Impact of substrate finish on Sn/Ag/Cu alloy solder joint

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Abstract

In recent years, implementation of lead-free solder in the electronic industry is gaining momentum. Lower processing temperature and reliability of Sn/Ag/Cu alloy has made it a viable alternative and the industry is aligning towards this alloy. This paper investigates Impact of substrate finish on Sn/Ag/cu alloy for Ball grid array packages. The scope of this paper includes study of lead-free alloy Sn/Ag/cu, Sn/Ag & Sn/Cu, its interaction with substrate plating finish, intermetallic at substrate- ball interface, shear force and failure mode. The type of substrate used in this study is buildup substrate with electroless nickel gold finish and laminate substrate with electrolytic nickel gold finish.

Experimental results show that copper containing alloys exihibited failure mode at IMC/ Nickel interface, when shear test was performed on the units reflowed three times at 260deg. The conclusion from the above study is, Sn/Ag/Cu solder alloy used in ball grid array can result in fracture at IMC /Electrolytic Nickel interface. Impact force from testers or drop test can result in such brittle fracture between IMC and Nickel. Increasing the copper percentage in Sn/Ag/Cu alloy can increase the chance of this brittle fracture between the IMC and electrolytic nickel interface.

1. Introduction

Lead is the major constituent of solder, used in BGA parts as solder ball. The need for a lead-free solder system is driving the investigation on alternative alloys to replace lead. There are technical papers in the past, which has dealt with the microstructure, intermetallics, reliability and fatigue life of Sn-Ag-Cu lead-free solder system. The industry is alligning to Sn-Ag-Cu lead-free solder system based on fatigue life properties and low processing temperature of the alloy. The need to understand these alloys from assembly perspective of package assembler who does a ball attache process onto the substrate is essential. The solder ball is assembled to the package substrate of various types, The prominent ones are laminate substrates which are mostly used in wire bonded PBGA type packages and build up substrates which are mostly used in flip chip type array packages. This paper details the study on impact of substrate finish on Sn/Ag/Cu alloy for ball attache process.

2. Assembly-Ball attache process.

Assembly of solder balls to the substrate involves fluxing the substrate, placing the balls onto the substrate and reflowing the substrate. Two type of substrates were used in the investigation. One is four layered FR4 Laminate substrate with electrolytic Nickel gold finish. The nickel thickness is 7um and gold thickness is 0.7um. The other type of substrate is buildup organic substrate with electroless nickel gold. The nickel thickness is 7um and gold thickness is 0.05um for this substrate. Solder ball used in the assembly is thirty mil diametre. The reflow was conducted in a nine zone IR oven. The reflow profile was optimized for each of the lead free solder alloy type as follows:

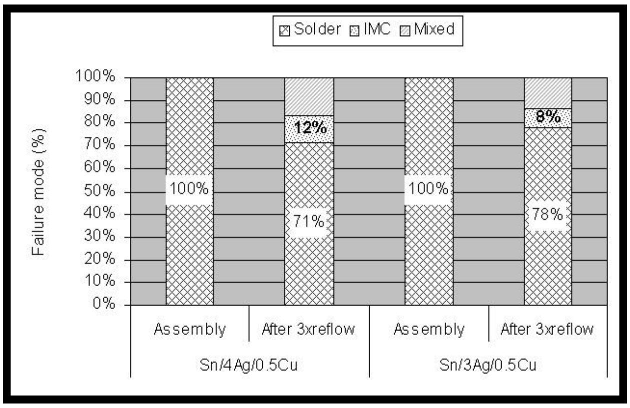
1. Sn/Ag/Cu solder was reflowed at a peak reflow temperature of 230degc with hold time 80sec above 217degc.
2. Sn/3.5Ag solder was reflowed at a Peak reflow temperature of 235degc with hold time 94sec above 221degc.
3. Sn0.7Cu solder was reflowed at a Peak reflow temperature of 245degc with hold time 98sec above 227degc.

The reflow profile optimization was based on wetting of the alloy, grain size and shear strength.

3. Experiment

The first experimental run is assembling Sn/Ag/Cu solder system consisting of two types of SAC alloys, Sn/4Ag/0.5Cu and Sn/3Ag/0.5Cu to laminate substrate. Both these alloy were assembled at reflow peak temperature of 240 deg. The assembled Units were picked randomly and again reflowed at 260deg three times. Shear force testing was performed on the units subjected to 1x and 3x reflow. Failure mode at the sheared location was observed and classified as Solder failure, IMC failure and mixed failure as shown in picture A. Solder failure is fracture at solder across the entire pad. This is ductile fracture. IMC failure is brittle fracture with IMC exposed greater than 50% of pad area. Mixed failure is IMC exposed less than 50% of pad area.

Figure 1 ; Results of first run of experiment



The results from the first experimental run showed that for Sn/4Ag/0.5cu & Sn/3Ag/0.5Cu alloy, Failure mode observed during shear test was fracture at solder on 100% of the units sheared after assembly. But the failure mode of these alloys shifted to 12% & 8% fractures at IMC after 3x reflow. (Refer Figure1)

Picture A: Classification of failure mode

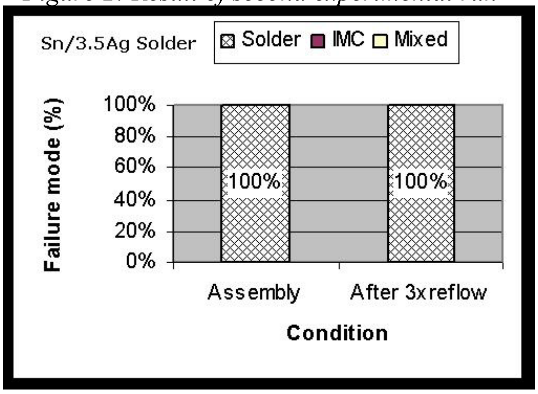
Solder failure

IMC failure

Mixed failure

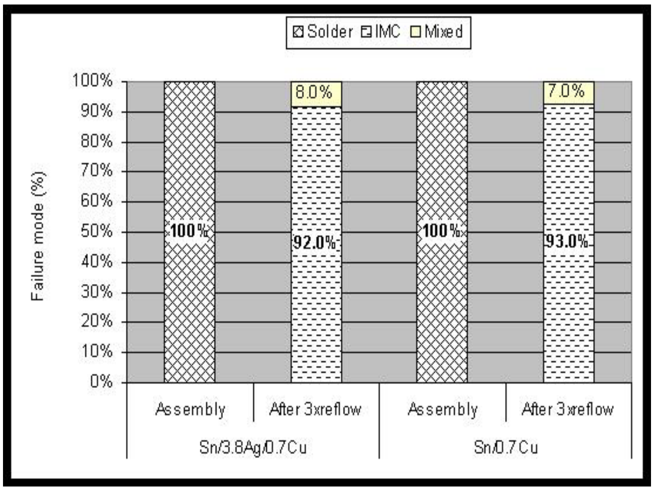
The second experimental run is assembling Sn/3.5Ag solder ball on laminate substrate. Shear test was done on the units subjected to 1X and 3X reflow. Results from this experimental run showed that failure mode was fracture at solder on 100% of the units subjected for shear test. (Refer figure 2).

Figure 2: Result of second experimental run



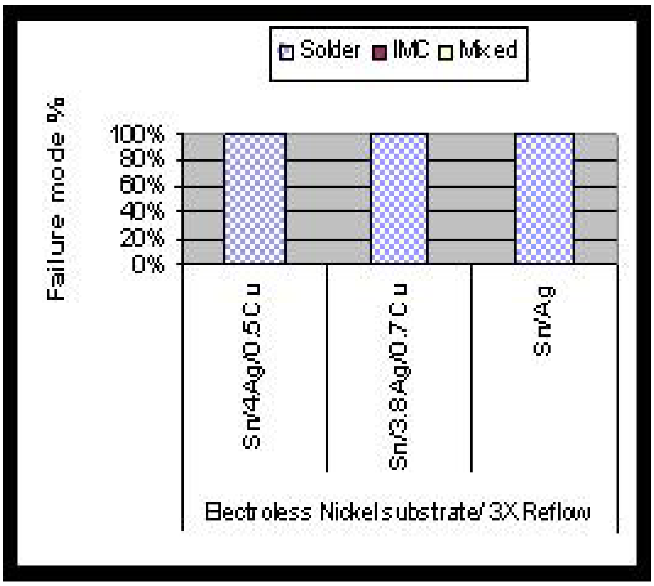
Inference from the first and second experimental run showed that, only copper containing alloys fractured at IMC. Solder alloys with no copper presence fractured at solder. To confirm this inference, the third experimental run was designed to add more copper percentage in SAC alloy. So the choice of alloys for this leg of experiment was Sn/3.8Ag/0.7Cu which contains 0.2% more copper than SAC405. The other alloy used in this run was Sn/0.7Cu solder which does not have the silver component but packs more copper percentage. Results from this experimental run showed that 90% of joints fractured at IMC for Sn/3.8Ag/0.7Cu & sn/0.7cu solder alloy(refer figure 3). This surge in percentage of IMC fracture with increase in presence of copper in lead-free alloys shows that there is an effect due to presence of copper. From the first three experimental run, it was observed that copper containing alloys exhibited fracture at IMC-Nickel interface and solder system devoid of copper exihibited ductile solder fracture.

Figure3: Result of third experimental leg



The first three experimental legs was assembly of lead-free alloys on laminate substrate where the substrate plating finish was electrolytic nickel gold. Based on the above results, there is a need to understand if these failure pattern of lead-free alloys has some dependence on substrate plating finish. Inline with this thought, fourth leg of experiment was included to assemble all the above lead-free alloys on Buildup substrate with Electroless Nickel gold plating finish. Units were reflowed at 260deg three times and shear test was performed on the units reflowed 1X and 3X times. The Results from this experimental run showed that lead-free alloy assembled to buildup substrate did not follow the same failure pattern as in laminate substrate. As seen from figure4 solder joints fractured 100% at solder in both Sn/Ag/Cu and Sn/Ag alloy at 1X and 3X reflow condition.

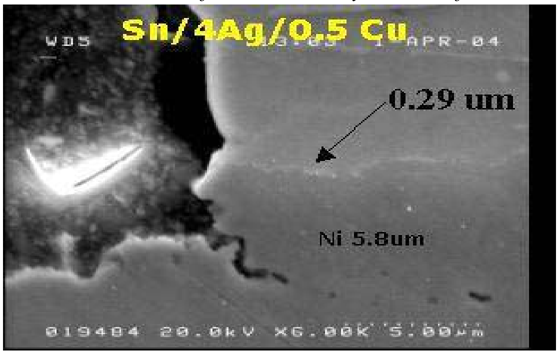
Figure 4: Result of fourth experimental leg



4. Analysis on fracture and intermetallics

Sample units from 1X and 3X reflow condition, across experimenatl legs was cross-sectioned. IMC formed at the interface and bulk solder was identified, Intemetallicgrowth and nickel depletion was measured. SAC405 alloys forms Sn-Ni-Cu IMC at the interface. At 1X reflow condition the intermetallic thickness is 0.29um which grows to 0.97um during 3X reflow condition.

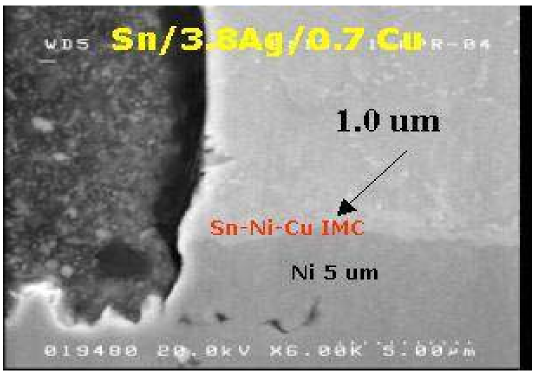
Pic B1: Cross-section of SAC405 alloy at 1X reflow cond



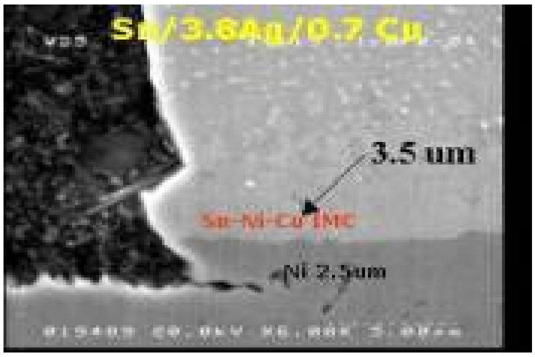
Pic B2: Cross-section of SAC405 alloy at 3X reflow cond

As the copper presence in the solder increases, intermetallic thickness increases. In case of Sn/3.8Ag/0.7Cu alloy the Intermetalic thickness at 1x reflow is 1um and 3X reflow is 3.5um (Ref.Pic C). At 3x reflow condition, the IMC growth in Sn/3.8Ag/0.7cu alloy is 3.5um, which is significantly higher than 0.97um growth in SAC405 alloy (Ref PicB). The thickness of nickel also reduces significantly in case of Sn/3.8Ag/0.7cu alloy when compared to SAC 405 alloy at 3X reflow condition(Ref Pic B2 & C2).

Picture C1: Cross-section of Sn/3.8Ag/0.7Cu alloy at 1X reflow condition

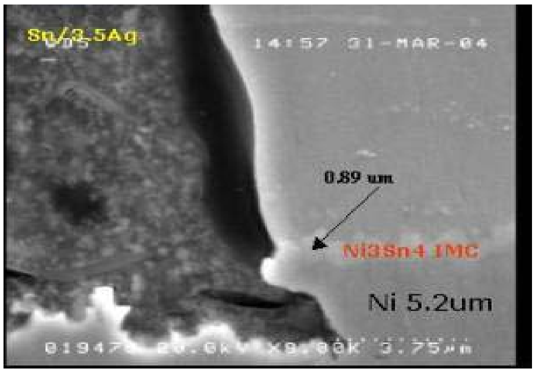


Picture C1: Cross-section of Sn/3.8Ag/0.7Cu alloy at 1X reflow condition.

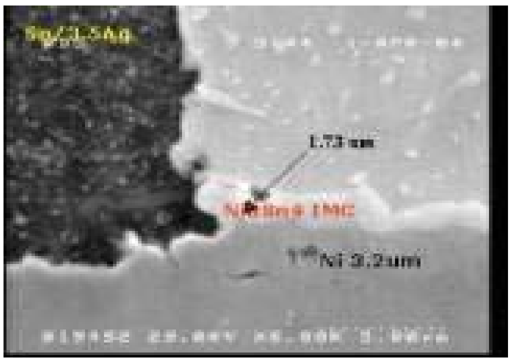


Sn/Ag forms a single stable Ni3Sn4 IMC at the interface. IMC growth after assembly is 0.8um, which grows to 1.73um at 3X reflow condition (Ref Pic D). The Nickel thickness reduces from 5.2um at initial stage to 3.2um after 3X reflow.

Pic D1: Cross-section of Sn/Ag alloy at 1X reflow cond



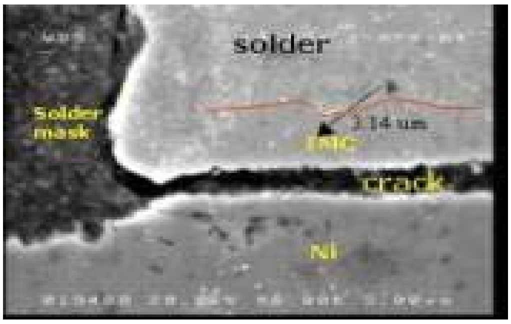
Pic D2: Cross-section of Sn/Ag alloy at 3X reflow cond



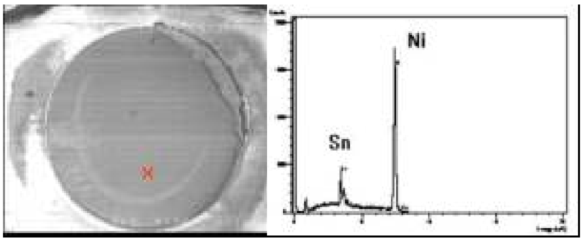
The fracture discussed here is brittle fracture. The need to understand IMC failure mode exhibited by copper containing solder system is our focus. To analyze the fracture location, we chose the units which saw most IMC failures. The units assembled with Sn/3.8Ag/0.7Cu solder ball on laminate substrate and reflowed 3X times was cross-sectioned. An interesting observation made on this cross-section was fracture has initiated at IMC/nickel interface and propagates along and through IMC/Nickel interface

(Ref.Pic.E). There was no fracture observed at IMC/Solder interface. Analysing the fracture location and intermetallic thickness across alloys The critical thickness of IMC would not have played a key role in this failure mode, going by the argument that IMC growth in Sn/Ag alloy is higher than SAC405 alloy, yet we have not seen IMC fracture in case of Sn/Ag solder. Depletion of Nickel layer is also higher in Sn/Ag solder than SAC405 alloy. Nickel thickness in SAC405 alloy after 3X reflow condition is 5um compared to 3um thickness in Sn/Ag solder. So these factors would not be the major factors for this IMC/ nickel fracture.

Pic E1: Cross-section of fracture location in SAC solder assembled to laminate substrate.

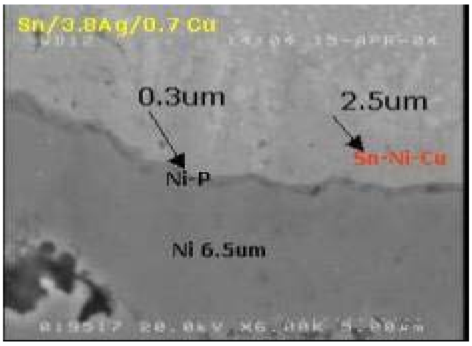


Pic E2: EDX analysis at fracture location.



Comparison analysis between the buildup substrate and laminate substrate will help us identify potential cause for fracture at IMC/Nickel interface. Units assembled using Sn/Ag/Cu solder on build up substrate and reflowed 3X times was cross-sectioned. Two intermetallics was identified one is Sn-Ni-Cu intermetallic whose thickness is 2.5um. The other intermetallic is Ni-P which is 0.3um thick and sandwiched between Nickel and Sn-Ni-Cu intermetallic (ref pic F). Buildup substrates are plated with electroless nickel gold. Electroless nickel plating has phosporus presence which results in Ni-P intermetallic. Ni-p intermetallic was one difference between laminate susbstrate and buildup substrate. Ni depeletion was not high in electroless nickel substrate. Nickel thickness was measured 6.5um in units reflowed 3X times. This was not the case in electrolytic substrate, only 2.5um thick nickel was observed in units reflowed 3x times. Comparing the experimental results of laminate and buildup substrates and inference from the intermetallic growth and crack propagation suggests that residual stress at Sn-Ni-Cu IMC and electrolytic nickel interface is higher than Sn-Ni-Cu IMC/ electroless Nickel interface. Sudden impact force due to drop / handling can cause fracture at IMC- Electrolytic nickel interface and result in defect like missing ball. The solder mask thickness and geometry of electrolytic nickel substrate can add to the stress on the weak IMC-electrolytic nickel interface formed by the copper containing lead-free alloys.

Pic F: Cross-section showing interface of buildup substrate assembled using Sn/Ag/Cu solder system



Conclusions

The conclusion from the above study is, Sn/Ag/Cu solder alloy used in ball grid array can result in fracture at IMC /Electrolytic Nickel interface. Impact force from testers or drop test can result in such brittle fracture between IMC and Electroless Nickel. Increasing the copper weight in Sn/Ag/Cu alloy can increase the chance of this brittle fracture between the IMC and electrolytic nickel interface.

Acknowledgments

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