International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Probond Approach a Key to Minimizing the Effects of Bond Pad Anomaly

Ernani Padilla[1], Conrado Villanueva[2]
[1, 2]Back-End Manufacturing & Technology, STMicroelectronics, Inc., Calamba City, Laguna, Philippines 4027

Abstract— *Wirebonding integrity is always a challenge in assembly manufacturing as sudden changes on wafer fabrication wherein no visual manifestation is detectable but results to a high rejection of non-stick on pad. Identifying the rootcause and communicating what needs to be corrected on the wafers requires a thorough analysis and validation. As it would take time to correct the problem, delivery of products must still be sustained and breakthrough solution to mitigate the effect of bond pad anomaly is essential.*

This technical paper went through a lot of extensive characterization to arrive at the rootcause of low palladium plating thickness of the bond pad through correlation. Collaboration with wafer fab was done to arrive at the optimum thickness that will yield good wirebond response. Probond feature of existing wirebond machine was utilized while wafer fab improvements is underway.

Keywords— *Probond for Fab defects.*

I. INTRODUCTION

The quad flat no leads – multi row, QFN-mr package is one of the new generation package from ST that uses a tape less lead frame and utilizing BIPOLAR-CMOS-DMOS, BCD wafer technology with NiPd die pad structure. By design this package will have more I/O at smaller footprint & thinner package thickness and more complex wire bonding. To further add to the complexity, it uses copper wire to have unit cost leverage.

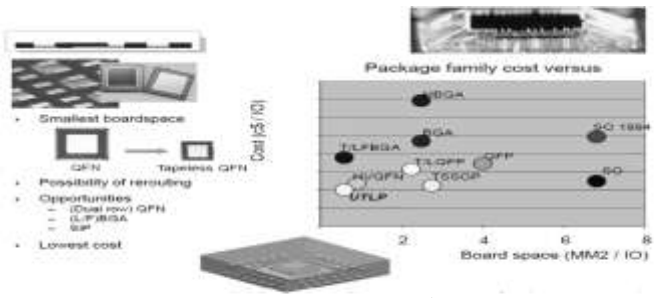


Figure. 1 Tapeless QFN visual and package family vs. cost graph

With Cu wire bonding the most significant concern is a poor quality bond being made, since the process window is made considerably smaller due to the less favorable properties of copper. Studies have shown that the most prevalent defects is ball lift.

The process window is considerably smaller with copper due to its higher hardness and oxidation tendencies. If too little energy is used, the risk is a bond with inadequate bonding area that can will either be detected at time zero or worst fail early in the field. To consistently hit a tight process window one needs a thorough optimization process that ensures bond parameters near optimum are found.

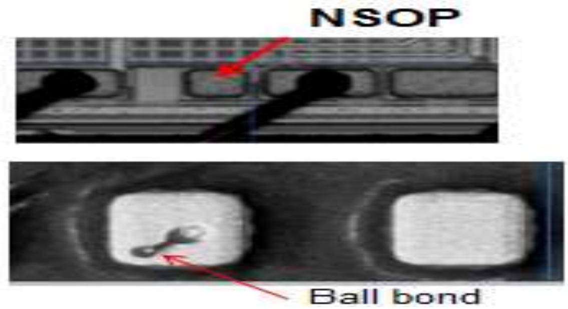


Figure 2. Ball bond unable to stick on pad during bonding

Following this, one needs to ensure that all the critical variables are well controlled during manufacturing but for this study we will be concentrating on the effects of bond pad plating thickness as a consistent and solid support under the bond pad is required for transfer of the thermosonic energy to the bond surface. This scrubbing energy is what allows the displacement of surface oxides and films that then allows metal-to-metal welding.

Widely used approach in optimizing is to perform design of experiment, DOE for first bond parameters force, power and time. However for this case even at high settings lifted ball is still encountered. For extreme cases of bonding pads a different approach is necessary, this paper we will be using the probond technique in reducing lifted ball caused by bond

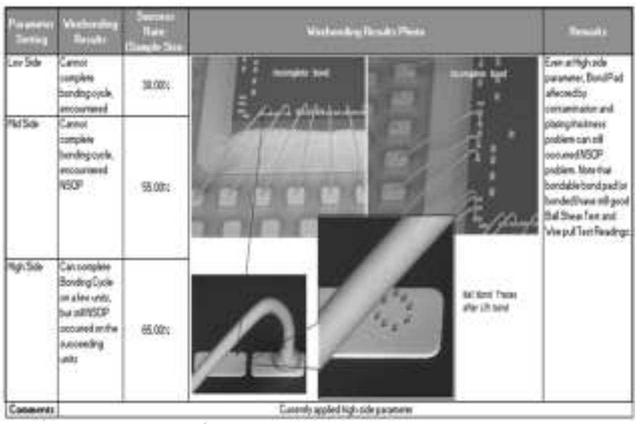


Figure 3. 1st bond parameter design of experiment

1.1 Copper Wirebond Performance

QFN-mR assembly yield performance is not meeting its target mainly due to the high level of lifted ball or non-stick on pad, NSOP has the highest contributor at 38%.

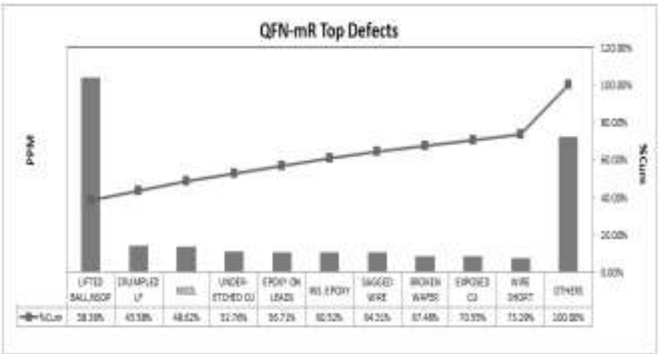


Figure 4. QFN-mR top defect pareto

1.2 *Ball Shear Comparison*

Comparison of good units and lifted ball units with respect to ball shear shows significant difference.

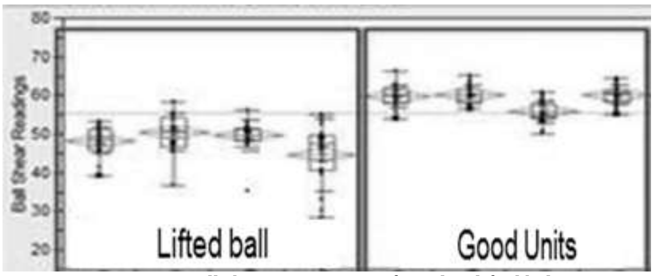


Figure 5. Ball shear comparison of good vs lifted bal

1.3 *Failure Analysis*

1.3.1 *Visual Inspection*

As per analysis of bond pad surface, there is no difference in the visual appearance between good units and with lifted ball under high magnification.

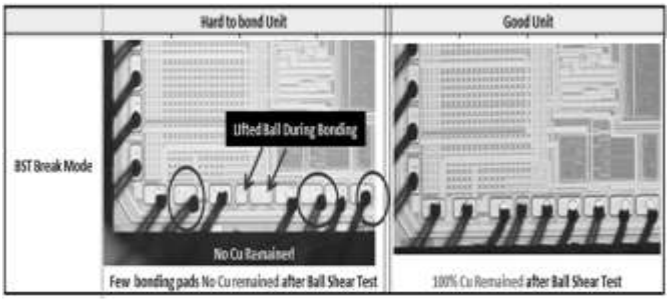


Figure 6. Visual comparison of good vs. lifted ball

1.3.2 *Pad analysis for contamination*

Pad analysis was also compared between bare die, bonded good and with lifted ball but did not reveal any difference.

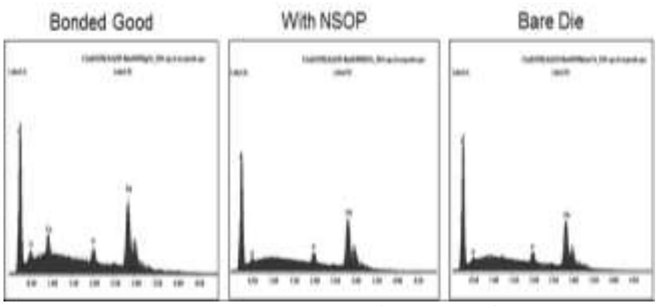


Figure 7. EDX comparison of bonding surface.

1.3.3 *Cross sectional analysis*

During cross sectional analysis of the good and high lifted ball units, it was observed that good units has passing Pd thickness of > 300nm specs while high lifted ball has below Pd thickness specs.

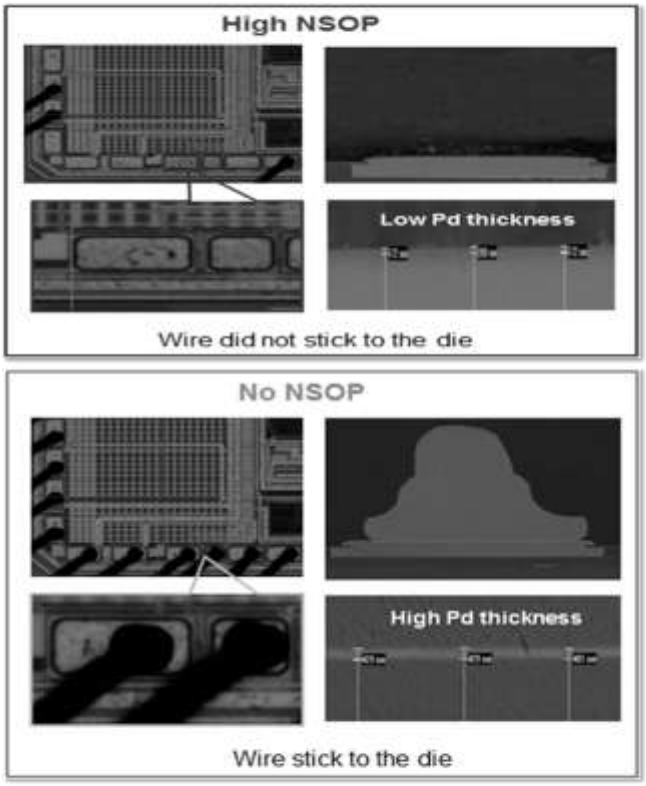


Figure 8. Cross section of good and lifted ball unit

II. Review of Related Literature

2.1 *Nickel Based Bond Pad for Copper Wirebonding*

High performance devices are increasingly relying on the low-k materials under the bond pads. Unfortunately, the 33% greater hardness of Cu compared to gold places even greater stress on these inherently fragile materials. This can result in difficulties with pad damage, and cratering of the underlying structures. Advancement have been made to copper wirebonders, tools and wire that have resolved many of these issues and made fine fitch copper wire bonding feasible.

Ni-based bond pads have emerged to solve the pad damage problem. Nickel is about 50% harder than copper and four times harder than aluminum so that it provides greater protection against the higher stress resulting from Cu ball bonding, as well as damage during probing. This is especially beneficial for devices with low-k active circuitry under the bond pad. Ni-Pd, Ni-PdAu and/or Ni Au have demonstrated their great robustness to receive the Cu wire bonding with a huge wire bonding window without any splash and with excellent reliability.

Electrolessly plated Ni-Pd and immersion plated Au has become an established technology in electronic component manufacturing. Recently it has become popular for wafer level, low cost flip-chip under the bump metal application because of its low cost, maskless deposition and compatibility with Cu and Al substrates. A rather new approach is an additional palladium intermediate layer between Nickel and gold or pure palladium as top metal layer. Acting as an additional protective barrier, the palladium significantly improves the bond pad stability, the corrosion resistance of the nickel And the stress impact of the metallization stack. The complete metal stack is more resistant to the metal diffusion during thermal processing steps. Especially the stress impact can be minimized as the individual metal layer can be thinned down without risking nickel corrosion. Palladium not only allows minimizing the thickness of the nickel layer from 5um to less than 3um, but also eliminates necessity of gold as bondable pad surface finish.

Table 1. Ni-Pd-Au surface finishes

Sample	Ni (µm)	Pd (µm)	Au (µm)
Al Ref	0	0	0
A	3	0.3	0.03
B	3	0.3	0
C	3	0.1	0.03
D	1	0.1	0
E	1	0.1	0.03
F	1	0.3	0.03
G	3	0.1	0
H	1	0.3	0

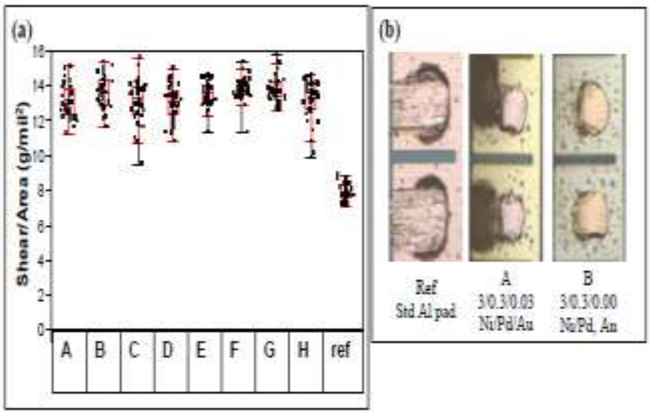


Figure 9. (a) Shear/Area for plating finishes in table 1 (b) optical images of the failure mode in shear test

Study shows that the shear/area response on all of the Ni/Pd/Au plated devices was essentially the same with average shear per area between 12 and 14 g/mil^2 each case. The shear/area values were about 6 g/mil^{2}higher than those on the Al reference pads. The shear failure mode was through the Cu ball in all cases on the Ni/Pd/Au pads, but failure at the Al-Cu interface for the Al reference device. Top-of-loop pull strengths were between 9 and 9.5 g on all devices, including the Al reference. All wires broke at the neck of the balls.

2.2 Probond parameter at wirebond

Probond is a wirebond approach for setting bonding parameters wherein the parameters are organized in segments that provide an intuitive time progression through the formation. It provides better flexibility in the application of USG, Force and scrubbing for ball formation.

Force segments provide USG and force for the defined time. Force and USG levels are constatnt through the segment if ramp parameters are inactive. If ramping is active, USG and force levels are ramped to as a percentage of the time parameter.

Scrub segments provide USG, force and cyclical scrubbing with optional USG and force ramping. Segment time is based on number of scrub cycles. Probond makes use of the latest alogrithms known as spiral. Spiral scrubbing geometries include ramping to improve the overall scrub geometry.

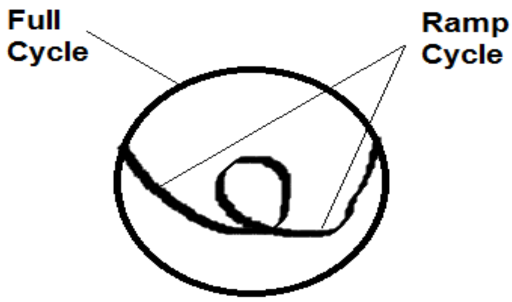


Figure 10. Probond scrub geometry

III. EXPERIMENTAL SECTION

The experimental will be covering to factors namely Pd thickness and probond approach at wirebond. First experiment is to statistically validate the correlation of Pd thickness to lifted ball occurrence. While for probond a DOE will be conducted to optimize the bond time by subjecting it to two segments.

Lifted ball occurrence and ball shear will be the primary concern for this experiment. Assembly quality characteristics such as wire pull, ball height, ball diameter and cratering will also be analyzed that can also be impacted by probond parameter.

3.1 Materials

For this experiment, existing WB machine which has probond capability will be utilized. Test vehicle will be device A which is affected by high lifted ball. Sample collection will be based from lifted ball lot ppm for the correlation while same diffusion will be used for the Probond DOE. All other materials and machines will be blocked.

3.2 Procedure

For the correlation, samples of lifted ball of different reject rate and reference good units will be collected. All units will be subject for cross sectioning of the bonding pad to measure the Pd thickness.

For Probond, full factorial designed was performed. The Responses are the NSOP to Minimize, Ball Shear to Match Target and Wire Pull to Maximize. Four factors have considered, Time Seg1, USG Seg2, Time Seg2 and Force Seg2.

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

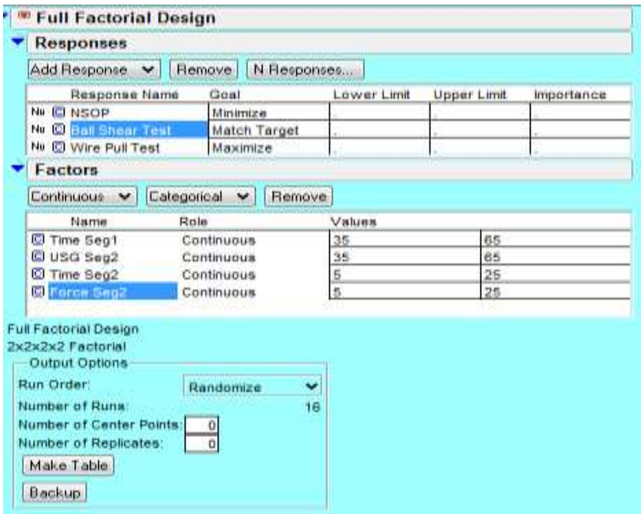


Figure 11. Full factorial design for Probond

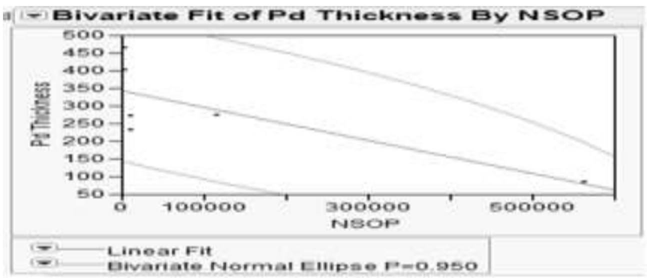
Generated parameter combinations or runs will be validated on the actual wire bonding. Output responses will compare and determine the target thru prediction profiler and its interaction effect. The parameter combination that meets the requirement will apply for small scale validation and followed by large scale validation thru line stressing as part of the evaluation.

From the results validation, will now determine the effectiveness of the parameters and its window. With the good results, Probond 1st bond parameter combination will be fan-out.

III. RESULTS AND DISCUSSION

3.1 Correlation of Pd Thickness and Lifted Ball

Based from the result of the correlation study with a correlation value of -0.78, there is a high negative correlation between Pd thickness and lifted ball rejection. As the Pd thickness is increased the lifted ball defect becomes lower.

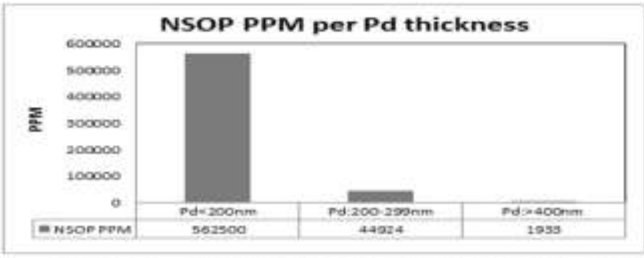


Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
NSOP	116856.3	222667.1	-0.78035	0.0671	18
Pd Thickness	288.85	133.3196			

Figure 12. Correlation plot between Pd thickness and lifted ball

Also based from the data, 300nm Pd thickness is not sufficient to have a lifted ball ppm at a level comparable with other packages. At >400nm Pd thickness, lifted ball ppm is already flat at <3000ppm



Diffusion	NSOP(ppm)	Pd Thickness(ave,nm)
5350481	562500	165.9
5317978	115000	274.8
5347107	10573	271.8
5319736	9200	232.5
5350481	1448	403
5336505	2417	465

Legend:
Pd<200nm
Pd:200-299nm
Pd:300-399nm
Pd:>400nm

Figure 13. NSOP PPM per pad thickness

3.2 Probond DOE

Based from the prediction profile the setting of the following parameters are as follows Time Seg1 at 45.42, USG Seg2 at 44.67, Time Seg2 at 21.84 and Force Seg2 at 25. Predicted values of the response characteristics NSOP, wire pull, ball shear, ball height and ball diameter can shown on the graph with its corresponding tolerances using 100% diserability.

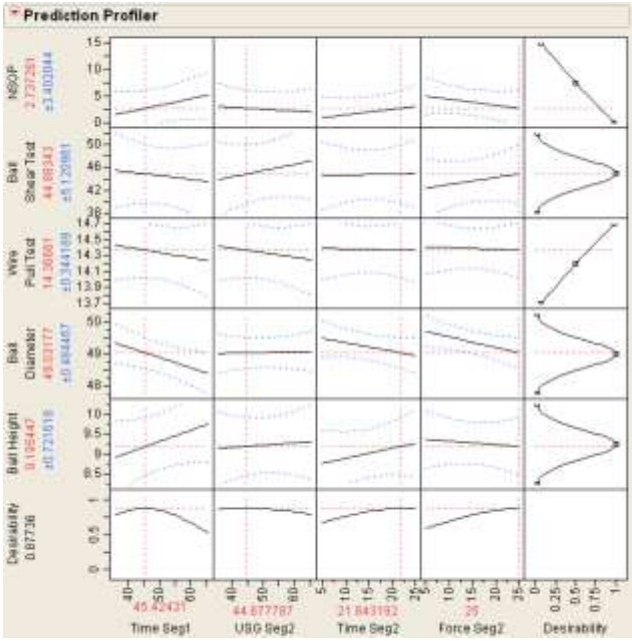


Figure 14. DOE Matrix design and Prediction profiler.

As per validation of the optimized parameter from the DOE, 5000ppm can be realized with mid to high setting against the reference of 50000ppm.

Ernani Padilla and Conrado Villanueva, "Probond approach a key to minimizing the effects of bond pad anomaly", *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 3, pp. 509-514, 2019.

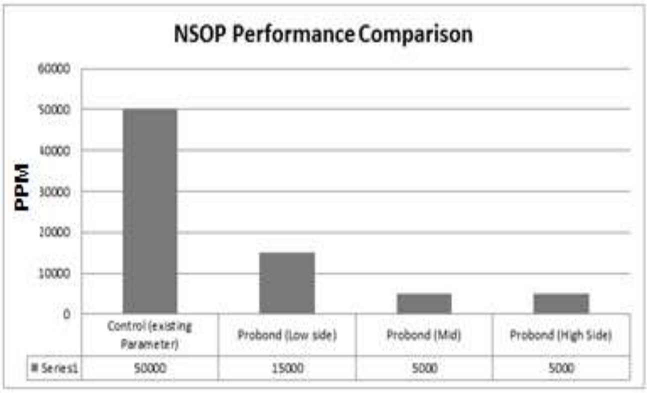


Figure 15. NSOP comparison control vs. probond

3.3 Wirebond Quality and Reliability

Probond process window shows passing quality response check for wire pull, ball shear, ball height, ball diameter and cratering.

Samples was subject to reliability with condition JL3 + TC (-65^{o}C/150^{o}C), TC 100 for gate and 500 for monitoring which all passed.

Large Scale Validation (0hr data results)

Category		Probond (Low side)	Probond (Mid)	Probond (High Side)
Ball Bond Photo				
Ball Shear	Min	40.027	42.58	43.716
	Max	49.739	54.5	56.17
	Ave	43.74	46.70	49.77
Ball Pull or Wire Pull	Min	12.001	12.197	12.699
	Max	17.065	16.144	16.236
	Ave	14.33	14.29	14.51
Ball Height	Min	9	8	8
	Max	11	10	9.3
	Ave	9.6	9.2	8.9
Ball Diameter	Min	48	48	48
	Max	50	50	52
	Ave	49	49	50
Cratering Test		no bond pad crack	no bond pad crack	no bond pad crack
After TMCL100				
Ball Shear	Min	39.142	42.081	42.999
	Max	48.612	48.914	55.253
	Ave	43.60	45.22	49.15
Ball Pull or Wire Pull	Min	8.128	7.523	9.023
	Max	11.806	11.296	10.481
	Ave	9.82	9.58	9.69
Cratering Test		No Bond Pad Crack Passed	No Bond Pad Crack Passed	No Bond Pad Crack Passed

Probond Reliability Result

		Qual	Lot 1	Lot 2	Lot 3
		Parameter	LL	MM	HH
Rel Activities	JL3acc + TC (-65°C/150°C)	Level 3acc@ 260°C	completed	completed	completed
		Final Test	1/80 marginal proceed	2/80 marginal proceed	2/80 marginal proceed
		100x	completed	completed	completed
		Final Test	0/80 PASS	1/80 Marginal proceed	0/80 PASS
		500x	Aug 6 - 16	Aug 6 - 16	Aug 6 - 16
		Final Test	Aug 18 - 20	Aug 18 - 20	Aug 18 - 20

Note: JL3 + TC (100 for gate and 500 for monitoring) Pull out 8units - 5pcs for pull/ball shear + cratering test on 3 units after 100TC.

Figure 16. Wirebond quality and reliability result

3.4 Classic and Probond Comparison for 400nm Pd Thickness

Actual validation of 400nm Pd thickness on classic wirebond approach (current) and probond showed further improvement using probond for lifted ball from 3818 ppm to 750ppm.

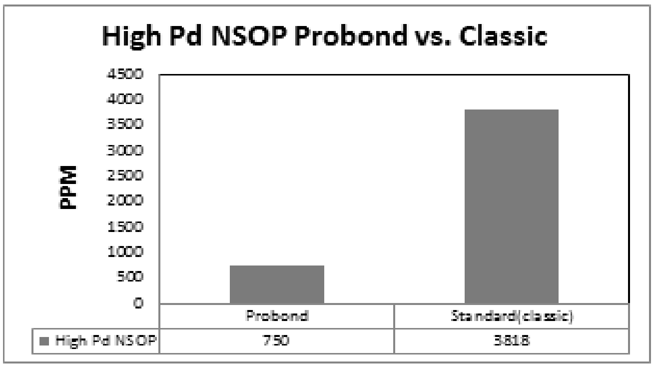


Figure 17. High Pd Lifted ball comparison Probond vs. classic

However, applying probond was validated to reduce wirebond productivity by 32%. Current classic approach at wirebond is still best to support manufacturing and application of probond should be done only on problematic wafers only.

IV. CONCLUSION

We conclude that Pd thickness is inversely correlated to lifted ball occurrence, meaning as Pd thickness is increased the lifted ball occurrence becomes lower. For BCD devices 400nm Pd thickness minimum is required to have lower lifted ball.

Applying probond approach can further reduce the lifted ball occurrence as compared to current classic approach however it reduces wirebond productivity.

V. RECOMMENDATIONS

It is recommended to update Pd thickness specs for BCD wafers from 300nm to 400nm minimum to have lower lifted ball occurrence.

Also, other sources of pad abnormalities should be studied for further improvement lifted ball occurrence so that use of probond will no longer be necessary.

ACKNOWLEDGMENT

We bring back all the glory and honor first and foremost to GOD who gave as the strength and knowledge to make this possible.

Our respective families who serve as our inspiration to persevere in work.

We also would like to acknowledge Jun Bernabe our Assy MT for his commitment to support us in the resolution of the problem. Joseph Tuazon, who served as my adviser. Caterina Riva from wafer Fab for supporting the recommendation on Pd thickness and collaboration on further actions for continuous improvement.

REFERENCES

[1] Bob Chylak, et al., "Next generation Nickel-based Bond pads enable copper wirebonding", Kulicke and Soffa Ind. Inc.
[2] Jon Brunner, :User Guide – Probond , Kulicke and Soffa Ind. Inc.
[3] KnS Maxum Ultra Operations manual

ABOUT THE AUTHORS

Ernani D. Padilla is a licensed Electronics and Comm. Engineer from the Univ. of the East. Currently employed at ST Calamba as a Technical Staff Engr leading Process Engineering breakthrough group. A certified blackbelt by Neville Clark.

Conrado Adrian M. Villanueva is a graduate of Electronics and Communications Engineering from Rizal Technological University. He is now currently working as Wirebond Process Engineer under breakthrough group in ST Microelectronics Calamba.