THE EFFECT OF IMMERSION SILVER THICKNESS ON INTERMETALLICS FORMED IN Sn-3.8Ag-0.7Cu LEAD-FREE SOLDERS

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THE EFFECT OF IMMERSION SILVER THICKNESS ON INTERMETLLICS FORMED IN Sn-3.8Ag-0.7Cu LEAD-FREE SOLDERS

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Abstract

Immersion silver is one of an alternative surface finish to printed circuit board electronic assembly in electronic packaging industry. In this study, the effect of immersion silver thickness on interfacial reactions or IMC that occur during soldering between Sn-3.8Ag-0.7Cu (SAC3807) lead-free solder on immersion silver surface finish is investigated. Solder joint reliability is also examined by performing solid state thermal aging at 150°C for up to 1000 hours. The results revealed that after reflow soldering, Cu_6Sn_5 IMC is formed between solder and substrate while after aging treatment a new IMC was found between Cu_6Sn_5 IMC and substrate known as Cu_3Sn. Aging of solder joints results in an increase of IMC's thickness and change in their morphologies to become more spherical, denser and with larger grain size. Examination of solder joints microstructures also revealed that several types and morphologies of intermetallics formed after reflow soldering and solid state ageing. However, the thickness of immersion silver surface finish metallurgy investigated was found to have no effect on the type or morphology of intermetallic compounds formed, although with thicker silver layer the intermetallic compounds grew in thickness

KEYWORDS: Lead-free; solder; immersion silver; intermetallic compound; aging; surface finish

1. Introduction

Lead-containing solders have been used extensively in microelectronics applications to form electrical interconnections between packaging levels, to facilitate heat dissipation from active devices, provide mechanical/physical support, and to serve as a solderable surface finish layer on printed circuit boards (PCBs) and lead frames. However, the recent trends of worldwide environmental legislation for toxic materials and consumer demand for "green" products have accelerated the transition from Pb-containing solders to lead-free solders in electronic industry. This trend has driven the technology of surface finishes for printed circuit boards (PCBs) is seeing a dramatic shift from hot air solder leveling (HASL) which lead is a major components, towards alternative surface finishes such as ENIG, immersion silver and immersion tin [1,2].

Surface finishes are applied to printed circuit board (PCBs) to prevent oxidation of exposed copper on board, thus ensuring a solderable surface when components are added at a later processing stage [5]. Immersion silver is one of an alternative surface finish to printed circuit board electronic assembly in electronic packaging industry. Besides that, it consists of a very thin (0.15-0.55 μm) coating of nearly pure silver. In this aspect, immersion silver is 100 times thinner than traditional electroplated silver. A slightly amount of organic material is typically deposited within the immersion silver intended to prevent tarnish and electro-migration. Benefits of immersion silver include flatness, Pb-free, inspectability at assembly, lack of solder mask attack and surface functionality. Relative to other PCB coatings or surface finishes, immersion silver does not suffer from black-pad interfacial fracture phenomenon, tin-copper intermetallic shelf life reduction, whiskers formation, or sensitivity to weak fluxes [4].

In this study, we investigate the intermetallic growth and thickness between Sn-3.8Ag-0.7Cu (SAC3807) lead-free solder with immersion silver surface finish and also the effect of immersion silver thickness on interfacial reaction or intermetallics during reflow soldering and isothermal aging treatment.

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2. Experimental procedure

The copper substrate is cut into pieces with dimensions 45 x 15 x 1 mm from sandwich copper sheet. The substrate was a commercial oxygen-free copper where the samples were lightly grinded and then was first subjected to a pre-treatment process to remove oxides and activate the copper surface before the immersion silver process is started. This process is also very important to remove potential contaminants such as oxides, grease and oil and render it clean for the subsequent plating process. In this study, the surface finish is focused on immersion silver (ImAg). The plating solution used is made up of 50g/L of *ethylene diamine tetra-acetic acid (EDTA)*, 20.4g/L of *sodium hydroxide* and 1g/L of *silver nitrate*. In the present study the immersion silver is deposited into two different thicknesses: ~0.4μm and ~0.8μm, which are labeled here as thin and thick silver layer respectively.

The immersion silver plating is conducted in two stages. Firstly, the substrates (e.g. for thin coating) was immersed in pre-plating beaker for one minute and then immersed in a second beaker for seven minutes to start plating, and one plus eleven minutes for thick coating . The operating temperature of the plating bath was set up to 45°C. After that, all the samples were laminated with a layer of dry solder mask in order to restrict the molten solder from flat spreading during reflow soldering. Next step is the solder mask together with the patterned film was cured by ultraviolet (UV) light in order to produce small openings of 0.38 mm in diameter. After that, a thin layer of no clean flux is applied onto the substrate to remove the oxide layer and also to improve the wetting of molten solder during reflow soldering. Then, the substrates were manually populated with solder balls with a diameter of 700μm arranged in several rows. Bonding to form the solder joints was made by reflow in a furnace with the peak reflow temperature set at ~250°C. The total time taken from ambient to peak temperature (reflow temperature) was about 26 minutes.

After reflow soldering, each sample was subjected to ageing treatment at 150 °C for 250 hours, 500 hours and 1000 hours. Characterisation of samples involved both at top surface and cross section of solder joints. Several techniques including optical microscopy, scanning electron microscopy (SEM) and energy dispersive x-ray analysis (EDX), image analyzer and field emission scanning electron microscope (FESEM) were used for the intermetallics characterization.

3. Results and discussion

3.1 Intermetallic compounds

During soldering, the solder alloy melts and reacts with the substrate to form intermetallic compounds (IMCs) at the joining interface. The growth of interfacial reaction during solid-state aging in solder joints is of particular interest to the electronic industry [3]. The top surface morphology of Cu_6Sn_5 after reflow soldering is clearly shown in Figure 1 where the size of Cu_6Sn_5 with thin Ag is smaller than in a thick Ag layer. These grain sizes were confirmed by measuring grain size diameter (average), and the result revealed that the diameter of the grain size between thin and thick Ag layer is around 2.5μm and 2.8μm respectively.

In this solder alloy the results show the formation of Cu_6Sn_5 which has been observed in the bulk solder just above the Cu_6Sn_5 IMC interface. The coarse needles with hexagonal cross sections of Cu_6Sn_5 at interface in bulk solder were detected only on the thin Ag while for thick Ag layer only particles of Cu_6Sn_5 were detected.

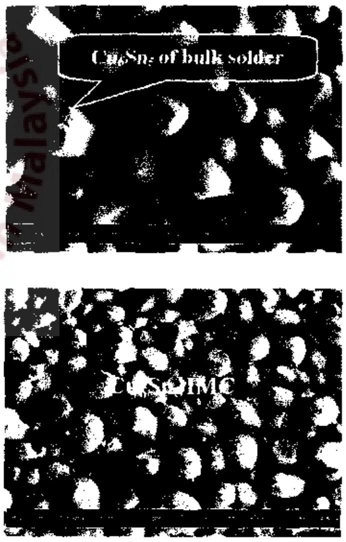

Figure 1: Top surface morphology of Cu_6Sn_5 using SAC 3807 after reflow (a) Thin Ag layer (b) Thick Ag layer

Consistent with the top surface examination, the cross section examination of Cu_6Sn_5 IMC between solder and substrate for both Ag layer had the scallop type morphology as shown in Figure 2. This IMC was confirmed by EDX analysis.

Besides that, the formation of Ag_3Sn after reflow soldering was identified. For both Ag layer thicknesses, there were Ag_3Sn and Cu_6Sn_5 intermetallics formed in the bulk solder joints as revealed in Figure 3. The Ag_3Sn grew in large plate-like morphology and the Cu_6Sn_5 grew into long rod, some were solid and others were hollow as shown in Figure 3(a).

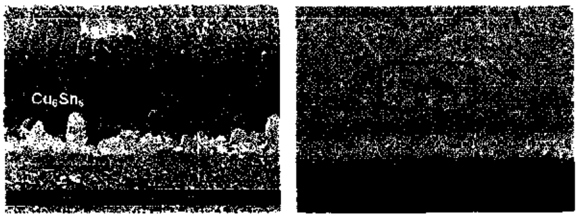

Figure 2: Cross section morphology of Cu_6Sn_5 between ImAg and SAC 3807 solder after reflow by using (a) SEM (b) Nikon with 500x magnification

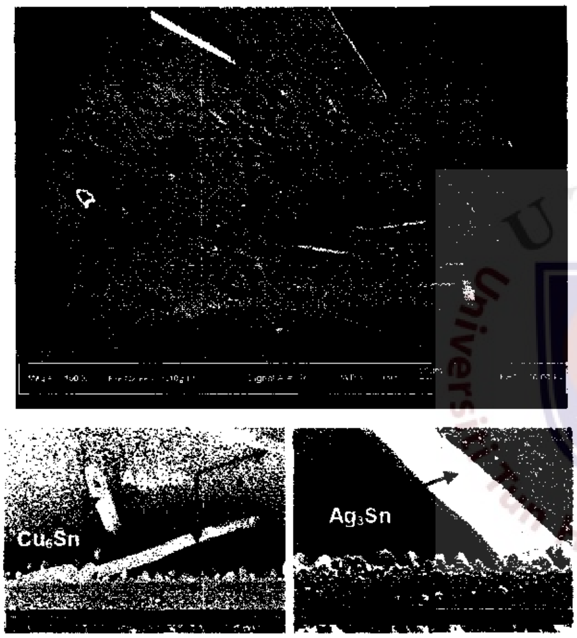

Figure 3: The formation of Ag_3Sn after reflow (a) and (b) Thin Ag (c) Thick Ag layer

After isothermal aging treatment, the scallop type Cu_6Sn_5 IMC observed after reflow has transformed into a uniform and continuous layer and also Cu_3Sn appeared between the Cu_6Sn_5 and substrate. The morphology of Ag_3Sn also changed into more spherical and rounded shape as shown in Figure 4.

Figure 4 also shows the presence of Kirkendall voids which appeared in the Cu_3Sn layer. This is in agreement with the work by Li *et al.* (2005) who reported that Kirkendall voids form in the Cu_3Sn layer during the long-time ageing. In such case, the main diffusion element is Sn in Cu_6Sn_5 but Cu in Cu_3Sn. Diffusion of Sn in Cu_6Sn_5 is very slow, which determines the entire growth of the IMCs, leading to a shortage of Sn to react with Cu in Cu_3Sn layer. The lacking Sn in the lattice spaces in Cu_3Sn can therefore result in the formation of Kirkendall voids.

Peng *et al.* (2007) explained that a Cu_3Sn IMC is a brittle material. A porous Cu_3Sn layer due to Kirkendall effect makes the solder/Cu bonds very weak. Kirkendall void formation in the solder joint on Cu occurs by two steps. First, vacancies are generated in Cu near the Cu_3Sn layer after the Cu atoms have left the Cu pad and diffuse towards the solder. Second, the vacancies coalesce into voids. The vacancy generation in Cu is unavoidable because of the unbalanced inter-diffusion of Cu and Sn. Therefore, the key to slow down the formation of Kirkendall voids in the Cu3Sn layer is to prevent coalescence of vacancies into voids. This can be realized if the vacancies can be dispersed into the bulk Cu. Grain boundaries as easy diffusion paths in Cu can enhance this process.

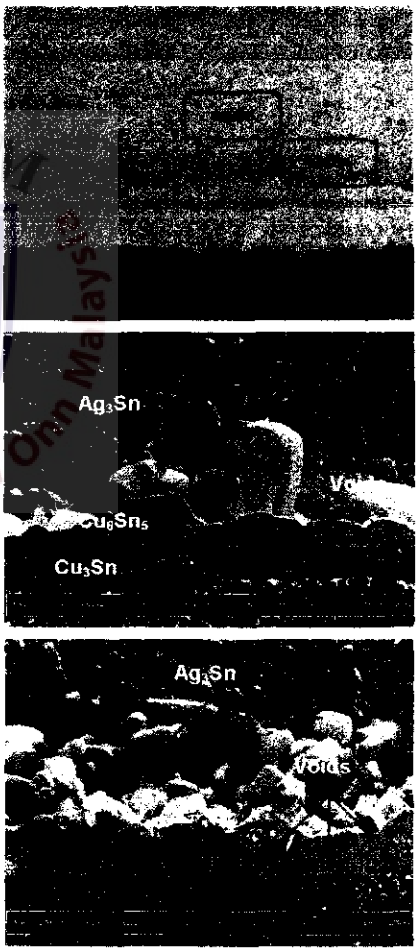

Figure 4: Cross section morphology between ImAg and SAC 3807 solder after aging 500 hours (a) Nikon with 500x magnification (b) Thin Ag (c)Thick Ag layer.

Figure 5 shows the top surface morphology of Cu_6Sn_5 using SAC3807 solder after isothermal aging for both Ag thicknesses. As mentioned before, the Ag_3Sn formation also shows more spherical shape and some of them are also present as small particles.

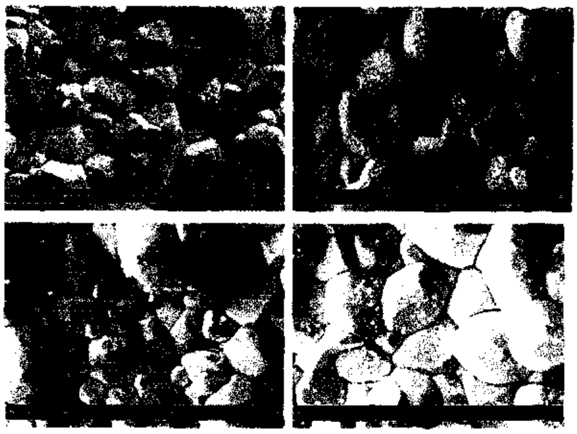

Figure 5: Top surface morphology of Cu_6Sn_5 using SAC 3807 after isothermal aging (a) 250 hrs with thin Ag layer (b) 250 hrs with thick Ag layer (c) 1000 hrs with thin Ag layer (d) 1000 hrs with thick Ag layer

Based on the graph shown in Figure 6, the grain size of top surface morphology of Cu_6Sn_5 is also proportional to aging duration. The grain size becomes bigger, coarser and spherical in shape for the thicker Ag layer compared to the thinner Ag layer. For example, for thick Ag layer the grain size was found to be 11.2µm which is the highest value compared to 9.0µm for the thin Ag layer.

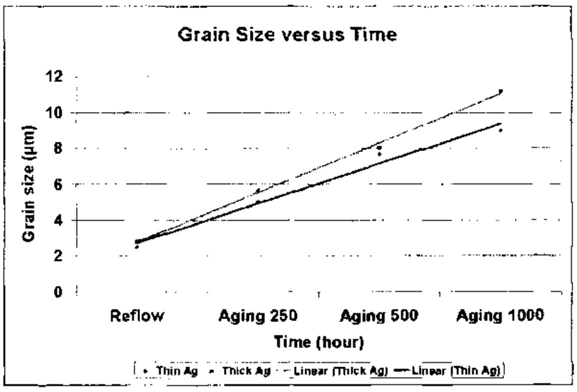

Figure 6: The Cu_6Sn_5 grain size on top surface morphology using SAC 3807 after reflow and isothermal aging

3.2 Thickness of intermetallic compound

Excessively thick reaction layers, which grow between the solder and substrate can significantly degrade the physically and mechanical properties of the solder joint particularly in high impact loads environments. In addition, IMC thickness data provide a valuable input which can calculate long term thickness values from minimum amount of short term experimental measurements. This analytical approach will improve the predictability of substrate solderability and solder joint reliability. Therefore, the information of IMCs produced by soldering in electronic packaging is essential [3].

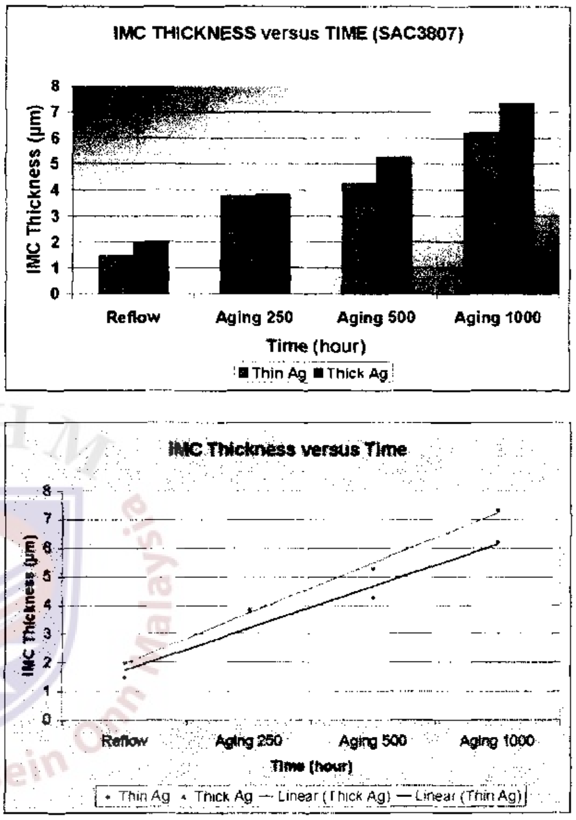

Figure 7: Intermetallic compound thicknesses versus time after reflow soldering and aging treatment (a) Histogram (b) Graph

Figure 7 shows the intermetallics thicknesses after reflow soldering and isothermal aging. The graph shows that the intermetallic compound is proportional to the time and silver thickness as well. It is clear from the plot that the thin Ag layer has a slower IMC growth rate compared to the thick silver layer.

As with the IMC thickness after reflow soldering, the IMC thickness after isothermal aging increased significantly for both Ag thicknesses as depicted in Figure 7, especially after aging up to 1000 hours

In addition, the IMC thickness for thick silver layer is greater than that in the thin silver layer either after reflow or isothermal aging. It happened because the silver coating on the top surface of substrate promotes nucleation sites for the formation of Cu-Sn intermetallics between solder and substrate. So, the thickness of silver layer will affect the IMC thickness where a thicker Ag layer will give a thicker IMC compared to a thinner Ag layer.

4. Conclusion

In this study, the results of the microstructure showed that the IMCs has been studied when a SAC 3807 lead free solders react with immersion silver (ImAg) surface finish. Only Cu_6Sn_5 IMC was found between solder and substrate after reflow soldering while both of Cu_6Sn_5 and Cu_3Sn IMC have been observed after isothermal aging. Aging of solder joints results in an increase of IMC's thickness and changes their morphologies to become more spherical, dense and with larger grain size. However, the thickness of immersion silver surface finish metallurgy investigated was found to have no effect on the type or morphology of intermetallic compounds formed, although with thicker silver layer the intermetallic compounds grew in thickness. In addition, the results also revealed that the thickness of intermetallics formed is proportional to the aging duration.

5. Acknowledgment

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