Enhancing Unit Per Hour (UPH) for XDFN 1x1 PCC Wire Devices via DOE Methodology

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ABSTRACT

Degradation of UPH (Unit Per Hour) is one of the consequential effects when Au (Gold) wire is converted to PCC (Palladium Coated Copper) wire at wire bond process. The result of the degradation impacted the decrease in capacity that causes the WIP (Work in Process) to build up at wire bond and increased the lot cycle time due to constraint in capacity.

The cost savings initiative at Tarlac last 2023 involved the conversion of all 1x1 XDFN (xtremely Small Dual Flat No Leads) Au devices (highest loading) to PCC, cost savings wise the project is effective in comparison with Au price versus PCC price but the effect on UPH was not scope causing capacity loss due to UPH degradation. 30% UPH degradation became the challenge for the PCC wire conversion.

This paper discusses the improvement action done to improve the UPH of PCC wires. Parameter baselining, Low, Mid, High parameter validation, DOE run are used to further understand how to improve the UPH for 1x1 XDFN devices.

Furthermore, this paper explains how UPH for 1x1 XDFN devices was improvement using different validation run and parameter experimentation to decrease the bond time by achieving a comparable result on the Existing parameter (low UPH).

1. 0 INTRODUCTION

In wire bonding process, one of the most fundamental materials with a high significant cost is the Au wire. Au is the most used wire at wire bond to interconnect the die to substrate with proven quality and reliability results.

Wire conversion is one of the most critical improvement processes at wire bonding, Au (Gold) to PCC wire conversion is very cost effective in terms of cost savings but consequential effect comes to follow when UPH degradation observed when Au wire is converted to PCC wires.

When Au wire is converted to PCC one of the challenges is to achieve a comparable result compared to Au wire in terms of intermetallic, ball shear strength, manufacturability, and reliability. To achieve this, bond time was increased, and additional Step bond are added to the wire bond parameters to achieve reliability passing results. Increasing the bond time on 1st bond, 2nd bond and added additional step on the bump bond is the safest method to implement the PCC with a passing reliability result without considering the UPH degradation.

This project analyzed, evaluated, and validated the wire bond performance when bond time on 1st bond and 2nd bond is decreased and reduced the step bond on the bump. Learning from Existing PCC wire performance will be compared on the proposed PCC wire parameters. Improvement on the bond time for 1st bond and 2nd bond using the existing parameters range for Force and Power but added additional scrub to achieve a comparable result versus the existing parameter and reduced the step bond of bump parameter from 3step bond to 2 step bond.

2. 0 REVIEW OF RELATED WORK

This Study did not used any reference form a previous study; thus, this section is Not Applicable for the study

3.0 METHODOLOGY

This Project is conducted on High end NeoCu wire bond machine using Design of Experiment method to fully understand on how to enhance the wire bond parameter to improve the UPH at wire bonding for 1x1 XDFN PCC devices with a comparable result on the existing PCC wire parameter. Parameter Baselining, Data gathering, mean test analysis to compare the existing versus the proposed parameter, and series of Low, Mid, High validation run.

3.1 1st Bond Parameter Experiment

Using the Existing Parameter with bond time decrementing by 1ms, added scrub parameter to improve the bonding and check the non-sticking failure rate as baseline, this is to validate what is the maximum speed (bond time) that can be achieved without any quality issue and compare the ball shear performance of the existing parameter versus the proposed parameter. Please refer to Table 1.

Bond Time(ms)	Scrub Cyle	Ball on leads Nonsticking(Fall out)
10	2	-
9	2	-
8	2	-
7	2	-
6	2	-
5	2	-
4	2	-
3	2	-

Table 1. Bond Time Parameter versus Ball on Leads Non-Sticking Fail rate (50 units per condition).

3.2 2nd Bond Parameter Experiment

Same method as the 1st bond parameter validation using the Existing Parameter with bond time decrementing by 1ms, added scrub parameter to improve the bonding and check the non-sticking failure rate as baseline, this is to validate what is the maximum speed (bond time) that can be achieved without any quality issue. Compared the ball shear performance of the existing parameter versus the proposed parameter. Please refer to Table 2.

Bond Time(ms)	Scrub Cyle	2nd bond Non sticking(Fall out)
10	1	-
9	1	-
8	1	-
7	1	-
6	1	-
5	1	-
4	1	-
3	1	-

Table 2. Bond Time Parameter versus 2nd bond Non-Sticking Fail rate. (50 units per condition).

3.3 Bump Parameter Experiment

Reduced the Step bond from 3 step bonding(20ms) to 2 step bonding(10ms).
Performed Parameter baseline. Please refer to Table 3. And performed full factorial DOE on the bump refer to Table 4. for the DOE plan. Sample Size on the DOE plan is 160 units per leg.

Parameter	Lower Limit	Upper Limit
Pre Us Power	200	300
Det. Threshold	80	100
Bond Force 2	80	110
US power 2	370	410

Table 3. Parameter baseline

Pattern	Pre US Power	Det. Threshold	Bond Force 2	US Power 2	X	Y	Z	BST	WPT	Bump Peel Off
----	200	80	80	370						
---+	200	80	80	410						
--+-	200	80	110	370						
--++	200	80	110	410						
-+--	200	100	80	370						
-+-+	200	100	80	410						
-++-	200	100	110	370						
-+++	200	100	110	410						
0	250	90	95	390						
+---	300	80	80	370						
+--+	300	80	80	410						
+-+-	300	80	110	370						
+-++	300	80	110	410						
++--	300	100	80	370						
++-+	300	100	80	410						
+++-	300	100	110	370						
++++	300	100	110	410						

Table 4. DOE plan for Bump parameter. (BST= Ball Shear Test, WPT= Wire Pull Test)

3.4 Low, Mid and High parameter Experiment

Perform comparison of Low, Mid, and high parameter versus the existing parameter in terms of Wire pull, Ball Shear, SEM Profile, Intermetallic Coverage test, Pad crack test and % PMD.

4.0 RESULTS AND DISCUSSION

4.1 1st Bond Parameter Experiment Results

As per results, the fastest bond time at 5ms shows no anomaly in terms of ball non sticking issue refer to Table 5. Lower than 5ms, ball non sticking is evident showing degrading results.

Bond Time(ms)	Scrub Cyle	Ball on leads Nonsticking(Fall out)
10	2	50/50
9	2	50/50
8	2	50/50
7	2	50/50
6	2	50/50
5	2	50/50
4	2	38/50
3	2	26/50

Table 5. Bond Time Parameter versus Ball on Leads Non-Sticking Fail rate results (50 units per condition).

Comparing the Ball shear performance of existing bond time(10ms) and the proposed bond time(5ms). Extreme Speed parameter shows a lower ball shear reading compared to existing but still above the specs limit, referring to Figure 1. for the comparison results.

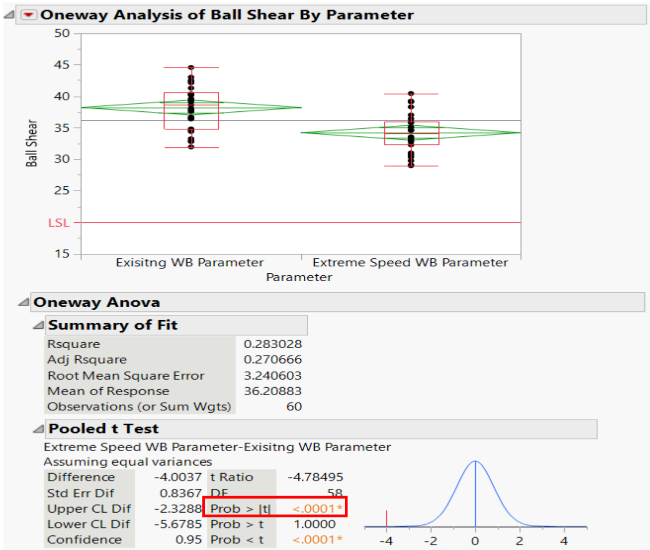

Figure 1. t test comparison of Existing bond time parameter versus the speed up 1st bond time parameter

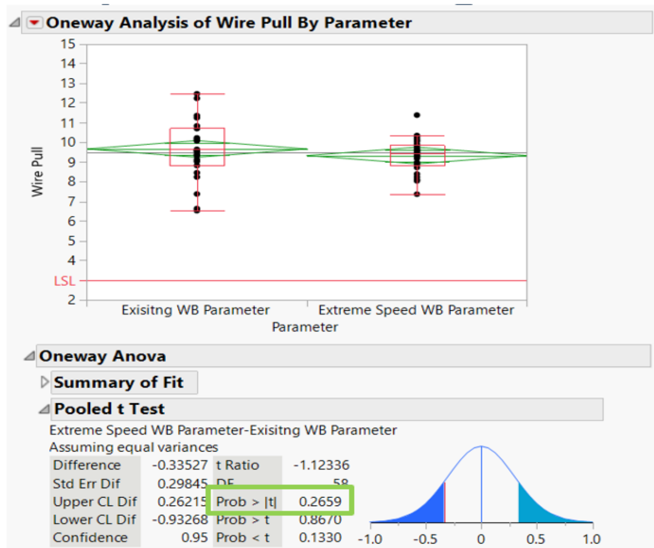

Figure 2. T test comparison of Existing bond time parameter versus the speed up 2nd bond time parameter.

4.2 2nd Bond Parameter Experiment Results

As per results, the fastest bond time at 5ms shows no anomaly in terms of 2nd bond non sticking issue refer to Table 6. Lower than 5ms 2nd bond non sticking is evident showing degrading results same.

Bond Time(ms)	Scrub Cyle	2nd bond Non sticking(Fall out)
10	1	50/50
9	1	50/50
8	1	50/50
7	1	50/50
6	1	50/50
5	1	50/50
4	1	45/50
3	1	37/50

Table 6. Bond Time Parameter versus 2nd bond Non-Sticking Fail rate results (50 units per condition).

Comparing the Wire pull performance of existing bond time(10ms) and the proposed bond time(5ms). Extreme Speed parameter shows no significant difference in wire pull reading compared to existing, referring to Figure 2. for the comparison results.

4.3 Bump Parameter Experiment Results

Bump parameter DOE leg run completed with data shown in Table 7. Including the prediction profiler with the highest desirability of .76 shown in Figure 3.

Pattern	Pre US Power	Det. Threshold	Bond Force 2	US Power 2	X	Y	Z	BST	WPT	Bump Peel Off
----	200	80	80	370	58	60	11	36.11	8.79	0
---+	200	80	80	410	59	59	11	35.55	8.66	0
--+-	200	80	110	370	62	63	9	40.63	8.72	0
--++	200	80	110	410	61	63	9	41.75	8.81	0
-+--	200	100	80	370	59	60	11	37.39	8.48	1
-+-+	200	100	80	410	59	61	10	39.39	8.84	4
-++-	200	100	110	370	61	63	9	40.47	8.43	0
-+++	200	100	110	410	62	63	10	38.44	8.95	0
0	250	90	95	390	59	61	10	40.44	8.70	0
+---	300	80	80	370	59	58	12	33.49	8.82	0
+--+	300	80	80	410	58	59	11	35.67	8.86	0
+-+-	300	80	110	370	60	61	10	40.32	8.65	0
+-++	300	80	110	410	61	63	8	39.73	8.42	0
++--	300	100	80	370	59	61	11	37.71	8.84	0
++-+	300	100	80	410	59	60	11	37.89	8.76	0
+++-	300	100	110	370	61	62	10	41.21	8.60	0
++++	300	100	110	410	61	62	10	43.31	8.31	0

Table 7. DOE plan results for bump parameter

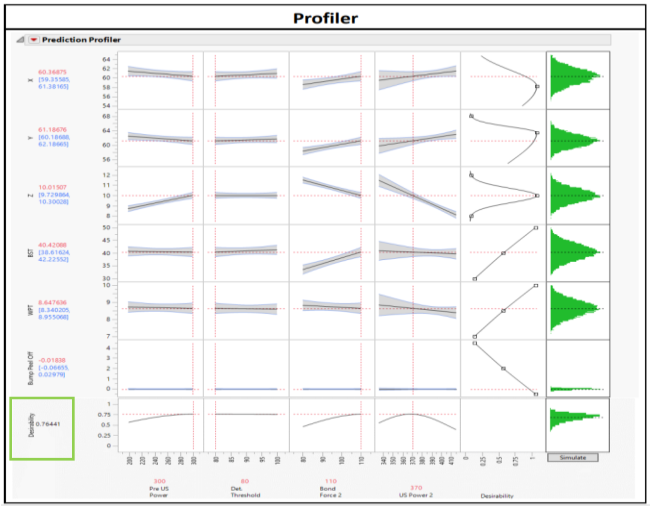

Figure 3. Prediction profiler with desirability value

Contour Profile showing the low and high parameter to be used on the low, mid, and high validation at Figure 4 and Figure 5.

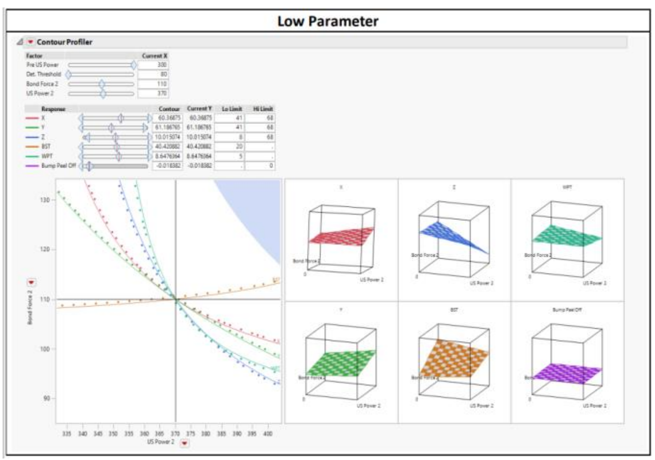

Figure 4. Contour profiler for Low parameter.

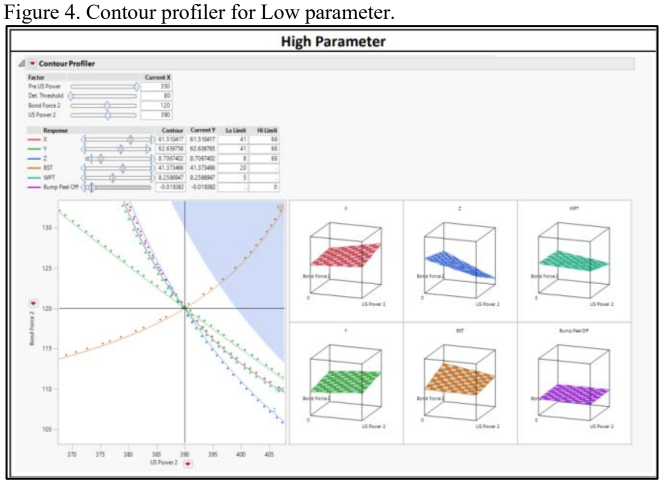

Figure 5. Contour profiler for High parameter.

Summary of parameters is shown at Table 8. To use during the Low, Mid and High validation.

4.4 Low, Mid and High parameter Experiment Results

All conditions (LMH) Passed the Wire Pull requirement of >5gf refer to Figure 6. for the Wire pull results and Table 8. For the break mode with passing results (Ball Neck). All conditions also passed the Cpk requirement of >1.67 Cpk refer to Figure 7.

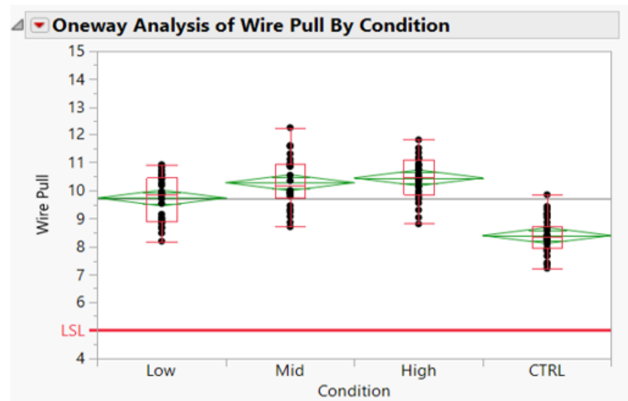

Figure 6. Wire pull results for Low, Mid, and high parameter validation.

Break Mode	Low	Mid	High	CTRL
1	0	0	0	0
2	30	30	30	30
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0

Table 8. Break Mode results.

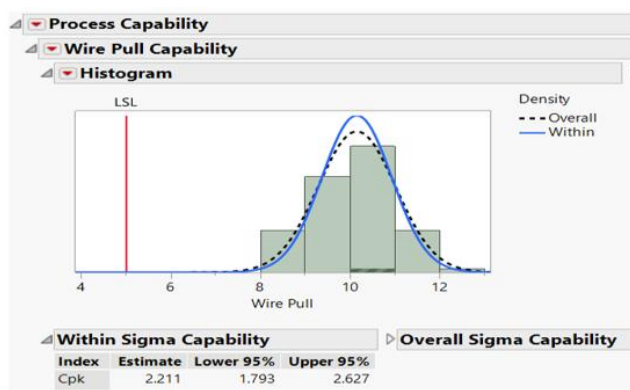

Figure 7. Cpk Results for Wire pull LMH validation.

All conditions (LMH) Passed the Ball Shear requirement of >20gf refer to Figure 8. for the Wire pull results and Table 9. For the break mode with passing results (With Al Trace). All conditions also passed the Cpk requirement of >1.67 Cpk refer to Figure 9.

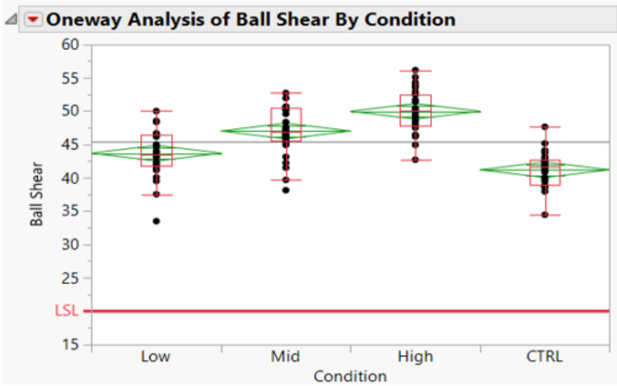

Figure 8. Ball Shear results for Low, Mid, and high parameter validation.

Break Mode	Low	Mid	High	CTRL
1	0	0	0	0
2	0	0	0	0
3	30	30	30	30
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0

Table 9. Break Mode results.

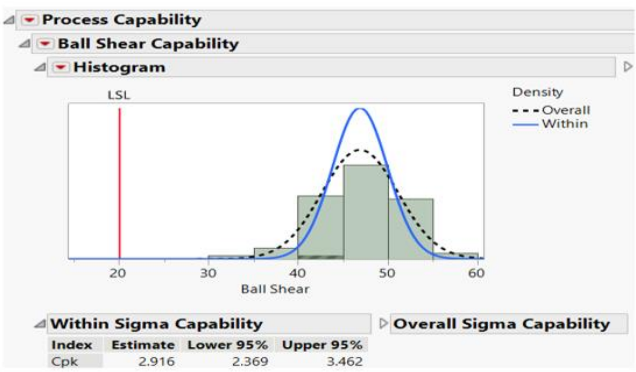

Figure 9. Cpk Results for Ball shear LMH validation.

Good Ball Profile and Stitch profile was observed in all Conditions as shown of Figure 10.

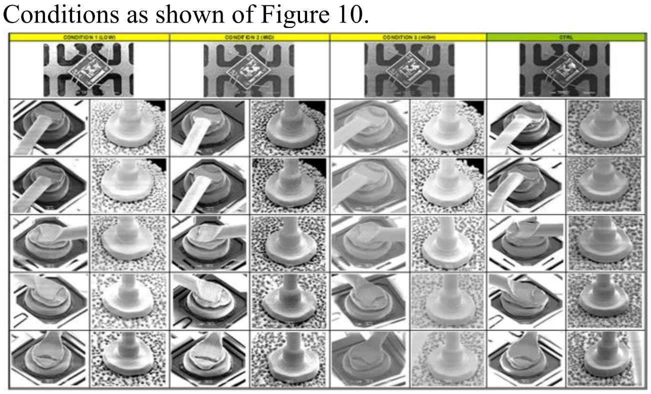

Figure 10. SEM profile off all conditions.

% PMDR, Pad Crack Test and IMC Passed all conditions. Refer to Figure 11 for the % PMD results, Figure 12. For the Pad crack test and Figure 13. For the IMC results.

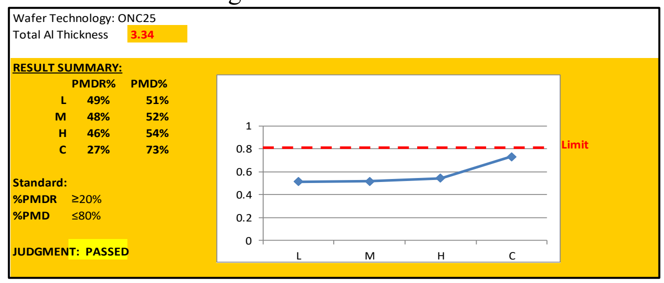

Figure 11. %PMD results of all conditions are passed.

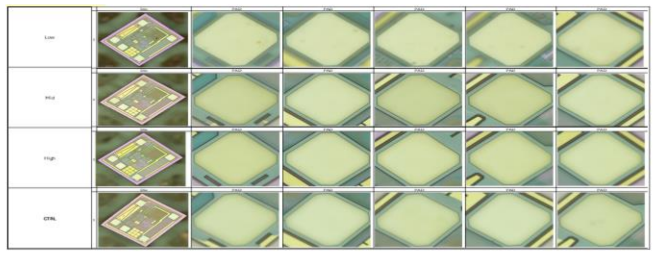

Figure 12. Pad Crack results of all conditions show no anomaly.

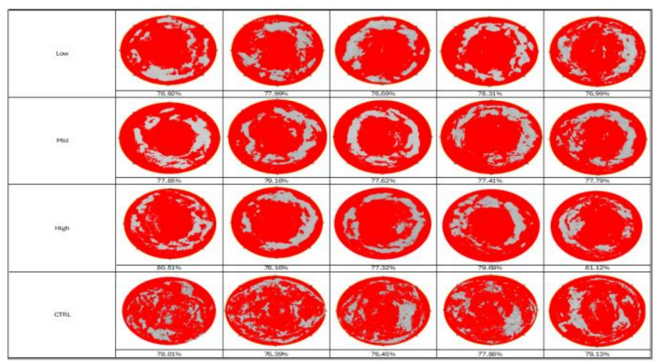

Figure 13. IMC results on all conditions are comparable with the control with passing results.

Reliability test results passed with no failure on all Rel test results. Refer to Table 10. For the Reliability summary results.

Qualification Results and Analysis:

Test	Name	Test Conditions	End Point Req's	Test Results	(rej/ss)	(rej/ss)	(rej/ss)	(rej/ss)
				Read Point	Lot A	Lot B	Lot C	Lot D
Prep	Sample preparation and initial part testing	various	---	Initial Electrical	done	done	done	done
HTSL	High Temp Storage Life	150°C for 1008 hours	c = 0, Room	504 hrs	0/77	0/77	0/77	0/77
				1008 hrs	0/77	0/77	0/77	0/77
PC	MSL1 Preconditioning	3 IR @ 260 deg C	c = 0, Room	Post MSL	0/231	0/231	0/231	0/231
TC-PC	Temp Cycle + Preconditioning	-65/+150 C	c = 0, Room	Post PC Electrical	0/77	0/77	0/77	0/77
				500 cyc	0/77	0/77	0/77	0/77
				1000 cyc	0/77	0/77	0/77	0/77
HAST-PC	Highly Accelerated Stress Test + Preconditioning	TA= +130°C, RH = 85%, PSIG= 18.8, bias	c = 0, Room	Post PC Electrical	0/77	0/77	0/77	0/77
				96 hrs	0/77	0/77	0/77	0/77
				192 hrs	0/77	0/77	0/77	0/77
UHAST-PC	Unbiased Highly Accelerated Stress Test + Preconditioning	Temp= +130°C RH=85% p = 18.8 psig unbiased	c = 0, Room	Post PC Electrical	0/77	0/77	0/77	0/77
				96 hrs	0/77	0/77	0/77	0/77
SAT	Scanning Acoustic Tomography	Compare for Delamination before and after PC	Compare to existing data	PRE MSL	0/22	0/22	0/22	0/22
				POST MSL	0/22	0/22	0/22	0/22
DPA	Destructive Physical Analysis	Following PC + 500cyc TC	AEC Q101 - 004	Results	0/2	0/2	0/2	0/2
CDPA WP	Custom Destructive Physical Analysis – Wire Pull	Following PC + 1000cyc TC	MIL 883E	Results	0/6	0/6	0/6	0/6
CDPA BS	Custom Destructive Physical Analysis – Ball Shear	Following PC + 1000cyc TC	AEC -006	Results	0/3	0/3	0/3	0/3
CDPA X Section	Custom Destructive Physical Analysis – X section	Following PC + 1000cyc TC	AEC -006	Results	0/2	0/2	0/2	0/2
DPA	Destructive Physical Analysis	Following PC + 96h HAST	AEC Q101 - 004	Results	0/2	0/2	0/2	0/2
WBP	Wire Bond Pull	Cond C.	Min Cpk 1.67	Results [1]	0/30	0/30	0/30	0/30

Table 10. RMS#88314 Reliability test results passed.

After the Implementation of the improved wire bond parameters, significant improvement on UPH was observed. Safe launch lots shows UPH improvement above 40% compared to the current UPH of PCC. Refer to Figure 14. on the UPH results.

QFN Wire Bond

- NCP170 at UTC5000 – SKW-WB-00517/527/512/545/530/515
  - Average Actual UPH of 3,376.
  - Improved by ~41%
  - Safelaunch Lot Validation

WW	Date	Package	Device	Machine ID	Machine Model	Wire Type	Actual UPH	IE UPH	Delta	# of validation	Engg/Tech	Remarks
WW37	9/13/2024	XFN	NCP170AMX120TCG	SKW-WB-00517	UTC5000	PCC	3,366	2386	41.05%	1st validation	Majhed	Safelaunch Validation
WW37	9/13/2024	XFN	NCP170AMX120TCG	SKW-WB-00527	UTC5000	PCC	3,344	2386	40.16%	2nd Validation	Majhed	Safelaunch Validation
WW37	9/13/2024	XFN	NCP170AMX120TCG	SKW-WB-00512	UTC5000	PCC	3,335	2386	39.77%	3rd Validation	Majhed	Safelaunch Validation
WW37	9/13/2024	XFN	NCP170AMX120TCG	SKW-WB-00545	UTC5000	PCC	3,397	2386	42.36%	4th Validation	Majhed	Safelaunch Validation
WW38	9/18/2024	XFN	NCP170AMX120TCG	SKW-WB-00545	UTC5000	PCC	3,429	2386	43.72%	5th Validation	Majhed	Safelaunch Validation
WW38	9/18/2024	XFN	NCP170BMX190TCG	SKW-WB-00530	UTC5000	PCC	3,348	2386	40.30%	6th Validation	Majhed	Safelaunch Validation
WW38	9/18/2024	XFN	NCP170AMX120TCG	SKW-WB-00515	UTC5000	PCC	3,416	2386	43.18%	7th Validation	Majhed	Safelaunch Validation
							3,376		41.51%			

Figure 13. UPH validation results after the implementation of the speed up parameter achieved 40% improvement.

Correlating the yield performance of the affected device after the implementation of the speed up parameters shows that the yield performance of the improved parameter is comparable to the existing parameter. Refer to Figure 14.

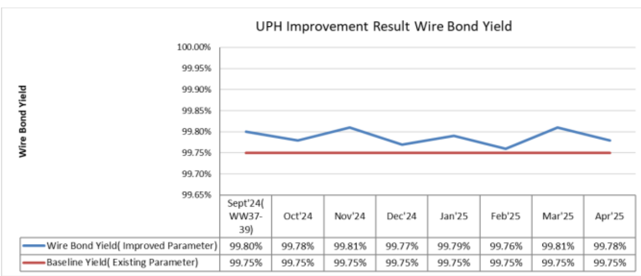

Figure 14. Wire bond Yield results of the Improved wire bond parameter versus the existing wire bond parameter

Achieved 52k USD cost saving for the month April 2025. Highest cost savings attainability is for the month of Oct'2024 of 72K USD Table 11.

	Actual Savings							
	Sept'24(WW37-39)	Oct'24	Nov'24	Dec'24	Jan'25	Feb'25	Mar'25	Apr'25
Loading	3307027	15338684	14222168	7361682	14504058	5542004	7545193	11200226
Cost Savings/unit	0.00469472	0.00469472	0.004695	0.004695	0.004695	0.004695	0.004695	0.004695
Cost savings(USD)	15526	72011	66769	34561	68092	26018	35423	52582

Table 11. Monthly Actual cost savings of the UPH improvement at wire bond.

5.0 CONCLUSION

The Previous section showed that UPH for 1x1 PCC devices was significantly improved by thorough analysis, validation and experimentation, reducing the bond time to 5ms for both 1st bond and 2nd bond and reducing the step bond on the bump bond in combination with DOE is very effective in improving the UPH for the PCC device.

6.0 RECOMMENDATIONS

To study a new plasma parameter to even improve the bond ability results, with this recommendation we can reduce even further the scrub cycle on the 1st bond and 2nd bond and reduce the step bond on the bump bond from 2 step to single standard step bond.

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7.0 ACKNOWLEDGMENT

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Chester Aquino- QFN Process Engineer Manager
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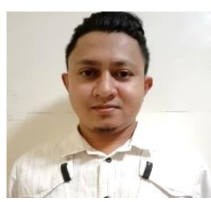
8.0 REFERENCES

1. LSS Training Material- Lean Six Sigma Pocket Tool Book Michael L. George, David Rowlands, Mark Price, and John Maxey.

9.0 ABOUT THE AUTHORS



Majhed Quismundo is a B.S. Electronics Communication Engineering graduate of Saint Louis University Baguio 2013 with more than 10 years of experience in Wire bonding process. Started his career at QFN assembly as Equipment Technician at wire bond, through his initiative and dedication on the process, he achieved many process improvement in many categories (Quality, Cost and Delivery) one of these projects is the UPH improvement, now he is the Senior process Engineer at wire bond process.

10.0 APPENDIX

This paper did not use the appendix section. All figures, tables and charts are already incorporated in the main sections of this paper.