IMPACT OF LOW SILVER SOLDER PASTES ON AREA ARRAY SOLDER JOINT QUALITY

Srinivasa Aravamudhan, Raiyo Aspandiar, Ph.D., Lilia May, Ph.D.,
Suddhasattwa Nad, Scott Mokler, and Dudi Amir

Intel Corporation
Hillsboro, OR. USA
Srinivasa.r.aravamudhan@intel.com

ABSTRACT

Reacting to increased silver metal costs in recent years, Personal Computer (PC) board assemblers are converting to low Ag SAC solder pastes, and transitioning away from the widely used SAC305 (Sn-3.0wt%Ag-0.5wt%Cu) composition. Previously, a few industry studies demonstrated similarities between low Ag SAC and SAC305 solder pastes in printability, slump, solder balling, and voiding [1-2]. However, no data has been published on the effect of using low Ag SAC solder paste on solder joint quality. Solder paste properties dictated by both flux composition and solder powder metallurgy are major determinants of solder joint defects such as head-on-pillow (HoP), non-wet open (NWO) and solder ball bridging (SBB) defects. In this study, flip chip ball grid array (FCBGA) packages were used to induce solder joint defects formation. These packages were then assembled using low Ag SAC solder pastes as well as standard SAC305 solder pastes from various suppliers. To precipitate failures caused by the dynamic warpage of the packages, the solder paste printed volumes were maintained at the low end of acceptable ranges, and air atmosphere was employed in the reflow oven. The surface mount technology (SMT) assembly solder joint yield was determined after reflow soldering from electrical testing of the daisy chain loops, as well as by failure analysis, which indicated the mode of solder joint defects. Analysis of the defects showed that the solder paste flux system was dominant over alloy metallurgy for determining solder joint yield. Moreover, to maximize solder joint yield when using low Ag SAC solder pastes, the peak reflow temperatures will need to be adjusted to higher levels than for that used for SAC305 solder pastes.

Key words: Low Ag SAC, Solder Joint Quality, HoP defect, NWO defect

INTRODUCTION

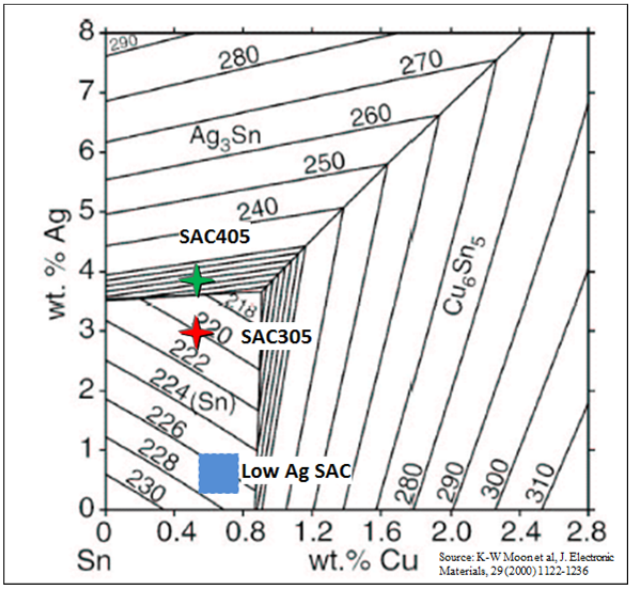
Low Ag (0.1 to 2 wt % of Ag) solder alloys, with and without dopant element additions, have been considered in the past and are already in use as the metallurgies for solder balls of BGA components. This change was mainly driven by the larger margin in mechanical shock and drop reliability provided by the low Ag SAC alloys [3-7].

Recently, the cost of silver (Ag) metal has increased by 8 to 10x from year 2000 which has led to increase in SAC305 metal and SAC305 powder containing solder paste cost, as shown in Figure 1 [8]. Increase in SAC305 alloy solder paste cost has motivated board assembly manufacturers to look for alternative lower cost solder alloy metallurgies for solder pastes. Low Ag (0.1to 1%) and zero Ag (SnCu based) solder alloys have been chosen as alternatives to replace SAC305 in solder pastes. Most solder paste suppliers have such low Ag and zero Ag solder pastes within their product portfolios [9-13].

Figure 1. Cost of solder paste alloys over time [6]

Though some studies [1-2] have evaluated low Ag SAC solder pastes for their processing performance there is minimal published data on the impact of these Low Ag SAC alloys to SMT solder joint defects, particularly for FCBGA solder joints. With the recent trends in shrinking of FCBGA ball pitch and the effect of warpage of the package, specific solder joint defects, such as NWO [14-15] and HoP [16-17] need to be evaluated. The primary focus of this paper is to evaluate the impact of using low Ag SAC and zero Ag (SnCu) based alloy solder pastes on the SMT solder joint quality, of BGA with SAC405 solder balls.

One of the primary concerns on the use of low Ag SAC alloy solder paste in SMT board assembly is the shrinkage of reflow process window. SAC305 alloy a liquidus temperature of 217^{o}C to 221^{o}C depending on the dopant in the solder paste. Moving to low Ag alloy (Ag content of 0.1 to 1.0%) increases the liquidus temperature to 225^{o}C to 228^{o}C based on the Ag and dopant content. As shown in Figure 2 [18], low Ag SAC alloys have higher liquidus temperature when compared to SAC305 alloys. Even though we use low Ag SAC alloy solder paste during board assembly, the final Ag content within the solder joints will primarily be dependent on the weight of the Ag in the solder ball and Ag in the solder paste for each land. If SAC405 solder balls are used in combination with low Ag SAC solder paste, the final Ag content within the solder joint will be close to that of the SAC305 alloy.



Source: K-W Moon et al, J. Electronic Materials, 29 (2000) 1122-1236

Figure 2. Sn-Ag-Cu Ternary Phase Diagram [18]

For SAC305 solder paste, 230°C to 250°C is used as a reference peak reflow temperature range. Though there is little difference in the wettability of the low Ag SAC alloy when compared to SAC305 at 250C [19], as the peak reflow temperature is lowered the wetting time increase is significant with decreasing Ag content in SAC alloys [7]. Therefore, the lower end of the reflow process window may need to be raised in temperature to avoid solder joint defects such as NWO and HoP. For this reason, the impact of peak reflow temperature on solder joint quality will be evaluated as part of this work. In addition, to evaluation the impact of reflow temperature, the impact of the solder paste flux chemistry to solder joint formation will also be evaluated in this study. Some studies [14-15, 20-22] had indicated that solder paste flux chemistry plays an important part in the generation and resolution of NWO and HoP defects.

DOE DESIGN

The main objective of this work was to evaluate the impact of Low Ag solder alloy on SMT solder joint formation. Two questions that needed an answer were:

- What is the impact of Low Ag alloy and paste flux system on the SMT failure rate and failure mode?
- What is the impact of reflow temperature on Low Ag solder joint formation?

To evaluate the impact of a low Ag alloy and paste flux system, an industry survey was performed to identify the commonly used Low Ag SAC solder pastes for the evaluation. A survey of the industry showed that SAC 0307 (0.3% Ag) was a commonly used base alloy composition for solder paste. Various solder paste suppliers added dopant elements to this base composition to impart specific properties. Table 1 below shows the lists of solder paste used in the evaluation. Low Ag solder alloy solder pastes from a few commercial suppliers were used in the evaluation. As shown in Table 1, each solder paste had their unique combination of flux system and dopants to improve the performance of the solder paste. In addition to evaluating low Ag metallurgies in solder paste, Zero Ag solder paste (99.2Sn/0.5Cu/0.3Bi) was also included in this evaluation. Use of low Ag solder paste from multiple suppliers for this study included the impact of flux chemistry and supplier to supplier variation.

Table 1. List of low Ag & zero Ag solder paste used

Supplier	Flux System	Metal Alloy Designation	Metallurgy Type	Composition
A	Flux A	SAC0307 with dopants	Low Ag	Sn/Ag 0.3/Cu 0.7/ Bi 0.08/Sb 0.01/Pb0.01
	Flux A1	SAC0307	Low Ag	Sn/Ag 0.3/Cu 0.7
B	Flux B	SAC0307	Low Ag	Sn/Ag 0.3/Cu 0.7
C	Flux C	SAC0307 with dopants	Low Ag	Sn/Ag 0.3/Cu 0.7/ Ni 0.005/Ge 0.005
B	Flux B	99.2Sn/0.5Cu/ 0.3Bi	Zero Ag	Sn/Cu 0.5/ Bi 0.3/Co 0.005

Table 2. SMT Build Matrix to evaluate the impact of Low Ag solder alloy on SMT defects

DOE Leg	Paste Flux System	Solder Alloy	Reflow Temp (°C)	SMT Qty
1	Paste A	SAC305	235 to 240	15
2		SAC0307	235 to 240	15
3	Paste A1	SAC305	235 to 240	15
4		SAC0307	235 to 240	15
5	Paste B	SAC305	235 to 240	15
6		SAC0307	230 to 235	15
7			235 to 240	15
8		SnCu	230 to 235	15
9			235 to 240	15
10	Paste C	SAC305	235 to 240	15
11		SAC0307	235 to 240	15

SAC305 and SAC0307 alloy solder pastes were procured from different suppliers using the same flux formation, to obtain a direct comparison between two alloys using the same flux system. Leg 6&7 and 8&9 was designed to compare the impact of reflow temperature to solder joint defects. As highlighted in Table 1, solder pastes from 3 solder paste suppliers were used for the evaluation. Type 4 solder powder was used for all the solder pastes used in evaluation

BGA packages were assembled on PCBs using a conventional SMT process. Dimensions of the test board were 142.24 mm x 160.02 mm (5.6inch x 6.3inch), with a thickness of 0.08mm (0.032inch). The test board was made with halogen free laminate material and organic solderability preservative (OSP) surface finish on Cu lands. PCB land sizes ranged from 15-mil circular lands to 12-mil circular lands. BGA packages with a body size of 40mm x 24mm, ball pitch of 0.65mm and 16-mil SAC 405 balls were used for the evaluation. To induce failures with a minimal sample size, (i) BGA packages with skewed peak-to-valley warpage at reflow temperatures were selected for this DOE and (ii) a minimal paste volume was printed on the PCB land for BGA package assembly. Boards were reflowed in ambient air using standard lead-free reflow profile with 50 to 70 sec TAL. 15 boards were assembled for each leg of the experiment.

After the SMT process, 13 boards were selected for BGA failure analysis from each leg to understand the failure mode and failure rate. For the BGA failure experiments, a nut was attached to the top of the BGA package using a two-part epoxy and allowed to cure. After cure, the nut was attached to a universal test machine and the BGA pulled away from the PCB. This pull method was found to be more reliable than many other techniques in identifying and recording various types of solder joint defects. After package pull, the total number of defective joints detected by visual examination under an optical microscope was used as a metric to quantify the impact of solder alloy on SMT defects. The remaining two boards were cross-sectioned to inspect the quality of solder joints and to compare IMC thicknesses and for elemental analysis of the SAC305 and Low Ag solder alloy metallurgies.

RESULTS

Results from the evaluation of low Ag SAC and Zero Ag alloy are summarized in the variability chart below Figure 3. In the below plot, Y-axis shows the number of defective per board found from the BGA pull and the X-axis shows the factors considered for the DOE (Solder Paste Flux System, Solder Alloy and Reflow temperature). Each dot in the plot refers to the total number of failure joints from a single board. The results show that the paste flux system is a critical factor to reduce number of defective joints per board; followed by the solder alloy system. Detailed analysis on the impact of paste flux system, solder alloy metallurgy and reflow temperature are discussed in the following sections.

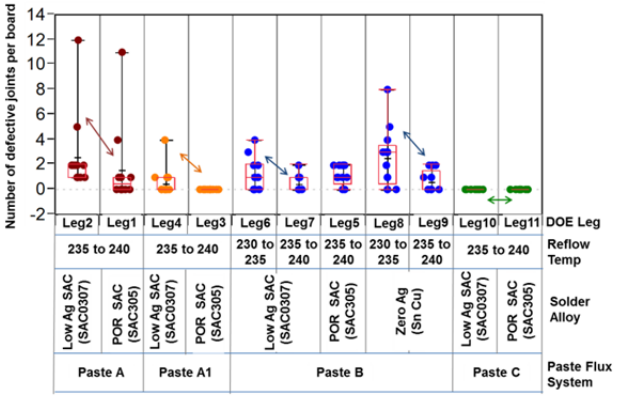


Figure 3. Total number of defective joints per board as a function of paste flux system, solder alloy and reflow temperature

Impact of Paste Flux and Alloy Metallurgy

Results from data analysis show solder paste flux system is the dominant factor over the solder alloy metallurgy to determine the impact to solder joint yield (a shown in Figure 4). Comparison of defect rates across Paste A, A1, B & C, show that Paste C had the least amount of defects (i.e., 0) for POR SAC & Low Ag SAC alloy. This result highlights the impact of solder paste flux system over the solder alloy metallurgy. Solder Paste A & A1 response was expected; its defect rate increased when solder alloy was changed from SAC305 to SAC0307 alloy. Paste A used outdated flux chemistry know from previous build s to generate high number of solder joint defects. Whereas A1 is newly developed flux system to mitigate SMT defects with SAC305 alloy, yet somewhat weak with low Ag powder. It is well understood that wetting of SAC solder pastes to FCBGA solder balls decreases as amount of Ag goes down partially due to increase in surface tension of molten solder mass. However Paste B showed a reverse effect with a decrease in the defect rate for the SAC0307 alloy solder paste when compared to the SAC305 alloy solder paste.

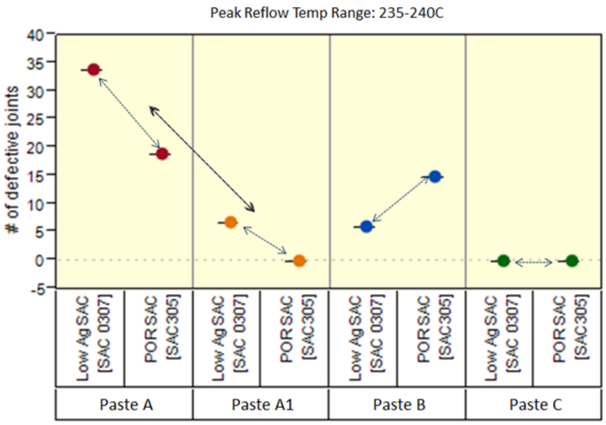


Figure 4. Impact of Paste Flux and Alloy metallurgy to solder joint defect rates

The results highlight the importance of selecting an appropriate solder paste flux system.

Impact of Reflow Temperature

For low Ag and zero Ag SAC solder alloy metallurgies, the reflow temperature has a significant impact on the defect rate.

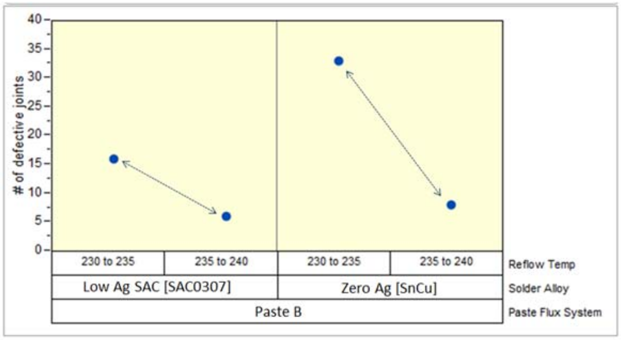


Figure 5. Impact of Reflow Temperature on solder joint defect rates

Figure 5 shows the results on the impact of reflow temperature on solder joint defect rates. Impact of reflow temperature was only evaluated on paste flux system 'Paste B' as highlighted in Table 2. Results show that an increase in the peak reflow temperature decreases the defect rate for Low Ag and Zero Ag SAC solder alloy metallurgy. Decrease in defect rate in Low Ag and Zero Ag SAC solder alloy is due to higher melting temperature of the alloys when compared to SAC305 solder alloy metallurgy.

Differential Scanning Calorimetry (DSC) was used to compare the alloys. Results showed that low Ag and Zero Ag SAC solder alloy solder pastes have higher liquidus temperature when compared to SAC305 alloy (Table 3). Increase in reflow temperature allows the Low Ag metallurgy to reach its liquidus temperature and form acceptable solder joint formation. This explains the need to increase the minimum peak reflow temperature for low Ag and zero Ag SAC solder alloy metallurgies during SMT board assembly.

Table 3. DSC Data for Solder Pastes with Flux System B

Solder Paste Alloy	Temperature of Liquidus Peak ^{o}C
SAC305	233.7
SAC0307	240.5
SnCu	243.5

IMC and Elemental Analysis

Energy-dispersive X-ray (EDX) spectroscopy and scanning electron microscope (SEM) analysis was performed to measure IMC thickness and elemental analysis of the IMC formation.

SEM analysis showed IMC thickness is comparable between SAC305 and SAC0307 (Low Ag) solder alloy metallurgy as shown in Figure 6. Since the contribution of solder paste is minimal in the solder joint formation when compared to solder ball metallurgy, the impact of Low Ag solder alloy to IMC formation is diminished.

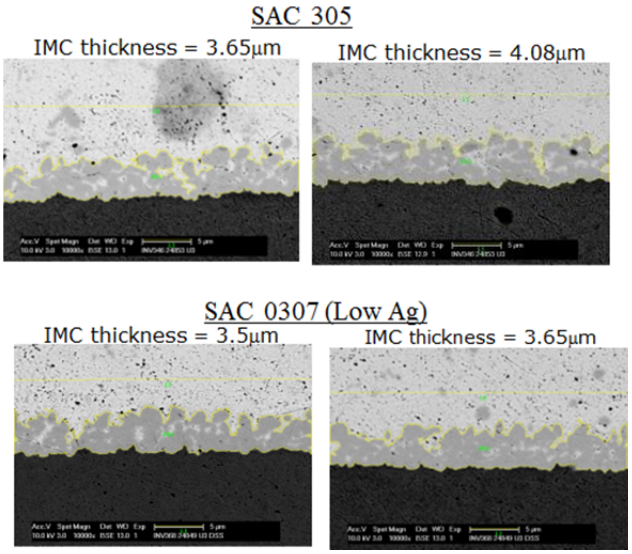


Figure 6. IMC Thickness Comparison of SAC305 and SAC0307 (Low Ag) Solder Alloy Metallurgy

EDX analysis showed comparable elemental peaks between SAC305 and SAC0307 (Low Ag) solder alloy metallurgy in the IMC area of the solder joint formation as shown in Figure 7.

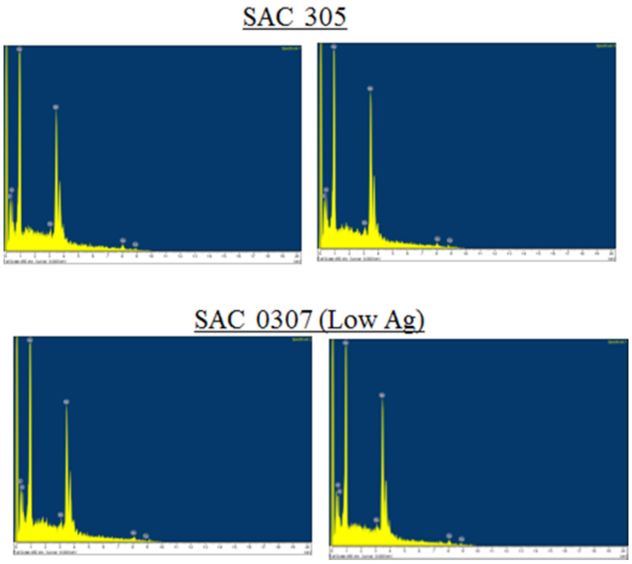


Figure 7. EDX analysis of IMC for SAC305 and SAC0307 (Low Ag) Solder Alloy Metallurgy

Failure Modes

Detailed failure analysis show failure modes between SAC305 and Low Ag/Zero Ag solder alloy metallurgy were primarily driven by the solder paste flux system. For solder paste flux system B, the SAC305 alloy showed NWO defects to be the primary failure mechanism and the same failure mechanism was observed with Low Ag and Zero Ag solder alloy.

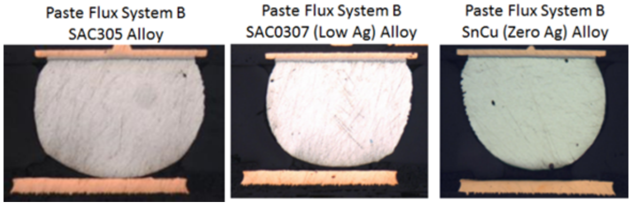


Figure 8. Failure Mode for SAC305, SAC0307 (Low Ag) and SnCu (Zero Ag) solder alloy metallurgy

This illustrates that the solder paste flux system is the primary driver for SMT failure modes, whereas the solder alloy metallurgies of the solder paste play a secondary role.

CONCLUSIONS

Results from the study show that the selection of the right solder paste flux system is critical for low Ag or zero Ag solder alloy metallurgies to influence SMT process yields.

Additionally, an increase in peak reflow temperature may be required to improve SMT yield and reduce solder joint defects. Due to the increase in liquidus temperature for low Ag and zero Ag, the minimum peak temperature should be increased based on the alloy used for the SMT assembly. However, an increase in minimum peak reflow temperature may result in an adverse impact to other components on the board that need additional evaluation.

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