Bumping BGA's Using Solder Paste Printing Process for RFI Shields Packaging

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Abstract
One manufacturing process used to attach RFI shields for medical applications/cellular phone circuit board assemblies consists of "snapping" the shell-like shields onto solder spheres that are soldered to printed circuit board [PCB] pads [1]. The snapped on RFI shields do not require soldering onto the printed circuit board and can be removed if necessary. In order to create a large enough solder balls for the shell to snap onto, a large quantity of material must be available.

Currently this process is a two-step process. The first process step requires solder paste to be printed onto the printed circuit board pads using standard solder paste printing process. The second step is to print or place solder spheres onto the printed solder paste deposits. The printed circuit board with solder paste and solder spheres are then reflowed to achieve a ball height sufficient for the RFI shield to snap onto. This two-step process requires either the use of a component placement machine (pick and place) or the use of specially designed print head that is available on only limited printing equipment. The goal of this experimentation is to develop a process that can achieve the ball height requirement using only standard solder paste printing technique and virtually any solder paste printing equipment.

Recently, work has been completed to identify a stencil design and solder paste formulation that will allow sufficient solder paste to be printed and form a large solder sphere after reflow to permit RFI shield attachment. This 'SnapShot' shield attach process eliminates the requirement to purchase solder balls and the additional equipments need to place or print the solder balls. This paper will present the results from formal studies that have been completed to verify the performance of the solder paste printing process for the 'SnapShot' shield attach process.

Introduction

The recent development in shielding technology is the use of thermoformed metallized plastic shields instead of the metal enclosures or cans. This technology is superior to the current shielding technology (metal cans) because it can be reworked if necessary. To attach the shield to PCB, a series of solder spheres are placed or printed onto the solder paste along the periphery of shield device and reflowed along with the components. The shields have a series of holes around its perimeter and these holes are used to snap and attach the shield to PCB. The spheres are used to provide both electrical and mechanical connection to the shield and the PCB.

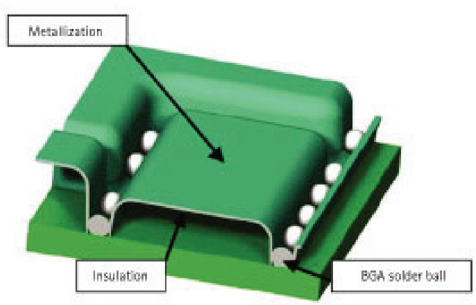

Figure 1 - Example of a Shield
[Ref: http://www.devicelink.com/mem/archive/04/10/011.html]

The BGA solder ball or spheres can be attached to the PCB using the following process

1. Surface Mount Pick and Place Machine: A standard Pick and place machine can be used to place the solder spheres onto the PCB (solder balls are available in a tape and reel or bulk format). However, this process would have an impact on the throughput of the entire assembly process.

2. Two Step Printing Process: In two-step printing process, the first step is to print solder paste onto the component pads using standard stencil printing process. For the second step, a specially designed stencil (with cut away for pads underneath the stencil) is used to print the solder spheres. The printing of solder spheres can be done using two processes. The technology currently used is to print solder balls using specially designed enclosed system. The alternative approach is to use the standard solder paste printing process to print solder paste and form solder balls during reflow. However, currently this process is limited due to the technology of solder paste and stencil design. This paper will discuss the process steps and the stencil design that will overcome the shortfalls and produce consistent solder balls. By using the standard solder paste printing process cost benefits can be achieved, because this process eliminates the need to buy additional equipment such as an enclosed print head system. Additionally, we can use well-established and understood solder paste printing technology to achieve the same goal.

The use of stencil printing process for the second step in the process has been limited due to poor process yield. The height requirement for BGA balls used in the attach process is 35-mil (890 microns) with 100% yield. To achieve the 35-mil ball height, thicker stencil with larger stencil openings has to be used. However, the use of a thicker stencil with large opening using currently available solder pastes will lead to solder bridging or solder robbing defects during reflow process. The occurrence of defects during reflow process prevents the use of standard solder paste for second step in 'Two-step printing process'. Recently work was carried out to develop stencil design rules using a new solder paste formulation that will allow sufficient solder paste to be printed and form a 35-mil (890 microns) solder sphere after reflow with fewer defects. The following factors are critical to achieve successful process using solder paste printing:

- Printing technique
- Stencil design
- Paste formulation
- Reflow process
- Substrate flatness

Results from the evaluation of printing technique, stencil design and paste formulation are presented in this paper. To provide perfect substrate flatness for the substrates during printing, a dedicated work holder was used.

Experimental Design

To evaluate the performance of solder paste printing process a designed experiment approach was used. Tin-lead and Pb-free pastes from different manufacturers were used in the DOE. The matrix below shows the various factors and their corresponding levels used in the DOE. Also the fixed factors for this study are listed below.

<u>Factors for DOE</u>

Solder Paste:	3 (Paste 'A' SnPb and Paste 'B' and Paste 'C' Pb-Free pastes)
Stencil Thickness:	2 (15 and 18 mils thick)
Stencil Opening:	4 (63, 61,59 and 57 mil square openings)
Reflow Oven Type:	2 (7 Zone convection reflow oven and Stand alone Batch oven)
Squeegee Blade Material:	2 (Metal and Polyurethane blades)

<u>Fixed Factors</u>

Stencil Manufacturing Process:	Laser Cut with electropolish
Paste Particle Size:	Type 3 powder
Reflow profile type:	Based on the Recommendations from solder paste manufacturers

The various levels in stencil opening were incorporated in one stencil design, thereby reducing the numbers of samples required for the experimentation. The runs were blocked by solder paste. The response variables used for the analysis were

1. Ball height distribution
2. Ball height range
3. Yield percentage

The Paste 'A' SnPb and Paste 'B' LF was a commercially available paste with type 3 powder. Paste 'C' LF was also commercial available solder paste with type 3 powder but it was designed to bump taller BGA balls. The paste was designed to be resistant to cold slump during printing and hot slump during reflow [2].

Test Vehicle Design

The test vehicle is a 7.36"x 2.28"x 0.062" FR-4 board. Figure 2 shows the test vehicle used for this study. The substrate contained four arrays with 400 UBMs in each array. The dimension of the UBM was 23.6 mils (600 microns) with a 78.7 mils (2000 microns) pitch. Each board was visually inspected for defective UBM before printing.

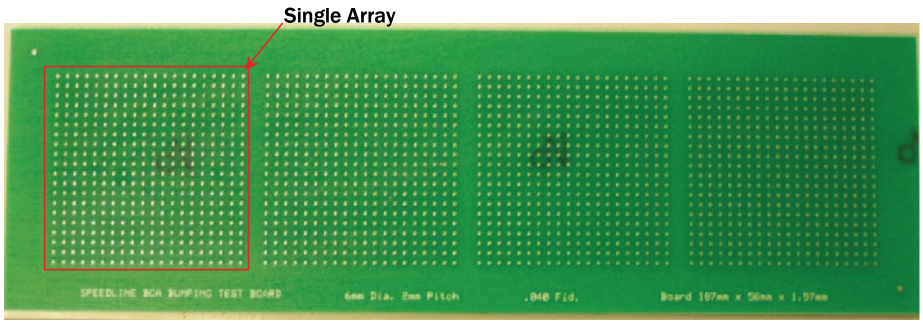

Figure 2 - Test Vehicle for Bumping BGA Balls

Stencil Design

A 15 mil (381 microns) and 18 mil (457 microns) thick laser cut stencil was used in the study. Since the substrate had four arrays of the same type, four different sets of aperture openings were used in the same stencil. The stencil apertures were designed as squares to maximize the amount of paste deposited per site. Figure 3 shows the layout of the stencil. Array 1 had a stencil opening of 63.0 mil (1600 microns), Array 2 had a stencil opening of 61.0 mil (1550 microns), Array 3 had a stencil opening of 59.0 mil (1500 microns) and Array 4 had a stencil opening of 57.0 mil (1450 microns).

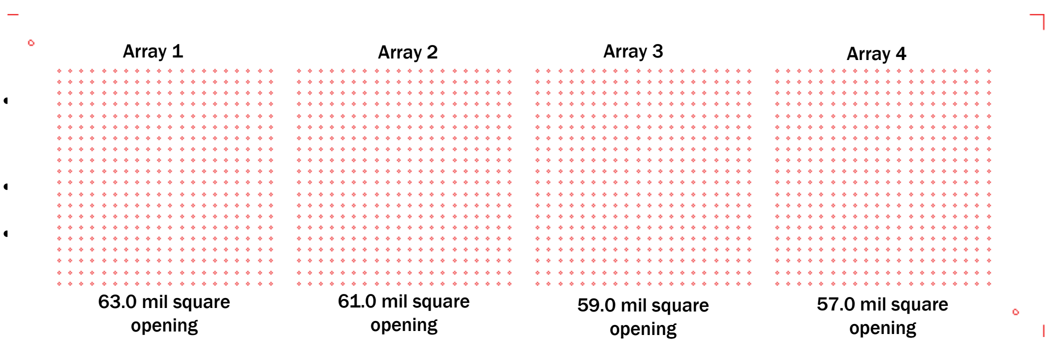

Figure 3 - Stencil Design

Process Parameters

Printing was carried out using a Speedline UP3000 printer with a dedicated work holder for the board. The boards were printed at a speed of 0.5 in/sec with a print pressure of 1.5 lbs/inch on a 10-inch long blade. These parameters ensured a clean print sweep with the minimum pressure used and proper filling of the apertures. Snap-off printing was used to alleviate flux-bleeding problems and improve the print definition.

Figure 4 shows a sample profile used for reflowing Paste 'A' SnPb. For reflowing Paste 'B' and Paste 'C' lead-free pastes recommended lead-free profile from the paste manufacturers were used. All the samples were reflowed in nitrogen atmosphere with an oxygen level of less than 20 ppm. A longer low temperature soak time was provided during the reflow to drive off the lower boiling point volatiles. This procedure was used to reduce the hot slump of paste during reflow and hence reduce and or eliminate bridging.

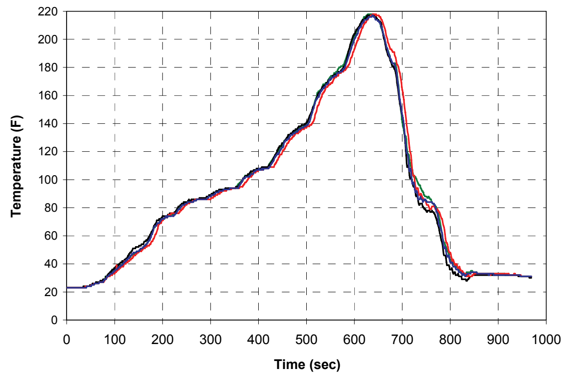

Figure 4 - Sample Reflow Profile used for Paste 'A' SnPb

Screening Experiment

Screening experiments were performed to reduce the number of factors considered in the DOE. Two different experiments were completed to evaluate the impact of oven configuration type and squeegee material on solder ball height and ball yields. Even though these factors were considered as an integral part of main DOE, we decided to perform a screening experiment to understand their influence in more detail.

Effect of Oven Configuration type

Four boards were printed with Paste 'A' SnPb paste using the above mentioned print parameters and setup. Two boards were reflowed for each oven configuration. For analysis only the results from Array 1 stencil opening was used. Array 1 stencil design was the hardest design to print and reflow. We anticipate that if a paste can print and reflow without any issues for Array 1 stencil design, then it should be able to print and reflow the remaining designs with out any issues. The resultant ball heights were measured using a laser profilometer. The height measurements were performed on the defect free solder balls. The response variables used for analysis were

1. Ball height distribution
2. Ball yield percentage

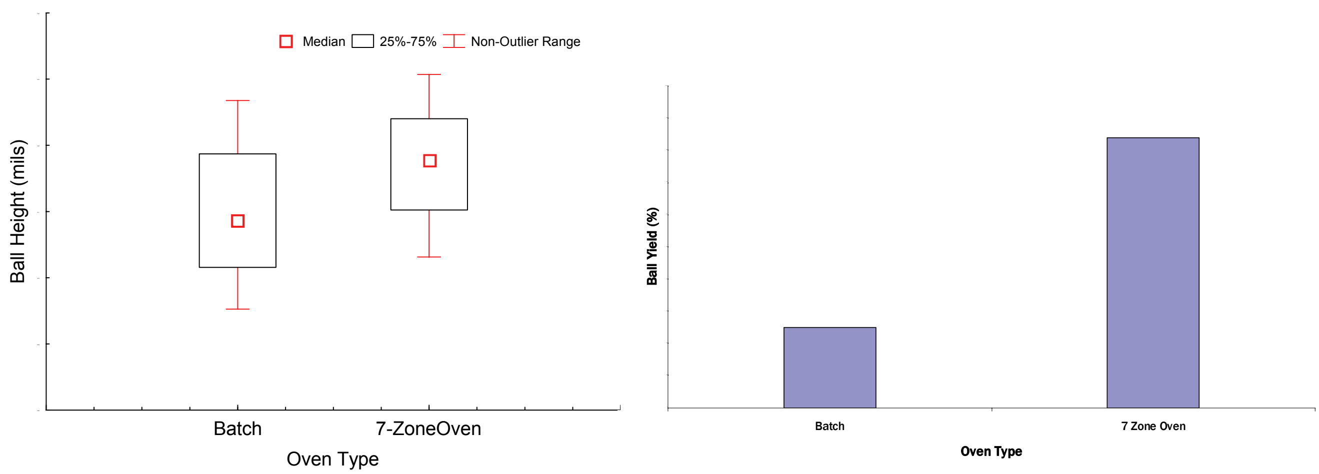

Figure 5 - Ball Height Distribution (Left) and Yield Percentage (Right) Results for Oven Configuration Comparison

The above plots show that the 7-zone oven provided a higher ball yield percentage compared to the board reflowed in a batch oven. The ball height from both the reflow process is comparable and there is no statistically significant difference in the ball height measurements. Based on the above results, it was decided to use 7-zone convection reflow oven for remainder of the experiments.

Comparison of Squeegee Material (Metal vs. Poly)

This screening experiment was performed to compare the effect of squeegee material on ball height distribution and yield percentage. Metal and Polyurethane (90 durometer) blades were used for the comparison. Two boards were printed with each squeegee material using Paste 'A' and the boards were reflowed in 7-zone convection oven. Data collected from Array 1 was used for analysis. The height measurements were performed on the defect free solder balls. As in the above experiment, the response variables used for analysis were

1. Ball height distribution
2. Ball yield percentage

Figure 6 below show the results from the squeegee material comparison experiment. The plot shows that metal blades produced taller and consistent solder ball heights compared to the polyurethane blades used in the experiment. The ball yield percentage shows that metal blades produced slightly higher yield percentage compared to the poly blades. Based on the above results, it was decided to use metal blades for the rest of experiments.

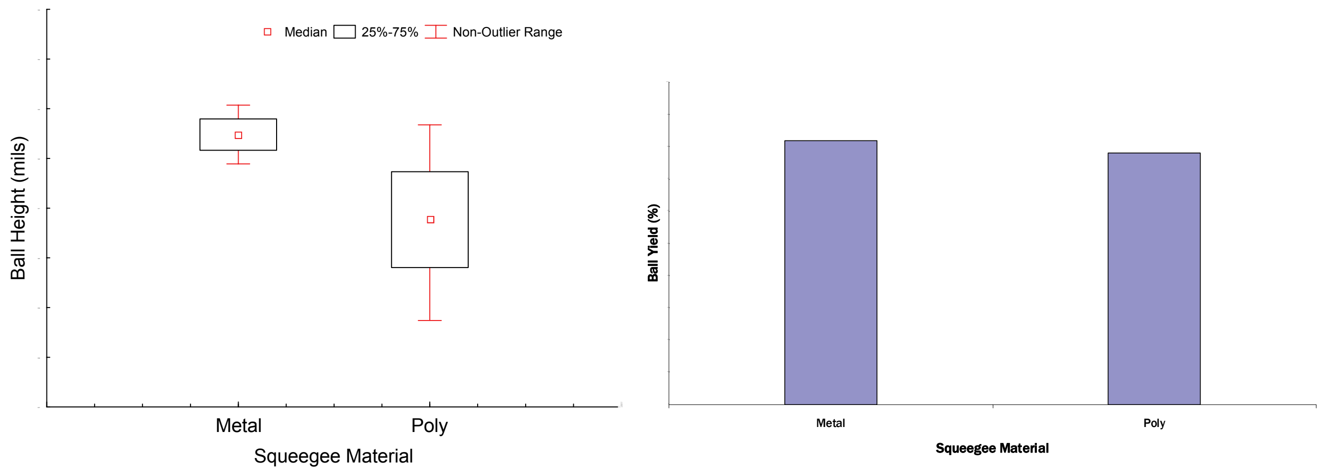

Figure 6 - Ball Height Distribution (Left) and Yield Percentage (Right) Results for Squeegee Material Comparison

Experimental Results

The results from the DOE factors of solder paste, stencil opening and stencil thickness are discussed in the following sections of the paper. For the solder paste and stencil aperture size evaluation, four boards printed at each combination using a 15-mil thick stencil.

<u>Effect of Stencil Thickness</u>

The analysis of stencil thickness data shows that a taller ball height is obtained using the 18-mil thick stencil. However, it was observed that 18-mil thick stencil has a larger height distribution compared to the 15-mil thick stencil. The comparison of yield percentage shows that 18-mil thick stencil (62.25%) had a lower yield compared to 15-mil thick stencil (81.75%). The results show that even though a higher ball height is achieved with 18-mil thick stencil, the poor yield percentage makes it less attractive. Therefore, trade offs have to be made between the achievable ball height and the yield. In this experiment 15-mil thick stencil was chosen because it provided higher yield percentage compared to 18-mil thick stencil. Figure 7 below shows the results for stencil thickness comparison.

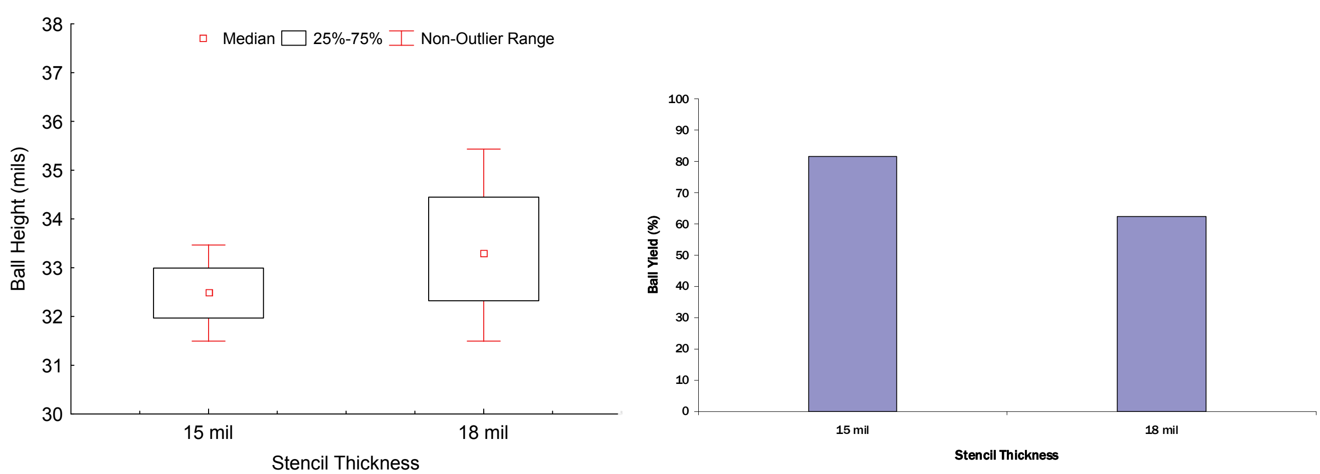

Figure 7 - Ball Height Distribution (Left) and Yield Percentage (Right) Results for Stencil Thickness Comparison

Effect of Solder Paste
The results show that selection of solder paste has a significant impact on the ball height distribution and the yield percentage. Figure below show the ball height distribution and ball yield percentage for Array 1. The results show that Paste 'C' produced taller ball height with a tighter distribution compared to Paste 'A' and Paste 'B'. Additionally, 100% yield was achieved with Paste 'C', while Paste 'A' and Paste 'B' had a yield of 80% and 78%. The results show that a consistent taller ball height with 100% yield is achieved with Paste 'C'.

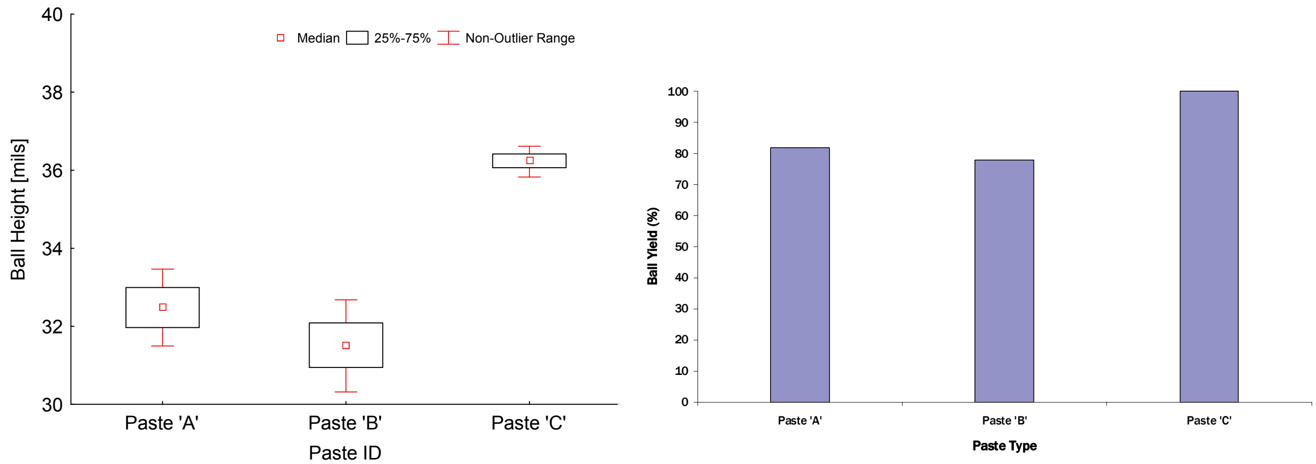

Figure 8 - Ball Height Distribution (Left) and Yield Percentage (Right) Results for Solder Paste Comparison

Effect of Stencil Aperture Size
Figure 9 below shows the ball height distribution for various stencil openings on a 15-mil thick stencil with Paste 'C' reflowed in the 7-Zone reflow oven. The plot shows that increase in stencil aperture size increases the ball. The above result was expected and nevertheless verified. However care must be taken not to increase the stencil aperture size beyond a certain size, because it might lead to bridging after the print process or during reflow affecting the process yield.

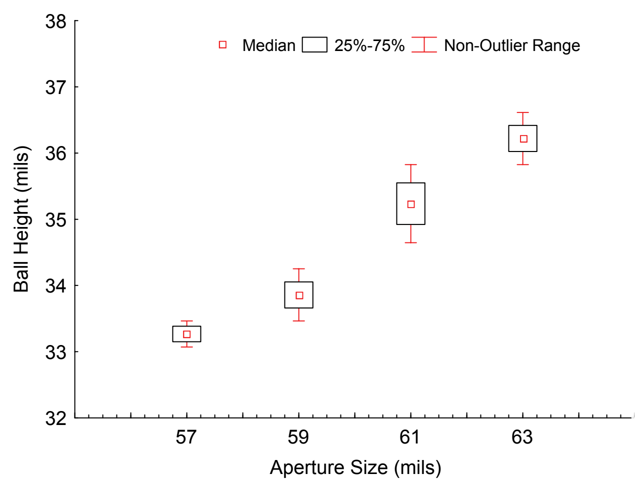

Figure 9 - Ball Height Distribution Results for Stencil Aperture Size Comparison

The plot show that a target ball height of 35 mil, is achieved with a stencil opening of 61 mil on a 15 mil thick stencil using Paste 'C'. Figure 10 below show the 100% yield BGA balls achieved for a 61-mil stencil opening. The image on the right side shows the side angle view of the ball and the consistency of reflowed BGA balls height.

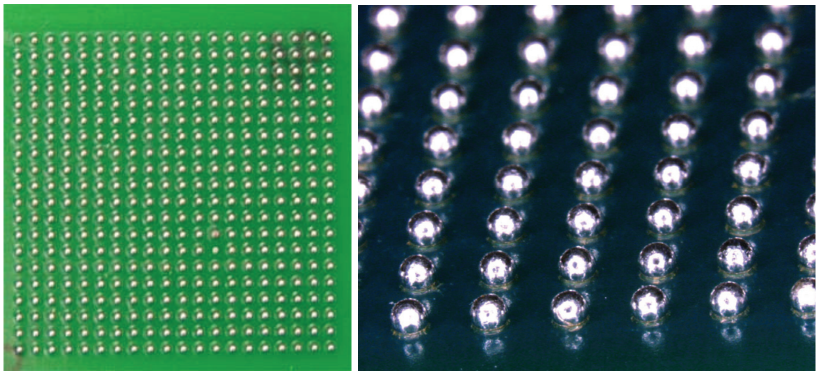

Figure 10 - 100% Ball Yield for 61 mil Stencil Opening (Left) and Side Angle Shot of Array 2 (Right)

Recommendations for a Successful Bumping Process

The following section discusses process recommendations to successfully bump BGA balls for 'SnapShot' attach process using solder paste printing process.

Stencils

The key factor in stencil design is to maximize the stencil opening while optimizing the stencil thickness. Based on the solder volume requirements, the thickness and the stencil opening should be determined. Spacing between the apertures should be greater than 7.9 mils (200 microns). The results show that a web width of less than 7.9 mils leads to solder bridging and solder robbing. The stencil can be a Laser Cut stencil or Electroform stencil.

Solder Pastes

The paste bumping experiment has been conducted with three different pastes. The test results show that Paste 'C' LF had a superior performance compared to the other two pastes. The Paste 'C' was designed to easily release from stencil apertures and the higher metal content makes the paste resistant to cold and hot slump.

Reflow

To minimize the occurrences of solder bridging and solder robbing during reflow, the profile should be modified to have a longer low temperature soak time to drive off the lower boiling point volatiles. Additionally, the substrates should be reflowed in an inert atmosphere to prevent oxidation. The nitrogen level should be less than 20 ppm of oxygen.

Printing

The above results show that ball height requirements is met using the stencil printing process. During the printing process the parameters (Print Speed, Print Pressure and Separation speed) should be selected to insure a clean print sweep with the minimum pressure and proper filling of the apertures.

Conclusions

Standard solder paste printing technology and equipment can be used to achieve the required solder ball height used in the shield attach process. The 100% yield of BGA balls in this process development work verifies that capability. Results show that by properly selecting the process conditions (i.e., paste, stencil and print parameters), it is possible to push the limits of the stencil printing process. This study indicates that, the solder paste stencil printing process can be attractive, cost effective alternative process for the mass bumping of BGA balls in the shield attach process.

Reference

1. World Wide Web, 'http://www.devicelink.com/mem/archive/04/10/011.html'
2. Huang, Dr. Benlih and Lee, Dr. Ning-Cheng, "Low Cost Solder Bumping Via Paste Reflow", Journal of SMT, Volume 15, Issue 1, 2002.