Title：Novel programmed defect mask blanks for ML defect understanding and characterization
Authors：Kazuaki Matsui; Takagi Noriaki; Isogawa Takeshi; Yutaka Kodera; Sakata Yo; Akima Shinji
Publisher：Photomask Japan 2012（SPIE）

Citation：Kazuaki Matsui; Takagi Noriaki; Isogawa Takeshi; Yutaka Kodera; Sakata Yo; Akima Shinji, "Novel programmed defect mask blanks for ML defect understanding and characterization," *SPIE* 8441, Photomask and Next-Generation Lithography Mask Technology XIX, 84411A (June 1, 2012); doi:10.1117/12.975824

DOI abstract link：http://dx.doi.org/10.1117/12.975824

Novel Programmed Defect Mask Blanks for ML Defect Understanding and Characterization

Kazuaki Matsui[a], Noriaki Takagi[b], Takeshi Isogawa[a], Yutaka Kodera[a], Yo Sakata[a], Shinji Akima[a]

[a]Toppan Printing Co., Ltd., 7-21-33 Nobidome, Niiza, Saitama, 352-8562 Japan
[b]EUVL Infrastructure Development Center Inc., 16-1 Onogawa, Tsukuba-shi, Ibaraki 305-8569, Japan

ABSTRACT

EUV blank inspection is the key technology for EUV mask fabrication. To assess blank inspection tools, it is important to obtain appropriate test blanks with properly characterized defect types. In this study, new programmed defect blank was fabricated with conventional programmed defect fabrication and several new methods for natural-like programmed defects. And defect characterization work has been conducted to verify the difference of conventional programmed defects and natural-like programmed defects, and confirmed wide range of defect sizes from minimum below 1nm-height x 18nm-width to micron order defects were successfully fabricated. Furthermore, the blank was inspected by Actinic Blank Inspection (ABI) tool and evaluated the effectiveness of the new defect fabrication methods. And it was confirmed that the new programmed defect showed similar characteristics as natural defects.

Keywords: EUV mask, EUV blank, Multi layer, Multi layer defect, Phase defect, Bump, Pit, Inspection.

1 INTRODUCTION

According to the recent surveys, the predominant lithography techniques for the 2x nm node are EUV (Extreme Ultraviolet), DP (Double patterning) and SMO (Source Mask Optimization). Other advanced technology may also be used for these nodes such as NIL (Nano Imprint Lithography) and EBDW (Electron Beam Direct Writing), along with several lithography techniques highlighted today. However, not only 2x node but also 1x node and beyond technologies are considered together, the leading contender for the next generation lithography is EUV.

Considering volume manufacturing of 2x and 1x nm node masks, mask makers need to be ready to produce defect free masks in near futures, however, blank defect is the one of the major issues for the good quality mask. Especially, ML (multi layer) defect (a.k.a. phase defect) is one of the difficult defect types which EUV mask/blank industry has to overcome. In these years, several inspection tools specific for ML defects have been developed and introduced to the industry.[1,2] But it is very important to consider how sensitivity performance of these tools should be evaluated, and furthermore, it has to be considered how to obtain appropriate test blanks with programmed ML defects. And types and sizes of the programmed ML defects need to be properly characterized. In the past, several evaluation results of programmed ML defects which were fabricated by EB writing and etching process have been reported.[3,4] In these reports, normally the cross-section shape of the programmed defects are rectangle. On the other hand, very curious result are reported that defect printability and defect detectability of rectangular shape programmed defects and natural defects are very different.[4,5] It is considered that such phenomenon could happen because multilayer formation may be different between natural defects and programmed defects due to the shape of defect source as shown in Figure 1. In other word, shape of natural defect is more complicated. It is unlikely happened that cross-section shapes of natural defects are rectangular and top and bottom of natural defects are perfectly flat. From these evaluation results, it is requested to fabricate test blanks with programmed ML defects which show similar characteristics as natural defects.

In consideration of circumstances described above, availability of new programmed ML defect blank was evaluated.

Firstly, sources of programmed defects were fabricated on substrate by conventional and newly developed methods and built new programmed ML defect blank by depositing multi layer on the substrate. Secondly, characterization work has been conducted by SEM and AFM to verify the difference of conventional programmed defects and natural-like programmed defects. And finally, the test blank was inspected by Actinic Blank Inspection (ABI) tool and evaluated the effectiveness of the new defect fabrication methods.

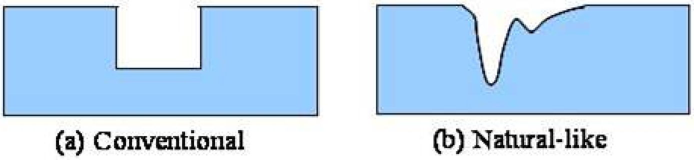


Fig.1 Schematic view of source of programmed defect

2 EXPERIMENTS

2-1 Programmed ML defect blank fabrication

Generally, programmed defects have been patterned by e-beam writing and mask process (resist develop, etching and resist strip). In this conventional method, it is easy to fabricate many same height defects by one process cycle. But minor point of this method is that multiple mask processes are necessary to fabricate various defect heights defects. It means the number of mask process cycle increases as number of designed defect height increases.

Figure 2 shows the procedure to manufacture programmed defect blank. In case of conventional procedure, defect formation process needs to be repeated as required. On the other hand, new procedure has only one process for defect formation. Source of programmed defects were fabricated on substrate. For defect source fabrication, proper process was applied for required defect types from several processes. After defect source fabrication, defect sizes and shapes were measured and characterized by SEM and AFM. Multilayer was deposited on top of the source of programmed defects under normal deposition conditions using an ion beam deposition tool. Then defect sizes and shapes after multilayer deposition were measured by SEM and AFM again.

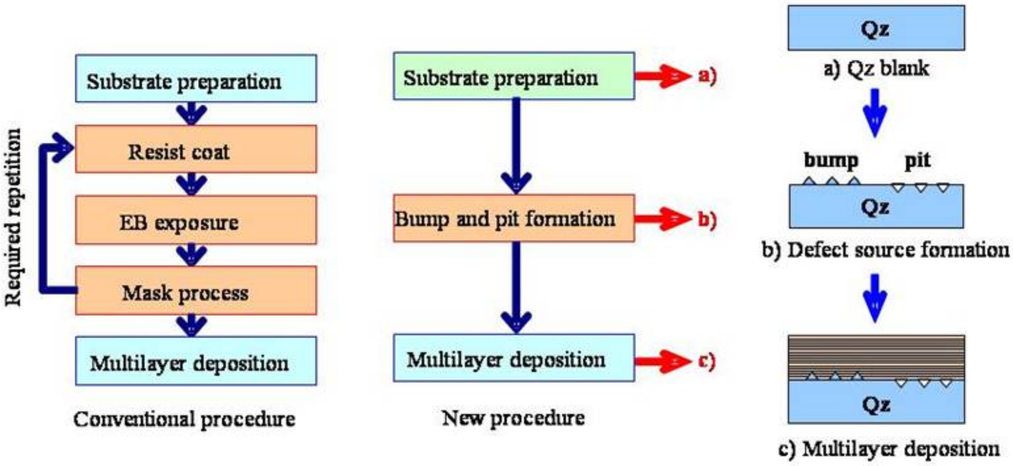


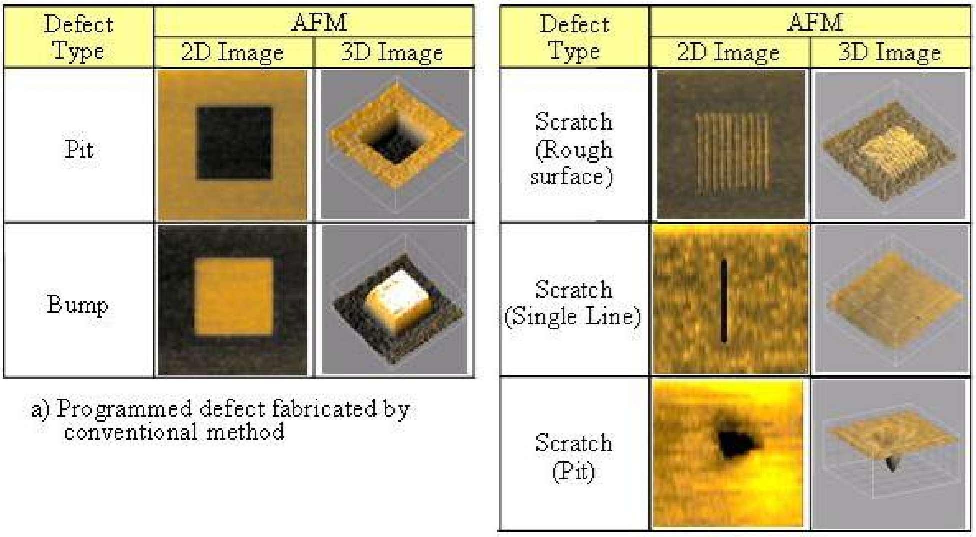
Fig.2 Experimental procedure for programmed defect mask fabrication

The new defect fabrication process introduces flexibility of defect fabrication. Because the tools for defect source fabrication are all existing tools, and process controls, especially defect height control, can be more flexible than conventional method. It means, it is easy to fabricate multiple defect height as required. Minor point of this new method is that it is not suitable to fabricate many same height defects.

2-2 Programmed ML defect types

In this study, several processes were applied for programmed ML defect source formation. Figure 3 shows fabricated programmed ML defect types. One of the pit defects and bump defects has rectangle shape. It means, if conventional method is applied for defect formation, programmed defect shape is normally rectangle. So we attempted to reproduce similar defect shape as conventional method by our new method. Other 3 types of programmed defects were fabricated by new processes. It is attempted to fabricate rough surface defect, single line scratch defect and pit. These three types of defects are suspected to be similar to real substrate defects which are occurred by polishing or cleaning in actual blank fabrication process.

Five different defect types are located in different defect area. Defect sizes were designed from18x18nm to 1000x1000nm width and wide range of defect height from 1nm to 30nm. All dimensions of these programmed defects are on mask dimensions.



a) Programmed defect fabricated by conventional method

b) Programmed defect fabricated by new method

Fig.3 Schematic view of fabricated programmed ML defects

2-3 Test blank inspection

The fabricated programmed defect blank was inspected by ABI tool to confirm whether the new defect fabrication method is effective for blank inspection tool evaluation work.

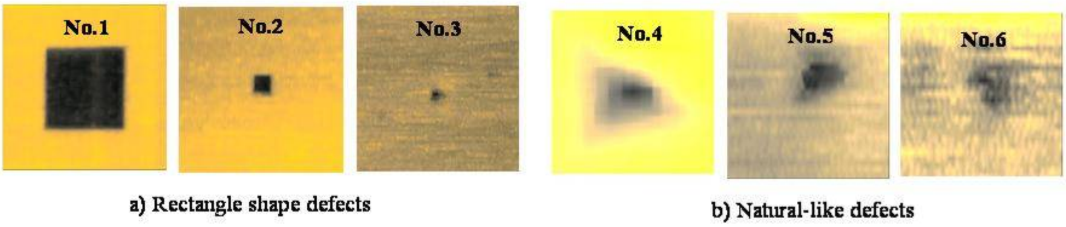
3 RESULTS AND DISCUSSION

3-1 Characterization work of programmed defects

Source of programmed ML defects were fabricated on Qz substrate. There are a couple of things that need to be considered. Firstly, the target sizes of the programmed ML defects are relatively smaller than that of regular programmed defects which were historically fabricated for optical mask and it is necessary to measure not only defect width but also defect height or depth. So defect size measurement would be one of the key for programmed defect characterization. Secondly, defect shape on bottom of multilayer and on top of multilayer may be different due to multilayer deposition models, and it is very important to understand how the defect shapes transit from the surface of Qz substrate to the top of multilayer. Because difference of ML defect formation models may cause defect printability difference on wafer. So the size of the ML defects needs to be measured before and after multilayer deposition process.

SEM and AFM were applied for characterization work of fabricated programmed defects. Fig.4 shows AFM top view images of the fabricated pits. Both rectangle shape defects and natural-like defects are fabricated successfully by new programmed defect fabrication method. The images show that new defect fabrication method can provide flexibility for defect source fabrication.

Figure 5 shows defect depth measurement result for both rectangle shape pits and natural-like pits. From the measurement results, new defect formation method shows linear relation between designed defect depth and actual defect depth. Rectangle shape defect shows around 3-4nm gap between design and actual, however, it is judged defect size control will not be difficult if the small gap is considered at defect source fabrication. On the other hand, natural-like defects were successfully fabricated as designed. From these measurement results, it is confirmed that source of the ML defects were successfully fabricated on Qz substrate and new defect formation method is applicable to generate a few nm order ML defect source.



a) Rectangle shape defects

b) Natural-like defects

Fig.4 Top view of programmed defect

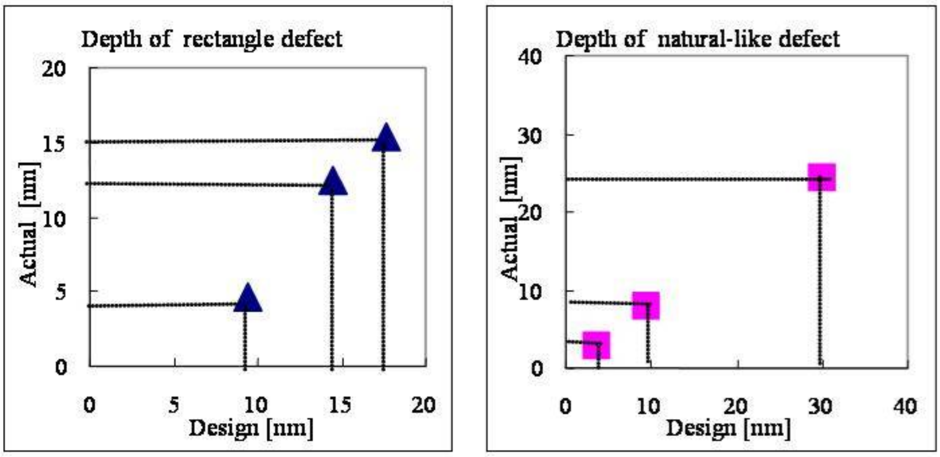


Fig.5 Programmed defect size between design and actual

3-2 Defect comparison between natural defect and programmed defect

As mentioned above, defect shape and size may be different on bottom and on top of multilayer. 2 different models have been proposed as conformal and non-conformal models. Figure 6 shows defect size transition model before and after multilayer deposition. In case of conformal model, W_{bottom} and D_{bottom} mean defect width and defect depth on bottom surface, and W_{top} and D_{top} mean defect width and depth on top surface. And in case of Non-conformal model, V_{bottom} and V_{top} mean respectively defect volume on bottom and on top.

In the conformal model, the defect dimensions at the surface and the bottom of the multilayer are assumed to be same. It means, $W_{bottom} = W_{top}$ and $D_{bottom} = D_{top}$. On the other hand, in the non-conformal model, the volume of the defect on the surface layer is assumed to be the same as that on the bottom layer, where the height (or depth) and width of the defect are also the same. It means $V_{bottom} = V_{top}$.

Size of fabricated defects on the bottom of multilayer and on the top of multilayer was compared. Figure 7 shows AFM measurement result of rectangle pit and natural-like pit. In case of rectangle pit, the shape on top of multilayer was rounded as compared to the shape on bottom surface, however, it is considered that defect transition model was similar to conformal model. On the other hand, natural-like pit shows different tendency from rectangle shape defect. Depth of the defect on top surface was drastically reduced and width got slightly bigger than that on bottom surface. From the measurement result, it is considered that rectangle shape defect is formed in accordance with conformal model and natural-like defect is formed in accordance with non-conformal model. It is assumed that these multilayer formation differences may cause ML defect detectability by blank inspection tool.

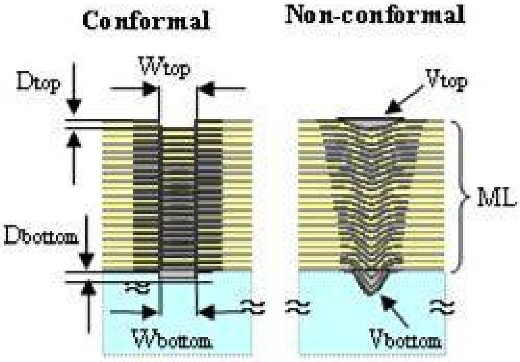


Fig.6 ML defect transition model

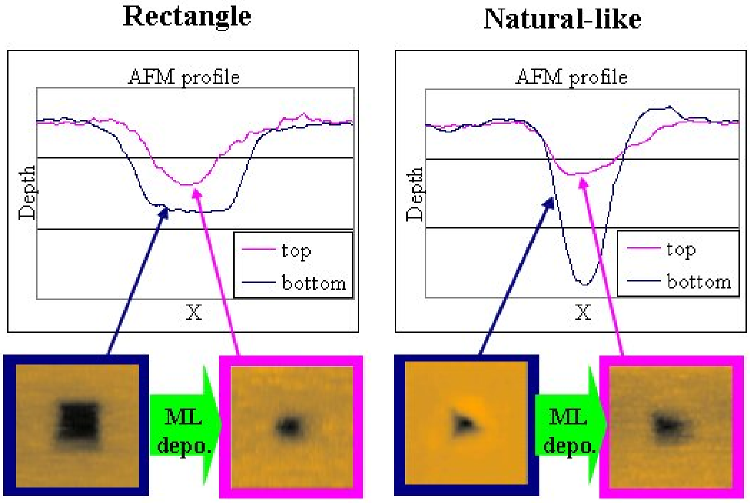


Fig.7 Defect shape change between before and after ML deposition

3-3Defect signal comparison by blank inspection tool

After completing multilayer deposition, defect images were captured by actinic blank inspection tool, and defect signal of rectangle defects and natural-like defects were compared. In fact, it has been reported that the defect signal intensities of natural defects were almost the same as that of the smallest programmed defect.[1] It means natural defects show different signal tendency from rectangle shape programmed defects as shown in Figure 8.

Figure 9 shows the relationship between defect volume and defect signal intensity of fabricated programmed defect blank. From this result, in case of rectangle shape defects, the relation between defect volume and signal intensity is linear, however, it is confirmed that natural-like defects show bigger signal than rectangle shape defects even if defect size is small. This tendency is supposed to be the same as the case of natural defect reported in Figure 8.

As a result, it is judged that these defect fabrication methods are capable for both rectangle and natural-like programmed defects. And especially for natural-like defect, it is supposed that our defect fabrication method is capable to reproduce similar situation as natural defects.

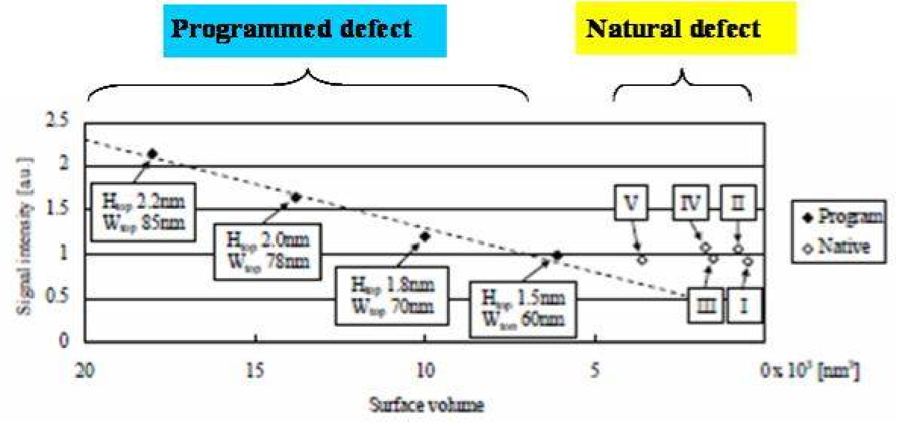


Fig. 8 Relation between surface volume and signal intensity of the programmed and native defects

Reference: Proc. of SPIE Vol.7748 774803-1

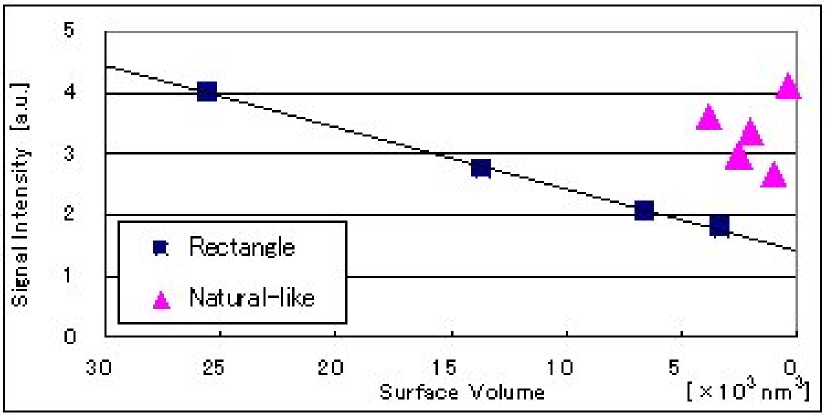


Fig.9 Relation between defect volume and signal intensity of rectangle and natural-like defects.

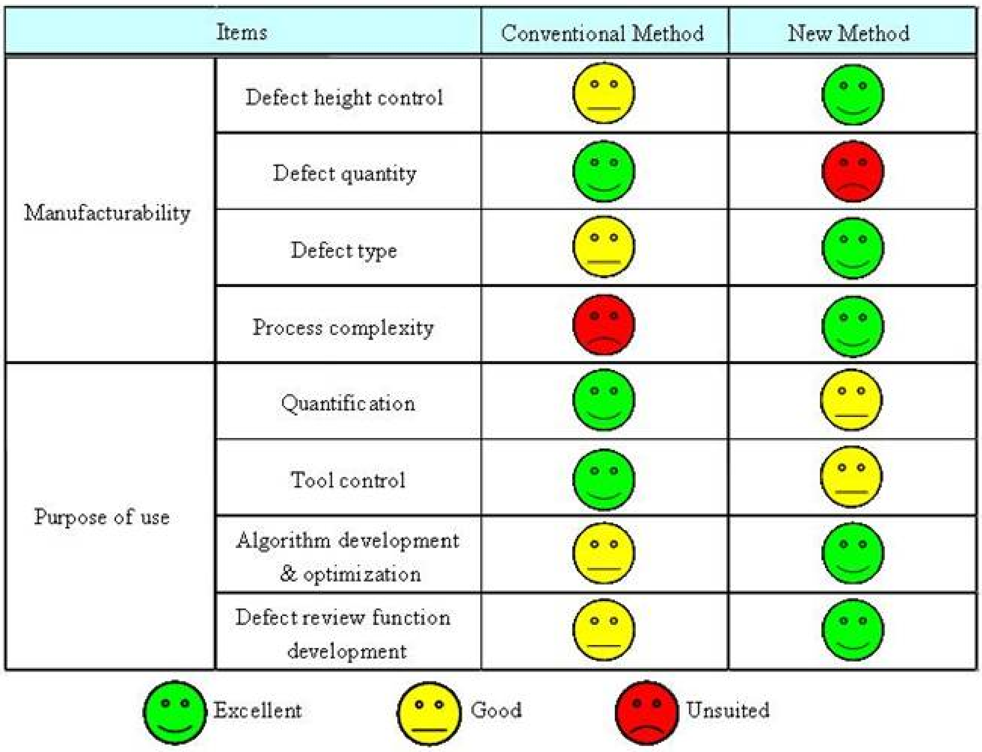
But it is assumed that conventional method and proposed new method in this paper have both high point and low point. Characteristics of these 2 methods are shown in Table 1.

The new defect fabrication method is very flexible to control defect sizes, but it is not easy to fabricate multiple defects with same height, same width and same shape. On the other hand, it is very easy to fabricate a lot of same height defects by conventional method, but it is necessary to repeat defect formation process several times to make all required defect heights. It means, defect formation process gets longer as number of designed defect height increase.

Focusing on purpose of use, quantification for defects by new method may need consideration because defect shape can be very complex like natural defects. But defects by conventional method are essentially rectangle shape. Thus defect characterization work will be very simple and easy. And these characterized defects are expected to be suitable for inspection tool control.

Regarding mask usage for algorithm development, sensitivity optimization work and defect review function development, rectangle shape defects are not supposed to be suitable because defect shape in real situation are totally different from the finely shaped programmed defects. So the programmed defects with complex shape by new method are expected to be suitable for tool evaluation and qualification.

Table 1 Characteristics comparison between 2 defect fabrication methods



Items		Conventional Method	New Method
Manufacturability	Defect height control	😐	🙂
	Defect quantity	🙂	☹
	Defect type	😐	🙂
	Process complexity	☹	🙂
Purpose of use	Quantification	🙂	😐
	Tool control	🙂	😐
	Algorithm development & optimization	😐	🙂
	Defect review function development	😐	🙂

🙂 Excellent 😐 Good ☹ Unsuited

4 CONCLUSION

In this study, programmed multilayer defect blank has been fabricated.

Firstly, both rectangle shape defects and natural-like defects were fabricated successfully by new method. Secondly, characterization work has been done by SEM and AFM. From the results, it was confirmed the size of the programmed defects were well controlled and natural-like programmed defects were successfully fabricated on substrate by new method as expected. And finally the programmed defect blank was inspected by ABI tool, and it was confirmed defect signal of natural-like defects showed different signature from that of rectangle shape defects. The characteristics of the fabricated natural-like defects are likely to be similar to natural multilayer defects.

To conclude, new programmed defect fabrication method showed good effectiveness to provide proper test vehicle which consists of natural-like defects like real situation. And the defect fabrication technique is expected to be useful for future tool evaluation and qualification.

5 ACKNOWLEDGEMENT

This work was supported by New Energy and Industrial Technology Development Organization (NEDO).

The authors would like to thank several groups of people who contributed to this work. Especially, Emily Gallagher (IBM), kindly supported the study.

REFERENCES

1. Takeshi Yamane, Toshihiko Tanaka, Tsuneo Terasawa, Osamu Suga, “Actinic EUVL mask blank inspection capability with time delay integration mode”, Proc. SPIE Vol. 7748, 774803 (2010).
2. Joshua Glasser , Stan Stokowski, Gregg Inderhees, “Inspecting EUV mask blanks with a 193-nm system”, Proc. SPIE Vol. 7748, 774808 (2010).
3. Pei-Cheng Hsu, et al, “Printability of Buried Mask Defects in Extreme-UV Lithography”, Proc. SPIE Vol. 7969, 79691D (2011).
4. Hyuk Joo Kwon, et al, “Printability of Native Blank Defects and Programmed Defects and Their Stack Structures”, Proc. SPIE Vol. 8166, 81660H (2011).
5. Takeshi Yamane, Toshihiko Tanaka, Tsuneo Terasawa, Osamu Suga, “Phase defect analysis with actinic full-field EUVL mask blank inspection”, Proc. SPIE Vol. 8166, 81660G (2011).