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Effect Of Solder Volume On Interfacial Reaction Between SAC405 Solders And EN(B)EPIG Surface Finish

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Abstract. The electronic packaging industry is now being driven towards smaller, lighter, and thinner electronic products but with higher performance and more functions. Thus, smaller solder ball sizes are needed for fine solder joint interconnections to fulfill these requirements. This study investigates the interfacial reactions during reflow soldering and isothermal aging between Sn-4.0Ag-0.5Cu (SAC405) and electroless nickel (boron)/ immersion palladium/immersion gold (EN(B)EPIG). Reliability of solder joint has also been investigated by performing solid state isothermal aging at 125°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 of solder joints resulted in an increase in IMC thickness and a change in morphology into more spherical, dense and with larger grain size. By using optical microscope, the average thickness of the intermetallics was measured and it found that the larger solder balls produced thicker IMC than the smaller solder balls during reflow soldering. However, after aging the smaller solders produced thicker IMC than the larger solders.

Introduction

Nowadays, driven by the trend to smaller, lighter, and thinner electronic products, smaller packages have been developed. Therefore, chip scale packages have been widely used for mobile products. Furthermore, the newest mobile products need not only smaller size but also higher performance and more functions. In order to satisfy these requirements, more input/output (I/O) pads are needed, resulting in smaller interconnections which in turn require smaller solders. However, decrease in solder ball sizes could change the solder joint characteristics such as interfacial reactions and mechanical properties [1].

Understanding the interfacial microstructure could help to improve the reliability of the solder joints [2]. During reflow soldering, metallurgical reaction between molten solder and metal substrate forms a layer of intermetallic compound (IMC) at the solder/substrate interface by diffusion reaction [3]. It is desirable that there is a good metallurgical bond formed between the solder and the substrate. However, due to the brittle nature of the intermetallic layer and the mismatch of physical properties (such as the coefficient of thermal expansion and the modulus of elasticity) between the IMC and the solder matrix, excessive intermetallic growth often degrades the interfacial integrity. This might result in deleterious effect on the reliability of the solder joint. With increasing miniaturization and more input/output terminals in packaging, integrated circuit (IC) devices with high-density substrates generate more heat during service. The heat is dissipated through the solder joints and this could result in temperature increase in the joints. This higher temperature has the capability to accelerate the diffusivity of elements in the solder joints and lead to IMC layer growth at the interface [4, 5]. Moreover, higher density interconnections, which are related to reduced solder joint size, will probably create more difficulties since the entire solder volume may take part in the interfacial reactions between solder and surface finish to form intermetallic compounds during soldering [6].

The selection of an appropriate surface finish and solder alloy combination is very important because it will influence the intermetallics formation at the interface. Electroless nickel deposits have been studied extensively, since Brenner and Ridell [7] discovered the electroless deposition process. The electroless nickel processes are grouped as Ni-P, Ni-B and pure Ni, based on the reducing agents used (i.e., hypophosphite, borohydride or dialkylamino borane and hydrazine) in the plating bath [8]. Thus, Ni-B coating has received considerable research attention in the Cu interconnects technology, due to its ability to act as a diffusion barrier layer to prevent the diffusion of Cu [9]. The nickel-boron (Ni-B) is deposited by an autocatalytic reduction of nickel ions by borohydride compounds, typically sodium borohydride [10]. The properties of the Ni-B deposits are known to be influenced by the B content [8]. However, our knowledge of the interfacial reaction between solder and Ni-B plating layer still remains insufficient since many aspects of the structural and crystallization behavior of the deposits are not yet clear at the moment.

Thus, in this study, experimental results of the effect of solder size on interfacial reaction between Sn-4.0Ag-0.5Cu (SAC405) lead-free solder and electroless nickel (Boron) / electroless palladium/immersion gold (EN(B)EPIG) surface finish especially on intermetallic growth and thickness surface during reflow soldering and isothermal aging have been investigated.

Experiment

The soldering reaction between SAC405 solders and Ni-B (EN(B)EPIG) of the resulting SAC405/Ni-B joint were examined in this study. The copper composite sandwich substrate (FR-4) with dimensions 45 x 50 x 2 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 (EN(B)EPIG) plating process is started. The nickel (Ni-B) plating solution was used and conducted at 85°C. This bath composition produces Ni-B deposits with about 3wt% of boron. Then, layer of electroless palladium was deposited on top of Ni layer followed by a gold layer through immersion plating without any pretreatment except rinsing in running tap water with the bath temperature set at 45°C and 93°C respectively. All samples were then laminated with a layer of solder mask and a thin layer of no-clean flux is applied onto the substrate. Then, the substrates were manually populated with solder balls with a diameter of 300μm and 700μm arranged in several rows. Bonding to form the solder joints was made by reflow soldering in a furnace at temperature ~250°C. Then, each sample was subjected to aging treatment at 125°C for 250 hours, 1000 hours and 2000 hours. Characterisation of samples involved both 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.

Results and Discussion

Intermetallic compounds formation. During reflow soldering, the Ni-B layer reacts in the same manner as Ni-P. When the substrate comes in contact with the molten solder, it dissolves. At the same time, Sn in the solder reacts with the substrate metal to form intermetallic compound (IMC) at their interface. Typical top surface and cross-sectional micrographs made between SAC405 on EN(B)EPIG with different solder ball sizes of 300μm and 700μm are shown in Fig. 1(a, c) and Fig. 1(b, d) respectively. EDX spectrum analysis shows the IMC layer compositions at the interface are consistent with the stoichiometry of the compound $(Cu,Ni)_6Sn_5$. The formation of this IMC was previously reported [11]. Deep etching indicated that the morphology of $(Cu,Ni)_6Sn_5$ was blocky-like compound for both solder sizes (Fig. 1a and 1c). The morphology of IMC also increases in size with increasing solder size. From the cross-sectional examination, scallop-like of $(Cu,Ni)_6Sn_5$ layer IMC (Fig. 1b and 1d) was detected along the interface as the typical phase for the reaction between Cu and Sn-based solder during liquid-solid reaction.

Isothermal aging treatment is commonly used as long-term reliability test. Thus, the growth of intermetallic compound (IMC) during solid-state aging in solder joints is important because of its interest to the electronic industry [3]. When the substrates are subjected to aging treatment, the IMCs formed during reflow soldering will continuously grow by diffusion process between Sn in solder and Ni from substrate but at a much slower rate. Besides, the IMC morphology may also become larger, denser and more compact [12].

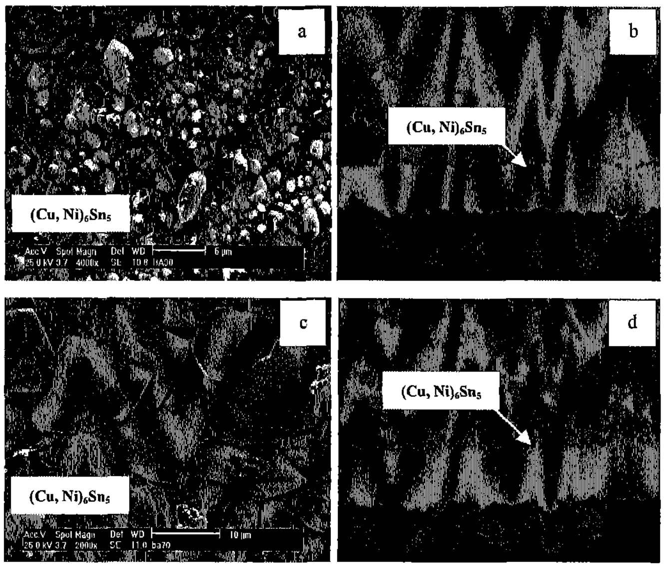

Fig.1. SEM top surface and cross-sectional view of EN(B)EPIG reflowed with Sn-4Ag-0.5Cu solder (a, b) Ø300μm, (c, d) Ø700μm

Furthermore, a new IMC was formed beneath the $(Cu,Ni)_6Sn_5$ IMC at the interface during this solid-state aging known as $(Ni,Cu)_3Sn_4$. Yoon *et al.*[13] reported that the formation of $(Ni,Cu)_3Sn_4$ IMC may be the result of a decrease in Cu diffusion into the interface. That is, during its growth, the $(Cu,Ni)_6Sn_5$ draws Cu available in the solder, but since this source of Cu is not infinite, its concentration is gradually decreased and as a result, Ni-rich $(Ni,Cu)_3Sn_4$ IMC forms between the $(Cu,Ni)_6Sn_5$ IMCs. However, such IMC later could only be detected from cross-sectional view by using optical microscope as shown in Fig 2.

Effect of solder sizes on interfacial reaction. Understanding the volume effect (solder size) of SAC solders on intermetallic compound growth, under-bump-metallization or surface finish degradation of solder bump interconnect structures is crucial in the design and development of the next generation packages. Thus, Fig 3 illustrates the effect of solder volume or solder joint size on interfacial reactions occurring during soldering and isothermal aging between SAC405/EN(B)EPIG finish after aging at 125°C for durations of 250 hours up to 2000 hours. It is quite evident from this figure that the intermetallics grow faster when soldering with a larger solder volume compared with those formed in smaller solder volume. This is because of limited the concentration of Cu atoms available in a small solder and the formation of the Pd-Sn IMC may change the type of IMC that forms at the interface. This Pd-Sn formation at the interface may inhibit the IMC growth rate and hence by retard the IMC growth. Consequently, the IMC grows thinner compared to IMC that grows on surface finish without Pd layer. The present findings are in good agreement with those claimed by Laurila *et al.* [14].

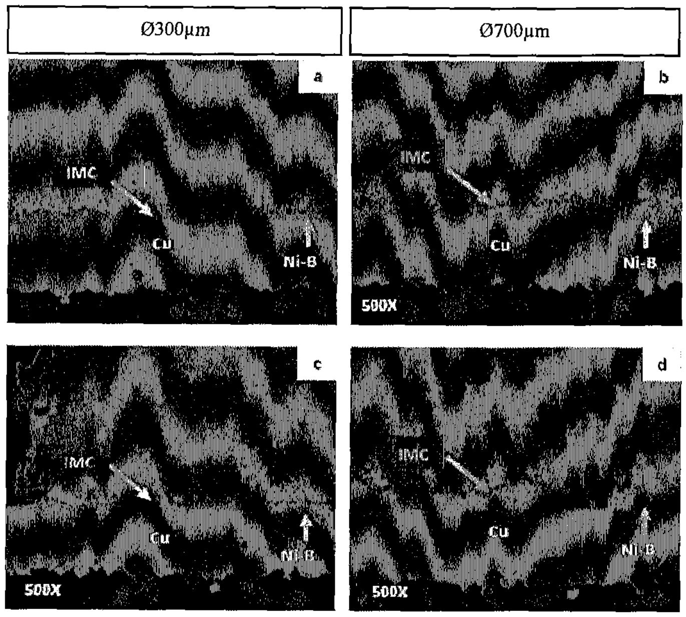

Fig.2.Cross sectional view of SAC405/EN(B)EPIG at 125°C for Ø300μm and Ø700μm after isothermal aging (a, b) 250 hours (c, d) 2000 hours.

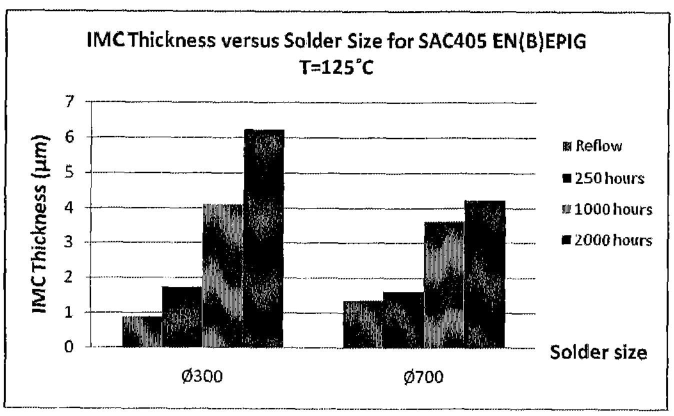

Fig. 3 IMC thickness of SAC405/EN(B)EPIG after reflow soldering and aging at 125°C with solder size Ø300μm and Ø700μm

In contrast, smaller solder size produced thicker IMC than the larger solders after isothermal aging. The reason is that in larger solders it appears that since there was no Pd-Sn IMC formed ahead of the interface, the Cu-Ni-Sn IMC is able to grow relatively faster than in smaller solders. Besides that, it was believed that the dissolution phenomena of metals involved in the interfacial reactions are dependent on the ratio of solder volume to contact pad area (V/A) [15]. Schaefer *et al.* [16] explained with an increase in this V/A ratio the diffusion distance for Cu to saturate the liquid solder increases, thus resulting in slower interfacial reactions. In the present study, since the metal pad used is constant for all joints and the solder ball diameters were 300 and 700 μm, the ratio V/A increases with increasing the solder ball diameter. Thus, thinner IMC's are produced in larger solders after aging treatment, which reconcile well with the findings of Ourdjini *et al.* [6] and Azmah [17].

Conclusion

The results of interfacial reactions showed that when a SAC405 solder reacts with EN(B)EPIG surface finish, only (Cu, Ni)$_6$Sn$_5$ IMC was formed at the interface after reflow soldering while both (Cu, Ni)$_6$Sn$_5$ and (Ni, Cu)$_3$Sn$_4$ IMC have been observed after isothermal aging. Aging duration 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. The solder bump size or solder volume was found to have a significant effect on the thickness of intermetallics formed at the solder joint. The average thickness of the intermetallics for larger solders is thicker than smaller solders during reflow soldering. Meanwhile, smaller solder sizes produced thicker intermetallics than larger solders after aging. In addition, the results also revealed that the thickness of intermetallics formed is proportional to the aging duration.

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