EUV mask pattern inspection with an advanced electron beam inspection system

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ABSTRACT

Readiness of defect-free mask is one of the biggest challenges to insert extreme ultraviolet (EUV) lithography into semiconductor high volume manufacturing for 22nm half pitch (HP) node and beyond. According to ITRS roadmap updated in 2008, minimum size of defect needed to be removed is 25nm for 22nm HP node in 2013 [1]. It is necessary, therefore, to develop EUV mask pattern inspection tool being capable of detecting 25nm defect. Electron beam inspection (EBI) is one of promising tools which will be able to meet such a tight defect requirement.

In this paper, we evaluated defect detection sensitivity of electron beam inspection (EBI) system developed by Hermes Microvision, Inc. (HMI) using 88nm half-pitch (HP) line-and-space (L/S) pattern and 128nm HP contact-hole (C/H) pattern EUV mask. We found the EBI system can detect 25nm defects. We, furthermore, fabricated 4 types of EUV mask structures: 1) w/ anti-reflective (AR) layer and w/ buffer layer, 2) w/ AR layer and w/o buffer layer, 3) w/o AR layer and w/ buffer layer, 4) w/o AR layer and w/o buffer layer. And the sensitivity and inspectability for the EBI were compared. It was observed that w/o AR layer structure introduce higher image contrast and lead to better inspectability, although there is no significant different in sensitivity.

Keywords: EUV lithography, EUV mask, Electron beam inspection, Defect-free mask

1. INTRODUCTION

EUV mask defectivity is one of the most challenging road blocks for applications of the EUV lithography in 22nm technology node integrated circuit manufacturing. There are two major defect types of EUV mask: multi layer (ML) phase defects and absorber pattern defects. ML phase defects are mainly caused by the decoration of defects on substrate during ML deposition. Even a few nanometer height differences on the ML could cause the printable phase defect because of the short wavelength of 13.5nm in EUV lithography. The ML phase defects are mainly inspected using

confocal microscope with ultraviolet (UV) and deep UV (DUV) wavelength [2], [3]. Recently, actinic inspection of ML phase defects with EUV wavelength was also reported [4]. On the other hand, absorber pattern defects are normally formed during absorber layer patterning process. Most pattern defect inspections have been performed using optical inspection system with DUV wavelength [5], [6], [7]. However, there is still gap between current optical inspection capability and industry requirement of sensitivity for 88nm HP pattern. Electron beam inspection (EBI) tool is another option which may meet the tight target in sensitivity. In this study, inspection sensitivity of EBI system developed by Hermes Microvision, Inc. (HMI) was investigated using advanced EUV mask with 22nm half-pitch (HP) line-and-space (L/S) patterns and 32nm HP contact hole (C/H) pattern included programmed defects.

Comprehensive studies with various program defects on the EUV masks showed the EBI could detect 25nm defects for 88nm HP L/S pattern with good image contrast, showing sufficient capabilities to inspect the 22nm HP node EUV mask. We also evaluated material dependencies of absorber layer on the sensitivity and inspectability. It was clarified that w/o AR layer structure lead to better image contrast, resulting in better inspectability, although there is no significant different in sensitivity.

2. EXPERIMENT

The fabricated EUV masks for EBI system evaluation have 88nm, 108nm and 128nm HP L/S pattern and 128nm and 152nm HP C/H pattern. In this paper, we mainly focus on the results from 88nm HP L/S pattern and 128nm HP C/H pattern. To investigate the detail of inspection sensitivity, we designed various program defects into these patterns. The program defects have 10 categories for L/S and 9 categories for C/H with various defect sizes. These categories are shown in figure 1 and 2: 0) pin hole, 1) pin dot, 2) line cut, 3) bridge, 4) 1x1 clear extension, 5) 1x1 opaque extension, 6) 1x2 clear extension, 7) 1x2 opaque extension, 8) small CD and 9) large CD for LS pattern and 0) pin hole, 1) pin dot, 2) large miss CD , 3) small miss CD, 4) corner intrusion, 5) corner protrusion, 6) large miss size, 7) small miss size, 8) hole connect for CH pattern. Every defect category has 30 defect sizes. All of program defects were characterized using SEM for defect size and defect condition. Defect size except type 8 and 9 for L/S pattern are defined as square root of area measured by SEM. Defect size of type 8 and type 9 for LS pattern are calculated by subtraction of defect line CD from reference CD.

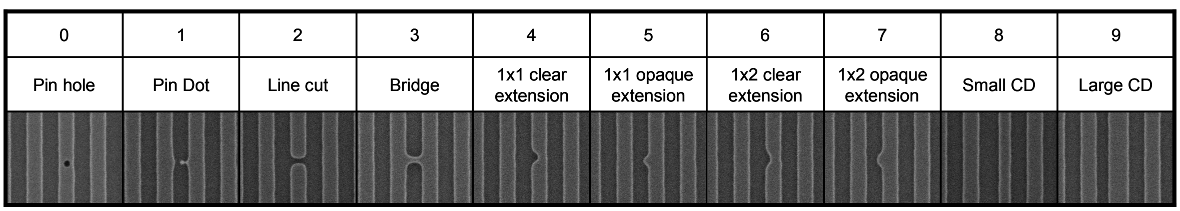


Figure 1. Program defect categories for L/S pattern: 0) pin hole, 1) pin dot, 2) line cut, 3) bridge, 4) 1x1 clear extension, 5) 1x1 opaque extension, 6) 1x2 clear extension, 7) 1x2 opaque extension, 8) small CD and 9) large CD

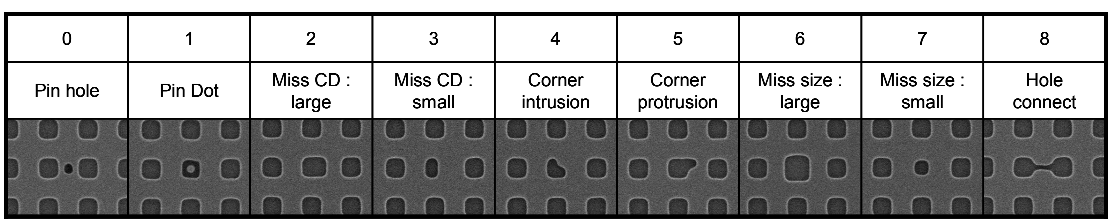


Figure 2. Program defect categories for C/H pattern: 0) pin hole, 1) pin dot, 2) large miss CD , 3) small miss CD, 4) corner intrusion, 5) corner protrusion, 6) large miss size, 7) small miss size, 8) hole connect

The EUV masks were fabricated using advance process with 70nm anti-reflective (AR)-TaBN absorber layer on CrN buffer layer and 10nm Si capped Mo-Si (ML) multilayer blanks [8], [9]. To evaluate EUV mask material dependencies on sensitivity and inspectability for EBI system, we fabricated 4 types of EUV mask structure showing figure 3: 1) w/ AR layer and w/ buffer layer, 2) w/ AR layer and w/o buffer layer, 3) w/o AR layer and w/ buffer layer, 4) w/o AR layer and w/o buffer layer. AR layer of type 3 and type 4 were removed after absorber patterning.

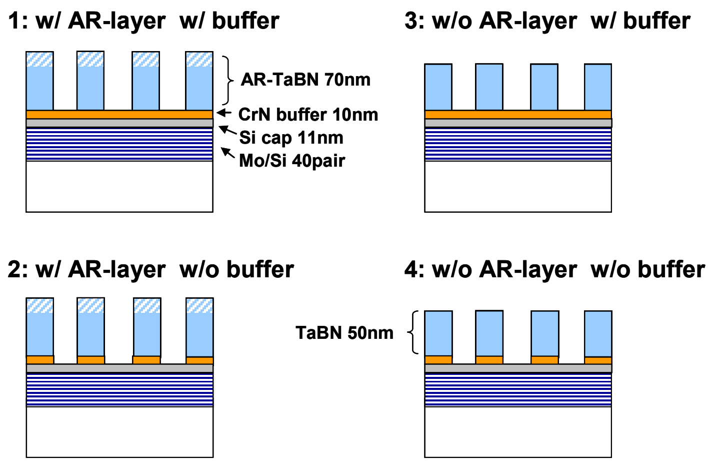


Figure 3. 4 types of EUV mask structure

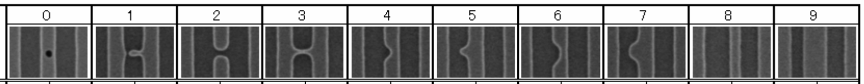
We used EBI system newly developed by HMI. This is the first EBI system dedicated to mask inspection. This inspection tool has 10nm resolution and can run inspection with 10nm pixel size at leap scan mode and 20nm pixel size at continuous scan mode. We applied continuous scan mode in this study to minimize the overhead caused by stage movement to get certain level of throughput time. The inspection pixel size was 20nm. Die to Die inspection mode was used for sensitivity evaluation.

3. RESULTS AND DISCUSSION

3.2 Inspection sensitivity

Figure 4 shows sensitivity chart of 88nm L/S pattern on type 1 mask structure (w/ AR layer and w/ buffer layer). There are 10 defect categories. For each defect category, left column display the characterization results using SEM. Here, the number in cell is the defect size and highlighted colors represent defect condition. Navy color shows the defects which are not resolved due to current EB writing capability or eliminated from design during mask data preparation due to data biasing. Light blue and light green shows the defects not resolved well and recognized as CD change (light blue) and break and bridge defect (light green) instead of expected defect category, respectively. Right column indicate whether the EBI system could detect or not. Cell highlighted by blue color indicates the captured defect and white color stand for no detection. The red solid line indicates 25nm defect size needed to be removed for 22nm HP node pattern in 2008 ITRS road map. As can see in this chart, the EBI system satisfies 25nm size defect target for extension edge defect. For isolated defect like type 1 and type 2, we didn't determine the sensitivity because the isolated defects were not well resolved due to limited resolution during mask fabrication for 88nm pattern.

Inspection images and SEM images of minimum captured defect for extension edge defect are shown figure 5. Inspection images have good image contrast for 88nm LS pattern and are easy to recognize the program defect despite the defect is as small as about 25nm. It should be noted that the EBI system keep good contrast even at 88nm EUV mask pattern.



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	

Figure 4. Sensitivity chart for 88nm L/S pattern on type 1 mask structure. Red solid line indicate 25nm defect size as target.

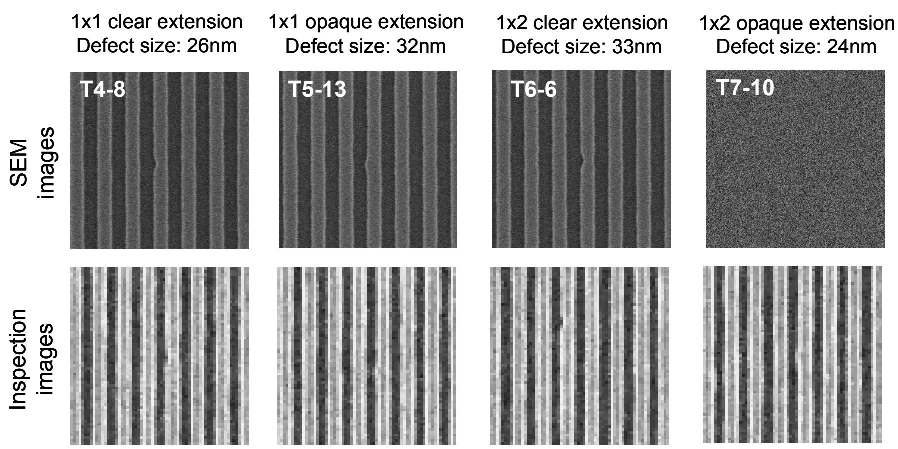


Figure 5. Inspection images and SEM images of minimum captured program defects for extension edge defects. For 1x2 opaque extension edge defect (category 7), the second smallest captured defect image is shown due to the image availability.

Showing in Figure 6 is the sensitivity chart of 128nm C/H pattern on type 1 mask structure (w/ AR layer and w/ buffer layer). There are 9 defect categories. Similar to the chart for L/S pattern, for each defect category, left column display characterization results using SEM and right column shows sensitivity. The red solid line indicated in the chart is 25nm defect size target. The EBI system could catch 30nm edge defect on 128nm C/H pattern. In contrast to L/S pattern,

defect requirement for C/H pattern is more complicated because pattern is not one dimension any more. To discuss the sensitivity requirement for C/H pattern, we need further understanding of printability data using EUV lithography tool or AIMS tool. For isolated defect, 55nm defect was detected showing the type 0 defect category in chart.

Figure 7 shows SEM images and inspection images for minimum capture defects in edge defect category. It should be noted that the defect as small as 30nm defect are clearly visible in inspection image and the inspection image have sufficient contrast at 32nm HP C/H pattern.

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

Figure 6. Sensitivity chart for 88nm L/S pattern with type 1 mask structure. Red solid line indicates 25nm defect size as target.

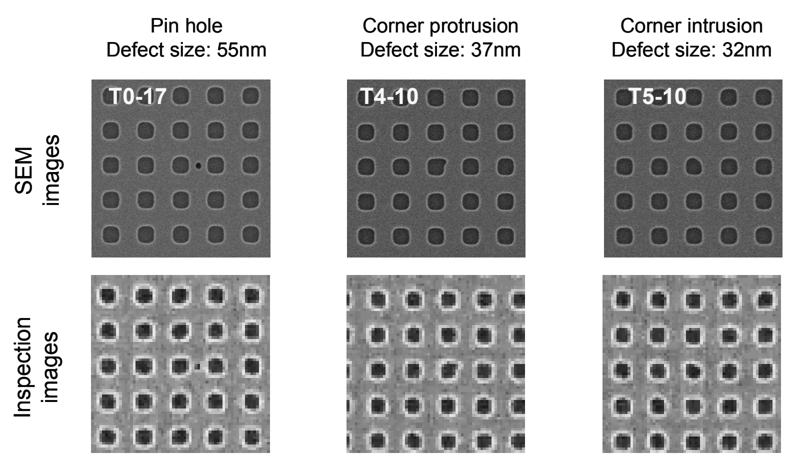


Figure 7. Inspection images and SEM images of minimum captured program defects for pin hole and corner defects

3.3 Mask material dependency: sensitivity

Figure 8 and 9 show the inspection sensitivity dependencies of the EBI system on the EUV mask material differences. 4 types of EUV mask structure shown in figure 3 were fabricated. The EUV masks were inspected by EBI system with same inspection condition (pixel size, landing energy and etc.) and compared by detection sensitivity. Figure 8 indicates minimum captured defect size for every programmed defect category on 88nm L/S pattern. It seems that there is no significant difference in the defect size. This result can be interpreted that the minimum captured defect size is sensitive to inspection condition, especially pixel size, however not sensitive to the mask structure difference. Figure 9 shows minimum captured defects for 128nm HP C/H pattern. There seem to be slightly difference, showing w/o AR layer structure is slightly better than with AR layer. We believe this is because w/o AR layer introduce less charging effect than w/ AR layer and it leads to higher sensitivity.

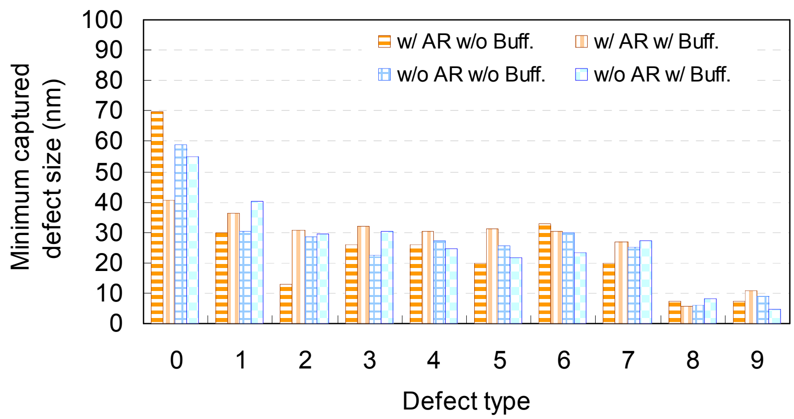


Figure 8. Minimum captured defect size dependency for 88nm L/S pattern on material differences

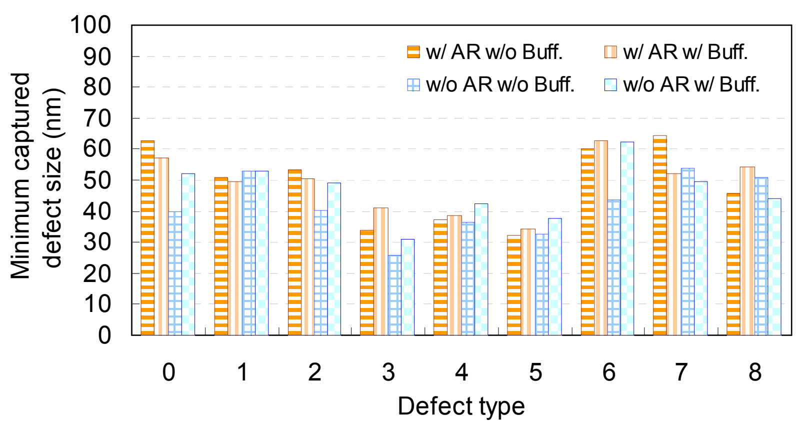


Figure 9. Minimum captured defect size dependency for 128nm C/H pattern on material differences

3.4 Material dependency: inspectability

To understand inspectability of EBI system for each EUV mask structure, we obtained review images on each material surface and compared them. Showing figure 10 is review images and their corresponded histogram for gray level (GL). As can be seen here, w/o-AR-layer absorber indicates higher white level and w/o buffer layer shows lower

blank level, resulting in higher image contrast. Higher contrast enable us better inspectability which is fewer nuisance defects and higher throughput by less averaging time. Considering mask manufacturing flow, EUV mask inspection need to be done before buffer layer etching because the buffer layer play a role to protect ML during repair process. Therefore, it is necessary to inspect the EUV mask with buffer layer. However, w/o AR layer structure is likely ideal one for EBI because it will lead to less charging issue and higher contrast.

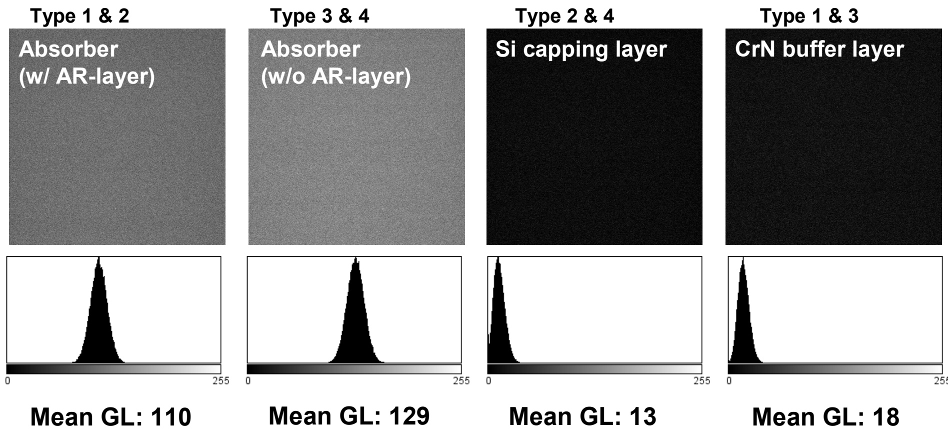


Figure 9. Review images (top) of 4 material surfaces and corresponded histogram (bottom): w/ AR layer absorber, w/o AR layer absorber, Si capping layer and CrN buffer layer

4. SUMMARY

We investigated defect capture sensitivity on EUV mask using electron beam inspection (EBI) system developed by Hermes Microvision, inc. (HMI). We found the EBI system is capable of detecting 25nm edge defect and 55nm isolate defect with sufficient image contrast. The effect of EUV mask structure on sensitivity and inspectability were also evaluated. The results showed w/o Anti-reflective (AR) layer on absorber lead to higher image contrast, although inspection sensitivity is no significant difference.

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