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TAKE A LOOK INSIDE:

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Best Paper Award - JPM13

A Study of phase defect measurement on EUV mask by multiple detectors CD-SEM

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ABSTRACT

We have studied MVM (Multi Vision Metrology) -SEM® E3630 to measure 3D shape of defects. The four detectors (Detector A, B, C and D) are independently set up in symmetry for the primary electron beam axis. Signal processing of four direction images enables not only 2D (width) measurement but also 3D (height) measurement. At last PMJ, we have investigated the relation between the E3630's signal of programmed defect on MoSi-HT and defect height measured by AFM (Atomic Force Microscope).[1] It was confirmed that height of integral profile by this tool is correlated with AFM. It was tested that E3630 has capability of observing multilayer defect on EUV. We have investigated correlation with AFM of width and depth or height of multilayer defect.

As the result of observing programmed defects, it was confirmed that measurement result by E3630 is well correlated with AFM. And the function of 3D view image enables to show nm order defect.

1. Introduction

The VLSI pattern width shrinking is continuing and EUVL is expected for 1xnm and below. One important issue of EUV mask is phase defects handling. Zero phase defects on EUV mask is required and number of defects is decreasing year by year, but it is supposed to be difficult at the moment. Therefore the fiducial mark is discussed for methodology to avoid phase defects. We had fabricated natural-like programmed defect[2] and estimated ABI (Ac-

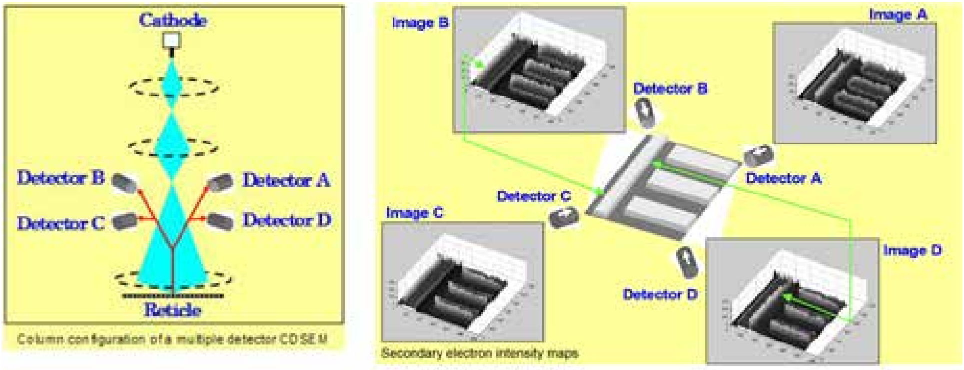

Figure 1. Left figure shows the schematic view of MVM-SEM® E3630 and right one shows the view of secondary electron images by 4 channel detectors.

EDITORIAL

We're All Together Again For The First Time

Peter D. Buck, Toppan Photomasks, Inc.

In 1973 Atlantic Records released a compilation of live recordings of Dave Brubeck with a band composed of members from previous bands some of whom had never before played together. The album was called "We're All Together Again For The First Time". It is a mesmerizing set of tunes to a Brubeck fan, particularly the first song "Truth", which is a fast, powerful song driven by strong rhythmic chord progressions from Brubeck on piano. As each performer takes his solo, the diversity of the band members becomes apparent, especially the stylistic differences between the two saxophonists, Paul Desmond and Gerry Mulligan. Desmond is cool, restrained, melodic, refined – it is possible to imagine him in his trademark suit and bowtie, a minimalist, not wasting a single note. Mulligan, on the other hand, is the complete opposite – brash, powerful, raw, dressed in West Coast style in a Hawaiian shirt, untucked. Listening to this music it is difficult to think of two Brubeck combos with such different musicians, but it is clearly evident that the combination together makes magic.

I recently changed jobs, moving to a new employer after almost 15 good years at my previous employer. I walked around the office, getting introduced and reintroduced, amazed at how many people I knew, some as co-workers at previous jobs, some as colleagues from suppliers, customers, and competitors, some from the neighborhood, and even some I just knew by sight from the Saturday farmers market. I've been in this photomask industry for 36 years now, 40 if I count my college years that coincidentally began the year "We're All Together Again For The First Time" was released. It was comforting to see all the people I knew. It was going to be a different, demanding, challenging new job but at the same time it was going to be with people I knew, respected, and had shared experiences with.

When I took my first photomask job in 1977 I had no idea that I would spend practically my entire career in this industry - there are so many other things to do. Yet here I am, this time in a different segment of the same industry, still focused (yes, perhaps single-mindedly) on the technical and economic challenges of producing optical tooling for the semiconductor industry. I think the reason must be the people, this close-knit community that is both adaptable and tenacious, adjusting as necessary to fit the ever changing challenges of the industry.

I felt lost when I left my previous job. It was like a divorce, leaving good people who did not share in the decision. I thought why do we do this, making life difficult for ourselves, creating uncertainty and risk that could have been avoided by staying put? The compulsion to make a change, to mix it up, to remake one's self one more time is strong. And like the band Brubeck put together out of previous bands, a remix of personnel and environment can produce magic. Striving to produce magic is what makes life worth living. I look forward to re-engaging with the industry, my old and my new colleagues in this new reincarnation. We're all together again for the first time.

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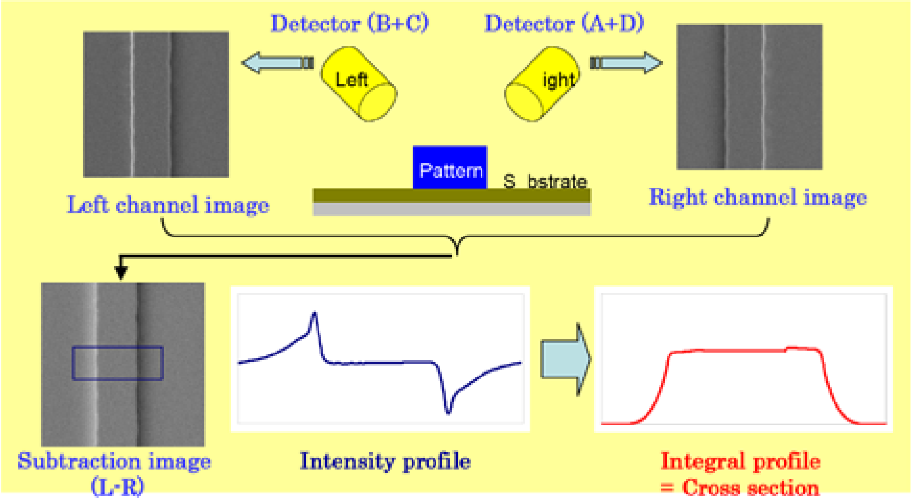


Figure 2. The generation method of subtraction image by using 4channel images and calculation of cross section.

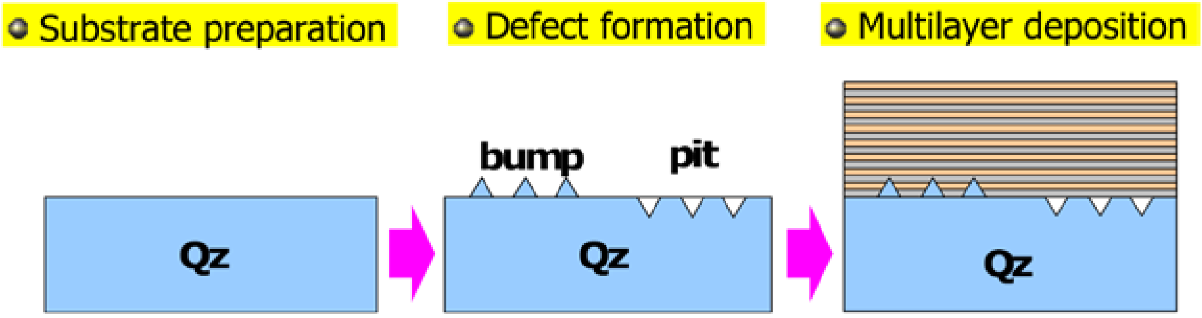


Figure 3. Fabrication procedure of multilayer programmed defect blank.

tinic Blank Inspection) signal intensity of that. It was found that the trend of signal intensity of natural-like defects is different from that of rectangle defects. The phase defect printability is different depending on 3D shape of defect. So it is necessary to measure characteristics of 3D shape of defects.

Currently, AFM is mainly used for measurement of 3D defect shape. The measurement accuracy is good but there are concerns about throughput. On the other hand, CD-SEM is applied for 2D measurement. The measurement repeatability is less than 0.3nm @3sigma by latest CD-SEM. And it has high stage accuracy and measurement throughput is less than 10 seconds. But conventional CD-SEM does not have 3D measurement function. It is found that CD-SEM does not have capability to observe multilayer defect.[3] So, we have developed multilayer defect shape measurement using MVM-SEM® E3630 that has 3D observation function.

2. The structure of MVM-SEM® E3630

2.1 The schematic view and secondary electron image

E3630 column configuration with four channel detectors is illustrated in left side of Figure 1. The four detectors (Detector A, B, C and D) are independently set up in symmetry for the primary electron beam axis. The secondary electrons emitted from the mask surface enter into one specific detector among the four detectors depending on the emission area. As a result, secondary electrons detected by each detector are distributed as shown in right figure, where pattern edges are emphasized in accordance with the each detector location. Four images are obtained simultaneously by the electron beam scanning. The image A is taken by the detector A. Similarly, the image B, C and D are taken by the detector B, C and D respectively.

2.2 The generation method of cross section

E3630 can detect secondary electrons with four detectors respectively and generates four images from signals which are detected by each detector simultaneously. By combining some of these images, a left channel image, a right channel image and a subtraction image between opposed detectors are generated. In the intensity profile of subtraction image, the rising edge of pattern is positive peak and falling edge of pattern is negative peak. Using this intensity profile, the cross section image of pattern can be generated by integral profile as shown in Figure 2.

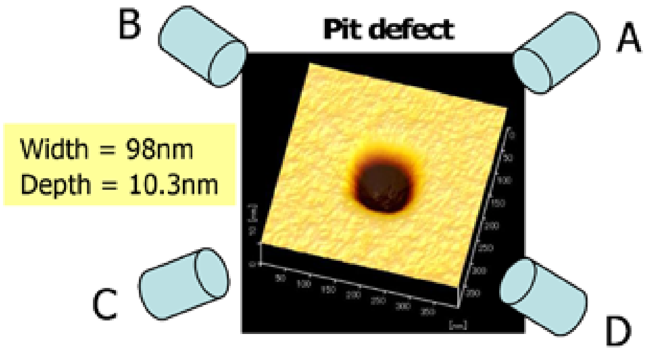


Figure 4. AFM image of big pit defect.

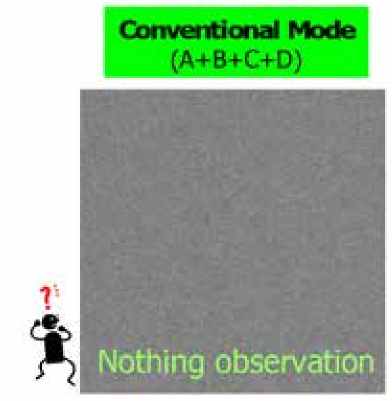
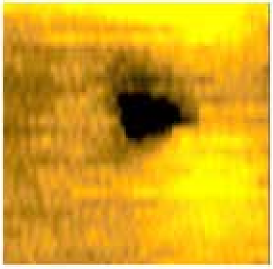
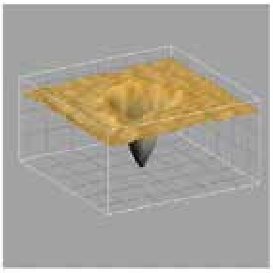
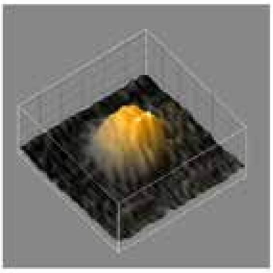


Figure 5. SEM image of pit defect by conventional mode.

Table 1. The sample images of programmed multilayer defects.

Defect Type	**Natural-like Pit**	**Natural-like Bump**
2D Image		
3D Image		

3. Experiment

3.1 Programmed multilayer defect

Figure 3 shows programmed multilayer defect blank fabrication procedure. At first, the Qz substrate is prepared and Bump and Pit defects formed on substrate. Finally, multilayer is deposited on the substrate. All programmed defects are measured size and 3D shapes on multilayer by AFM. It is confirmed that various shape of defects are formed as natural-like defect in Table 1.[2] The size of natural-like defect is 20x20nm square and above and depth or height is 1.0nm and above by AFM. In this study, our measurement target is smaller than 50nm width and 1.0 nm depth or height of multilayer defects.

3.2 Observation of multilayer defect

At first, it is tested whether E3630 has capability to observe multilayer defect. Figure 4 shows a big pit defect which has 98nm width and 10.3nm height by AFM. Figure 5 shows a SEM image of this pit defect using conventional mode that is combined with four channel images. It is found that nothing can be observed even though big pit defect exists. Next, SEM images using four channel parallel mode are shown in Figure 6. In this time, we can observe clear signal of pit defect on each channel image. Then, it is confirmed that multilayer defect observation is available by four channel mode.

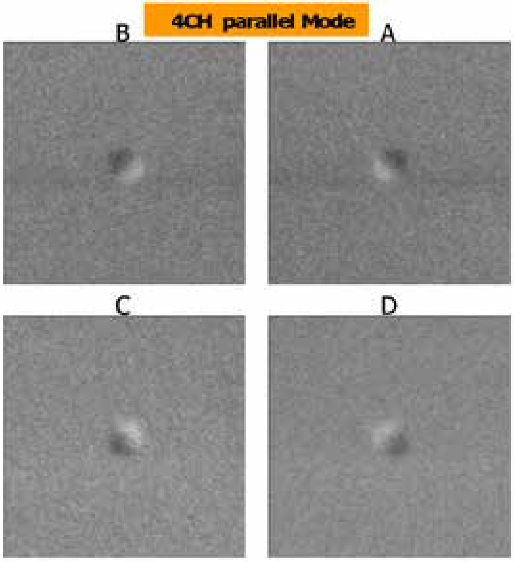


Figure 6. SEM images of pit defect by four channel parallel mode.

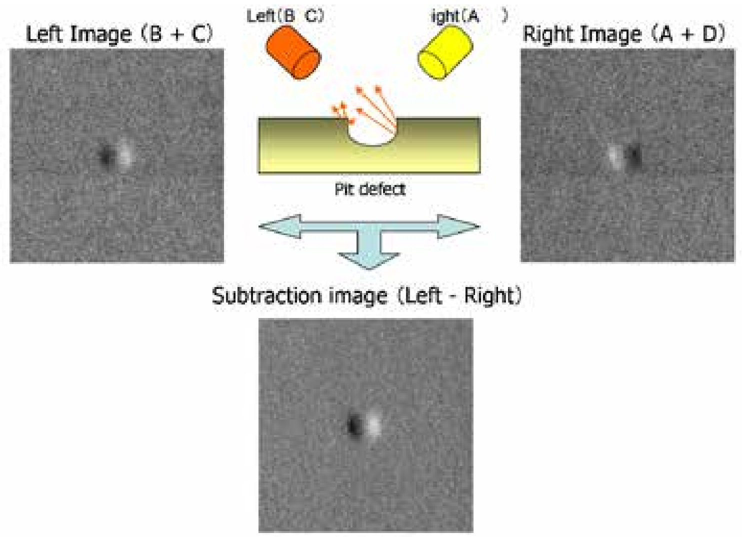


Figure 7. Image processing method to generate subtraction image.

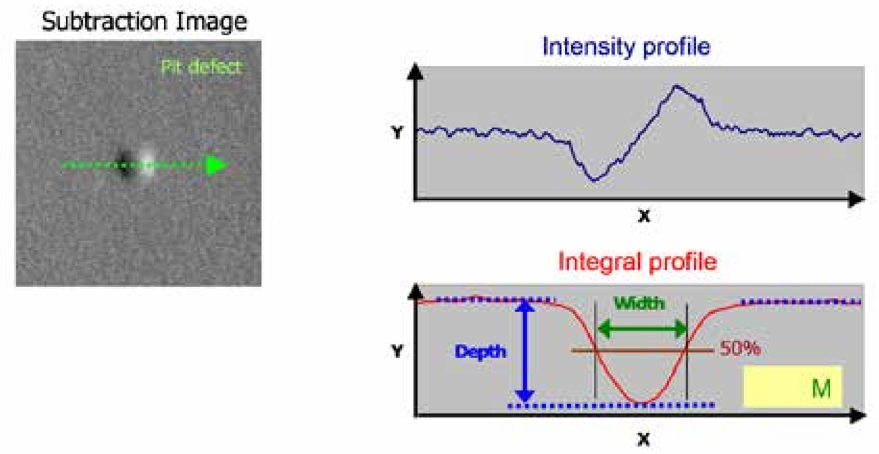


Figure 8. The quantification method of multilayer defect.

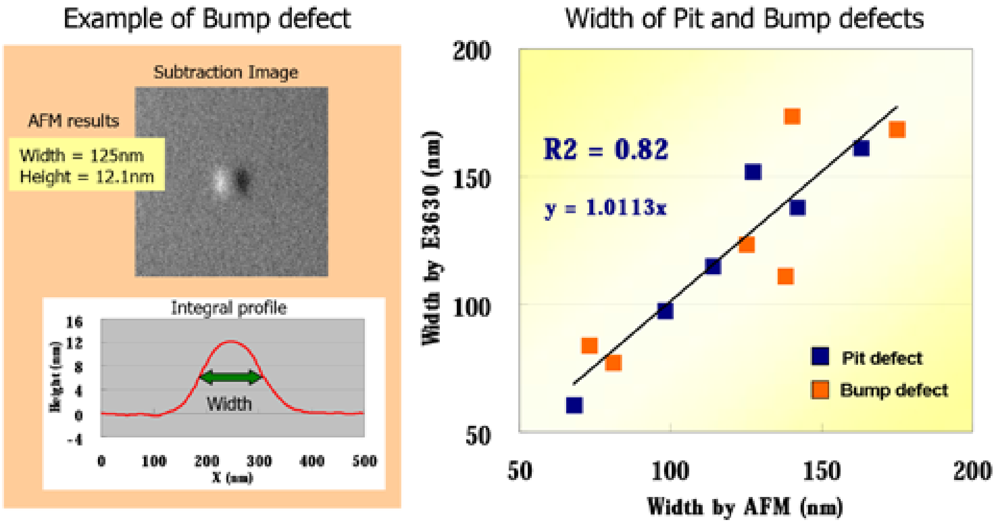


Figure 9. The subtraction image and integral profile in case of Bump defect and measurement result of width Pit and Bump defects.

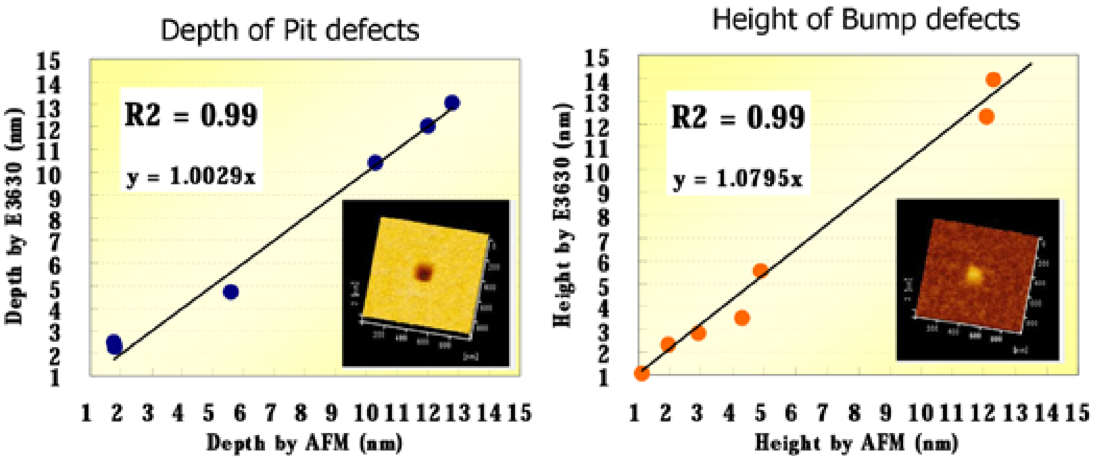


Figure 10. Measurement result of depth and height on Pit and Bump defects.

3.3 3D measurement method

Figure7 shows the image processing method to generate subtraction image and characteristic of secondary electron intensity. Left image is combined from channel B and C. Right image is combined from channel A and D. As shown in the figure, secondary electron is emphasized from right sidewall of Pit defect in left image. On the other hand, secondary electron is emphasized from left sidewall of Pit defect in case of right image. To generate subtraction image, right image subtracted from left image. This subtraction image is used for 3D measurement process.

And Figure 8 shows the method of quantification of multilayer defect. E3630 generates intensity profile of multilayer defect on subtraction image. Amplitude of profile peak is corresponded to sidewall angle of defect, and profile peak width is corresponded to sidewall width of it. Therefore, cross section is reconstructed by integral calculation of intensity profile of subtraction image. As shown in lower graph of Figure 8 defect width and depth are quantified of integral profile. Y length as shown in "depth" of integral profile corresponded to defect depth and X length as shown in "FWHM" corresponded to defect width.

4. Experimental result

4.1 The cor relation of defect width with AFM

It is confirmed that measurement result of width both Pit and Bump defects. The left figure in Figure 9 shows example of subtraction image of Bump defect and integral profile. The right graph shows the correlation of AFM and E3630 about width of Pit and Bump defects. It is found that correlation factor is 0.82 and the tool is well correlated with AFM.

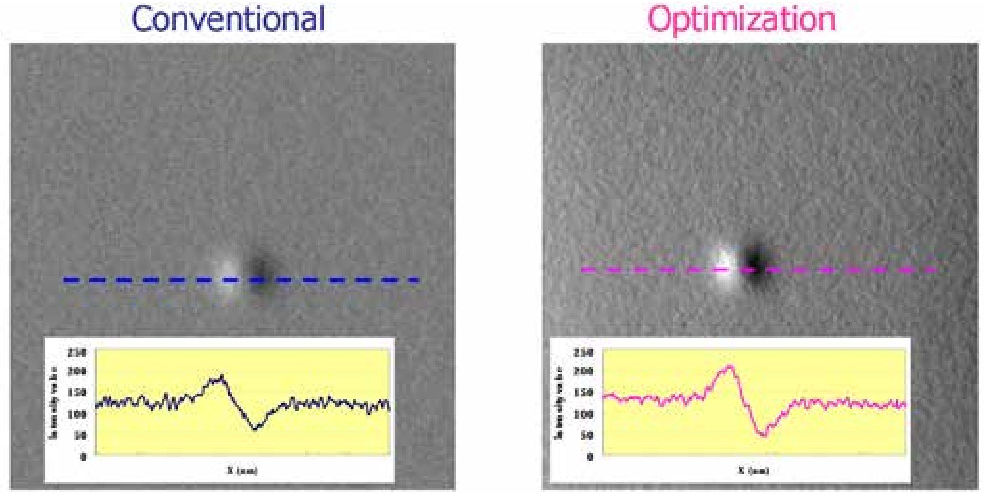


Figure 11. Comparison of SEM image between conventional and optimization condition.

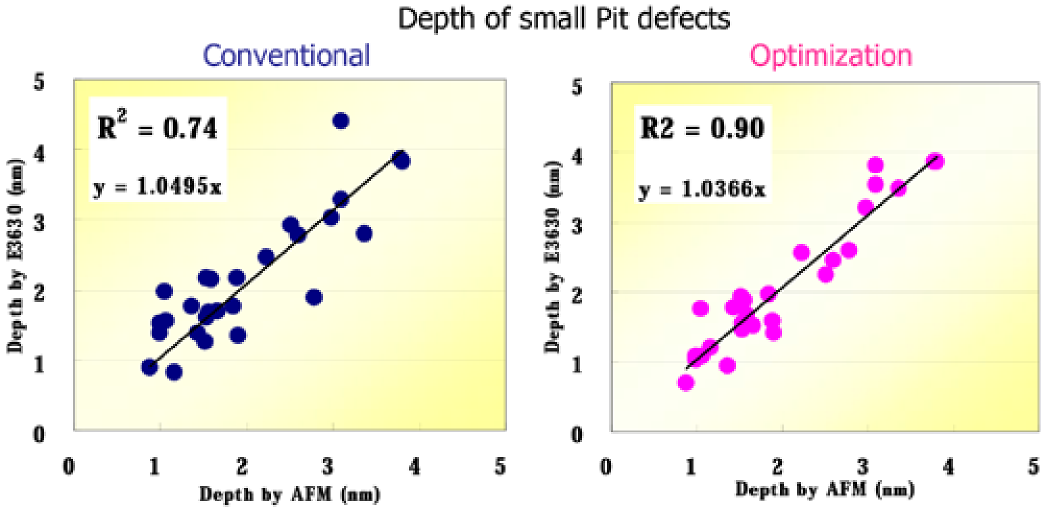


Figure 12. The comparison of correlation factor with AFM in case of conventional and optimization.

4.2 The correlation of defect depth / height with AFM

Figure10 shows measurement result of depth and height of defects. Left one is correlation graph about Pit defect measurement result between AFM and E3630. Right graph shows correlation about Bump defect measurement. It is found that correlation factor is 0.99 on both defects and the tool is well correlated with AFM.

4.3 Effect of image quality improvement

It is confirmed that detail correlation of measurement depth between E3630 and AFM in case of small pit defect which depth range is from 1 to 4nm. The left graph in Figure 12 shows the correlation with AFM. The result shows that correlation factor is 0.74 and gap between E3630 and AFM is big. Then, it was attempted to optimize SEM parameter settings (ex. Acceleration voltage, IP current, Scan condition) to improve SEM image quality. Figure11 shows comparison result of subtraction image on Bump defect between conventional and optimization condition. Both graph in Figure 11 shows intensity profile of Bump defect in subtraction image. The result shows SEM image quality and the SN of defect signal are improved by optimized condition. Hereby, the correlation of defect depth measurement between E3630 and AFM is improved in the right graph of Figure 12. And it was achieved that correlation factor is 0.90 at measurement of a few nm depth defects.

4.4 Distribution map of detectable defect

Figure 13 shows distribution map of all measured programmed defects by E3630. X-axis shows width and Y-axis shows depth or height of defect. The value of our measurement target is shown as dot line. From the result, minimum defect size which E3630 could quantify was Width = 22.8nm and Depth =

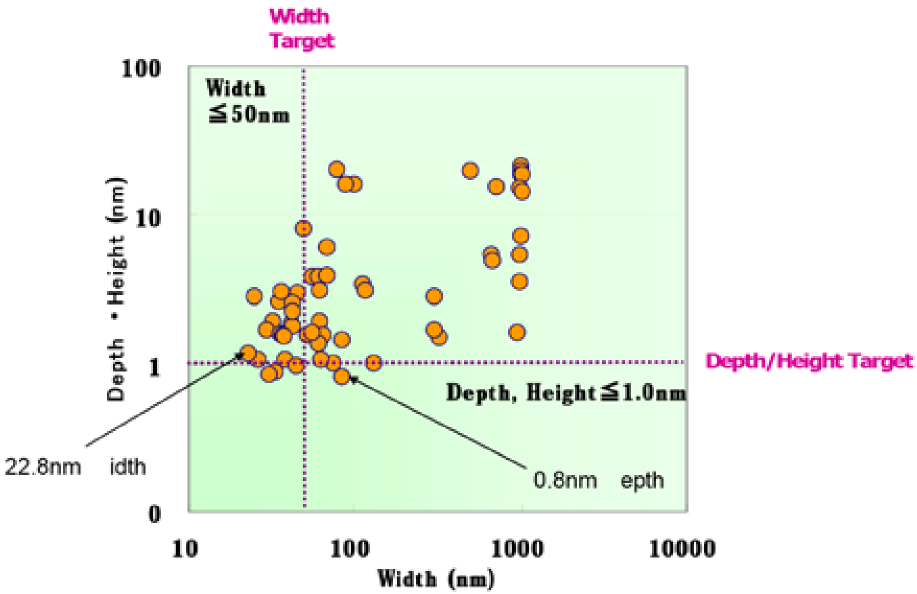


Figure 13. The distribution map of width and depth (height) of multilayer defects.

0.8nm. It is confirmed that our target defect size is successfully achieved by the proposed method.

4.5 The function of 3D view

3D view function was developed using four channel images to show 3D view like AFM. Figure 14 shows 3D view image comparison of Pit defect between AFM and E3630. The result shows that 3D view of E3630 is similar to AFM measurement result.

And it was tried to reconstruct 3D view image of complex shape Pit defect. As shown in Figure 15, it was succeeded to generate 3D view image from E3630 SEM image, and the image looks very similar to AFM image.

5. Conclusion

We have developed 3D measurement function to characterize multilayer defect. At first, it was confirmed E3630 has capability to observe multilayer defect using four channel modes. Next, the method of 3D measurement is proposed by integral calculation of subtraction image. Finally, it was confirmed that E3630 has enough capability to measure 3D profile of multilayer defect by using programmed natural-like multilayer defect mask. And it is successfully achieved to measure our target size and correlation factor above 0.9. Furthermore, 3D view function was developed, and it was confirmed the function enables to show defect 3D view image like AFM tool.

In conclusion, multilayer defect is measurable and observable with MVM-SEM® E3630. And the function is expected to be useful to provide printable defect free EUV mask assurance.

7. Acknowledgments

The authors would like to thank Kazuaki Matsui & Yutaka Kodera of Toppan Printing Co., Ltd. to provide programmed multilayer defect EUV blank.

8. References

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[2] K.Matsui, et al. “Novel programmed defect mask blanks for ML defect understanding and characterization”, **Proc. of SPIE Vol. 8441**, 84411A-1.

[3] R.Jonckheere, et al. “Repair of natural EUV reticle defects”, **Proc. of SPIE Vol. 8166**, 8166-1G AFM.

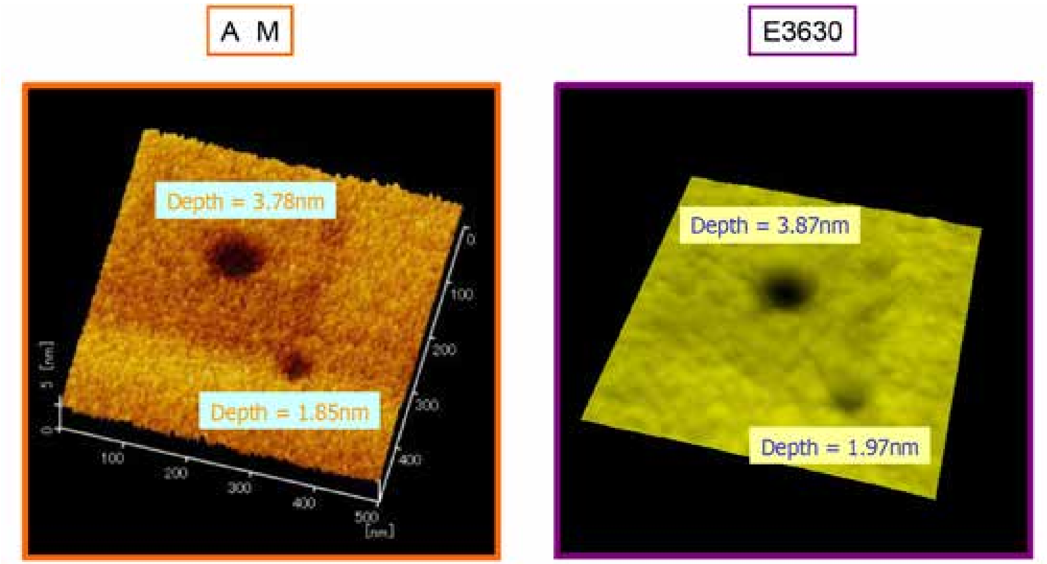

Figure 14. The image of 3D view of multilayer defect by AFM and E3630.

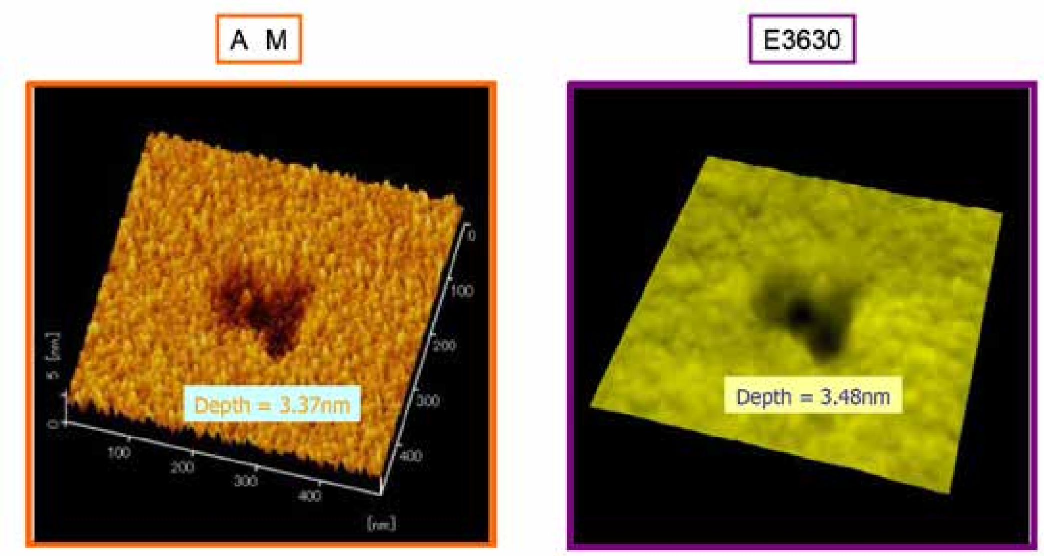

Figure 15. The image of 3D view of complex shape defect by AFM and E3630.

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Industry Briefs

Photronics Announces Successful Completion of Tender Offer to Acquire Outstanding Shares of its Majority-Owned Taiwan Subsidiary, PSMC

BROOKFIELD, Conn.—(BUSINESS WIRE)—Photronics, Inc. (NASDAQ: PLAB), a worldwide leader in supplying innovative imaging technology solutions for the global electronics industry, today announced the successful completion of the tender offer to acquire the outstanding shares of Photronics Semiconductor Mask Corporation ("PSMC"), a majority-owned subsidiary of Photronics, Inc. As of the expiration of the offering period on June 18, 2013, a total of 50,259,277 shares were tendered at the offering price of NT$16.30 with the total costs of the transaction of approximately US$28 million. As a result of the transaction, Photronics owns 98% of the outstanding shares of common stock of PSMC.

http://investor.shareholder.com/photronics/releasedetail.cfm?ReleaseID=772405

Leti: 450mm Wafers Essential Below 7nm

Economics will dictate a move to 450mm wafers for chips with features below 7nm, according to French semiconductor research lab Leti.

"We think economics is not an issue down to 10nm, or probably 7nm, then you will need 450mm," said Leti CEO Laurent Malier.

He is looking into the future, where the laws of physics make smaller transistors difficult, and the cost of masks and lithography is becoming prohibitive.

Finfets, championed by Intel amongst others, are one way to make viable transistors in smaller sizes. Planar fully-depleted silicon-on-insulator technology—backed by Leti, STMicroelectronics, IBM and Global Foundries—is the other big option, although currently less favoured than finfet.

Between the two, finfet has had more development, uses simple silicon wafers, and delivers plenty of drive current, at the cost of complex 3D processing. FD-SOI requires expensive SOI wafers, but only simple planar processing, and doesn't need high drive current.

Which approach will be most effective for which applications is not yet clear.

Both technologies have small features, and small features demand either multiple patterning, requiring multiple sets of expensive masks, or a move to EUV lithography, which will cost a great deal and is proving difficult to get working.

Against this, the expensive and difficult move to 450mm wafers could bring the cost per chip down because twice the number of chips are made per wafer processing step.

"The cost of development of each technology and design platform is high. Finfet has been a huge step. The cost of each design, with its masks etc., is increasing, and clearly EUV is very costly," said Malier. "I think 7nm will exist, my guess is on 300mm. It will probably be a mixture of 300 and 450mm. My guess is, for certain applications, wireless is one, a few players like Samsung and Qualcomm can afford to design even if it is very expensive."

http://www.electronicsweekly.com/news/manufacturing/leti-450mm-wafers-essential-below-7nm-2013-07/

SEMI Sees 21% Increase in Chip Equipment Spending for 2014 Mid-year Forecast for Chip Equipment Industry Shows Improving Outlook

SAN FRANCISCO, Calif. — SEMI forecasts semiconductor equipment sales will reach $43.98 billion in 2014, a 21 percent increase over estimated 2013 equipment spending, according to the mid-year edition of the SEMI Capital Equipment Forecast, released here today at the annual SEMICON West exposition.

Following two years of conservative capital investments by major chip manufacturers, semiconductor equipment spending is forecast to grow to $43.98 billion in 2014, up from $36.29 billion projected this year. Key drivers for equipment spending are significant NAND Flash fab investments by Samsung in China and Toshiba/Sandisk in Japan, and investments by Intel, including its fabs in Ireland. Most major regions of the world will see significant equipment spending increases. Front-end wafer processing equipment will grow 24 percent in 2014 to $35.59 billion, up from $28.70 billion in 2013. Test equipment and assembly and packaging equipment will also experience growth next year, rising to $3.18 billion (+6 percent) and $2.9 billion (+14 percent), respectively. The forecast indicates that next year will be the second largest spending year ever, surpassed only by $47.7 billion spent in 2000.

"Continued strong demand by consumers for smart phones and tablet computers is driving chip manufacturers to expand capacity for memory, logic and wireless devices," said Denny McGuirk, president and CEO of SEMI. "To meet the pent-up demand for capacity, particularly for leading-edge devices, we expect capital spending to increase throughout the remainder of this year and continue through 2014 — to post one of the highest rates of global investment for semiconductor manufacturing ever."

Growth is forecasted in China (82 percent), Europe (79 percent), South Korea (31 percent), Japan (21 percent), North America (9 percent), and Taiwan (2 percent). Taiwan will continue to be the world's largest spender with $10.62 billion estimated for 2014, followed by North America at $8.75 billion and Korea with $8.74 billion. The following results are given in terms of market size in billions of U.S. dollars and percentage growth over the prior year:

http://www.semi.org/en/node/46196

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