Bondability and Reliability for Ultra Fine Pitch Bonding Process With Small Ball/Large Wire Capability

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1.0 Abstract

With the rapid advancement in wire bonding technology, ultra fine pitch (UFP) bonding with 60µm bond pad pitch (BPP) and below has fast become a reality. While the standard capillary design meets many current industrial needs from their proven reliability, demands for small ball size formation with large wire size in UFP bonding application requires a different tool design and configuration to contain the amount of gold squashed out during bonding. Using an unconventional approach in bonding tool design, a small hole to wire clearance for larger wire size with adequate chamfer diameter (CD) have been achieved.

Research and development on special tool design for UFP bonding on QFP and BGA material has been carried out to address the issue of small ball formation with large wire size. This paper discusses the bonding tool design aspects to control the desired MBD with the use of 25µm Au wire on a 60µm BPP platform. The intent is to establish the design feasibility to be used on the 50 and 40µm BPP at a later stage. Comparison of various bonding responses between standard and new bonding tool design obtained in both laboratory and manufacturing environment was also demonstrated.

2.0 Introduction:

In UFP bonding, the most difficult tasks are the small ball consistency with a reliable stitch formation. In most cases, the eventual mashed ball diameter (MBD) is only 5 to 8µm smaller than the bond pad opening (BPO). Such tight constraint on the ball bonds would require a consistent small ball formation, high PRS resolution, high positional accuracy and a tight control on the bonding tool dimensions. In addition, the use of large wire diameter (23 or 25µm) requires the hole diameter to be at least 30µm for a consistent looping. These constraints, together with those problems like open wire, bond lift off, looping performance, surface contamination, etc, have now become a critical process control requirement to achieve a stable wire bond process yield.

3.0 Objective

The main intent of this study is to establish and demonstrate the actual bonding response capability of the UFP capillary with the new design concept on a 60µm BPP platform. Reliability performance of the bonded wires is analyzed through etching test and cross-sectioning after the temperature cycle test.

4.0 Experimental Setup

The evaluation was performed on a high frequency wire bonder, using test chip die attached on BGA 256 substrate and QFP 208 copper lead frame with silver coating.

Special capillary for 60µm BPP was used based on the capillary design consideration (See next section). SPT capillary, DFXE-33ZB-AZM-1/16XL was used for the BGA device and DFXE-30ZQ-AZM-1/16XL for QFP device.

A 25µm diameter gold wire was used for this purpose.

For the optical inspection and measurement, a high power microscope of 0.5µm resolution was used for ball height, ball size, and loop height measurement.

Ball shear strength and stitch pull test was performed on the shear tester. For the ball shear test, the shear height was set at 3µm.

All responses and measurements were taken with a sample size of 25 readings.

Temperature cycling was performed at -150°C to +150°C for the BGA device. Ball shear and wirepull reading were taken at 100, 500, 1000, and 2000 cycles.

4.1 Capillary Design Considerations

For the ultra-fine pitch bonding, the given BPP and BPO requires a much smaller wire diameter (WD) of 20µm and below. Although this offers an advantage in cost reduction and a simple and straight forward capillary design, the problem takes place in wire sweeping during wire bonding, and molding process. The solution has reverted back to use larger wires ranging from 23µm to 25µm. However, various problems arise on using larger WD on a smaller BPO as explained below.

Firstly, for a WD of 23µm, the minimum hole size need to be at least 28µm. Considering a tolerance of +2/-0 µm, the minimum CD need to be at least 34µm for a reliable stitch bond. Such a CD size will almost be impossible to achieve an average ball size of 38µm for a 50µm BPP bonding.

Secondly, considering that the smallest Free Air Ball (FAB) size at 1.4 times the wire diameter (WD) that the current bonder can attained consistently, the deformed ball size cannot be further reduced as shown in Figure 1.

Figure 1: Ball sizes comparison for larger wire size

To address the above-mentioned issues, a unique capillary configuration know as DFX capillary has been designed to contain the amount of gold squashed out during bonding. Together with high precision impact force control on the bonder, such design has proven to be able to control the desired mashed ball and hence reduce the ball size to a smaller dimension. The effect of such capillary design is illustrated in Figure 2.

In addition to the special capillary design configuration, consistent ultrasonic transfer is crucial for the ball size formation. This can be achieved by using the slimline bottleneck capillary with higher tip breakage resistant and consistent dimension repeatability.

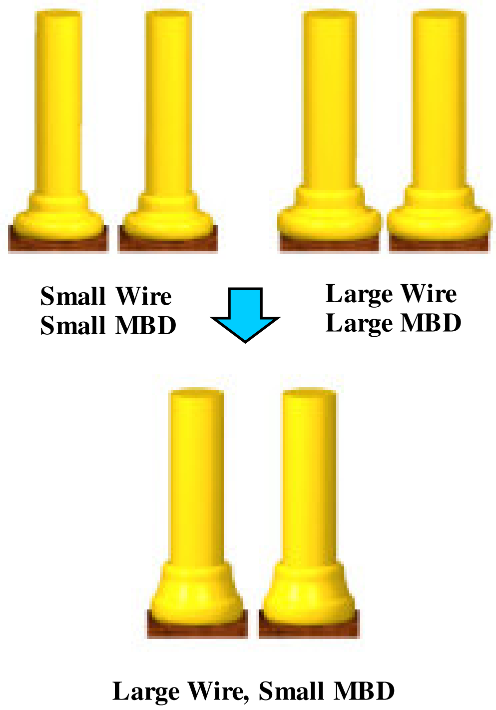


Figure 2: Special capillary configuration for small ball/ large wire capability

4.2 Results & Discussion:

A comparison study was carried out to check on the the performance of both the Standard and the new DFX capillary . Results were then discussed based on the bonding responses performance as well as the intermetallic coverage.

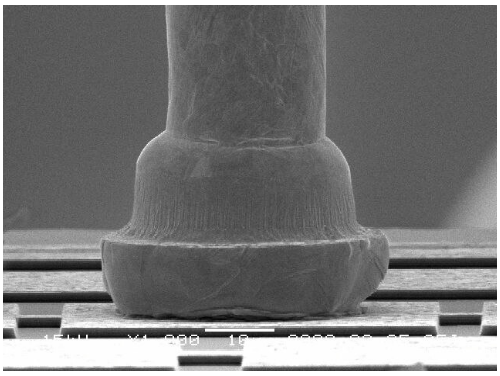
4.2.1 Bonding Response

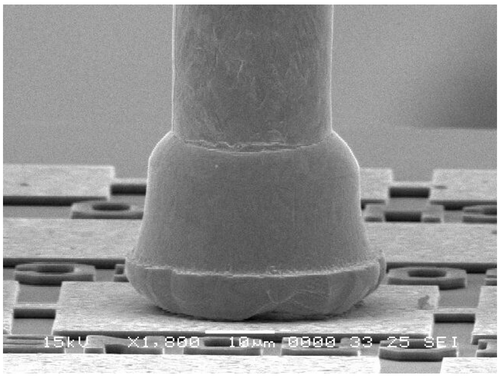
A design of experiments (DOE) was conducted to determine the optimized process window for both the standard and DFX design capillary on a QFP platform. A selected single point parameters was used for bonding response comparison with the result as shown in Figure 3 and 4.

Capillary Design	Standard Design	DFX Design
Device	QFP 208	QFP 208
Capillary Type	SBNE-30ZA	DFXE-30ZA
Wire Diameter µm	23	23
Ball Dmtr µm		
Average	42.6	39.2
Std Dev.	0.59	0.56
Ball Shear Strength,gm		
Average	15.4	11.9
Std Dev.	1.04	0.66
Ball Shear Stress N/mm^2		
Average	106.4	96.8
Std Dev.	5.3	3.9
Wirepull Strength gm		
Average	5.8	5.7
Std Dev.	0.2	0.2

Figure 3: Bonding response comparison for standard and DFX design capillary

Standard Design





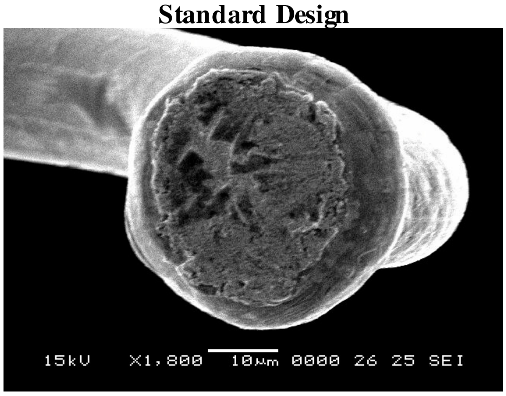
DFX Design Capillary

Figure 4: SEM picture for standard and DFX design capillary

4.2.2 Inter-metallic Analysis

Inter-metallic analysis was analyzed through the etching test to further understand the effect of the new capillary design on the inter-metallic formation. From the pictures shown in Figure 5, no significant difference was observed between the standard and DFX capillary.

Standard Design



DFX Design Capillary

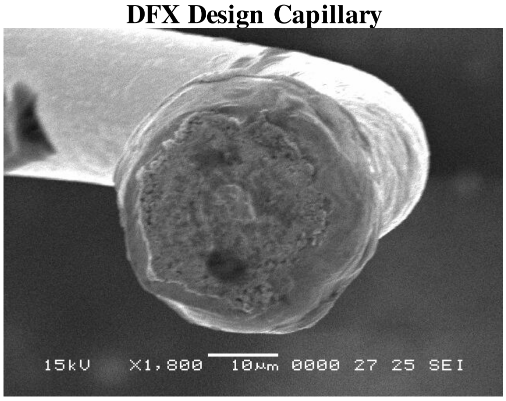


Figure 5: Intermetallic analysis for standard and DFX design capillary

From the bonding response and inter-metallic analysis, it can be seen that the DFX design capillary is capable of producing a smaller ball size as compared to the standard design with a minimum ball shear stress of 90 N/mm^2 ($6g/mil^2$). Hole and CD dimensions remain the same for both capillary designs.

Having validated such design concept, a similar experiment was conducted with the new DFX design but with a larger hole and CD dimensions. The main purpose is to investigate the possibility of using a bigger hole diameter for larger wire application while maintaining the average bonded ball size at 42µm.

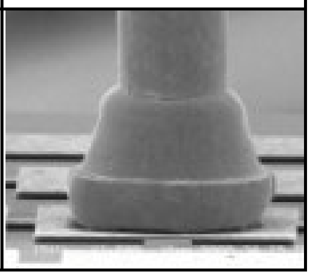
Capillary Design	DFX Design
Capillary Type	DFXE-33ZQ
Wire Diameter µm	23
Ball Dmtr µm Average Std Dev.	 41.9 0.62
Ball Shear Strength,gm Average Std Dev.	 15.8 0.75
Ball Shear Stress N/mm^2 Average Std Dev.	 112.5 4.2
Wirepull Strength,gm Average Std Dev.	 5.6 0.3
SEM Picture	

Figure 6: Bonding response for DFXE-33ZQ

Results from the various bonding responses have indicated that a similar ball size can be achieved with a larger CD and hole diameter with acceptable bond quality. Therefore, a larger wire size can be used with such a design feature for UFP application with controlled ball size.

4.3 Reliability Analysis

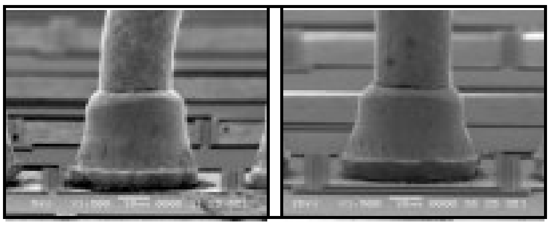
Having understood the bonding behavior of the DFX design, reliability study was conducted with temperature cycling at condition -150°C to +150°C for a standard 256 BGA device on various bonded ball thickness. Again, Esec3018 with 125KHz was used for this purpose.

Since the evaluation is mainly to check on the reliability of the different ball thickness resulted from the new capillary design, important parameters such as Bond Force, Bond Power and Bond Time were kept constant whilst three different Free Air Ball (FAB) parameters were used. Details of the evaluation parameters is as in Figure 7.

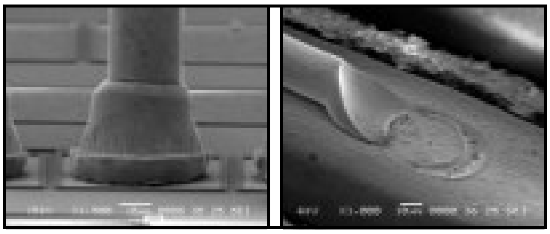
	Eval #1	Eval #2	Eval #3
1st Force	280mN	280mN	280mN
1st Time	15ms	15ms	15ms
1st Power	23.1%	23.1%	23.1%
2nd Force	530mN	530mN	530mN
2nd Time	15ms	15ms	15ms
2nd Power	25.50%	25.50%	25.50%
Auto FAB	40	42	44

Figure 7: Evaluation layout

All samples were then subjected to the temperature cycling at condition -150°C to +150°C for 100, 500, 1000 and 2000 cycles. Responses were taken both after wirebonding process as well as after each cycle.



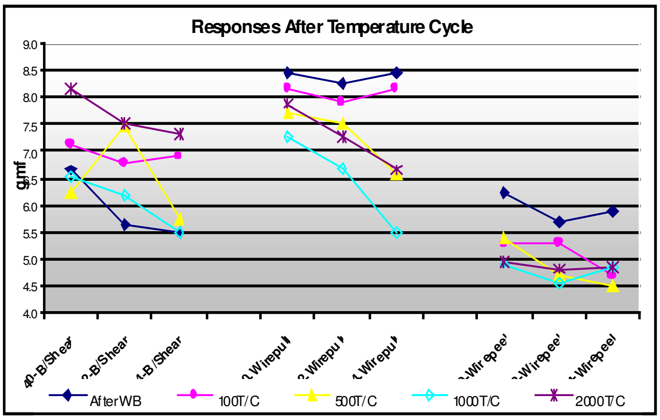
Eval #1 Eval #2



Eval #3 Stitch bond

Process	Response	Auto Free Air Ball (FAB)		
		40.00	42.00	44.00
After WB	Ball Dmtr (µm)	Av:46.33 SD:2.17	Av:49.21 SD:1.49	Av:50.62 SD:1.78
	Ball Hgt (µm)	Av:5.50 SD:1.76	Av:11.35 SD:2.25	Av:15.80 SD:1.94
	Wirepull (gm)	Av:8.45 SD:0.24	Av:8.27 SD:0.19	Av:8.45 SD:0.22
	Wirepeel (gm)	Av:6.21 SD:0.35	Av:5.68 SD:0.42	Av:5.88 SD:0.55

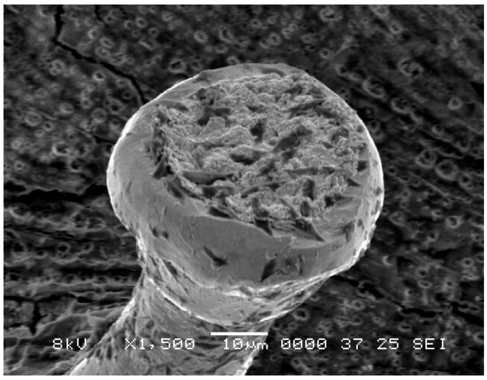
Figure 8: Bonding responses after wire bond



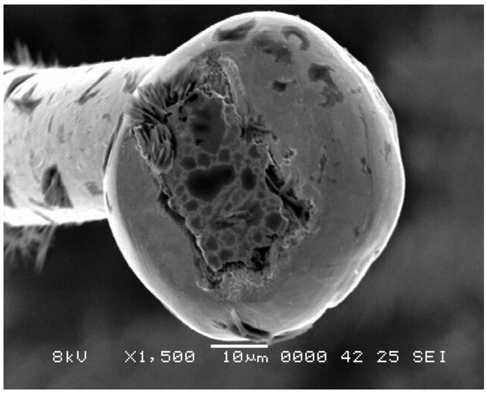
Note: Data was based on average value

Figure 9: Responses after temperature Cycle

With the same bonding parameters, a smaller FAB setting result in a lower ball height but with a higher ball shear reading. This may be due to the efficient transfer of the ultrasonic energy through the capillary to the smaller amount of squashed gold that helps to develop the intermetallic formation between the Al pad and the Au ball. This observation was verified with an etching test on those units with different ball height readings as shown in Figure 10.



Ball Height = 6µm



Ball Height = 16µm

Figure 10: Intermetallic analysis for different ball heights

Result indicates that the inter-metallic coverage for the thinner gold ball is approximately 15% more than those for the thicker ball. A sufficient coverage of inter-metallic is very crucial in the UFP bonding that requires small and thin bonded ball to cater for the narrow pitch requirement and at the same time did not sacrifice on the bonding performance.

In addition, the degradation of the interface between the bonded ball and the Al pad during temperature cycle was also studied by monitoring the ball shear strength. Fluctuation in the ball shear stress was observed at each read out with the highest reading recorded at 2000T/C. No interface degradation was observed for all units. In fact, there was an increase in the ball shear stress at certain read out.

On the other hand, wirepull and wirepeel strength using the new capillary design concept was comparable to the standard design before temperature cycle test. However, a gradual decrease in the pull and peel strength was observed in most cases but still beyond the above the 4gm minimum limit. Such observation has little impact on the FAB setting since the stitch quality was basically controlled by the FA, OR and T dimensions of the capillary.

In addition to the various bonding responses, a cross section on the ball bond was performed on units for eval#1 with the results as shown below.

500T/C

1000T/C

2000T/C

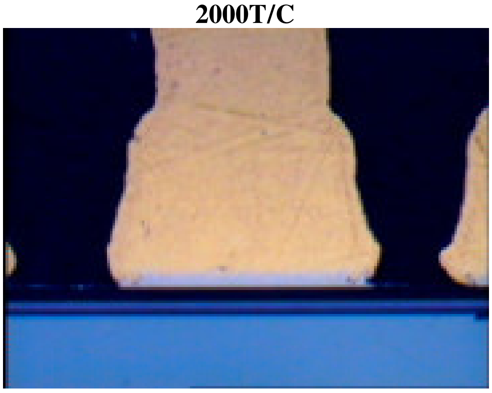


Figure 11: Cross section analysis

Measurement for the inter-metallic thickness revealed that compound thickness varies from 1.5µm to 3µm with no significant difference between 0 and 2000T/C.

On the overall, temperature cycling effect did not have significant impact on ball height variation. Likewise, stitch performance remains within the acceptable quality after temperature cycling.

5.0 Conclusion

Wire bonding experiment with the new capillary design concept for ultra fine pitch bonding has shown that the ball and stitch bonds can be bonded with equivalent quality as compared to the standard design. The bondability and reliability tests have confirmed that the new capillary design can be introduced for volume production, without any bonding reliability issue. Results from the bonding test have also demonstrated that a minimum ball size of 10% larger than the CD dimension can be achieved in a production environment for a 25µm wire size on a 60µm BPP. The findings and reliability data provide a useful platform for such design to be used on even smaller pitch bonding application, which required a small ball size formation with large wire size.

6.0 Future Development

With the development and verification of the new capillary design on a 60µm BPP, the emphasis by the assembly houses is to incorporate such capillary design for their 50µm BPP using 23µm wire size. In-house testing has demonstrated that such design is capable of bonding on a 50µm BPP platform with a 23µm wire size with acceptable bond quality.

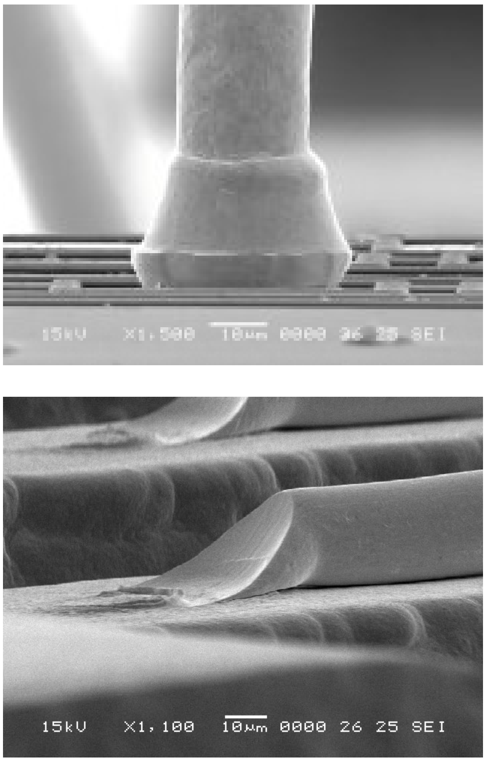


Figure 12: 50µm BPP capability

References:

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