New-Generation, Low-Temperature Lead-Free Solder for SMT Assembly

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Abstract
Sn3Ag0.5Cu (SAC305) is the major solder alloy after RoHS was adopted by the European Union. Since its melting temperature is relatively higher than eutectic SnPb alloy, the peak reflow temperature increases. This transformation in the assembly industry impacts the component requirement, where the deformation probability (warpage) of a flat component is increased, which impacts the production yield. A lead-free, low-temperature SMT solder is needed to resolve this dilemma.

Low-temperature SMT assembly refers to the reflow process with a peak temperature less than 200°C. The new process provides a few advantages like reducing energy consumption, reducing BGA component warpage during reflow and diminishing non-wetting open (NWO) and head-on-pillow (HoP) defects. The SnBi alloy is one of the candidates used in low-temperature SMT assembly. However, the brittle mechanical property of conventional SnBi alloys will degrade the reliability of the assembly. The SnBi alloy properties can be altered via several means.

In this paper, the roles of additive and bismuth content will be discussed. Eutectic SnBi and three newly designed SnBi-based alloys (Sn57Bi1AgX, Sn48Bi1AgX and Sn40Bi1AgX, X represents <0.5wt.% of additive element) were experimented upon. Solder pastes that were blended with the aforementioned alloys and flux were used to assemble on the PCB with BGA components that have SAC305 solder spheres pre-mounted. The same reflow profile was used for all pastes. Cross-sectional analysis, shear testing, drop testing and thermal cycling testing were conducted to determine the microstructure, shear force, drop reliability and thermal reliability. The results show that the microstructure, especially the bismuth-rich phase, became finer and the shear force was elevated when the additive was added. On the other hand, the drop reliability improved with decreasing bismuth content, and the thermal reliability improved with increasing bismuth content.

Introduction
Low-Temperature Solder (LTS) refers to a solder alloy with liquidus below eutectic Sn37Pb (183˚C). The common LTS is eutectic Sn58Bi alloy, with a melting point of 139˚C[1,2]. For the SMT process, the peak reflow temperature of the LTS paste should be below 200˚C.

The main driving force for the LTS transition is increasing demand for ultra-thin packages. Reduction in package thickness increases its warpage, and this warpage generates production yield loss[3].Also, the reflow temperature of SnAgCu series solder paste is much higher than the glass transition temperature (T_g) of the substrate. This is another factor increasing substrate and PCB warpage. LTS paste can reduce the reflow temperature to below 200˚C, hence decreasing both PCB and substrate deformation.

LTS Benefits and Drawbacks
LTS provides numerous benefits. The four most notable are listed below.

<u>Improved production yield</u>
The reflow temperature of LTS is lower than SAC305. As a result, the deformation of PCBs and substrates is relatively small, and it subsequently improves the packaging yield of BGA components.

<u>Reduced thermal stability requirement of PCBs and components</u>
Because the reflow temperature is decreased, PCBs and components no longer need to withstand 240~250°C. Additionally, the product designer can choose components and PCBs with low thermal stability, thereby reducing product cost (Figure 1).

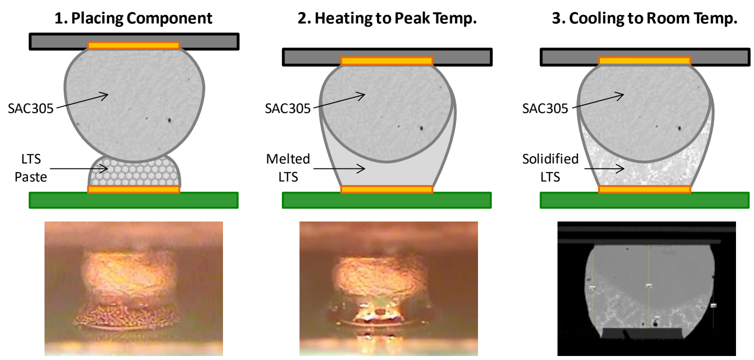

Figure 10. SAC BGA component/LTS paste hybrid soldering process

On-board Reliability Test – Drop Test

The BGA component on the PCBA for drop testing had added corner glue (CG), and each test board had 15 BGA components. As shown in Table 2, for the Sn58Bi+CG test group, the first fail occurred at the 82nd drop. Four BGA components failed after 100 drops. For the Sn57Bi1AgX+CG test group, the first fail occurred at the 92nd drop. One BGA component failed after 100 drops. The Sn48Bi1AgX+CG and Sn40Bi1AgX+CG test groups had no fails after the one hundred 1500Gs accelerated drop condition. This indicated that the drop performance was improved by Ag and X element addition with drop performance elevated further with decreased Bi content.

Table 2. Drop test result

Test Sample	First Fail (Drop No.)	Survival Rate after 100 drop
Sn58Bi + Corner Glue	82	11/15, 73%
Sn57Bi1AgX + Corner Glue	92	14/15, 93%
Sn48Bi1AgX + Corner Glue	No fail after 100th drop	
Sn40Bi1AgX + Corner Glue	No fail after 100th drop	

On-board Reliability Test – Thermal Cycle Test

The thermal cycle test results are shown in Table 3. Each test group had five BGA components on-board. Only one BGA component failed in eutectic Sn58Bi test cell. The three newly designed alloys had no fails after the thermal cycle test of 1,000 cycles, indicating that the thermal cycle performance was improved by Ag and X element additions.

Table 3. Thermal cycle test result

Test Sample	First Fail	Survival Rate
Sn58Bi	719 cycle	4/5, 80%
Sn57Bi1AgX	-	5/5, 100%
Sn48Bi1AgX	-	5/5, 100%
Sn40Bi1AgX	-	5/5, 100%

Overall Performance

Figure 11 shows the overall performance comparison between Sn58Bi with the three new alloys, the performance is compared in five aspects:

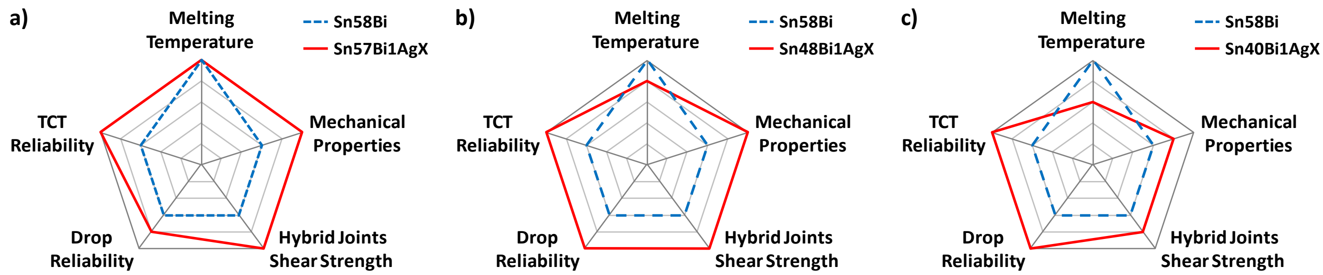

Figure 11. Overall performance comparison between eutectic Sn58Bi with (a)Sn57Bi1AgX, (b) Sn48Bi1AgX, (c) Sn40Bi1AgX

Melting Point
A lower final melting temperature could lower the reflow peak temperature, and hence reduce thermal damage on the PCB and components. According to the DSC results, the eutectic Sn58Bi and Sn57Bi1AgX had the lowest final melting temperature among the four alloys.

Mechanical Properties
Higher ductility provides better toughness performance. In this study, Sn57Bi1AgX and Sn48Bi1AgX show the highest ductility among all the alloys.

Hybrid Ball Shear Test
The compatibility of SnBi-based alloys with SAC305 has been tested. The result showed that Sn57Bi1AgX and Sn48Bi1AgX have the best hybrid ball shear.

Drop Reliability
The drop test results showed that, after 100 times of a 1500Gs accelerated drop, Sn48Bi1AgX+CG and Sn40Bi1AgX+CG had no fails.

TCT Reliability
Three newly designed Ag and X element added alloys had no fails after 1,000 thermal cycle testing, indicating that the three alloys have better performance than the eutectic Sn58Bi.

Conclusions

The result of this study showed that the Bi phase became finer with Ag and X element additions in the SnBi-based alloy, and hence altered the mechanical performance and reliability of the SnBi-based alloy. It was also found that the three newly designed alloys have the following features:

1. The solidus and final melting temperature of Sn57Bi1AgX is close to the eutectic SnBi alloy. The Bi phase becomes non-continuous and needle-like with Ag and X element additions, significantly improving mechanical properties and thermal cycle reliability.

2. Sn48Bi1AgX has less bismuth content than the eutectic SnBi, hence the final melting temperature is 12˚C greater than the eutectic SnBi. The thermal cycle performance and drop reliability are better with Ag and X element additions.

3. Sn40Bi1AgX has better performance in the thermal cycle and drop tests than the eutectic SnBi; however, the final melting temperature is 30˚C greater than the eutectic SnBi, showing that a higher peak temperature is needed.

References

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