Automatically High Accurate and Efficient Photomask Defects Management Solution for Advanced Lithography Manufacture

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ABSTRACT

Defect review is a time consuming job. Human error makes result inconsistent. The defects located on don't care area would not hurt the yield and no need to review them such as defects on dark area. However, critical area defects can impact yield dramatically and need more attention to review them such as defects on clear area. With decrease in integrated circuit dimensions, mask defects are always thousands detected during inspection even more. Traditional manual or simple classification approaches are unable to meet efficient and accuracy requirement. This paper focuses on automatic defect management and classification solution using image output of Lasertec inspection equipment and Anchor pattern centric image process technology. The number of mask defect found during an inspection is always in the range of thousands or even more. This system can handle large number defects with quick and accurate defect classification result.

Our experiment includes Die to Die and Single Die modes. The classification accuracy can reach 87.4% and 93.3%. No critical or printable defects are missing in our test cases. The missing classification defects are 0.25% and 0.24% in Die to Die mode and Single Die mode. This kind of missing rate is encouraging and acceptable to apply on production line.

The result can be output and reloaded back to inspection machine to have further review. This step helps users to validate some unsure defects with clear and magnification images when captured images can't provide enough information to make judgment.

This system effectively reduces expensive inline defect review time. As a fully inline automated defect management solution, the system could be compatible with current inspection approach and integrated with optical simulation even scoring function and guide wafer level defect inspection.

Key words: Haze, defect classification, ESD, photo mask

1. Introduction

Haze or Photo-induced defects on masks for 193nm lithography have been a serious problem. The most widely accepted explanation of the root causes of haze defects is the cleaning chemical residues remaining on the mask surface and unavoidable outgas molecular from pellicle materials when exposed to DUV high energy radiation [1][2][3][4].

Managing mask defects is a critical issue, which is more important in advanced semiconductor FABs with immersion lithography process. Mask defects detection usually occurs during mask inspection or, in the worst case, as a result of a yield loss event. Modern FABs have implemented a number of containment strategies, such as time- or exposure-based mask inspection. Suspected masks are returned to the mask shop for re-cleaning. But the measures incur expensive loss of time and are harmful to mask lifetime.

The mask defects located on don't care area would not hurt the yield and no need to review them such as defects on dark area. However, critical area defects can impact yield dramatically and need more attention to review them such as defects on clear area. With the continuing decrease in integrated circuit dimensions, mask defects are always thousands detected during inspection even more. Traditional manual or simple classification result is unable to meet efficient and accuracy requirement. This paper describes our efforts for building a automatic defect management solution using image output of Lasertec inspection equipment and Anchor pattern centric image process technology, SMDD system which can handle large number defects with ease and generate accurate defect classification result.

The system is built to classify defect into 12 types including Particle OnClear, Clear Extension, Dark Extension, PinHole, PinDot, ESD and so on. Further requirements include zero missing critical defects and the ability to 28nm technology node and beyond.

We tested our system in Die to Die and Single Die modes. The classification accuracy can reach 87.3% and 90.6% with about 1000 and 500 cases within 4 to 5 months test period. No critical defects are missing in all test cases. The miss classification rates of defect are less than 0.01% and 0.05% in Die to Die mode and Single Die mode. This kind of missing rate is encouraging and acceptable in manufacturing production line.

The result also can be passed back into inspection machine to have further review. This step helps user to validate some unclear defects with clear and magnification images when captured images can't provide enough information to make judgment.

This system effectively reduces expensive inline defect review time. As a fully inline automated defect management solution, the system could be compatible with current inspection approach and integrated with optical simulation even scoring function and guide wafer level defect inspection.

2. Current solution

Haze defects are caused by the exposure of high energy on the photomask surface. They reduce masks' life time and productivity in semiconductor mass production. The harmful of haze defects can be reduced by manufacturing process control during mask making and lithography printing. Photomask inspection is an effective method to monitor the growth of haze defects. The defect number trend at different inspection timing is important reference information for haze defects monitor. Inspection equipment usually provides simple defect classification with report. Based on these defect classification results, user still needs to review defects and do further classification manually. This is a time consuming step and may contains human error when hundreds of defects are involved. For more than one thousand defects, manual defect review becomes infeasible.

Most of haze defects are located on non-critical area. If a tool can provide the function to classify "do not care" defects in separated groups, this can save a lot of review time and let a user focuses on critical or potential critical defects review only.

3. Software solution

Based on this idea, we have applied Anchor pattern centric image technology to develop a high accurate and cost effective defect auto management system to classify and handle inspection results. The system can process the output data from inspection equipments including images and detected defects information. This software solution is that no critical defects shall be classified at the groups that user doesn't need to review - "Do Not Care" groups. This brings a key requirement of the benefits to save unnecessary equipment in-line review time and cost.

Defect types:

Currently the system is confirmed to classify defect into12 defect types including Particle OnClear, Clear Extension, Dark Extension, PinHole, PinDot, ESD and so on (see figure 2).

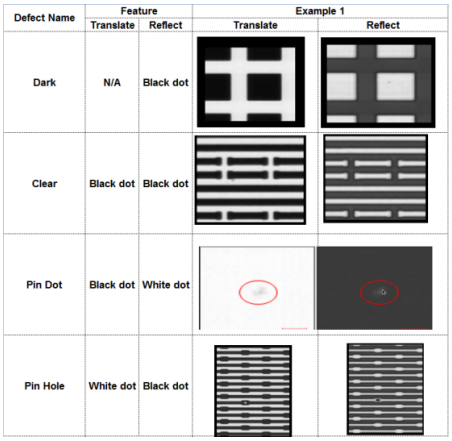

Figure 1 Examples of defect classification by image comparison

Defect Type	
1	Particle OnClear
2	Clear Extension
3	Dark Extension
4	PinHole
5	PinDot
6	ESD
7	TBD
8	Partical OnDark
9	Whitespot
10	False
11	PDI
12	NoMIPM

Figure 2 Auto defect classification types

Particle OnClear, Clear Extension, Dark Extension, PinHole, PinDot, ESD defects are classified as “Must Review” defect category and user also must review TBD. Particle on Dark, Whitespot, False, PDI (pattern design issue) and NoMIPM (inspection equipment issue) are classified as “No Need to Review” defect category.

Missing rate and false rate:

There are two major categories in this defect classification, “Must Review” and “No Need to Review”. When “Must Review” defects are classified at “No Need to Review” types, we count it as classification missing. If “No Need to Review” defects are classified at “Must Review” types, we count it as classification false. Except TBD group, the classification result in other groups requires high accuracy. The requirement of this software solution classification is 85% in both “Die to Die” inspection mode and “Single Die” inspection mode.

Figure 3 Critical and Must Review defect types

Figure 4 No Need to Review defect types

Pattern centric image technology:

The inspection equipment provides defective and its reference image from Die to Die mode and defective image from Single Die mode. Either type has transmitted and reflected type images and other detective defect information in text file. Through image comparison, polygon edge lines are detected and defects are identified by Anchor pattern centric image technology [5]. Based on correlation between defect and patterns, we can classify them into it corresponding defect types.

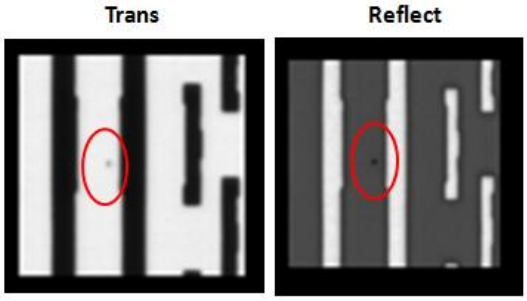

Figure 5 Identified defect

4. Performance and results

We prepared about 1000 cases and 500 cases from different photomasks and layers to test accuracy of this software auto classification solution in Die to Die mode and Single Die mode. There are more than ten thousands of Die to Die inspection mode defects and over ten thousands of Single Die inspection mode defects totally. Manually review these defects to validate the accuracy of software auto classification. When "Must Review" defects are classified into "No Need to Review" category, we count it as classification missing. If "No Need to Review" defects are classified into "Must Review" category, we count it as classification false. The classification accuracy of Die to Die mode is 87.3% with less than 0.01% missing rate, 2.75% false rate and 9.94% TBD (which needs human review). Single Die mode has 90.6% accuracy with 9.35% false rate and less than 0.05% missing rate. During the test period, no critical or printable defects are missing in our cases. Compared to our 85% criteria line, the software solution does pass our accuracy requirement.

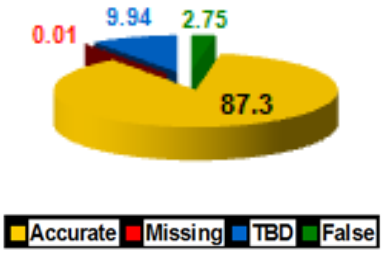

Figure 6 DD mode auto classification accuracy

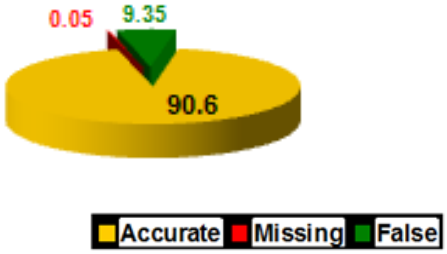

Figure 7 SD mode auto classification accuracy

The review GUI of classification displays the corresponding inspection images, distribution map and pre-defined table. This helps users to find and review interested defects quickly without expensive inspection equipment time. Besides, most of nuisance "Do Not Care" defects can be skipped and save more equipment inspection review time. Furthermore, it reduces human error at classification and makes classification more consistent.

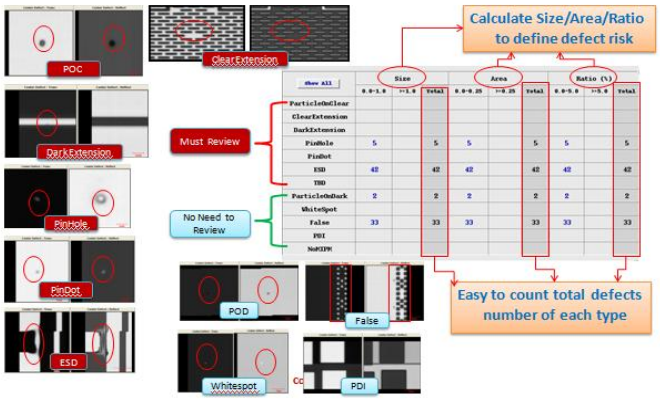

Figure 8 Auto defect classification result

ArF lithography photomask defect catch rate:

Among the defects, printable defects are most important of all. First we look the ArF lithography photomask performance on AA, Poly and Contact masks total 11 cases for this test. The defects in each case had been classified as printable and non-printable categories by wafer printing verification. The defect number in each case ranges from 271 to 8546. Compared to software auto classification results, all high risk printable defects are caught in "Must Review" category, 100% catch rate. 2 AA layer cases have missing defects at low risk non-printable category. The non-printable defect catch rates at these two cases are 99% and 93.2% (Missing rate 1% and 6.8%). The catch rates for low-risk non-printable defects on other 9 cases achieve 100%.

Mask Type	Mask Name	Total Defect	Printable hard defect (High Risk)	Not Printable hard defect (Low/No Risk)	
			Catch (Haze/ESD)	Catch (Haze/ESD)	Missing
AA	AA-1	3658	100%	100%	0
	AA-2	1755	100%	100%	0
	AA-3	5114	100%	99%	1%
	AA-4	2000	100%	93.2%	6.8%
Poly	Poly-1	3238	100%	100%	0
	Poly-2	405	100%	100%	0
	Poly-3	653	100%	100%	0
	Poly-4	8546	100%	100%	0
	Poly-5	271	100%	100%	0
	Poly-6	328	100%	100%	0
Contact	CT-1	647	100%	100%	0

Figure 9 The auto classification performance on different cases

I-line lithography ptotomask defect catch rate:

We also tested this solution on i-line lithography photomasks. We pre-classified them as printable and non-printable defect types as ArF test masks did. Compared to software auto classification results, this solution has 100% catch rate on both printable high risk defects non-printable low risk defects.

Mask Name	Total Defect	Printable hard defect (High Risk)	Not Printable hard defect (Low/No Risk)	
		Catch (Haze/ESD)	Catch (Haze/ESD)	Missing
A	1761	100%	100%	0
B	1992	100%	100%	0

Figure 10 The auto classification performance on I-line lithography photomasks

ESD defect catch rate:

ESD (electrostatic discharge) is a mask damaged defect type resulting from mask interaction with its environment. The semiconductor design and manufacturing process often results in varying degrees of damage from ESD. We pre-classified ESD hundreds of defects from 26 masks and compared it with software auto classification result. According to tested result, we have a good catch rate for all found ESD, most of defects are classified as ESD group except a few non-printable ESD defects which are classified into TBD for user's further review, which needs user to check the mask particularly to avoid any damage before production. This step helps user to validate some unclear defects with clear and magnification images when captured images can't provide enough information to make judgment.

5. Future development

Current auto classification is based on defect image properties on photomasks. What a user really cares are the printing results on the wafer. In the future, we plan to integrate this auto classification into a fully solution with the printability of wafer aerial image simulation capability to timely ensure mask quality and enhance productivity. Furthermore, we will add scoring function based on the result of wafer aerial image simulation and be able to guide wafer level defect inspection. This would make the wafer defects be easily controlled in early stage.

6. Summary

The photomask quality control is one of most important manufacturing issues in mass production FABs. Its quality can impact yield dramatically. Haze issue monitoring is one of the top issues. Inspection tool is well-known as one of high cost investment in FABs. "Do Not Care" defects are nuisance and unnecessary to review them one by one. This software auto classification effectively reduces the high cost review time of inspection and enhances FAB masks quality control. It supports both Die to Die and Single Die modes. With multiple real cases testing, we can reach at least 85% accuracy and no critical printable defects missing. In the future, wafer defect aerial image printing simulation capability will be added to this inline solution. It will provide better and cost-efficient defect management and photomasks quality control.

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