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Effect of Different Aging Temperatures on Interfacial Reaction between SAC305 and ENEPIG Surface Finish

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Abstract. In electronic packaging industry, they are now driven technology to green product by replacing leaded-solder with lead-free solder in order to fulfill the European Restriction of Hazardous Substance (RoHS) compliance. Thus, Sn-Ag-Cu lead-free solder family is one of candidates can fulfill this requirement. This study investigates the interfacial reactions during reflow soldering and isothermal aging between Sn-3.0Ag-0.5Cu (SAC305) and electroless nickel/ immersion palladium/immersion gold (ENEPIG). Reliability of solder joint is also examined by performing solid state isothermal aging at 125°C and 150°C for up to 2000 hours. The results revealed that after reflow soldering, $(Cu, Ni)_6Sn_5$ IMC is formed between solder and substrate while after aging treatment another IMC was found between $(Cu, Ni)_6Sn_5$ and substrate known as $(Ni, Cu)_3Sn_4$. Aging time and temperature 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. In addition, the results also revealed that the thickness of intermetallics formed is proportional to the aging duration and temperature.

Introduction

As the trend of miniaturization continues, the size of electronic components and the solder joints are being continuously scaled down [1, 2]. This will makes the brittle nature of intermetallic compound (IMC) layer at the interface tending to occupy a large volume percentage of the solder joint, which is quite crucial to the failures of the portable devices such as digital cameras, i-pods, PDA's and MP4 caused by brittle of the solder joints [2, 3]. Besides that, the increasing of operating temperature will speed up the IMC growth further. Hence the prevention of excessive growth of IMC in solder joint becomes a challenging task for materials researchers. It is because the various materials in an interconnect joint will interact with each other and the joints microstructure will evolve during service. Thus, the product evaluation requirement is become more challenging and the same time must meet and fulfill the European Restriction of Hazardous Substance (RoHS) compliance. Thus, the need to have lead-free surface finishes and solder ball is very important. The selection of an appropriate surface finish and solder alloy combination therefore influences the properties and reliability of the joints [1, 2, 3].

In this study, experimental results of the intermetallic growth and thickness between Sn-3.0Ag-0.5Cu (SAC305) lead-free solder and ENEPIG (electroless nickel / electroless palladium/immersion gold) surface finish and effect of different aging temperature on interfacial reaction during reflow soldering and isothermal aging have been investigated.

Experimental Procedure

The soldering reaction between SAC305 solders ball and Ni-P (ENEPIG) of resulting SAC305/Ni-P joint were examined in this study. The copper polymer sandwich substrate (FR-4) with dimensions 45 x 50 x 1 mm was prepared and then was subjected to a pretreatment process in order to remove oxides and activate the copper substrate surface before the electroless Ni/electroless Pd/immersion Au (ENEPIG) plating process is started. The nickel (Ni) plating solution used is made up from 28g/L of nickel sulfate, 17g/L of sodium acetate, 24 g/L of sodium hypophosphite, 1.5 mg/L of lead acetate and conducted at 85°C. After that, electroless palladium were applied on Ni layer and followed by deposited with gold layer through immersion plating without any pretreatment except rinsing in running tap water with bath temperature was set up at 45°C and 93°C respectively. Then, all samples were laminated with a layer of solder mask to restrict the molten solder from flat spreading during reflow. Next step is the solder mask together with the patterned film was cured by ultraviolet (UV) light in order to produce small openings of 0.15 mm in diameter. After curing samples, 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. Then, the substrates were manually populated with solder balls with a diameter of 300μm arranged in several rows. Bonding to form the solder joints was made by reflow soldering in a furnace at temperature ~230°C. Then, each sample was subjected to aging treatment at 125°C and 150°C for 250 hours, 1000 hours and 2000 hours. Characterisation of samples involved both at top surface and cross-section of solder joints. Several techniques including optical microscopy, NIKON optical microscope, 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.

Results and Discussion

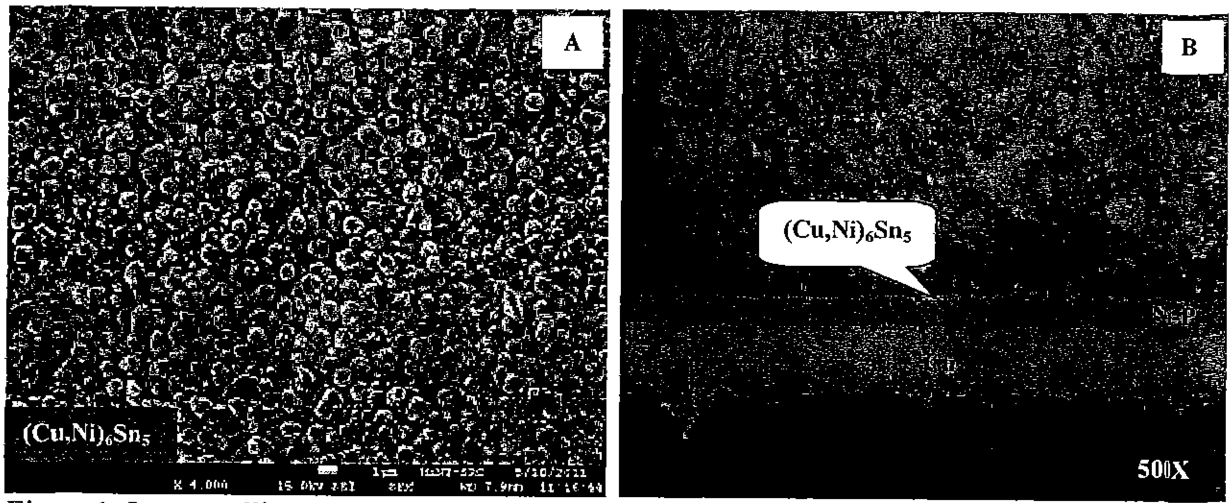

Figure 1: Intermetallic compound of (Cu, Ni)$_6$Sn$_5$ between ENEPIG and Sn-3Ag-0.5Cu solder after reflow soldering at Ø300μm (a) top surface view of SEM (b) Cross-sectional view using NIKON

During reflow soldering, the solder joint or intermetallic compound (IMC) will form between melted solder and metal substrate which created by diffusion reaction. Figure 1 shows the intermetallic compound formed during reflow soldering between Sn-3Ag-0.5Cu (SAC305) solder and ENEPIG (Ni-P) surface finish. In this interfacial reaction, (Cu, Ni)$_6$Sn$_5$ IMC was found at the interface which formed as rod-like morphology as can seen in figure 1(a) while in figure 1(b) shows a scallop-type of (Cu, Ni)$_6$Sn$_5$. Similar IMC also revealed by Yoon *et al.* [4] when soldering SAC solder with Ni-P substrate. The phenomena of (Cu, Ni)$_6$Sn$_5$ formation was explained by Sundelin *et al.* [5]. This author reported that Ni barrier at the interface between solder and Cu pads prevent significant diffusion of Cu atoms from the pads into the solder, and the (Cu, Ni)$_6$Sn$_5$ layer is based mainly on the copper originated from the solder alloy. Even though there are plenty of Ni and Sn sources at the interface, Cu-Sn IMC firstly formed on all over Ni-P TSM (top surface metallurgy).

The growth of intermetallic compound (IMC) during solid-state aging in solder joints is of particular interest to the electronic industry. Therefore, the thickness of IMC after reflow soldering and isothermal aging was measured using image analyzer in order to investigate the IMC growth. After reflow soldering process, the substrate were subjected to isothermal aging at 125°C and 150°C for up to 2000 hours. During this solid-state aging, the IMCs will keep growing by inter-diffusion process between the Sn in solder and Ni substrate. Figure 2 shows the interface of cross-sectional microstructure for the SAC305 solder with different aging time and temperature. It was clearly seen that the new IMC formed beneath the (Cu, $Ni)_6Sn_5$ IMC layer after aging which known as (Ni, $Cu)_3Sn_4$. Since the (Cu, $Ni)_6Sn_5$ growth is suppresses by lack of Cu atoms, the formation of (Cu, $Ni)_6Sn_5$ was ended and make (Ni, $Cu)_3Sn_4$ formation begin at the interface. The scallope-type of (Cu, $Ni)_6Sn_5$ were present during initially (after reflow) and both IMC was grew thicker and became continous layers after aging treatment. This findings also claimned by Luo *et al.* [9].

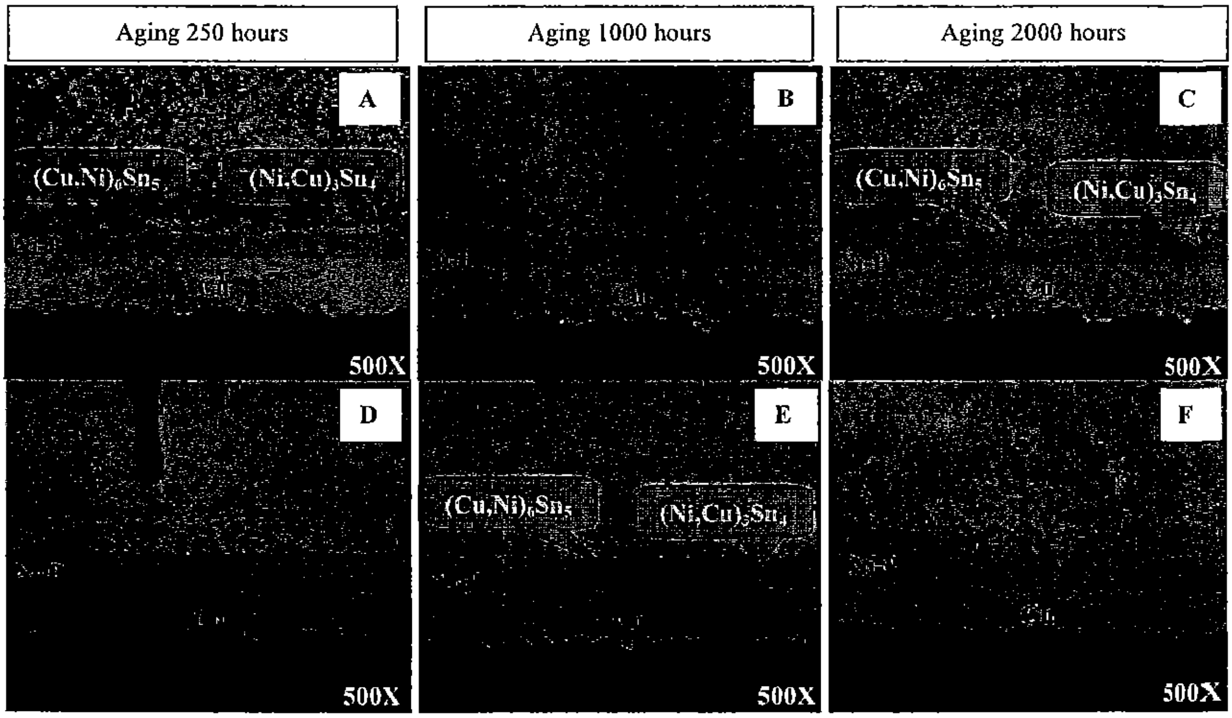

Figure 2: Top surface view of SEM between ENEPIG(P) and Sn-3Ag-0.5Cu solder with solder size Ø300 µm (a,b,c) aging at 125°C and (d,e,f) aging at 150 °C with magnification 500x

Besides that, the IMC thickness in solder joint aged at different temperatures and time were measured as represent in figure 3. The bar chart indicated that the IMC slightly eased as the aging temperature and duration increased. An average IMC thickness which exposed at 150°C is much thicker than 125°C. From this observation, temperature also play important role in the growth of IMC formation. With relatively high aging temperature and long aging time, scallop of (Cu, $Ni)_6Sn_5$ and continues layer of (Ni, $Cu)_3Sn_4$ grows up and smashes into the solder. Moreover, IMC layer will be enlarged and flattened with the increase of aging time [8].

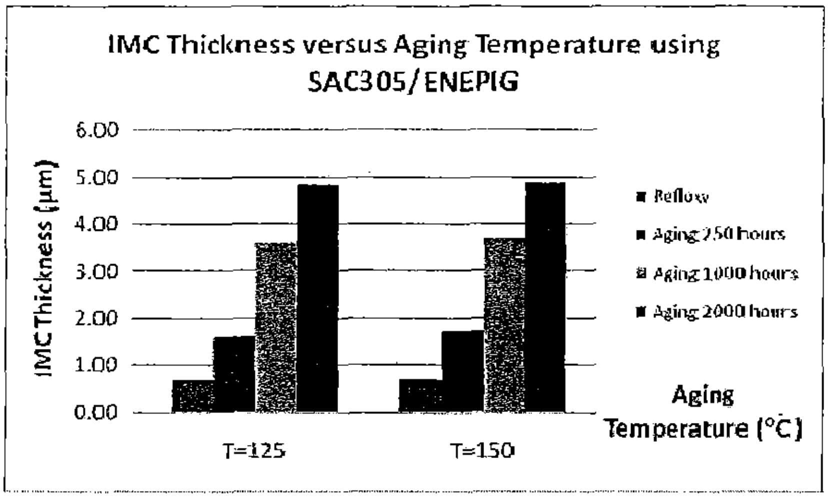

Figure 3: IMC thickness versus solder size between SAC305 solder and ENEPIG at 125°C and 150°C

The coarsening of (Cu, Ni)$_6$Sn$_5$ IMC grains was pronounced after aging for 2000 hours. The rod-like (Cu, Ni)$_6$Sn$_5$ grains have disappeared and tend to have stout-rod-like morphology when subjected to isothermal aging as represent in figure 3. Moreover, the grain size of (Cu, Ni)$_6$Sn$_5$ IMC was slightly increased when aging duration and temperature was gradually increased. From the top surface view, the (Ni, Cu)$_3$Sn$_4$ was detected as rod-like morphology in figure 4(a) and 4(b), and the grains was smaller than (Cu, Ni)$_6$Sn$_5$ because the (Ni, Cu)$_3$Sn$_4$ layer was formed beneath this layer. According to Laurila *et al.* [6], it should also be noted that if solid-state aging follows soldering, the resulting morphology after aging is dependent on the initial morphology formed during the solid-liquid contact. In the case of Ni$_3$Sn$_2$ IMC formation as shown in figure 4(a), it supposed to be a (Cu,Ni)$_6$Sn$_5$ IMC if we considered solubility of Cu (less percentage of Cu) from EDX spectrum analysis. However, in present study when EDX spectrum analysis of Cu shows less than 10 at%, it is considered as no solubility of Cu existed or in other words by ignoring the solubility of Cu. This is also has been observed by Vuorinen *et al.* [7].

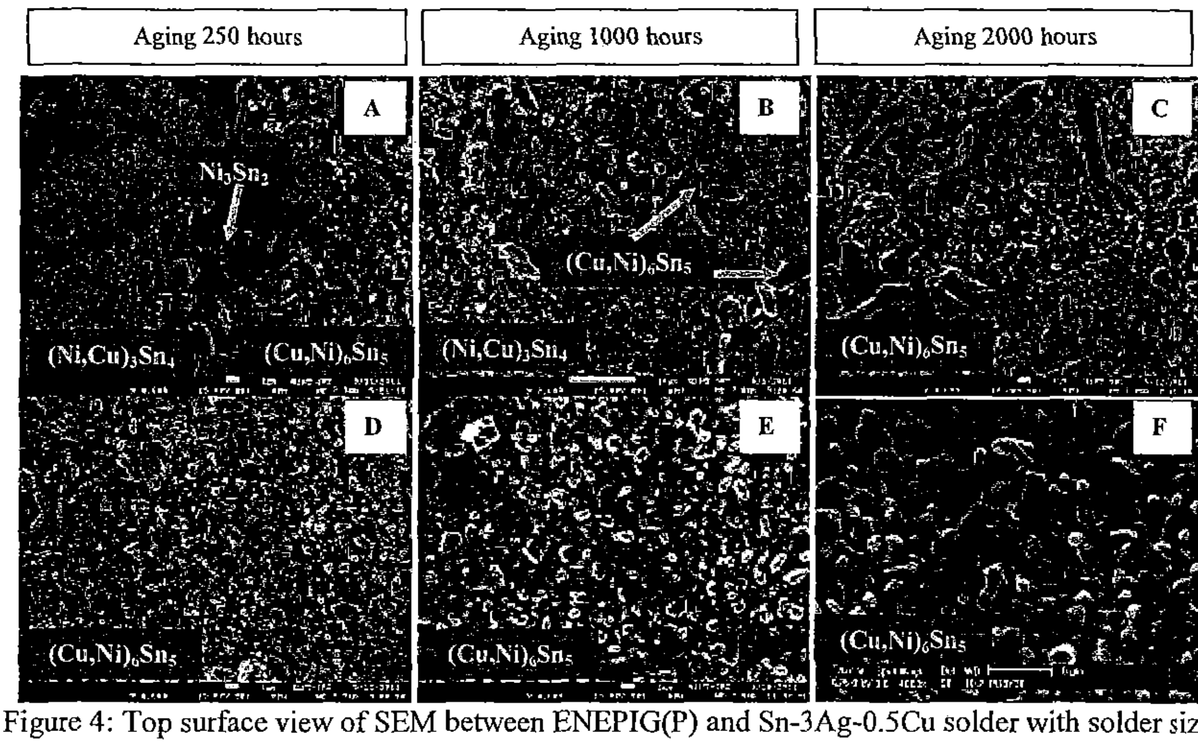

Figure 4: Top surface view of SEM between ENEPIG(P) and Sn-3Ag-0.5Cu solder with solder size Ø300 μm (a,b,c) aging at 125°C and (d,e,f) aging at 150 °C.

Summary

The results of microstructure showed that when a SAC305 solder react with ENEPIG surface finish, only $(Cu, Ni)_6Sn_5$ IMC was found at the interface after reflow soldering while both $(Cu, Ni)_6Sn_5$ and $(Ni, Cu)_3Sn_4$ IMC has been observed after isothermal aging. Aging duration and temperature 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. In addition, the results also revealed that the thickness of intermetallics formed is proportional to the aging duration and temperature.

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References

[1] Kumar, A. *et al.* Surface & Coatings Technology 198 (2005) p.283 – 28

[2] Li, G. *et al.* International Conference on Electronic Packaging Technology & High Density Packaging (ICEPT-HDP) (2009)

[3] Milad, G. Circuit World 34/4 (2008) 4-7

[4] Yoon, J.W. *et al.* Journal of Electronic Materials (2011).

[5] Sundelin, J. J. *et al.*Materials Science and Engineering, Vol. 420, (2006) 55-56.

[6] Laurila, T. *et al*, Materials Science and Engineering R 49 (2005) p.1–60

[7] Vuorinen *et al.* Journal of Electronic Materials, Vol. 37, No. 6 (2008)

[8] Li, D. *et al.*, Materials Science and Engineering A 391 (2005) p.95–103

[9] Luo, W.C. *et al.* Materials Science and Engineering A 396 (2005) p.385–391