WARPAGE STUDIES ON LARGE BGA SITE AND CORNER BRIDGING MITIGATION METHOD

Steven Perng, Weidong Xie, Cherif Guirguis
Cisco System, Inc.
San Jose, CA, USA
sperng@cisco.com

ABSTRACT

During the process development of large BGA's, it is observed there are corner bridging formed in some cases, where both package and fab are within spec based on Thermal Moiré technology measurement. A test vehicle is designed to study the impact of PCB features, such as VIPPO design, on soldering dynamics and subsequent defects. The results show the VIPPO and non-VIPPO mixed design tends to have more corner bridging than all dog bone or all VIPPO design. Due to the limited sample size, more study is needed to have further understanding the impact of PCB features on the rigidness of PCB material during the SMT reflow process. Before a conclusive root cause and solution is found, the Corner Standoff Block (CSB) can be used as a corner bridging mitigation tool for 1.0mm pitch BGA's.

Key words: BGA, warpage, corner bridging, standoff height, Corner Standoff Block.

INTRODUCTION

There have been extensive studies on Large ASIC BGA component warpage due to CTE mismatches among materials packed into the package. The phenomenon is well known with defined industry specs. However, as the routing density and transfer speed is getting higher, special PCB design features like VIPPO and back drill becomes more and more common for high-end products. These features may introduce additional warpage due to the interaction between package and PCB through the reflow process, which could results in assembly defects such as corner joint bridging.

Aims to address these new challenges, this work studied warpage behavior of 55mm ceramic BGA on high speed/high density board with VIPPO and/or back drill. On PCB side, Thermo Moiré warpage measurement on BGA site has been conducted through the process, including incoming, post 1st reflow, post 2nd reflow, and post rework. On package side, component has been 100% inspected for coplanarity, and been characterized by Thermo Moiré for Warpage mode.

After the BGA been placed on the board and reflowed, a large magnitude of warpage around the corner is observed from the Moiré measurement. In some cases, it may induce and form the bridging defect. A non-destructive 3D X-ray Microscopy (XRM) is used to measure the standoff height and ball-to-ball clearance. The non-destructive data has been verified against the cross-section measurement. These data were then fed into a numerical simulation model to estimate the minimum standoff height required in mitigating the risk of corner bridging.

Based on the analysis, a high precision Corner Standoff Block (CSB) has been designed to prevent the corner bridging issue by providing a minimum standoff height during assembly reflow. The Corner Standoff Block is in tape and reel form and ready for high speed SMT Pick & Place process. To be compatible with current SMT process, the joint of CSB to PCB pad could be either by solder paste printing process or epoxy dispensing. The effectiveness of CSB to mitigate corner bridging has been validated though process yield data, it is therefore considered as a cost-effective mitigation for large BGA corner bridging defect.

In summary, extra warpage has been observed around the corner of large BGA. It is believed the warpage resulted from the interaction between BGA package and PCB. Further study would be required to better understand the mechanism. A collaborative effort among the packaging house, fab, OEM, and CM are needed to further understand and address the issue.

WARPAGE ON LARGE BGA SITE

During the process development of a 55mm CBGA, the warpage measurement on package side and flatness measurement of BGA site on PCB side are among the critical factors to ensure the process yield in a production environment.

Industry Standards

There are two widely referenced industry standards for package warpage. The first one is JEDEC Publication No. 95[1]. It states, for BGA's great than 15mm with 1mm pitch and 0.6mm ball diameter, the flatness requirements during reflow should be within 0.23mm (or 9.2mil) for positive flatness (convex).

The second is in JEITA ED-7306[2]. As in Explanatory Table 1, the maximum permissible package warpage for 1.0mm BGA and FBGA (Absolute value) is 0.22mm (or 8.8mil)

It is noted that both standards are based on experimental data. JEDEC 95 is based on a survey of task group participants for “Know Good” and “Known Fail” data; while the JEITA ED-7306 is calculated from experimental data with pre-defined assumptions. Though approaching from different directions, the warpage specs from JEDEC 95 and ED-7306 are landed in a similar range, which is 9.2mil vs. 8.8mil.

Warpage Measurement

To understand the warpage behavior, both 55mm CBGA and board went through warpage characterization through the assembly process using Thermal Moiré technology.

On package side, the warpage is in the range of 3mil from room temperature to peak temperature (Figure 1), which reflects the stiff nature of ceramic substrate.

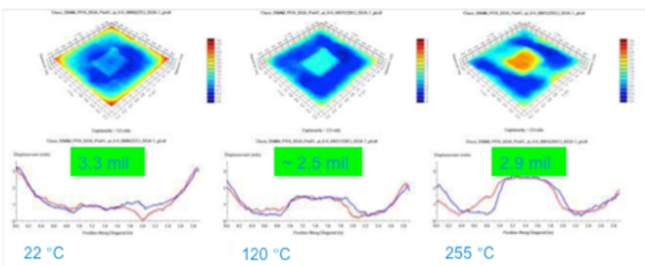

Figure 1 – Thermal Moiré warpage measurement of a 55mm CBGA

On PCB side, the emphasis is to measure the warpage change through the SMT process. The warpage measurement was performed at three different process steps. First measurement was performed at incoming. The warpage measurement on CBGA site was performed from the topside of PCB at both room temperature and elevated temperature. After the CBGA is mounted, measurement from the top is blocked by the component. Therefore, the second measurement was performed from the bottom side of CBGA site. Then, the CBGA is removed and the third warpage measurement was performed from the bottom side as well.

The maximum PCB warpage on BGA site from these three steps are shown in Table **1**.

Table 1 Maximum PCB Warpage on BGA site

Unit: mil	Site 1	Site 2
Room temp, Bottom	2.0	2.2
Room temp, Top	1.2	1.6
Bare board at elevated Temp, Top	4.0	5.7
After Placing CBGA, Bottom	10.3	11.1
After Removing CBGA, Bottom	2.1	3.0

The room temperature measurements are well within spec. At elevated temperature, the warpage are slightly higher. It may due to relaxation or stress relieve when the temperature goes over the material curing temperature.

The warpage drastically increased after mounting the CBGA. It increases from 4~6 mils to 10~11mils range. In this case, the CBGA is 55mm mounted on a 125mil PCB.

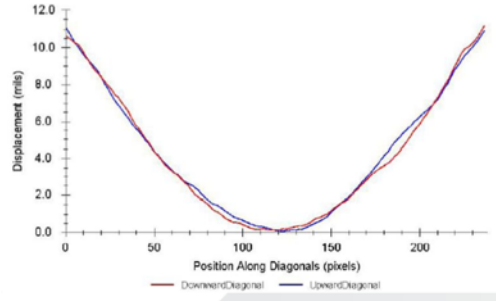

Figure 2 – PCB warpage measurement on BGA site after mounting

The size of BGA (Figure 2) and the thickness of board may have certain impact on large warpage amount change. However, any PCB design features, which may change PCB rigidness, are possible source of causing excessive warpage. As the routing density and transfer speed is getting higher, certain PCB features, i.e. Via In Pad Plated Over (VIPPO) and back drill (Figure 3), have become more popular in high end product.

As shown in Figure 3, VIPPO is adding a Cu barrel directly under the soldering pad from top to bottom, which increases the local stiffness. Though the traditional dog-bone design also has a Cu barrel, it does not connect to the soldering pad directly. The through hole via connects to a fan out via pad. Therefore, it is not adding stiffness to the soldering pad itself. On the contrary to VIPPO adding local stiffness, the back drill feature is reducing the local stiffness by drilling out part of the Cu barrel. It is even less rigid than dog bone design. Will the local stiffness or rigidness have any impact on soldering dynamics during reflow process? If it does, will the impact induce any soldering defect, such as bridging or open?

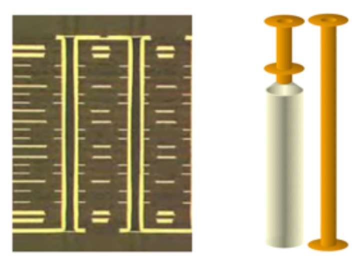

Figure 3 – VIPPO (left) and back drill (right)

To study the phenomenon, a test vehicle is designed to compare the defect rate among different via designs, including all dog-bone, all VIPPO, and the mix mode. The test vehicle is 125mil in thickness with eight 55 BGA's, four with ceramic substrate and four with organic substrate. The study is to do a qualitative investigation on the impact of VIPPO design on soldering defect.

The results are analyzed based on the substrate and the via designs. For the substrate, the organic substrate tends to have more corner bridging than that of the ceramic substrate. It may be an indication that the PCB via design has more impact on soldering dynamics of the organic substrate (which is prone to warp) than that of the ceramic substrate (with stiffer in nature).

As shown in Figure 4, for the group with organic substrate, the VIPPO and non-VIPPO mix mode tends to have more bridging than that of the all dog-bone or all VIPPO. The organic substrate is known to have more warpage. However, it has much less solder bridging on all VIPPO and all dog-bone design than that of mix mode. It is also noted that most of the corner bridging are on two cross corners, which is consistent with the "potato chip" warpage mode.

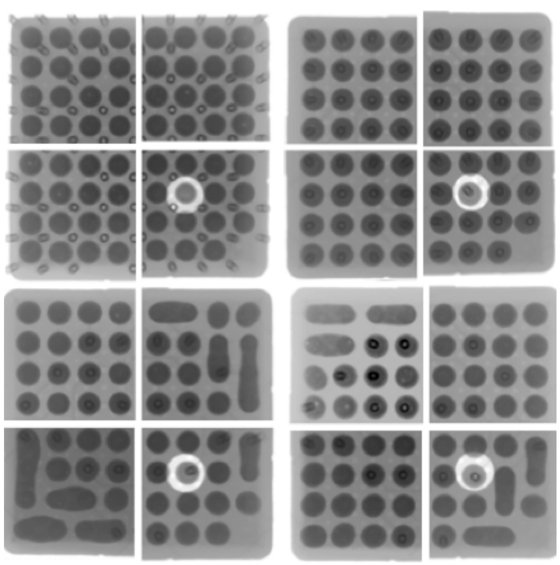

Figure 4 – Corner bridging of different via designs
All dog-bone (Top left), All VIPPO (top right),
Mix mode (Bottom left & right)

The results are based on limited sample size. For a more conclusive result, further study with larger sample size may be needed.

The VIPPO and back drill PCB features have been introduced to the engineering community for few years. It may take few more years to fully understand the impact of these features on PCB rigidness, soldering dynamics, and subsequent soldering defects, particularly on BGA site larger than 40mm.

To control the process yield and quality, it is desired to have a mitigation tool before the root cause is found and solved. The idea of Corner Standoff Block[3] (CSB) is therefore comes up and designed as a mitigation tool for the corner bridging defect.

Standoff Height Analysis

In order to mitigate corner bridging defect, the Corner Standoff Block has to be manufactured precisely with certain height, which can prevent corner bridging from forming during reflow process. The ideal height should be lower than the typical 1.0mm pitch BGA standoff height in such a way that the substrate lands on the block only when the substrate exhibits an excessive warpage. If the substrate warpage is within spec, there should be a gap between the substrate and the block.

Typical Range of Standoff Height for 1.0mm Pitch BGA

Before the minimum standoff height is defined, the typical standoff heights of 1.0mm pitch BGA's have to be surveyed. Two BGA's with 1.0mm pitch are analyzed.

The first case is to simulate the worst scenario (Figure 5). The standoff height is 11.85~19.39mil. At 11.85mil, there is still a clear gap between two balls with no bridging formed.

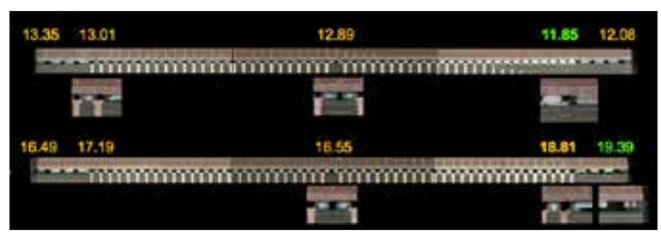

Figure 5 – Typical standoff height range of 1mm pitch BGA

The second case is a 55mm CBGA representing typical case. The standoff height range is 15.2~16.8mil.

Based on these two cases and other data from survey, appropriate minimum standoff height can be set at around 12mil.

Minimum Standoff Height

In addition to the cross-section analysis, numerical analysis based on Surface Evolver[4] has been also performed to calculate the ball clearance vs. standoff height. The modeling includes two scenarios. The first one is to simulate self alignment with no shifting and no tilting; while the other is to simulate the warpage measurement in Table **1**, with 1mil shifting and 0.56° tilting. As shown in Figure 6, with 12mil standoff height, the ball-to-ball clearance is in 7mil range.

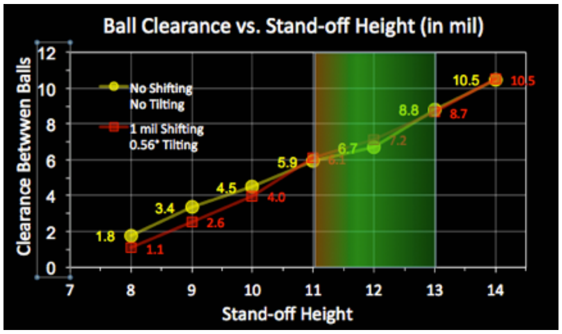

Figure 6 – Numerical Modeling of Ball-to-Ball Clearance vs. Standoff Height for 1mm pitch BGA

Minimum standoff height definition can also be found in JEITA ED-7306[2], which states the lowest solder joint height without solder bridge for 1.0mm pitch BGA is 0.28mm (or 11.2mil). In a footnote, it also states "It is known that the balls do not bridge as far as the collapse of solder balls does not make the ball diameter expand beyond 80 % of the ball pitch." For a 1.0mm pitch BGA, the 20% clearance is 0.2mm (or 8mil).

Based on the cross-section data, the numerical modeling, and the JEITA ED-7306, it should be appropriate to set the minimum standoff height of 1.0mm pitch BGA at 12mil.

CORNER STANDOFF BLOCK (CSB)

Corner Standoff Block (Figure 7) is a cylindrical Cu block plated with NiAu with 30mil in diameter and 12mil in thickness. It is in tape-and-reel form ready for high speed SMT pick & place process.

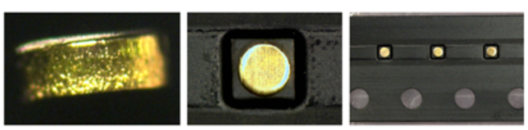

Figure 7 - Corner Standoff Block in Tape & Reel Form

The Corner Standoff Block can be interconnected to the pad by either solder paste printing process or epoxy dispensing process. The post process overall height are verified through test vehicles.

Post-process overall peak height verification

For solder paste printing process, total of 1,440 blocks are placed, reflowed, and measured by OGP for peak height. As shown in Figure 8, the range of post reflow peak height is from 11.5~13.3mil. There is a drifting down trend as the stencil aperture is going larger from 20mil to 25mil to 30mil. The drifting may due to the available peripheral spacing of pad, which is to be used as the reference plane by OGP. As the solder covering the edge of the pad, the reference plane is gradually getting higher, and results in a lower measured height. After correction, the overall post reflow height is in the range of 12~13mils with few outliers.

For the epoxy dispensing process, a matrix of 48 glue dots are dispensed on an open solder mask area. After placing the block and curing, the post curing overall peak height is in the range of 12.1~12.3mil, which is only 0.1~0.3mil higher than the 12mil block spec height.

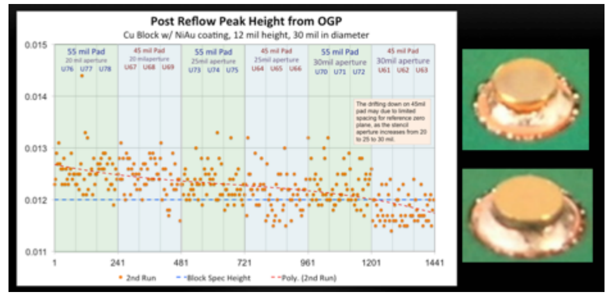

Figure 8 – Post reflow peak height measurement of Corner Standoff Block (CSB) by OGP

Implementation

After the manufacturing process been defined and verified, the Corner Standoff Block is implemented on a test vehicle.

The 55mm organic substrate BGA on the test vehicle has experienced about 30% corner bridging issue in previous built (as shown in Figure 2). With no additional design change, the Corner Standoff Block is added to each of the four corners of the BGA by epoxy dispensing process. After placing the Corner Standoff Block, the corner bridging defect rate drops to zero.

Exception I – Asymmetric Solder Formation

During the development process, there are pre-defined assumptions on soldering dynamics and solder ball formation. These assumptions are used for numerical modeling as well as the corner bridging formation. The key assumptions are

- Circular, parallel, coaxial wetted pads.
- Energy is surface tension of free surface.
- Both pads represented with constraints.
- Liquid entirely bounded by facets.

During the cross-section analysis, there are some corner bridging formations are out of the assumptions of numerical modeling. The solder formation is very asymmetrical (Figure 9). As flowing out toward one side of the pad, the solder formation is on top of solder mask and not as spherical as the other side, which is still wetted with the NSMD pad. With solder flowing toward one direction, the solder bridging can be formed with less solder volume. This formation is not within the assumptions of current numerical modeling.

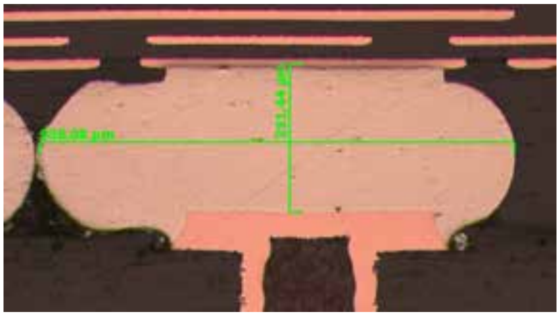

Figure 9 – Asymmetric solder formation

It is also noted the gap between the two solder balls in Figure 9 are very small. Similar formations are also observed in other BGA locations. What keeps these two solder balls from merging and bridging together is not clear. Further studies in this area may help to understand factors keeping the two solder not merging together. And, possibly use the factor as a bridging prevention tool.

Exception II – Corner bridging with CSB

The Corner Standoff Block has been implemented on few hundreds BGA locations with only one corner bridging defect reported.

The corner bridging is on a 55mm organic BGA. The defect location is placed in a non-destructive 3D X-ray Microscopy (XRM) to have a three dimensional view on the solder formation. Then, have cross-section on five different lines for standoff height measurement.

From the 3D X-ray images on the left (Figure 10), the bridging can be seen clearly with a necking in the middle. And, the bridging is likely not in touch solder mask.

From the image on the right, it shows two solder balls are close together (~0.62mil) without forming a bridging. This phenomenon is similar to Exception I.

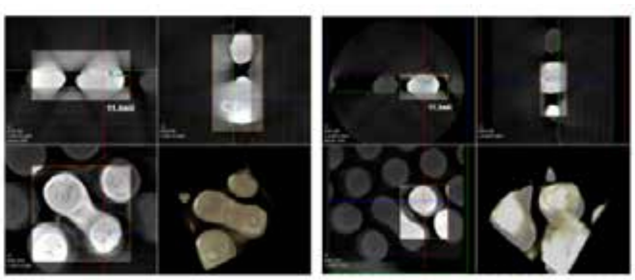

Figure 10 – 3D X-ray images around the bridging pins

After the non-destructive 3D X-ray, the fail location is cross-sectioned along 5 lines for standoff height measurement (Figure 11). The block height is 12.08mil, which is close to the spec on 12mil. The standoff heights of the three corner pins on first row are also close to 12mil; while the 5 pins on 2nd row are higher on the edge (12.32~12.28mil) and lower in the lower right corner at 12.04 mil. The diagonal standoff height is from 12.08mil to 12.76mil to 12.80mil toward the center, which is as expected to have lower in the corner and higher in the center.

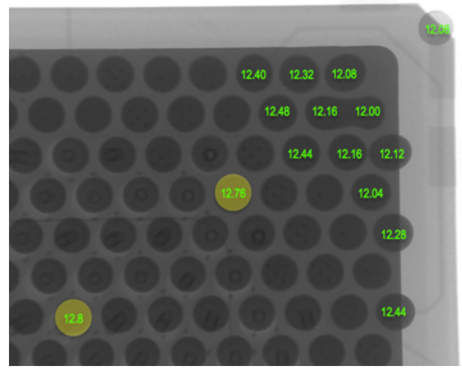

Figure 11 – Standoff height measurement around the bridging location

Based on numerical modeling, JEITA ED-7306, and previous cross-section data, 12mil standoff height should be sufficient to keep the neighborhood solder balls from forming a bridging. Therefore, it is not clear, during the reflow process, were the standoff height of the first two rows lower than the 12mil corner standoff height supported by the Corner Standoff Block? Or, there are other soldering dynamics, we are not aware of, induced the bridging.

CONCLUSION

Corner solder joint bridging is one of the most common defects especially for large BGA components during assembly. The defects have been observed, in some cases, even both the package and fab warpage are within spec. New board design features and new PCB materials may exacerbate the occurrence of the defect. The phenomenon, though is believed to be rooted from the interaction between BGA components and PCB, further study is a necessity to understand and address the issue. The Corner Standoff Block (CSB) has been developed and adopted in production as an effective mitigation for preventing the corner bridging defect.

The paper calls for attention to SMT community as a collaborative effort would be needed to understand the mechanism of package-PCB interaction, which by far is believed to be the root cause of BGA corner bridging. More studies and field data are needed to have further understanding and possible solution for this yet fully understood issue.

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