ADDRESSING CRITICAL WIREBOND LOOP CHALLENGES ON AUTOMOTIVE MEMS DEVICE WITH STACKED-DICE CONFIGURATION

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ABSTRACT

In the introduction of microelectromechanical systems (MEMS) with multi-dice design and stacked-dice technology for new product development, has brought up challenges in wirebond process dealing with the loop formation. Looping includes determining the loop height on specific die and its location. Loop height is an important factor to be defined with accurate considerations of each tolerances since it will project a major role in terms of reliability and performance of the device. High loop could induce wire sweep and shorting in between wires whereas very low loop could cause clearance issues between the wire and the die, both are critical to automotive devices. Conservative loop height should be defined using 1 mil (25.4 µm) wire diameter, wire gap to edge die, standard to automotive devices. Ultimately, the desired wire looping was achieved for this critical MEMS device of automotive applications, through the extensive works of design modeling and simulation, package stackup and tolerance analysis, process evaluation and optimization, statistical analysis, and the advanced technique using the 2D X-ray imaging.

1. 0 INTRODUCTION

Wirebond is the process which connects the die to package leads or die to die interconnection, The primary bonding cycle starts with the free air ball, then forms the first bond on the die, and connects the wire to the lead of the package, forming the second bond and cut the wire for the next cycle. The formation of the wire from the first to second bond is called 'looping', wherein the wire which is fed between the bonds takes the form of an arc. The arc formed when the bonding tool traveled in ‘wire loop'. The wire loop is characterized by its shape, length, and height, all of which define what is known as the wire's 'loop profile', as depicted in Fig. 1. Nowadays, wirebond machine technology is capable of providing different loop profiles based on the requirement of the package and the die technology.

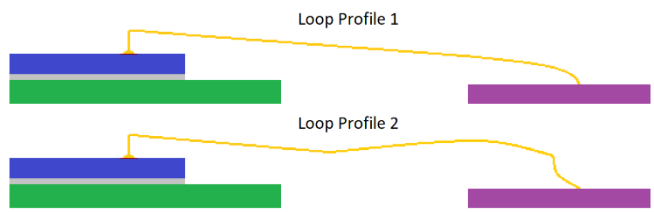


Fig. 1. Wirebonding loop profiles.

Loop profile 1 shows standard formation of loop common for die to lead technology whereas loop profile 2 shows the behavior of kink in the formation of loop. The kink shows a vital role in stacked-dice technology wherein the edge of die to wire distance is critical. Fig. 2 shows the assembly of multiple and stacked-dice and that capillary should have leeway on the loop formation.

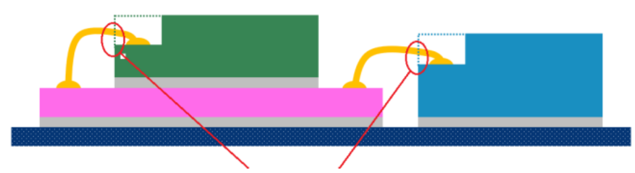


Fig. 2. Critical points in wirebonding of multi and stacked-dice technology.

Although wirebond technology is being continuously developed, challenges are inevitable especially in the application of wirebonding in the assembly manufacturing of semiconductor devices [1-4]. Nevertheless, the understanding of the behavior of the components on the process of wirebond is a significant approach in determining a robust loop formation which is the primary objective of this study.

2. 0 REVIEW OF RELATED WORK

Semiconductor package advancement and continuous technology trends have provided manufacturability challenges especially on devices of automotive applications.

One great challenge is the difficulty on the wire looping given the complex configuration. Works discussed in [5-7] deal with this challenge on the tight wire loop as shared in Fig. 3.

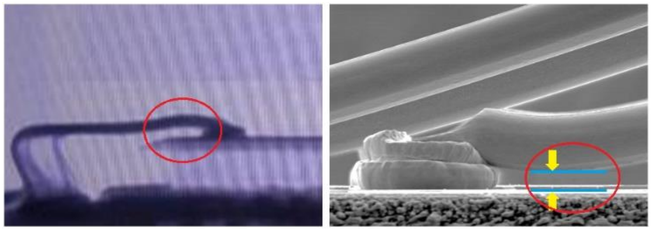


Fig. 3. Examples of tight wire looping.

A critical aspect to consider is the avoidance of the wire-to-die shorting between the wires and the die/s with large thickness. With this scenario, wire looping characterization and optimization is critically needed to satisfy the requirements in wirebonding process.

3.0 METHODOLOGY

For wire loop characterization, the capillary profile in Fig. 4 showing the Tip Diameter (TD) Bottle Neck Height (BNH) and Bottle Neck Angle (BNA) are determined with the given loop height, minimum bond pad opening (BPO), bond pad pitch (BPP), and average ball size. The capillary in discussion is for 1 mil wire size or diameter.

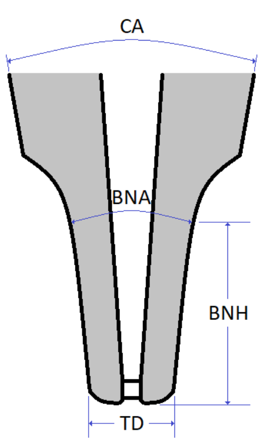


Fig. 4. Capillary profile for bottle neck.

Different capillary profiles were simulated using 3D modeling as shown in Fig. 5. Tip diameter vs. the die pitch with ultrasonic generator (USG) consideration during bond formation was checked.

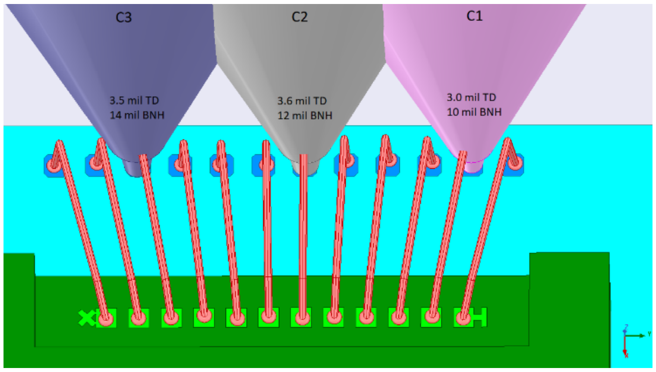


Fig. 5. Wirebond capillary 3D simulation on bond pad pitch.

The same technique for the capillary for the loop simulation using 3D modeling was used for risk assessment in terms of loop height. Fig. 6 shares capillary profile vs. the loop height requirement.

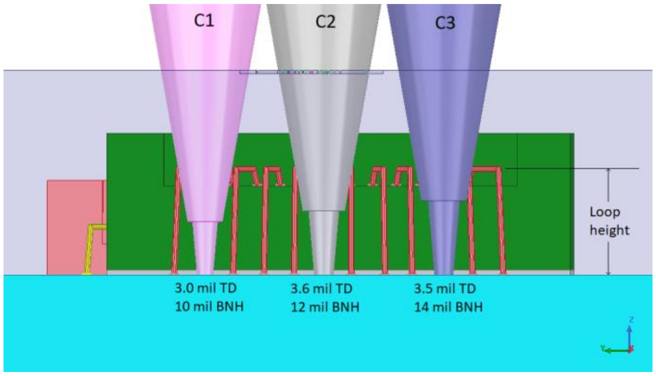


Fig. 6. Wirebond capillary 3D simulation with loop height.

After selection of capillary, the next step is to the selection of applicable loop profile on each die. Loop profile was defined based on the requirement of each die for standard bonding and reverse bonding method as discussed on the loop profile selection. With the loop profile, increase in kink angle would significantly impact on the shape factor mitigating the wire-to-die edge shorting risk.

For the loop height specifications, critical factors to be considered are as follows: (1) Top level clearance, (2) Shorting wire occurrence, (3) wire-to-die clearance with 1 diameter gap tolerance for automotive standards.

Package stackup analysis was completed given the cross-sectional details in Fig. 7 to define loop height applicable to each of die with considerations on the associated factors and risk assessment in defining robust loop height specifications.

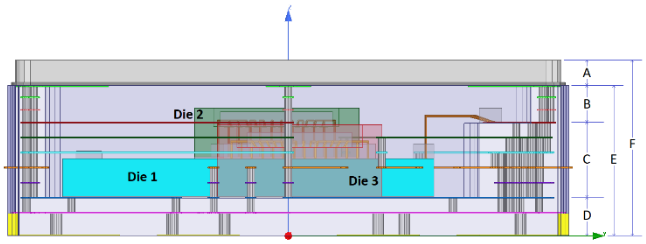


Fig. 7. Package design model cross-sectional view.

4.0 RESULTS AND DISCUSSION

Modeling and simulation was done for the wirebond capillary as shown in Fig. 8, from the given dice thicknesses and loop height of > 0.5 mm, BPP of < 0.1 mm, BPO of < 0.1 mm and ball size target > 0.06 mm.

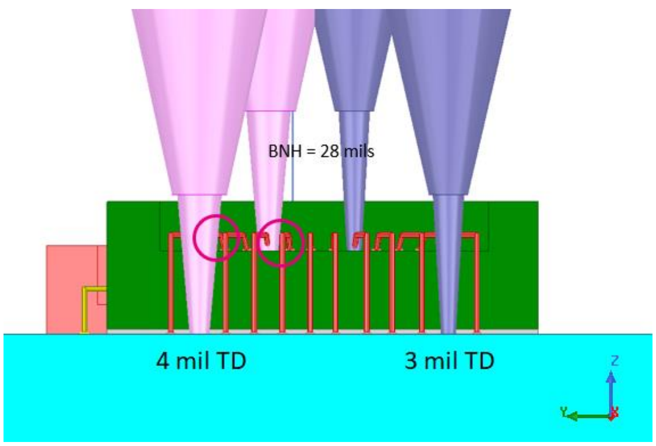


Fig. 8. Simulated capillary on 3 mils and 4 mils tip diameter.

The recommended capillary for the stacked-dice technology is at 3 mils TD and with 28 mils BNH. Thus, it was validated no risk on the use of capillary profile from the simulation in terms of ball formation and looping, Actual performance were justified on the qualification run where all the specification requirements were achieved. Specifically for the requirements under statistical process control (SPC) for destructive and ball aspect ratio, it was attainable at process capability (Cpk) value of > 1.67.

The stackup analysis was able to determine the loop height specifications considering the clearance for the max loop height and encapsulation, wire to edge of die gap and defects related to looping such as shorting wire and or sway wire.

Table 1. Loop Height Specifications

Location	Range
Die 1 to lead	0.525 to 0.575 mm
Die 1 to Die 2	0.475 to 0.525 mm
Die 1 to Die 3	0.203 to 0.254 mm

The advanced technique resulted in a higher confidence level with statistical data using t-test of P-value < 0.05. The given specifications show significant change in loop height, from the old parameter baseline. It was known from the start the old parameter would induce risk associated with gap of wire to edge of die which is a critical issue especially when dealing with thin die package assembly. Loop height specified on the new range was able to compensate the risk analyzed during technical gap analysis and design rule engineering analysis. As mentioned, there were advancements in the techniques developed, it should always begin with identifying the standards and risk mitigation. The statistical t-test result in Fig. 9 deals with the old parameters which was off specifications from the baseline and the new parameters conforming with the loop height specifications.

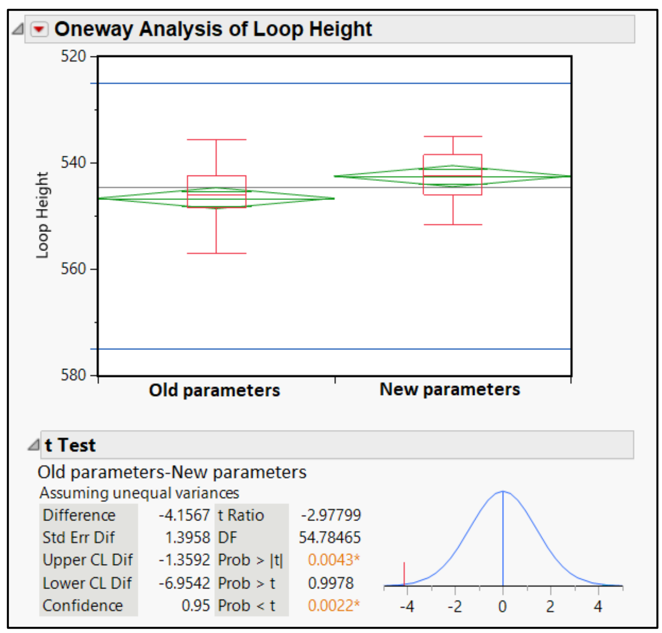


Fig. 9. Statistical analysis between 2 parameters.

Upon specifying and implementation of the given loop height specifications, this study introduced another advanced technique using 2D X-ray imaging to measure the gap of wire edge to die. This technique was managed with the failure analysis with accurate results comparable to z-height measurement. Fig. 10 shows the image of the wire against the die for accuracy in measurement.

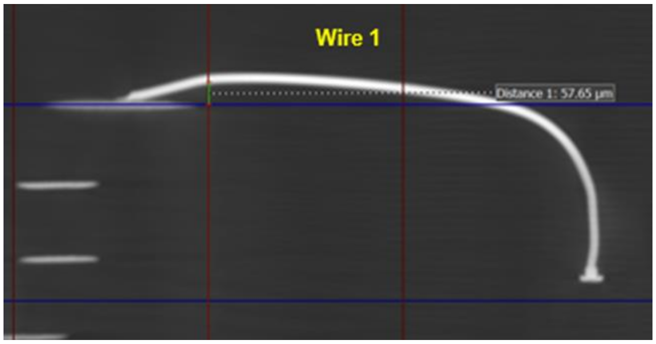
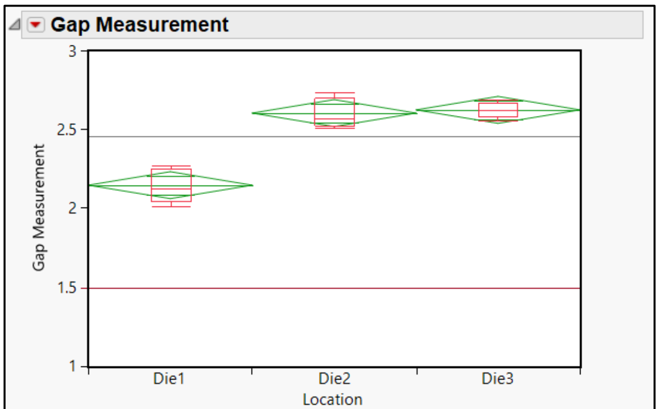


Fig. 10. Wire-to-die edge clearance measurement using 2D X-ray.

The table in Fig 11 shares the result of the gap measurement using 2D X-ray wherein the data shows > 2 mils gap which is robust enough to prevent wire-to-die short issues.



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
Die1	2.009	2.009	2.048	2.131	2.2565	2.27	2.27
Die2	2.509	2.509	2.528	2.569	2.7015	2.736	2.736
Die3	2.557	2.557	2.582	2.625	2.67	2.694	2.694

Fig. 11. Wire-to-die gap measurement at the 3 locations.

Above all, this study was able to achieve higher stability of looping for stack-dice assembly, mitigating risk discussed. A reliability test on trials was released and shows no problem related to bonding. Fig. 12 reveals the scanning electron microscope (SEM) photos of the device with the desired and optimized wire looping. This is a breakthrough in defining a robust automotive standard connection called wirebond.

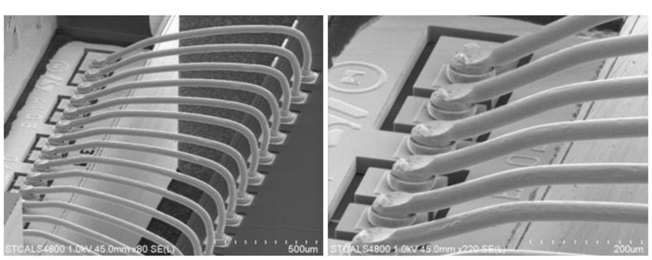


Fig. 12. SEM photos of wire loop in oblique view.

5.0 CONCLUSION

It is known that there were different techniques and methodology to use in wirebond process specifically for the looping which was the primary objective of the study. Wirebond capillary 3D modeling shows how to accurately define the profile of capillary tool to be used in this die stacked-dice technology. It is best also to select the loop profile which meets the bonding sequence and how the parameters would react upon adjustments. In knowing the parts of loop, it would be easier to identify and measure the rate of adjustments. Statistical data shows that defined specifications on the loop height passed the criteria with considerations on the risk associated with it. The overall conclusion dwells on step by step methodology approach and understanding the relationship between material to material, material to machine, machine to method, in this way all were taken into considerations. Through the collective contributions of design modeling and simulation, process evaluation and optimization, statistical analysis, and the advanced technique using the 2D X-ray imaging, the required wire looping and wire-to-die gap were successfully established for this automotive MEMS device with multiple and stacked-dice configuration.

6.0 RECOMMENDATIONS

Further improvement to robust approaches could be explored on defining specifications in terms of looping. It should always be taken into account the standards of wirebond process requisites to fit in the requirement of the package. All factors should be considered and the most is to understand the principles of looping. Discussions and learnings shared in [5-10] are useful in reinforcing robustness and optimization of package design and assembly processes particularly at wirebonding process.

7.0 ACKNOWLEDGMENT

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