Detection of Bond Pad Discolorations at Outgoing Wafer Inspections

S. N. David Chua, S. Mohamaddan, S. J. Tanjong, A. Yassin, and S. F. Lim

Abstract—**Deployment of an automatic visual inspection system in semiconductor industry has become increasingly popular than ever not only due to its relatively high value as a yield analysis tool of outgoing products but more importantly for the prevention of defect escapee. A lot of studies are done on the application of in-line defect scan but the application of outgoing wafer inspection at post-fab environment has been very limited and rarely found in literature. With rapid growth of automotive application in worldwide industry, the importance of quality of the wafer at die level has never been so critical. This paper provides a method for detection of bond pad discolorations at outgoing quality check especially in semiconductor industry. An effective method for detection of the bond pad discolorations was proposed. The advantages and disadvantages of the detection method are discussed. Factors that are affecting the performances of the detection method are also described and analyzed.**

Index Terms—**Polyimide, outgoing, inspection, wafer, bond pad, discoloration.**

I. INTRODUCTION

IT IS well-known that the current trend of electronic devices is heading towards the idea of the smaller the better. Researchers and manufacturers are vying to produce small and smaller die feature size with shrinking circuitries. As a result, the requirements for the integrated circuitry (IC) processing and packaging in all facets are getting higher and more stringent as well. Producing a die that is able to meet its functionality is simply not good enough as the cost of production can be extremely high due to prevalence of screening tests that need to be set up and performed. One of the ways to reduce the cost is to introduce inspections on the wafer. Inspection is one of the important criterion to ensure the quality of the device, at the same time it helps to prevent faulty parts being delivered to customers which is very important for wafer fabrication manufacturers.

A lot of studies are done on the application of in-line defect scan [1]–[5] but the application of outgoing wafer inspection at post-fab environment has been very limited and rarely found in literature. Very few or almost none of the studies can be found in literature to describe the importance of bond pad inspection methodology during outgoing wafer inspection [6]. Most of the studies found in literature focused on probe-mark inspection [7]–[9] rather than primitive bond pad condition after wafer process is completed. It could be due to the fact that the impact of the excessive marking on bond pad has been well-established as an oversized, deep or misplaced probe marks can result in poor adhesion with the wire bonds [10] used for connections between die and substrate. This indeed poses a huge problem in semiconductor manufacturing industry in terms of yield loss and device reliability.

Unlike in-line inspection where it sets in mainly to cater for process monitoring and prevention of defect occurrence [11]. Outgoing wafer inspection is mainly to prevent defects being escaped to the next process such as probing or sawing. Ones might argue that outgoing wafer inspection should be done after sort probing test. However, the importance of the bond pad inspection prior to sort probing test should not be neglected. One of the significant factors is it reduces any risk of damage to probe cards that might be caused by any particulate contaminants on the bond pad. If the defect can be detected and screened out prior to the sort probing test, the cost of ownership [12] can be reduced dramatically. A number of manufacturers have implemented pre-probe inspections to minimize the risk. As technology advances, more and more backend semiconductor assembly and packaging manufacturers have begun to use the wafer map facilities in a form of electronic coding provided by front end wafer fabrication manufacturers. Any reject detected by an automatic visual inspection tool can be encoded in the electronic map. As such, the defective dies can be segregated prior to next process without having worried about the concerns of misuse.

II. MATERIALS AND METHODS

In general, wafer inspection process is carried out in 3 stages; defect detection, defect review and defect classification. This paper would mainly focus on the defect detection at bond pad areas in particular bond pads discoloration induced by polyimide process. Polyimide is a protective layer that covers the die surface. Difficulty often arises from the polyimide process during the opening of the bond pads. Over etch would result in bond pad discoloration while under etch can cause

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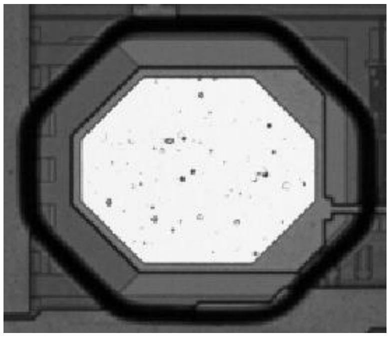

Fig. 1. An example of a good bond pad which is free from discoloration.

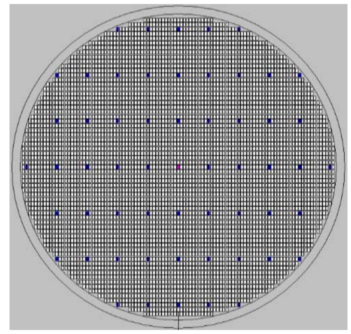

Fig. 2. Selected dies across the wafer for the generation of golden image.

polyimide residue remain on the bond pad. The shortcomings are not favoured as far as wafer fabrication manufacturer is concerned. It can introduce a lot of problems to backend assembly especially during wire bonding process which failure mode of non-stick on pad (NSOP) is a major concern.

Conventional visual inspection of wafer was done by humans using a microscope. Implication evoked as they became less reliable and time-consuming in particular if ones were to venture into automotive industries which requirement for full wafer inspection was almost impossible. In consideration of this, the requirement for automatic visual inspection tools as one of the most important gauges in defect detection is of absolute critical. This is in order to achieve the purpose of catching various defect sizes, particles and submicron contaminants that are generated during wafer fabrication processes. An automatic visual inspection tool is a tool that is used to perform the wafer surface screening. The wafer surface images are captured by the camera of the tool and processed within the tool to give the final result of the screening process. The tool would prompt the inspector to reject if there is any discrepancy found that is not within the acceptable tolerance between the golden image and the image screened. The mismatch between the intended defect size and inspection tool capability would pose difficulties and challenges to engineers to capture the defects without even considering other factors like threshold setting and methodology as well. Therefore, a proper set up and a range of studies should be clearly defined. The automatic visual inspection tool used for the application is commercially available in the market. The tool type and model used would not be disclosed in the paper due to proprietary issue. Nevertheless, it should not hinder the objective of the studies. The purpose of the studies was to demonstrate the need of a method used for bond pads discoloration inspection over conventional inspection method.

One of the challenges in bond pad inspection is the ability to suppress false alarms. There are many reasons of bond pad discoloration. For instance metal grains on aluminium bond pad, pitting, residues, embedded foreign material, particles, block etch issue, and etc. It is a general description for the bond pad when visual distinction of the bond pad is observed. There are many algorithms being developed [13]–[16]. Question is how to get rid of the false defects (e.g., metal grain) and only the intended defects (e.g., pitting) are highlighted.

A design of experiment was carried out to simulate the dominant factors that might result in bond pad discoloration. A test vehicle was then prepared with purposely induced bond pads discoloration on the wafer. The benefit of the purposely induced bond pads discoloration wafer is it covered a wide range of grey scale levels. It allowed the study on the impact of the inspection methodology towards a gradual change in grey scale level rather than extreme condition with obvious differences in contrast. Fig. 1 shows an example of a good bond pad from the wafer. It can be seen that, the bond pad is free from any impurities.

III. Training Dies

The approach used for defect detection of bond pads was a comparison method with reference die or so called golden image generated from a pool of image selections. These dies are stacked on top of each other to generate a mean image and a standard deviation image. The selection of dies for training a good model must be as less noise as possible. In order to make the reference image statistically reliable, a selection of 57 sample dies was identified (Fig. 2) for the generation of the golden image. Each die was inspected prior to the selection for training purposes. It was to ensure the dies selected were free from any defects which might introduce variations and add inconsistency to the image processing. The selected dies were distributed around the wafer randomly. The intention was to embrace the possible variations induced by the wafer fabrication process and yet possessed the capability to discern between good and bad dies.

IV. Recipe Set Up

A sample of defects are manually inspected under a microscope to confirm the existence of bond pad discoloration on the wafer. The wafer was then subjected to the inspection processes with different set up algorithms. A total of four recipes was created with two different methodologies namely 3x and PMI as shown in Table I. The 3x inspection pass is a conventional method used to screen the bond pads based on the concept of pixel to pixel image comparison with the golden image. The PMI inspection pass uses different concept whereby the averages of the grey scale values within the bond pad area are used for comparison. Illumination is one of the most important criterion in setting up a robust recipe

TABLE I
FOUR DIFFERENT INSPECTION RECIPES FOR BOND PAD INSPECTION

Recipe	Method	Illumination (%)	Inspection Pass
1	A	40	3x
2	B	40	PMI
3	A	50	3x
4	B	50	PMI

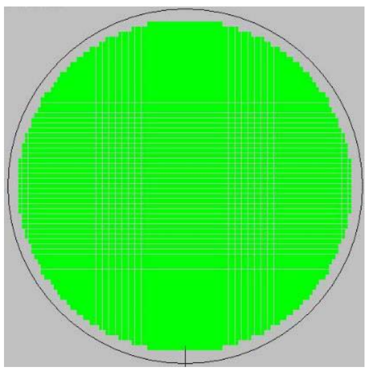

Fig. 3. Wafer map result of inspection generated by recipe 1.

for the inspection process. The optimum illuminations used after a few round of optimisations was found to be 40% for method B and 50% for method A. The optimum illuminations were determined based on the highest count of true defects found on the bond pads of the wafer.

V. ILLUMINATION LIGHT

The illumination light bulb used for the experiment was newly replaced but it was pre-conditioned for stabilisation. The healthiness of the illumination light was checked prior to the tests. It is important to check the performance of the illumination light to ensure it operates within a normal range as it might affect the threshold setting of the bond pad discoloration. The confirmation was done by checking the grey scale level of a golden wafer or calibration wafer prior to the test.

VI. RESULTS AND DISCUSSION

Table II gives the summary of the inspection results in terms of total defective dies detected by each recipe. Fig. 3 $\sim$ 6 show the locations of bond pad discolorations detected on a wafer map by each recipe. The yellow colour represents the bad dies detected by the tool after inspection while the green colour represents the good dies with no abnormality found. There are several bond pads in a die. Once a bond pad is found with bond pad discoloration, the die is considered as a bad die.

The inspection results showed that recipe 1 could not detect any bond pad discoloration on the wafer at all. Recipe 2 was

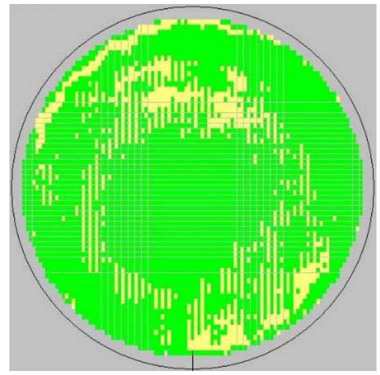

Fig. 4. Wafer map result of inspection generated by recipe 2.

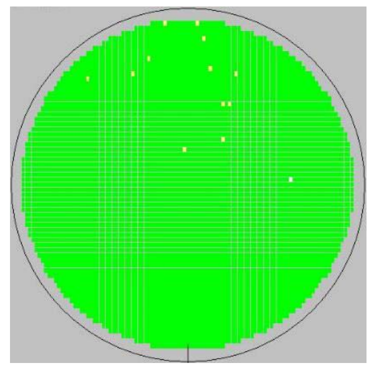

Fig. 5. Wafer map result of inspection generated by recipe 3.

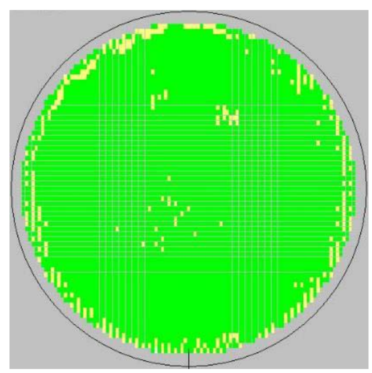

Fig. 6. Wafer map result of inspection generated by recipe 4.

the most robust recipe with 1038 bad dies found by the inspection tool. It was followed by the recipe 4 with 318 bad dies and recipe 3 which could only detect 13 bad dies with bond pad discoloration on the wafer. Recipe 2 and 3 were created based on the standard normal procedure used for creating a recipe for production use. These recipes are used to inspect actual production wafers in the line. Recipe 1 and 4 were intentionally created for the purpose of illustration to show the impact of different inspection passes at different illumination levels.

Based on the inspection results, it is clearly shown that 3x inspection pass (recipe 1 and 3) is not very sensitive or useful to detect the bond pad discoloration. The recipe 1 with 40% illumination in particular failed to detect even a single defect of bond pad discoloration on the wafer. This is due to the fact that 3x inspection pass uses pixels to pixels

TABLE II
THE RESULTS OF THE FOUR DIFFERENT INSPECTION RECIPES FOR BOND PAD INSPECTION

Recipe	Method	Illumination (%)	Inspection Pass	Total bad dies detected	Wafer map
1	A	40	3x	0	Fig. 3
2	B	40	PMI	1038	Fig. 4
3	A	50	3x	13	Fig. 5
4	B	50	PMI	318	Fig. 6

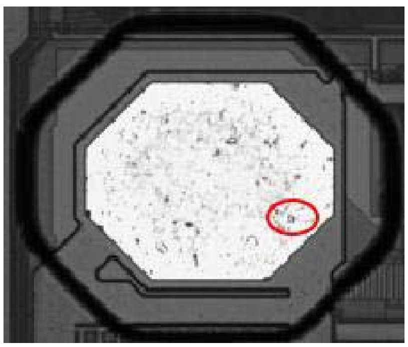

Fig. 7. A localised defect (grain) detected by the tool.

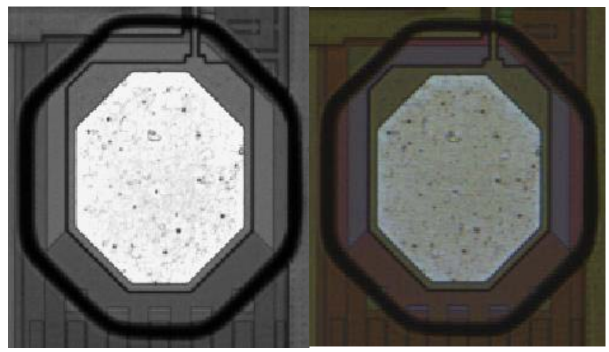

Fig. 8. A mild bond pad discoloration in grey scale and colour image.

comparison method to compare with the golden image. The variation of grey scale level within the pixels of the golden die is somewhat high for 3x inspection pass. This is normal and acceptable in general production mode in order to cater for wafer process variations like different processing tools or different batches of raw materials but it is not very effective to detect the bond pad discolorations. Some inherits nature of process variation like wafer edge to wafer center is inevitable as well. Therefore, unless there is a prominent localised defect on the bond pad, this method would not be able to detect the abnormality. Unfortunately, bond pad discoloration does not fall into this category since the nature of the defect is often very mild, not localised and widely spread. Despite that, it was observed that a few bad dies were detected by the recipe 3. Upon checking the result, the tool actually caught on the localised defect (grain) rather than the bond pad discoloration as shown in Fig. 7.

The PMI inspection pass is useful to detect the bond pad discoloration. This is evidenced through the recipe 2 and 4. The PMI inspection pass is more sensitive towards bond pad discoloration or any kind of grey scale shift because it takes the averages of the grey scale levels within a defined region like the bond pad area for comparison. It is less sensitive to miniature localised defect since the defect would be diluted once it is averaged out within the defined region. The contribution of an localised defect is depending on the size of the defined region. In other words, it is the ratio of the size of the defect versus the defined region.

Illumination also plays an important role in terms of detection of bond pad discoloration. It can be clearly seen based on the total bad dies detected by the recipe 2 and recipe 4 respectively. The utilisation of PMI inspection pass is less effective without a proper adjustment of illumination level. This explains the reason only one third of the total bad dies was detected by the recipe 4 in comparison with the recipe 2. The higher illumination level in recipe 4 resulted in the moderation of the image (grey scale value) of the bond pad. It made the image to image comparison very weak in terms of grey scale value distinction especially for mild bond pads discoloration.

Fig. 8 shows a bond pad that was classified as mild discoloration. It is often a challenge for inspectors to detect this kind of mild bond pads discoloration either by inspection tools or human through microscopes. Mild bond pads discoloration are often escaped from the detections which resulted in field return by automotive standard even though the level of acceptance for mild bond pads discoloration is also varied amongst customers. In order to prove that the method proposed (PMI) was effective, the mild bond pads discoloration were also subject to the inspection. It is evidenced that the PMI method is able to detect this kind of defects as shown in Fig. 4 and Fig. 6.

VII. CONCLUSION

A method for detection of bond pad discoloration was proposed. In order to overcome the inherent deficiencies of the conventional method (method A) in detection of different severities of bond pad discolorations, PMI inspection pass is of utmost important and necessary to reduce defect escapees. The PMI inspection pass uses the averages of grey scale values of each pixel within the defined region to represent the entire unit of the bond pad as a single entity. The threshold can then be set to determine pass or fail by inspectors easily. Unlike the conventional method which uses the concept of pixel to pixel comparison method. This is useful to detect localised defects but not feasible for the detection of bond pad discoloration as a whole especially very mild bond pads discoloration.

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