

Lead-Free Solder Ball Attach Improvement on FCPBGA with SOP Pad Finishing

Wong Tzu Ling¹, Eu Poh Leng¹, Nowshad Amin², Ibrahim Ahmad²

¹*Freescale Semiconductor Malaysia Sdn. Bhd.
No. 2, Jalan SS 8/2 Free Industrial Zone
Sungei Way Petaling Jaya 47300
Tel: 603-78734247*

²*Faculty of Engineering, Department of Electrical, Electronics & System,
National University of Malaysia
43600 Bangi, Selangor, Malaysia
Tel: 603-89216322 Fax: 603-89216146
Email: B16177@freescale.com*

Abstract

In the recent years, lead-free solder material have been increasingly applied to the green semiconductor products for RoHS compliance. For Flip Chip Plastic Ball Grid Array (FCPBGA), recent industry trend is changing from ENIG pad finishing to Solder-on-pad (SOP) pad finishing using Sn3.0Ag0.5Cu to improve board level reliability due to black pad issue on ENIG pads. However, SOP has posted a challenge in ball attachment process due to higher oxide level on SOP pads. The use of Sn3.8Ag0.7Cu solder ball on SOP pad finishing has been facing slanted ball and wrinkled ball issues after ball attach reflow. Slanted ball is a defect as it fails the solder ball radius-true- position and coplanarity specification.

In this paper, Sn3.5Ag solder ball on 33x33 FCPBGA with SOP was being compared to conventional Sn3.8Ag0.7Cu solder ball. After assembly, samples were subjected to laser scanning for slanted ball inspection. Visual inspection under low power scope was done to check for wrinkled balls. Cold ball pull (CBP) was used to evaluate the solder joint strength at 3 conditions, namely after assembly (T0), after six time reflow and after 168 hours high temperature storage (HTS). In addition, tray drop test and packing drop test were conducted to assess solder joint integrity due to handling and impact force. Solderability test was also performed per Jedec standard to assess board mounting reliability.

Finally, Sn3.5Ag is recommended to replace Sn3.8Ag0.7Cu ball for 33X33mm FCPBGA package to resolve the wrinkled and slanted ball issue and improve the overall solder joint reliability.

Key words: Flip Chip Plastic Ball Grid Array, wrinkle, lead-free solder, cold ball pull, solderability

Introduction

In the recent years, lead-free solder material have been increasingly applied to the green semiconductor products for RoHS compliance. Among the mass production lead-free solders, the Tin-Silver-Copper (SnAgCu) family solder materials have been widely used as solder ball alloy for Ball Grid Array products. In Freescale, Sn4.0Ag0.5Cu family which includes Sn3.8Ag0.7Cu solder ball alloy are the conventional solder materials commonly used for Ni/Au pad finishing, including electrolytic or ENIG.

For Flip Chip Plastic Ball Grid Array (FCPBGA), recent industry trend is changing from ENIG pad finishing to Solder-on-pad (SOP) pad finishing to improve board level reliability due to black pad issue on ENIG pads. A typical SOP solder is Sn3.0Ag0.5Cu. However, SOP has posted a challenge in ball attachment process due to higher oxide level on SOP pads. The use of Sn3.8Ag0.7Cu solder ball on SOP pad finishing has been facing slanted ball and wrinkled ball issues after ball attach reflow. Slanted ball is a defect as it fails the solder ball radius-true-position and coplanarity specification. And wrinkled ball surface topography has also been a

concern that it may cause solder voids in the solder joint after board mounting and therefore is of critical importance to solder joint reliability.

In this paper, Sn3.5Ag solder ball on 33x33 dimension FCPBGA package with SOP was being compared to conventional Sn3.8Ag0.7Cu solder ball. After assembly, samples were subjected to laser scanning for slanted ball inspection. Visual inspection under low power scope was done to check for wrinkled balls. Cold ball pull (CBP) was used to evaluate the solder joint strength at 3 conditions, namely after assembly (T0), after six time reflow and after 168 hours high temperature storage (HTS). In addition, tray drop test and packing drop test were conducted to assess solder joint integrity due to handling and impact force. Solderability test was also performed per JEDEC standard to assess board mounting reliability.

The result of this study showed that Sn3.5Ag solder ball resolved the slanted and wrinkled ball issue. The cold ball pull result showed significantly higher pull strength with Sn3.5Ag solder ball at T0, six time reflow and 168 hours HTS. Also, no ball drop in tray and packing drop test. Both the solder alloy passed solderability test. Finally, Sn3.5Ag is recommended to replace Sn3.8Ag0.7Cu ball for 33X33mm FCPBGA package to resolve the wrinkled ball which is a customer concern, and to prevent slanted ball yield loss in production, as well as enhancing the overall solder joint performance with higher pull strength.

2. Study Design

This study comprises 4 parts:

1. Assembly of samples with 33X33 FCPBGA substrates from two different C5 lead free solder ball, namely Sn3.5Ag and Sn3.8Ag0.7Cu (SAC387).
2. Cold Ball Pull measurement for after assembly, after 168 hours high temperature storage and after 6 times reflow.
3. Tray drop test and packing drop test.
4. Solderability test.

3. Subjects and Methods

3.1. Subjects

In this study, 33x33mm FCPBGA with SOP solder pad finishing was used as test vehicle. This test vehicle was the most stringent FCPBGA package with the biggest package size among all the FCPBGA packages assembled in Freescale KL FCBGA line, and with SOP pad finishing which is new and challenging to ball attach process. Details of this package are displayed in Table 1.

Table 1. Details of package used in this study

Package Type	FCPBGA
Ball Count	1023
Package Size	33x33mm
Ball Pitch	1.00mm
Ball Size	0.60mm
Solder Mask Opening Diameter	0.55mm
Solder Pad to Ball Diameter Ratio	0.92
Cold Ball Pull LSL	700g

3.2. Methods

3.2.1. Samples Preparation

2 lots of samples were assembled, where 1 lot was attached with Sn3.5Ag solder ball, and the other lot with SAC387 solder ball. Sample size per lot was 120 units. One reflow profile was applied to both solder ball type with peak temperature at 240°C (235 to 245°C range). The same profile works perfectly well for both Sn3.5Ag and SAC387 with excellent melting and formation of reliable solder joint system. The reflow profile used in the study is displayed in Figure 1.

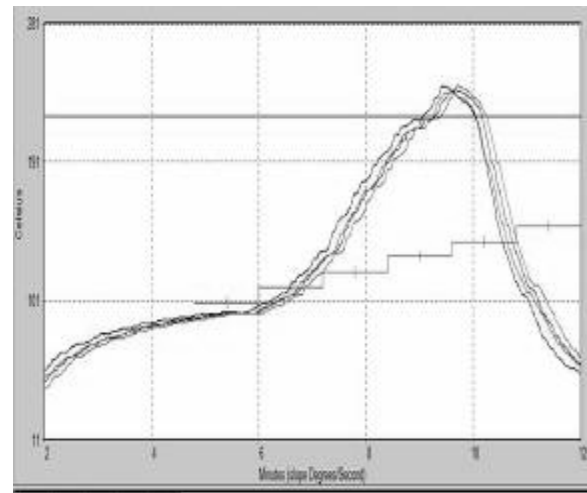


Figure 1. Reflow Profile

All the samples were assembled and subjected for Robotic Visual System Inspection (RVSI) to screen out any slanted balls. Final Outgoing Inspection (FOI) under low power optical scope was performed to detect any wrinkled ball.

Next, data at time zero were gathered and all the samples were then divided in two groups, with one group to go through six additional reflow using profile in Figure 1 to simulate board mounting process, and 2nd group to go through 168hrs high temperature storage baking at 150°C.

3.2.2. Cold Ball Pull Test

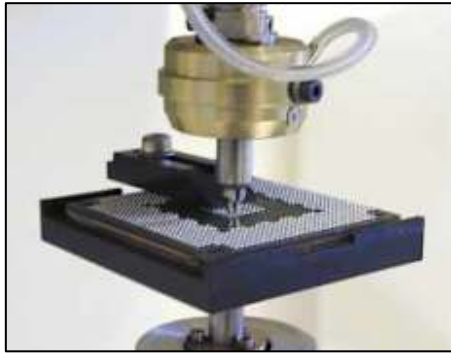


Figure 2. Cold Ball Pull Tester

Cold Ball Pull (CBP) test was developed by Dage in 1998 as a new method to assess the integrity of the bond between solder balls and their mating pad. This test method grips the ball mechanically without the need to reflow it as in Hot Ball Pull test, while conventional ball shear method tests the joint by shearing the ball. A paper was later published by Dage that outlined the CBP test methodology and design features [1]. A simple illustration of CBP test is shown in Figure 1 below.

For the past few years, cold ball pull was found to be a more reliable outgoing metrology to gauge solder joint performance especially for leadfree products. Advantages of CBP were found to be 2 folds: 1. CBP test produces more IMC brittle failures which is more stringent to differentiate the performance of different elements within the lead-free solder ball alloy and the solder pad; 2. CBP brittle failures represent a measurement of joint strength under dynamic load conditions and it correlates to drop test results.

In this study, cold ball pull test were performed to assess the solder joint strength at time zero, after high temperature storage, and after six times reflow. The CBP speed used are 5mm/sec and used 25 mil Jaw size. Sample size used is 10 samples per cell. 8 outer corner balls were tested per sample with 2 balls at each corner of the sample. The corner balls were perceived to have the weakest joint strength as they have the longest distance from the package center point (also called neutral point). Thus the corner balls will experience highest stress and

strains during ball attach reflow process which will result in weaker joint strength.

The failure modes are stated in Table 2 below. The acceptable ball pull failure mode is mode 1 and 4. Mode 2 is acceptable if pull strength is above 700g.

Table 2. Cold Ball Pull Failure Mode

Mode 1		Ductile Failure
Mode 2		Brittle Failure
Mode 4		Pad Lifted

3.2.3. Tray Drop Test and Packing Drop Test

In this study, two types of package level drop tests were performed. They were tray drop test and packing drop test. The purpose was to assess the solder joint robustness against vibration & impact shock. Tray drop test was done to assess package solder joint integrity during handling in the production floor, while packing drop test is to assess the handling during product shipment and transportation to customers. This was done using corner shelf support trays. The procedure is illustrated in Figure 3 and 4. During drop tests, if there is any broken tray, it will be replaced to prevent tray chips from inducing any ball drop.

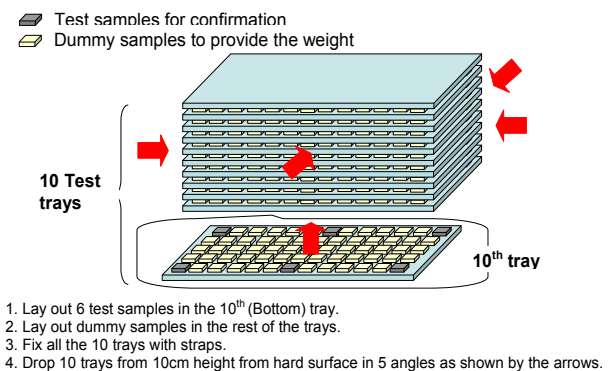


Figure 3. Schematic drawing of tray drop test

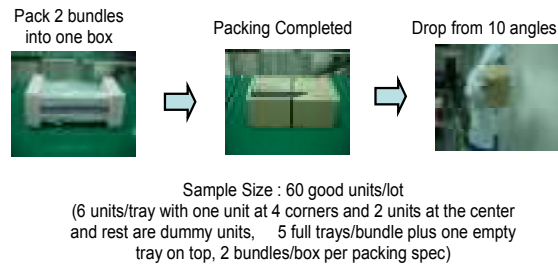


Figure 4. Schematic drawing of packing drop test

3.2.4. Solderability Test

Solderability test was performed to assess the ability of component attachment to Printed Circuit Board (PCB). Sample size used is 15 samples for each lot. Prior to solderability test, all samples were stressed through steam aging with 100C/100%RH for 8 hours and followed by 1 hour baking at 125°C. The solderability test procedure is shown in Figure 5.

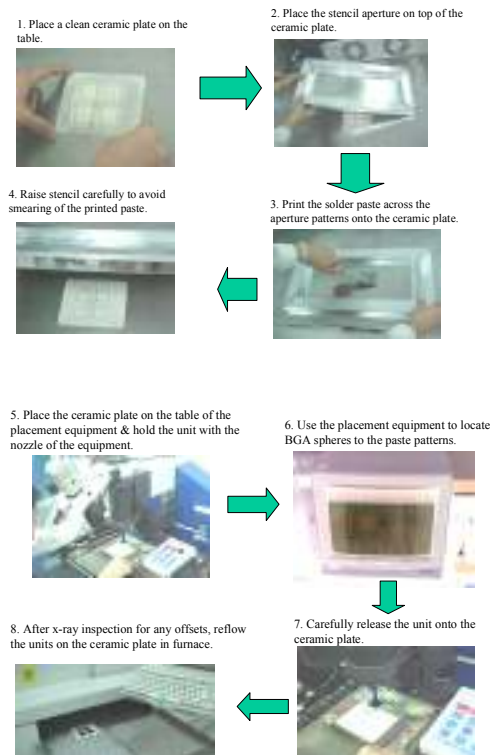


Figure 5. Solderability Test Procedure

After solderability reflow, units were removed for the ceramic plate. The balls were inspected under 30x scope for any of the following failure modes :

a. Satellite balls as shown in Figure 6:



Figure 6. Satellite balls

b. Solder remain on ceramic plate
If there is any solder paste remained on the ceramic plate, this shows solder paste is not fully absorbed by the balls on the component which indicates non-wetting failure.

4. Results and Discussion

4.1 RVSI and FOI result

In this study, all the assembled lots were put through RVSI scanning and FOI after the ball attach and solder ball reflow process. The purpose of the scanning is for co-planarity inspection and checking for slanted ball. From the RVSI scanning result, SAC387 failed 5/120 units or 41.7kppm yield loss due to slanted ball, while Sn3.5Ag solder sphere passed 100%. The slanted ball failure is illustrated in Figure 7.



Figure 7. Slanted balls found only in SAC387

FOI result showed SAC387 solder sphere had wrinkled solder surface for all samples and Sn3.5Ag ball did not show any wrinkled ball. Figure 8 and 9 display the SAC387 wrinkled ball and Sn3.5Ag non-wrinkled ball. As claimed by some Japanese customers, wrinkled ball surface may trap flux or foreign material and cause solder void after

board mounting reflow. Hence it is not acceptable and needs to be prevented as much as possible. From this study, Sn3.5Ag had shown its capability to resolve wrinkled ball issue.

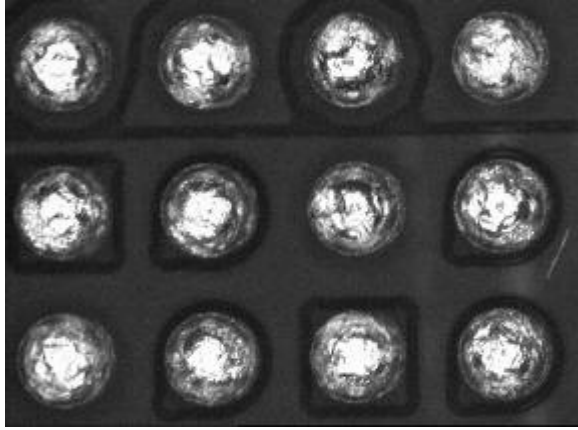


Figure 8. SAC387 wrinkled ball after assy

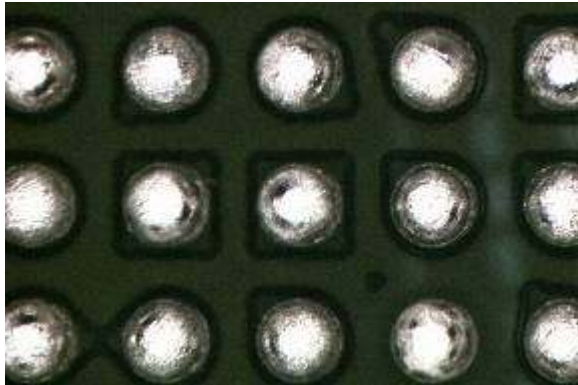


Figure 9. Sn3.5Ag without wrinkled ball after assy

As compared to ENIG solder pad finishing, solder pad with SOP finishing had SnO_2 and Ag_3Sn on the pad surface that reduced the wettability of solder ball on the SOP during ball attach process. Higher flux volume and flux activity will be required to remove the oxide layer on the SOP as well as on the solder ball surface during reflow. However, too high flux volume will cause solder bridging issue due to higher chance for ball movement. On the other hand, higher flux activity will be too corrosive to the package and may leave higher flux residue after flux cleaning. Hence, an acceptable flux volume and flux activity was determined through several testing. Reflow profile with shortest soak time was also needed to prevent flux drying before reaching the peak temperature zone, to ensure maximum flux activity during reflow in order to promote effective

oxide removal and maximum solder wetting. Even with such optimum condition, only SAC387 appeared to have slanted and wrinkled ball. The result had showed that SAC387 near eutectic solder with three elements is less robust than Sn3.5Ag eutectic composition with only two elements. The higher number of elements in the SAC387 solder alloy had caused more complicated melting and cooling behavior of the solder due to higher melting and cooling temperature range (from 217 to 222 degree C) as compared to Sn3.5Ag with almost one point melting and cooling temperature at 221 degree C.

4.2. Cold Ball Pull Result

In this study, CBP tests were performed at time zero, after high temperature storage at 150°C, and after 6 times reflow.

4.2.1. CBP at time zero after assembly

Table 3 and Figure 10 display the CBP result at time zero (T_0) after assembly. T-test value showed Sn3.5Ag solder ball had significantly higher pull strength than SAC387 solder ball. The result also showed that Sn3.5Ag had smaller standard deviation, hence had higher Cpk value.

Table 3. CBP strength after assembly

	Time Zero	
	SAC387	Sn3.5Ag
Max (g)	1912.9	1994.5
Min (g)	1500.5	1475.0
Mean (g)	1741.3	1866.7
Std.Dev (g)	93.0	89.4
T-test (2 sample, 1 tail)	2.069E-15	

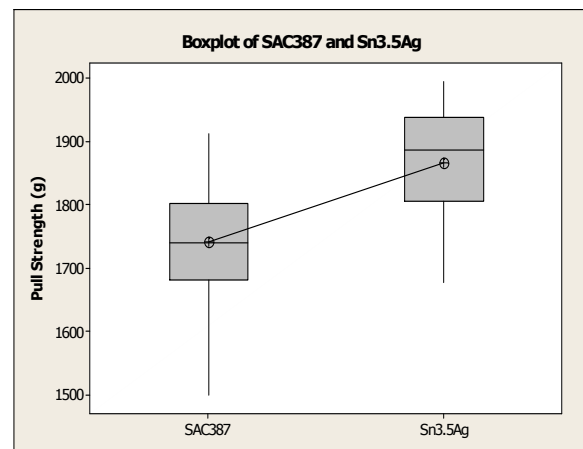


Figure 10. CBP strength after assembly

4.2.2. CBP after six times reflow

Table 4 and Figure 11 show the CBP result after six times reflow. T-test value again showed Sn3.5Ag solder ball had significantly higher pull strength than SAC387 solder ball.

Table 4. CBP strength after six times reflow

	6 time reflow	
	SAC387	Sn3.5Ag
Max (g)	1994.9	2109.1
Min (g)	1520.4	1346.1
Mean (g)	1758.7	1947.2
Std.Dev (g)	123.4	165.1
T-test (2 sample, 1 tail)	2.956E-07	

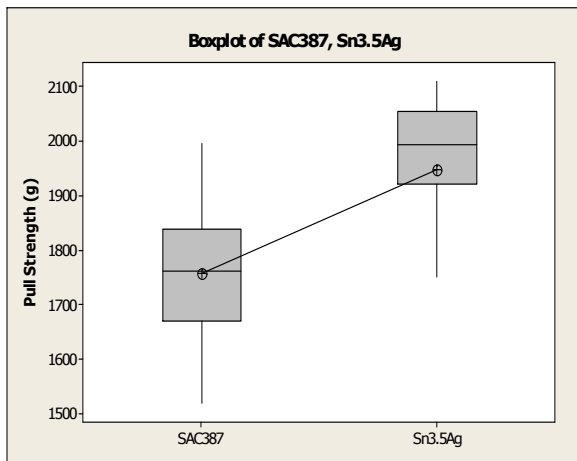


Figure 11. CBP strength after six times reflow

4.2.3. CBP after 168 hours high temperature storage

Table 5 and Figure 12 depict the CBP result after 168 hours high temperature storage at 150°C. T-test value showed Sn3.5Ag had significantly higher pull strength than SAC387 solder sphere. And with lower standard deviation, Sn3.5Ag had higher Cpk than SAC387.

Table 5. CBP strength after 168 hours HTS

	168 hours HTS	
	SAC387	Sn3.5Ag
Max (g)	1907.7	2158.2
Min (g)	786.7	1784.4
Mean (g)	1678.9	1988.9
Std.Dev (g)	196.3	72.3
T-test (2 sample, 1 tail)	1.565E-12	

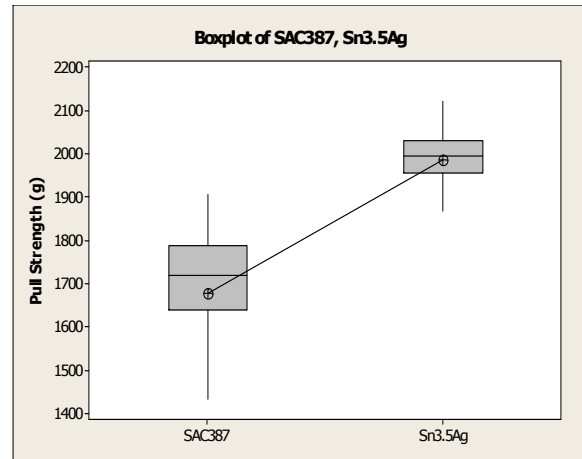


Figure 12. CBP strength after 168 hours HTS

4.3. Tray Drop Test and Packing Drop Test

For package level drop tests, 60 samples were tested for each lot. From the result, both SAC387 and Sn3.5Ag solder balls did not have dropped balls after packing drop test. 30 units were tested in tray drop test and the result showed both solder balls did not have dropped ball after tray drop test. Table 6 displays the 33x33 FCPBGA packing and tray drop test results for SAC387 and Sn3.5Ag solder ball.

	Number of Samples tested	SAC387	Sn3.5Ag
		Number of Dropped Ball	Number of Dropped Ball
Packing Drop test	60	0	0
Tray Drop test	30	0	0

Table 6. Packing and tray drop test result

4.4. Solderability Test

All units from Sn3.5Ag and SAC387 solder sphere passed the Solderability test. Table 7 and figure 13 and 14 show the solderability result after steamaging.

Table 7. Solderability test result

Lot Description	Sample Size	With Steamage
SAC387	15 units/readpt	Pass
Sn3.5Ag	15 units/readpt	Pass

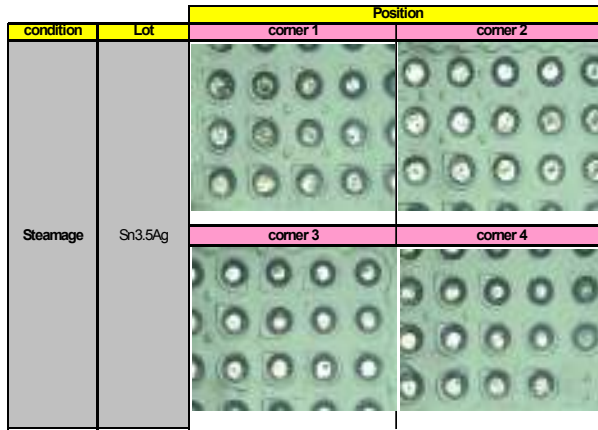


Figure 13. Sn3.5Ag solder sphere after solderability test.

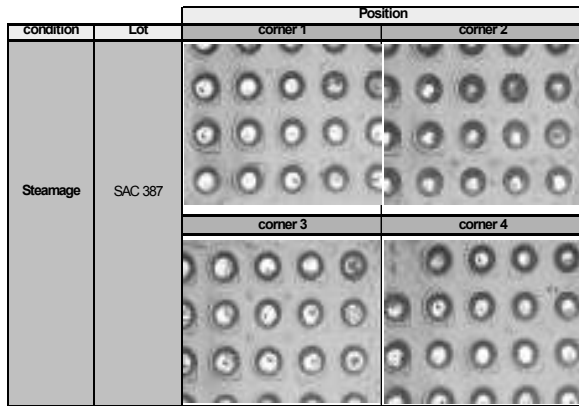


Figure 14. SAC387 solder sphere after solderability test.

Conclusions

From the result of this study, Sn3.5Ag solder ball had proven to resolve the slanted and wrinkled ball issues. The cold ball pull result showed significantly higher pull strength with Sn3.5Ag solder ball at T0, six time reflow and 168 hours HTS. Also, no ball drop in tray and packing drop test. Both the solder alloy passed solderability test.

In conclusion, Sn3.5Ag is recommended to replace Sn3.8Ag0.7Cu ball for 33X33mm FCPBGA package to resolve the wrinkled ball issue which is a customer concern, and to prevent slanted ball yield loss in production, as well as enhancing the overall solder joint performance with higher pull strength.

References

- [1] G.Ghosh, "Interfacial Reaction between Multicomponent Lead-Free Solders and Ag, Cu, Ni and Pd Substrates, Journal of Electronic Materials, Vol 33, No.10, 2004.
- [2] Chi-Won Hwang, Katsuaki Suganuma, Masayuki Kiso, and Shigeo Hashimoto, "Influence of Cu Addition to Interface Microstructure between Sn-Ag Solder and Au/Ni-6P Plating, Journal of Electronic Materials, Vol.33, No.10, 2004.
- [3] Guh-Yaw Jang, Jyh Wei Lee, and Jeng Gong Duh, "The nanoindentation Characteristics of Cu_6Sn_5 , Cu_3Sn and Ni_3Sn_4 intermetallic compounds in the solder bump, Journal of Electronic Materials, Vol.33, No.10 2004
- [4] Sang Won Jeong, Jong Hoon Kim, and Hyuck Mo Lee, "Effect of Cooling Rate on Growth of the Intermetallic Compound and Fracture Mode of Near Eutectic Sn-Ag-Cu/Cu Pad: Before and After Aging, Journal of Electronic Materials, Vol.33, No.12, 2004.
- [5] Nah, Jae-Wong et al "Flip chip assembly o PCB substrates with coined solder bumps" Proc 53th Electronics components and technology conf, new orleans, LA, May 2003, pp.244-249.
- [6] Laurila, T, Vuorinen, V, Mattila, T, Kivilahti, J.K. , "Analysis of the Redeposition of AuSn_4 on Ni/Au Contact Pads when Using SnPbAg, SnAg, and SnAgCu Solders, Journal of Electronic Materials, Vol.34, No.1, 2005
- [7] D. R. Frear et. al, Pb-Free Solders for Flip-Chip Interconnects, Journal of Materials, Vol. 53, No. 6, 2001, pp.28-32.
- [8] Masazumi Amagai, Masako Watanabe, Masaki Omiya, Kikuo Kishimoto, Toshikazu Shibuya, "Mechanical characterization of Sn-Ag based lead free solders, Microelectronic reliability 42(2002)951-966

- [9] Paik, K.W., Jeon, Y.D. & Cho, M.G. 2004. Interfacial Reactions and Bump Reliability of Various Pb-Free Solder Bumps on Electroless Ni-P UBMs. *2004 Electronic Components and Technology Conference*.Pg. 675-682.
- [10] Young-Doo Jeon, Adreas Ostmann, Herbert Reichi and Kyung Wook Paik, "Comparison of Interfacial Reactions and reliabilities of Sn3.5Ag, Sn4.0Ag0.5Cu, and Sn0.7Cu Solder Bumps on Electroless Ni-P UBMs. 2003 IEEE
- [11] Xiao-yan Li, Ben Sheng Wu and Xiao-hua Yang, "The Formation and Evolution of IMC and its Effect on the Solder Joint Properties 2005 IEEE
- [12] Lee et al. 2004. Journal of Electronic Materials, Effect of Adding Sb on Microstructure and Adhesive Strength of Sn-Ag Solder Joints
- [13] Birzer et. al Drop Test Reliability Improvement of Lead Free Fine Pitch BGA Using Different Solder Ball Composition
- [14] Lai et al 2005, Board Level Reliability of Chip Scale Packages Subjected to JEDEC Drop Test Condition, Proc. IMAPS Taiwan Technical Symposium
- [15] Robert Sykes, Pull testing of solder balls on BGA and CSP packages without reflow, Dage Precision Industries Ltd, England