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Characterization of Alignment Strategy to Achieve a Reliable Alignment Accuracy in Advanced Lithography

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ABSTRACT

One of the most crucial challenges in lithography is achieving rapid and accurate alignment under a wide variety of conditions brought about by different processing steps. Processing steps may change the nature of alignment mark. Either the mark is deformed or the mark profile is asymmetric, a change in the nature of alignment mark may affect its generated signal behavior. Hence, the objective of this work is to choose a robust alignment mark so that even though there is an extreme process variation, the alignment process still produced reliable alignment accuracy. Unreliable alignment accuracy increased the rework rate, lowered the yield, and eventually may lead to device failure. In this work, several type of alignment mark was evaluated over a range of process variation. From this set of evaluated alignment marks, B2 is the most robust alignment mark within the specified process variation.

Keyword: Alignment mark, overlay, alignment performance, lithography

ABSTRAK

Salah satu aspek yang penting dalam lithografi adalah untuk mencapai penjajaran yang tepat walaupun terdapat variasi dalam persekitaran proses yang berbeza. Variasi dalam persekitaran pemprosesan boleh menyebabkan perubahan sifat asal tanda penjajaran. Perubahan ini boleh menyebabkan kesan buruk ke atas penjajaran signal yang dihasilkan. Kualiti penjajaran signal yang buruk akan menghasilkan jajaran yang tidak tepat dan akan meninggikan kadar 'rework', seterusnya merendahkan. Oleh yang demikian, adalah penting untuk memilih penjajaran yang baik. Dalam kertas kerja ini, beberapa jenis tanda penjajaran telah dinilai. Hasil daripada penilaian ini akan cuba untuk dikaitkan dengan teori optics. Daripada beberapa set tanda penjajaran ini, satu penjajaran strategi yang berkesan dan efektif akan dipilih

Kata Kunci: Tanda penjajaran, ketepatan pelapisan, pencapaian penjajaran, litografi

INTRODUCTION

Although exposure tools are able to produce smaller feature, its ability to perform alignment in order to achieve the desired overlay requirement limits the practicality to produce such a small feature in mass production (Levinson, H.J. 2001). According to International Technology Roadmap for Semiconductor (ITRS) 2000 (ITRS 2000), overlay requirement becomes tighter as feature size becomes smaller. As a rule of thumb, overlay requirement is 25% to 40% from feature size (Wolf S. & Tauber R.N. 2000 & Hibbs M.S. 1998). If 180 nm node size requires 65 nm overlay, 90 nm requires 31 nm overlay and 65 nm node requires 26 nm overlay (Levinson, H.J. 2001). Alignment accuracy becomes a challenge for such small feature.

Alignment process is assisted by a structure printed on a wafer known as alignment mark. Alignment mark is a diffraction grating structure with two different grating sizes. The grating sizes are 8.0μ and 8.8μ as shown in Figure 1. Grating size is fixed and depends on the scanner alignment hardware. Usually, this grating is optimized to enhance a certain reflected light order. This structure is going through exactly the same process steps as the circuit structure.

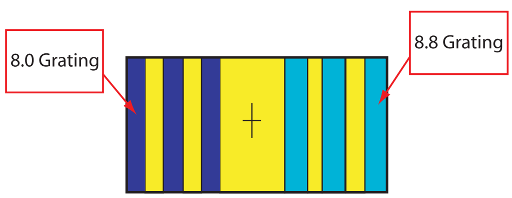


FIGURE 1. A Typical Alignment Mark Architecture

The basic principle of alignment process is to find the location of alignment mark from signal generated by the alignment target and correcting the translation, rotation, and expansion parameter error accordingly (Cui Y. et al. 2004). Therefore, it is important to ensure that the signal quality is good to ensure the aligned position is accurate. Since alignment mark also went through the same process as the rest of the circuit structure, there is a possibility that processing steps such as deposition and planarization changed the nature of alignment target (ASML 2004). Planarization process reduced the visibility of alignment mark from alignment system optical view (ASML 1999). The system may not recognize the structure as alignment mark. Planarizations together with deposition process change the alignment mark profile.

There are several parameters can be used to represent the signal quality. The percentage of reflected signal from wafer alignment mark compared to signal reflected by a baseline alignment mark, a difference between aligned position determined by 8.0μ reflected light and 8.8μ reflected light, the difference between the measured aligned position and the expected aligned position and how well the reflected signals from wafer alignment mark can be fitted to baseline signal are usually used to indicate the signal quality (Cui Y. et al. 2004). However, these three parameters alone cannot guarantee a good overlay performance. The ultimate proof of alignment performance robustness is overlay parameter, which is a misalignment measurement with respect to the previous layer. The first three parameters are collected during the alignment process, while overlay measurement is done after the exposure process completed.

In this paper, evaluation will be done using AH32, AH53, and AH74 alignment marks. Each of mark was designed to enhance a certain light order. AH32 is optimized for third order, while AH53 is optimized for fifth order and AH74 is optimized for seventh order. Different type of alignment mark have different trench size since increasing number of grating reduced the alignment mark trench size. AH32 has the biggest trench size compared to AH53 and AH74 alignment mark. Trench size will determine how processing such as deposition and planarization affects the nature of alignment target (Boston University 1999).

BACKGROUND

Alignment Mark Formation for Contact Layer

Alignment mark is printed on the wafer. This means that it is going through exactly the same process as the rest of the circuit structure. The first step in order to produce a contact structure is to deposit oxide material at certain required thickness. Since the deposition process does not produce a flat surface, hence, planarization process is required. Then, the oxide material will go through a patterning and etch process to produce the desired shape. Figures 2 illustrate the post lithography and etch process alignment mark.

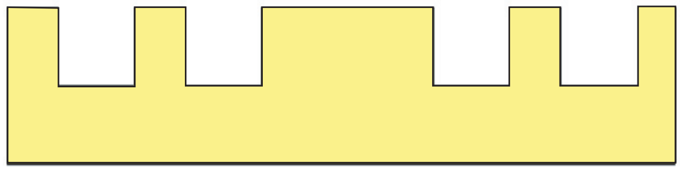


FIGURE 2. Post lithography and etch contact alignment mark

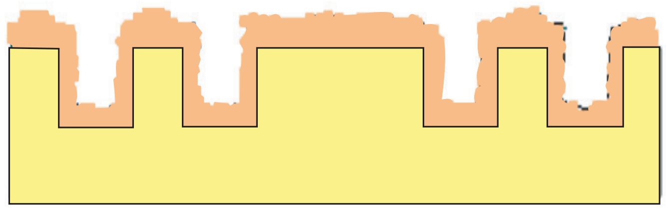


FIGURE 3. Alignment Mark Profile after Tungsten Deposition

FIGURE 4. Post Tungsten CMP Profile

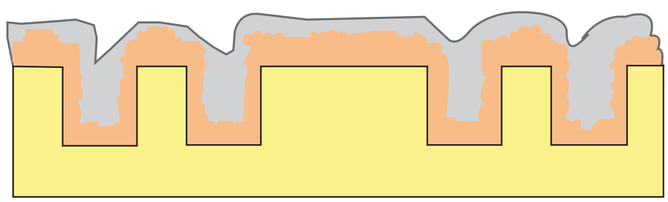


FIGURE 5. Post Aluminum/Metal Layer Deposition Profile

After that, tungsten material will be deposited. Tungsten material has to be completely removed from oxide upper surface. Tungsten is removed through chemical mechanical planarization (CMP) process. Contact hole will be completely filled by tungsten due to its small feature size. However, alignment mark trench won't be completely filled since its trench size is much larger than the tungsten deposition thickness (Figure 3). Figure 4 illustrates the alignment mark profile after tungsten planarization process.

Finally, metal/aluminum layer will be deposited on the existing structure through physical deposition process (PVD). Usually, the asymmetric profile becomes significant after this process. Figure 5 shows the possible profile after metal layer is deposited. This is final profile of contact alignment mark. The reflected signal behavior during metal1 layer alignment depends on this profile.

From the above explanation, 4 processes had been identified to possibly affecting the nature of alignment mark. The four processes are oxide planarization, tungsten deposition, tungsten planarization, and metal deposition. All of these processes are controlled by thickness except tungsten planarization, which control by over polish time. Alignment mark feature/trench sizes integrated with these four processes contribute to the overall alignment performance.

RESEARCH METHODOLOGY

Based from the fact that alignment performance is affected by wafer fabrication process and alignment feature size, a partial factorial DOE with 4 factors (n=4) and 9 centre points, which require 25 runs was designed in order to investigate the effect of grating/trench size on the alignment performance across some values of process variation. The four fast are post oxide

TABLE 1. Process Split based from DOE

Split	Final ILD CMP Thickness (Angstrom)	W1-Dep Thickness (Angstrom)	W1-CMP Over Polished Time (s)	Met1 Dep Thickness (Angstrom)
A	9200	3200	60	4620
B	7800	2800	0	3780
C	8500	3000	30	4200
D	7800	3200	60	3780
E	7800	2800	60	4620
F	7800	3200	0	4620
G	9200	3200	0	3780
H	9200	2800	0	4620
I	9200	2800	60	3780

planarization thickness, tungsten deposition thickness, tungsten planarization over polished time, and aluminum deposition thickness. Each of the alignment mark will be evaluated for each particular condition. Split C acts as a center point in this DOE (refer to Table 1). The alignment performance is indicated by both alignment parameter and overlay parameter values. The best alignment mark is when all alignment parameters and overlay gives the lowest variation and within the acceptable limit.

Metal1 layer is selected for evaluation since it is the first back end architecture where its alignment to contact layer is very important. Several type of alignment mark will be used for evaluation purposes. The baseline alignment mark is AH53-CV2V4 SCR. However, it is not unusual if several other alignment marks also can be used or shows a better alignment performance than the recommended ones. Thus, it is important to perform characterization in order to determine the most robust alignment strategy.

In this experiment, three main types of alignment mark were used which are AH32, AH53, and AH74. Please refer to Table 2 for the details of alignment mark used in this experiment.

TABLE 2. Alignment Mark Type and their optimized light order recipe

Mark Type	Subtype	Optimized Light Recipe
AH32	A1	Third Order Light
	A2	
AH53	B1	Fifth order Light
	B2	
	B3	
	B4	
	B5	
AH74	C1	Seventh Order Light
	C2	
	C3	
	C4	

Alignment is a process of positioning a special mark on reticle at the correct orientation onto a specific spot above the wafer. In ideal cases, the reticle alignment mark and wafer alignment mark will corresponds with each other. The basic algorithm to find the alignment mark location is to find the centroid location of the alignment signal. Hence, it is important to ensure that the generated signal quality is good.

In ASML scanner system, several parameters are collected during alignment process and use as an indicator to the signal quality. The parameters are Wafer Quality (WQ), delta shift, mark residue, and multiple correlation coefficients (MCC). All of the parameters will be collected and recorded in this experiment. Wafer quality (WQ) is percentage of actual signal strength with reference to signal generated by fiducial mark. It is recommended that WQ values should be more than 1% in order to obtain a reliable alignment results. Delta shift is a shift value between signal generated by 8.0 micron and 8.8 micron grating. It is advisable for delta shift value not to be more than $\pm 0.3\mu m$. If a delta shift value is too big, the system will recognize it as 8.0-micron error. This error is detected when wafer expansion (measured by scanner alignment system) value becomes too big. Mark residue is an error value between the actual alignment mark coordinate and theoretical alignment mark coordinate obtained from wafer model. The acceptable values should be within ± 130nm. Multiple correlation coefficients (MCC) are a measure of fit for actual signal with reference to the fiducial signal. The values should

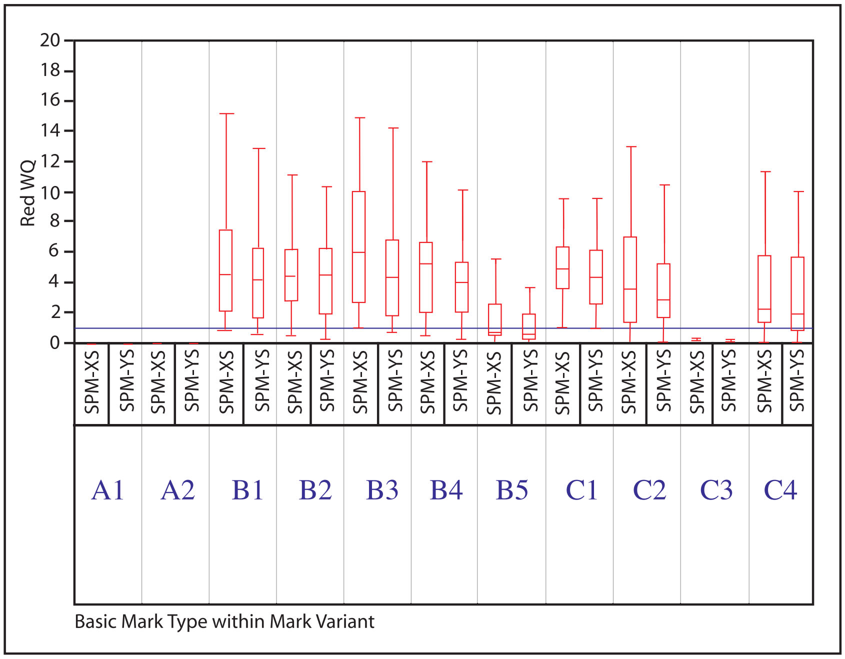


FIGURE 6. Alignment Signal Strength Quality vs. Number of Alignment Mark Grating.

be within 1 and 0.7. MCC values equals to 1 means a perfect fit.

After exposure process, overlay (the lateral positioning between two consecutive layer with respect to previous layer) is measured by overlay metrology tool. Misregistration/misalignment/overlay is the lateral positioning measured with respect to the previous layer. Expansion, rotation, and translation are generated based from misregistration values. Expansion is a shift of the field with respect to the wafer center. Besides field shifting, the field also will expand. The expansion value is different from field to field. The farther the distance from wafer center, the higher the expansion values. Rotation is a rotation of all the fields altogether with respect to the wafer center. Overlay performance in this experiment will consider consist of misregistration, expansion, and rotation.

Alignment performance consists of both alignment parameter and overlay performance. Thus, both types of parameters were used as evaluation criteria in this experiment. Since several alignment marks are available together with several alignments and overlay parameter, Weighted Average Criteria Matrix was used in order to determine the most robust alignment strategy.

RESULT AND DISCUSSION

Alignment mark is a reflection diffraction grating structure. When the incident light hit the surface, the reflected light will get dispersed into a certain order (Eric R. et al. 1997). Unless specifically constructed, a grating will have efficiency of only a few percent (Pistor T.V. & Socha R.J. 2002). Thus, to cater alignment needs, alignment mark grating is usually designed to enhance a specific light order. This could be done by designed the wall of the alignment mark at a specific angle (blazing angle) (Palmer C. 2002). Therefore, reflected surface will be at a certain angle that able to concentrate most of the incident intensity into a particular reflected light order (Palmer C. 2002). In our cases, AH32 grating is optimized for third order light, AH53 is for fifth order, and AH74 is for seventh order light.

Based on diffraction grating theory, first order reflected signal have the strongest strength, followed by second order, second order, and so on (www.ipm.virginia.edu 2000 & Palmer C. 2002). Reflected signals tend to get weaker for higher order reflected light. Hence, it was expected that the AH32 alignment mark would give the strongest alignment signal since AH32 mark use third order light for alignment, while AH53 mark use fifth order light and AH74 mark use seventh order light.

However, based on Figure 6, AH32 mark type gives the worst signal (almost zero WQ). This result does not conform to the initial hypothesis. The almost zero values indicate that the reflected signal undergoes an overall destructive interference and four grating alignment mark gives a comparable alignment signal (WQ). Except for AH74-CV2V4-SCR and AH53S-CV2V4-SCR, the rest of alignment mark gives a comparable WQ values.

This phenomenon could be due to different feature size of the mark. Table 3 shows the feature size of each particular mark. Size of grating decrease as the number of grating increased, which means that AH32 have the largest feature size compared to AH53 and AH74 alignment mark. Big feature size profile is easily affected by processing condition.

TABLE 3. Alignment Mark Grating Size

Mark Type/ No. Of Grating	Grating/Feature/Trench Size (µm)
AH32	2.6
AH53	1.6
AH74	1.15

Alignment mark used in this experiment will be under filled since their trench size is far greater than tungsten deposition thickness. An under filled alignment mark is very sensitive to mark depth variations since the depth will determine how the metal shapes around the mark trench corner during aluminum deposition (http://physics.bu.edu 1999). Shadowing effect on mark profile becomes a determinant factor on alignment signal quality.

Tungsten is deposited onto the substrate using chemical vapor deposition (CVD) process. CVD process does not contribute much to final profile behavior since it provides more uniform thickness throughout the structure compared to physical vapor deposition (PVD) process (Wolf S. & Tauber R.N. 2000). PVD process is used during aluminum layer deposition.

At trench structure, most of the incident atom generated during PVD arrived at the center of the trench due to the shadowing effect by mark sidewall (Yang Y. 2000). For wider trench, aluminum atom may not be able to diffuse to the far corner as shown in Figure 7 which means that material deposited at the corner is lesser than at the trench center. The same theory also applied on deep marks. Thickness at the corner are lesser compared to the other area, which lead to a formation of asymmetric mark profile. Please refer to Figure 8. Besides deposition process, asymmetric profile also can be introduced during tungsten planarization (CMP) process (Cui Y. et al. 2004; ASML 1998, Golz J. 1997). This effect is severe for a large feature size as in our AH32 mark (Levinson H.J. 2001)

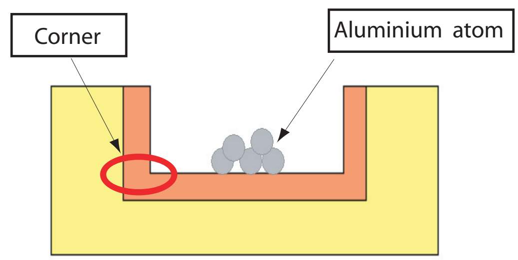


FIGURE 7. Aluminum Deposition Process

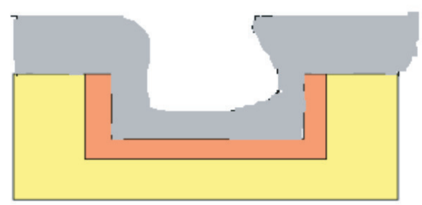
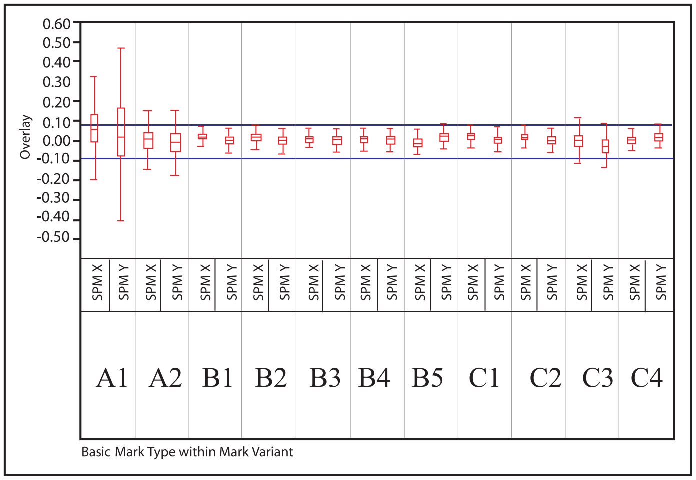


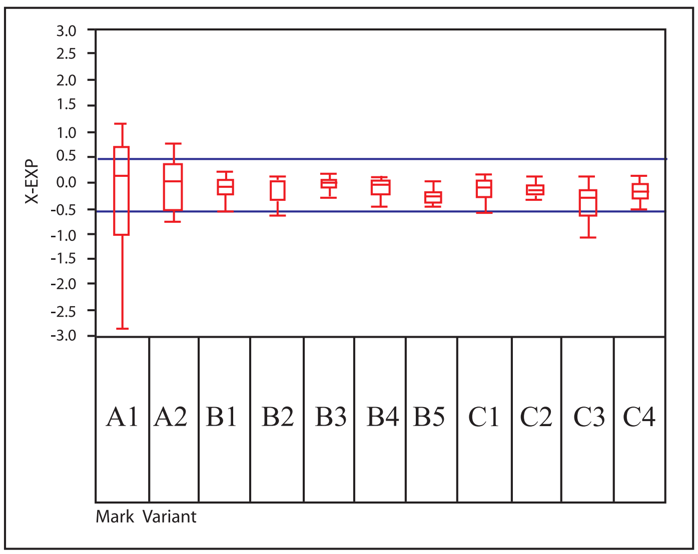
FIGURE 8. Asymmetric Alignment Mark Profile post Aluminum Deposition Thickness

Asymmetric profile would change the grooves angles of alignment mark. This means that the reflected surface won't be at the blazing angle anymore. The diffraction efficiency is very low at angle other than the blazing angle, which leads to a low reflected third order signal intensity (low WQ) for AH32. Asymmetry profile provide non-uniform reflected surface for the incident light. Non-uniform reflected surface increase the tendency for interference to occur since one reflected light may interfere with thousands of other reflected lights.

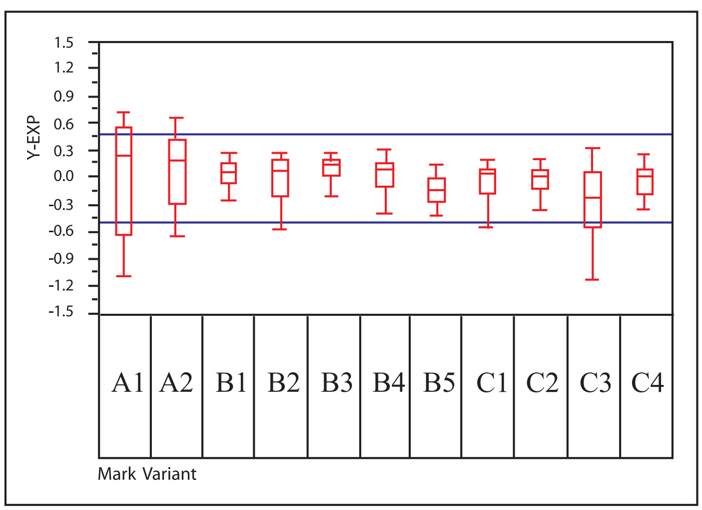
In A1, A2, and C3 mark type cases, an overall destructive interference was generated. This can


Overlay
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
SPM X SPM Y SPM X SPM Y SPM X SPM Y SPM X SPM Y SPM X SPM Y SPM X SPM Y SPM X SPM Y SPM X SPM Y SPM X SPM Y SPM X SPM Y SPM X SPM Y
A1 A2 B1 B2 B3 B4 B5 C1 C2 C3 C4
Basic Mark Type within Mark Variant

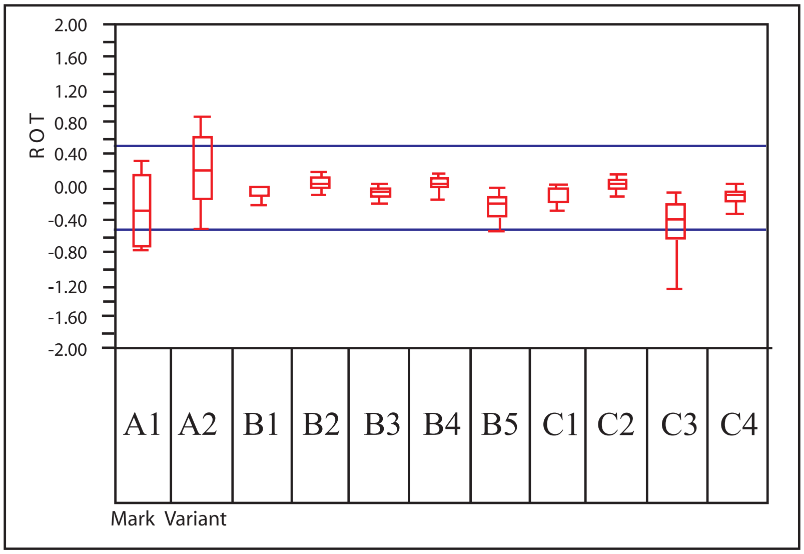
(a)


X-EXP
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
A1 A2 B1 B2 B3 B4 B5 C1 C2 C3 C4
Mark Variant

(b)


Y-EXP
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
A1 A2 B1 B2 B3 B4 B5 C1 C2 C3 C4
Mark Variant

(c)



(d)

FIGURE 9. Overlay Parameter vs. Alignment Mark Grating. (a) Overlay/Misregistration (b) X Expansion (c) Y Expansion (d) Rotation

clearly be seen from Figure 6, where the resulted signal is almost zero. The peak for weak alignment signal may not be clearly differentiated in order to pick the correct peak of 8.8-micron alignment signal. This causes delta shift to be huge for A1, A2 and C3 mark type. Figure 12 shows comparable values for delta shift and a slight high variation for A1 and A2 mark. However, during exposure process using A1 and A2 mark, more than 10 wafers cannot be aligned due to high delta shift and mark residue values.

The low alignment signal cannot be fitted into a baseline signal, which indicates a bad signal quality. This fact is supported by low multiple correlation coefficient (MCC) value for A1 and A2 mark as shown in Figure 11. MCC is a parameter that measures how well the resulted alignment signal can be fitted to the fiducial signal. However, MCC values for C3. A weak alignment signal can still be used to calculate the alignment mark location. But, there is a high possibility for the calculated position to be wrong. Results from Figure 10 agreed to this statement where A1, A2, and C3 marks gives a huge mark residue variation. This result indicates that the aligned position is wrong, since mark residue is a comparison between actual calculated position and an expected position determined by the software model. Furthermore, the overlay parameter result for A1, A2, and C3 also shows high value beyond acceptable limit as shown in Figures 9 (a), (b), (c) and (d), which proved that alignment error occurred when aligning using A1, A2, and C3 mark.

As for the rest of the alignment mark, both alignment parameters and overlay parameters are comparable. From the graph, A1, A2, and C3 can be eliminated from our option. Hence, in order to determine the most robust alignment performance from the remaining alignment marks, Weighted Average Criteria Matrix will be used (Tague N.R. 2004). The evaluation criteria are alignment parameters (WQ, MCC, Delta shift, Mark Residue) and overlay parameters (misalignment, expansion, rotation). Cpk indexes for all criteria also will be evaluated to see which alignment mark gives a good process capability. Index Cpk is used instead of Cp due to Cp values only covered process variation while Cpk values cater both the process variation and how close the data to its target (Waxer C. 2002). The criteria are prioritized/weighted according to its importance level. A criterion with weight value equal to 10 is the most important criteria.

For criteria matrix, the total should not be less than 4590, which catered for every raw value must 90% inside the acceptable limit. From Table 4, B4 can be eliminated from our consideration since its total score is less than 4590. From MCC column (Table 4), all the raw values are inside the

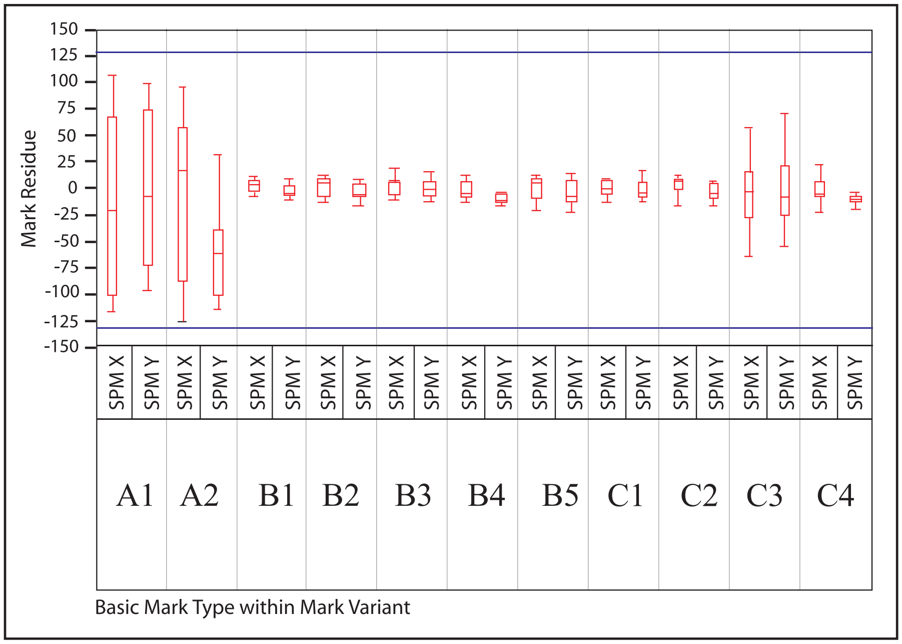


FIGURE 10. Mark Residue vs. Alignment Mark Grating. Acceptable values should be within +/- 130nm

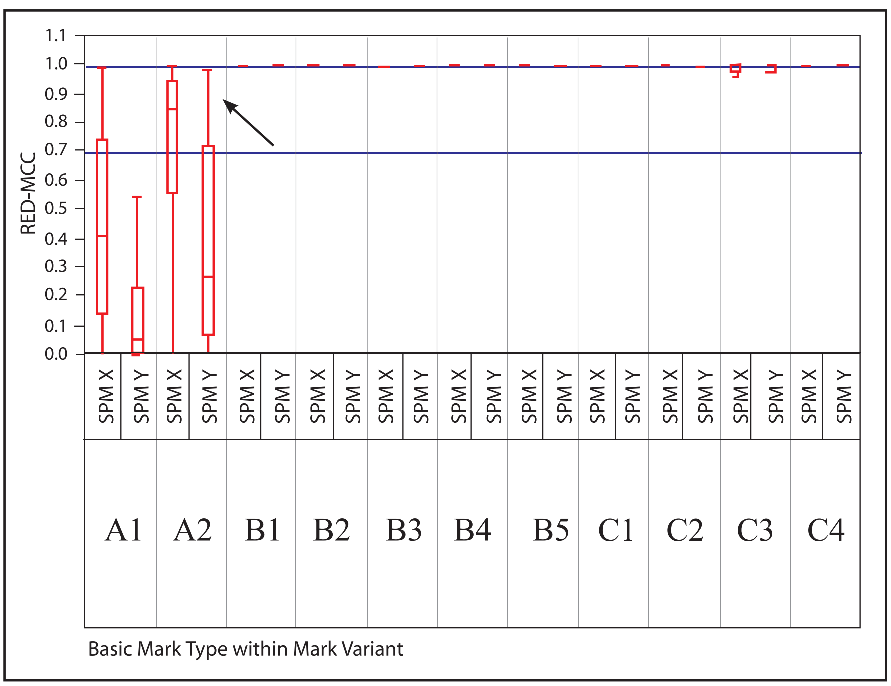


FIGURE 11. MCC vs. Alignment Mark Grating. Values should be between 1 and 0.7.

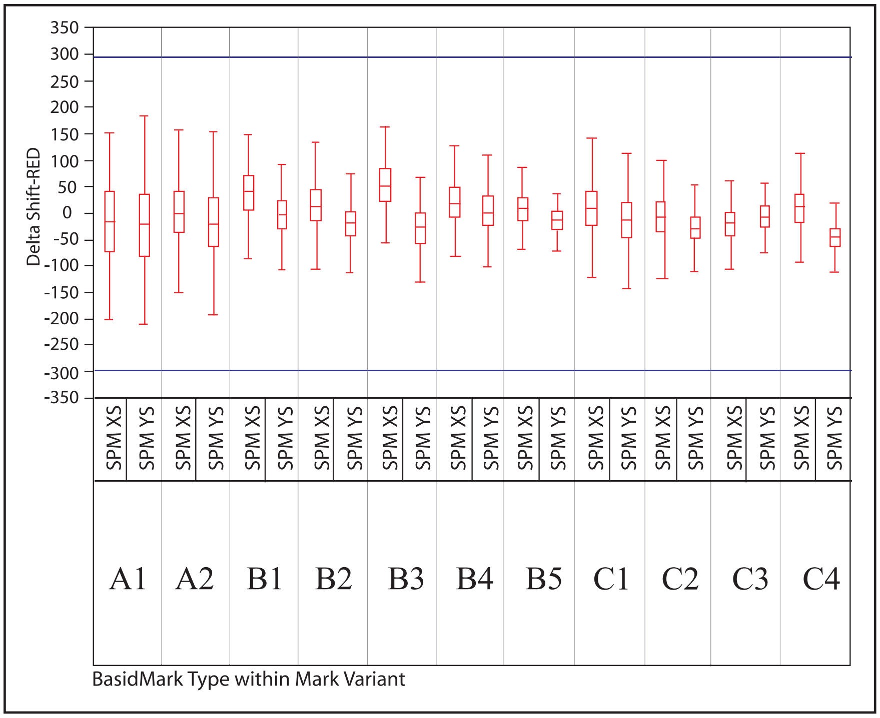


FIGURE 12. Delta Shift vs. Alignment Mark Grating. Values should be between +/- 0.3μm.

specification limit and from Figure 11, except for A1 and A2 mark type, MCC parameters has a very small variation. This parameter will eliminated from Cpk analysis since their Cpk may mislead us to make a conclusion. For Cpk, total values should not be less than 63, which cater for at least 1.33 Cpk values for each evaluation criteria. From Table 5, B1, B2, and C4 can be eliminated since their total score is less than 62.58. B2 is the most robust alignment strategy since it gives the highest score among the remaining alignment mark.

CONCLUSION

In general, alignment performances are greatly dependent on alignment mark profile. This dependency is due to basic design of grating shape, which the purpose is to enhance a certain reflected light order. Integrated effect of alignment mark feature size, planarization process, and aluminum deposition process contribute to the final alignment mark profile. This statement explained the reasons why different mark types have different alignment

TABLE 4. Weighted Average Criteria Matrix. The raw values is the percentage of data that is inside the acceptable limit

Criteria	WQ		Delta Shift		Mark Residue		Overlay		Rotation		X Expansion		MCC		Y Expansion		
Weight	10		5		4		10		6		6		4		6		Total
Alternative	Raw	Wtd	Raw	Wtd	Raw	Wtd	Raw	Wtd	Raw	Wtd	Raw	Wtd	Raw	Wtd	Raw	Wtd	
B1	96.934	969.34	100	500	100	400	99.769	997.69	100.00	600.00	91.67	550.00	100	400	95.83	575.00	4992.03
B2	90.645	906.45	100	500	100	400	99.827	998.27	100.00	600.00	95.83	575.00	100	400	100.00	600.00	4979.72
B3	97.436	974.36	100	500	100	400	99.884	998.84	100.00	600.00	100.00	600.00	100	400	100.00	600.00	5073.20
B5	86.378	863.78	100	500	100	400	99.884	998.84	100.00	600.00	100.00	600.00	100	400	100.00	600.00	4962.63
B4	38.726	387.26	100	500	100	400	99.248	992.48	95.83	575.00	100.00	600.00	100	400	100.00	600.00	4454.73
C1	99.371	993.71	100	500	100	400	99.769	997.69	100.00	600.00	100.00	600.00	100	400	100.00	600.00	5091.40
C2	81.761	817.61	100	500	100	400	100	1000.00	100.00	600.00	87.50	525.00	100	400	91.67	550.00	4792.61
C4	75.16	751.60	100	500	100	400	98.263	982.63	100.00	600.00	100.00	600.00	100	400	100.00	600.00	4834.23

TABLE 5. Weighted Average Cpk Matrix. The raw values is Cpk index for each parameters

Criteria	WQ		Delta Shift		Mark Residue		Overlay		Rotation		X Expansion		Y Expansion		Total
Weight	10		5		4		10		6		6		6		
Alternative	Raw	Wtd	Raw	Wtd	Raw	Wtd	Raw	Wtd	Raw	Wtd	Raw	Wtd	Raw	Wtd	
B1	0.366	3.66	1.99	9.97	5.084	20.34	0.912	9.12	1.520	9.12	0.573	3.44	0.657	3.94	59.59
B2	0.472	4.72	1.96	9.78	6.676	26.70	0.94	9.40	2.384	14.30	0.831	4.99	0.879	5.27	75.16
B3	0.400	4.00	1.66	8.29	6.101	24.40	1.198	11.98	1.557	9.34	0.863	5.18	0.899	5.39	68.58
B5	0.454	4.54	2.04	10.19	4.769	19.08	1.205	12.05	2.130	12.78	1.225	7.35	0.989	5.93	71.92
C1	0.622	6.22	1.81	9.04	4.937	19.75	0.923	9.23	1.921	11.53	0.894	5.36	1.014	6.08	67.21
C2	0.316	3.16	1.92	9.59	3.749	15.00	1.006	10.06	1.448	8.69	0.498	2.99	0.610	3.66	53.14
C4	0.267	2.67	1.85	9.25	3.745	14.98	0.862	8.62	1.357	8.14	0.690	4.14	1.018	6.11	53.91

performance. A1, A2 mark type and C3 mark gives the worst alignment performance since it does not generate sufficient signal strength (low WQ) for the alignment system. From Weighted Average Criteria Matrix analysis, B4 can be eliminated since their total score is less than 4590, which indicates a lot of measurement data were outside the acceptable limits. Further analysis on Cpk indexes, eliminates B1, C2, and C4 due to total scores is less than 62.58. The highest total scores in Cpk analysis is the most robust alignment mark within a given range of process variation, which in this case is B2 mark.

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