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Interfacial Reaction between SAC3807 Lead-Free Solders and Different Copper Substrate via Reflow Soldering Process

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Abstract. The different composition material of copper substrate significantly affects the intermetallic compound (IMC) formation and the solder joints durability. This study was conducted on the interfacial reaction between lead-free solder and the different copper substrates via reflow soldering. The selected substrate is copper (Cu) and copper-beryllium (Cu-Be). The lead-free solder involved is Sn-3.8Ag-0.7Cu (SAC3807) solder ball with a diameter of 700 µm. All the samples were subjected to the isothermal aging process. The material characterization and analysis on the IMC formation were examined by scanning electron microscopy (SEM), optical microscope (OM), and energy dispersive X-ray analysis (EDX). After the reflow process, the result revealed that Cu_6Sn_5 and Cu_3Sn IMC layer formed at SAC3870/Cu and SAC3870/Cu-Be interface. The changes to a rod-like shape Cu_6Sn_5 and needle-shaped Cu_3Sn_4 occur after the aging treatment on SAC3870/ Cu. Meanwhile, the IMC layer for SAC3870/Cu-Be shows a rod-like shape transformed into a blocky-like shape Cu_6Sn_5 and Cu_3Sn_4 rod-shape. This result indicates that Ag_3Sn nano-sized was formed on the intermetallic surface during the aging process for both SAC3807/Cu and SAC3807/Cu-Be. The Ag_3Sn nano-sized element at SAC3807/Cu-Be is many compared to SAC3807/Cu. In addition, IMC thickness for SAC3807/Cu-Be shows a thicker layer than SAC3807/Cu. In addition, the element of Be in SAC3807/Cu-Be cannot be defined because the beryllium element is not easily detected as the percentage was very low.

Introduction

The soldering technique is familiar to connect the electronic chip with PCB in modern electronic devices. Solder alloy has many advantages as interconnecting material, as it can form a joint between two metal surfaces and provided electrical and mechanical connection [1]. For many decades lead-tin (Pb-Sn) solder have been used in the electronic industry as connecting material to connect the electronic chip with PCB. However, since July 1, 2006, European Union countries banned the use of Pb in the electronics industry, followed the rule Restriction of Certain Hazardous Substances (RoHS) [2]. Lead (Pb) is known as toxic and harmful to human health. Today, lead-free solder alloys such as Sn-Ag and Sn-Ag-Cu developed very aggressively. Due to their low cost and good mechanical properties, Sn-Ag-Cu solders are commonly used in the electronic packaging industry [3].

In an electronic device, numerous substrates are used, such as Ni substrates, Cu substrates, and Au/Ni/Cu substrates, etc. [4]. However, copper substrates are primarily used compared to others. The type of copper substrate will significantly affect the IMC formation at the solder joint. There are several types of copper substrate, for example, pure copper, FR4 copper and copper-beryllium (Cu-Be) substrate. Adding beryllium to copper makes the alloy respond to aging treatment and formed very high strength. There are two types of copper-beryllium, highly conductive alloys with 0.3-0.5 % beryllium content and high-strength alloys with 1.7-2.0 % beryllium content [5]. Cu-Be is used in the electronics industry compared with pure copper substrates because of its good corrosion resistance, good mechanical properties, and good wettability [1]. Due to its high strength, excellent thermal and electrical conductivity, Cu-Be has being used in aerospace, petrochemical and manufacturing fields [6]. Besides that, Cu-Be is also used in mold inserts for metal die casting and plastic injection molding [7]. Cu-Be alloys also can be processed through soldering, brazing, and standard fusion welding techniques [8]. However, the beryllium (Be) element is not easily detected in the alloys, and the limitation element of interest may be present below the detection limit of EDX, typically about 0.2-0.5% [9]. According to Ozkan & Turkuz [11], Be element had identified with Raman analysis on bare copper-beryllium surface. The peak between 510 and 540 cm^{-1} wavelengths corresponded to CuO, and at the peak of wavelength 610, 1080, and1180 cm-1 show the oxidation state of Be as shown in Figure 1.

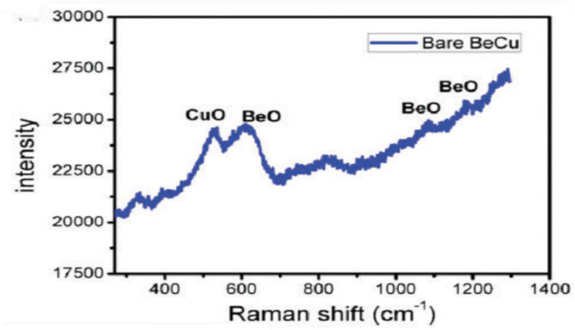

Fig. 1. Raman analysis of bare Cu-Be [11]

This study will aim to investigate an interfacial reaction between SAC3807 solder and Cu and Cu-Be substrates. The melting point for SAC 3807 is 217°C [10]. The formation of the solder joint during reflow soldering will be investigated and explained. The detailed microstructure analysis will show the IMC growth of solder in different copper board materials. Since the formation of IMC can provide an excellent metallurgical bond [7], an essential understanding of the formation and growth of the IMC layer is crucial.

Material and Methods

Copper (Cu) and copper-beryllium (Cu-Be) are used as substrates in this study. The solder ball is arranged as shown in Figure 2. Before placing the solder ball, no-clean flux was applied onto Cu surface. For the reflow process, the furnace was set at 230°C and reflowed in 20 minutes. After the reflow process, the sample needs to be clean with acetone to remove excess flux. Then, the samples undergo an isothermal aging process at a temperature of 150°C for 500 and 750 hours by followed the JEDEC standard (JESD22-A103C). The samples are then ground and polished for cross-section examination. The top surface examination will be immersed in an etching solution contains the hydrochloric acid solution and an ethanol solution. Finally, the samples will undergo material characterization analysis using OM, SEM, and EDX.

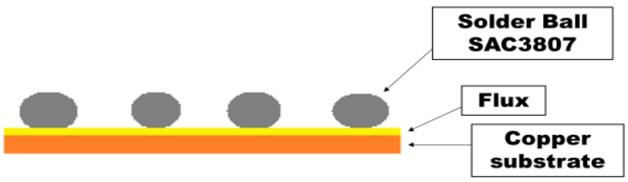

Fig. 2. Side view SAC3807 arrangement

Result and Discussion

Figure 3 and Figure 4 show the cross-sectional images for both SAC3807/Cu and SAC3807/Cu-Be after the reflowed process. A scallop-type IMC has appeared at the interface between solder and Cu substrates. It is happened due to Cu alloy diffusion from the solder to substrate. From EDX analysis, there are two composition IMC been identified which are Cu_6Sn_5 and Cu_3Sn after reflow soldering process. This situation is similar to the previous researcher [12], they mentioned two types of binary IMC layers formed at an early stage of reflow and are maintained throughout the process between the solder bump and the copper substrate which are Cu_6Sn_5 and Cu_3Sn that been identified by EDX analysis through colour contra on sample. The Cu_3Sn IMC seems growth beneath the Cu_6Sn_5 layer. Besides that, it can be clearly seen that the IMC thickness for SAC3807/Cu-Be is thicker than SAC3807/Cu where the thickness is 8.0 µm and 5.0 µm, respectively.

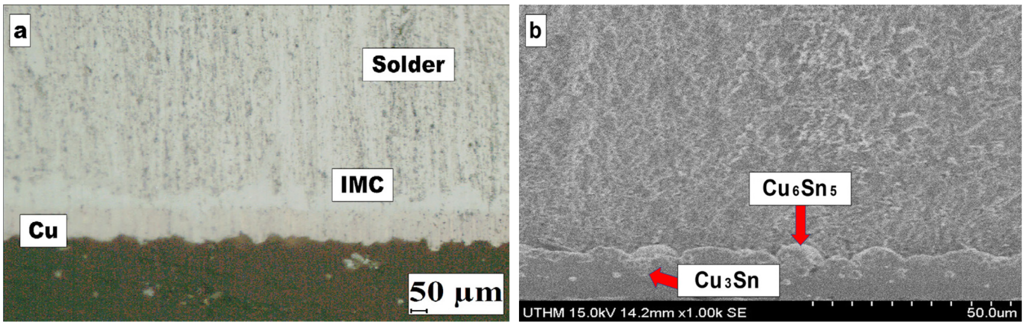

Fig. 3. Cross-sectional examination for SAC3807/Cu after reflow process

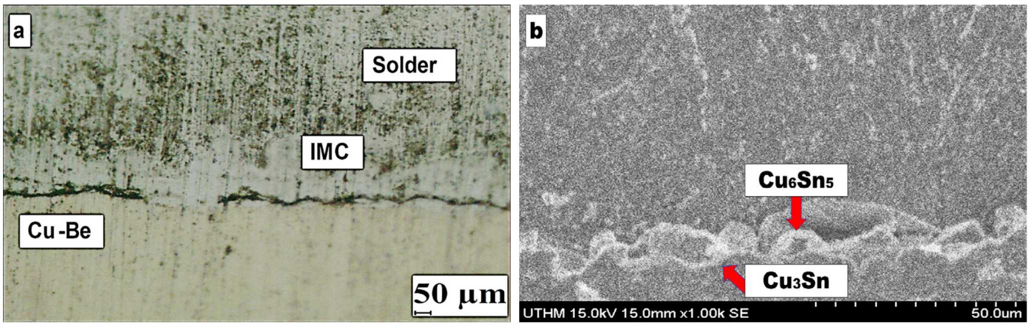

Fig. 4. Cross-sectional examination for SAC3807/Cu-Be after reflow process

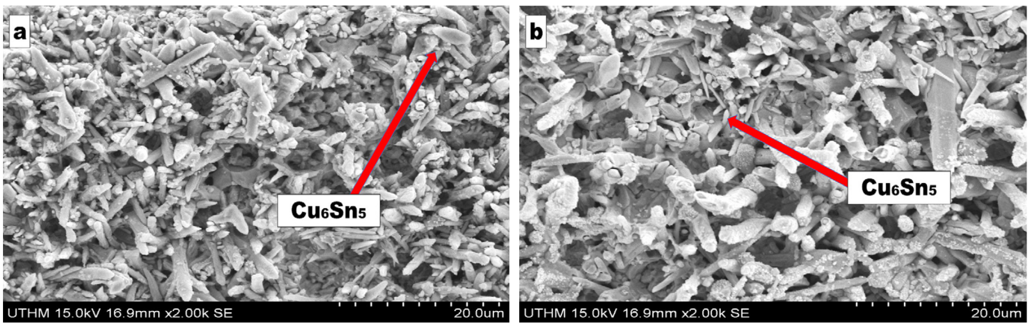

Fig. 5. SEM images of top surface a) SAC3807/Cu and b) SAC3807/Cu-Be after reflow process

For top surface examination, only Cu_6Sn_5 IMC can be detected since the Cu_3Sn layer grows beneath the Cu_6Sn_5 layer, as represented in Figure 5. Thus, it is difficult to observe the Cu_3Sn layer in the top surface view. Generally, both Cu_6Sn_5 morphology for SAC3870/Cu and SAC3870/Cu-Be are rod-like shapes. However, the IMC grain size for SAC3870/Cu-Be is bigger compared to SAC3870/Cu. It is consistent with the top surface examination where the IMC thickness of SAC3807/Cu-Be is thicker than SAC3807/Cu.

During isothermal aging process, the solder bumps were subjected to 500 hours and 750 hours of isothermal aging at 150 ºC. Both IMC formed during the reflow process been continuous growth and growth during the aging process. The rod-like Cu_6Sn_5 for SAC3807/Cu during reflowed was growth in same morphology after aging process at 500 hours. Meanwhile, SAC3807/Cu-Be IMC was transformed from rod-like Cu_6Sn_5 to blocky-type IMC, as shown in Figure 6. Fortunately, the Cu_3Sn_4 grain size can be observed in aging process. The Cu_3Sn_4 needle-shape is detected for SAC3807/Cu (Figure 6a) and Cu_3Sn_4 grain size for SAC3807/Cu-Be was rod-like, as can be seen in Figure 6(b). Furthermore, the variation of amount copper alloy in solder and substrate would produce different

IMC morphology. It shows that the reaction of IMC is strictly dependent on copper alloy composition in solder and substrate. Throughout the aging process, the interfacial reaction between the atom is continually diffused and the grain size constantly grows. It consistently with sample aged at 750 hours in Figure 7, the grain size of the IMC become bigger, compact and dense especially for SAC3807/Cu-Be (Figure 7b). In term of the IMC thickness, the thickness for SAC 3807/Cu after aging at 750 hours was 11.0 µm while SAC 3807/Cu-Be is 15.0 µm. Figure 8.0 presents the graph of IMC thickness against the reflow time for Cu and Cu-Be. From Figure 8.0, the IMC thickness was increase linearly when the aging time increased. When the samples was exposed to the heat continuously, the thickness and grain size of IMC also growth and increased.

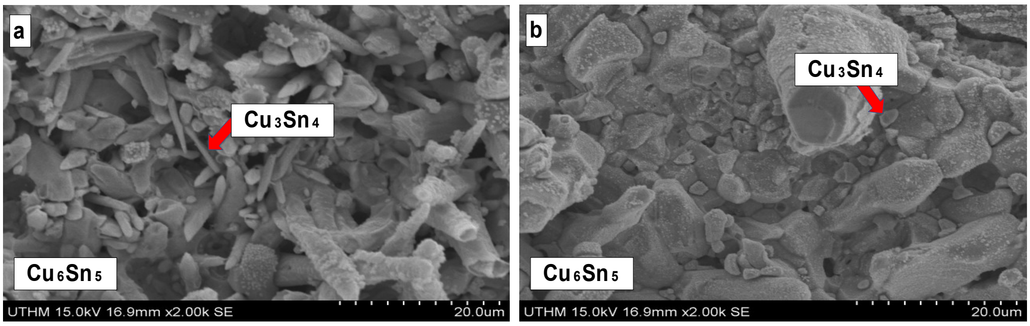

Fig. 6. SEM images of top surface a) SAC3807/Cu and b) SAC3807/Cu-Be after aging 500 hours

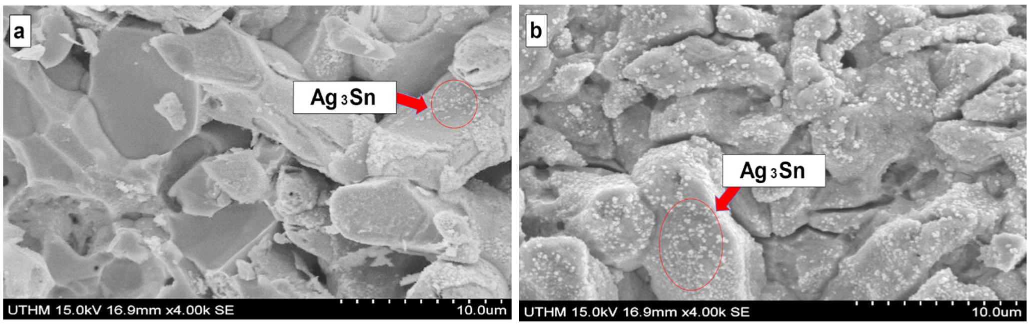

Fig. 7. SEM images of top surface a) SAC3807/Cu and b) SAC3807/Cu-Be after aging 750 hours

Besides that, the formation of Ag_3Sn also has been observed. According to Figure 7 (a), it shows the big grain of Ag_3Sn were placed above the Cu_6Sn_5 grain layer. Meanwhile, small particles distribution in the white spot of Ag_3Sn was found around the Cu_6Sn_5 grain (Figure 7b). Ag_3Sn can mostly appear in three forms that are particle-like, needle-like, and plate-like. The impact of the soldering time and temperature on the Ag_3Sn average particle sizes and the size of the IMC plays an essential role in the adsorption of Ag_3Sn particles [13]. Figure 7 (a) and (b) also show the difference between SAC3870/Cu and SAC3870/Cu-Be is the amount of Ag element at the IMC layer. It shows different particles of Ag_3Sn on the surface of intermetallic compound for both substrates. The value of Ag_3Sn for SAC3807/Cu-Be is higher compared to SAC3807/Cu. The excessive of Ag_3Sn is not good for the solder joint because it can cause crack propagation, which can affect the reliability of the PCB board.

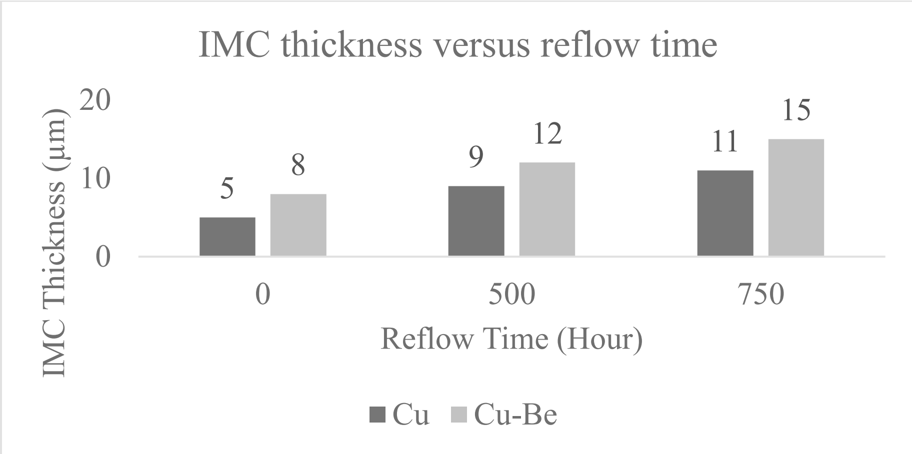

Fig. 8. Effect of aging time on the IMC thickness

Summary

In this study, the IMCs growth formation and morphology were different by using different copper board substrate on SAC3870. The result revealed that, after the reflow, the shape of IMC Cu_6Sn_5 for both SAC3870/Cu and SAC3870/Cu-Be has a rod-like shape. Then, both Cu_6Sn_5, Cu_3Sn_4 and Ag_3Sn_4 formed at the SAC3870/Cu and SAC3870/Cu-Be interface when the sample was exposed to isothermal aging proses. In 500 hours of isothermal aging, the rod-like Cu_6Sn_5 for SAC3807/Cu during reflowed was growth in same morphology after aging process at 500 hours. Meanwhile, SAC3807/Cu-Be IMC was transformed from rod-like Cu_6Sn_5 to blocky-type IMC. The Cu_3Sn_4 needle-shape is detected for SAC3807/Cu and Cu_3Sn_4 grain size for SAC3807/Cu-Be was rod-like. The SAC3870/Cu-Be grain size provided a thick intermetallic compared to the SAC3870/Cu intermetallic. In addition, the IMC thickness is proportional to aging duration.

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