Influence of Difference Solders Volume on Intermetallic Growth of Sn-4.0Ag-0.5Cu/ENEPIG

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Abstract. In recent years, portable electronic packaging products such as smart phones, tablets, notebooks and other gadgets have been developed with reduced size of component packaging, light weight, high speed and with enhanced performance. Thus, flip chip technology with smaller solder sphere sizes that would produce fine solder joint interconnections have become essential in order to fulfill these miniaturization requirements. This study investigates the interfacial reactions and intermetallics formation during reflow soldering and isothermal aging between Sn-4.0Ag-0.5Cu (SAC405) and electroless nickel/immersion palladium/immersion gold (EN(P)EPIG). Solder diameters of 300 μm and 700 μm were used to compare the effect of solder volume on the solder joint microstructure. The solid state isothermal aging was performed at 125°C starting from 250 hours until 2000 hours. The results revealed that only (Cu,Ni)₆Sn₅ IMC was found at the interface during reflow soldering while both (Cu,Ni)₆Sn₅ and (Ni,Cu)₃Sn₄ IMC have been observed after aging process. Smaller solder sizes produced thinner IMC than larger solder joints investigated after reflow soldering, whereas the larger solders produced thinner IMC than the smaller solders after isothermal aging. Aging duration of solder joints has been found to be increase the IMC's thickness and changed the IMC morphologies to spherical-shaped, compacted and larger grain size.

1 Introduction

During the last two decades surface mount technology (SMT) has become the dominant manufacturing technology for electronic products, mainly because of its cost-effective high-volume production capability. Thus, it has made possible the manufacturing of extremely high-density portable electronics with good quality and reliability [1]. Generally, smaller electronic devices are faster because of the signals do not have to travel as far within the device. Packing more functionality into a smaller or same-sized device reduces the cost of electronics. With this continuous miniaturization and increasing functionality of electronic components, the microelectronic industry keep moving towards fine pitch devices. Area

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array components have evolved to meet the demands of the industry and the chip scale package (CSP) is therefore becoming one of the main products in the integrated circuit (IC) industry [2].

Besides, this chip scale package (CSP) mostly use flip chip technology where solder bumps are used as interconnects between the chip and substrate. The substrate provides the connection from the chip to the exterior of the package. In flip chip technology, solder bumps are grown on pads deposited throughout the chip area. The number of solder bumps and the number of solder pads depend on the diameter of each solder bump and pad pitch respectively. The chip is placed face down onto a substrate with matched pad locations [3].

This study is focused to the interfacial reaction between different sizes of Sn-4.0Ag-0.5Cu (SAC405) lead-free solders and EN(P)EPiG (electroless nickel/electroless palladium/immersion gold) surface finish. Besides that, the effect of different aging duration on interfacial reaction also has been investigated.

2 Methodology

The copper substrate (FR-4) were cut into 45 x 50 x 1 mm and then a pretreatment process was conducted to remove oxides and activate the copper substrate surface before the electroless plating process is begun. The Ni-P layer was plated at 85°C then the deposition of a layer of electroless palladium will be plated and followed by gold deposition using immersion plating. Then, the samples were laminated with solder mask to restrict the molten solder from flat spreading during reflow. Next, the solder mask and patterned film was cured by ultraviolet (UV) light in order to produce small openings. After curing samples, a thin layer of no-clean flux was applied onto the substrate to remove the oxide layer and also to improve the wetting of molten solder during reflow. The substrates were manually arranged the solder balls with a diameter of 300µm and 700µm in several rows. The samples then was reflowed in a furnace with temperature setting at 230°C and followed by aging treatment at 125°C for 250 hours, 1000 hours and 2000 hours. Characterisation of samples involved both at top surface and cross section of solder joints. Optical microscopy, scanning electron microscopy (SEM) equipped with energy dispersive x-ray analysis (EDX) and image analyzer were used for characterizing the intermetallics.

3 Results and Discussion

Fig.1 shows SEM top surface micrographs of the interfaces between the Sn-4.0Ag-0.5Cu (SAC405) and EN(P)EPiG pads just after reflow soldering. It can be clearly seen that the dominant intermetallic compound (IMC) formed was identified as (Cu,Ni)₆Sn₅ and exhibited rod-like and/or needle-shape morphology for the smaller and larger solder size. The present results are consistent with previous research [4]. The cross section view revealed that the IMC layer is formed at the SAC405/ EN(P)EPiG interface has a typical scallop-like morphology as represented in Fig 2. The thickness of this IMC layer for the Ø300µm solder was found to be 0.71µm which is relatively thinner than that recorded in the Ø700µm solder at 1.71µm.

Fig.1. SEM top surface morphology of EN(P)EPIG reflowed with Sn-4Ag-0.5Cu solder at near center region with solder size: (a) Ø300µm and (b) Ø700µm

Fig.2. Cross sectional view of Sn-4Ag-0.5Cu/EN(P)EPIG for reflowed sample with magnification 500x using solder size (a) Ø300µm and (b) Ø700µm

Fig.3 shows the SEM micrographs of the interface as function of aging time on the growth of IMC. It is clear that a new IMC layer was created below the $(\text{Cu,Ni})_6\text{Sn}_5$ layer and EN(P)EPIG/Cu substrate. EDX analysis was confirmed this IMC as $(\text{Ni,Cu})_3\text{Sn}_4$ layer. During the solid-state aging treatment, the IMC will keep growing by inter-diffusion process between the Sn in solder and EN(P)EPIG substrate. Since the $(\text{Cu,Ni})_6\text{Sn}_5$ growth is suppressed by a lack of Cu atoms will caused the formation of $(\text{Ni, Cu})_3\text{Sn}_4$ is formed at the interface.

The scallope-type of $(\text{Cu,Ni})_6\text{Sn}_5$ IMC which formed during reflow and the $(\text{Ni,Cu})_3\text{Sn}_4$ during aging, both grew thicker and became continous layers after aging. Moreover, both IMCs also are proportional to an aging time and caused the coarsened and flattened IMC [5]. The reason of this planarization process can happened has been detailed discussed in previous paper [6].

Fig.3. Cross sectional view of SAC405/EN(P)EPiG at 125°C for Ø300µm and Ø700µm for aged samples using optical microscope (a, b) 250 hours and (c, d) 2000 hours

The IMC thickness measured in both solder joints sizes was found to increase with increasing aging time up to 2000 hours as shown in Fig. 4. However, when comparing the solder size, the larger solder of Ø700µm exhibited thinner IMC for all aging times compared with the smaller solder size of Ø300µm (Fig. 4). This dissolution phenomena of metals involved are related to the ratio of solder volume to contact pad area (V/A). Besides, this explains why in larger solders the IMC layer grew slower than in smaller solders during aging treatment. Thinner IMC layer means a shorter diffusion path in high V/A samples (larger solders) [7, 8]. Hence, higher amounts of Sn and Cu atoms could diffused through the IMC barrier to speed up the growth of IMC. Moreover, with increasing the V/A ratio the diffusion distance for Cu to saturate the molten solder increases, and as a result the intermetallics will grow at a slower rate.

Fig.4. Intermetallic compound (IMC) thickness versus solder size between SAC405 solder and EN(P)EPIG exposed at 125°C

Fig.5. SEM top surface of EN(P)EPIG aged at 125°C with Sn-4Ag-0.5Cu solder (a,b) aging 250 hours and (c,d) aging 2000 hours

Fig.5 illustrates the IMC morphology of top surface examination during isothermal aging process for both solder sizes. The coarsening of (Cu,Ni)₆Sn₅ IMC grains was pronounced after aging for 2000 hours compared to the 250 hours sample. The rod-like (Cu,Ni)₆Sn₅ grains have disappeared and tend to have stout-rod-like morphology. In addition, the grain size of (Cu,Ni)₆Sn₅ IMC has slightly increased when aging duration and temperature was gradually increased. This also can be clearly observed on solder size of Ø700µm especially when aged for 2000 hours. The aging duration results showed an increase of IMC's thickness and changed the IMC morphologies to spherical-shaped, compacted and larger grain size.

4 Summary

The interfacial reaction between SAC405 lead-free solders and EN(P)EPiG surface finish has been examined. The results revealed that only (Cu,Ni)₆Sn₅ IMC was found at the interface during reflow soldering while both (Cu,Ni)₆Sn₅ and (Ni,Cu)₃Sn₄ IMC have been observed after aging process. Smaller solder sizes produced thinner IMC than larger solder joints investigated after reflow soldering, whereas the larger solders produced thinner IMC than the smaller solders after isothermal aging. Aging duration of solder joints results in an increase of IMC's thickness and changed the IMC morphologies to spherical-shaped, compacted and larger grain size.

This work was financially supported Ministry of Education, Malaysia through Fundamental Research Grant Scheme (Vot 1493) in Universiti Tun Hussein Onn Malaysia.

References

1. T. Laurila, V. Vuorinen, M. Paulasto-Kröckel, *Mat. Sci. Eng. R.*, **68**, 1 (2010)
2. M.K. Huang, C. Lee, P.L. Wu, S.R. Tzan, *Solder. Surf. Mt. Tech.*, **17**, 3 (2005)
3. K.K. Muchherla, J.G. Kumar, J.M.W. Roveda, *Microelectron. Eng.*, **114**, 57 (2014)
4. J.W. Yoon, B.I. Noh, S.B.J. Jung, *Electron. Mater.*, **40**, 1950 (2011)
5. D. Li, C. Liu, P.P. Conway, *Mater. Sci. Eng., A*, **391**, 95 (2005)
6. M.A. Azmah Hanim, A. Ourdjini, O. Saliza Azlina, Siti Rabiatal Aisha, *International Journal of Automotive and Mechanical Engineering (IJAME)* **8**, 1348 (2013)
7. W. Choi, *Reliability of Pb-Free Solders in Electronic Packaging Technology*, (Doctor Philosophy, University of California, 2002)
8. M. Schaefer, W. Laub, R.A. Fournelle, J. Liang, *Design Reliability Solder Interconnects*, ed. R.K. Mahidhara, D.R. Frear, S.M.L. Sastry, K.L. Murthy, P.K. Liaw and W.L. Winterbottom (Warrendale, PA: TMS, 1997)