Microstructural Evolution of Cu/Sn-58Bi/Sn-3.0Ag-0.5Cu Composite Solder Joint during Isothermal Aging

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Abstract. A composite solder joints made of Cu/Sn-58Bi/Sn-3.0Ag-0.5Cu (in weight percent) was successfully fabricated. The composite solder was made from combining a Sn-3.0Ag-0.5Cu solder ball and Sn-58Bi solder paste. The composite solder was refloved on Cu-OSP (copper-organic solderability preservatives) substrate to form a composite solder joint. The microstructure evolution of the composite solder joints under different reflow temperature and thermal aging conditions were investigated using an optical microscope. This study shows that a composite solder joint of SAC305/Sn-58Bi can be assembled at lower temperature (160 °C) and gradually mixed through isothermal aging.

1 Introduction

Electronic packaging processes in these few decades have been widely utilizing the eutectic tin-lead (Sn-Pb) solder alloys mainly due to their low melting point and performance against thermal fatigue. Nowadays, the usage of Pb has been strictly banned due to its the environmental and health issues [1,2]. Also, the disposal of Pb contained electronics became a global concern as the electronics industry is experiencing rapid growth. In surface mount technology (SMT) process, Package-on-Package (PoP) assembly by reflow soldering is a good technology in fabricating unit of chipsets [3]. However, variation between the coefficient of thermal expansion of Si chips and polymer substrates in electronic packages create thermal warpage [4,5].

One of an attractive method to reduce the effect of thermal-induced warpage is by mixing low and high temperature solder alloys during the reflow process. The Sn-3.0Ag-0.5Cu also known as SAC305 (in wt.%) with a melting point of 217 °C is particularly more preferred among the electronic manufacturers compared to other Pb-free alloy due to the endorsement of this alloy by the IPC (Association Connecting Electronics Industries) for SMT process [6,7]. While the Sn-58 wt.%Bi alloy (T_m = 139 °C) is a promising prospect for low
temperature solder in electronic packaging due to its good mechanical properties [8]. Shen et al. [3] have performed an in-situ observation on a Cu/SAC305-Sn-58Bi/Cu solder joint. They claimed that the composite solder SAC305/Sn58Bi in the form of foils (bulk) can be completely mixed by 190 °C. Moreover, the cost of soldering Sn-Bi is less than that of others Pb-free solders. However, frangibility and low ductility are two major problems restricting the use of Sn-Bi base solders in electronic packaging [9]. A combination of these two Pb-free solder alloys could improve the reliability of a solder joint.

In this study, composite solder was made from combining a SAC305 solder ball and Sn-58Bi solder paste. The solder joint was fabricated by reflow soldering process. These composite solders were reflowed on Cu-OSP (copper-organic solderability preservatives) substrate to form solder joints. The microstructure evolution of the composite solder joints was investigated at different isothermal aging temperatures.

2 Methodology

A composite solder joint was made by assembling SAC305 (Sn-3.0Ag-0.5Cu in wt.%) solder ball on Sn-58Bi (in wt.%) solder paste. In fabricating solder balls, thin sheets of SAC305 alloy bulk were prepared. These thinned sheets were cut into smaller pieces using a 1.25 mm puncher to get a solder ball with an average 900 μm in diameter. These punched sheets were melted on Pyrex plate at a temperature of 250 °C in a reflow oven with the aid of rosin mildly activated (RMA) flux. Spherical shaped solder balls with ~900 μm diameter were formed caused by the action of surface tension during melting and cooling of the solder samples.

In making of the composite solder joint, Sn-58Bi paste was firstly evenly spread on a Cu substrate printed circuit board (PCB) with an organic solderability perspective (OSP) surface finish with the help of a thin plastic cover (~0.1 mm in thickness). This plastic cover helps spread the solder paste equally on the Cu substrate and it is easier to remove any excess of paste. Also, the volume of solder paste can be controlled and equally distributed. Then, the SAC305 solder balls were put on the Sn-58Bi solder paste that has been spread on the Cu-OSP substrate. Fig. 1 (a) shows the arrangement on how the solder was prepared before reflow process.

![Fig. 1.](image)

Composite solder joints of Sn-58Bi/Sn-3.0Ag-0.5Cu/Cu were refloowed with four different peak temperatures (160 °C, 170 °C, 180 °C and 190 °C) to form permanent joints. Then, the composite solder joint will undergo isothermal aging at temperatures of 100 °C and 150 °C in the annealing furnace. The duration of aging was 5 days (120 hours). To observe
the cross-sectioned microstructures of the solder joints, the samples were cold-mounted in epoxy resin before ground with SiC paper and carefully polished. As for the analysis of the microstructure evolution, optical microscope (OM) was used to observe the microstructures of the composite solder joints after isothermal aging at different temperature for 5 days. J-Image software was used to evaluate the thickness of IMC layer. The measurements of IMC thickness \( t \) were calculated as the area of IMC \( A \) divided with the length of IMC \( L \) as shown in Fig. 1 (b).

3 Results and Discussion

Fig. 2 shows representative microstructures of the composite solder joints after reflowed at different peak temperatures. The least reflow temperature at 160 °C was carried out, which is just above the melting point of Sn-58Bi at 139 °C. The result show that the Sn-58Bi solder paste has melted and diffused into the SAC305 solder ball.

![Figure 2](image)

**Fig. 2.** Representative cross-sectioned optical micrographs of composite solder joints after reflowed at (a) 160 °C, (b) 170 °C, (c) 180 °C, and (d) 190 °C; (e) zoomed-in image of diffusion area in (d).

The diffusion area of Sn-58Bi has rapidly increased into the SAC305 rich area as the reflow temperature increases. The melted Sn in Sn-Bi solder paste has mixed with the solid
Sn in SAC305 solder ball during the reflow (see Fig. 2 (e)). This indicates that a permanent solder joint consists of mid-range temperature solder of SAC305 (melting point at around 217 °C) can be done at lower temperatures less than 200 °C by using this assembly method. Nevertheless, higher reflow temperature can increase the diffusion area by facilitating the dissolution of Sn from the SAC305 bulk alloy into the Sn-58Bi rich area. Isothermal aging at 100 °C and 150 °C were done on samples that have been reflowed at 160 °C and 190 °C for 5 days. The interfacial IMC layer grows thicker, and more Sn-Bi rich alloy area has been diffused into the solid SAC305 solder ball (see Fig. 3).

![Representative cross-sectioned optical micrographs of composite solder joints after aging.](image)

The interfacial IMC thickness results after aging is shown in Fig. 4. In samples reflowed at 160 °C, the average thickness of the interfacial Cu$_6$Sn$_5$ layer after isothermally aged at 100 °C and 150 °C were 8.1 μm and 16.5 μm, respectively. While the average thickness of the interfacial Cu$_6$Sn$_5$ layer after isothermally aged at 100 °C (11.2 μm) and 150 °C (27.7 μm) were thicker in samples that have been initially reflowed at 190 °C. Generally, IMC grows thicker as isothermal aging temperature increases. Intermetallic compounds are generally brittle in nature. Hence, a thicker IMC layer is usually not preferred since it could compromise the reliability of the solder joint. This study shows that a composite solder joint can be assembled at lower temperature (160 °C) whereby a complete mixed of SAC305/Sn-58Bi composite solder can be gradually achieved through isothermal aging.
Fig. 4. Interfacial IMC average thickness after isothermal aged for 5 days.

4 Conclusion

In conclusion, a composite solder joint made of Cu/Sn-58Bi/Sn-3.0Ag-0.5Cu (in weight percent) was successfully fabricated through a reflow process and isothermal aging. The Sn-58Bi can be melted and diffused with the solid SAC305 solder ball during the reflow process at lower temperature of 160 °C. The solder joint that has been assembled at reflow temperature of 190 °C formed a thicker IMC layer compared to the joint that has been fabricated through a reflow temperature of 160 °C.

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