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Effect of Post-Reflow Cooling Rate on IMC Formation between Sn-3.0Ag-0.5Cu-0.5Ni (SACN30505) Lead-Free Solders and Electroless Nickel/Immersion Silver (ENIMAG)

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ABSTRACT

The surface finish of printed circuit board (PCB) produce a critical interface between the bare copper of PCB and the electronic component. It is act as protection layer for underlying copper from oxidation and provides surface solderability and wettability. When the optimization and development of a new alternative surface finish of Electroless Nickel/Immersion Silver (ENIMAG) has been successful made, hopeful-ly it can offer better properties and reasonable price. Therefore, this study will focused on the effect of post-reflow cooling rate on formation and growth of the intermetallic compound (IMC) between Sn-3.0Ag-0.5Cu-0.05Ni (SACN30505) lead-free solders and Electroless Nick-el/Immersion Silver (ENIMAG). The morphology, thickness, type and size of the intermetallic compounds formed was observed from three different cooling medium which are furnace-cooled, air-cooled and water-cooled at reflow state. The characterization of intermetallic com-pound formed was made by using Optical Microscope (OM), Field Emission Scanning Electron Microscope (FESEM) and energy disper-sive X-ray analysis (EDX). The result revealed that water cooled media shows a faster cooling rate compared to furnace-cooled media. However, in term of intermetallic compound thickness represents the thickness of IMC through furnace-cooled is thicker than the air-cooled. Besides that, only $(Cu,Ni)_6Sn_5$ layer was formed between SACN30505 solder and ENIMAG interface after reflow soldering process

Key words : ENIMAG, reflow soldering, lead-free solder, intermetallic compound, cooling rate.

1. INTRODUCTION

The move towards lead-free soldering has resulted in the surface finish requirements to become an even important aspect in today's printed circuit fabrication. Although several alternative surface finishes have been developed over the years but electroless nickel/immersion gold (ENIG) surface finish has become a popular choice in electronic packaging as its provides an uniform flat surface finish, an excellent solder attachment process control and high performance [1, 2]. However, with significant volatility in precious metal pricing and the constant demand for better products at cheaper prices made manufacturer are being driven to search for ways to reduce cost whilst not sacrificing quality such as using alternative surface finish on printed circuit board [3, 4]. Thus, surface finish plays an important role in the interfacial reaction between solder and substrate and also influences the microstructure of intermetallic formation (IMC).

In soldering process, post-reflow cooling rate is an important parameter which can effect the morphology and growth of intermetallic compound form between the solder and substrate [5, 6]. The cooling process requires being sufficiently slow to prevent thermal shock damage to the packaging and substrate materials. However, an excessively slow cooling rate may unnecessarily lengthen the fabrication process. Moreover, cooling rate also affects the microstructure of both bulk solder and the intermetallic compounds layer at the interface, which can caused the reliability problem of the solder joint [7, 8]. Therefore, this study aims to study the effect of post-reflow cooling rate on IMC formation between Sn-3.0Ag-0.5Cu-0.5Ni (SACN30505) lead-free solders and electroless nickel/immersion silver (ENIMAG).

2. MATERIALS AND METHODS

Sample Preparation: The substrates used in this research were prepared from copper-polymer (FR-4) as substrate materials for the depositions of ENIMAG coatings with dimensions of 52 mm x 72 mm x 1.2 mm. before undergoing electroless nickel and immersion silver process, the Cu substrate was subjected to pre-treatment process. Then, the substrates were immersed in the plating bath that contained the electroless nickel and immersion silver solution. The plating bath for both substrates was maintained at 90°C and 40°C, respectively.

Reflow process: The reflow samples were prepared by arrangement of the solder ball on the substrate. The solder ball of Sn-3.0Ag-0.5Cu-0.05Ni (SACN30505) with diameter Ø500 µm was arranged on the Cu/ENIMAG substrate with a thin flux above the substrates. The substrates were reflowed in the oven at 240˚C for 20 minutes and were cooled in different ways which are furnace-cooled, air-cooled and water-cooled.

Characterization methods: Both cross-sectional and top surface examinations were prepared for observations of the IMC morphology. The IMC characterizations in term of thickness and morphology were investigated by using the Optical Microscope (OM) and Field Emission Scanning Electron Microscope (FESEM). Energy dispersive x-ray (EDX) was used to identify the element of IMC formation.

3. RESULTS AND DISCUSSION

Post-reflow cooling rate can influences the microstructure, morphology and the growth of intermetallic compound (IMC). This process was taken just after the reflow process is ended. Three medium of cooling were used which are furnace-cooled, air-cooled and water-cooled. Table 1 shows the data obtained by using a thermocouple for three different mediums. From the result, it can clearly seen that water-cooled media shows a faster cooling rate with 1.84 (°C/s), then followed by air-cooled media with 0.26 (°C/s) and furnace-cooled media with 0.01(°C/s).

During the cooling process, the grain structure of fast cooling media (water-cooled) was retarded due to the experiencing temperature shock. Other than that, the period for the structure to fully developed and continued the growth rate was too little and short. This theory was support by Hardinnawirda *et al.* [6]. In contrast, when the sample undergoing slow cooling (furnace-cooled), the period where the grains structures was exposed to the temperature is longer. This situation will caused the growth rate increase and IMC become thicker and bigger.

Table 1: Cooling rate for three different medium

Medium	Cooling rate (°C/s)
Furnace-cooled	0.01
Air-cooled	0.26
Water-cooled	1.84

Figure 1 shows the cross sectional of intermetallics compound (IMC) during reflow soldering for three medium of cooling rate. As shown in figure, the IMC of $(Cu,Ni)_6Sn_5$ layer was formed at interface. Apart from that, the Ag layer was dissolved into the molten solder which was due to liquidation of Ag into the Sn during reflow. The continuous layer of $(Cu,Ni)_6Sn_5$ is a genuine ternary compound, and no trace of dissolved Ag layer was detected after reflow.

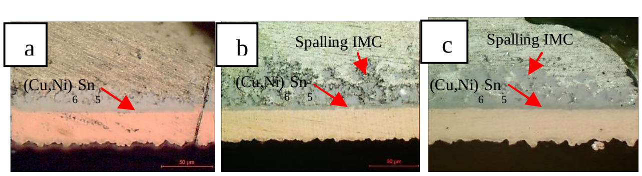

Figure 1: Cross sectional of IMC during reflow soldering (a) Furnace-cooled, (b) Air-cooled, (c) Water-cooled

The average of IMC thickness for three different cooling media has been plotted in Figure 2. From the graph, specimen that undergoes faster cooling (water-cooled) after reflow soldering has thinner IMC with approximately 0.53µm followed by air-cooled with approximately 2.84µm and furnace-cooled with approximately 4.32µm. These results strongly support the fact that the water-cooled specimen undergoing temperature shock and cause the retardation of IMC structure.

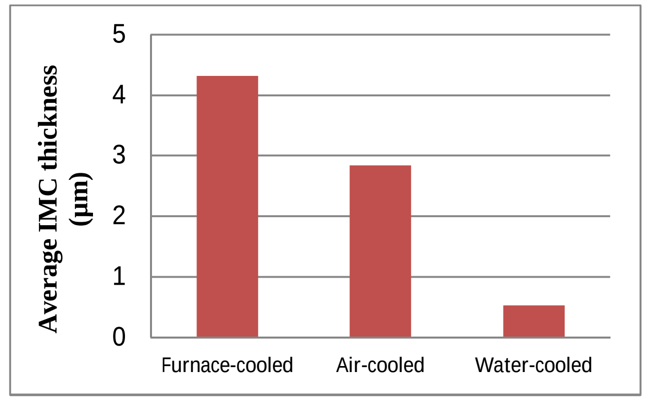

Figure 2: Average of IMC thickness versus type of cooling

Other than that, the formation of spalling IMC has been detected at interface. Zhanga *et al.* stated that spalling IMC can occur in lead-free interfacial reactions [9]. It is because during reflow process, the interfaces between the thick compound layer and the substrate have high interfacial energies that induce internal stress. This situation cause the spalling of the IMC layer occurs in order to release the stress by bending. This phenomenon can be clearly seen in Figure 1(b) and Figure 1(c).

Figure 3 shows the top surface of intermetallics compound (IMC) during reflow soldering for three medium of cooling rate. From the results, we can see that the formation of $(Cu,Ni)_6Sn_5$ IMC. This formation can be explained by the earliest formation of binary Cu_6Sn_5 during reflow, followed by $(Cu,Ni)_6Sn_5$ after reflow process. It is due to the fact that the Cu diffusion in Sn(Cu) toward the interface could controlled the growth of $(Cu,Ni)_6Sn_5$ layer [10, 11].

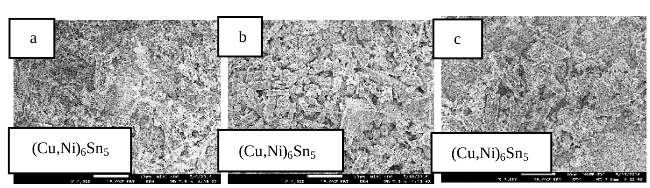

Figure 3: Top surface morphology of IMC during reflow soldering (a) Furnace-cooled, (b) Air-cooled, (c) Water-cooled

From top surface examination, two types of $(Cu,Ni)_6Sn_5$ grains were spotted as irregular circle and rod-like shape grains. In addition, these grains did not experience massive changes various cooling conditions. However, the grain sizes in water-cooled were indicated to be smaller than the air-cooled followed by furnace-cooled. This result can be explained by the fact that, slower (water) cooling rate has shorter time and evolution of morphology can reduce interfacial and also energy. This is because the grain boundary area has high energy and can be reduced with slower cooling rate [12]. For furnace-cooled condition, the time of IMC growth is longer than water-cooled and air-cooled condition because of the sufficient time for Cu atom to precipitate on each grain of the existing $(Cu,Ni)_6Sn_5$.

4. CONCLUSION

From this study, there are several conclusions were obtained:

- The specimen that undergo water-cooled media shows a faster cooling rate with 1.84 (°C/s), then followed by air-cooled media with 0.26 (°C/s) and furnace-cooled media with 0.01(°C/s).
- The grain size and thickness of IMC after reflow process that undergoes water-cooled has thinner IMC with approximately 0.53µm followed by air-cooled with approximately 2.84µm and furnace-cooled with approximately 4.32µm.
- The irregular circle and rod-like shape of $(Cu,Ni)_6Sn_5$ were formed between both SACN30505 solders and ENIMAG surface finish after reflow process.
- The grain sizes in water-cooled smaller than the air-cooled followed by furnace-cooled

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