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Morphology, Evolution and Performance of IMC in SAC105 Solder/UBM (Ni (P)-Au)

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Abstract

To enhance the ability of lead-free solder joint to resist failures induced by mechanical impact and shock, some researchers have introduced low-Ag lead-free solder. In this study, the formation and evolution of IMC, the fracture morphology and performance of solder joint between SAC 105 solder and under bump Metallization (UBM) have been studied after different temperature storage aging and multi-reflow for WLCSP. The morphology and fracture surface of IMC have been analyzed by SEM, EDX and deeply etching techniques. The behavior of IMC and correlation with fracture mode of joint at high speed ball pull (HSBP) test has been investigated. It has been found that high temperature storage (HTS) aging results in IMC growing from one layer that is (Cu_6Sn_5) IMC to two different layers that are ($(Cu,Ni)_6Sn_5$ and $(Cu,Ni)_3Sn_4$). Multi-reflow results in the IMC layer thickness increasing a little and some needle-like IMC grain spalling into the solder.

Introduction

With the development and promotion of portable electronic devices, the ability of electronic packages and assemblies to resist the sudden shock impact is becoming a growing concern. Some new kinds of solders have been introduced to improve the brittle fracture–resistance of solders joint (1-4). It has been reported that the solder joint between Low-Ag solder and under ball metallurgy (UBM) appears higher resistance to drop impact than high-Ag solder (4-8). But the fracture morphology and mechanism in Low-Ag SAC Solder/UBM for wafer-level chip-scale packages (WLCSP) are unclear, typically, under high speed pull condition. The formation and evolution mechanism of intermetallic compound (IMC) and their relation with joint strength need to be investigated.

In this study, the formation and evolution of IMC, the fracture morphology and performance of solder joint between SAC 105 solder and UBM have been studied after different temperature storage aging and multi-reflow for WLCSP. The morphology and fracture surface of IMC have been analyzed by SEM, EDX and deeply etching techniques. Also, the difference of IMC in interface has been compared with high-Ag solder. The behavior of IMC and correlation with fracture mode of joint at high speed ball pull (HSBP) test has been investigated.

Experimental Procedure

Solder alloy: SAC105 (Sn-1Ag-0.5Cu),

UBM: Electroless Nickel Immersion Gold (ENIG).

Accelerated aging methods: two sorts of high temperature storage (HTS) aging process are as followed:

1) HTS aging at 150 ℃ for 500Hrs, 1000hrs, 2000hrs.

2) HTS aging at 200 ℃ for 20hrs, 80hrs, 160hrs, 280hrs.

Multiple reflow profile is as Fig. 1

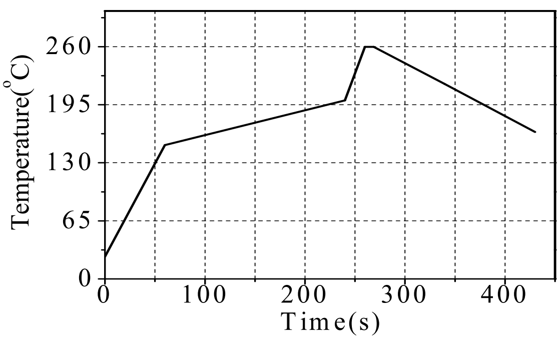

Fig. 1 Reflow soldering profile

Solder joint strength assessment: HSBP test is down in Dage series 4000HS machine. Pulling velocity is 1200mm/s.

Sample preparation for microanalysis:

Cross sections of solder joint were prepared with standard metallographic methods. Some were slightly etched and some were deeply etched to clean up the solder materials and made the IMC visible. Fracture surface analysis was performed by SEM, EDS and deeply etched technology.

Results and Discussions

HTS Affects the Morphology and Evolution of IMC

Some experiments proved that HTS affects the Morphology and Evolution of IMC in interface significantly.

Fig. 2 shows the evolution of IMC in SAC105/UBM in room temperature aging and after HTS aging at 200℃ for 280h respectively.

Fig. 2 a) and c) are the top view interfacial IMC grains after removing the solders by deep-etching technology. Fig. 2 a) shows the morphology of IMC grains at room temperature. And Fig. 2 b) shows the morphology of cross section. The composition of IMC grains are similar to $(Cu,Ni)_6Sn_5$ which is identified by EDS and the composition of point "o "is shown in table 1.

Fig. 2c) and d) show two different layers IMC $(Cu,Ni)_6Sn_5$ and $(Cu,Ni)_3Sn_4$ after aging. Also, the composition of point A and point B are shown in table 1. From Fig. 2c), only $(Cu,Ni)_6Sn_5$ layer can be seen but from Fig. 2d), $(Cu,Ni)_3Sn_4$ is visible.

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Table 1 The composition of IMC before and after aging

areas	Sn	Cu	Ni	Sort of IMC
O	54.25	23.19	22.56	$(Cu, Ni)_6Sn_5$
A	45.90	20.27	33.80	$(Cu, Ni)_6Sn_5$
B	53.23	3.70	43.37	$(Cu,Ni)_3Sn_4$

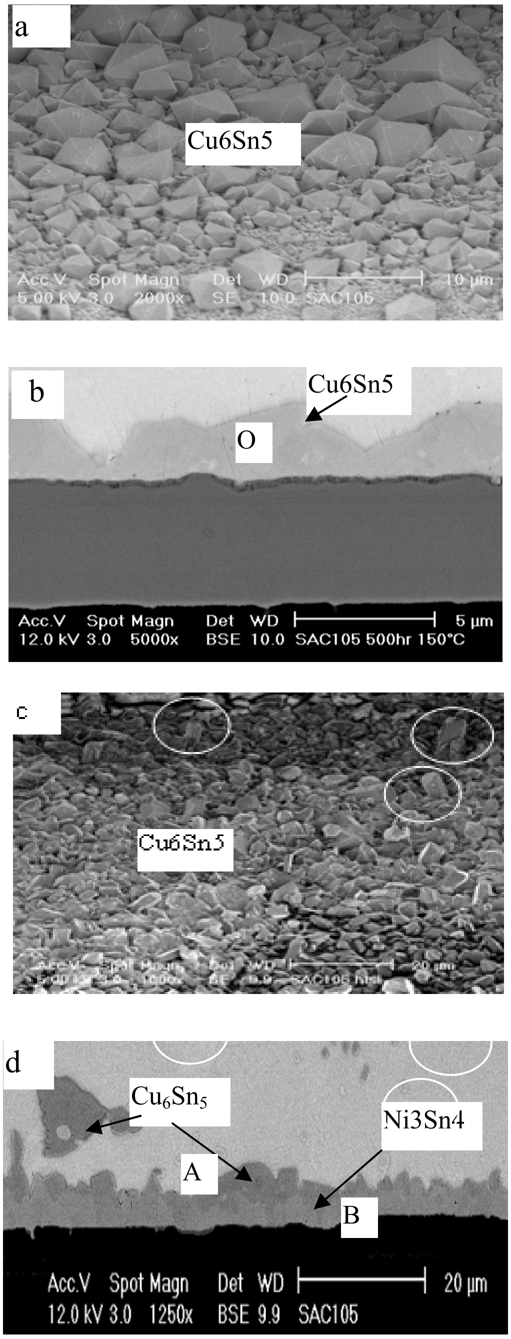

Fig. 2 Evolution of interfacial IMC

In Fig. 1 c), it can be found that the grains (in the circle) of $(Cu,Ni)_6Sn_5$ have grown longer than before aging. So, it could be deduced that HTS aging can change the IMC shape from one to another.

Above mentioned results of formation and evolution of IMC are similar to the results of reference (6). Both SAC105 used in this paper and SAC405 used only in reference (6) appears two layers IMC which are stone-like $(Cu, Ni)_6Sn_5$ and needle-like $(Cu,Ni)_3Sn_4$. But the aging conditions are different.

The only difference is that HTS were carry out at 200 ℃ for 280hrs for SAC 105, but in the paper (6) reflow were carry out at above 300 ℃ for 1min for SAC 405. So, it can be considered that the Ag content does not effect the performance of IMC nearly, especially the composition of $(Cu, Ni)_6Sn_5$ and $(Cu,Ni)_3Sn_4$. The key factor to lead IMC to growing and developing is Cu content in solder and the thickness of Ni layer of UBM.

It should be pay attention to that there is no $(Cu,Ni)_3Sn_4$ appearance nearly in the interface after aging at 150℃ for 2000hrs and it appears only after at 180℃ for 2000hrs. This indicates that SAC 105 appears a better ability to resist-aging.

Multiple Reflow Affects the Morphology and Evolution of IMC

The reflow profile is as Fig. 1 and the cross section morphology of solder joint is as Fig.3. Reflow affects the morphology of IMC, but the composition of IMC is no evident change and both are similar to $(Cu,Ni)_6Sn_5$. Fig. 3 a) b) show the cross section morphology of IMC after one time reflow and 6 times reflow respectively. After one time reflow as in Fig. 3a), some IMC grains grow as a stone-like attaching to the surface of UBM discontinuously. The average grain size is about 3.0µm. But, after 6 times reflow, the IMC grains were broken and spalled into solder. The thickness of IMC area is about 20µm.

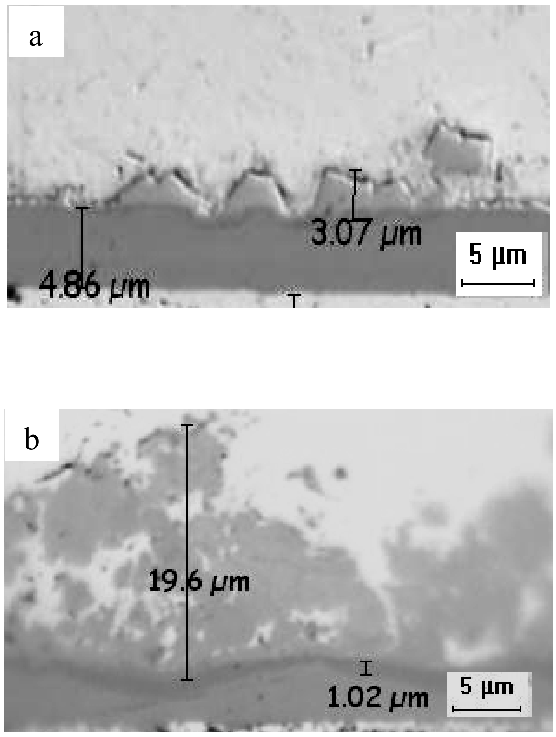

Fig. 3 IMC morphology after multiple reflow

According to the result of solder joint strength assessment by HSBP test as in Fig. 4, multiple reflow process no decrease the joint strength evidently. Every numerical value in the diagram is the medial value of 10 times measurement results in case error.

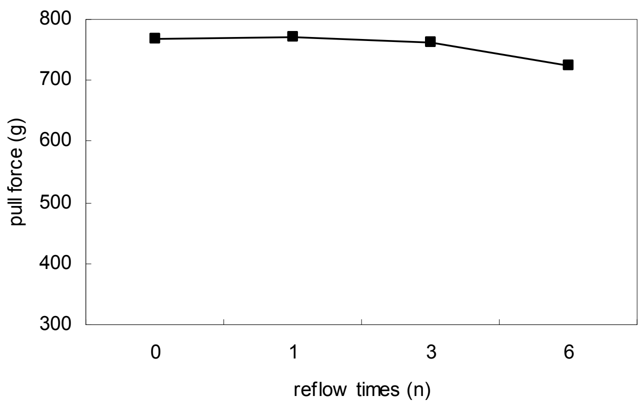

Fig. 4 Reflow affects HSPS of joint

Multiple reflow (peak temperature 260 ℃) makes the IMC grains broken and spreaded into larger region in solder near the interface than before. The hardness of IMC area would be decreased because the IMC was broken. So the brittleness of IMC layer and stress concentration of solder joint would not be increased after multiple reflow. This is why the HSBP not to be decreased evidently after multiple reflow. But the thickness of IMC layer would increase if raising the peak temperature (above 300℃) and extending the keeping-time which has been proved by paper (6). This is the key factor to affect the performance of IMC.

The correlation between fracture mode of joint and IMC

After HTS aging, the IMC in SAC105/UBM appears two layers: one is (Cu,Ni)6 Sn5, the other layer near Ni-P is Ni3Sn4. Fig 5 shows the different fracture surface of IMC. According to some test results that fracture often occurs between the two layers (see Fig 5 a). In Fig. 5a), the lift area is uper layer and the right is lower layer. Also fracture occurs between Ni3Sn4 and UBM (see Fig 5 b). Occasionally the numeral value of HSBP is lower if fracture occurs between $(Cu,Ni)_6$ Sn_5 and $(Cu,Ni)_3Sn_4$. Fig. 5c) is the sketch diagram to describe the fracture mode.

Discussion

In the Fig. 5a) lift area, some nuclear grains appear and their composition is similar to $(Cu,Ni)_6Sn_5$. Based on the phenomenon, it could be deduced that $(Cu,Ni)_6Sn_5$ grain grow again because of the growth of new $(Cu,Ni)_3Sn_4$ layer. As pointed out by (9-11), Grain boundary diffusion of Cu atoms through the interfacial IMC layer is the controlling mechanism of the dissolution of Cu into the molten solders. Cu diffusion from in IMC $(Cu,Ni)_6Sn_5$ to from $(Cu,Ni)_3Sn_4$ may be possible.

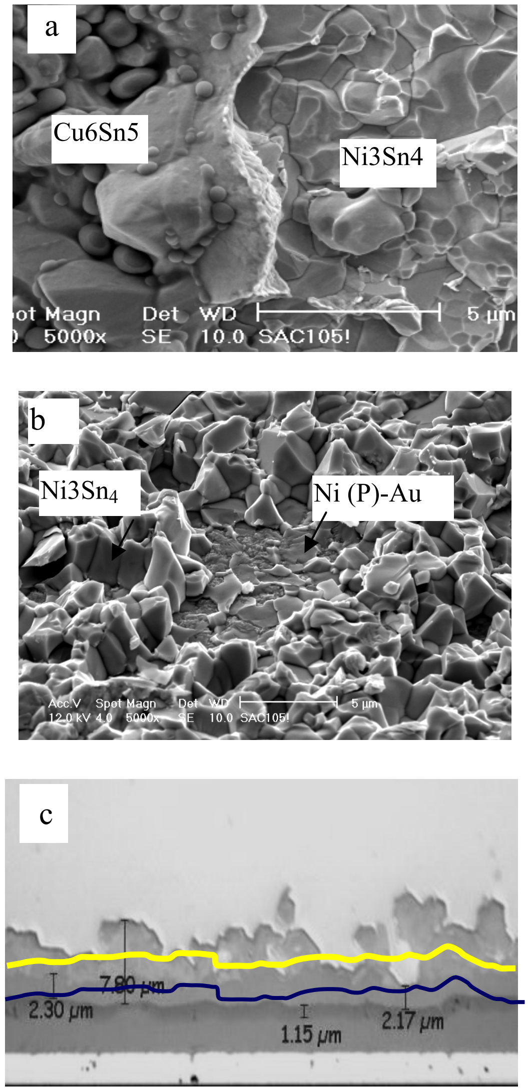

Fig. 5 Fracture surface of IMC

Conclusions

At room temperature storage, $(CuNi)_6$ Sn_5 exists in a stone-like in the interface of solder/UBM in SAC105. HTS aging results in IMC growing from one layer $(CuNi)_6$ Sn_5 IMC to two different layers IMC, and upper layer is $(Cu,Ni)_6$ Sn_5 and lower layer near Ni-p layer is $(Cu,Ni)_3Sn_4$. Moreover, HTS aging results in $(CuNi)_6$ Sn_5 grains growing toward solder ball direction.

By HSBP, the solder joint fracture often occurs at the interface of two IMC layers and the joint strength is lower. Sometimes fracture occurs in the interface Ni3Sn4 layer and UBM which lead to higher joint strength.

Acknowledgments

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