High Performance and Cost-Effective Wafer Bumping Approach with Solder Paste Printing for Small LED Die

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Abstract

The increasing trend of LEDs die size reduction driven by the demand for high-resolution displays and compact wearable devices, presents significant challenges for assembly packaging. Achieving sufficient paste volume and maintaining low void rate in the solder paste during the die mounting on the substrate process is crucial for high performance LED applications. This paper presents a novel approach to wafer bumping using solder paste printing process. It demonstrates the methods used to achieve good solder paste printing volume with low void rate via three reflow steps using different stencil designs. Sn/Cu alloy solder paste with T7 powder (2~11um) is used for the study. Solder paste bump height post-reflow process and the void rate in the solder paste were measured and analyzed with 3D AOI and X-ray, respectively. The study and methods used with Heraeus solder paste achieved good package reliability, function test passing 85°C/85% & 60°C/90% Wet High Temperature Operating Life (WHTOL) 1000 hours, and Powered Temperature Cycling (PTC) ON/OFF 1000 cycles, -40°C ~ 85°C Temperature Cycle Testing (TCT) 1000 cycles. The result from this study offers valuable insights and solutions for addressing the assembly challenges associated with small LED die sizes. It offers a good solution for achieving high-performance and cost-effective wafer bumping process for miniLED applications.

Key words

LED wafer level printing, Voids, Solder paste, Sn/Cu alloy and package reliability

Introduction

Solder paste printing is a fundamental process in electronics manufacturing, traditionally used for applying solder paste to material surfaces[1]. Over the years, advancements in printing equipment have expanded its applications beyond the conventional realm. One notable use case is wafer level printing, where solder paste is directly applied to semiconductor wafers.

In contrast to the traditional chip mount assembly process, which involves applying adhesive to the lead frame or substrate, wafer level printing offers several advantages:
1) Speed and Efficiency: By using a stencil, solder paste can be rapidly printed onto the wafer surface. This streamlined process reduces assembly time and enhances overall efficiency.[2]

2) Stencil Design Impact: The height of solder paste bumps on the wafer is influenced by the stencil design. Optimizing the stencil parameters ensures consistent and reliable printing results.[3]

3) Powder Size and Paste Properties: The choice of solder paste powder size and its properties significantly affect the printing outcome. Fine-tuned formulations lead to better solder joint quality.

In this study, we compare two solder pastes: Heraeus Welco SnCu T7 and standard SnCu T6. Our evaluation focuses on two critical aspects: 1) printing stability, we assess the stability of the printing process using both pastes. Factors such as paste flow, stencil release, and consistency play a crucial role. 2) void performance, after a 4-hour staging time and three reflow cycles, we examine the occurrence of voids in the solder joints. Void-free joints are essential for reliable electronic connections.

II. Experiment setup

A. Materials

We have selected the following two materials for our study:
1) Heraeus Welco solder paste with SnCu T7 powders made by Welco technology,
2) A standard solder paste with SnCu T6 powders.
B. Stencil Designs and Volume Areas: (the paper only includes results from POR and Design1. No mention of other designs)

POR	7500 um^3
Design1	8250 um^3
Design2	9000 um^3
Design3	8800 um^3
Design4	9075 um^3
Design5	9350 um^3

C. Machine Specifications
The experimental setup includes the following equipment:

1) High-accuracy printer: accuracy: ±12.5 µm, printing directly onto the wafer surface, stencil release and consistency are critical factors for successful printing.
2) Furnace reflow system: heat 8 zones, cooling down 2 zones, oxygen concentration: 25 ppm. Reflow soldering ensures proper bonding and joint formation.

D. Application
Printing on the same 4-inch LED wafer with stencil volume areas matching those of the Welco paste and standard solder paste SnCu T6

III. Results and Discussion

After the reflow process, we measured the solder paste bump heights for both SnCu T7 and standard SnCu T6 pastes across various stencil designs. Here are our findings:

1) Welco SnCu T7:

Demonstrated consistently higher bump heights compared to standard SnCu T6 paste.

Standard SnCu T6: Showed lower bump heights in all stencil designs after printing and reflow. The difference in bump height between SnCu T6 and Welco T7 was noticeable as shown in Figure 3.

One of the key factors affecting bump height consistency is the paste release volume consistency. Several factors influence the printing release performance of solder paste. The most important factor to ensure consistent paste release at fine stencil openings, is the quality of the solder powders. Welco SnCu T7 powders as shown in Figure 1 demonstrates extremely narrow particle size distribution between 2 to 11um, perfectly spherical shapes, and defect-free smooth surfaces with minimal oxide level. This ensures the solder paste can be released at consistent volume from the stencils onto the substrates, which will translate into consistent bump volume and height after reflow.
It has been established that substrate warpage significantly affects printing defects, particularly in stencil openings as small as 55µm with a 90µm pitch. To mitigate this, it is recommended to use a universal vacuum pallet support during printing. Additionally, Solder Paste Inspection (SPI) equipment has limitations in measuring paste volume due to pixel size and algorithm constraints. The pixel size of the SPI equipment is crucial for ensuring the quality of 55µm solder paste printing. Thus, selecting SPI equipment with a 3.5µm pixel size is vital for manufacturers striving for high throughput and reliability in their solder paste printing processes. To address measurement errors, the threshold method is necessary. For a solder volume requirement of 55µm, a 3.5µm pixel size and a threshold height method are advised. Design of Experiments (DOE) has determined the optimal parameters for zero defects for T7 solder paste at 55µm stencil opening and 90µm pitch. Printing pressure between 4.2 and 6.2kg, printing Speed from 20 to 31mm/s, and separation speed above 17mm/s were optimal conditions found.

Another key factor affecting bump height will be the void% of the solder bumps formed after reflow, as illustrated in Figure 8. It is desirable to have low and consistent average void % and single void % (largest void size in a single joint) even after multiple reflows, so that the bump heights do not vary over the wafer bumping and subsequent assembly processes. Factors affecting void % include 1) oxide amount on the solder powder surface 2) flux design 3) reflow profile. Oxide on powder surfaces are removed by the flux system during the reflow process, where reactions take place and release gases which should escape from the solder bump and not get trapped to become voids. For Welco solder powders with spherical, smooth and defect-free surfaces as shown in Figure 1, the surface areas are at minimum which also means the lowest mount of oxide possible. Combined with a well-designed flux system that removes oxide easily without trapping excessive gases, Welco T7 paste certainly met the lower void and consistent bump height requirement. Fine-tuning the reflow process parameters can further minimize void level and bump height. Extensive DOE has been conducted to obtain the best reflow profile (Figure 2), which results in minimal void even after multiple reflows as shown in Figure 4 to 7. Both Heraeus Welco T7 paste and standard T6 paste showed good void % over multiple reflows, if we set the average void % specs at 5%. There are fewer outlier points with high void % for Welco T7 paste, likely due to the advantage of smooth and round Welco powders with minimal oxide.

In summary, Welco SnCu T7 outperformed SnCu T6 in terms of bump height level and consistency. However, the choice of bump height should align with the specific assembly needs and overall reliability goals. Users can consider factors such as joint reliability, thermal cycling performance, and overall assembly quality. The paste printing bumped dies demonstrated robust reliability by passing the 1000hrs and 1000 cycles reliability test as shown in Table 1

WHTOL 85°C/85%	1000 hrs
WHTOL 60°C/90%	1000 hrs
PTC ON/OFF	1000 cycles
TCT -40°C ~ 85°C	1000 cycles

Table 1. Reliability test conditions for miniLED dies

IV. Conclusion

Our experiment with Heraeus Welco SnCu T7 paste reveals several key findings related to wafer level printing, where Welco SnCu T7 consistently demonstrates superior printing volume release, good and stable bump height, and excellent reliability result. This characteristic is essential for precise and efficient solder paste application. The total void rate remains low and stable. Single void occurrence is also minimal. These factors contribute to reliable solder joints. Welco SnCu T7 is suitable for small-sized die and multi-assembly processes. Its performance withstands multiple reflow cycles. In summary, Welco SnCu T7 stands out as a reliable solder paste choice for wafer level printing applications. Its consistent performance ensures high-quality assembly results. In fact Heraeus Welco solder paste series have been in mass production for years for wafer bumping applications, demonstrating excellent reliability, faster throughput and thus potentially lower cost of ownership than other approaches including ball drop and plating.

Acknowledgment

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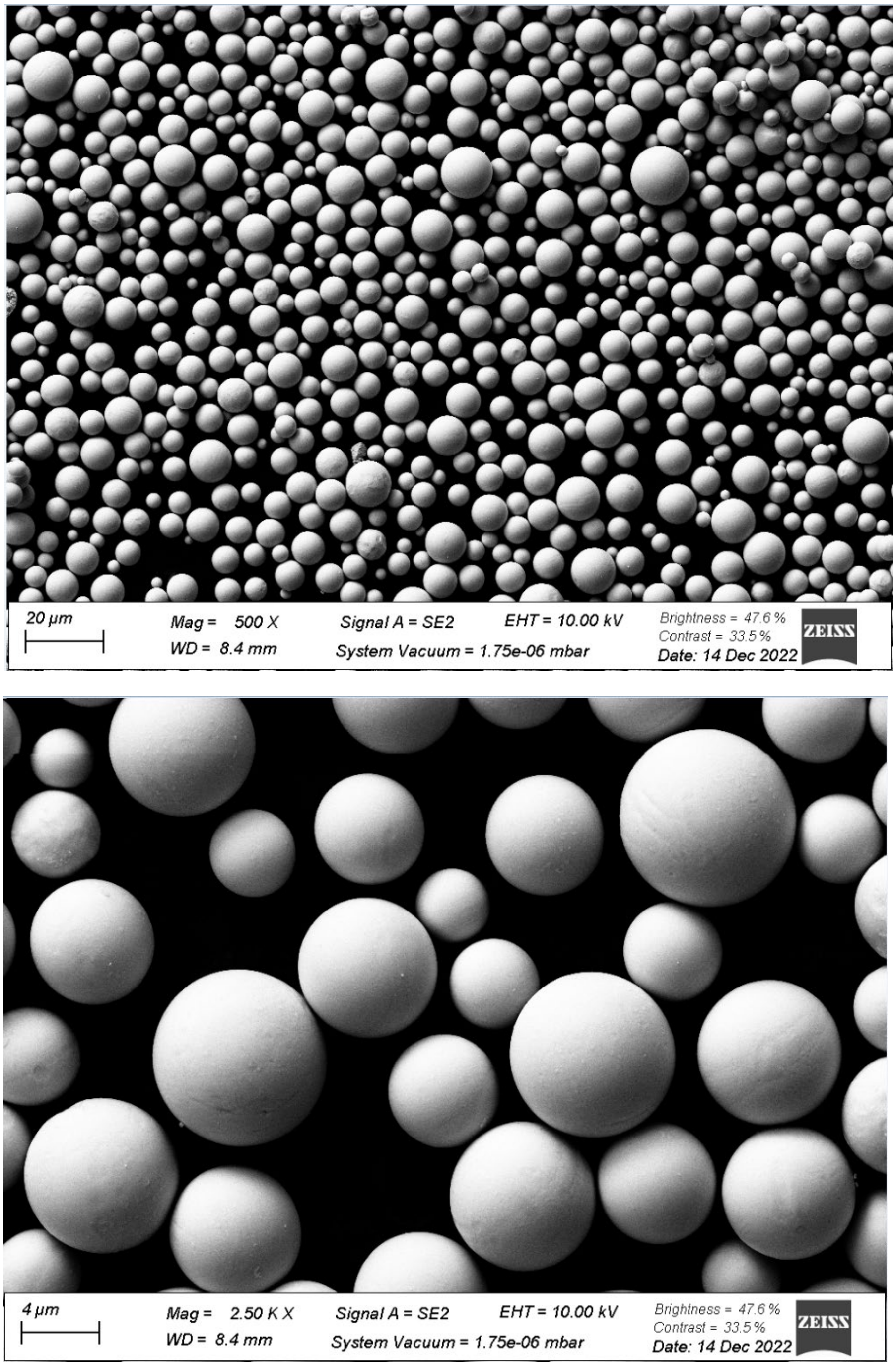

Figure. 1. Heraeus Welco T7 SnCu powders SEM images at 500x & 2500x magnifications.

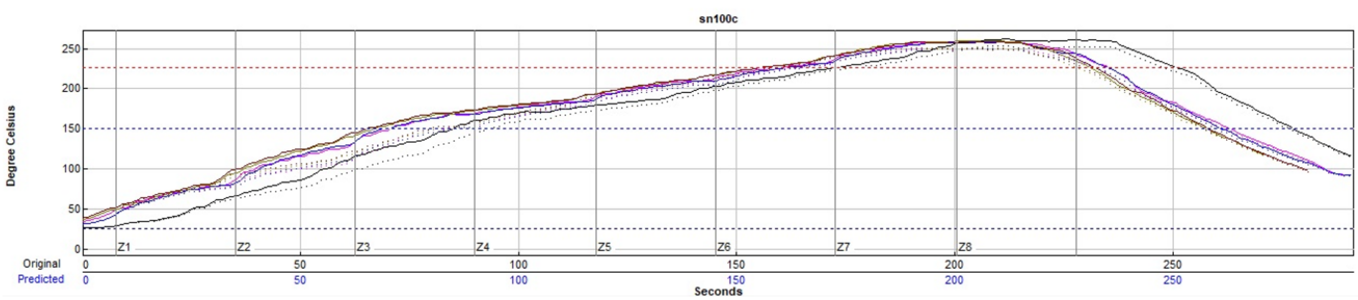

Figure 2. Furnace Reflow profile.

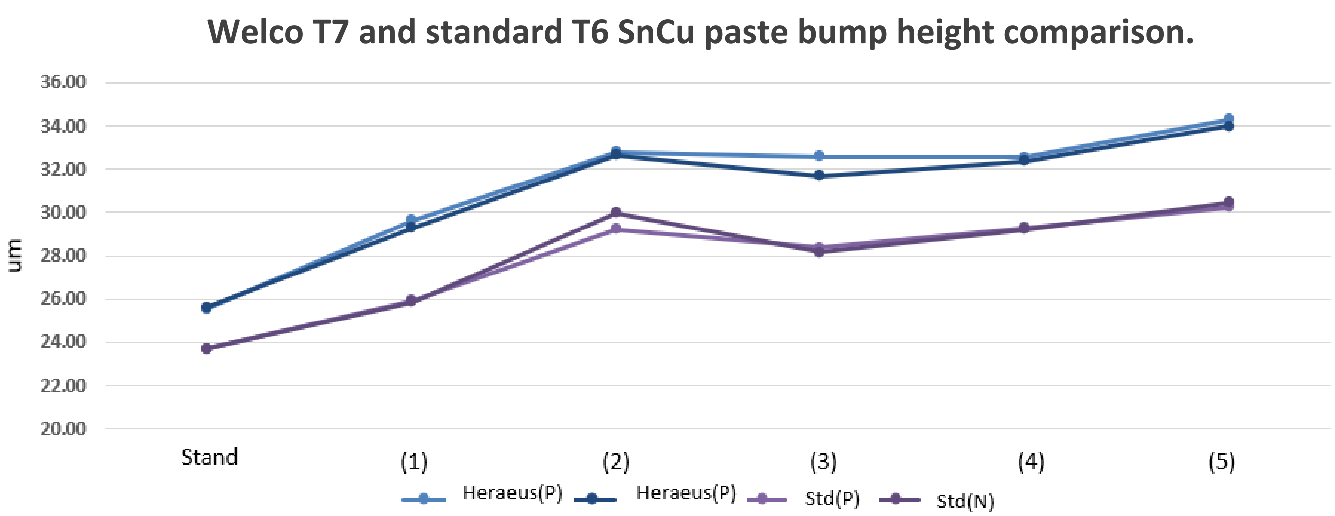

Figure 3. Heraeus Welco SnCu T7 shows consistently higher bump heights after reflow compared to standard SnCu T6.

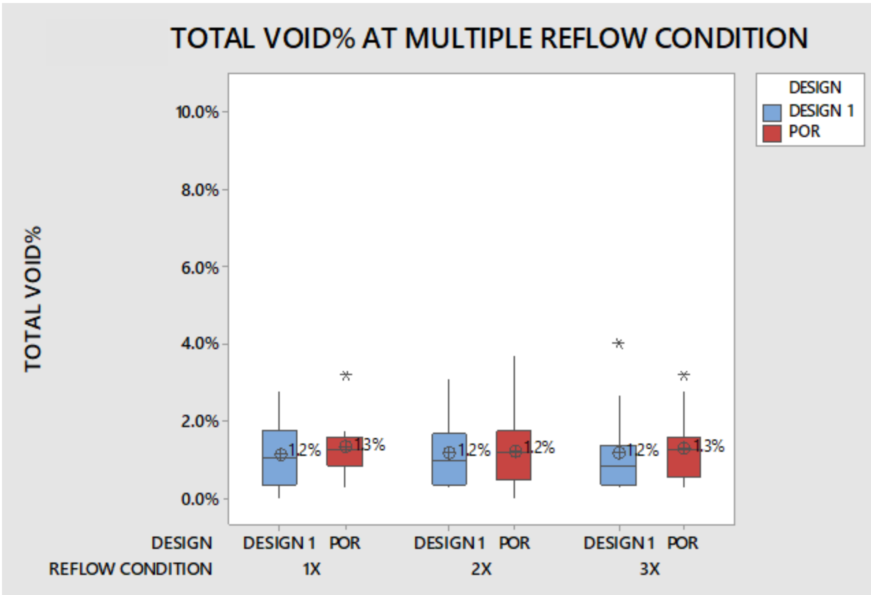

Figure 4. Welco SnCu T7 (DESIGN 1) shows stable 1.2% total void rate after 3 times reflow, and has fewer outliers than standard T6 (POR).

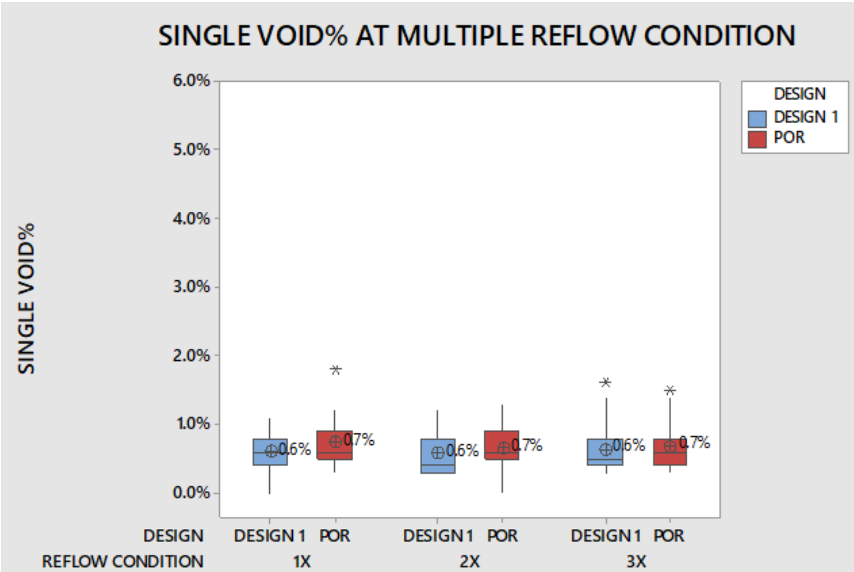

Figure 5. Welco SnCu T7 (DESIGN 1) shows stable 0.6% single void rate after 3 times reflow, and has fewer outliers than standard T6 (POR).

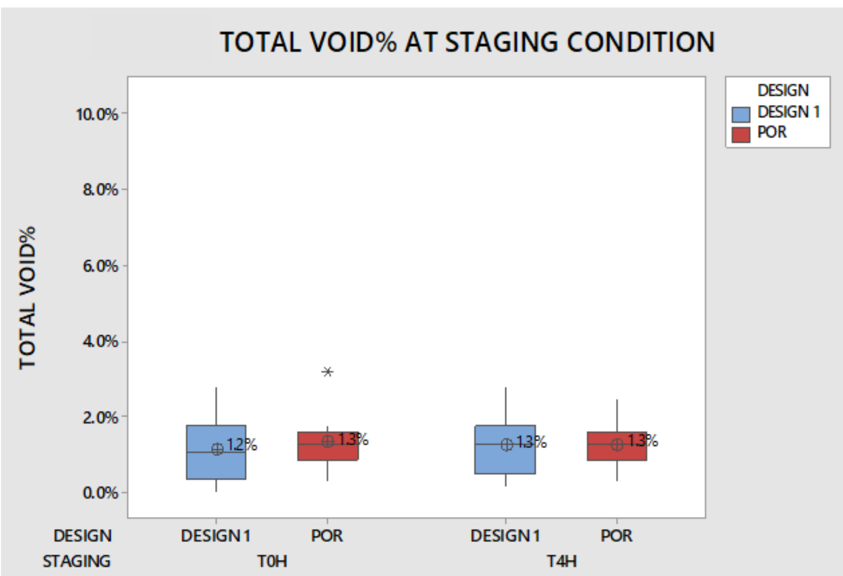

Figure 6. After staging 4hrs, Welco SnCu T7 (DESIGN 1) shows stable 1.3% total void rate, and has fewer outliers than standard T6 (POR).

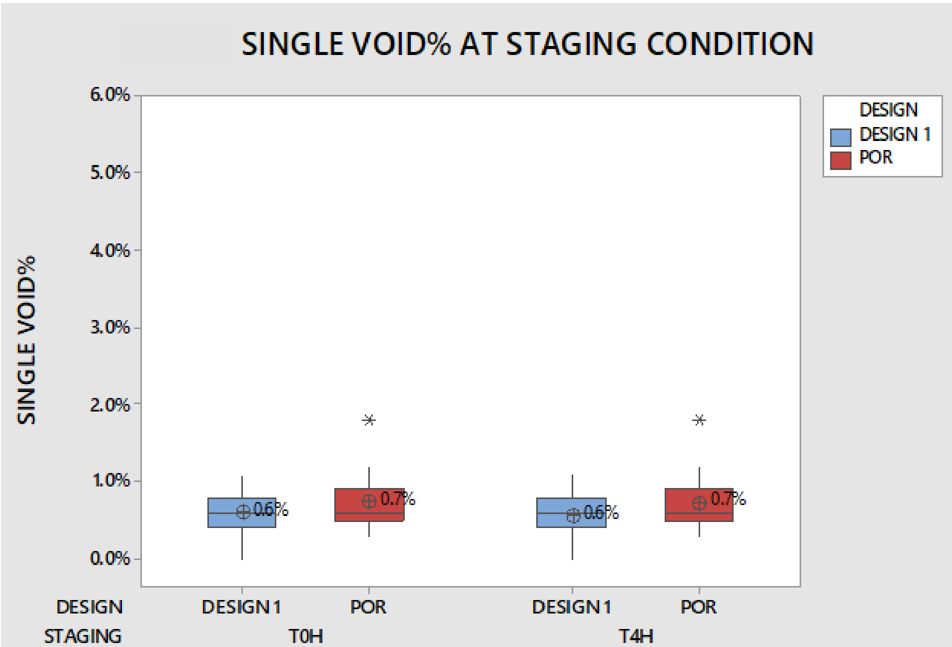

Figure 7. After staging 4hrs, Welco SnCu T7 (DESIGN 1) shows stable 0.6% single void rate and has fewer outliers than standard T6 (POR).

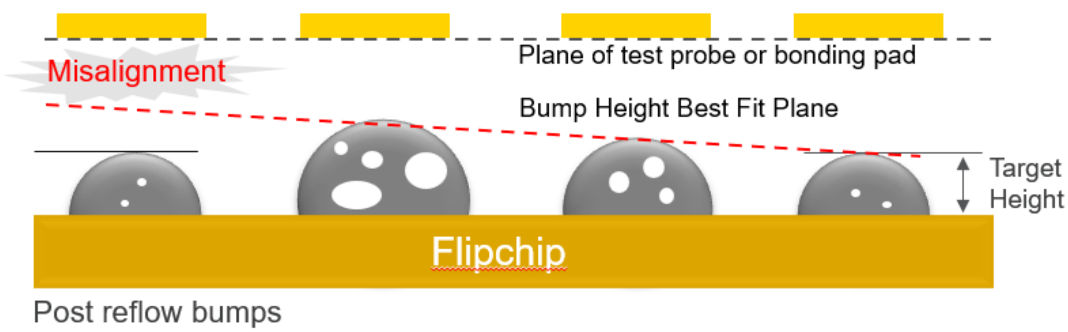

Figure 8. Illustration of voids and bump height consistency