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Wafer Saw Defects Mitigation through Laser Grooving Technology

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Abstract— *The paper presented a technical study on laser (light amplification by stimulated emission of radiation) grooving as breakthrough and vital solution in wafer saw process. The technical paper is intended to address various defects such as chippings, metal dangling and peel off, cracks, and other wafer-related defects induced during wafer saw 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.*

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, with laser grooving technology complex errors and top reject contributor of identified critical processes are corrected and required process capability index is achieved.

Keywords— *Laser grooving; wafer saw, mechanical blade; DOE.*

I. INTRODUCTION

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 end-customer. This is one of the biggest challenges for any semiconductor company in order to maintain its competitive market position and value. Conversely, failure to provide customer expectation will result to possible business failure.

Wafer saw is a 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 technical 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.

A. 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.

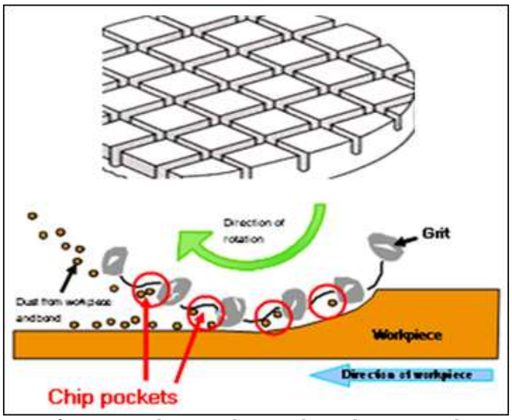

Fig. 1. Wafer saw mechanism showing how chipping pockets occur.

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

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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.

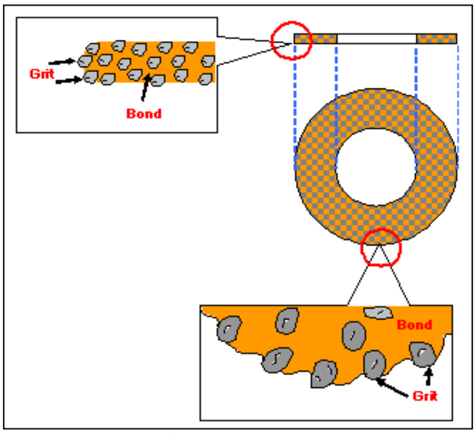

Fig. 2. Elements of blade structure and their purpose.

The blade is composed primarily of grit and bond. The grit is what actually performs the processing. The bond's role is to the 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.

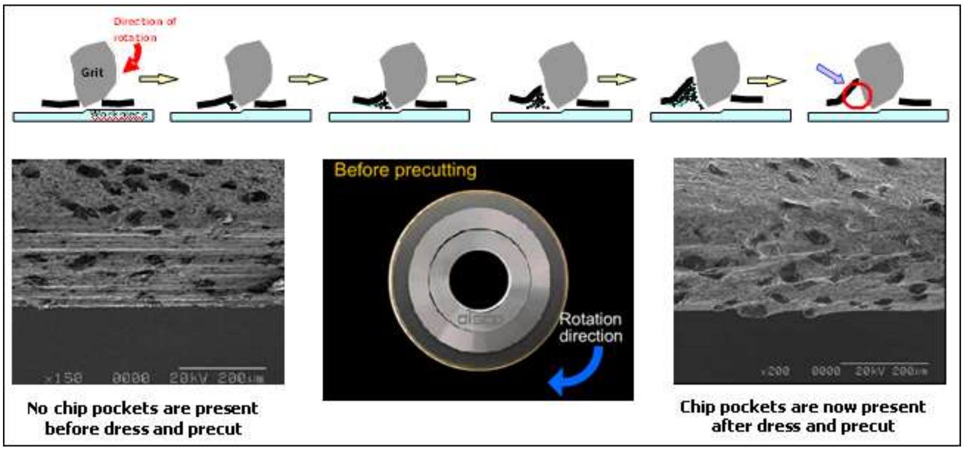

Fig. 3. Dressing and pre-cutting mode.

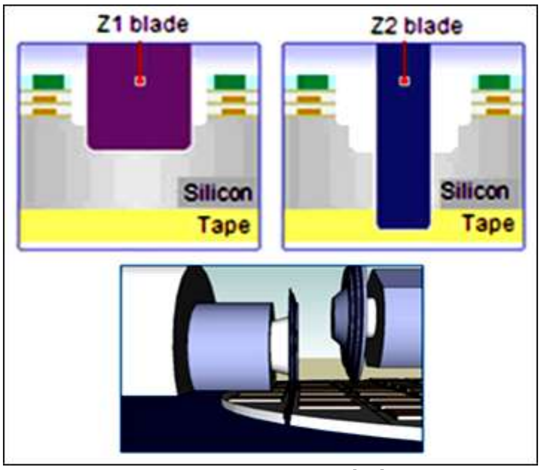

Fig. 4. Step-cutting method.

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.

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

B. 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.

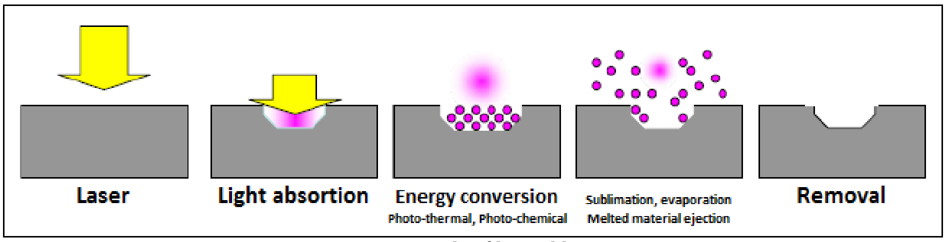

Fig. 5. Principle of laser ablation.

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], 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.

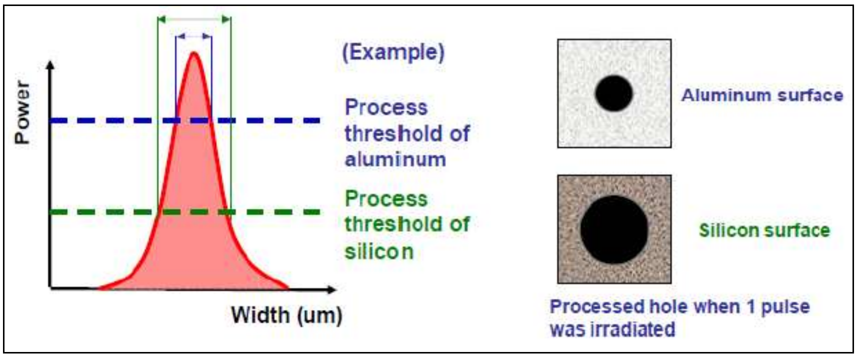

Fig. 6. Cutting result versus material type.

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

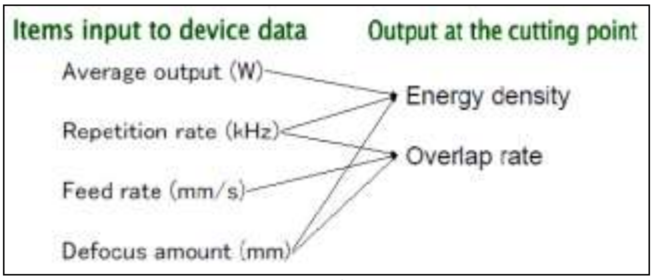

Fig. 7. Relationship diagram of laser grooving parameters.

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.

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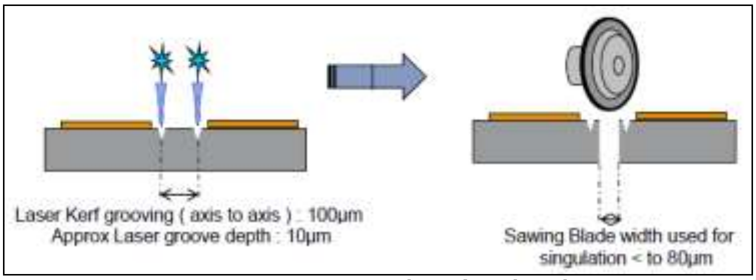


Fig. 8. Laser groove + mechanical cut-through.

C. 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], [9], [10], [11]. 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.

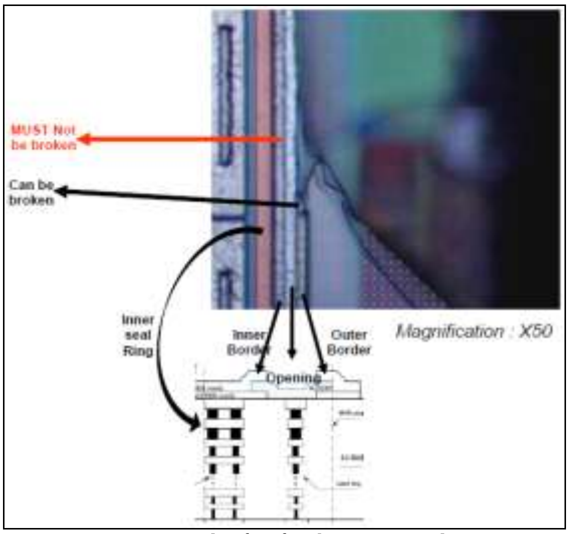


Fig. 9. Example of wafer chipping or peeling.

D. 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.

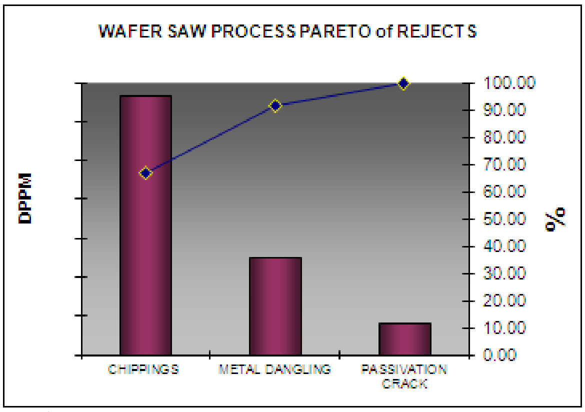


Fig. 10. Pareto diagram of rejects showing the top contributor (actual DPPM values intentionally not shown).

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.

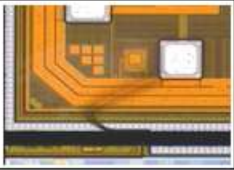
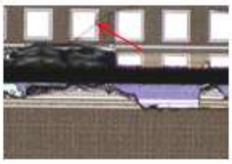
CRITICAL RISKS	DEFECT MECHANISMS	CRITERIA	REMARKS
Frontside Chippings / Peeling		NOT ALLOWED	FAILED
Metal Dangling		NOT ALLOWED	FAILED
Passivation Cracks		NOT ALLOWED	FAILED

Fig. 11. Top defect signature of critical risks.

E. *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.

II. Design of Experiments

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.

2x2x2 Factorial
Design 2x2x2 Factorial
Screening
Model

Columns (7/0)
Pattern
Frequency *
Power *
Feed Speed *
Passivation Cracks *
Chippings *
Metal Dangling *

	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 [12], 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.

III. 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.

	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.

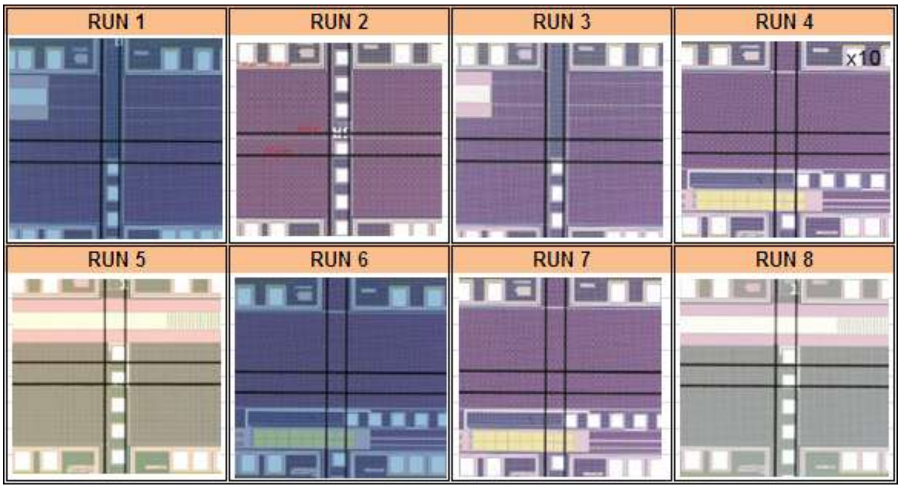


Fig. 14. DOE representative photo per run.

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.

A. 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.

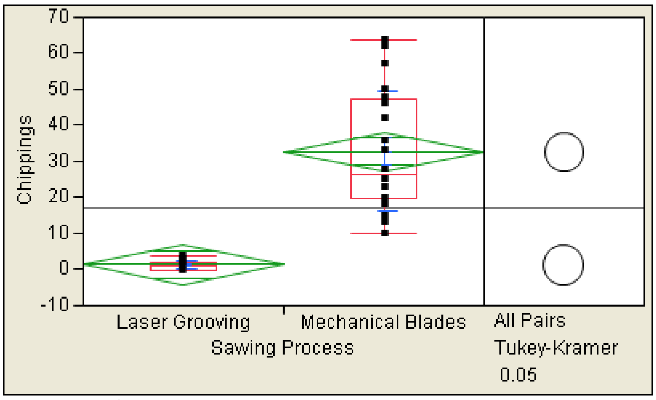


Fig. 15. Analysis of variance (ANOVA) between laser grooving and mechanical blades.

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B. 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 I shows that 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.

TABLE I. 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

C. 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 II.

TABLE II. 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

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.

D. 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.

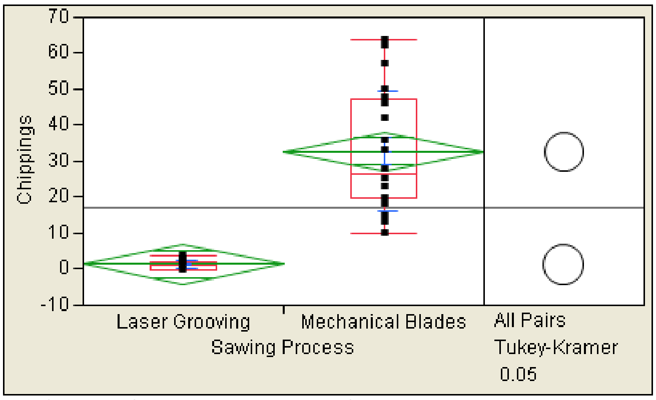

Fig. 16. Identified risks trend before and after the implementation of laser grooving (actual DPPM values intentionally not shown).

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.

E. 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 III 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.

TABLE III. 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

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IV. CONCLUSION AND RECOMMENDATIONS

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 highly recommended that the assembly manufacturing processes observe proper ESD controls. Opportunities presented in [13], [14] are useful to help ensure ESD check and controls. Continuous improvement is important for sustaining the quality excellence of any product and of the semiconductor manufacturing plant.

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REFERENCES

[1] Doering R, Nishi Y., Handbook of semiconductor manufacturing technology, 2nd ed., CRC Press, USA, July 2007.
[2] May GS, Spanos CJ., Fundamentals of semiconductor manufacturing and process control, 1st ed., Wiley-IEEE Press, USA, May 2006.
[3] Geng H., Semiconductor manufacturing handbook, 1st ed., McGraw-Hill Education, USA, May 2005.
[4] Sumagpang A, Gomez FR. "Line stressing critical processes optimization of scalable package passive device for successful production ramp-up," *Journal of Engineering Research and Reports*, vol. 3, issue 1, December 2018.
[5] DISCO Corporation, Electroformed bond hub blades – high performance hub blades that take on the challenges of cutting. https://www.disco.co.jp/eg/products/catalog/pdf/nbczh.pdf.
[6] DISCO Corporation, Fully automatic dicing saw – advanced performance for 300mm dicing. https://www.disco.co.jp/eg/products/catalog/pdf/dfd6361.pdf.
[7] Jovic S, Radovic A, Sarkocevic Z, Petkovic D, Alizamir M., "Estimation of the laser cutting operating cost by support vector regression methodology," *Applied Physics A*, Springer, vol. 122, issue 9, pp. 798-803, September 2016.
[8] Ji L, Yan Y, Bao Y, Jiang Y., "Laser crack-free cutting technique for thick and dense ceramics," *2009 Conference on Lasers & Electro Optics & The Pacific Rim Conference on Lasers and Electro-Optics*, Shanghai, China, August 2009.
[9] Tsukada Y, Kobayashi K, Nishimura H., "Trend of semiconductor packaging, high density and low cost," *4th International Symposium on Electronic Materials and Packaging*, Taiwan, December 2002.
[10] Sumagpang A, Adrales F, Manuel, LJ., "Laser grooving: A breakthrough and ultimate solution on various wafer sawing defects," Presented at the 24th ASEMEP Technical Symposium, Manila, Philippines; June 2014.
[11] Liu Y, Irving S, Luk T, Kinzer D., "Trends of power electronic packaging and modeling," *10th Electronics Packaging Technology Conference*, Singapore; December 2008.
[12] SAS Institute Inc. JMP statistical discovery software. https://www.jmp.com/en_ph/software.html
[13] Gomez FR, Mangaoang T., "Elimination of ESD events and optimizing waterjet deflash process for reduction of leakage current failures on QFN-mr leadframe devices," *Journal of Electrical Engineering, David Publishing Co*., vol. 6, no. 4, pp. 238-243, July 2018.
[14] Gomez FR., "Improvement on leakage current performance of semiconductor IC packages by eliminating ESD events," *Asian Journal of Engineering and Technology*, vol. 6, no. 5, October 2018.