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Intermetallic Growth of SAC237 Solder Paste Reinforced with MWCNT

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ABSTRACT

The formation of intermetallic compound (IMC) layer at the interfaces of pad finishes has been studied. The growth of IMC layer as a reflow process and its properties were also discussed. In this study, solder alloy SAC237 (Sn: 99 wt.%, Ag: 0.3 wt.%, Cu: 0.7 wt.%), reinforced with 0.01 wt.% Multi-Walled Carbon Nanotubes (MWCNTs), was mixed to form a composite solder paste and soldered on Electroless Nickel Immersion Gold (ENIG) and Immersion Tin (ImSn) pad finishes. Reflow process was conducted in oven with specific reflow profile. The growth and properties of IMC layer were analysed using optical microscope with image analyser. Results showed that the thickness of IMC layer for ENIG and ImSn were 1.49 and 2.51 µm, respectively. Floating IMC and voids within the solder bulk and IMC layer were also identified in the samples. In addition, the measured wetting angle for ENIG and ImSn were 16.21° and 34.32°, respectively.

Keywords: As reflow, ENIG, SAC237, immersion tin, intermetallic compound, multi-walled carbon nanotubes

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INTRODUCTION

Soldering is a process of joining two or more metals by melting and flowing a filler known as a solder paste to create joining parts. This solder paste usually has lower melting temperature than the adjoining metal. Solder paste has been used in electronic assembly process for many decades. This solder paste is applied to perform good joining between the electronic parts and printed circuit board

(PCB). Previously, tin lead (SnPb) was extensively used as one of the soldering requirements in electronic assembly process in many countries. This is because lead based solder has low melting point and a good wetting behaviour. However, due to the high toxicity of lead (Pb), this solder paste has brought on the development of new solder paste which is free from lead, known as lead-free solder (Bieler & Lee, 2010, pp. 1-12). The solder paste that is in focus by industry and researcher nowadays belongs to the tin-silver-copper (SAC) solder alloys group such as SAC405, SAC305 and SAC387 (Collins et al., 2012, pp. 240-248; McCormick et al., 2007). These number represents the composition of the materials and varies depending on its intended use. Unfortunately, this solder alloy paste has a higher melting temperature compared to eutectic tin lead. Combining SAC solder alloy paste with CNTs will create a new solder paste known as a composite solder paste. By adding the reinforcement to the SAC solder alloy such as carbon nanotubes (CNTs), it will enhance the performance of a solder in terms of mechanical and thermal properties (Nai et al., 2006, pp. 166-169). Besides, the existence of the second phase particles will also obstruct the movement of dislocations and pin grain boundaries to protect the solder matrix from plastic deformation (Shi et al., 2008, pp. 507-514). Generally, there are two factors that influence the performance of solder joint. These include the microstructure of bulk solder joint and formation of the intermetallic compound (IMC) layer. In order to have good IMC layer formation, the effects of reflow profile, composition of the solder paste and pad finishes are the critical aspects to be studied (Crandall, 2011). In this study, SAC237 with 99 wt.% of Sn, 0.3 wt.% of Ag and 0.7 wt.% of Cu reinforced with 0.01 wt.% of multi-walled carbon nanotubes (MWCNTs) was prepared and soldered on Electroless Nickel Immersion Gold (ENIG) and Immersion Tin (ImSn) pad finishes. The samples underwent a reflow process in order to observe and compare the formation of intermetallic compound (IMC) layer including the voids and floating of IMC, as well as wetting angle.

MATERIALS AND METHODS

The matrix solder SAC237 with 99 wt.% of Sn, 0.3 wt.% of Ag and 0.7 wt.% of Cu was mixed with 0.01 wt.% of the multi-walled carbon nanotubes by Electronic Packaging Research Society (EPRS) Malaysia. The reflow process was conducted using oven with specific reflow temperature and time. The samples were cold mounted in epoxy resins mixed with hardener at room temperature for several hours. Then, grinding and polishing were done using Metaserv250 twin model at a rotation rate of 150 to 200 rpm. Images of intermetallic compound layer, floating IMC and void formation were observed using Optical Microscope, OLYMPUS BX51RF model at 20x, 50x, and 100x magnifications. The thickness of IMC and wetting angle were measured using image analyser.

RESULTS AND DISCUSSION

Formation of Intermetallic Compound Layer

Figures 1(a) and (b) show the optical microstructure of the selected samples after as the reflow process for Electroless Nickel Immersion Gold (ENIG) and Immersion Tin (ImSn) pad finishes. The formation of intermetallic compound (IMC) layer was found at the solder bulk/copper substrate interfaces. It was also noticed that the shape of IMC layer has a scallop-like feature. This can be explained by the element of tin from the molten solder that melted during reflow process and immediately reacted with copper substrate to develop crystalline phases which quickly grew upwards into the direction of the solder bulk (Li et al., 2008, pp. 1-5).

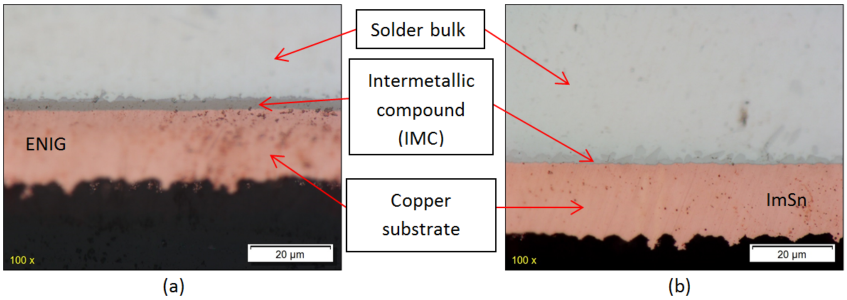

Figure 1. Optical microstructure of cross-section of printed circuit board on (a) ENIG and (b) ImSn pad finishes at 100x magnification

IMC Thickness

The growth of IMC is a measurement of the thickness of IMC layer formed in the samples. The thickness of IMC layer was measured by taking the average of eight different peaks that were chosen randomly. From Figure 2, the average IMC thickness for ENIG and ImSn was 1.49 and 2.51 µm, respectively. Another study by Choubey et al. (2008, pp. 1130-1138) also confirmed that the IMC thickness for ENIG was much lower than the other finishes. This could be justified by the lower reaction rate of nickel with tin compared to other IMC type formations at higher temperatures.

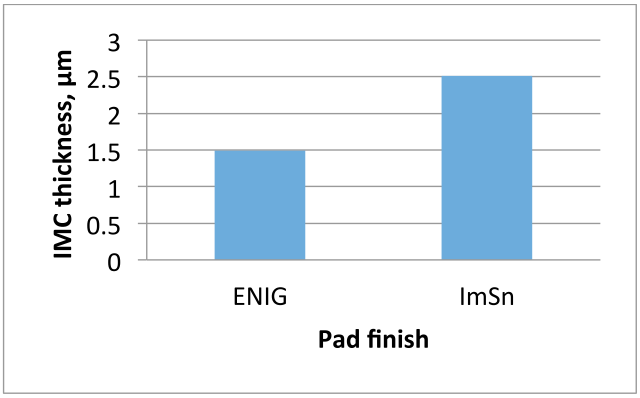

Figure 2. Measured IMC thickness on ENIG and ImSn pad finishes

Floating of IMC

Floating of IMC occurs when there are large differences in the density between the reinforcement and solder matrix (Guo, 2007, pp. 129-145). This may cause the reinforcement to have higher possibility to segregate within the layers. Figures 3 (a) and (b) clearly show the floating of IMC within the solder bulk layer for both pad finishes.

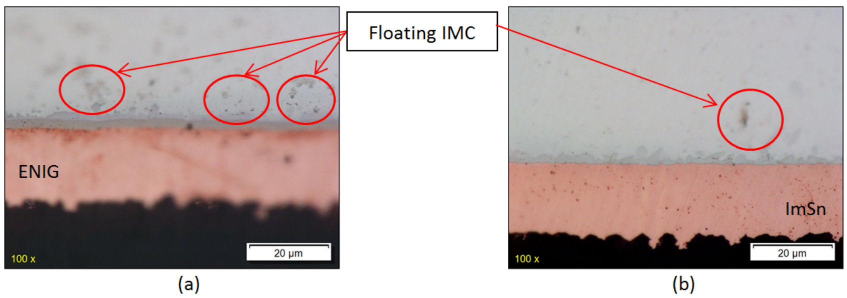

Figure 3. Optical microscope of the floating IMC within solder bulk layer on (a) ENIG and (b) ImSn pad finishes at 100x magnification

Formation of Voids

Floating of IMC and formation of voids are two different defects formed after the reflow process. As mentioned earlier, the floating of IMC occurs when the density difference between the reinforcement and solder matrix is bigger. The formation of voids occurs when there is entrapped air gas during the reflow process. As shown in Figures 4 (a) and (b), the formation of voids was observed within the solder bulk and IMC layer for both pad finishes. As reported in Ewald et al. (2012), there are two major factors that might have caused the formation of voids. These include reflow temperature profile and the properties of flux used in the solder paste (Ewald et al., 2012, pp. 1677-1683).

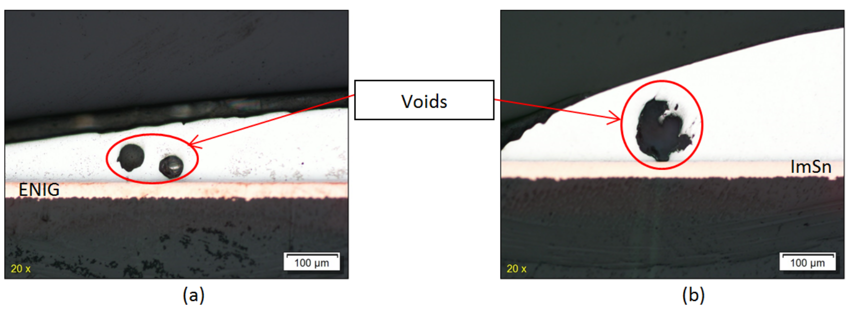

Figure 4. Optical microscope of the formation of voids within intermetallic layer on (a) ENIG and (b) ImSn pad finishes at 20x magnification

Wetting Angle

A suitable reflow profile can provide better wetting as well as microstructural joint. As shown in Figure 5, the measured wetting angle for ENIG and ImSn was 16.21° and 34.32°, respectively. According to Kripesh et al. (2001), the range of very good wetting angle was 0° ≤ θ ≤ 20°. Meanwhile, good and acceptable wetting angle was 20° ≤ θ ≤ 40°. The wetting angle higher than 40° is considered as bad and not acceptable (Kripesh et al., 2001 pp. 665-670). Thus, it can be concluded that the wetting angle of SAC237 reinforced with 0.01 wt.% MWCNTs for both ENIG and ImSn pad finishes is acceptable.

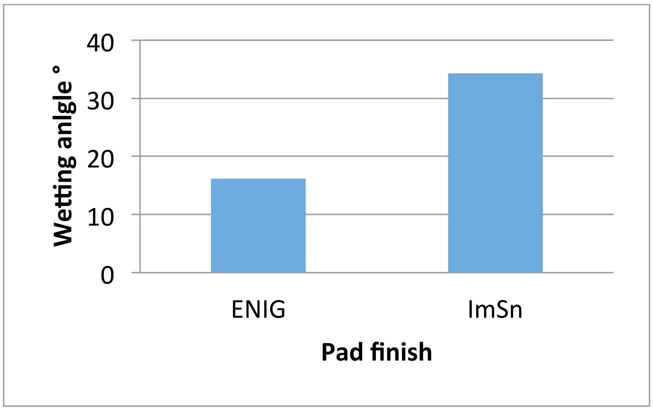

Figure 5. Measured wetting angle on ENIG and ImSn pad finishes

CONCLUSION

The study on the growth of IMC layer after as a reflow process was successfully performed on Electroless Nickel Immersion Gold (ENIG) and Immersion Tin (ImSn) pad finishes. The composite SAC237 reinforced with 0.01 wt.% MWCNTs solder paste was produced and subjected to specific reflow profile in oven. Based on the analysis of microstructure, the formation of IMC layer at the interfaces of solder bulk and pad finishes layer was compared. The thickness of IMC layer for ENIG and ImSn was measured and the values obtained were 1.49 and 2.51 µm, respectively. Both pad finishes were reported to have floating IMC within the solder bulk layer and formation of voids within IMC layer. ENIG pad finish have lower wetting angle of 16° which is good in soldering reliability as compared to ImSn pad finish which has a higher wetting angle of 34.32°. Based on these research data, ENIG is more suitable for long-life applications instead of ImSn because a lower IMC thickness is preferred for optimal solder joint reliability. This is due to the brittle nature of the IMC. However, more comprehensive studies need to be conducted for the final comparison between the pad finishes prior to industrial application.

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