

Introduction of Laser Grooving Technology for Wafer Saw Defects Elimination

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Authors' contributions

This work was carried out in collaboration amongst the authors. Both authors read, reviewed, and approved the final manuscript.

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ABSTRACT

The technical paper showcased a comprehensive study on laser (light amplification by stimulated emission of radiation) grooving as breakthrough and ultimate solution in wafer sawing. The project is intended to address various defects such as chippings, metal dangling/peel off, cracks, and other wafer-related defects induced during wafer sawing process. Series of process simulations, actual processing, benchmarking, and collaborations with suppliers are carried out to attain a zero defect in wafer sawing. Critical processes and controls on this new technology are shown and how the mentioned defects are properly addressed.

The laser grooving is the newest and latest developed state-of-the-art technology over conventional mechanical sawing using blades. Sawing process is considered as one of the challenges in the plant as it deals with different wafer technologies. Different blade types also need to be properly maintained. Compared to the conventional and universal mechanical sawing using blades, complex errors and top reject contributor of identified critical processes are corrected and required process capability index is achieved.

Keywords: *Laser grooving; mechanical blade; wafer saw; design of experiment.*

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1. INTRODUCTION

To keep-up with the fast-changing technology and development in semiconductor industry, one should be flexible and resourceful in adapting to change in order to have a very good impression from the eventual customer. This is one of the biggest challenges for any semiconductor company in order to maintain its competitive market position and value. Contrariwise, failure to provide customer expectation will result to possible business failure.

Wafer sawing is the vital process of any semiconductor Integrated Circuit (IC) manufacturing sites. It is the first front line operation in which a processing error can convert a high-priced wafer into thousand pieces of expensive scrap [1,2,3]. Proper dicing of wafers requires experience, judgment, and high-performance equipment [4]. Successful sawing requires selecting the correct saw blade from dozens of possibilities and finding the proper combination among dozens of control settings. The wrong blade or the wrong combination of parameters can damage the wafer. Selecting the sawing method, proper sawing parameters, blade type, and mounting tape are the key to success.

In this paper, blades as primary input factor were omitted. Moreover, mechanical sawing was replaced by laser (light amplification by stimulated emission of radiation) grooving. A process where mechanical contact on the silicon wafers that causes various sawing defects was eliminated. Using this latest technology trend, the paper discussed how this burden was turned into milestones.

1.1 Wafer Saw Process

Sawing is a very critical process. When abrasive blades cut or groove material, they are actually grinding and removing it. The mechanism is similar to that of a metal saw: the gaps between the teeth of the saw whisk material away from the point of processing. These gaps, called chip pockets, are illustrated in Fig. 1.

New blade has diamonds covered e by the bonding material and no diamonds (hammers) are exposed on the surface [5]. Therefore, diamonds cannot make cracks. If you cut the wafer with this condition, big chippings may happen, or the blade may be broken depending on the cutting speed [6]. After dressing, bonding material is removed and diamond comes out on

the surface as shown in Fig. 2. At the same time, small hole, which is called chip pocket, is created. This chip pocket will bring cooling water in the cutting area and will draw out small cutting chips temporarily storing in this pocket.

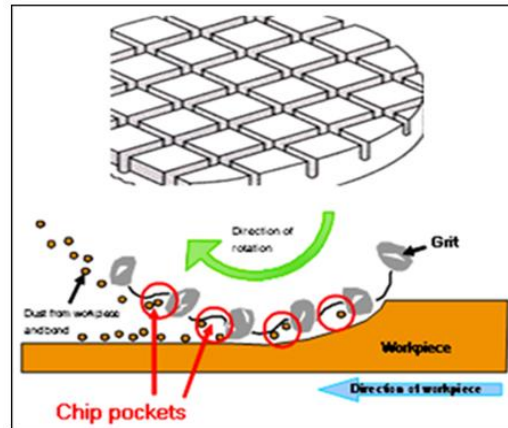


Fig. 1. Wafer saw mechanism showing how chipping pockets occur

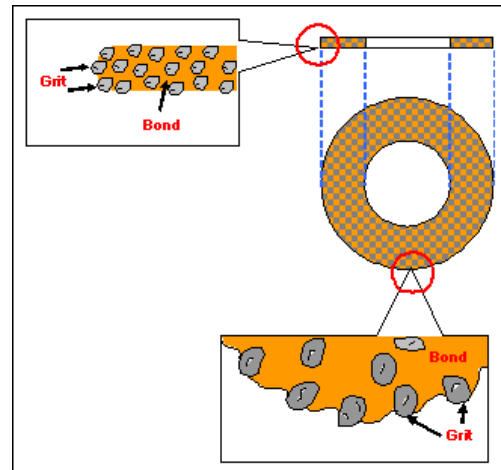


Fig. 2. Elements of blade structure and their purpose

The blade is composed primarily of grit and bond. The grit is what actually performs the processing. The bond's role is to hold the grit in place. Chippings are generally present on a new blade. Hence, blade dressing and precut are needed to be performed, as illustrated in Fig. 3. Blades are dressed before shipment. However, precut operation is still needed to condition the blade and to true the outside diameter, removes excess binder material or loose diamond particles, and minimize the load, creating a cooler and freer cut resulting to minimize occurrence of chippings.

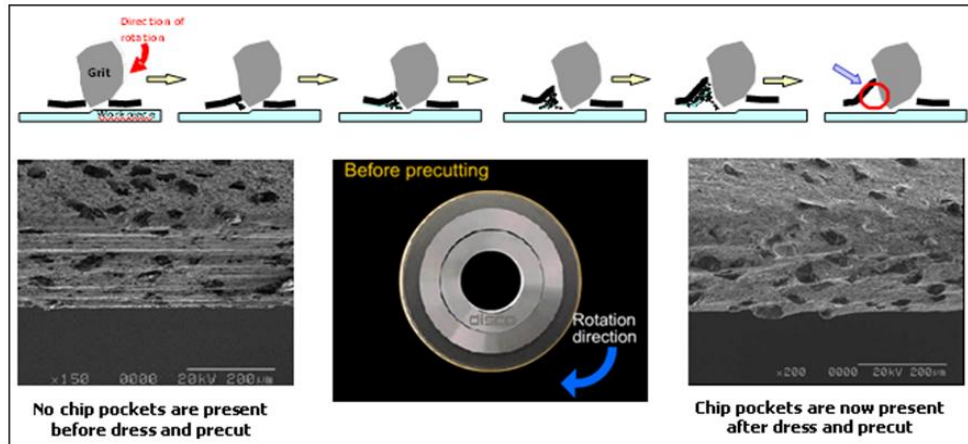


Fig. 3. Dressing and pre-cutting mode

Dressing and pre-cutting cannot simply eradicate chippings when using a single blade. Single blade carries a greater process load and thus, results in an increase in surface chippings. That is why a step-cutting mode was introduced to minimize chippings during cutting. Step-cutting method shown in Fig. 4 is done using two blades (Z1 and Z2). The Z1 will partially cut the wafer and Z2 will totally cut the wafer making it stress relief.

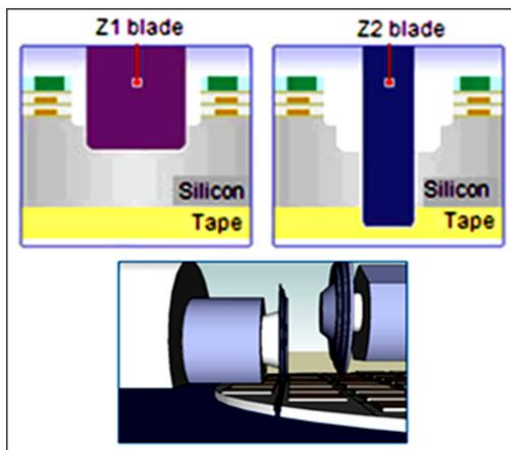


Fig. 4. Step-cutting method

With step-cutting method, lesser stress on the wafer is induced because the contact area is reduced, thereby, reducing chipping occurrence.

1.2 Wafer Laser Grooving

The Laser grooving or ablation is when the laser light irradiates a solid substance and the intensity

of the laser light is over a threshold. The light is converted into electrical, thermal, photochemical, and mechanical energy. The neutral atom, molecules, positive and negative ions, radicals, clusters, electrons, and light are released explosively and the surface of the substance is etched, as illustrated in Fig. 5.

When the energy density of a condense laser light is over a certain threshold irradiated on a work piece, it ablates, and as a result, it is cut. Different methods of laser cutting are presented in [7,8,9,10], for various materials and applications. Process threshold and cut depth varies depending on the material. Fig. 6 shows the typical example of the process threshold versus the material.

Four critical parameters are being controlled in order to achieve good energy density and overlap rate. Fig. 7 shows the relationship diagram.

Energy density and overlap rate affects the cutting quality. The value of each parameter will also depend on the wafer technology or the metallization or Test Element Group (TEGs) on the wafer street.

Different technique is also being used to achieve a defect-free product in using this kind of dicing technology. For thick wafers (~280µm), the most common technique is the parallel laser groove wherein the 1st process is used to ablate approximately 6 to 10µm from the surface followed by mechanical blade cut-through process. Figs. 8 shows example of the technique used for laser cutting.

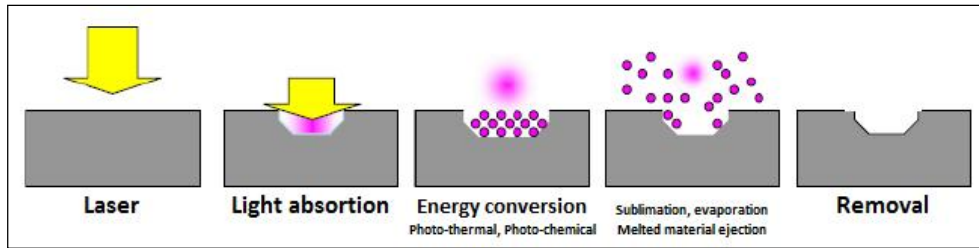


Fig. 5. Principle of laser ablation

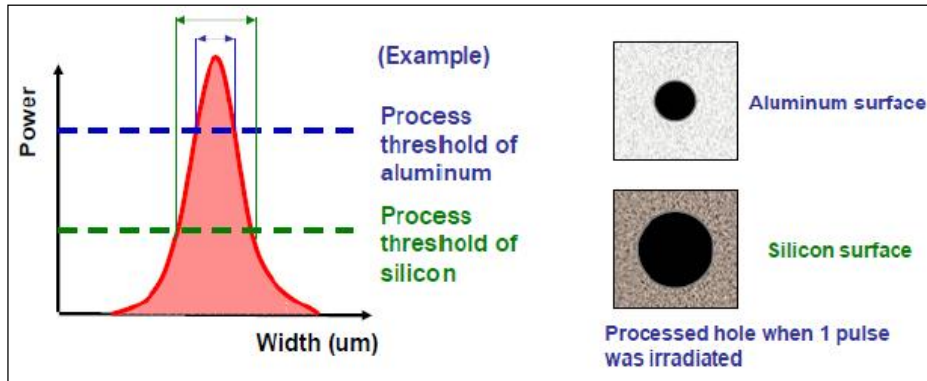


Fig. 6. Cutting result versus material type

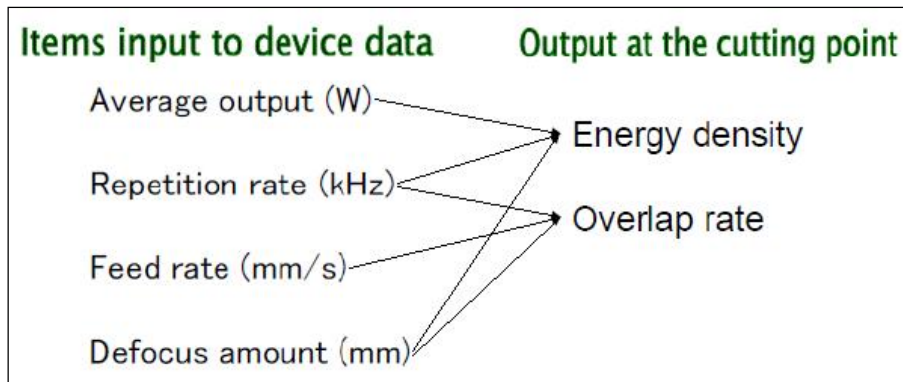


Fig. 7. Relationship diagram of laser grooving parameters

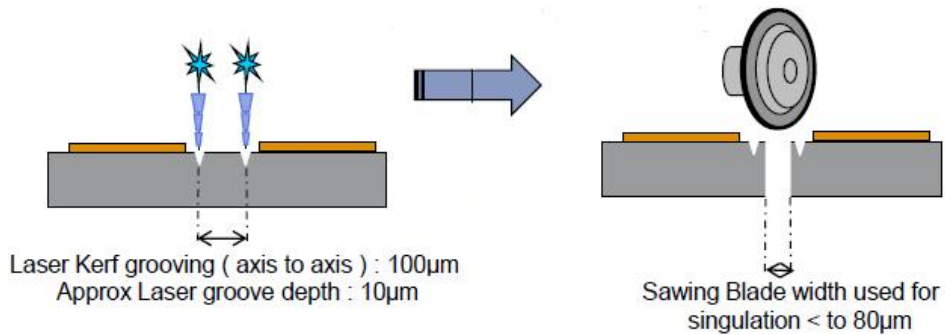


Fig. 8. Laser groove + mechanical cut-through

1.3 Wafer Technology

As the trend in semiconductor become more complex, it is inevitable to have a complex wafer design as well as the process [4,11,12,13]. Example would be the wafer technologies used for applications such as phone processor and high end fiber optic sensors. These wafer technologies are susceptible to chippings, delamination, and cracks using mechanical sawing due to its complicated structures on the sawing street. Fig. 9 shows an example where in the peel-off or chippings occur on sawing street with metalized scribe area.

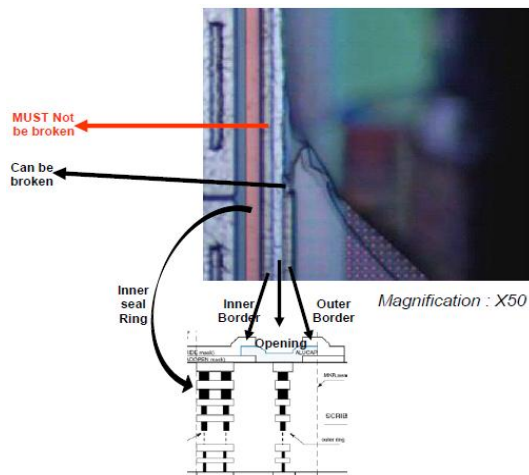


Fig. 9. Example of wafer chipping or peeling

1.4 Wafer Saw Process Pareto of Rejects

Top rejects at wafer saw process are shown in Fig. 10, affecting severely the line stressing mode with actual Defect Parts per Million (DPPM) intentionally not given. Note that parameter optimization is one of the factors to be checked for the particular device. Benchmarking for similar device from other manufacturing sites is being considered to have a baselining on critical process parameters.

Three critical risks were identified. Evaluation was focused on these identified risks with the use of laser grooving. Baseline reference is the historical data acquired using mechanical blades. Further analyses and investigations of failures were made by collecting actual reject samples. Fig. 11 shows the top defect signature.

1.5 Problem Statement

Top rejects (based on Pareto Analysis) using mechanical dicing saw substantially affects the

yield and quality of various product lines. Eliminating these defects are not possible through optimization and by using different blade types. A breakthrough solution was experimented and that is to use laser grooving during wafer saw.

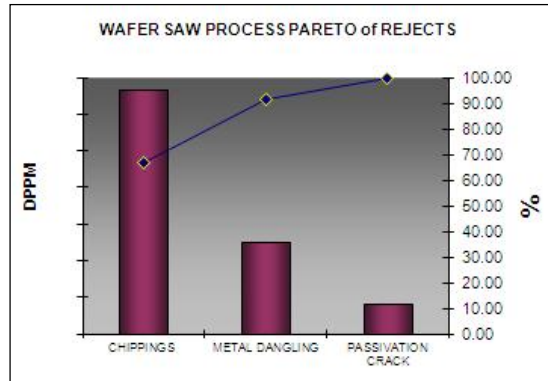


Fig. 10. Pareto diagram of rejects showing the top contributor
(Actual DPPM values intentionally not shown)

CRITICAL RISKS	DEFECT MECHANISMS	CRITERIA	REMARKS
Frontside Chippings / Peeling		NOT ALLOWED	FAILED
Metal Dangling		NOT ALLOWED	FAILED
Passivation Cracks		NOT ALLOWED	FAILED

Fig. 11. Top defect signature of critical risks

2. EXPERIMENTAL SECTION

Distinction of mechanical sawing versus laser grooving in relation to the critical risks in sawing process was mentioned earlier. Top rejects contributors brought about by mechanical dicing sawing were also presented. Now, a Design of Experiment (DOE) is necessary to statistically separate the two mentioned processes (mechanical sawing and laser grooving) with chippings, metal dangling, and passivation cracks as primary response. The DOE matrix in Fig. 12 focused on laser grooving parameters and its impact to three identified risks.

Design	Pattern	Frequency	Power	Feed Speed	Passivation Cracks	Chippings	Metal Dangling
1 +++	100	1	100	▪	▪	▪	
2 --+	50	1	50	▪	▪	▪	
3 ---	50	0.5	50	▪	▪	▪	
4 --+	50	0.5	100	▪	▪	▪	
5 -++	50	1	100	▪	▪	▪	
6 ++-	100	1	50	▪	▪	▪	
7 +++	100	0.5	100	▪	▪	▪	
8 +--	100	0.5	50	▪	▪	▪	

Fig. 12. Full factorial design showing the three identified risks as primary responses

Full factorial design with a total of eight runs was created using SAS-JMP [14], a system software for statistical analysis. Frequency, power and feed speed were identified as the most critical parameters. Note that since the new laser grooving machine is new to our process, the defined ranges reflected on the DOE runs are recommended by the Original Equipment Manufacturer (OEM). Hence, validation on these ranges are needed prior defining the set of parameters to be used in production line.

3. RESULTS AND ANALYSIS

Initial DOE on the three identified risks at wafer sawing was conducted to validate OEM default parameters. The three identified risks are front side chippings or peeling, metal dangling, and passivation cracks. Effectiveness of laser grooving was immediately seen as zero-defect was noted after using visual mechanical inspections on every run, as depicted in Fig. 13 and in Fig. 14.

Run	Pattern	Frequency	Power	Feed Speed	Passivation Cracks	Chippings	Metal Dangling
1	+++	100	1	100	0	0	0
2	--+	50	1	50	0	0	0
3	---	50	0.5	50	0	0	0
4	--+	50	0.5	100	0	0	0
5	-++	50	1	100	0	0	0
6	++-	100	1	50	0	0	0
7	+++	100	0.5	100	0	0	0
8	+--	100	0.5	50	0	0	0

Fig. 13. DOE results showing zero (0) defects on every trial

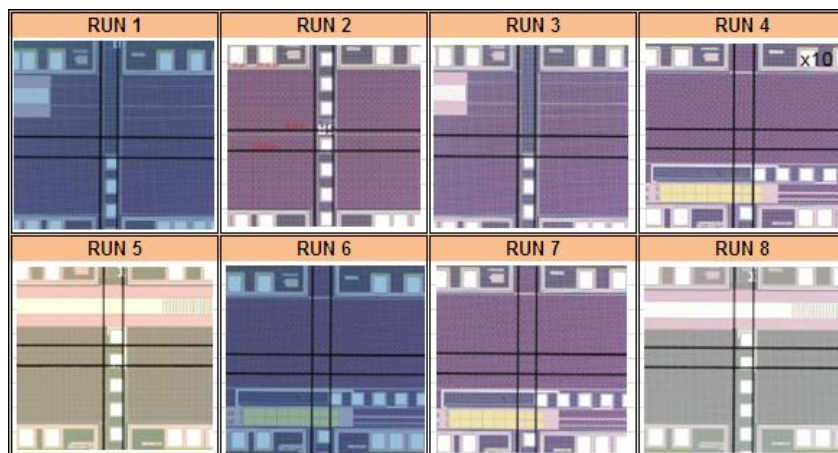


Fig. 14. DOE representative photo per run

Further data was made on a larger scale and Comparative Tests were used to statistically validate the results, with the aid of SAS-JMP. Tukey-Kramer test was used for it gives a more conservative estimate of results as compared to the other tests. Statistical graphs are provided for ease of interpretation and analysis.

3.1 Identified Risk #1: Front Side Chippings / Peel Off

The variances of laser grooving data against the mechanical data as illustrated in Fig. 15 are not equal with respect to chippings, with P-value lower than alpha of 0.05. This implied a significant difference between the two wafer saw processes, with laser grooving producing better result and causing minimal impact in the response. Maximum of 4µm was observed using laser grooving.

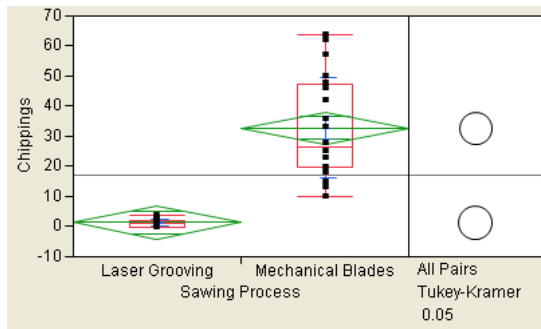


Fig. 15. Analysis of variance (ANOVA) between laser grooving and mechanical blades

3.2 Identified Risk #2: Metal Dangling

Low (L), mid (M), and high (H) for critical parameters on both laser grooving and mechanical blades were validated to check for metal dangling response. Table 1 shows that

Table 1. DOE matrix for low, mid, high parameters for metal dangling response

Process	Run1 (LL)	Run2 (LM)	Run3 (MM)	Run4 (MH)	Run5 (HH)
Mechanical blades	Yes	Yes	No	No	No
Laser grooving	No	No	No	No	No

Table 2. DOE matrix for low, mid, high parameters for passivation crack response

Process	Run1 (LL)	Run2 (LM)	Run3 (MM)	Run4 (MH)	Run5 (HH)
Mechanical blades	Yes	No	No	No	No
Laser grooving	No	No	No	No	No

regardless of parameter setting using laser grooving, zero (0) metal dangling was attained compared to mechanical blades where metal dangling is prominent on low side parameters using the same number of wafers run. This is the reason why on actual scenario, mid (M) or high (H) settings are used to avoid this risk but calls for frequent blade replacement.

3.3 Identified Risk #3: Passivation Cracks

Same experiment was done using low, mid, and high (H) for critical parameters on both mechanical blades and laser grooving to check for passivation cracks. The same results were attained using laser grooving where zero (0) passivation crack was noted. Whereas, passivation cracks occurred on low side parameters using the mechanical blades, as summarized in Table 2.

ALL of the above DOE results confirmed that when laser grooving is used during wafer sawing process, the three identified risks were minimized and even zeroed-out in large scale evaluations. The most denoted significant difference amongst the run is the elimination of surface chippings which are inherent to sawing process using mechanical blades.

3.4 Verification of Results

After the qualification of laser grooving, results were verified and levels of rejections were monitored. The graph in Fig. 16 shows the results before and after the implementation of laser grooving process.

Significant effect was achieved after using laser grooving and top reject contributor especially chippings were eliminated. This is a good indication of manufacturing preparedness for full production mode.

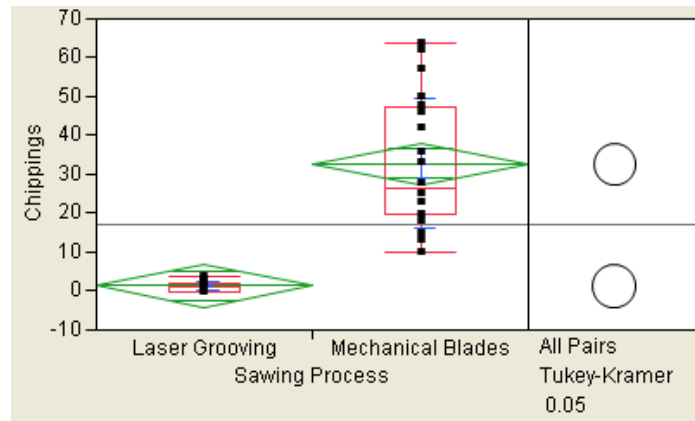


Fig. 16. Identified risks trend before and after the implementation of laser grooving (Actual DPPM values intentionally not shown)

Table 3. Potential problem analysis table for laser grooving

Potential problem	Potential cause	Action	EP level	Status
Topside contamination	Particle deposition caused by laser grooving	Use water soluble protective coating	2	Implemented
Difficulty in removing particles	Reaction of heat vs. the coating material	Use of atomizer in cleaning the water	1	Implemented
Heat affected zone	Excessive power setting / to low feed speed	Parameter optimization	2	Implemented

3.5 Potential Problem Analysis for Laser Grooving

Potential problem analysis was employed and formulated in as part of readiness in case problem arises during mass production using laser grooving process. Three potential problems were identified in Table 3 and actions were put in place as best solutions. Error-proofing (EP) levels were used as bases to evaluate the defined best solutions and contingency plans.

4. CONCLUSION AND RECOMMENDATIONS

Although, this study involves some investments, long term solution is what matters most. Employing in depth engineering analysis with the aid of statistical tools in solving top reject contributors were presented on this paper. Using these statistical tools lead us to pinpoint the critical risks that need special attention and focus during risk production. The three identified risks such as metal dangling, passivation cracks and especially chippings which are inherent at wafer sawing process can be eliminated using state-of-the-art technology such as laser grooving.

It is recommended that the learnings gained using laser grooving be sustained and be monitored with its effectiveness until mass production mode. This paper presented a robust solution in eliminating various sawing defects using state-of-the-art-technology as breakthrough solution. In-depth methodological analysis was employed to identify contributing factors on the top rejects, with practical simulations and validations through statistical tools. This new technology of laser grooving is recommended to attain significant improvements and to achieve a permanent fix to chronic wafer sawing issues. It is imperative that when new technology is coming in, critical processes are needed to be identified and that appropriate corrective actions and solutions be made so that when full production are set, deliveries will not be at stake.

It is also highly recommended, if not necessary, that the assembly manufacturing processes observe proper ESD controls. Opportunities presented in [15,16] could be very useful to help ensure ESD check and controls. Ultimately, continuous improvement is important for sustaining the quality excellence of any product and of the manufacturing assembly and test plant.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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