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EUV MET printing and actinic imaging analysis on the effects of phase defects on wafer CDs

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ABSTRACT

Extreme ultraviolet (EUV) lithography technology has gradually developed, and the industry is now progressing toward beta EUV lithography processes. However, very little has been reported on the effects of phase defects on wafer critical dimension (CD) and on tolerable defect sizes.
We have fabricated programmed defect masks with programmed substrate pits and absorbing iso line patterns. The substrate pit depth measured with AFM ranged from ~2-3 to ~6-10 nm and the full width half maximum (FWHM) varied from 45 to 150 nm. A line-pattern was etched into the reflective multilayer coating using focused ion beam (FIB) milling. The iso line pattern is 225nm wide, corresponding to 45nm on a wafer in 5x demagnification tool we used for the EUV exposure.
In this paper, we will present an analysis of the measured relationship between phase defect size and CD change using data obtained with an EUV micro-exposure tool (MET) and with an actinic imaging microscope at Lawrence Berkeley National Laboratory. Printable distance between pit and line edge will also be discussed according to pit sizes. Comparison result between real test and aerial image simulation will be reported to confirm the simulation.

Keywords: EUV, Lithography, EUV Masks, EUV defect, printability, EUV inspection,

1. INTRODUCTION

For the high volume manufacturing EUV lithography, mask blank defect specifications is a critical issue due to the difficulty of simultaneously meeting flatness specifications. To meet the flatness requirement, blank mask makers introduced several polishing processes that create many defects and make it difficult to reduce defects on the substrate[1]. Thus they are demanding that the defect or flatness specifications on substrates or multilayers be relaxed. In addition, third generation blank defect inspection tool should be introduced to support blank defect reduction efforts and the timing should be determined based on the blank defect specification. SEMATECH has been working on these defect-related efforts[2] for quite some time and currently has the infrastructure to study the printability of phase defects in such tools as the EUV microexposure tool(MET), a mask defect fabrication and analysis system, a multilayer ion beam deposition tool, the newest DUV blank defect inspection tool, and the actinic inspection and imaging tool. Thus, programmed defect masks can be fabricated and characterized at the Mask Blank Development Center (MBDC) and printed by the SEMATECH EUV exposure tool in Berkeley and the results can be compared with EUV imaging and inspection results from the SEMATECH Berkeley actinic inspection tool. We studied this substrate defect printability in real tests using SEMATECH infrastructure and compared with the aerial image simulation. This paper reports the results.

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2. EXPERIMENT

A programmed defect mask was fabricated using facilities at the SEMATECH North MBDC. Figure 1 shows the programmed defect mask structure. Substrate pits of various sizes were made on a Qz substrate using focused ion beam-scanning electron microscopy (FIB-SEM). Targeted depths were (a) 2, 4, and 6 nm, and widths were (b) 50, 100, and 150 nm by full width half maximum (FHWM). Forty Mo/Si bi-layers were deposited on the programmed pits using ion beam deposition (IBD) at the MBDC, and FIB-milled lines were fabricated near the substrate pits.

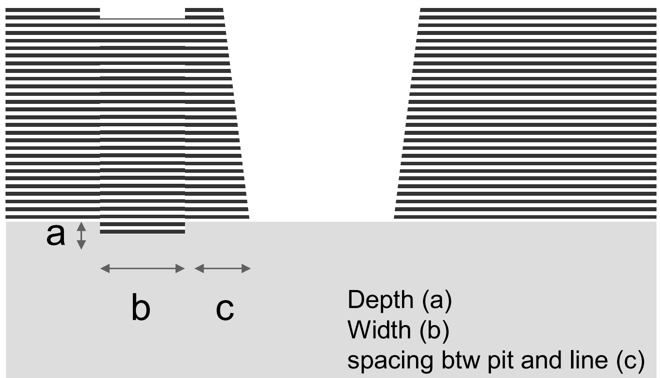
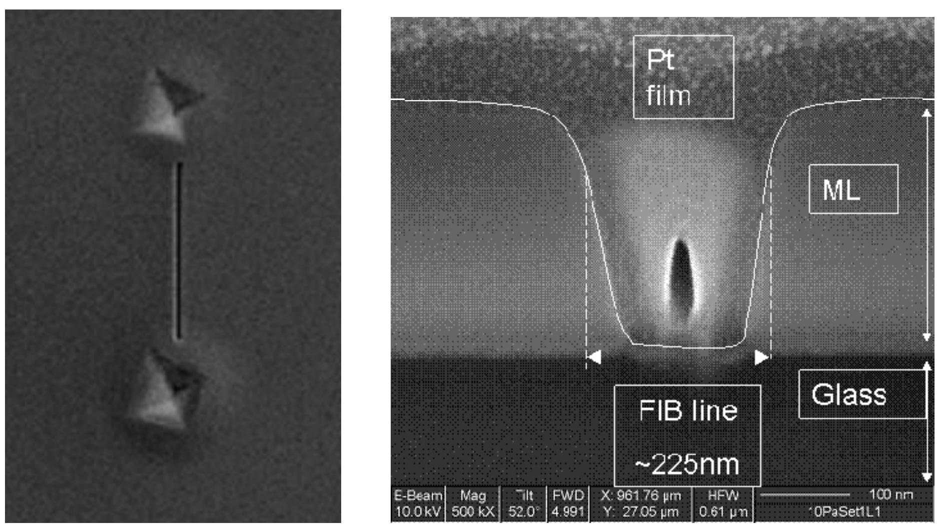


Figure 1 Programmed defect Mask Structure.

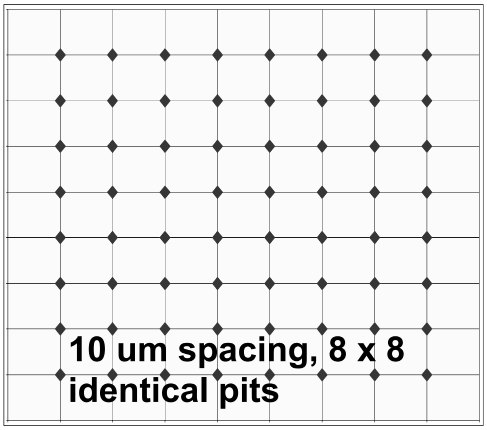


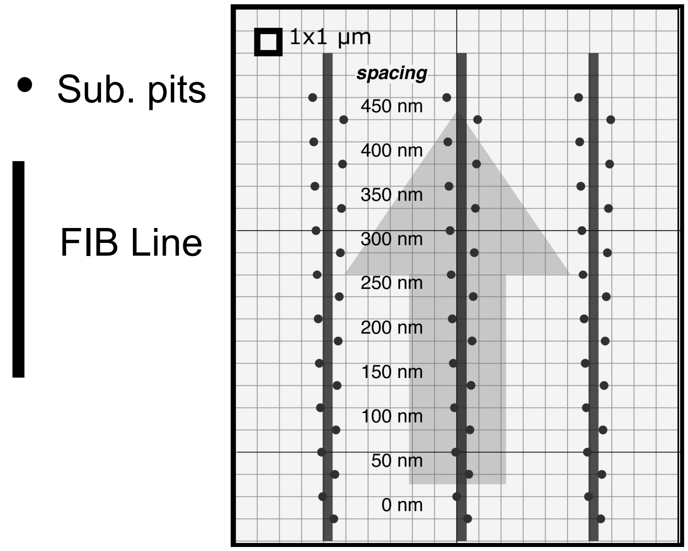
(a) (b)

Figure 2 (a) FIB line and alignment mark (top view) (b) FIB line cross-section image

Figure 2 shows top view and cross section FIB-SEM images of the FIB-milled line, respectively. In the top view image (a), M1350 fiducial marks were used to align the line and substrate pits. The cross-section image (b) shows that a FIB line was created with some side angle; the width was about 225 nm, corresponding to 45 nm on a wafer in 5X demagnification exposure tool which we used for this test.

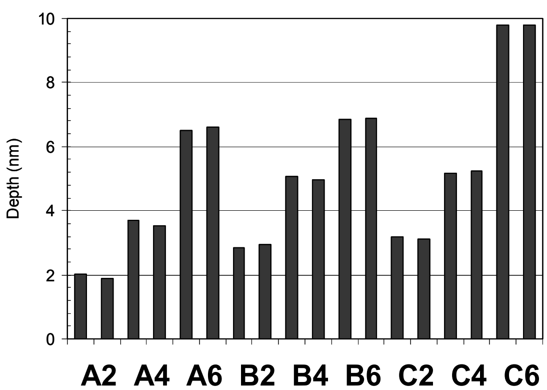
Figure 3 shows programmed defect layouts; (a) shows isolated pits to be used for scanning inspection and (b) shows a FIB line near the substrate pits. In figure (b), substrate pits have lateral spacing from 0 to 450nm with a 50 nm step on one side, a 25 nm step on both sides. A 50 nm step on the 5X demagnification exposure tool corresponds to a 40 nm step on the 4X demagnification tool. We created the substrate pits on both sides in case alignment is not accurate.

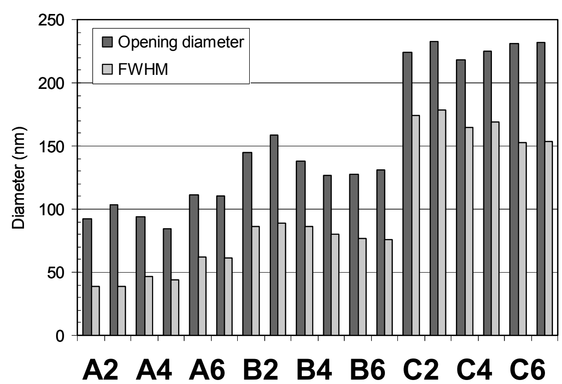




(a) (b)

Figure 3 Programmed defect mask layout (a) Isolated pits array (b) Isolated lines near the substrate pits.





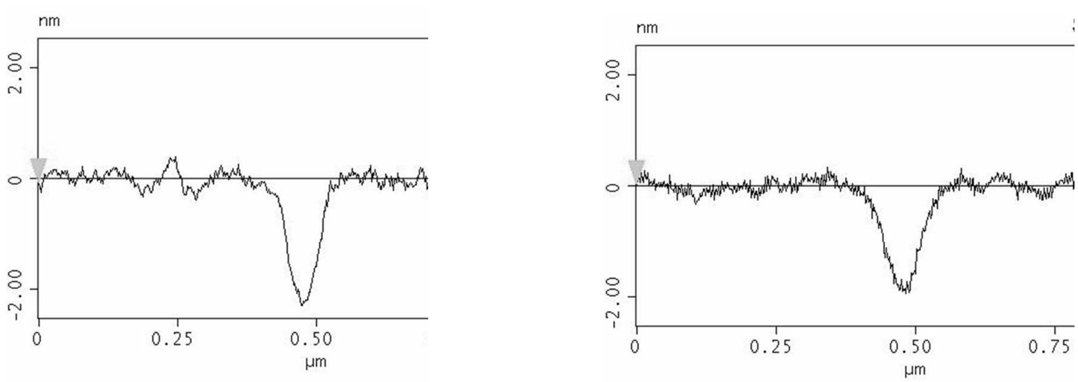
(a) (b)

Figure 4 Pit sizes measured by AFM, A, B and C represent 50nm, 100nm and 150nm by FWHM. Following number means target depth. (a) Measured depth (b) Measured FWHM and diameter

FWHM		Depth	
Target	**Measured**	**Target**	**Measured**
50 nm (A)	**40-60 nm**	**2 nm**	**2-3 nm**
100 nm (B)	**75-90 nm**	**4 nm**	**4-5 nm**
150 nm (C)	**150-170 nm**	**6 nm**	**6-9 nm**

Table 1 Comparison of target depth and width with measured values.

Figure 4 shows substrate pit size measured by atomic force microscopy (AFM). A, B, and C represent 50 nm, 100 nm and 150 nm target widths, respectively, and the numbers are the targeted depth. Overall measurement data are well matched to the targeted numbers as shown in Table 1. For substrate pits 100 nm and 150 nm wide, the pits are a little deeper than the targeted value but the differences are below or about 1 nm for pits up to 100 nm wide. 150 nm pits are clearly expected to be printed and the width of interest is below 100 nm. In this level, measured depths are almost the same as the targeted depth. Note that the widths of pits with a 100 nm target are about 75 to 90 nm in (b).



(a) (b)

Figure 5 AFM measured crosssection (a) before deposition and (b) after deposition

Figure 5 shows substrate pit shape obtained by AFM before and after multilayer deposition. After deposition, pits are wider and deeper but the difference is less than 10%. This coincides well with a normal characteristic of the MBDC standard recipe, which results in a size difference of less than 20%. Pit shape depends on elements of the deposition recipe such as incident angle of the ion beam and deposition angle on the mask surface.

EUV exposures were conducted using the SEMATECH MET microstepper with 5x demagnification and 0.3NA to print the programmed pit mask at Lawrence Berkeley National Laboratory (LBNL), R&H EUV resist was spin-coated and soft baked (130°C/60sec) and rotated dipole illumination was used.

3. RESULT AND DISCUSSION

Figure 6 shows MET-printed resist images of 150 nm-6 nm pits (a), 100 nm-6 nm pits (b), and 100 nm-2 nm (c) pits obtained from SEM. Each image was composed of several 100kX images carefully connected. Figure (a) clearly shows a periodical CD change along the isolated line with 400nm spacing on one side. Printable pit to line edge spacing can be estimated from printed pit number. Six pits were printed on the right side, thus the lateral spacing between the first pit and the last one is 200nm considering we used 5x demagnification exposure tool instead of 4x demagnification one. This means pits about 230 nm away from the line impacted the CD of the line. Printed pits do not start from the same position because the line alignment with pits using the Lasertech fiducial mark was difficult due to the large size of the mark. From figure (b), 100 nm-6 nm pits also print clearly, but the printed pits are reduced to only 3, corresponding ~80 nm spacing laterally from the line in the 4X exposure system. Figure (c) shows a printed image with the line with 100 nm-2 nm pits. There are no extrusions with 400nm spacing, representing that pits are not printable.

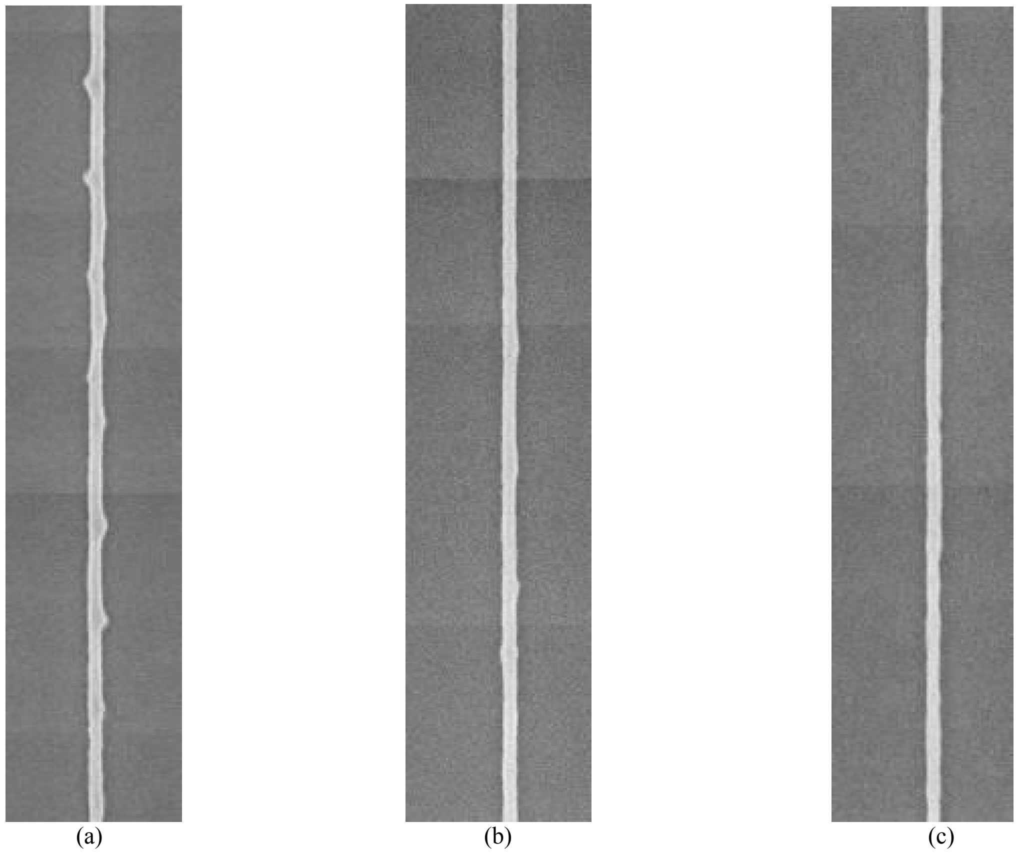
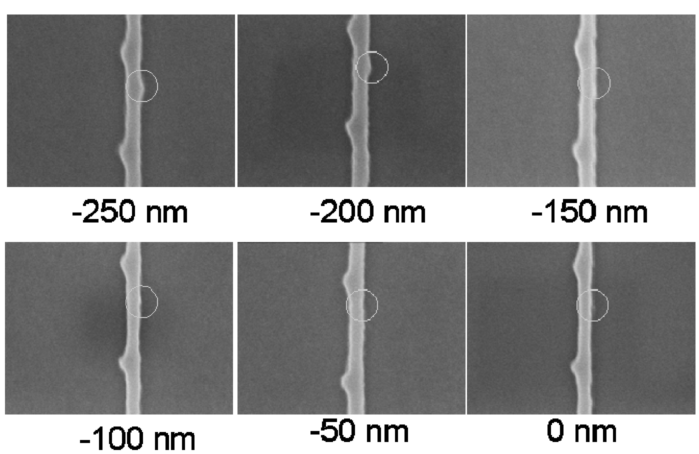
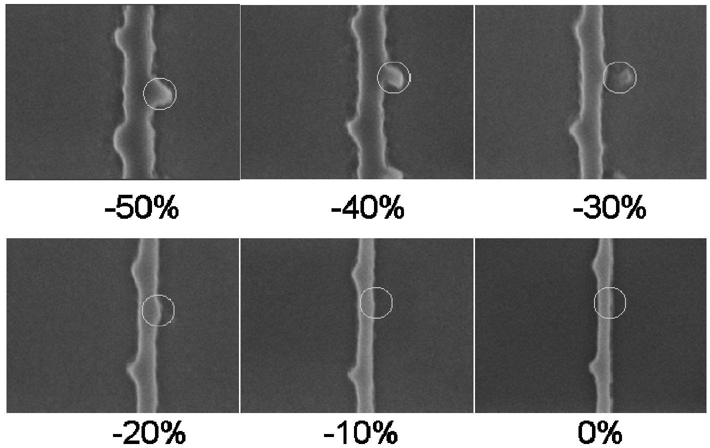


Figure 6 Printed resist SEM images obtained from (a) Pits 150 nm wide and 6 nm deep (b) Pits 100 nm wide and 6 nm deep (c) Pits 100 nm wide and 2 nm deep

The printability of pits depends on exposure conditions such as dose and focus. Figure 7 shows the dependence of printability on focus and dose obtained from 150 nm-6 nm pits, the largest ones to clearly see the focus effect on the printability as shown by circle in the figure. The printability of substrate pits increases as focus moves into multilayer and dose decreases.



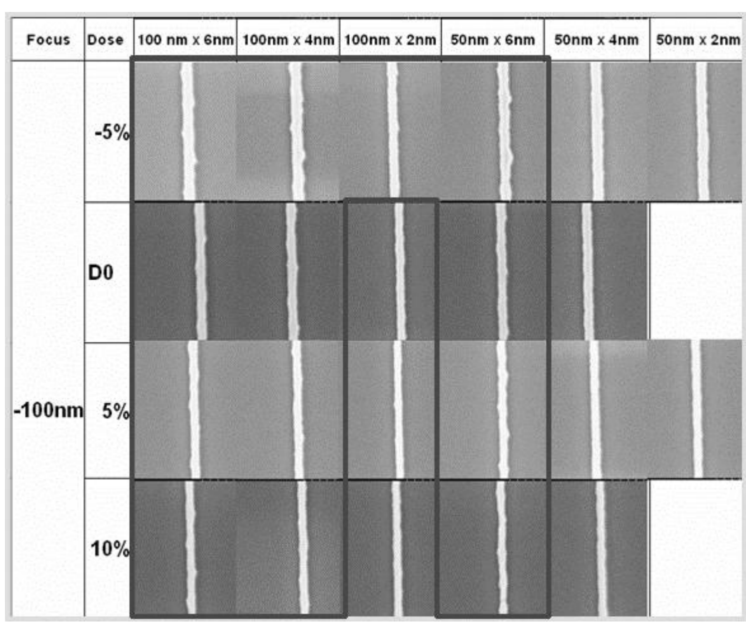
(a)



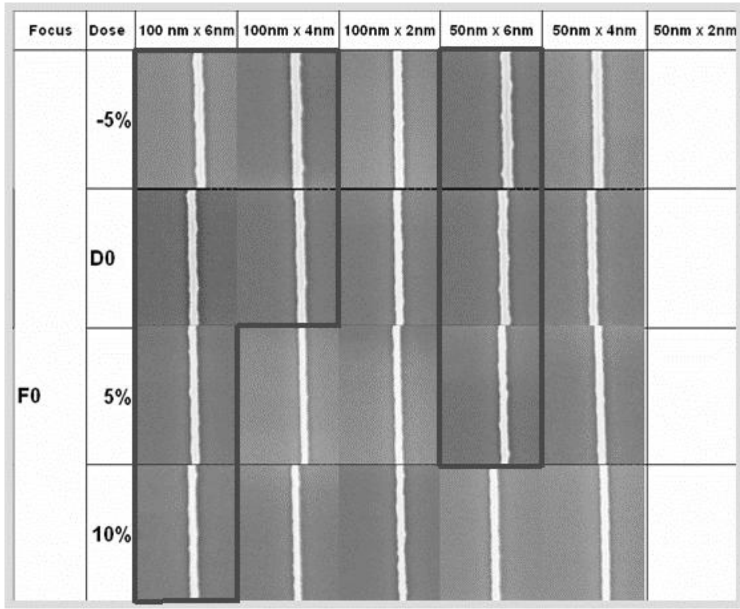
(b)

Figure 7 Resist printed images from pits 150 nm wide and 6 nm deep according to (a) Various focus and (b) Various doses

Figure 8 shows substrate pit printability at -100 nm focus according to dose. Printed pits are mostly only 2, which mean only pits below 80 nm from the line are printable. Printable defects are marked by an outline, assuming that extrusions with 400 nm spacing are printed from substrate pits regardless of CD changes because it is difficult to measure the CD change due to LER from resist and FIB milled line. 100 nm-2 nm pits look printable only at a -5% dose, while 50 nm-6 nm pits look printable up to a 10% dose. Considering the volume of the former should be larger than that of the latter, depth is a more critical parameter for printability. For pits at 0 nm focus from figure (b), CD changes due to substrate pits are less than that at -100 nm, which coincides with the result in Figure 7. It is also clear from these images that a higher dose makes pits less printable.



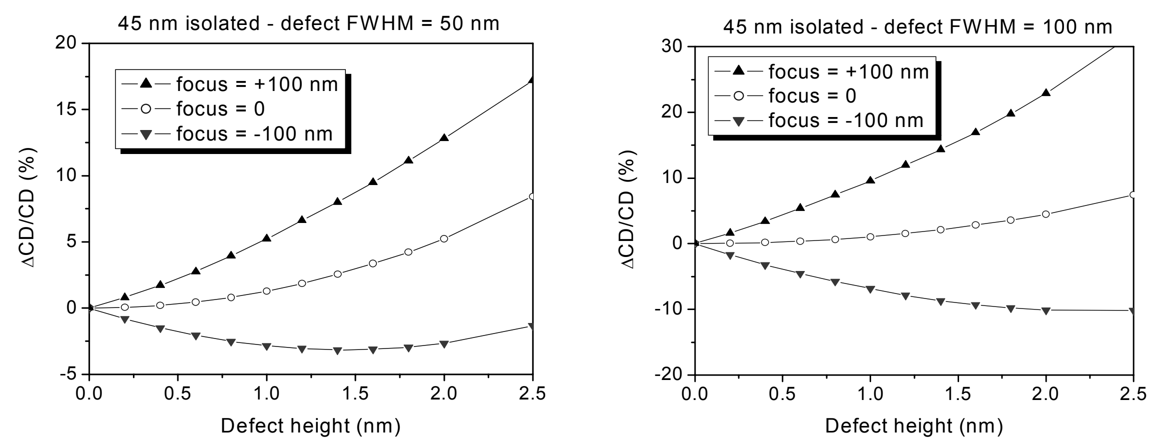
(a)



(b)

Figure 8 Printability according to dose and focus (a) focus: -100nm (b) focus: 0nm

An aerial image simulation was performed to compare with the real test results using a 45 nm isolated line. Figure 9 shows Gaussian bump-type defect printability according to FWHM and height at a fixed focus. This work was done in collaboration with EM Gullikson at LBNL using single surface approximation method[3]. The simulation result shows focus clearly affects defect printability. Figure 10 compares the real test and simulation results. Because defect shapes in the simulation were opposite those of the real test, simulation results at +100 nm are used to compare with real test at -100 nm. Width in the real test changed to 4/5, considering 4X exposure system. Both results are well matched at large defect sizes, but there are a1-2 nm differences in depth when pits are less than 100 nm wide. This may be because the aerial image mainly affects large defects, but bake diffusion or develop processes could cause smoothing of small resist extrusions. Based on this result, it is expected that the defect specifications for mask blanks could be relaxed.



(a) (b)

Figure 9 Aerial image simulation of printability of Gaussian bump defects at a 45 nm iso line (a) 50 nm FWHM (b) 100 nm FWHM

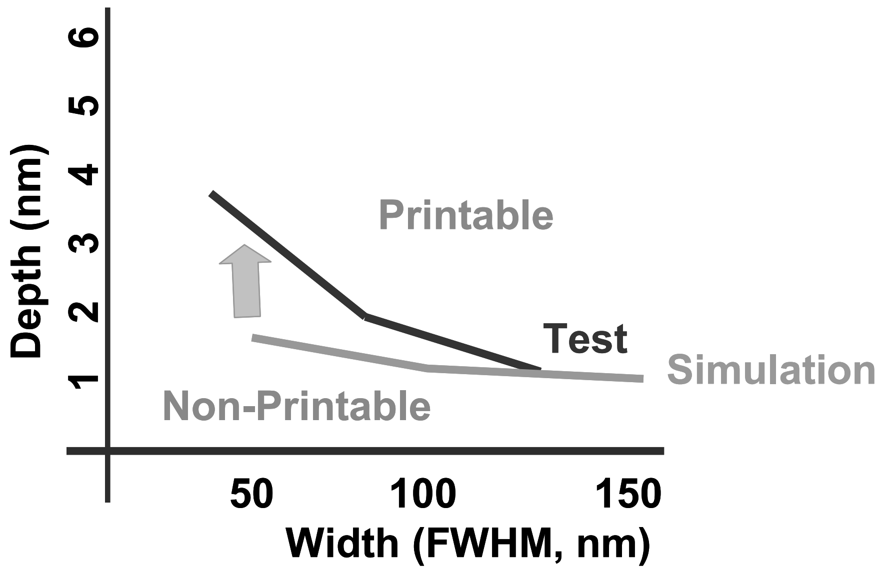


Figure 10 Comparison of printability test results with aerial image simulation

The SEMATECH Berkeley actinic inspection tool was used to capture EUV visual images of the mask. Figure 11 compares the printed resist image with one from the EUV aerial image measurement system with a 0.25NA zone plate imaging system. 50 nm-6 nm pits were used for this comparison. The resist image shows two tiny extrusions, but it is not easy to tell if they are from line edge roughness (LER), while the EUV image shows substrate pits clearly. Currently, the actinic tool[4] is being upgraded to provide aerial CD measurement by improving its aberration and illumination uniformity.

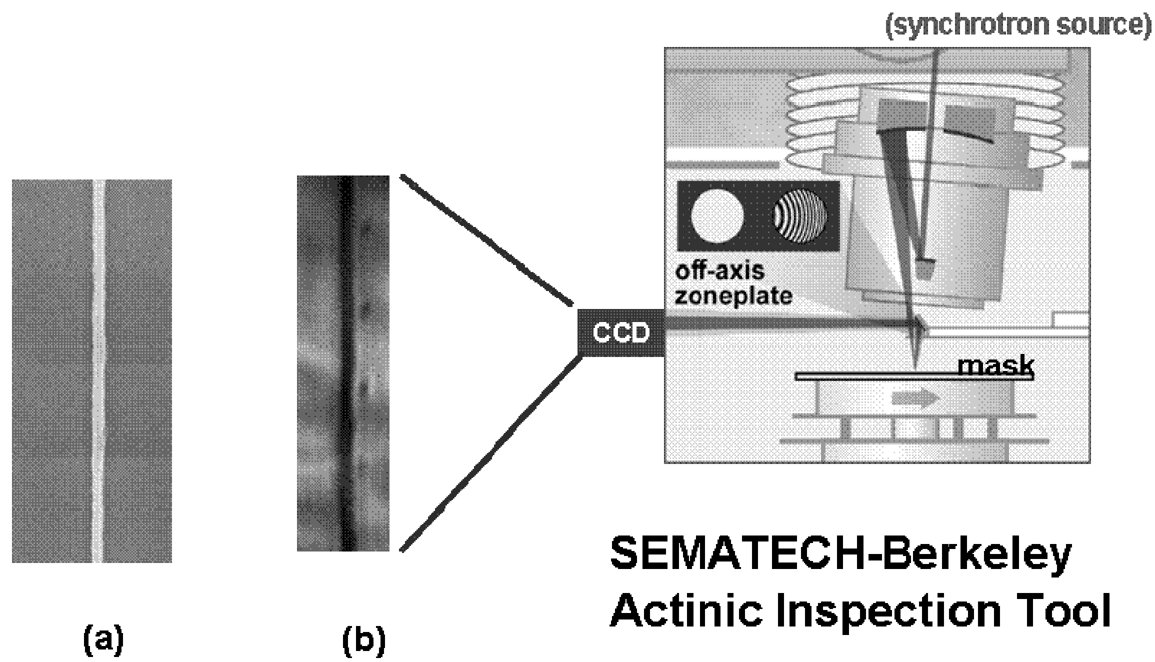
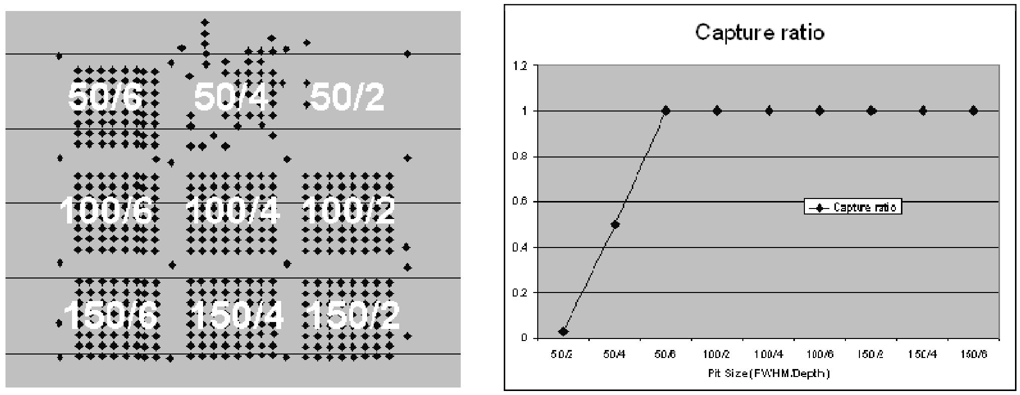


Figure 11 Comparison of a printed resist image (a) with an EUV CCD image (b)

Figure 12 is the MBDC M7360 inspection result of an isolated pit area after multilayer coating. The M7360 shows a good capture ratio down to 50 nm-4 nm pits, smaller than printable pit sizes at the 45 nm isolated line. Figure (b) shows the capture ratio from this result. After upgrading the SEMATECH Berkeley actinic inspection tool, a comparison study between the M7360 and the actinic tool will be performed. Figure (c) shows SEM images of printed resist from 150 nm-6 nm and 150 nm-4 nm isolated pits at a -20% dose and -200 nm focus. 150 nm-6 nm pits were clearly printed, but 150 nm-4 nm pits were barely printed.



(a) (b)

Figure 12 M7360 inspection results using isolated pits (a) detected isolated pits (b) capture efficiency according to pit size

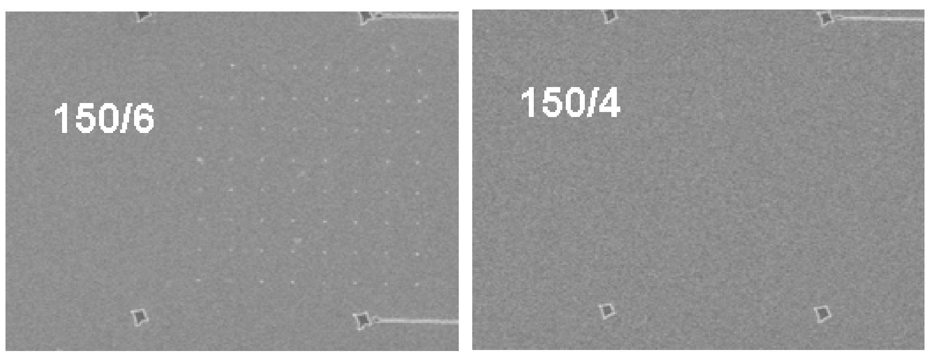


Figure 13 Resist-printed images of isolated pits

4. SUMMARY

Phase defect printability has been studied with SEMATECH's EUV lithography infrastructure to understand substrate pit-size effect on wafer CD. A programmed defect mask with substrate pits and isolated lines was fabricated using facilities at the MBDC at SEMATECH North. Isolated line width was 225nm, corresponding 45nm on a wafer in a 5x demagnification tool. EUV MET printing and printed resist SEM analysis show that substrate pits 50 nm wide and 4 nm deep are not printable and pits 100 nm wide and 2 nm deep are printable only at low dose and defocus. Comparison study between real test and aerial image simulation show real test result is more optimistic than that of simulation. This could be attributed to the bake diffusion or develop process. Thus, it is expected blank defect specifications could be relaxed about 1 nm in substrate pit depth. The M7360 captured pits down to 50 nm wide and 4 nm deep. A comparison study using the actinic inspection tool will be performed after completing the actinic tool upgrade.

5. ACKNOWLEDGMENTS

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REFERENCES

[1] SEMATECH EUV Mask Technology & Standards Workshop, Barcelona/Spain, 19 Oct. 2006. The workshop proceedings can be found at http://www.sematech.org/meetings/archives.htm.

[2] P. Kearney et al., Defect Mitigation and Reduction in EUVL Mask Blanks, International Extreme Ultra-Violet Lithography (EUVL) Symposia (2006).

[3] E.M. Gullikson et al., *Proc. SPIE* **5374**, 791 (2004).

[4] K.A. Goldberg et al., *J. Vac. Sci. Technol.* **B 24**, 2824 (2006).