After Development Inspection (ADI) Studies of Photo Resist Defectivity of an Advanced Memory Device

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Abstract

In this study, a 3x-nm after development inspection (ADI) wafer with focus exposure matrix (FEM) was inspected with both an advanced optical system and an advanced EBI system, and the inspection results were carefully examined. We found that EBI can capture much more defects than optical system and it also can provide more information about within reticle shot defect distribution. It has high capture rate of certain critical defects that are insensitive to optical system, such as nano-bridges.

Introduction

Electron beam (e-beam) defect inspection system has been widely used in integrated circuit (IC) chip manufacturing for the advanced nano technology node. It mainly used to capture the killer defects that optical system incapable to catch, such as electrical defects of short circuit, open circuit and device leakage. [1], [2] Because its higher resolution, it also provide an alternate solution for tiny physical defects that are beyond capability of optical defect inspection system. Based on International Technology Roadmap for Semiconductors (ITRS), at 32nm technology node, size of defects of interesting (DOI) could be as small as 16 nm. Even if defect capturing ability of inspection tool depend on defect type and material, the mainstream optical defect

inspection systems would have difficult to capture such small DOI, thus e-beam inspection (EBI) maybe required at that technology node.

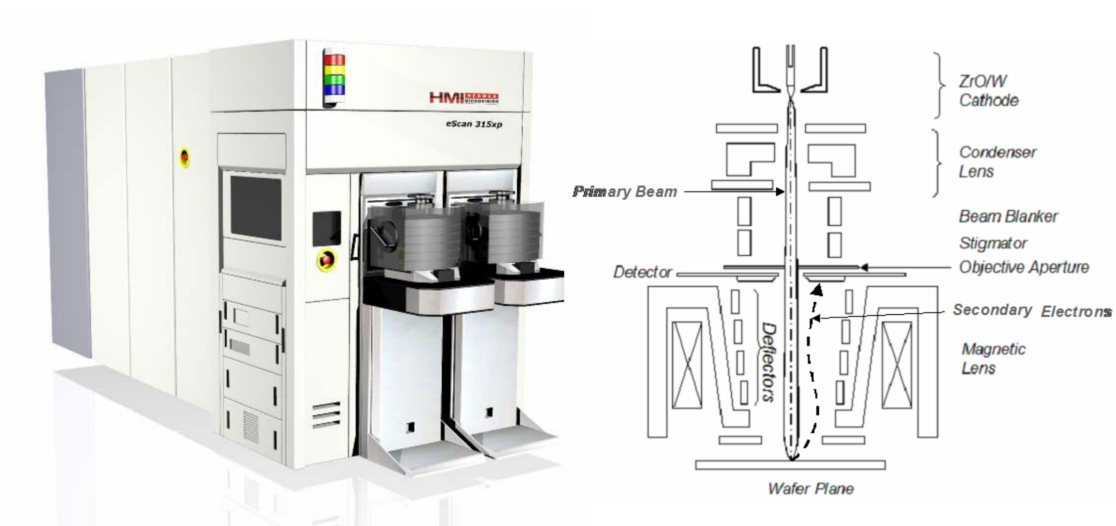
ADI is very important in photolithography process because it allows engineers to catch DOI earlier so that wafer can be reworked to remove photoresist (PR) and redo the RP patterning. Although its resolution is not as high as EBI system, the throughput and signal-to-noise ratio (S/N) of optical system is significantly higher than EBI system, due to the significantly larger amount of photons an optical system can focus on an inspection pixel, comparing the amount of electrons an EBI system can focus on an inspection pixel. As long as it can capture all the DOI, optical inspection system could be still the main stream tool in defect inspection of ADI wafer. However, while device dimension shrinking, optical inspection system may start missing some killer defects which are too small and beyond its resolution capability. In this case EBI could step in and play an important complementary role.

In the previous studies, we reported that e-beam inspection can detect 40-nm defects on a wafer with photo resist (PR) grating structure [3]. We also studied the critical dimension (CD) change before and after EBI in 65nm PR pattern, which showed less than 3% shrinkage. [4] We also studied the EBI application on PR with contact hole pattern and successfully demonstrated the capability to capture defect of bottom remain of PR on the hole with metal hard mask underneath the bottom anti reflective coating (BARC). [5]

EXPERIMENT EQUIPMENTS

In this experiment, both EBI and optical inspection systems are used. Figure 1a is the image of eScan®315xp an advanced EBI system developed by Hermes Microvision, Inc. and Figure 1b is the illustration of an EBI system. [6] It is a large field of view (FOV) scanning electron microscope (SEM) based EBI system designed for sub-45nm technology node applications to capture both physical and electrical defects on 300mm

wafers, such as after etch inspection (AEI) wafers and post chemical mechanical polish (CMP) wafers. With maximum scan pixel field up to 18k x 18k, FOV up to 600μm and, leap and scan inspection mode, it can be used to capture both systematic defects and random defects. With the lowest inspection e-beam current of 1nA and minimum pixel size of 10nm, it can be used to inspect ADI wafers to catch tiny physical defects on PR patterns.



(a) (b)

Figure 1. Image of eScan®315xp (a) and its schematic (b).

The optical inspection system used in the experiment is KLA-Tencor 2830. It is a bright field (BF) defect inspection system which can inspect 300mm wafer with minimum pixel size of 50nm. It equips with high intensity light source with multiple inspection wavelengths, blue-line, I-line, and broadband, to allow high throughput inspection of 3x-nm pattern wafers. Figure 2 is the schematic an optical defect inspection system.

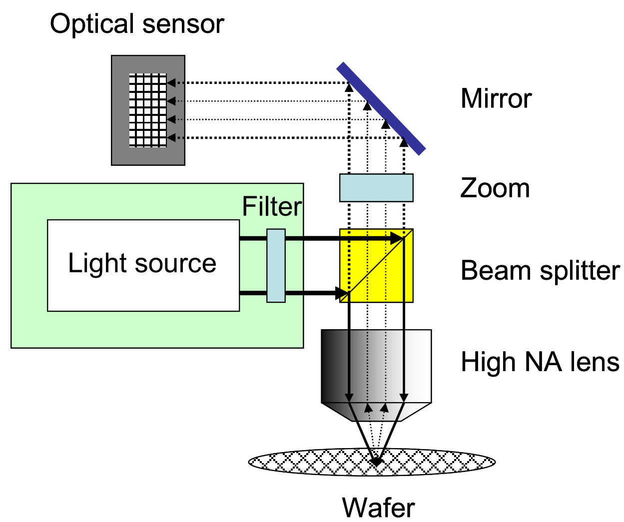
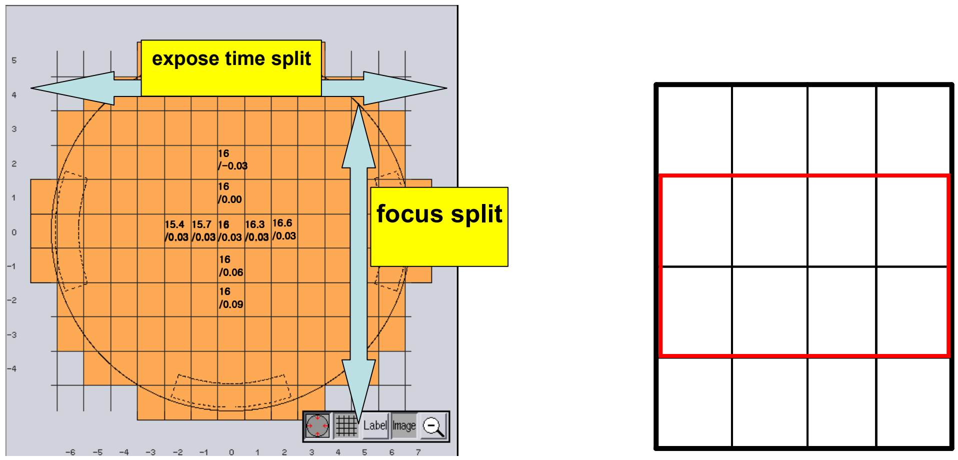


Figure 2. Schematic of a BF optical defect inspection system.

EXPERIMENT SAMPLE

In this experiment, a 300mm ADI wafer with 3x-nm line-space PR pattern was used. FEM was applied during photolithography process to generate the PR pattern with different critical dimension (CD) and defect densities. Figure 3a illustrated the wafer map of the FEM reticle shot distribution. There were 16 dies per shot, arranged in a 4x4 array, as shown in Figure 3b. We used the center 8 dies for the inspection, in 2x4 die array in the box illustrated in Figure 3b.



(a) (b)

Figure 3. Wafer map of litho FEM shot (a) and die distribution within a reticle shot. The box in the center 2x4 array is the area used for the inspection (b).

EXPERIMENT RESULTS

We first used 2830 to inspect 15 reticle shots, total 120 dies near the center of the wafer. They are in 3 rows, 5 reticle shots per row, 8 dies per reticle shot in center 2 rows, as illustrated in Figure 3b, and total 15 focus-exposure variations. We used blue-line, bright field, and 90nm pixel size for the inspection. The inspection results were shown in Figure 4. We found out that most of the defects were bridge defects and two of review SEM images were shown in Figure 5a and 5b. From Figure 4, we found that the density of bridge defect increased when exposure time reduced. This is understandable because the short the exposure time, the lower the exposure dosage, which cause larger pattern CD and narrower gap. Narrower gap with lower exposure dosage was easier to have bridge defects. We also found that the bridge defect density increased when focus shifted away from the center value, especially for these reticle shots with shorter exposure time.

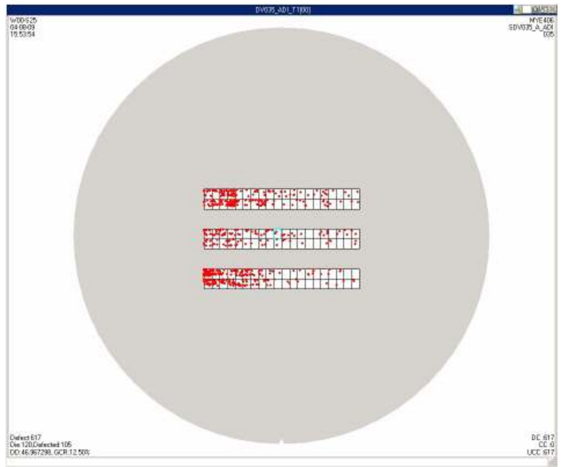
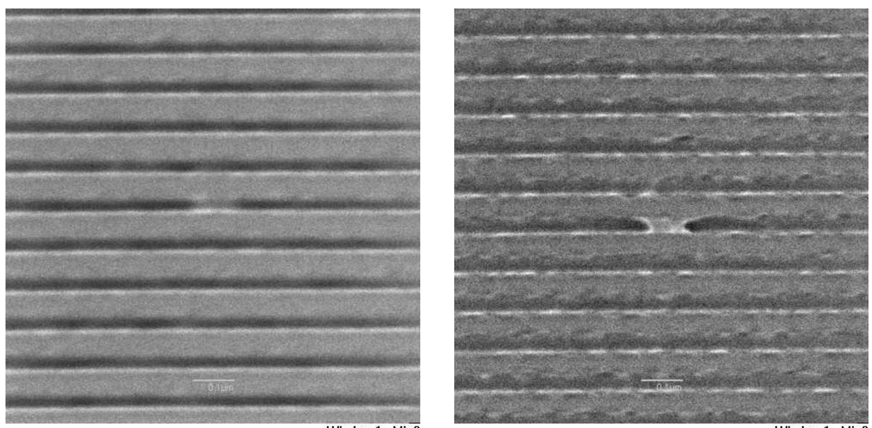


Figure 4. Defect map of optical inspection.



(a) (b)

Figure 5. Review SEM images of the bridge defects captured by optical inspection.

From Figure 5a and 5b, w can see that the bridge defect captured by the optical inspection are either cluster defects or a single bright with size about 100nm x 30nm.

We used eScan®315xp to inspect the same wafer at the same die area. We inspected 9 reticle shots, with 8 dies per shot, as shown in Figure 6. The EBI condition used were: landing energy (LE) 1200eV, e-beam current 2nA, pixel size 15nm, and scan

rate 100MHz with 8 averages, equivalent scan rate 12.5MHz. The within reticle shot defect signatures are illustrated in Figure 7. Because defect density of the reticle shot (15.7, 0.03) is too high, we sampled 25% of the shot area for the inspection.

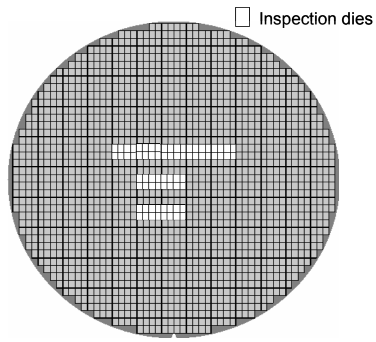


Figure 6. EBI sample plan.

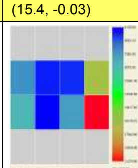
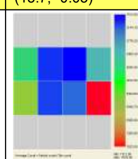
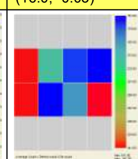
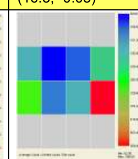
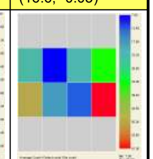
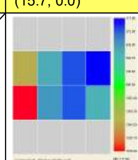
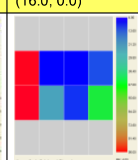
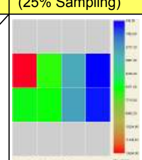
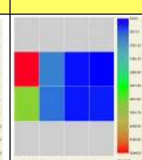
Litho Condition	(15.4, -0.03)	(15.7, -0.03)	(16.0, -0.03)	(16.3, -0.03)	(16.6, -0.03)
Reticle Map					
Defect amount	72283	27470	1908	1623	220
Litho Condition	(15.4, 0.0)	(15.7, 0.0)	(16.0, 0.0)	(16.3, 0.0)	(16.6, 0.0)
Reticle Map					
Defect amount		4795	265		
Litho Condition	(15.4, 0.03)	(15.7, 0.03) (25% Sampling)	(16.0, 0.03)	(16.3, 0.03)	(16.6, 0.03)
Reticle Map					
Defect amount		~ 150760	9853		

Figure 7. EBI defect count and defect distribution within different litho conditions.

Because the high defect sensitivity of EBI, we could see clear defect signatures within the reticle shot. Figure 8a, 8b, 8c and 8d showed the within shot defect signatures

and total defect counts under different litho conditions. We could see that most within reticle shot detect had some kind of signature following the trend that shorter focus tended to have defect denser on two sides of the reticle shot while longer focus tended to have more defects on one side, left side for notch down configuration.

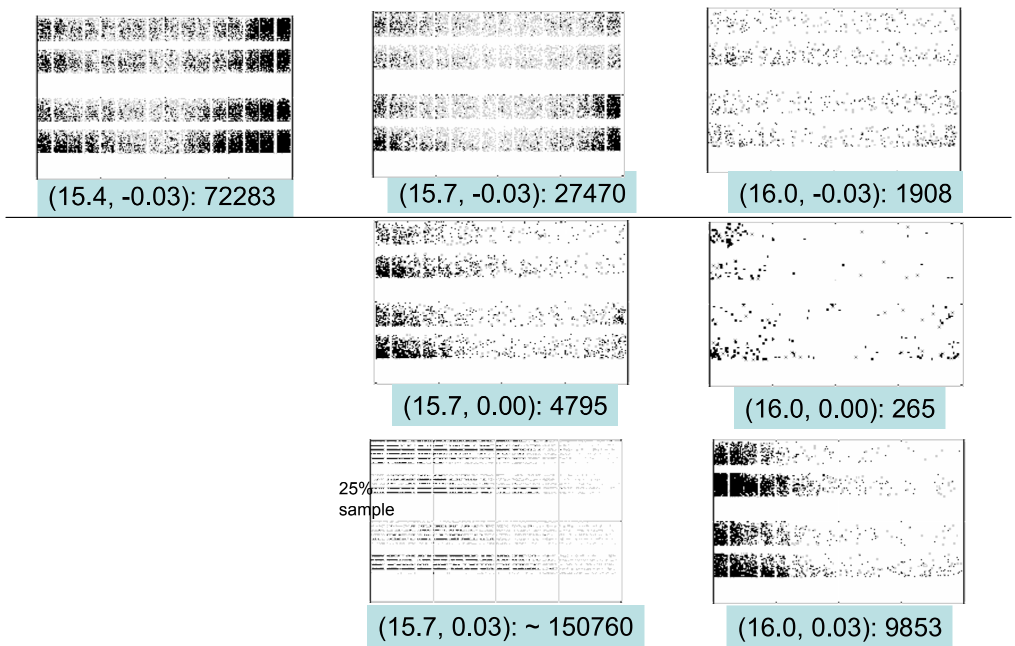


Figure 8. EBI defect counts and defect distributions within different litho conditions.

Table 1 listed the defect counts of EBI and optical inspection of eight reticle shots. We can see that the EBI defect count is much higher, indicated that 15nm pixel size EBI has significantly higher sensitivity to the bridge defect with size of 20nm x 30nm. Figure 9 illustrated the correlation of EBI defect counts and optical inspection defect counts. We could see that the data are correlated well.

Litho condition	(15.4,-0.03)	(15.7,-0.03)	(16.0,-0.03)	(16.3,-0.03)	(16.6,-0.03)	(15.7,0.0)	(16.0,0.0)	(16.0,0.03)
EBI defect count	72283	27470	1908	1623	220	4795	265	9853
BF defect count	135	53	22	19	8	25	20	14

Table 1. EBI defect count and optical inspection defect counts of 8 reticle shots.

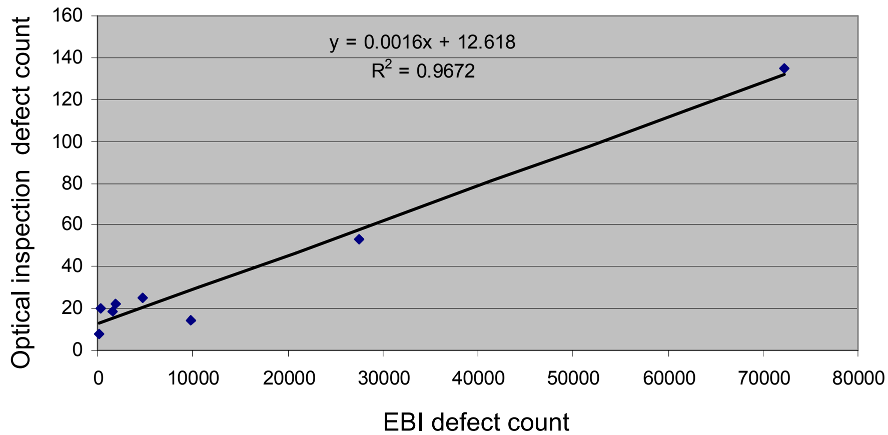
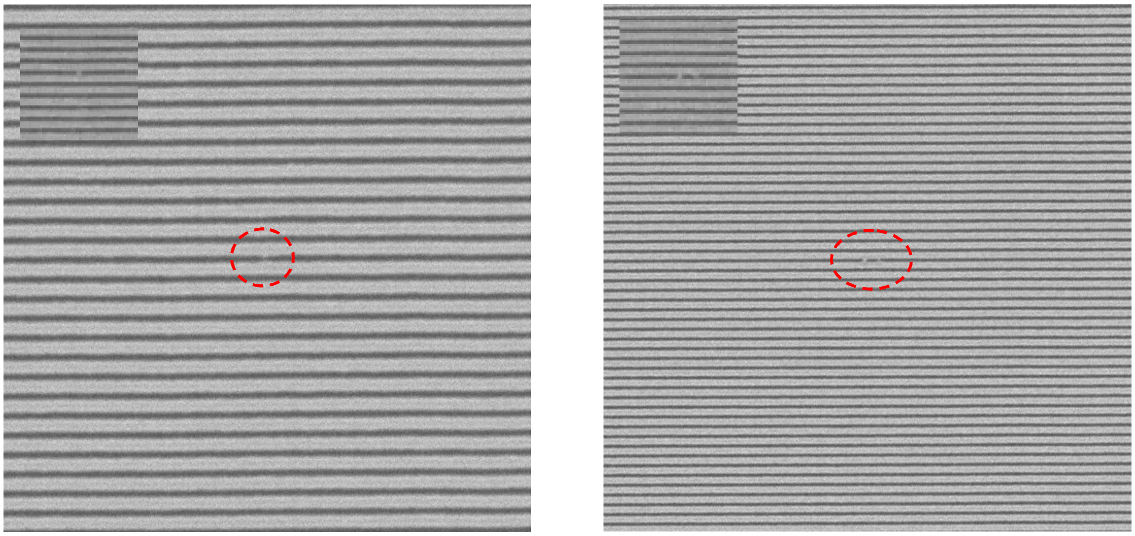


Figure 9. Correlation between EBI defect count and optical inspection defect counts of 8 litho conditions.

The 15nm pixel size inspection patch image (insert) of a single bridge and its review image took with eScan®315 using 5nm pixel size were shown in Figure 10a, and a 15nm pixel size inspection patch image (insert) and its review image using 10nm pixel size were shown in Figure 10b.



(a) (b)

Figure 10. Single bridge defect captured by 15nm pixel size EBI (inserted patch image) and its 5nm review image (a). Double bridge defect captured by 15nm pixel size EBI (inserted patch image) and its 10nm review image (b).

SUMMARY

In this study, we inspected photoresist pattern on a 3x-nm after development inspection (ADI) wafer with both an advanced optical defect inspection system and an advanced EBI system. The inspection results were carefully examined. We found that EBI have much higher sensitivity to capture tiny bridge defects than that of optical inspection system. EBI also could provide useful information of within reticle shot defect distribution. EBI can be a very useful tool to play complementary/supplementary role for the photolithography process development.

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