DEVELOPMENT AND CHALLENGES OF HIGH FEED SPEED WAFER DICING PROCESS FOR SILICON WAFERS

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ABSTRACT

Progress in wafer dicing technology is driven by endless demand of consumers for high-volume, high-performance devices to cope with the fast-growing market for modern technologies. Hence, innovations that improve quality, reliability, and productivity without trade-offs are critical to meet these demands. With the advancement of technology over the years on materials – blade, tape, wafers – the team explored the possibility of solving a wafer chip-out issue through high feed speed optimization towards improved product reliability and productivity.

In this study, a new set of blade and machine parameters were defined capable of high feed speed process (i.e., > 100 mm/s). The new dicing parameters were able to eliminate a recurring triangular chip-out issue and improve back chipping Cpk from 1.26 to 1.76, while increasing overall capacity by 11.9%. Several learnings are also shared in the study such as disparity of chipping performance based on cutting sequence, saw dust accumulation, and increased blade wear out because of high feed speed which are typically overlooked on process optimization.

1. 0 INTRODUCTION

1.1 Die Preparation

Die preparation is a critical process in semiconductor assembly where the individual dies in a wafer are separated in preparation for succeeding processes (i.e., die attach, pick and place). With continuous development and high demand of semiconductor devices for modern technologies, there is a continuous need for faster processing time while maintaining high quality of the singulated dies[1]. Several singulation technologies have been developed over the years to meet a wide array of requirements such as laser dicing, stealth dicing, laser grooving and plasma dicing. However, wafer saw dicing remains as the most cost-effective method due to its simplicity and cheap processing costs[2]. In this method, wafers are mechanically sawn using a diamond grit blade rotating at high speeds.

Wafer dicing also has its limitations. Due to its mechanical nature, wafer dicing produces chip-outs on the edge of the dies. These chip-outs, which manifest along the front and back side of the die, can damage the active circuitry of the die or affect die integrity as they can serve as stress concentrators during assembly. Such effects can impact yield, quality, and reliability of the final product. Therefore, chip-out size typically serves as the primary quality indicator for wafer dicing and controlled through process optimization.

1.2 Wafer Dicing: Dichotomy of Speed and Quality

General wafer dicing knowledge states that quality and throughput are inversely correlated. Throughput is primarily affected by feed speed which is the speed the wafer approaches the dicing blade during cutting. The faster the feed speed, the shorter the processing time but the chipping is larger and vice versa.

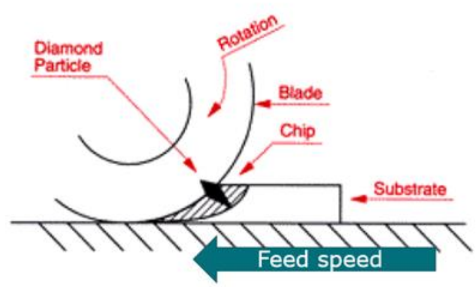

Fig. 1. Blade cutting mechanism. Diamond grit cuts through the wafer as wafer approaches the spinning blade. Feed speed defines throughput.

Fig. 1 shows the mechanism of feed speed during cutting. At higher feed speed, larger chip-outs occurs as the blade tends to collide with the wafer instead of cutting through. This affects blade and cutting surface integrity. Clark et al.[1] pointed out that a trade-off must be made to balance the needs of production while maintaining quality requirements of the product.
However, with the advancement technology on the materials – blade, tape, wafers – the team explored the possibility of solving a chip-out issue through high feed speed optimization as well as increasing capacity.

1.3 Triangular Chip Issue

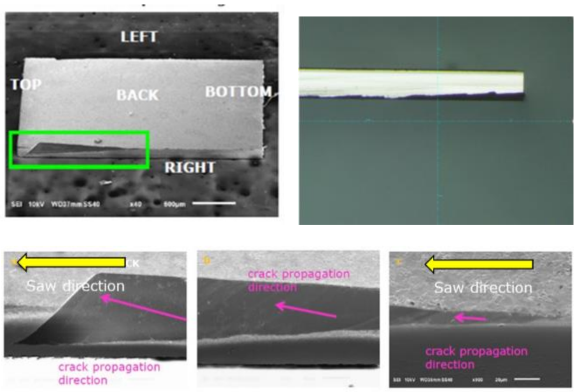

Fig. 2. Triangular chip-out signature. Chip-out located at ST1 and ST3 locations along the second cut for DMAN wafers as the blade exits the die.

One recurring issue noted in central die preparation for LFPAK wafers is the triangular chip-out signature located at ST1 and ST3 locations of the die after cutting. Failure mechanism shows that a chip propagates parallel to the edge during the second cut as the blades exit the die as shown in Fig 3.

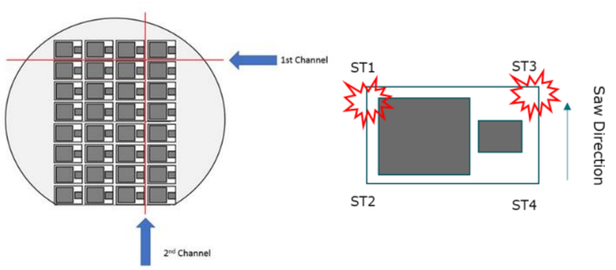

Fig. 3. Triangular chip-out mechanism. A chip-out flakes off during the 2nd cut as the blade exits the die.

Although chip-out sizes are within specifications (i.e. <50% die thickness), the triangular chip-outs were observed as the primary contributor for the biggest chip-out readings and are potential risks as crack initiators. Typical signature of chip-outs is of the "mouse bite" appearance which appears as semi-circular notches along the edges. The triangular chip-out signature is of higher risk than the mouse bites due to the size and shape as explained by fracture mechanics. Optimizations on existing blade and speeds (i.e. <60 mm/s) show no significant impact on eliminating the signature.

In this paper, the team proposed a solution to eliminate the triangular chip-out signature and to improve chipping performance through high feed speed dicing which is contrary to common knowledge. Challenges and new learnings because of high-speed process were also shared.

2. 0 REVIEW OF RELATED WORK

Several studies explore and optimize wafer dicing process across different wafer thickness. In the study of Shi, Liu, and Chen[3], max chipping width was minimized by including cooling water flow and shower water flow on optimization. Water flow keeps the blade cool and the die surface clean during cutting. On other studies, optimal cutting parameters were typically achieved through blade replacement. Clark, Brown and Evans[1] suggest back chipping issues be solved by either slowing down the feed speed or using different blades for surface and backside cutting through step cut. Luo, Li, and Lao[4] resolved chipping issues from aluminum pads on the saw street effectively by replacing the blade. By selecting an appropriate blade, process windows for the cutting parameters can be expanded resulting to better yield and capacity.

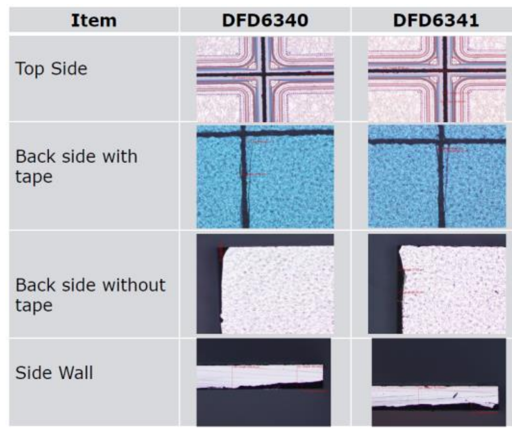

Fig. 4. Test cut using two machines using the ATSN site parameters. Parameters: ZHZZ-CA, 1.66d x 4.16d mm/s, and 0.78c RPM. Observe the triangular chip issue along ST1 and ST3 locations. Please check Appendix

Limited literature explores the potential of high feed speed >100 mm/s for chipping optimization. All studies reviewed shown optimizations limit their feed speed within the standard values of 20-60 mm/s for the selected blades. Observations were a consequence of old dicing blade technologies with softer bond materials that cannot cater >100 mm/s feed speed and the pre-existing notion of quality issues on high feed speed[1]. Only reference is the wafer saw parameters used in ATSN site which uses (d+40) x (d+190) mm/s and 0.78c RPM (See Table 1-2). Review and test cut using the same set of parameters and blade yield the same issue of triangular chip-out as seen in Fig. 4. The team established the feasibility of high feed speed process but will require optimization to eliminate the existing chip-out issue.

3.0 METHODOLOGY

DMAIC approach was adapted to select the best set of parameters for high feed speed processing.

3.1 Define

3.1.1 Scope and Objective

The main objective of the study is to define a new set of high feed speed parameters with good chip-out performance.

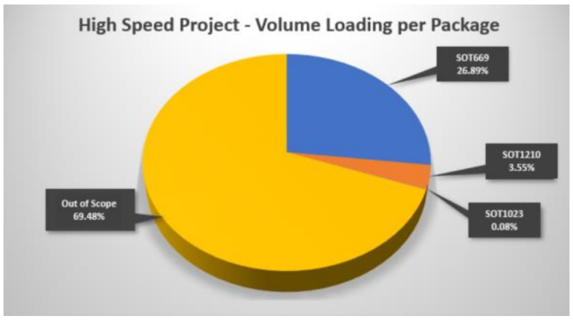

Fig. 5. Volume distribution of wafers affected by high feed speed project. Packages affected include all DMAN wafers under LFPAK line except SOT1205. Data based on 2021 volume projections per package.

Project scope was identified for all Clipbonded packages using DMAN wafers except for SOT1205. This scope covers ~30% of volume based on 2021 loading as seen in Fig 5.

3.1.2 Materials and Equipment

Based on learnings and capability of existing process, a change of blade is required to be capable of high feed speed process. Table 1 shows the selected candidates for high feed speed process based on assessment.

Table 1. Comparison of blade recommendations

		ZH05-BA blade	ZHZZ-CA blade	ZHZZ-CB/BB blade	Remarks
Thickness	lower	0.015 mm	0.015 mm	0.020 mm	Industry values for A and B thickness
	upper	0.020 mm	0.020 mm	0.025 mm	
Exposure	lower	0.510 mm	0.640 mm	0.510 / 0.640 mm	Industry values for C and B exposure
	upper	0.640 mm	0.760 mm	0.640 / 0.760 mm	
Bond Type		Normal	Hard	Hard	
Grit Size		a*	a	1.14a	Finer grit size for ZHZZ-CB/BB blade compared to baseline
Concentration		b*	b	0.55b	Lower concentration for ZHZZ-CB/BB compared to baseline
Remarks		Production / Baseline	ATSN blade	Recommendation	

* Baseline values with reference to production: grit size = a, concentration = b, spindle speed = c, feed speed = d.

Key change is the transition from normal to hard bond dicing blade. Harder bonds allow the blade to withstand faster feed rate without breaking. ZH05-BA is the existing production blade running at standard feed speed (see Table 2). ZHZZ-CA is the high feed speed blade used for ATSN site while ZHZZ-BB and ZHZZ-CB blades were shortlisted as high feed speed candidates based on learnings on back chipping improvement[5].

All evaluations were performed on Disco DFD6340 / 6341 machines for the sawing process. Saw quality metrics were measured by in-line machine measuring tool for kerf width and Hisomet high magnification scope for chipping size. Project scope was limited to Si wafers with thickness of 150-200 um and backside metallization.

3.2 Measure

3.2.1 Baseline Metrics

Baseline parameters and metrics were identified in Table 2. Capacity was identified as main metric for productivity due to the expected increase in feed speed. Kerf width and chipping size (i.e., front, back, lateral) were identified as metrics to quantify saw quality. Of the three chipping measurables, back chip and lateral were identified as potential source of improvement.

Table 2. Baseline Parameters and Metrics

Parameters	ATCB existing (Baseline)	ATSN Existing (Reference)
Dicing Blade	ZH05-BA	ZHZZ-CA
Spindle Speed (rpm)	c	0.78c
Feed Speed (mm/s)	d x d	(d+40) x (d+190)
Metrics	**Baseline**	
Capacity	344 kpd*	[redacted]
Backside Chip Cpk	1.26**	[redacted]
Lateral Chip Cpk	2.3**	[redacted]

*Per Machine capacity (DFD6000 series).

*Baseline values with reference to production: grit size = a, concentration = b, spindle speed = c, feed speed = d.

**Based on package project scope (See fig. 5)

3.2.2 Measurement System Analysis on Saw Quality Metrics

Gauge R&R characterization were conducted on the measuring tools used for kerf width and chipping size measurements to validate accuracy and precision of the data. Kerf width is measured in production using the in-line measuring tool on sawing machines. For the GR&R, three different blade thickness were identified and sawn on a wafer to serve as parts. As shown in Fig. 6, kerf width passed GR&R with 8.27% total gauge R&R. Chipping size is measured using an external high magnification measuring scope (i.e., hisomet) using 50x magnification. Dice are manually picked from sawn wafers and placed on the scope for measurement. For the GR&R, ten different dice with specific chip-outs were prepared for measurement. As shown in Fig. 7, chipping size passed GR&R with 3.01% total gage R&R.

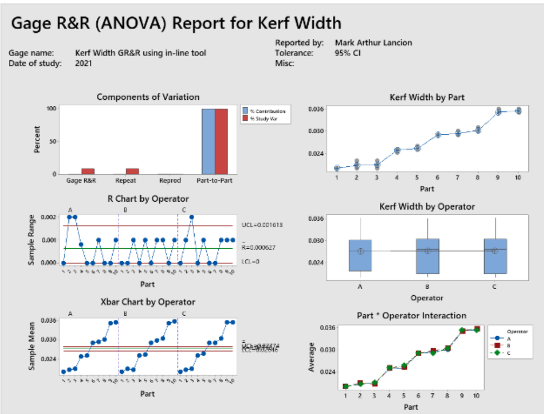

Fig. 6. Gauge R&R results for Kerf Width. Total GRR = 8.27%. Repeatability at 8.27% while reproducibility at 0.00%. Number of distinct categories at 16.

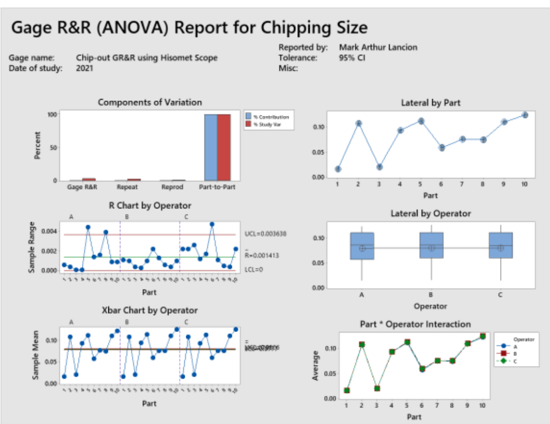

Fig. 7. Gauge R&R results for chipping size. Total GRR = 3.01%. Repeatability at 2.76% while reproducibility at 1.22%. Number of distinct categories at 46.

3.3 Analyze

Ishikawa Diagram and Cause & Effect Matrix was utilized to identify all critical variables affecting adhesive strength. Each variable was then scored and ranked according to its criticality and occurrence of related to FMEA scoring.

3.4 Improve

The project was divided into three (3) phases based on learnings and challenges. Matrix for phase 1 and phase 2 are shown in Table 3. Thirty readings were taken on each quality metric for comparison.

(1) For phase 1, DOE was conducted on ATSN blade (ZHZZ-CA) with feed speed and spindle revolution as factors to find optimal parameters for wafer saw.

(2) Based on learning on ZHZZ-CA optimization, additional legs were run on phase 2 by changing the tape and by using ZHZZ-BB blade.

Based on learning on phase 2, ZHZZ-BB and ZHZZ-CB (longer exposure) performance were compared using the same parameters identified at phase 2.

Table 3. DOE Matrix for Phase 1 and 2.

StdOrder	Tape	Blade	Blade Height	Feed Speed 1st Cut (CH2) mm/s	Feed Speed 2nd Cut (CH1) mm/s	Spindle RPM
10	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d + 140	0.67c
9	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d + 90	0.88c
8	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d + 90	0.78c
4	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d + 40	0.67c
1	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d - 10	0.67c
2	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d - 10	0.78c
6	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d + 40	0.88c
3	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d - 10	0.88c
7	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d + 90	0.67c
5	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d + 40	0.78c
12	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d + 140	0.88c
11	Nitto SWT10+R	ZHZZ-CA	0.050 mm	d + 140	d + 140	0.78c
13	Adwill D-175	ZHZZ-CA	0.065 mm	d + 140	d + 40	0.88c
14	Nitto ELP WS-02T	ZHZZ-CA	0.063 mm	d + 140	d + 40	0.88c
15	Nitto SWT10+R	ZHZZ-BB	0.050 mm	d + 140	d + 40	c
16	Adwill D-175	ZHZZ-BB	0.065 mm	d + 140	d + 40	c
CTRL1	Nitto SWT10+R	ZH05-BA	0.050 mm	d	d	c
CTRL2	Adwill D-175	ZH05-BA	0.065 mm	d	d	c

[a] Phase 1: Leg 1-12
[b] Phase 2: Leg 13-14 using UV tapes while Leg 15-16 use ZHZZ-BB
*Baseline values with reference to production: grit size = a, concentration = b, spindle speed = c, feed speed = d.

4.0 RESULTS AND DISCUSSION

4.1 Identification of Critical Parameters

Critical parameters were identified during team assessment. Figure 8 shows all the factors that affect output saw quality. Factors were then screened using the C&E matrix based on the degree of effect on chipping size.

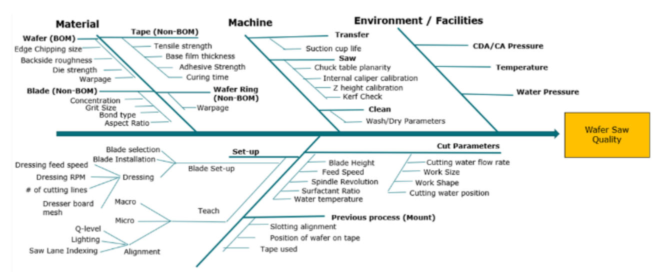

Fig. 8. Ishikawa Diagram of wafer dicing. Feed speed is pre - determined as experimental factor. All other variables were considered to optimize at high feed speed. See appendix 10.1 for larger image

As shown in Fig. 9, dicing blade is identified as critical since it is the cutting tool in direct contact with the wafer. Feed speed and spindle revolution are also critical since the machine parameters directly control the mechanical movement of the blade.

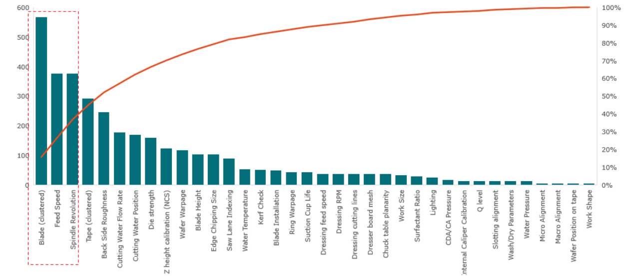

Fig. 9. Pareto of Critical Factors for high feed speed wafer saw. Scoring based on C&E matrix and then re-arranged based on priority. Top 3 factors considered for high-speed optimization are the blade, feed speed and spindle speed. See appendix 10.2 for larger image.

4.2 Challenge #1: Limitations of ZHZZ-CA blade

Parameter optimizations on legs 1-12 were performed for ZHZZ-CA, benchmarked high speed blade, to eliminate the triangular chip-out signature for phase 1. However, all legs still exhibit the same signature and have worse performance compared to control legs (see: Fig. 12).

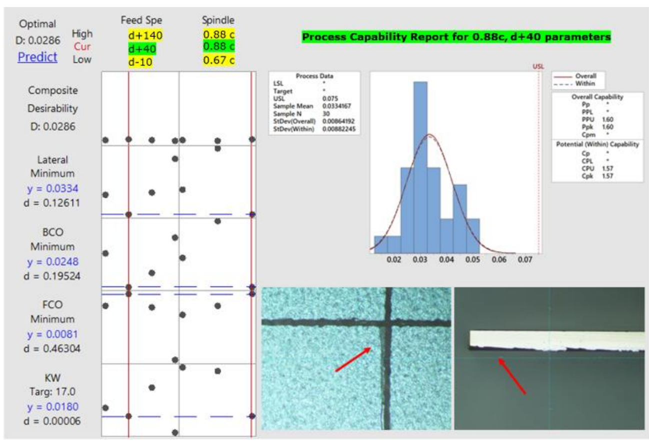

Fig. 10. Optimal setting for ZHZZ-CA based on response optimizer using 3.33d x 1.66d mm/s feed speed. Even on optimal setting, triangular chip-out still observed but with reduced size. Observed jagged edges which has risk to become crack initiators. See Appendix 10.3 for larger image

As shown on Fig. 10, (d+140) x (d+40) mm/s with high spindle revolution were identified as optimal settings for ZHZZ-CA. By increasing the spindle revolution, the cutting rate of the blade is increased which improves the cutting performance. Also, chip-out performance for the first cut and second cut were observed to be significantly different which was attributed to stability as shown on Fig. 11. Based on this learning, high feed speed can be applied on first cut (i.e., d+140 mm/s) without issue while optimizing the speed for the second cut.

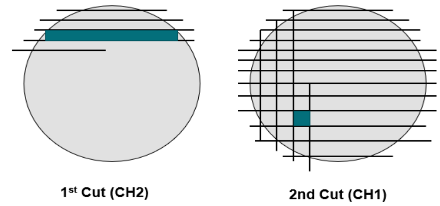

Fig. 11. Contact area of singulated wafer during cutting. Higher stability of die strip compared to singulated die due to larger contact area. This correlates to better chip performance at first cut than second cut.

Optimal parameters from phase 1 (based on response optimizer) were then benchmarked for phase 2 by changing the tape (leg 13-14) to increase stability and new blade (leg 15-16) as shown below on fig. 12.

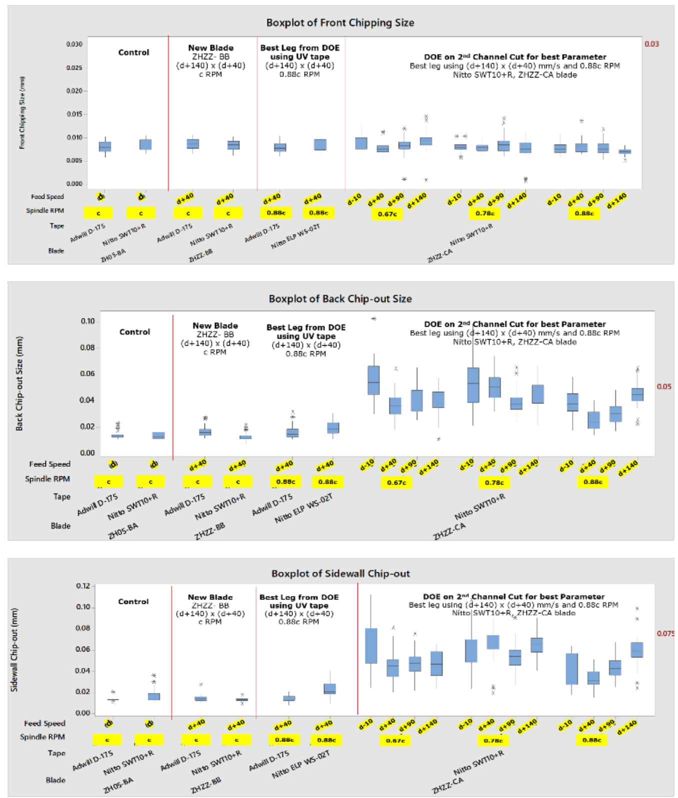

Fig. 12. Front side (top), back side (mid), and lateral chip-out (bottom) performance of ZHZZ-CA and ZHZZ-CB blades. Feed speed was varied for 2nd cut only; first cut feed speed is fixed at d+140 mm/s. See appendix for 10.4 for larger image

Significant improvement back side and sidewall chip-out size by using UV tapes due to a more rigid base film. However, best chipping quality was observed using ZHZZ-BB blade. Triangular chip-out signature was eliminated as shown on Fig. 13. Good chipping performance was attributed to higher blade thickness of ZHZZ-BB, finer grit size and lower grit concentration which contributes to the cutting ability and stability.

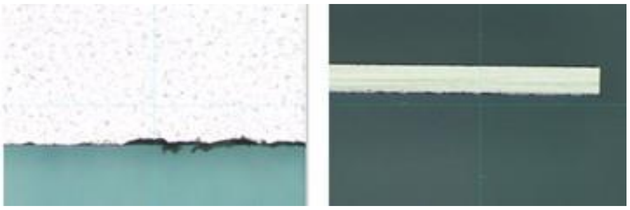

Fig. 13. Backside and lateral chip-out signature of ZHZZ-BB blade using (d+140) x (d+40) mm/s and c RPM. No triangular chip-out signature observed on all dies.

4.3 Challenge #2: Blade wear as a consequence of speed.

One issue that was not anticipated was the significant increase in wear out of the new blade and parameters compared to existing production parameters using ZH05-BA blade.

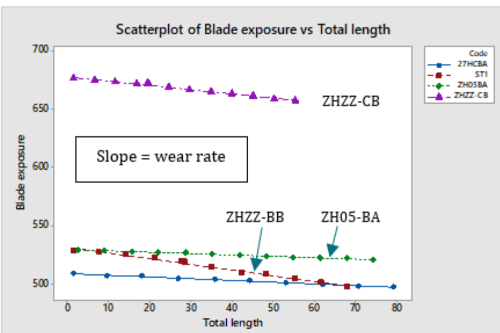

Fig. 14. Comparison of blade wear-out of ZHZZ-CB, ZHZZ-BB, and production blade parameters. ZHZZ-CB and ZHZZ-BB blade observed to have higher slope which corresponds to higher wear out.

Current ZH05-BA production blade parameters were estimated to have **0.1204 um / meter** wear out while ZHZZ-BB blade parameters were estimated to have **0.4891 um / meter** wear out based on log data analysis. These translate up to x4 blade consumption on the new blade. Initial assumption was that blade wear out will decrease due to the harder bond material and higher thickness. Instead, higher wear out was observed to increased blade stress due to high feed speed.

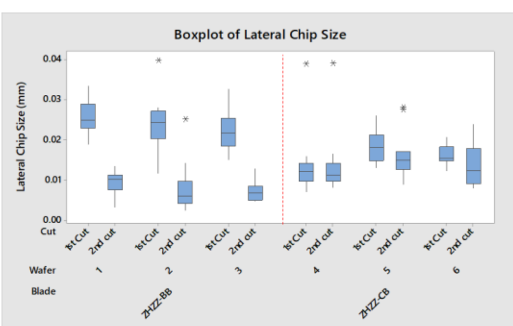

Fig. 15. Comparison of lateral chip-out performance of ZHZZ-BB and ZHZZ-CB. Average chipping performance noted to have no significant difference between the two blades.

To compensate for the higher blade consumption, new blade with same parameters as ZHZZ-BB but longer blade exposure was qualified (ZHZZ-CB). With the change, expected blade life is higher with an estimate of x2.3 increase in blade consumption. No significant difference on chip-out performance between ZHZZ-CB and ZHZZ-BB blade during validation as shown in Fig. 15.

4.4 Challenge #3: Saw dust accumulation as a consequence of speed.

During volume run validation of the ZHZZ-CB blade and its parameters, saw dust accumulation on die surface was observed during cutting and after wash on several machines. Saw quality is good but saw dust was not washed off even after wafer clean as seen on Fig 16.

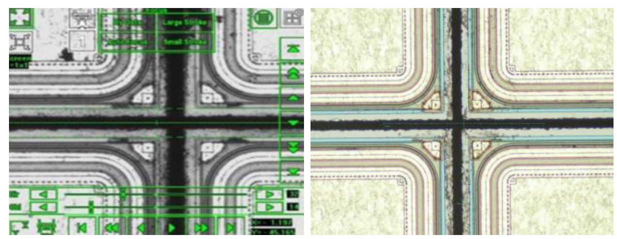

Fig. 16. Photos of saw dust accumulation on saw lane during cutting (left) and after clean (right). Saw dust appeared to have adhered on saw lane and wafer surface which can impact the electrical integrity of the die.

Due to increased feed speed, exposure time of the sawn surface to the cutting nozzle was reduced causing the buildup of saw dust. Based on analysis of affected machines, saw dust adherence along the saw lane and active are of the die was a consequence of low exhaust pressure on the cutting and washing modules of the machine. New parameters just aggravated an existing issue wherein the old parameters have slow enough speed that gives enough time to for the nozzle to wash off the excess saw dust. Issue did not re-occur after correction of the exhaust pressure.

4.5 Control Phase: Final parameters and Metric Comparison

New and final parameters as shown on Table 4 were used in volume production runs and time study to validate the results. Noted 11.9% overall improvement in wafer dicing capacity. Also, overall increase in backside (cpk = 1.76) and lateral chip-out capability (cpk = 4.34) due to elimination of triangular chip-out signature on project scope.

Estimated yearly savings is projected at $106,800. Although dicing blade consumption and price change increased (-$72k/yr), the capacity increase allowed shutdown of 5x old machines resulting to $92k facilities savings on facilities resource and freed up 8x operator resulting to $46.8k salary savings. DFPC cost improvement projected at $40k/yr while quality cost savings from potential customer issue avoidance is still not accounted.

To maintain all learnings and findings, all new parameters were documented and set-up for affected machines. FMEA was also updated to include all learnings during the optimization.

Table 4. Comparison of Parameters and Metrics

Parameters	Baseline	New
Dicing Blade	ZH05-BA	ZHZZ-CC
Spindle Speed	c RPM	c RPM
Feed Speed	d x d mm/s	(d+140) x (d+40)
Parameters	**Baseline**	**New**
Capacity	344 kpd[a]	385 kpd[a] 11.9% Capacity Increase 46% UPH increase
Backside Chip Cpk	1.26[b]	1.76
Lateral Cpk	2.3[b]	4.34
Impact	**Savings**	**Remarks**
Dicing blade consumables	$ (72000) / yr	• Change in blade price and consumption
Energy Conservation (5x machine shutdown)	$ 92000 / yr	• Machine shutdown of old machines. See appendix for computation
Estimated operator headcount Savings	$ 46800 / yr	• Freed up headcount based on 5x Enercon machines
Estimated DFPC cost improvement	$ 40000 / yr	• Based on processing time improvement and $0.02 per kpcs improvement • Based on H222 PCA volume
Estimated Savings	$106 800 / yr savings	

[a] Per Machine capacity (DFD6000 series)
[b] Based on package project scope (See fig. 5)

5.0 CONCLUSION

High feed speed wafer dicing parameters were successfully established to increase capacity by 11.9% and improve chipping performance of singulated dice. The change in dicing blade was critical in order to be capable of high feed speed process and to eliminate the triangular chip-out signature. Several challenges / learnings were also observed:

(1) First cut has better chipping performance vs second cut due to higher contact area and stability on dicing tape.
(2) Increasing the feed speed significantly increases blade wear out resulting to higher blade consumption / shorter blade life.
(3) Saw dust accumulation is a consequence of high feed speed process due to decreased wash off time. Any existing issue on nozzle configuration, flow rate or exhaust pressure are aggravated by high feed speed.

6.0 RECOMMENDATIONS

With the success of the high feed speed implementation for DMAN wafers, we also recommend doing fan-out studies on other wafer types from other fab sites using the learnings from this study.

7.0 ACKNOWLEDGMENT

The team would like to thank Aswafi Bin Abdul Aziz and Jing Alabin, and the whole CDP group for their valuable contributions.

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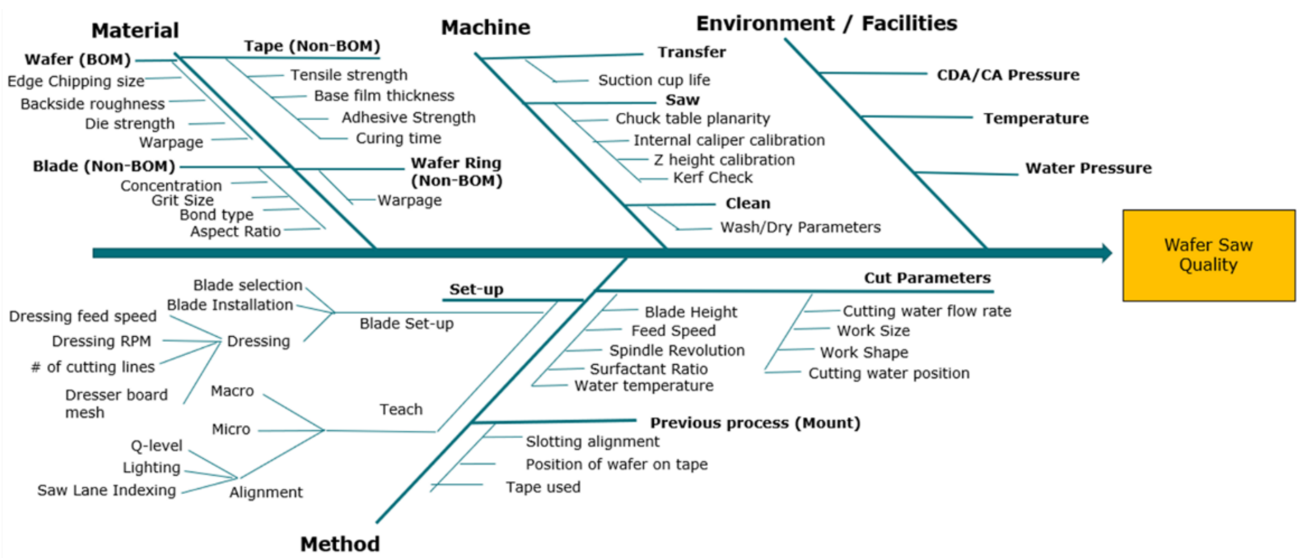
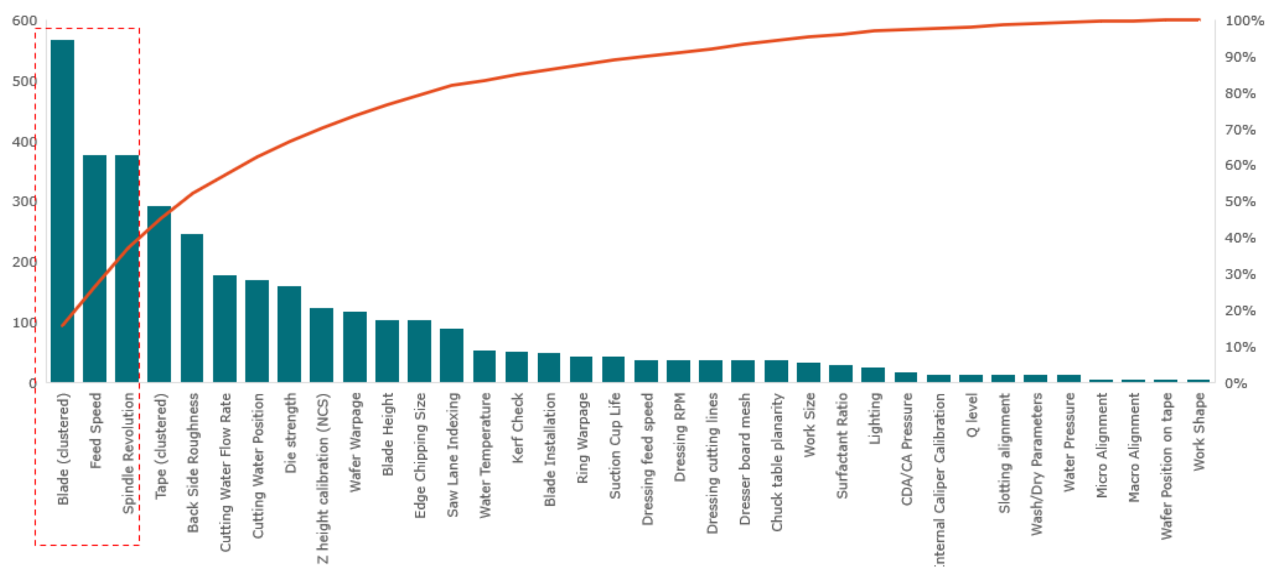
10.0 APPENDIX

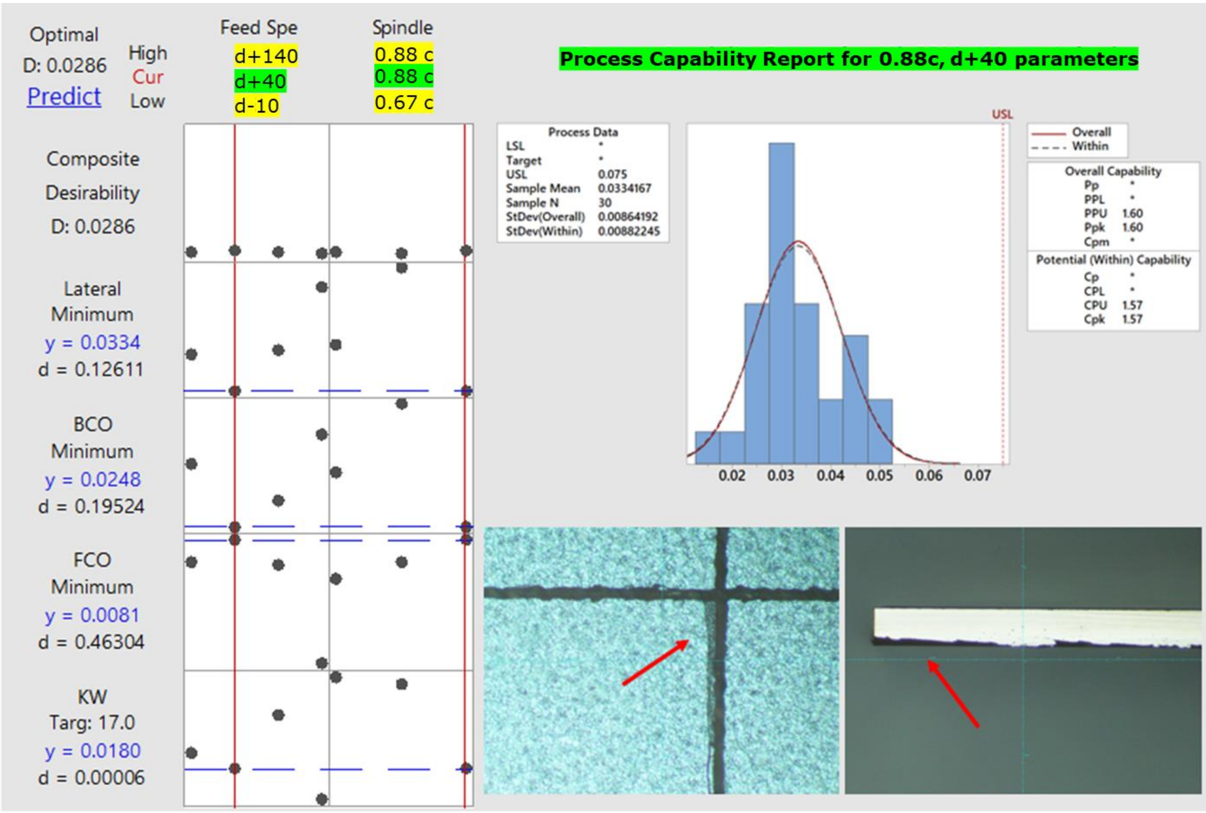
10.1 Ishikawa Diagram



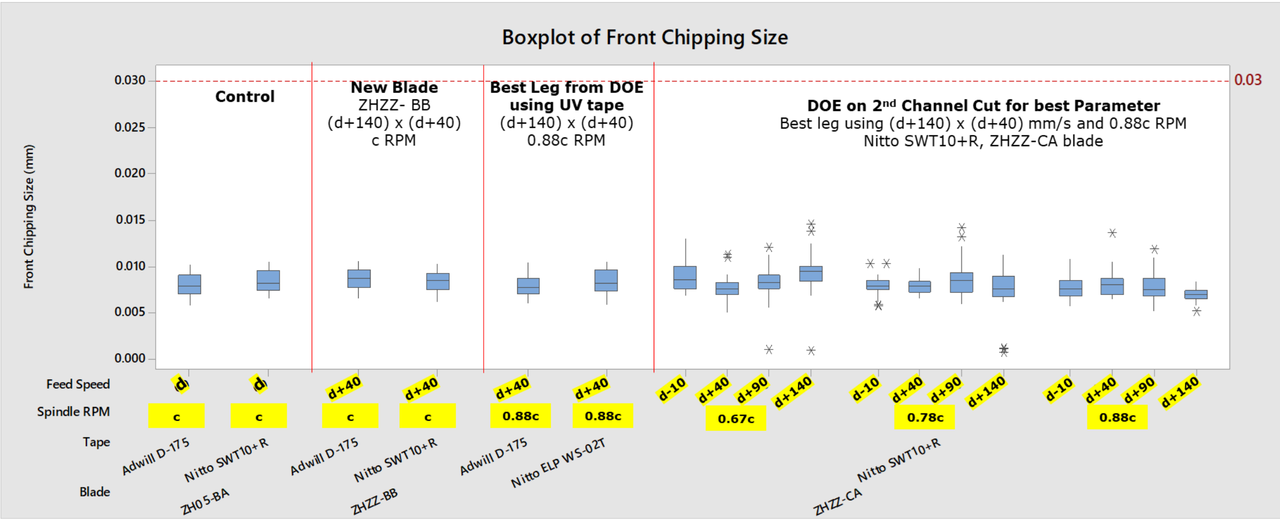
10.2 Cause & Effect Matrix

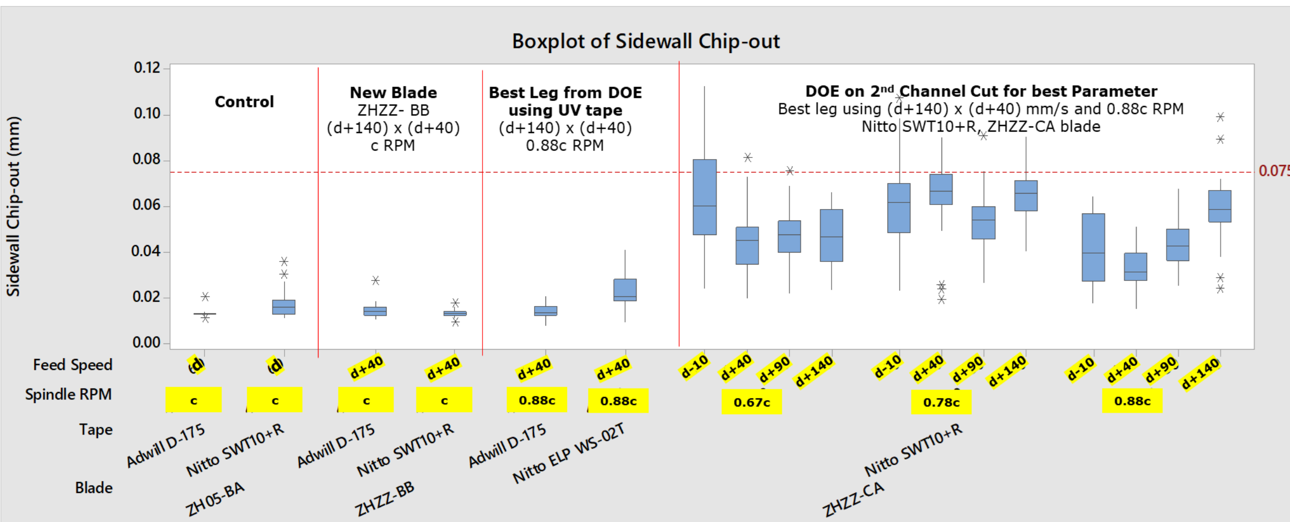


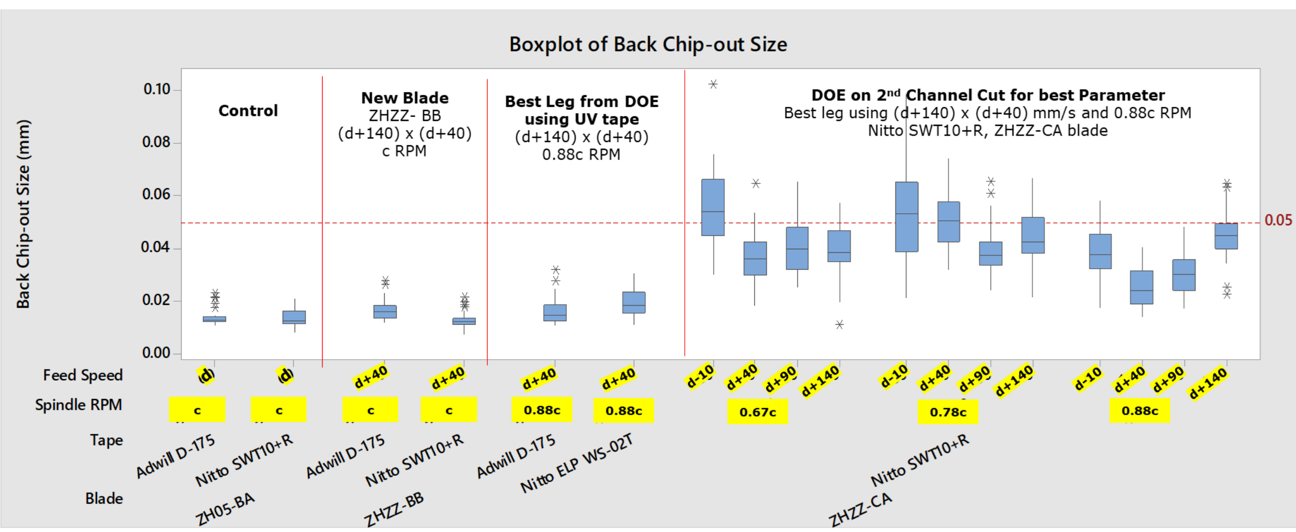
10.4 Response Optimizer (Fig. 10)



10.3 Chipping Performance Comparison (Fig. 12)







10.4 The Team


PASSION
PERSEVERANCE
PERFORMANCE
Our attitude to obstacles, agility with purpose, our ability to innovate through challenges.
values