Influence of Fly Ash Geopolymer Ceramic Powder Addition on Sn-3.0Ag-0.5Cu Solder Joints

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Abstract. This paper reports the effect of 1.0 wt.% fly ash (FA) geopolymer ceramic powder addition in Sn-3.0Ag-0.5Cu (SAC305, in wt.%) solder joint. Powder metallurgy route was used to fabricate the new composite solder. Solder balls were formed from the new composite solder and reflowed on Cu substrate. The effect of FA as ceramic reinforcement on the bulk microstructure and the interfacial intermetallic compound layer formation of solder joints were investigated under optical microscope. Microstructure observation showed that the β-Sn dendrite size was refined in SAC305-1.0FA/Cu bulk solder joint sample than that in the non-reinforced sample. The addition of FA geopolymer ceramic powder into the solder matrix also produced a thinner intermetallic compound layer.

1 Introduction

In recent years, more studies have been focusing on the development of more reliable tin (Sn)-based lead (Pb)-free solder alloys for used in high temperatures application [1,2]. Lead-based solder alloy has been used as an assembling material in electronic packaging for decades due to its good properties, workability, ductility, and low cost [3]. However, strict actions were taken by The European Reduction of Hazardous Substances (RoHS) to ban Pb-based usage mainly due to the toxicity of Pb, which can affect neurological and physical to human health as well as environmental pollution [4]. Although Pb-free solder materials have been widely utilized in consumer electronics products, their application in some critical applications (e.g., defense, medical, etc.) are still not fully recommended. Moreover, the application of Pb-free solder increases the complexity of interconnection metallurgies in smaller products [5].

The majority of the Pb-free alloys systems available in the market today are composed of Sn-rich alloys that are incorporated with other beneficial elements or additives. Most recent
studies on Pb-free solder have been focusing on improving the mechanical reliability of Sn-Cu, Sn-Ag, and Sn-Ag-Cu solders [4]. While, the widespread use of Sn-3.0Ag-0.5Cu (SAC305) Pb-free solder alloys was due to endorsement of this alloy by the IPC, the Association Connecting Electronics Industries [4,6]. One of the alternatives that were found could improve the solder joint properties was through reinforcement of ceramic powder into the solder matrix [7–10].

One of the most important part of soldering is the formation of intermetallic compound (IMC) layer which signifies good bonding between the solder and substrate. The phase of the intermetallic layer will grow during the soldering because of interaction between solder alloy and solder substrate. However, excessive formation of IMCs is not favorable due to its brittleness which could reduce the reliability of solder joint. Accordingly, ceramic addition into the solder matrix of Pb-free solder could potentially minimizes the excessive growth of IMC layer [11]. Previous study by Mohamad Zami et al. [7,12] showed that the addition of kaolin geopolymer ceramic into the SAC305 solder decreases the formation of β-Sn area and forms finer intermetallic of Cu₆Sn₅ and Ag₃Sn in the eutectic region. In this study, we report the influence of 1.0 wt.% fly ash geopolymer ceramic powder addition on SAC305 solder joints.

2 Methodology

Sn-3.0Ag-0.5Cu (SAC305, in wt.%) with an average particle size in the range of 25–45 μm was used as the base matrix material for the composite solder. Fly ash (FA) geopolymer ceramic powder was prepared by mixing with alkaline activator sodium hydroxide (NaOH) and soluble alkali material sodium silicate (Na₂SiO₃) for 5 minutes. Then, the mixture was poured into the mold and cured for 24 hours to allow geopolymerization. After 24 hours, the hardened geopolymers were then sintered in the tube furnace at the temperature of 900 °C for 2 hours. The sintered FA pellet was then crushed by a mechanical crusher to produce fined powder as shown in Fig. 1(b).

![Fig. 1. (a-e) Composite solder joint preparation, optical micrographs of sintered solder pellets of (f) SAC305, and (g) SAC305-1.0FA samples.](image-url)
The powder metallurgy method was used to prepare the geopolymer-reinforced composite solder. First, both SAC305 alloy powder and 1.0 wt.% of FA geopolymer ceramic powder were weighed, poured, and sealed in a plastic container. Then, the sealed container was put inside a planetary mixer. A homogeneous SAC305-1.0FA composite solder mixture was obtained after mixed for an hour at a speed of 200 rpm. An approximately 1 g green compact pellet with a 12 mm diameter and ~1 mm height was obtained using a Specac-15-Ton Manual Hydraulic Press with a load of 4.5 tons. This green compact pellet was sintered at 185 °C using a hybrid microwave sintering technique under ambient conditions for 3 minutes [7].

Next, the sintered pellet was rolled into thin sheets and cut into smaller pieces using a 1.25 mm puncher (see Fig. 1). 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 average 900 μm in diameter were formed by the action of surface tension between the molten solder and Pyrex plate during melting and cooling of the solder samples. Finally, a composite solder joint was formed by reflowing the solder ball on a 900 μm ball pitch size of Cu substrate printed circuit board (PCB) with an organic solderability perspective (OSP) surface finish.

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. An optical microscope was used to observe the microstructure of the solder joints. J-Image software was used to evaluate the thickness of interfacial intermetallic compound (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. 2.

![Fig. 2. Representative cross-sectioned optical micrograph image showing the measured area and length of interfacial IMC layer.](image)

### 3 Results and Discussion

Fig. 3 shows representative microstructures of the solder joints. The addition of 1.0 wt.% fly ash (FA) geopolymer ceramic powder shows more homogeneous β-Sn grains area with less primary Cu₆Sn₅ found on the solder bulk area. The size of primary Cu₆Sn₅ and Ag₃Sn IMCs were also refined with the addition of ceramic reinforcement. The interfacial IMC thickness result is shown in Table 1. The IMC thickness of SAC305 with the addition of fly ash showed a decrease in IMC thickness. Previous study by Zaimi et al. (2018) also shows that the thickness of the IMC layer of composite solder decreases with the addition of non-metallic particles, SiC, compared to the pure composite solder [13]. The addition of non-reactive 1.0
wt.% FA geopolymer ceramic into the SAC305 solder matrix could have inhibited the growth of interfacial IMC layer by limiting the reaction between Sn in solder bulk area and Cu at the solder/substrate interface.

Fig. 3. Representative cross-sectioned optical micrograph images of (a-b) SAC305/Cu, and (c-d) SAC305-1.0FA/Cu.

| Sample             | Average interfacial IMC thickness, μm |
|--------------------|--------------------------------------|
| SAC305/Cu          | 5.43 ± 0.15                          |
| SAC305-1.0FA/Cu    | 2.73 ± 0.46                          |

**4 Conclusion**

The effect of the addition of fly ash (FA) geopolymer ceramic powder on microstructure of SAC305 was successfully investigated. It is found that the addition of FA geopolymer ceramic reinforcement in SAC305 could potentially refines the bulk microstructure with the formation of more homogeneous β-Sn grains area. The formation of large primary Cu₅Sn₅ IMCs was found to be unlikely in the composite solder joint sample. Also, thinner interfacial IMC in SAC305-1.0FA/Cu solder joint if compared to the monolithic sample. It can be concluded that the addition of fly ash geopolymer ceramic powder has the potential to enhance the properties of Pb-free solder joints.
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