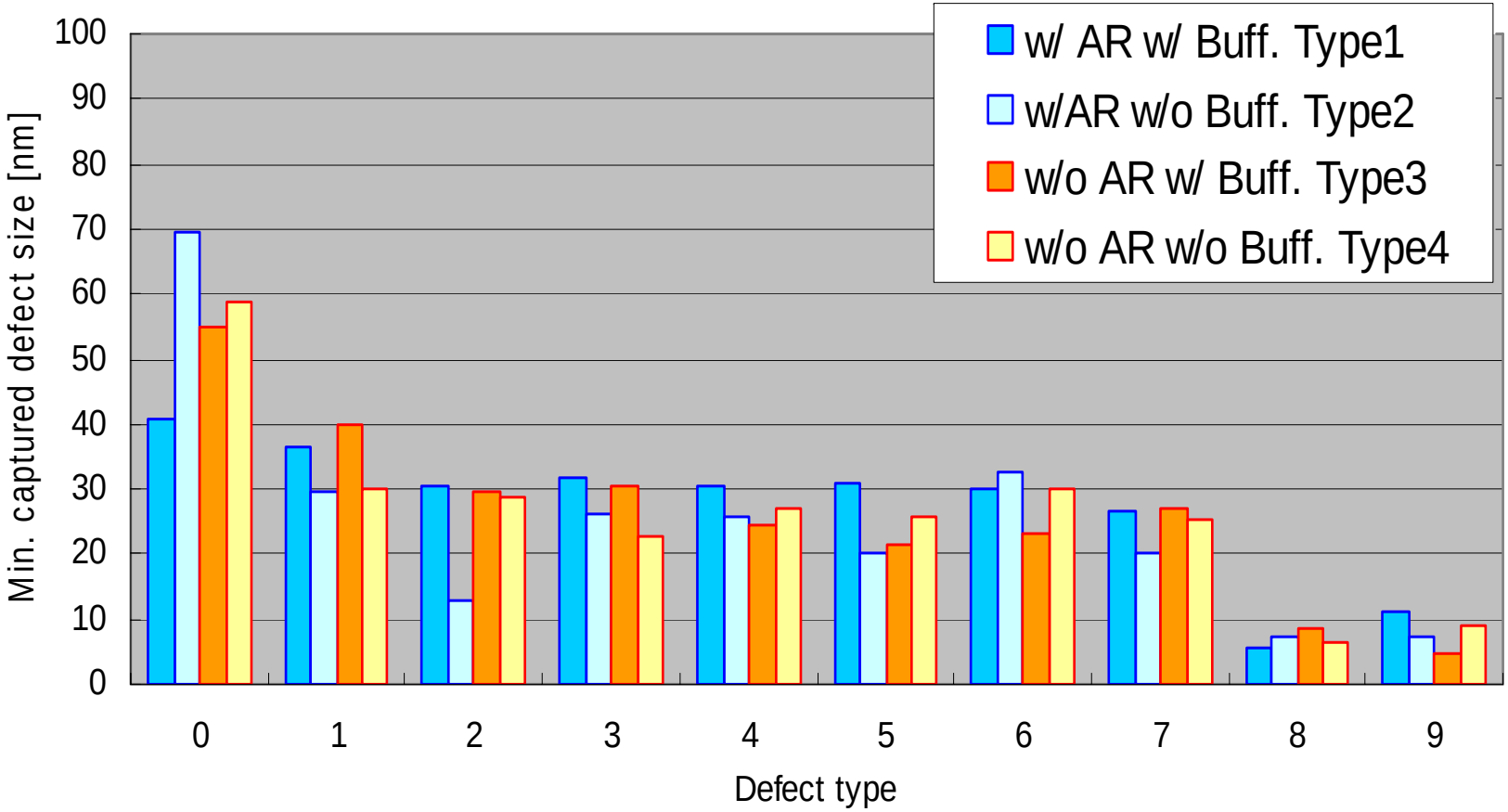
(ITRS 32nm HP)

Not detected
Detected by EBI

Minimum captured PDs: SEM images and inspection images

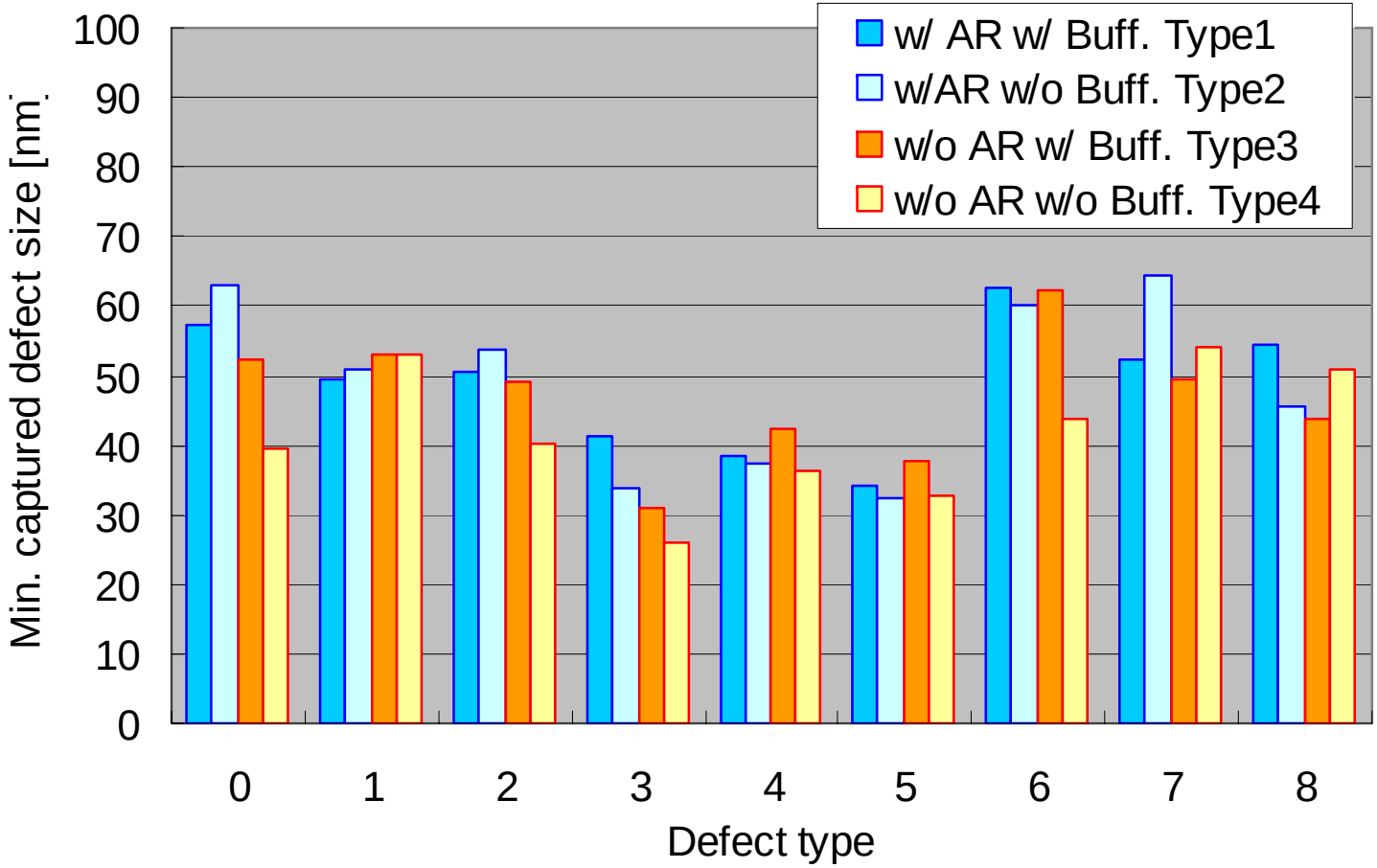
	Pin hole Defect size: 55nm	Corner protrusion Defect size: 37nm	Corner intrusion Defect size: 32
SEM Images			
Inspection Images			

Minimum captured PD size with different mask structure: Line pattern



- **There is no significant difference in sensitivity between each mask structure**

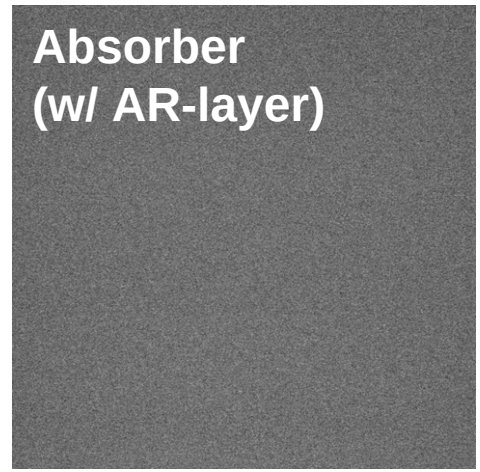
Minimum captured PD size with different mask structure: Hole pattern

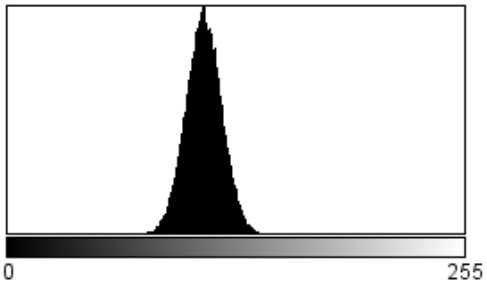


- **There is no significant difference in sensitivity between each mask structure**

Review images on each surfaces

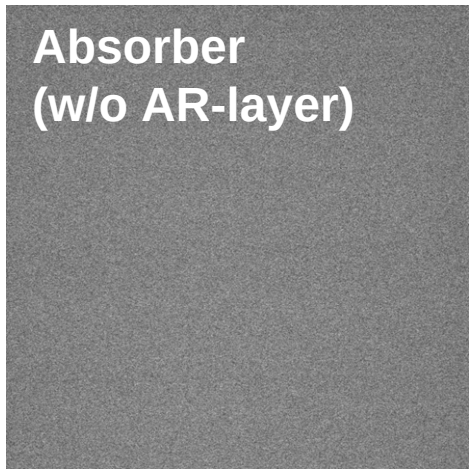
Type 1 & 2

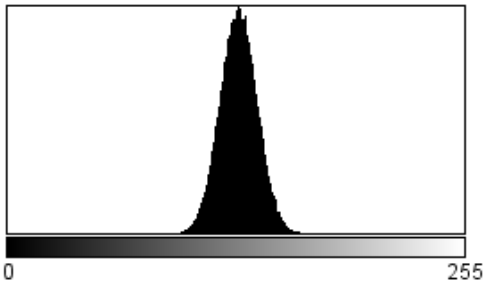




Mean GL: 110

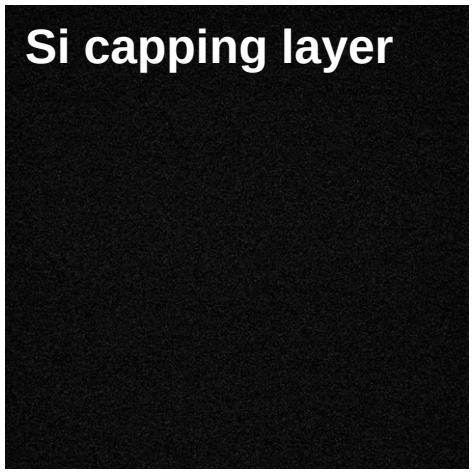
Type 3 & 4





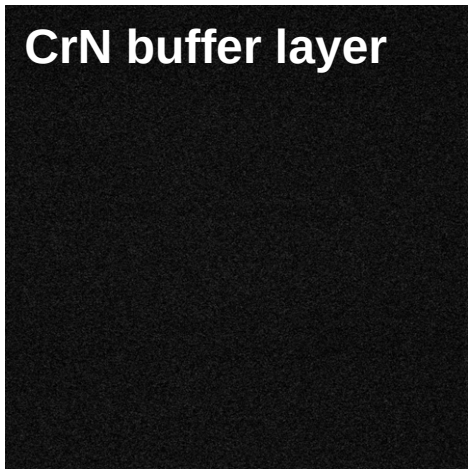
Mean GL: 129

Type 2 & 4



Mean GL: 13

Type 1 & 3



Mean GL: 18

- **Highest material contrast expected on the type 4 structure :**
  - **Type 4: w/o AR-layer and w/o buffer**
  - **Might lead to improvement of inspectability (fewer false defect, etc)**

Throughput time for EB inspection

- ~50cm^2/hour @ 100nm pixel size
- Inspection area, pixel size and number of averages are the main factors.
- Catch killer defects first, then try to do it faster.

<u>Ways to improve throughput:</u>

- ➢ Reduce averaging number
- ➢ Increasing scan speed

Summary

- EBI is capable of detecting 25 nm defects on 88 nm L/S pattern with sufficient image contrast
- No significant difference in sensitivity between each mask structure
- Higher image contrast obtained without AR-layer on absorber layer which might lead to fewer false defect counts
- Throughput time is the biggest challenge for implement EBI in high volume manufacturing