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Effect of Bismuth Additions on Wettability, Intermetallic Compound, and Microhardness Properties of Sn-0.7Cu on Different Surface Finish Substrates

(Kesan Penambahan Bismut kepada Kebasahan, Sebatian antara Logam dan Sifat Mikrokekerasan Sn-0.7Cu terhadap Substrat Akhir Berlainan Kemasan)

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ABSTRACT

The influence of bismuth (Bi) addition on wettability, thickness of interfacial intermetallic compound (IMC), and microhardness properties of Sn-0.7Cu + xBi solder alloy using different types of substrate were examined. The 0.5, 1.0, 1.5, and 2.0 wt. % Bi was added into Sn-0.7Cu and fabricated using the casting process. The result shows that the influence of 1.5 wt. % Bi in the Sn-0.7Cu solder soldered on copper organic solderability preservative (Cu-OSP) and immersion tin (Im-Sn) surface finish has improved the wettability and microhardness. Subsequently, the IMC thickness of Sn-0.7Cu+1.5Bi solder alloy on Im-Sn surface finish gives a better result than reflowed on Cu-OSP. Generally, with the addition of 1.5 wt. % Bi in Sn-0.7Cu solder alloy reflowed on the Im-Sn surface finish had enhanced the performance in terms of wettability, thickness of IMC and microhardness properties compared to on Cu-OSP surface finish.

Keywords: Bismuth; solder alloy; surface finish; wettability

ABSTRAK

Dalam kajian ini, kesan penambahan bismut (Bi) terhadap kebasahan, ketebalan antaramuka sebatian antara logam (IMC) dan sifat mikrokekerasan pateri bebas plumbum Sn-0.7Cu + xBi menggunakan pelbagai jenis substrat telah dikaji. Penambahan 0.5, 1.0, 1.5 dan 2.0 bt. % Bismut ke dalam Sn-0,7Cu dibuat menggunakan kaedah peleburan. Hasil kajian menunjukkan bahawa penambahan 1.5 bt. % Bi pateri Sn-0.7Cu yang dipaterikan pada permukaan Cu-OSP dan rendaman timah (ImSn) meningkatkan kebasahan dan mikrokekerasan. Selain itu, ketebalan IMC untuk pateri Sn-0.7Cu + 1.5Bi pada kemasan permukaan Im-Sn memberikan hasil yang lebih baik berbanding aliran semula pada permukaan pada Cu-OSP. Secara keseluruhan, dapat disimpulkan bahawa 1.5 bt. % Bi dalam pateri Sn-0.7Cu yang telah dialirkan semula pada permukaan ImSn telah meningkatkan ciri-ciri kebasahan, ketebalan IMC dan sifat mikrokekerasan berbanding pada permukaan Cu-OSP.

Kata kunci: Aloi pateri; bismut; kebasahan; kemasan permukaan

Introduction

Over the past few years, the tin lead (Sn-Pb) solder has been used in electronics application because it has good soldering, reliability and pricing (Cheng et al. 2017). Nevertheless, it was found that lead is toxicity and harmful to humans. Due to that, many researchers extensively developed to find the suitable Pb-free solder candidates. The two most preferred substitutes to the common Sn-Pb solder were tin silver copper (Sn-Ag-Cu) and tin copper (Sn-0.7Cu) (Hu et al. 2015). The Sn-0.7Cu solder is one of anticipated replacements solder as it is low cost solder with great solder joint performance.

However, the wettability and mechanical properties of Sn-07Cu solder are recognized as a poor solder due to the brittle behaviour of intermetallic compound (IMC) in the solder (Izwan Ramli et al. 2020a). Hence, the alloying method has been considered as additives such as bismuth (Bi) (Belyakov et al. 2017), nickel (Ni) (Ventura et al. 2011), and zinc (Zn) (Ng et al. 2015) elements to expand the properties of the Sn-0.7Cu solder. Besides alloying element, the printed circuit board (PCB) assembly process with a surface finish become a focus in electronic industry. In addition, there are limited studies regarding the different surface finish including Cu-OSP and immersion tin. Thus, this paper focused on the influence of Bi addition on Sn-0.7Cu solder on Cu-OSP and ImSn surface finish.

MATERIALS AND METHODS

The base material which is Sn-0.7Cu was mixed with bismuth (Bi) granules with different compositions (0.5, 1.0, 1.5 and 2.0 wt. %) via casting technique. Firstly, the Sn-0.7Cu alloy were heated up at 250 °C in a casting furnace. After the Sn-0.7Cu solder become melted, the different composition of Bi granules was added. The new solder alloy was stirred frequently for homogenisation and poured into a stainless-steel mould. The Sn-0.7Cu solder with Bismuth addition was removed and the solder ball was fabrication for microstructure and interfacial IMC analysis. Meanwhile, for wettability, the Sn-0.7Cu+xBi solder were weighted at 0.5 g before reflowing on substrate. All samples were then reflowed using a F4N reflow oven with small addition of flux and two types of surface finish underlying on the copper substrate which is Copper-Organic Solderability Preservative (Cu-OSP) and Immersion Tin (ImSn) PCB FR4 type. Subsequently, to observe the cross-section area, the samples were cleaned and perform grinded and polished.

Wettability of solder was determined with respect to the contact angle of Sn-0.7Cu+xBi solder form on copper substrate as showed in Figure 1. A cross-sectional sample were prepared for each composition and surface finish. The Optical Microscope (ECLIPSE L300N) and Image-J software was used to examine the sample. The average of thickness IMC also measured by using the Image-J software as define in Figure 2. Subsequently, for the microhardness testing, samples were measured by using the FV-700e Vickers microhardness following ASTM standard E-384. Before conducting the experiments, the samples were metallographically ground and polished into flat area in order to get proper indention and accurate reading. The measurement was made using 1 kgf indention load and a dwell for 10 s with 5 different indentation points for each sample.

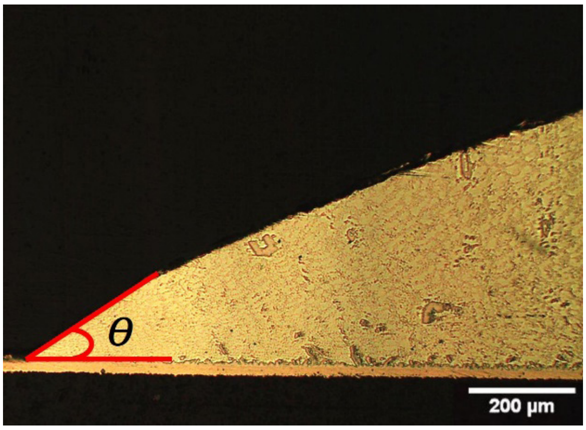

FIGURE 1. Measurement of contact angle of solder on Cu-OSP and Im-Sn substrate

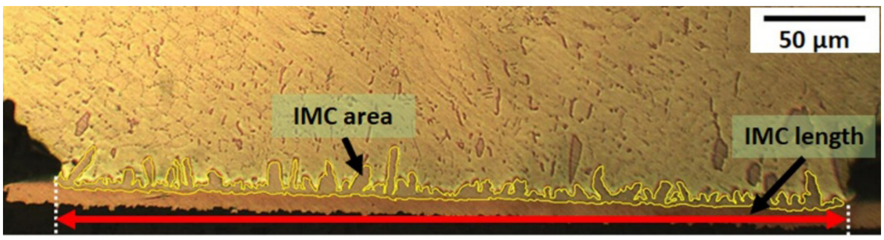

FIGURE 2. Illustration of the area and length of the measured IMC layer thickness

Results and Discussion

WETTABILITY BEHAVIOUR

The wettability of solder alloy was determined based on the contact angle (θ) to the Cu-OSP and Im-Sn surface finish (Mohd Salleh et al. 2011). According to Mhd Noor et al. (2016a), smaller contact angle give the better wettability of the solder. As reported by Rita et al. (2015), they claimed that the range between $20° \leq \theta \leq 40°$ was the acceptable range for contact angle. Moreover, the contact angle considered inaccurate when the value is more than 40°. Figure 3 shows the variation of wetting angle of Sn-0.7Cu+xBi solder on Cu-OSP and Im-Sn surface finish. For Cu-OSP surface finish, the contact angle decreased from 31.44° to 26.94° with addition of 1.0 wt. % of Bi. However, with the addition of 2.0 wt. % of Bi, the contact angle of Sn-0.7Cu solder alloy increased to 30.9° due to higher surface tension.

Meanwhile, for Im-Sn surface finish, the contact angle continued to decrease from 23.88° to 14.38° when 1.5 wt. % of Bi was added. Then, the trend was slightly increased from 14.38° to 17.63° when Bi addition up to 2.0 wt. % of Bi. The observation shows that the Cu-OSP has largest contact angle than the Im-Sn surface finish. Comparable result was found in studies by Muhd Amli et al. (2019) which investigated the wettability of the Sn-3.0Ag-0.5Cu solder on four different surface finish including the Cu-OSP and Im-Sn. The result shows that the Cu-OSP has the largest contact angle compared to Im-Sn, ENIG, and ImAg. Moreover, Muhd Amli et al. (2019) also found that the Im-Sn has better contact angle due to the lower surface tension compare to Cu-OSP surface finish. The adding of 1 wt. % Bi element reduces the contact angle, hence improves the wettability properties (Said et al. 2015). The contact angle of Sn-0.7Cu solder had improved with suitable amount of addition Bi.

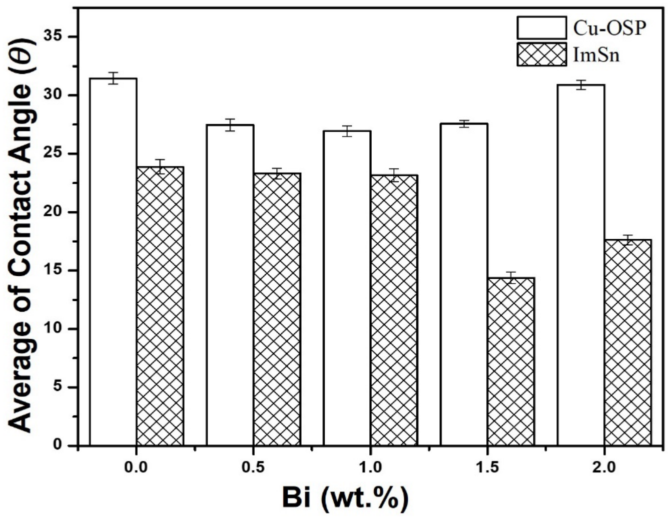

FIGURE 3. Average of contact angle of Sn-0.7Cu+xBi soldered on Cu-OSP and Im-Sn substrate

THICKNESS OF INTERMETALLIC COMPOUND

In the electronic packaging, the thickness of the intermetallic compounds (IMCs) is crucial since it is related to the reliability of the solder joint (Said et al. 2015). The thickness of IMC measurements of Sn-0.7Cu+xBi on Cu-OSP and Im-Sn surface finish is shown in Figure 4. The acceptable range for thickness intermetallic compound was not more than 25.0 µm for as-reflowed sample. The results show that the thickness of IMC using Sn-0.7Cu solder on Cu-OSP substrate decreases from 21.29 to 19.48 µm with addition 0.5 wt. % Bi. However, the thickness of IMC increase with increases of Bi addition on Sn-0.7Cu. For Im-Sn substrate, the thickness of IMC increased when 0.5 wt. % Bi was added into Sn-0.7Cu then slightly decreased to 11.76 µm for Sn-0.7Cu+1.5Bi. Comparing the IMC thickness on Cu-OSP and Im-Sn, it shows that the IMC thickness on Im-Sn is lower than Cu-OSP. This is because, when Sn-0.7Cu+xBi solder reflowed on Im-Sn, a thin layered of Im-Sn which coated the Copper substrate will act as barrier to prevent the excessive Copper diffusion from substrate towards solder. Study by Musa et al. (2015) reported on the influence of 1 wt. % Bi in Sn-2.8Cu-0.5Cu solder were able to inhibit the growth of IMC during thermal aging process. Mhd Noor et al. (2016b) also reported the thickness of IMC decreased after 10 wt. % Bi addition to the Sn solder alloy. In conclusion, the influence of small amount of Bi into Sn-0.7Cu solder alloy the excessive formation of interfacial IMC was able to be suppressed.

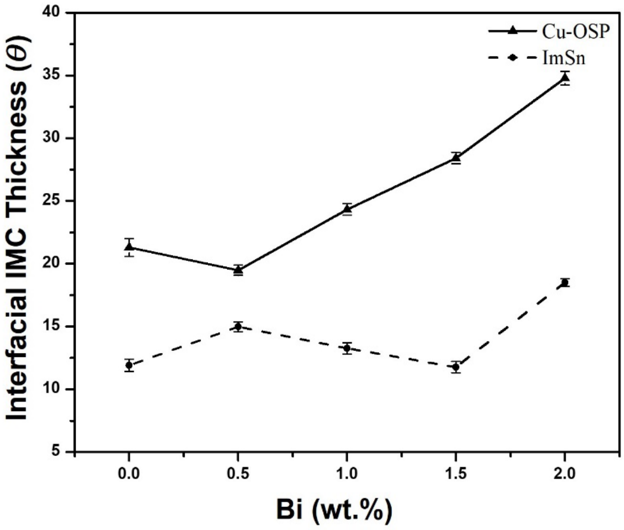

FIGURE 4. Intermetallics compound (IMC) thickness of Sn-0.7Cu+xBi soldered on Cu-OSP and Im-Sn substrate

MICROHARDNES PROPERTIES

In Figure 5, the average of microhardness value of Sn-0.7Cu+xBi solder soldered on Cu-OSP and Im-Sn surface finish. The optimal value of microhardness for Sn-0.7Cu+xBi solder soldered on Cu-OSP and Im-Sn substrates was 14.92 and 15.22 HV, respectively, with 1.5 wt. % of Bi element. However, with additions of 2.0 wt. % Bi, the value slightly decreases to 10.26 HV for Cu-OSP and 13.72 HV for Im-Sn surface finish. The decrement of microhardness is related to the solubility limit of Bi in Sn. Based on previous study reported by Izwan Ramli et al. (2020b) the solubility limit of Bi in Sn is 1.8 wt. %. Subsequently, when excessive addition of Bi element in Sn, it will reduce the strength properties of solder due to the brittleness behaviour of Bi element. It can be concluded that, the addition of 1.5 wt. % Bi element into the Sn-0.7Cu solder could improve the microhardness due to the solid solution strengthening effect in the β-Sn area. Similar results also reported by Liu and Sun (2013), that the addition Bi can enhanced the strength of SAC solder (Yang et al. 2013). Therefore, addition of 1.5 wt. % Bi on the Sn-0.7Cu solder alloy could enhance the microhardness performance of the solder alloy.

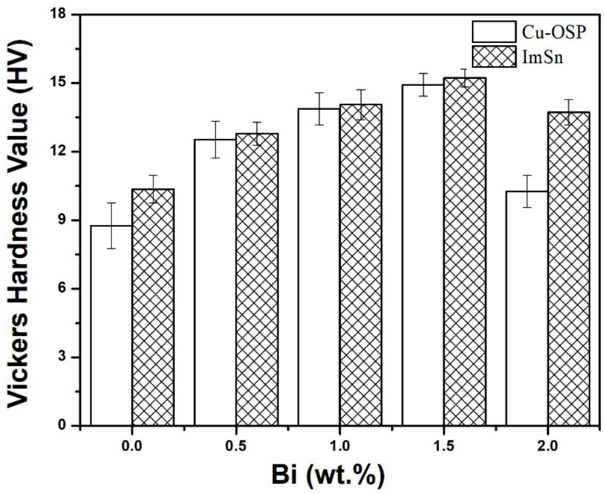

FIGURE 5. The average microhardness value of as-soldered Sn-0.7Cu+xBi on Cu-OSP and Im-Sn surface finish

Conclusion

The influence of different Bi addition in Sn-0.7Cu solder after soldered on Cu-OSP and Im-Sn surface finish have been investigated in this work. Several conclusions that can be summarised as follows. The wettability of Sn-0.7Cu+1.5Bi solder alloy on Im-Sn surface finish with 14.38° contact angle gives lower contact angle compared to on Cu-OSP surface finish with 26.94° contact angle, the addition of 0.5 wt. % of Bi in Sn-0.7Cu solder on Cu-OSP and 1.5 wt. % Bi on Im-Sn surface finish suppressed the formation of IMC layer, and the average microhardness of the Sn-0.7Cu solder increased by addition of 1.5 wt. % Bi.

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