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The Effect of Bismuth Addition on Sn-Ag-Cu Lead-Free Solder Properties: A Short Review

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Abstract: Sn-0.7Ag-0.5Cu lead-free solder is an alternative solder material suitable to replace Sn-Pb solder in electronic manufacturing. In this review, the change in the microstructure, elements, the structural and melting point of Sn-0.7Ag-0.5Cu after the addition of different compositions of bismuth were discovered. Besides, the influence of bismuth in lead-free solder alloys attracts to be studied due to its capability to improve the wettability and solder spread.

1. Introduction

To adapt the demands of dynamic innovation, the industry of electronics continuously updating to produce the new device generation. The interconnecting materials like solders are widely availed oneself of in electronic packaging. This is because of the developments in electronics to form functional circuits via mechanical and electrical components for joining technology [1-2]. The performance and reliability of solder alloys are essential in electronic assemblies. The most effective interconnecting material is Sn-Pb solder alloys. This is due to that material has a lower melting point and eutectic composition. It is also good wettability and great in solder joint physical, mechanical properties, wetting properties, and reliability [1]. However, lead toxicity increases concerns about the environment and health that push the microelectronics industry towards lead-free solders into the packaging [2, 4, 19].

This problem causes the overwork to enhance the most suitable lead-free solders with outstanding of the appropriate excellent soldering efficiency as solders from Sn-Pb [1] [2]. The development of lead-free solder considers a few properties that solder, mechanical, wetting, and reliability properties of the solder joint. As a replacement for Sn-Pb solders alloy, various alternatives lead-free solders have been developed to utilize in electronic applications [3, 4, 6, 10].

Besides that, with properties of soldering alloy such as low fusion temperature and excellent in mechanical, wettability, and thermal properties. Low cost and eutectic composition are also sufficient and resistant to corrosion whereas solder alloys are a critical component in the long-term acceptance

[1]. Sn-xAg-Cu (SAC) is known as one of the most promising substitutes for Sn-Pb solder alloys due to having good properties. The properties include low melting point, eutectic structure, low coefficient of thermal expansion, good mechanical properties, and high wettability [3, 20, 22].

One of the traditional methods for improving the performance of lead-free solders is via incorporating dopants. Other than that, it also can use by alloying elements into the solders' alloy to enhance solder alloy performance or to develop the new ones. The alloying factor is selectively integrated into soldering alloys to regulate and control the growth of intermetallic compounds (IMC). In fact, to prevent destructive phase changes, alter their morphology, improve strength and ductility, and regulate oxidation. One of the common alloying elements is Bi [3-5].

2. Bismuth in Lead-Free Solder

Bi has been one of the significant alloying components in lead-free solder because of its ability to minimize the solder's melting temperature, low cost compared to other materials, and considered less heavy metal poisonous [4, 6]. Bi is widely used to lower liquid temperature, improving the subsequent solder joints' mechanical properties in harsh conditions. In addition, a small amount of Bi to different lead-free solder alloy formulations deliberately improve the properties of wetting and spreading. In fact, to lower the melting temperature and improve the mechanical properties of the solder joints [9, 19]. The lower of Bi surface tension connected to the improvement of wetting behavior, which can reduce the alloy surface tension [21]. A low concentration of Bi addition to the near-eutectic SAC305 also can avoid the formation of IMC's [11].

Based on different Sn-based lead-free solders, the composition of Bi has been studied with different percentages whereas for 0-5wt%, 6-10wt%, 11-14 wt%, and more than 15wt% [11, 17, 18]. However, studies have shown that based on Sn, only a small amount of Bi that suggested being used in the lead-free solder is less than 4wt%. This is also supported by Ramli et al. (2020) wherein contrast to the typical requirements of high strength solder joint materials, they stated that by adding a higher amount of Bi for substantial solution reinforcement, more brittle solder may lead [17].

2.1. Melting Temperature

The most important aspect of the melting point is that it determines the reflow solder profile and is also known for influencing the wetting and solidification phase [4]. A transition from solid to liquid phase driven by changes in free energy is known as the definition of the melting. Apart from solid and eutectic temperatures, liquid temperature plays the most important role from the perspective of the melting temperature. The Sn-Pb eutectic temperature is 183 °C while the Sn-Ag-Cu solder's melting point is 217 °C, 34 °C higher than that of the eutectic Sn-Pb [7]. Through the reflowing temperature, the melting temperature increases and causes thermal damage to the polymer substructure. By adding Bi to a lead-free solder based on Sn which can withstand the solder's fusion temperature. As the amount of Bi increases the fusion temperature continually decreases [4, 7, 12].

In the present study, Mahdavifard et al. (2015) demonstrated that the differential scanning calorimetry (DSC) required to examine the impact of Fe and Bi augmentations on the melting temperature and pale run of the SAC105 combination. Hence, Table 1 appeared the posting of the solidus and liquidus temperatures and pasty range of the solder alloy which has been measured. Based on the result, for SAC105-0.05Fe-2Bi, the DSC test shows a diminishing in solidus temperature from 219.33 ℃ to 214 ℃. This includes 0.05wt.% Fe to SAC105 and 2wt.% Bi decreased undercooling from 12.3

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℃ to 9.8 ℃. The result is also supported by El-Daly et al (2015), which appeared a 6 ℃ lessening in dissolving temperature by including 3 wt.% Bi to SAC15 and 4 ℃ diminishments in undercooling [4].

Table 1. The summarized test result of DSC in the following representative alloys.

Alloys	Solidus temp. T_s (°C)	Liquidus temp. T_1 (°C)	Pasty range	The onset of solidified. temp. T_c (°C)	Under cooling, T_s-T_c (°C)
SAC105	219.3	231.7	12.4	207.0	12.3
SAC105-0.05 Fe-1 Bi	217.6	230.0	12.4	207.5	10.1
SAC105-0.05 Fe-2Bi	214.0	229.0	15.0	204.2	9.8

2.2. Microstructure and Formation of IMC

SEM and XRD used to observe the solder alloy element and microstructure. To form an image the SEM uses an electron beam. SEM used to observe the part and phases from gran boundaries that formed with the different composition of Bi after the annealing of the Sn-Ag-Cu solder alloy. The presence of intermetallic compound (IMC) particles can be observed in bright-field images via the cross-section, grain, and Sn's network structure [16, 18, 21].

Based on previous study by Moosavy, R. S, the base solder microstructure and SAC257-xBi solder combinations were characterized with the back-scatter electron SEM pictures. Based on this perception that the chemical composition of the base solder SAC257 is comparable to the eutectic composition, the β-Sn lattice shapes the stages Ag3Sn and Cu6Sn5 as appeared in Fig. 1a. agreeing to Fig.1 b-d, the microstructures alter by including bismuth to the SAC257 which is the morphology of the Ag3Sb and Cu6Sn intermetallic compounds show up to alter from a needle to an equiaxial shape [12, 16]. The scale of the intermetallic compounds will diminish when the degree of undercooling, was diminished. On the other hand, the Bi dissolvability in Sn is additionally diminished, and bismuth is stored independently for more than 1wt% Bi, which is unmistakable as a white stage in Fig. 1c, d [16]. The image can be refer on previous study by Moosavy, R. S.

2.3. Wettability

Solder wettability as defined as the molten solder's ability to expose a substratum during the reflow process. The heating temperature at a particular condition for the reflow process is only good wettability to the surface of the base material to form good wet spreading joints, namely to form solder joints. By adding an alloying factor is one of the best researchers to boost solder wettability [10-11].

Based on the previous study by Erer et al. (2018) stated that the contact angles of the quaternary Pb-free solder alloy Sn-2.0Ag-0.5Cu-1.0Bi (SAC-1Bi) were decreased by adding Bi to SAC305 as it can be measured at different temperatures (310, 280 and 250 °C) on the Cu surface in the Argon (Ar) atmosphere using a sessile drop method. In Fig. 2, it is show that wetting angles of the quaternary lead-free solder alloy SAC-1Bi which the surface tension decreases as the temperature increases, for instance as the adhesion increases. Thus, the wetting angle values decreased at 250, 280, and 310 °C respectively, with temperature changes of 57.2, 40.8, and 35.6. The adding of Bi to SAC305 alloy will reduce the wetting angle value. For example, for SAC305 solder alloy, the smallest angle value is 41.9 ° at 310 °C, while for SAC-1Bi solder alloy this value is calculated at 35.6 ° at the same temperature [8, 11]. The image can be refer on previous study by Erer et al. (2018).

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3. Conclusion

In conclusion, the addition of bismuth in SAC solder alloys would significantly improve SAC's mechanical and microstructural properties by reducing the melting point. Instead, the surface tension of the solder alloy during the melting. In addition, by adding bismuth to SAC solder alloys, the contact angle of the quaternary Pb-free solder alloy Sn-Ag-Cu-xBi (SAC-xBi) will increase the wettability.

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