Influence of Copper Substrate Roughness on the Growth of Intermetallic Compounds Layer in SAC305 Solder Joints

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Abstract. This study aimed to evaluate the effect of surface morphology of copper (Cu) substrate on the intermetallic compound (IMC) growth and interfacial reactions when soldered with SAC305 lead-free solder during a thermal aging process. The surface morphology conditions of the Cu substrate influence the growth activity of the IMC layer. This study used different grits of silicon carbide (SiC) abrasive paper (400, 800 and 1200) to grind the Cu substrate to produce different surface roughness. The resulting Cu surface morphologies were examined using an infinite focus microscope (IFM), and the parameters used in this stereometric analysis were profile roughness. Hand soldering was used to melt the SAC305 solder on the Cu substrates with different surface roughness. Subsequently, the samples were subjected to an aging temperature of 150 °C for 800 hours to grow the IMC layers. Thermal aging increased the IMC thickness at the Cu-SAC305 interfaces. After thermal aging, the IMC layer thickness and related parameters were measured and analyzed with the IFM. The growth of the IMC layer thickness depended on the different surface morphology of the substrate when the aging temperatures and Cu materials were maintained in this study. In general, the IMC morphology for the rougher Cu substrate had a scallop-shaped and uniformed layer compared to those IMC from the smooth Cu substrate. The Cu substrate ground surface roughness with 400 grit SiC abrasive paper produced an average roughness, $R_a$ of 505.02 nm; this roughness produced the thinnest IMC layers compared to the different Cu substrates ground by SiC abrasive paper of different grits.

1 Introduction

Lead-free solder joints are a common method of interconnecting components in the electronic industry. Copper (Cu) is one of the most often utilized materials for bond pads in lead-free solder joints, and it is one of the most frequently used substrates [1–3]. Various types of testing, including wettability and microstructure assessments, are used to assess the quality and dependability of solder connections connected to different morphologies of Cu substrates [4–6]. When measuring the adhesion of a solder joint, wettability is a commonly used test that involves measuring the contact angle of the joint immediately after the application of molten solder to the substrate (just after soldering). The evaluation of solder

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joint wettability, on the other hand, mainly explains the adherence and spreading of molten solder via the measurement of the physical appearance of the solder joint.

Solder joints on various morphologies of Cu substrates are examined for quality and reliability using microstructure inspection and intermetallic compound layer measurement at the interfaces of solder joints and Cu substrates [7,8]. Specifically, microstructure measurements are used in the assessment because they are performed at the micrometre scale and in cross-sectional views that reveal the internal structure of solder connections with Cu substrate. At the interfaces of lead-free solder and copper substrates, several investigations have been carried out to assess the solder and copper substrate's microstructure development and intermetallic compound (IMC) growth. According to Lee et al. [9], tin/silver/copper (SnAgCu) solder is the most common type of lead-free solder that has been utilised as an environmentally friendly product. Their findings revealed that the Cu₆Sn₅ and Cu₃Sn IMC layers were frequently found at the interface between SAC solder and copper substrate, respectively. Increasing solder reflow temperature and duration, both IMCs were increasing in thickness.

Although extensive research has been done on the microstructure and mechanical properties of SAC305 solder joints on Cu substrates, limited information is known about the relationship between Cu substrate surface roughness and the reliability and IMC growth of the growth SAC305 solder joints. A thorough evaluation is therefore particularly needed. Cu substrates with varying surface roughness’s were prepared in the research study using a wet grinding technique on various grits of silicon carbide (SiC) abrasive sheets. Hand soldering of SAC305 solder joints was performed on Cu substrates with varying average surface roughness ($R_a$). The SAC305 solder joints with Cu substrate were subjected to a reliability test or aging, which was carried out utilizing high-temperature storage (HTS). The cross-sectional image of the interface region between the SAC305 solder connection and the Cu substrate was used to assess the form of morphological changes and IMC growth.

2 Methodology

2.1 Material and Experimental

Copper, Cu substrates with dimensions of 2 cm x 1 cm x 0.3 cm were wet ground on silicon carbide, SiC abrasive sheets with grits of 400, 800, and 1200, respectively, to produce different surface roughness. After that, the Cu substrates were cleaned with ethanol and deionized (DI) water. The surface roughness of Cu substrates that have been subjected to the wet grinding technique on various grits of silicon carbide (SiC) abrasive sheets. The average roughness, $R_a$, was determined with the use of IFM.

The solder material utilised in the present research was SAC305 lead-free solder wire with a diameter of 1.0 mm. In order to solder the SAC305 lead-free solder wire onto three separate samples of Cu substrates that had been grounded with three different grits of abrasive papers, hand soldering at an applied temperature of 80 °C (hot plate) was performed. This resulted in three different samples of SAC305 solder joints on Cu substrates.

Three SAC305 solder joints with Cu substrates were subjected to a high-temperature storage (HTS) test in an oven based on the JESD22-A103C standard, with an applied temperature of 150 °C for 800 hours. This standard was chosen to be applied to the three samples of SAC305 solder joints with Cu substrates. Thus, the aim of this paper to evaluate the effect of copper substrate surface roughness on intermetallic compound layers in
SAC305 lead-free solder joints. As a result, for each sample with a varied roughness, three SAC305 solder joints with Cu substrate were produced.

3 Characterization

3.1 Sample preparation

Sample preparation for microstructure analysis of SAC305 solder joints with Cu substrates that have completed the HTS test after being exposed to high temperatures. The sample preparation was carried out following with the metallography method, with the samples initially being resin mounted. Following curing of the samples, wet grinding with 400, 800, and 1200 grit abrasive sheets was performed, followed by polishing with 1 μm and 0.25 μm diamond suspensions on silk cloth.

3.2 Morphology analysis

Cross-sectional microstructure analysis of SAC305 solder connections with Cu substrates that have undergone HTS testing was carried out using an Alicona IFM.

4 Result and Discussion

Fig. 1 shows the surface morphology of SiC grit paper a) 400, (b) 800 dan (c) 1200 by using SEM analysis. From Fig. 1 (a), the size of particle SiC grit paper of 400 is larger than 800 and 1200, which represent the larger particle of SiC that existed on the grit paper. In this study, the Cu substrate were ground with variation of SiC grit paper to produce the different surface roughness on the Cu substrate. It is noted that the study profile of surface roughness should be analyzed further before the soldering process takes place.

Fig. 1. SEM surface morphology of SiC grit paper a) 400, (b) 800 dan (c) 1200.

From Fig. 2 (a)-(c), the micrograph and the depth profile existed on Cu substrate with the variation of SiC grit paper. Among the factors influencing the wettability of solder spread on the Cu substrate, are wettability and surface tension to ensure the good soldering quality [10–12]. The range value of the peak height of the depth profile of the valley were considered with the extraordinary peak height and the valley depth probably is because of the sharp particles of SiC grit paper.
Fig. 2. Micrograph and the depth profile vertical and horizontal of existed on Cu substrate with the variation of SiC grit paper (a) 400, (b) 800, and (c) 1200.

Fig. 3 shows the variation of Cu substrate, $R_a$ towards SiC abrasive paper grits. In Fig. 1, it is shown that the trend of $R_a$ reduction as the increasing number of SiC grit paper increasing where the SiC abrasive paper with grit 400 produces the highest $R_a$ of 505.02 nm and reduce gradually for grit number of 800 and 1200 with $R_a$ of 338.35 nm and 172.61 nm, respectively.

Fig. 3. Variation of Cu substrate average surface roughness, $R_a$ towards SiC abrasive grits.

Fig. 4 (a) - (c) depicted the micrograph of Cu substrate with IMC layer and solder material after the aging temperature at 150°C for 800 hours with different of Cu substrate roughness. Fig. 4 (a) shows even two IMC layer, (b) irregular layer for the Cu$_6$Sn$_5$ IMC layer, (c) uneven layer mainly for upper layer Cu$_6$Sn$_5$ IMC layer. The different Cu surface
roughness responded to different IMC thickness leading to different reliability of SAC305 lead-free properties. The IMC layers grow in the middle of Cu substrate and solder. The shape of IMC layers grew aligned with other previous studies [10]. The scallop shape of the IMC layer was formed due to the effect of Gibbs-Thomson and “Ostwald ripening” [11]. There were two IMC layers formed on the Cu substrate with the variation of grit paper. The IMC layer was formed because of the bottom absorption layer of Cu$_3$Sn, and this layer was known as Cu$_6$Sn$_5$ same as the chemical equation as below [12]:

\[
\begin{align*}
3Cu + Sn & \rightarrow Cu_3Sn \\
5Sn + 6Cu & \rightarrow Cu_6Sn_5
\end{align*}
\]

Fig. 4. Micrograph of IMC layer after aging at 150 ℃ for 800 hours after the Cu substrate were ground with SiC with the variation of grit paper (a) 400, (b) 800, and (c) 1200.

In metallurgy, the IMC layer existed due to the soldering process that led to soldering reaction within the melting condition with Cu substrate in solid form. This reaction produces the IMC layer with a thinner thickness of around 1 μm [13]. This Fig. 4 (c) represents that the IMC layer's growth is due to the thickness layers is growing. The rougher surface of Cu substrate, the slower the soldering reaction of IMC growth layer.

5 Conclusion

The investigation of the interfacial reaction is essential to provide a more detailed analysis of the effect of Cu substrate surface roughness on the quality and reliability of SAC305 solder joints. It is observed that the application of SiC abrasive papers with grits of 400, 800, and 1200 produces Cu substrates with $R_a$ that can be split into three segments that are represented by the reduction methods in either gradually or suddenly change. The surface roughness of SAC305 with Cu substrate was determined by varying the grit of SiC abrasive paper. The surface roughness value produced by SAC305 with Cu substrate is reduced as the number of SiC abrasive paper grits is increased. When soldered or exposed to the HTS for the first time, the IMC of SAC305 solder joints on Cu substrates with a rougher surface has scallop-shaped and uniform IMC, especially Cu$_6$Sn$_5$, as opposed to those on Cu substrates with a smoother surface, which has non-uniform IMC, particularly Cu$_6$Sn$_5$. As a result, the method described in this research is a crucial first step for those looking to achieve the appropriate Cu substrate surface roughness to regulate the IMC development of SAC305 solder joints.

This work is supported by Universiti Kebangsaan Malaysia (UKM) under Geran Galakan Penyelidik Muda (GGPM-2020-036) and Redring Solder (M) Sdn. Bhd. for research materials and collaboration work.
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