THE QUANTITATIVE ASSESSMENT OF MIXED BGA JOINT WITH THE ELIMINATION OF LOW-MELTING POINT ALLOY RE-MELTING PROCESS

HongqinWang, Guanghui He and Daojun Luo
China Electronic Product Reliability and Environmental Testing Institute
Guangzhou, China
wanghongqin2013@163.com

ABSTRACT
A careful experimental investigation was undertaken to evaluate the soldering process and the reliability of solder joints of SnAgCu PBGA components formed using the Sn-Pb solder paste. Initially, a series of the reflow soldering profiles were developed to assure the complete mixing of the SAC ball and Sn-Pb solder. Analysis of as-assembled solder joints revealed that the degree of mixing between the BGA SAC ball alloy and the Sn-Pb solder paste varied with the different reflow soldering profile. The peak reflow temperature was observed to have a significant impact on the solder joint microstructural homogeneity.

Serious crack defects of the complete mixed solder joints happened after the waving soldering process. Then a series of the reflow soldering profiles and tests were developed to solve the crack phenomenon and the mechanism of the crack phenomenon was illustrated with the quantitative assessment of mixed solder joints.

The reliability of mixed solder joints after optimazaiton was studied with an accelerated thermal cycling(ATC) test in the temperature range of -40^{o}C to 125 ^{o}C for a maximum of 3000 cycles in accordance with IPC 9701A standard.

Key words: backward process, lead-free PBGA, mixed solder alloy, reliability

INTRODUCTION
Many component manufacturers have successfully transformed to lead-free process to meet market demands in the electronics industry. But a simultaneous shift of all involved parties (the component manufacturers, electronic product manufacturers and so on) from lead-tin to lead-free technology is impossible, a mix of technology cannot be avoided at the present stage. Therefore, soldering of lead-free component with lead-tin solder, which is termed as Backward Compatible Assembly, has to be investigated.

A considerable amount of work has been done so far to evaluate the process and reliability of Backward Compatible Assembly [1-6]. BGAs with SAC balls were soldered with SnPbAg solder paste using different temperature profiles and conveyor speeds in order to obtain a variation of process parameters in the peak zone [5]. The mixing of Pb was explored at 210°C for typical BGA ball sizes, at temperatures below the melting point of the Pb-free ball and the reliability of the mixed BGA was compared [6].

But most of the above research result has not concerned the reflow and waving total soldering process. In this paper, the backward processed BGA joint was formed with the reflow and waving soldering process. It was interesting to find that serious crack defects appeared at the mixed BGA solder joints. The optimization work was designed to solve the above problem and the reliability of the BGA solder joints after the optimization was evaluated. In addition, the mechanism of the iniatial cracking phenomennoe was disscussed. The details will be described in the following.

EXPERIMENTAL PROCEDURE
The PBGA component investigated in this study were a PBGA416, with a pitch of 1.0mm. These components were 27 mm square and 2.55mm thick and contained a dummy chip measuring 25mm square. The solder balls were in a 26x26 array with a cavity and had a diameter of 0.5mm and a height of 0.4mm, consisted of SnAg3.0Cu0.5 alloy. The PCBs used were made of glass epoxy FR4，whose total thickness were 2.9mm with 10 fully metallized inner layers. The PCBs had a HASL SnPb surface finish. The solder paste used was Sn63Pb37 with ROLO rosin-based flux.The solder used in the waving soldering was Sn63Pb37.

The reflow soldering oven had five temperature zones of which the last two zones were the peak zones. The representative temperature-time profile was measured with a type K thermocouple, as shown in Figure 1. The reflow soldering process parameters were summarized in Table 1. The mixed solder joint did not experience or experience the waving process as shown in Table 2. The wave soldering process parameters were summarized in Table 3.

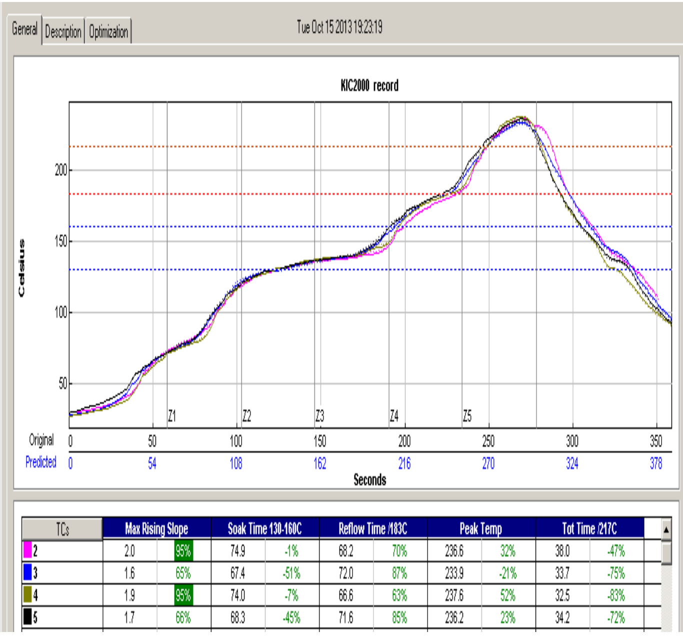


Figure 1. Representative reflow profile

Table 1: Assembly Test Matrix

Specimen number	Reflow profile number	With/ Without （Y/N）	Waving profile number
S1	R1	N	/
S2	R2	N	/
S3	R2	Y	W1
S4	R2	Y	W2

Table 2: Reflow Soldering Process Parameters

Reflow profile number	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	T5 (°C)	Conveyor Speed (cm/min)
R1	90	155	165	210	260	46
R2	100	160	165	228	285	43

Table 3: Wave Soldering Process Parameters

Waving profile number	Preheat (°C)	Pot Solder (°C)	Turbulent wave	Smooth wave	Conveyor Speed (cm/min)
W1	400	255	390	440	75
W2	360	235	390	440	120

To evaluate the effect of the process parameters on soldering, one specimen from each temperature/time combination was cross sectioned to observe the mixing of the SAC ball and the solder paste. Some of the specimens were checked with dye & pry method.

RESULT AND DISCCUSSION

Reflow soldering process

Cross section optical image of the specimen S1 solder joint was shown in Figure 2, whose enlarged image of a selected area was observed by SEM and shown in Figure 3. At the bottom of the picture is the pad of the PCB and at the top is the pad of the PBGA component. The cross section image of the PBGA solder joints clearly showed that the SAC balls have only partially reacted with the solder paste and two evidently separated zones can be observed in the Figure 2. No traces of Pb were found in the zone of the top of the SAC ball. No crack was in the specimen S1 solder joints.

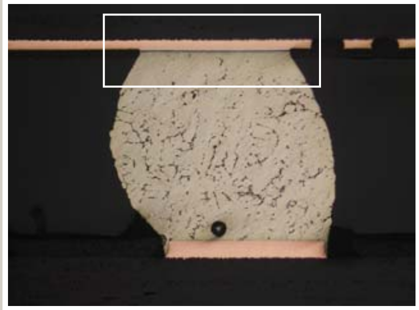


Figure 2. Cross-section optical image of specimen S1

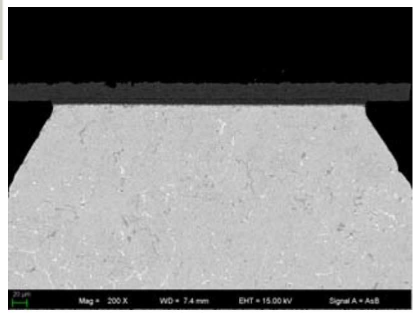


Figure 3. Enlarged image of a selected area of specimen S1 in Figure 2

Cross section optical image of the specimen S2 solder joint was shown in Figure 4, whose enlarged image of a selected area was observed by SEM and shown in Figure 5. The reaction of the SnPb solder paste with the SAC balls was more homogenous and the ball solidified with a dendrites structure throughout the entire volume. The dendrites as well as the Pb-rich phase are distributed throughout the volume of the ball. No crack was found in the specimen S2 solder joints.

Figure 4. Cross-section SEM image of specimen S2

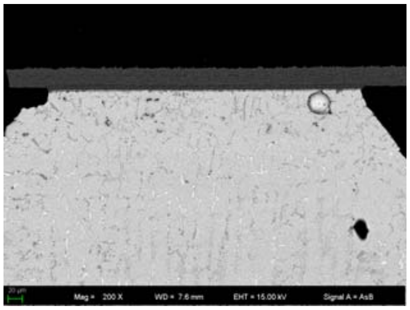
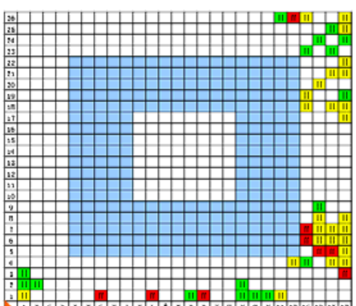


Figure 5. Enlarged image of a selected area of specimen S2 in Figure 4

Reflow soldering process and waving soldering process

Based on the above research, the reflow soldering profile was optimized as reflow profile number R2. Then the specimen S3 was processed with the reflow profile R2 and the waving profile number W1 in sequence, as shown in Table 1.

After the reflow and waving soldering process, the specimen S3 solder joints was checked with dye & pry method. It was surprised to find that cracks with various degrees appeared around the BGA chip. The failure mode indicated that the cracks were located between the chip and the ball, as shown in Figure 6. Figure 7 showed an SEM image depicting the same failure mode.



Crack Area	Crack Mode
Type A: 100%	Type Ⅰ：Between Chip pad and chip Matrix
Type B: 50%~100%	Type Ⅱ：Between Chip pad and Ball
Type C: <50%	Type Ⅲ：Among the Ball
Type D: No crack	Type Ⅳ：Between Ball and PCB pad
Type E: No joint	Type Ⅴ：Between PCB pad and PCB Matrix

Figure 6. The Dye and pry mapping for PBGA component showing the crack location and percent fracture of the mixed solder joint

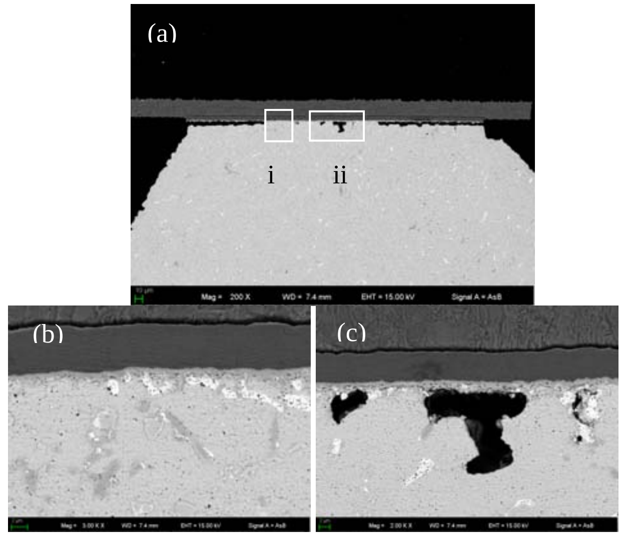


Figure 7. Cross-section SEM image of PBGA component solder joint (a) the entire top area (b) area i (c) area ii

A part-cracked solder joints was mechanically pulled off, whose fracture surfaces were observed and analyzed by SEM and EDS, which were shown in figure 8.

(a)

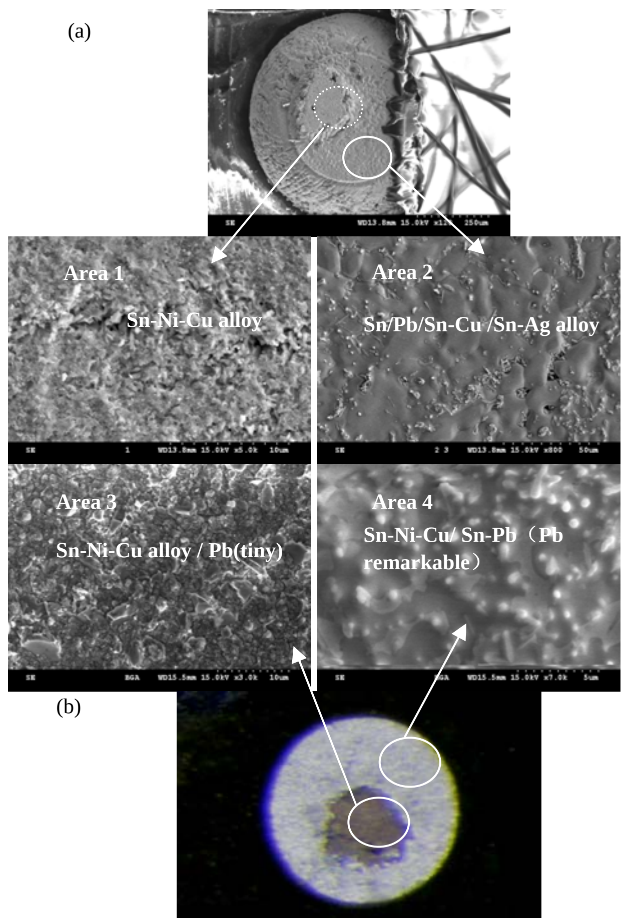


Figure 8. SEM observation of BGA after mechanically pulled off (a) PCB side (b) Chip side

It could be seen that the original cracking surface was very smooth regardless of the PCB side or the device side surface, which morphology indicated that the cracked area of the mixed solder joint should be free solidified without contact each other.

The melting point of the 100% cracked BGA ball in figure 6 was tested by DSC after cleaning and its result was shown in figure 9. It could be seen from the DSC result that the mixed PBGA solder ball began to melt at about 177^{o}C, which was consist with the finding of literature [7-8].

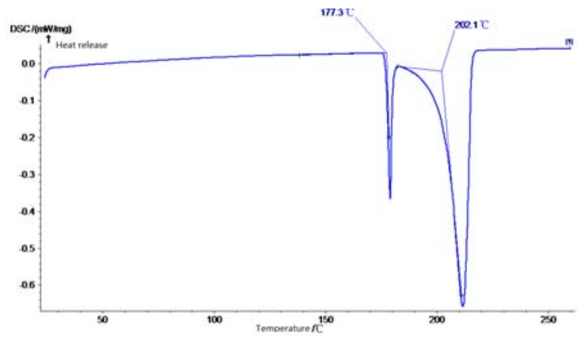


Figure 9. DSC result of entirely cracked BGA solder ball

The waving soldering was optimized to keep the temperature of PBGA solder joints below 175 ^{o}C, which was the waving soldering profile W2.

The specimen S4 was processed with the reflow profile R2 and the waving profile number W2 in sequence, as shown in Table 1. No crack was found in the PBGA solder joints and Pb distributed homogeneously in the entire solder ball. Cross section of S4 was observed by SEM, as shown in Figure 10.

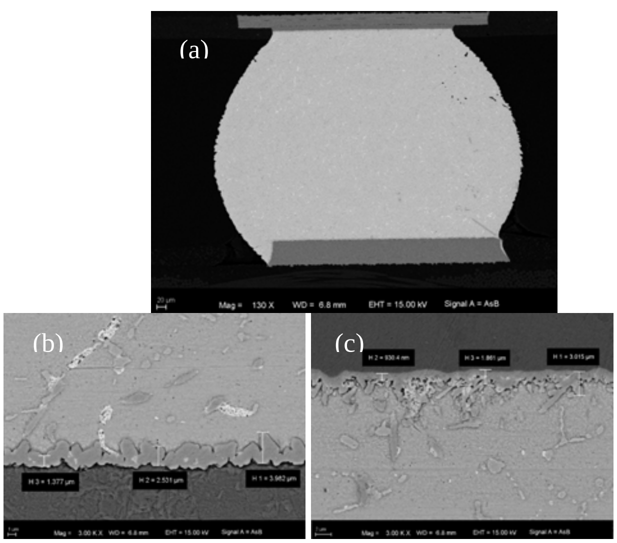


Figure 10. Cross-section SEM image of S4 solder joint (a) Entire solder ball (b) PCB Side (c) Chip Side

So combined all the above experiment results, the mechanism of PBGA joint crack could be illustrated as the following: in the waving soldering process, the temperature of PBGA solder joint reached to high temperature (in the experiment test, the peak was 186^{o}C), which exceeded the melting point of mixed solder ball, so the mixed solder ball partially melt and kept at liquid state during the cooling period (from the peak temperature to the solidification above 183^{o}C). Since the PBGA component tried to keep at the sad/positive (+) warpage, the tensile stress was applied on the mixed solder joints around the PBGA component. As a result, a lot of cracks emerged. To avoid such crack, fist the reflow soldering profile should be optimized to keep Pb distributed homogeneously in the entire ball and then control the temperature of solder joints below the melting point of the mixed solder ball in the waving soldering process, as we had done in this research.

The reliability of PBGA solder joints after optimazaiton was studied with an accelerated thermal cycling(ATC) test in the temperature range of -40^{o}C to 125 ^{o}C for 3000 cycles in accordance with IPC 9701A standard. After thermol cycling, the cross section of the solder joints was observed by SEM in Figure 11, which showed the fracture appeared near the pad interface on the component side, though the PBGA solder joints had not compltely failed yet.

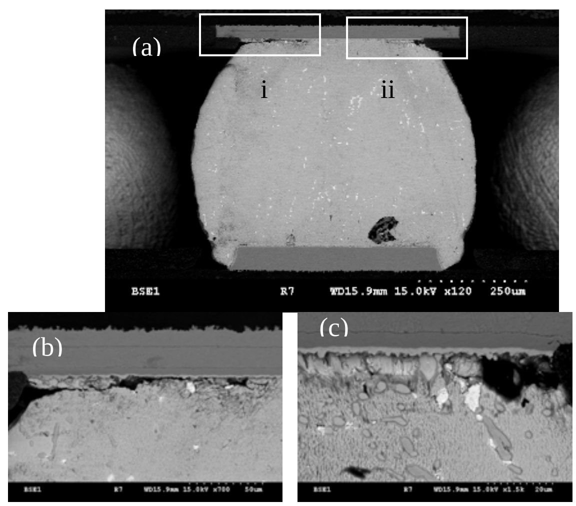


Figure 11. Cross-section SEM image of PBGA component solder joint (a) Entire solder ball (b) area i (c) area ii

CONCLUSION

In this paper, the properties of the mixed solder joints of SnAgCu PBGA components formed using the Sn-Pb solder paste was investigated, which was assembled by the reflow soldering and then experienced the following waving process.

The homogeneous microstructure of the mixed solder joints could be obtained by the optimization of the reflow soldering parameters. Crack defects happened when the specimen went through the waving soldering, where the peak temperature of the mixed solder joint reached higher than the melting point of the mixed solder alloy in the waving soldering period.

To avoid such cracks, the reflow soldering should assure the even distribution of Pb element in the mixed solder joint through the optimization of reflow temperature profile; and the temperature of the mixed solder joint should be controlled below the melting point of the mixed solder alloy in the waving soldering period by the optimization of the waving soldering parameters.

The reliability of mixed solder joints after optimazaiton could stand an accelerated thermal cycling(ATC) test in the temperature range of -40^{o}C to 125 ^{o}C for a maximum of 3000 cycles in accordance with IPC 9701A standard without function failure, through the microscopic crack appeared at the interface of component pad and the solder.

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