As originally published in the SMTA Proceedings.

DEVELOPMENT OF LOW COST AND HIGH PIN COUNT WAFER LEVEL PACKAGING

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ABSTRACT
Wafer level packages (WLP) are widely accepted in portable electronics and wearable electronics due to their small form factor and low cost. As the trend of high integration continues, increases in both die size and WLP pin counts are required to meet demand. Improvement in solder joint reliability is the key to enable larger, higher pin count WLP. In this work reliability improvement at low cost is achieved by using plastic core balls at selected ball locations. An 8x8 mm 16x16 array 0.4 mm pitch daisy chain WLP is used as the test vehicle. A manufacturing process to incorporate mixed solder ball types is developed. In addition, board assembly reworkability is evaluated. Board reliability tests are performed to confirm the improvements. It is found that that use of plastic core balls improves the solder joint reliability by 20% which allows a larger WLP size. Plastic core balls also improve assembly yield which enable finer ball pitch WLP.

Key words: WLP, Board level reliability, plastic core balls.

INTRODUCTION
Due to its advantages of low cost, small size, and low parasitics, wafer level packages (WLP) are widely used in portable electronics and wearable electronics. Due to solder joint reliability limitations, WLP use is currently restricted to products with a maximum die size of 5 mm on a side. As the trend of higher integration continues, both die size and WLP pin counts also continue to increase. In order to expand WLP to larger die size and higher pin count products, solder joint reliability must be improved.

Different WLP structures and associated solder joint reliabilities have been studied in the literature [1] – [5]. Solder joint reliability improvement with plastic core balls has been studied for BGA [6]-[7], and for WLP [8]. The improvement is mainly contributed to the low stiffness. In these studies, all solder balls in the packages are plastic core balls. Since plastic core balls cost more than normal uniform solder balls, replacing all balls in a package with plastic core balls is cost prohibitive. To improve reliability while minimizing the solder ball cost, options for placing plastic core balls at selected ball locations are explored. The solder ball cost comparison is illustrated in Figure 1. For options with mixed ball types, a new ball attach process needs to be developed.

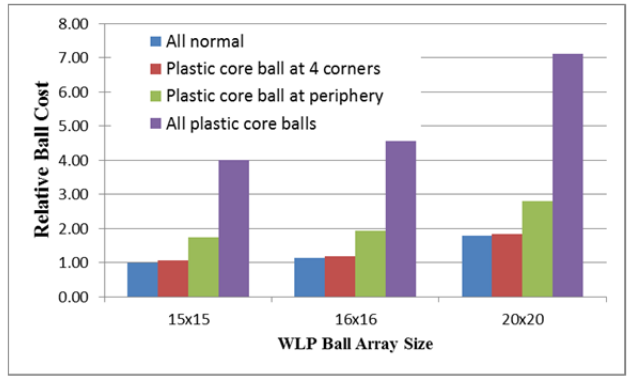


Figure 1. Relative Solder Ball Costs.

An illustration of a plastic core ball is shown in Figure 2. The plastic core ball consists of the plastic core at the center which takes approximately 30% of the ball volume and 70% of the ball height. A 7 um thick Cu shell surrounds the plastic core.

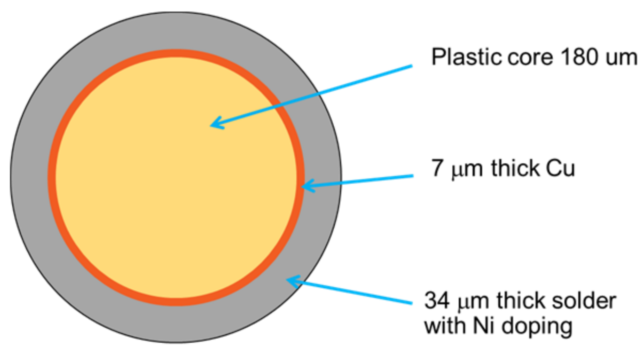


Figure 2. Construction of 260 um plastic core ball.

In order to quantify the reliability improvement with the minimum cost increase, a DOE is conducted.

In the following sections, an 8x8 mm 16x16 array WLP test vehicle and DOE are presented first. Manufacturing process and considerations are discussed next. They include the new ball placement process, plastic core ball appearance, SMT considerations and board reworkability. This is followed by board level reliability test results and failure analysis. Conclusions are made at the end.

DESCRIPTION OF TEST VEHICLES AND DOE SPLITS

An 8x8 mm 16x16 array 0.4 mm pitch daisy chain WLP is used as the test vehicle for this study. The daisy chain schematic is shown in Figure 3. The middle 8x8 balls are non-critical and they are allocated to other tests and failure isolations. They are not part of solder joint daisy chain. The board design allows options to include and exclude the three balls at every corner. In order to simplify the discussion, test data are presented only for the groups with all joints tested.

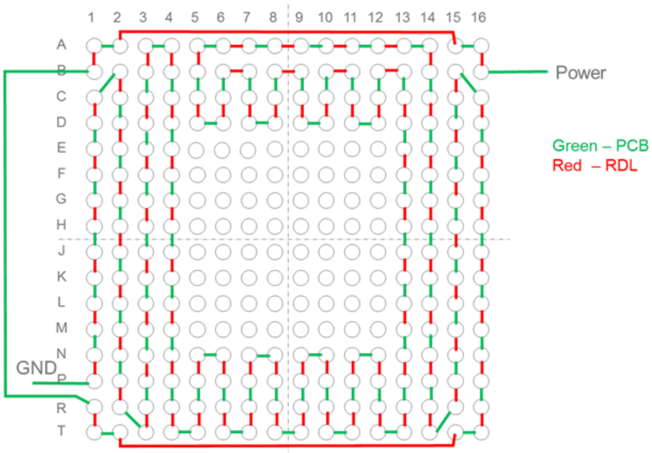


Figure 3. Daisy chain schematics.

To optimize the plastic core placement selection, three options are considered. They are illustrated in Figure 4. Option A is the control with all normal solder balls. Option B has total of four plastic core balls, with one ball at each corner of the ball array. This option has the minimum cost increase. Option C has plastic core balls placed along the entire periphery. The cost increase will vary by die size and always be greater compared to option B. Option C is expected to offer the best solder joint reliability. The objective of these three DOE options is to identify the best compromise between cost increase and solder joint reliability improvement for applications with different requirements.

In this study the solder sphere diameter is 250 μm for normal balls and 260 μm for plastic core balls.

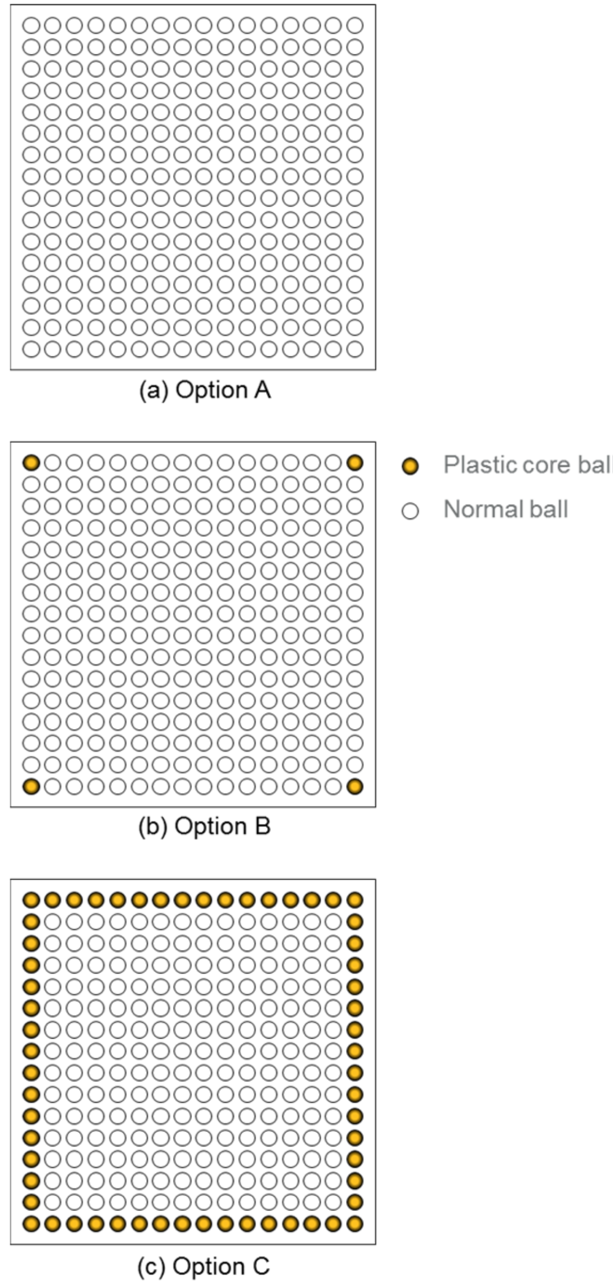


Figure 4. Three Plastic Core Ball Placement Options.

WLP AND ASSEMBLY MANUFACTURING

In order to accommodate mixed ball types, a two pass ball placement approach is used for plastic core options. This process is illustrated in Figure 5. The first step is to place all normal balls (c), and the second step is to place the plastic core balls (d).

The comparison of ball attach processes between WLP with all normal balls and WLP with plastic core balls is depicted in Figure 6. There is one extra ball placement step for plastic core balls. The flux printing and reflow/clean steps are common.

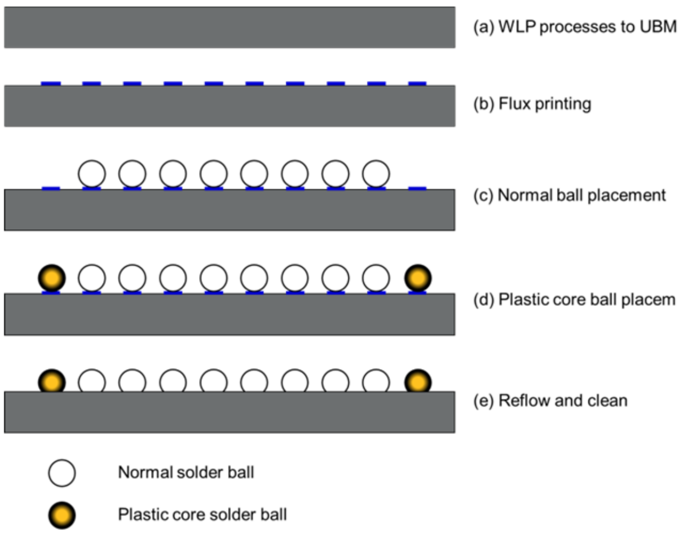


Figure 5. Manufacturing Process Steps of WLP with Plastic Core Balls.

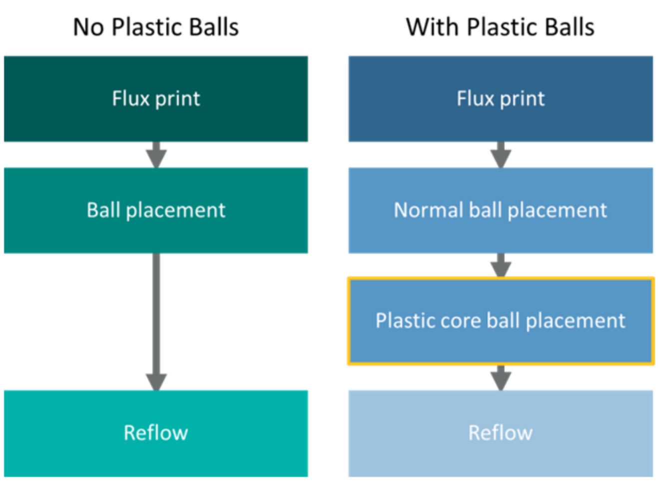


Figure 6. Ball placement process comparison between single and mixed ball types.

At this point, it is important to address the difference between two ball types and the effect on WLP as well as assembly manufacturing. Visual appearance is discussed first.

After ball attach, the sizes of the two types of solder balls are slightly different on WLP. The cross section photos of two types of balls shown in Figure 7. It is seen that the plastic core ball height is 24 um greater than a normal ball. To further assess the appearance difference, an optical photo of the WLP balls is shown in Figure 8. The plastic core solder ball appears darker and shinier than the normal solder balls. It is necessary to verify the impact on related WLP and assembly process. Automatic optical inspection (AOI) is the last step of WLP process. The AOI equipment is taught the appearance of plastic core balls so the non-uniform reflectivity of the ball does not cause problems at AOI. SMT evaluations were performed at two independent facilities. Both concluded that there is no difficulty in assembly associated to plastic core balls. 100% yield was achieved in SMT assembly. Therefore, the non-uniform reflectivity and size difference can be managed during manufacturing.

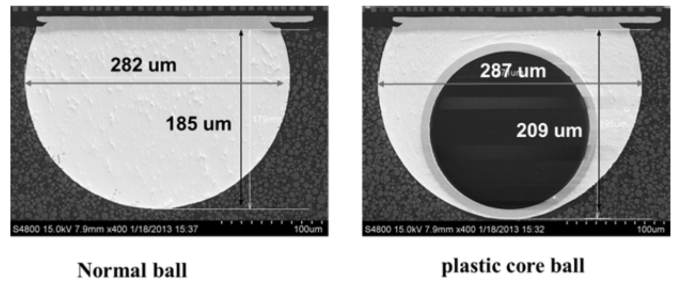


Figure 7. Comparison of Solder Height between a Normal Ball and a Plastic Core Ball.

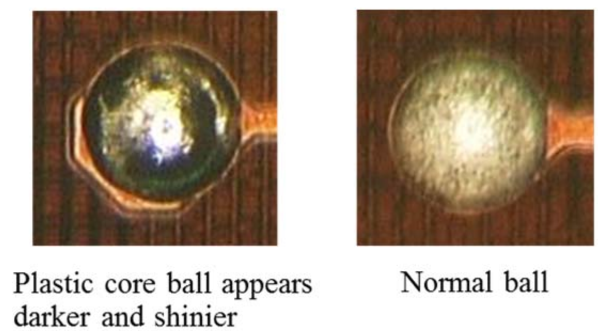


Figure 8. Plastic Core Ball Appearance In Comparison With Normal Balls.

WLP board assembly is investigated next.

X-ray is commonly used to verify solder joint quality. X-ray anomaly can lead to rejects and lot hold during assembly. It is important to assess the appearance of plastic core solder joints under x-ray. Figure 9 shows the X-ray photo of an option C WLP mounted on a PCB. As expected the light areas were shown at the middle of plastic core balls joints. Since they may be confused with solder joint voiding and result in false rejects and lot holds, proper training is necessary to acknowledge the different X-ray appearance of plastic core balls.

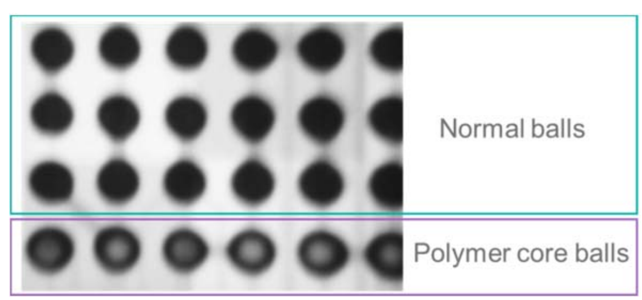


Figure 9. Appearance of plastic core ball joints in comparison with normal solder joints.

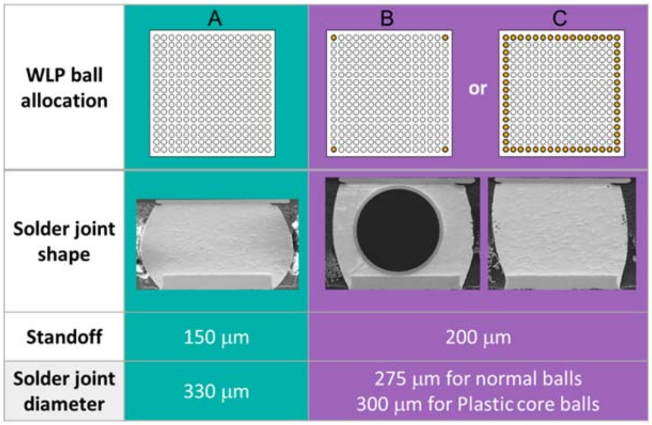


Figure 10. Solder Joint Shapes And Standoff For WLP Options A, B and C Assembled Onto Boards.

Solder joint sizes are studied next. With the presence of plastic core balls, there is less solder collapsing which results in taller and slender solder joints. Standoff is increased by 33% and solder joint diameter is reduced by 17%. Solder joint shapes are compared in Figure 10. It is commonly believed that higher standoff and smaller joint diameter provide better solder joint reliability. Smaller solder joint diameter also reduces the probability of bridging during surface mount assembly. This results in higher assembly yield and greater process margin. This is beneficial especially for very fine pitch WLP assembly.

To address the concern of board reworkability associated with plastic core balls. Evaluations are carried out to confirm if the units can be easily removed from the PCB and if there is solder remaining on PCB pads. 30 units with plastic core balls were selected for this rework evaluation with an MDR rework system. It was verified that WLP with plastic core balls can be removed with the same process as normal WLP. Figure 11 shows the photos of an example rework site. It is seen that solder paste residual on board is the same between plastic core and normal balls after WLP removal. After site dressing, all solder ball pads have the same quality. There is no concern on WLP re-attachment since the reworked board sites are normal. Therefore, it is verified that board rework has no known issue for WLP with plastic core balls.

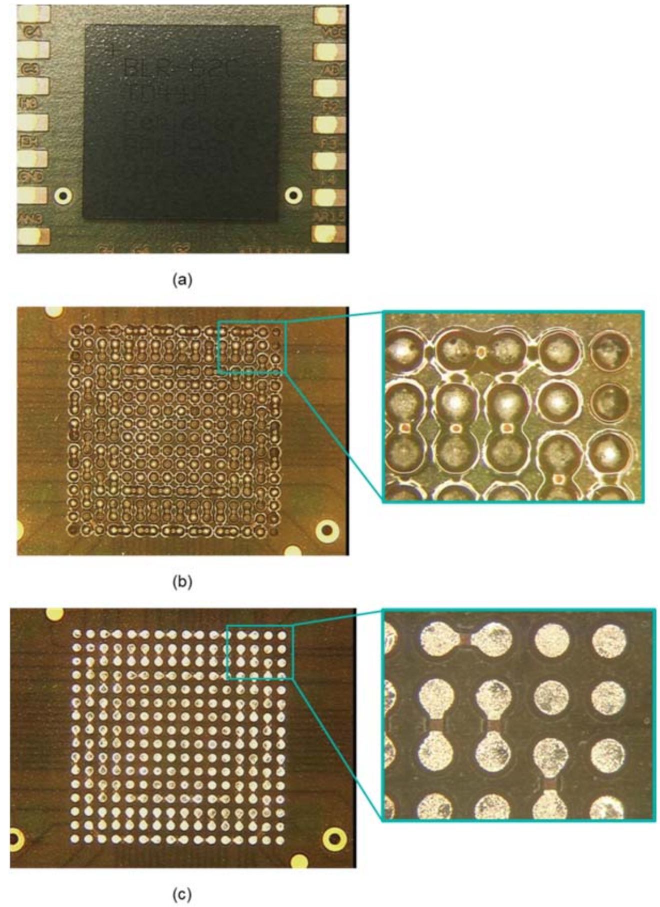


Figure 11. Pictures of the Test Boards during Board Rework of A WLP with Plastic Core Balls. (A) Before Rework, (B) After WLP Removal, And (C) After Site Dressing.

BOARD LEVEL RELIABILITY

Board level drop test and temperature cycle tests were performed to confirm the solder joint reliability. The drop test setup and board constructions follow JEDEC drop test standard [9]. JEDEC condition B (1500G/0.5ms) [10] are used. There is no failure from any of the three groups up to 1000 drops. Therefore, the WLP's with and without plastic core balls have sufficient drop reliability.

-40^{o}C to +125^{o}C temperature cycle test tests were performed for the three test groups as well according to JEDEC standard JESD22-A104 9 [11]. The temperature profile incorporates one cycle per hour cycling rate, 15 minute dwell and 15 minute ramp. The Weibull plots for the three groups are shown in Figure 12. Compared to option A with all normal balls, Option B (four plastic core ball at corners) achieved 12% higher fatigue life, and Option C (plastic core balls at periphery) achieved 20% improvement.

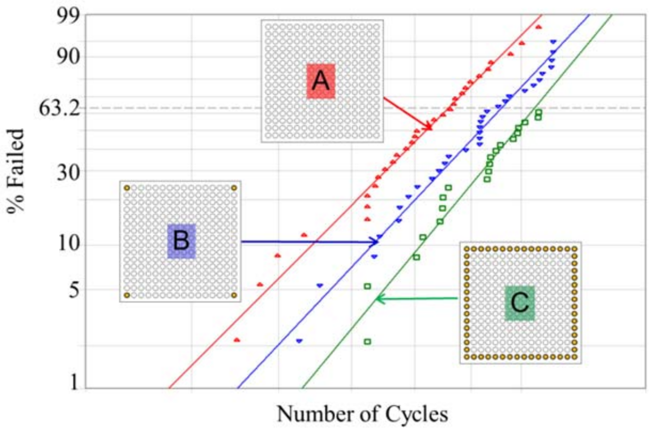


Figure 12. TC Weibull Plots For Three Plastic Core Ball Placement Options.

Failure analysis was performed to confirm that the failure mechanism is solder joint cracking at the WLP side for all three groups. The photos of the solder joint cracks from the first failed units of the three test groups are shown in Figure 13. It should be pointed out that the units analyzed here have been subjected to different TC test durations. Option A unit was stressed the shortest duration and option C unit the longest.

Cracks in a normal solder joint seem to have predictable paths. Solder joint cracks initiates from both inner and outer sides of the solder joint. This is illustrated by Figure 14 (a). The solder joint is open when the cracks initiated from both sides propagate towards the middle of the solder joint and meet. Solder joint cracks for a plastic core ball are initiated at the same locations and initially propagate along the same path (1) and (2) from two sides. When the cracks reach the Cu coating around the plastic core, however, the propagation paths are changed due to high fracture toughness of the Cu. The cracks propagate along the Intermetallic compound (IMC) outside the plastic core Cu. This is illustrated by paths 3 and 4 in Figure 14 (b). The cracks 3 and 4 eventually meet thus result in solder joint open failure. Since the stress in the direction perpendicular to the crack propagation is reduced along paths 3 and 4, the crack propagation is delayed. Therefore the plastic core balls survive longer than the normal balls. It is also expected that that partial cracks (1) and (2) will be common than full cracks for plastic core balls.

In order to further understand the effect of the crack propagation delay, a large number of solder joint cracks are investigated through dye & pry with units subjected to a given temperature cycle stressing duration. Selected solder joint crack maps are shown in Figure 15. It is seen that all plastic core balls have the same extent of partial cracks (correlate to (1) and (2) in Figure 14b). This confirms that the plastic core is effective impeding the crack propagation. On the other hand, normal solder ball cracks propagate at a more steady rate and they reach full cracks earlier. In addition it is evident that cracks initiate more easily in plastic core ball joint than normal solder joints.

Therefore, plastic core impeding the solder joint crack propagation appeard to be a major contributor to longer fatigue life under temperature cycle stressing.

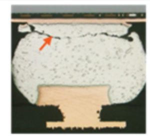
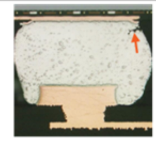
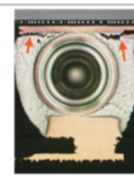
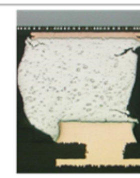
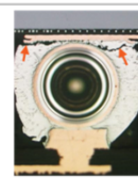
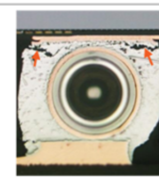
Option	Corner Joint	Non-corner Joint
A		
B		
C		

Figure 13. Solder joint cracks after temperature cycle testing.

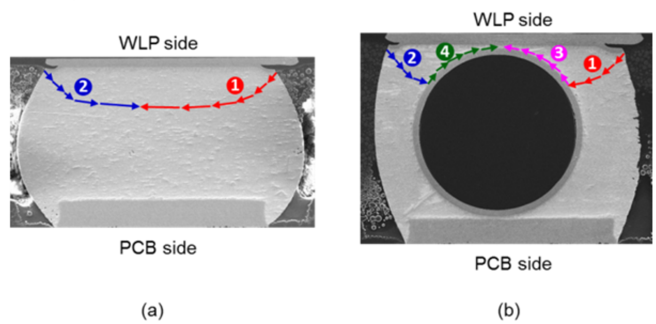
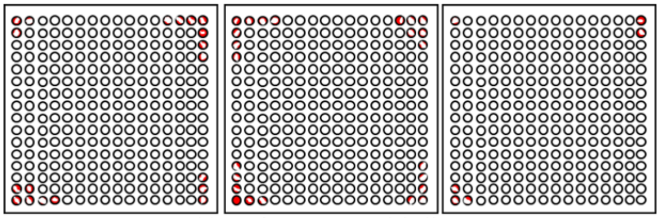
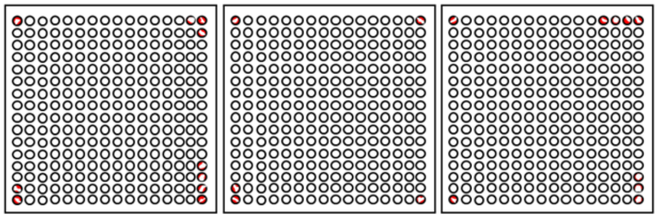
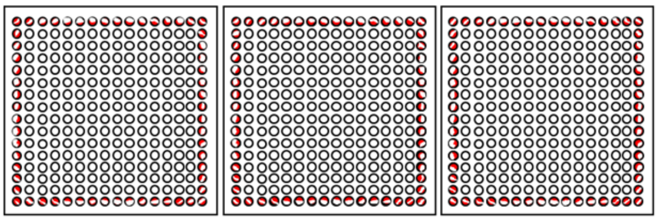


Figure 14. Illustration Of Solder Joint Crack Propagations. (a) Normal Solder Joint, And (b) Plastic Ball Solder Joint.


(a) Option A, normal balls


(b) Option B, plastic core balls at corners


(c) Option C, plastic core ball at periphery

Partial SJ Crack
Complete SJ Crack
No Crack

Figure 15. Solder Joint Crack Map Of Units Subjected To A Given TC Duration

CONCLUSIONS

In this paper, a large WLP is developed that meets board level reliability requirements through the use of plastic core balls at selected ball locations. A process is developed to place plastic core balls at selected ball locations. Manufacturability and reliabilities are assessed and the following conclusions are made:

(1) Large WLP with plastic core ball at selected locations is developed to achieve solder joint reliability improvement with low cost. WLP ball placement process is developed to accomplish mixed ball types.
(2) Up to 20% solder joint fatigue life improvement is achieved. Impeding crack propagation is one of the key contributors for the improvement.
(3) Standard assembly process can be used for WLP with plastic core balls. Plastic core balls reduce the risk of solder bridging and improve process margin since there is minimum solder collapsing. Based on the units considered in this study, there is no special requirement for board rework.
(4) Use of plastic core balls provides more SMT process margin which allows finner ball pitches.

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