ENHANCED AUTOMATED VISUAL INSPECTION MANAGEMENT FOR QUALITY CONTROL: AUTOMATIC DEFECT CLASSIFICATION (ADC)

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ABSTRACT

Inspection, especially automated visual inspection (AVI), is needed to detect any defects which has the possibility to cause device failure. Identifying such defects early in the production process avoids the wasted effort both of packaging them and of having to identify failure at a later process. A failure of Automated Visual Inspection is catastrophic to the integrity of both the product and the future of the company as this preludes distrust from the customer.

Artificial Intelligence (AI) presents vast opportunities. The potential of machines doing the human tasks in a process is a strategy we used to improve the AVI process to work without human intervention. This paper describes the journey on the road towards improvement of the AVI process to enable Automated Defects Classification (ADC) without human intervention, and how it can progress moving toward AI implementation to the system; thus, guaranteeing the avoidance of automated visual inspection failure.

1. 0 INTRODUCTION

In engineering activities inspection involves the measurements, tests, and gauges applied to certain characteristics in regard to an object or activity. The results are usually compared to specified requirements and standards for determining whether the item or activity is in line with these targets.[1] At bumping process for a semiconductor, AVI is the main inspection responsible for ensuring the quality of the finished wafers through inspection and measurement (Refer to Figure 1).

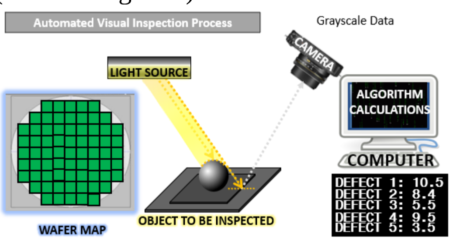

Figure 1. AVI Inspection

In AVI, the journey towards human reclassification of defects to auto-classification has been a step by step process. It all starts with the in-depth knowledge of the AVI machine and the AVI recipe.

An AVI machine has defined capabilities provided by the machine supplier. The machine has its limitations and its strength but making use of both through extensive knowledge can be an asset for the process. Hardware on the machine can affect the process of detection thus is highly recommended to be monitored on a defined frequency.

The AVI recipe was built through defining intricacies of complex die design coupled with stringent analysis of defect characterization. The reason behind was that previously identified non-critical defects may suddenly become critical defects to complex devices.

With these precursors, implementation of AI neural networks will be easier.

2. 0 REVIEW OF RELATED WORK

The term for AVI with AI of this kind of inspection system is smart inspection. Aerospace, Automotive, Pharmaceutical and Food industries use this system since a failed product can cause injury or even fatal outcomes[2]. In 2015, Huang and Pan studied AVI systems and reviewed their applications in the surface inspection of semiconductor products including wafer, TFT-LCD, and light-emitting diode (LED). They classified the inspection algorithms to projection methods, filter-based approaches, learning-based approaches, and hybrid methods [3]. Most literature have written about the study of using neural networks as AI. A latest trend in industry is to use AI-based visual inspection, in particular, convolutional neural networks (CNN). A CNN is a deep neural network containing image processing layers that are able to determine visual features at different granularity and its connections can be trained to adjust to specific problems given enough training data. Such AI-based visual inspection systems are primarily data-driven and have shown great performance in many scenarios including face detection, face recognition, and object classification [4]. There are more neural systems available in the market that can either work independently or together for a better AVI system.

3.0 METHODOLOGY

Automotive industry are key customers of the semiconductor industry and requires to have zero defects on the products they use. Best quality products involve the best process performance where consistency in correctly identifying a defect and rejecting it on the product is a requirement.

This paper is not focused on implementation of AI but on the journey to make the AVI process work without much human intervention.

The AVI process relies on conditions in order to correctly detect a defect. Identifying the best conditions and increasing the process margin for those conditions will provide the best both for process performance and the product.

3.1 Grayscale Value and Lamp Intensity

The first condition for the best AVI process is achieving the best lighting conditions. Calculations of the AVI machine to detect a defect are based on grayscale values. These are single number values of a pixel in an image representing the brightness. The difference between the brightness of a normal surface compared to the defect is called contrast. Recipe lighting conditions are affected by lamp intensity and in turn affects the contrast. It is monitored on the AVI machine and is also controlled during recipe generation since uncontrolled lamp intensity promotes non-detection of defects.

A variation on this lamp intensity is introduced from the use of different AVI machines. The recipe is device dependent and is created per machine. Each machine has a difference in light intensity as the lamp life of each machine is different. The older lamp provides darker images while a new lamp provides bright images. A defect may seem darker on an old lamp thus reducing this variation has been one of the main factors for the process readiness on automatic classification of defects.

With these factors identified as critical, these are monitored regularly. Checking of these factors are included in every preventive maintenance and any activity that can disrupt the normal operation of the AVI machine.

Standardizing grayscale is one way to reduce variation. Setting a target would always make sure that the AVI machine has a constant light intensity at any given time. This can be controlled via SPC charts and can be maintained by regular maintenance. Refer to Table 1 for the qualification checklist.

Table 1. Machine Qualification Check after Preventive Maintenance

Machine	Lamp Intensity	Grayscale Stability	Parameter 1	Parameter 2	Parameter 3
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3.2 Recipe Zoning

Formerly, the AVI recipe only uses 2 Zones for defect detection. Zones are the areas where the AVI machine will focus to detect the defects. With this AVI zone setup, all defects are categorized only in one defect. Inadvertently, in order to identify if there are critical reclassification of defects is performed. Critical defects would need a reaction to be performed as a control for quality once it is detected. This introduces the human decision variability and possibly lead to human error. Introducing additional zoning to the AVI recipe promoted the reduction of human intervention in the process. Refer to Table 2 for the comparison of AVI zoning count and Defect Classification.

Table 2. AVI Zoning Count

Zone	Before	After Additional Zoning	After Additional Algorithm
1	Defect 1	Defect 1	Defect 1, Defect 2 to Defect N+1
2	Defect 2	Defect 2	Defect A, Defect B to Defect Z
3	NA	Defect 3	Defect a, Defect b to Defect z
4	NA	Defect 4	Defect I, Defect II to Defect N+I
N	NA	Defect 5	Defect i, Defect ii, Defect n+i
N+1	NA	Defect 6	Defect X, Defect Y, Defect Z

Through the AVI Recipe algorithm that are pre-saved on the AVI machine, additional defects can be included for better automatic classification. Algorithms are the calculations mentioned during grayscale discussion. The recipe will use these algorithms depending on the defined use by the supplier but each algorithm can be tailored to cater to the need for detection by the user.

3.3 Defect characterization, Recipe Parameter, Defect criticality identification and Defect Location

The defect characteristics seen on the wafer products have diverse characteristics from color, shape, size and location or zone. We have defects coming from different processes, starting from fab related defects to bump induced rejects. This variability can cause non-detection if the recipe parameters are not controlled and monitored according to the defect characteristics. Due to this, each zone has their prioritization related to what is the criticality of the defects seen on that location. The recipe parameters were identified using statistical basis and has eliminated the possibility on non-detection.

Defect Location or zone can be further categorized depending on the criticality of the area (i.e. in between tight metal spaces) This allows the tool to isolate die features, and identify & predict possible defects location. Table 3 shows the Zoning and defect criticality.

Table 3. AVI Zoning and Defect Criticality

Zone	Defect	Criticality
1	Defect 1	2
2	Defect 2	1
3	Defect 3	3
4	Defect 4	5
N	Defect 5	4
N+1	Defect 6	6

The AVI recipe is generated using the average characteristics of good samples. This is the basis of AVI on what is good and bad during AVI scanning as it is carefully chosen during recipe generation from the available samples.

Each process on the production of wafers undergoes creates its own unique defect signature. From the studies conducted on the characteristics on each defect and identifying where in the wafer process step it is induced, this information is important as serves as a rule on classification of defects. The gathered images from the improved AVI recipe is stored and will soon be the defect library that can be used for the implementation of neural networks in the future.

Classification by human is done to align the auto-bin classification by the machine to the source process of defect. This process requires the personnel to have understood or memorized the defect library. This process is requiring them to rank multiple defects. To avoid this, hierarchy of all defects was established on the machine.

3.4 Statistical Process Control and Recipe Management System

Monitoring of the new procedure for the AVI process in exchange for the human monitoring, the use of process control charts has been employed. Yield charts are used as triggers for over-rejection of defects. These charts trigger after the scanning step has been completed. It is a signal for any sudden change from the normal performance of the AVI machine or it is a change in the wafer characteristics that is currently being inspected. This trigger for the machine's change in performance is one of controls in the new system. This will trigger equipment engineering troubleshooting activities in order to maintain the good performance of the AVI machine. Defect chart is another on the charts used as a small signal. Once it alarms, it works as a trigger to the process engineer to investigate the source of the increase in defects. This works not only as detection but also as data for root cause investigation.

Recipe Management System is a wholistic monitoring of all of the AVI recipes on multiple machines. One of the sub-systems is the recipe auditor.

Recipe Auditor is a tool used to manage the recipe parameters we have on the AVI recipe for each AVI machine. As the name implies it inspects each recipe's folder, sub folders, and files to screen out parameters that may have been missing, incorrectly typed, or those that may have been altered to become out of specification.

Another sub-system in recipe management is the recipe parameter checking. Recipe Parameter Checking or RPC is another control for AVI recipe. Similar with the auditor, it also checks parameters per recipe but this time it also checks per lot. Main difference is that, RPC can detect OOS parameters upon loading and during logout while the auditor routinely checks all recipes.

3.5 Wafermap Control

There are items that the AVI operator is checking during the reclassification process. One of those is the checking if the AVI machine has correctly aligned the actual wafer to the AVI reference die. Incorrect alignment will cause the AVI machine to reject the incorrect units. Refer to Figure 2 for the causes of misaligned wafermap.

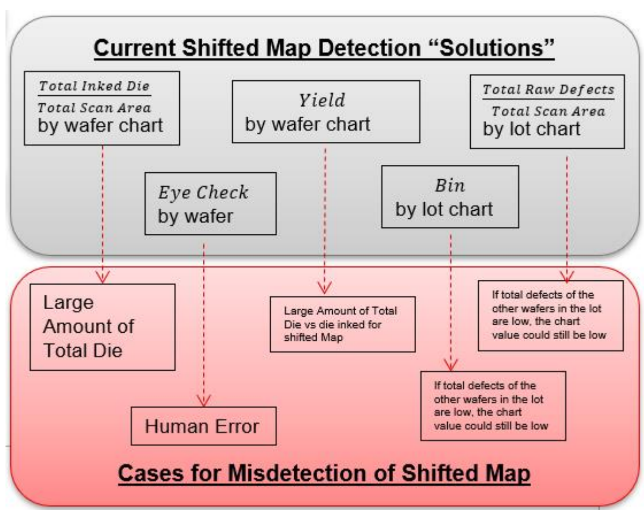

Figure 2. Misaligned Map Root Cause

In order to remove this activity from the operator, an AVI Map Shift Check was implemented through a Testware script logic. Refer to Figure 3 for the criteria of the system to flag a wafer as misaligned.

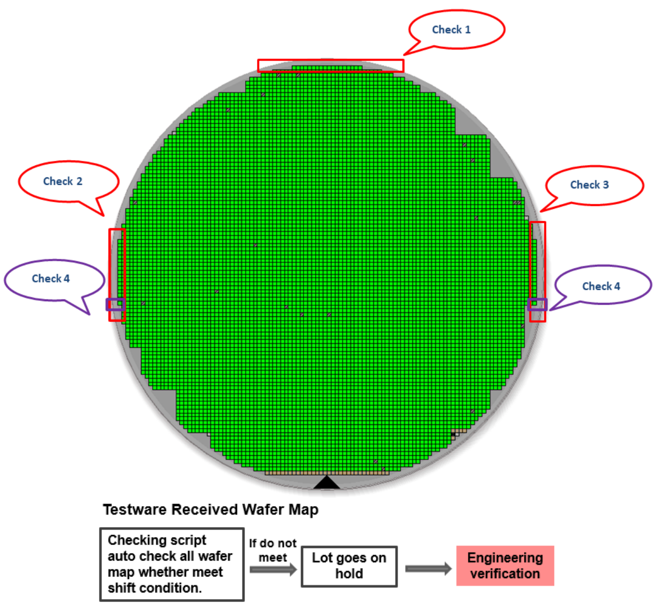

Figure 3. Misaligned Map criteria

4.0 RESULTS AND DISCUSSION

The AI systems that are being used in todays' automated visual inspection system relies on the goodness of the compiled defect library from bump processing.

The current AVI process that was created through the methodology described in this paper enabled us to gather the required good images for the defect library in preparation for the AI implementation. Good lighting on a properly created recipe – grayscale level, zone, algorithm, parameters, machine management on hardware and software and process management through SPC and recipe setup monitoring have been the pillars for the automatic classification of defects on our AVI process.

Reduction of AVI operator activities by 67% has been achieved by this project. Most importantly, this has enabled us to maintain our good quality scorecard for customer returns to zero for several years up until now.

5.0 CONCLUSION

The AVI system while most of the current neural networks do not have a high accuracy and still needs to be refined by producing more data for the purpose of deep learning and acquiring more advanced visual inspection system.

6.0 RECOMMENDATIONS

Neural network architecture is the next activity for the improvement process on automated visual inspection.

The library of defects being populated by the current automated defect detection process will be used for that phase of the project. This would create a continuous feedback system that will overtime increase the accuracy of the AI system.

The next step would be image matching. Once the AI system establishes its own library, it now needs to identify the same on diverse backgrounds. This will be done through image processing.

Unlike the current process with the recipe manually zoned by the engineers. The new system proposed has the capability to recognize device features through image recognition. With the defect library and the golden image data available the AI system could now distinguish defects better and at the same time automatically classify them into the right bins accordingly.

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