Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

Special Issue

CORRELATION STUDY BETWEEN INTERMETALLIC LAYER AND DROP TEST FOR POLYMER CORE LEAD-FREE SOLDER BALL UNDER RELIABILITY TEST

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ABSTRACT

Polymer core coated lead-free solder ball is one of an alternative in integrated circuit (IC) packaging interconnection. In order to verify the performance of polymer core coated solder balls, the reliability comparison of Nickel (Ni)-coated polymer core solder ball with non-coated polymer solder ball is carried out. The polymer core solder ball is coated with 1 µm thickness of Nickel (Ni) on the Copper (Cu). In this study, different thermal cycles; Temperature Cycle (TC) up to 1000 cycles and Autoclave (AC) up to 168 hours and tray drop test have been used to inspect the solder ball joint handling and impact force robustness. The results show that Ni-coated polymer core solder ball shows thinner IMC and better performance in drop test under TC and AC stress test compared than that of non-coated polymer solder ball. Thinner IMC provide better drop performance and vice versa.

Keywords: Polymer-core-coated-solderball; Intermetallic Compound; Thermal stress

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doi: http://dx.doi.org/10.4314/jfas.v9i7s.56

1. INTRODUCTION

Lead solder alloys are widely used in ball grid array (BGA) device at the early stage. However, due to the concerns of the lead toxicity which dangerous to human and the environment, the National Center for the Manufacturing Sciences (NCMS) and the National Electronic Manufacturing Initiative (NEMI) recommended the replacement of lead solder ball to the lead-free solder ball. In addition to that, in 2006, European Union issued International legislation Restriction of Hazardous Substances (EU RoHS) regulatory requirement restricted the use of lead in electronic assembly. Therefore, to support on this, many industrial are migrating to lead-free solder ball to replace tin-lead (Sn-Pb) solder ball. There are few types of Sn- lead free were introduced such as SnCu, SnZn, SnBi, SnIn and SnAg[1]. Most of commonly recommended lead-free solder ball contain high percentage of Sn alloy, which exhibits high strength and high modulus [2].

Many research found that the lead-free solder reliability due to the environment stress still exhibits inferior performance than that of lead solder balls in semiconductor products. There is a major reliability concern on the solder joint to the package when subjected to reliability stress test that incorporate lead-free solder balls. Thus, copper (Cu) was incorporating to lead-free solder ball producing tin/silver/copper (SAC) alloy that would perform similar to lead solder balls with adequate thermal fatigue properties and strength [3]. SAC solder ball was expected to have a good reliability, excellent resistance as well as good thermal fatigue[4], [5].Few studies had been demonstrated with regard to enhance the reliability of the lead-free solder ball including adding alloy such as nickel (Ni), cobalt (Co) and antimony (Sb) [6], adding micro-alloy[2]and also lowering silver (Ag) content in the solder ball [7]. Recently, Zhang et.al demonstrated enhanced SAC lead free solders by adding nanoparticle as the additive. It is presented that the wettability of SAC was improved attribute to the nitrogen (N_2) that can resist the oxidation of molten solder[8]. Thus, it is of paramount importance to ensure the solder joints in the microelectronic packaging fullfill the requirements of both physical as well as mechanical properties.

It is well known that solder ball,substrate and intermetallic compound layer (IMC) compose a solder joint with two main interfaces; solder/IMC and IMC/substrate interface. And the mechanical behavior of solder joints is relying on these constituents. IMC layer thickness shown to be one of the main parameter that affects the solder joint reliability[9]. When the solder joint is subjected to thermal aging process, the microstructure of the solder ball, substrates as well as the IMC transform continuously [10]. Despite of IMC important role in die-attached materials by connecting chips to substrates[11]it could as well induce a detrimental effect on both the solder-ability and on the solder joints mechanical properties, as these interfaces are brittle compared to the solder[12]. Phander et. al presented a range of micro-alloy additive that could act as diffusion modifiers which slow the inter-diffusion between substrates and solder ball. This micro-alloy is able to reduce the IMC thickness that simultaneously reduces the tendency for void formation[2].

Previously, our group presented a lead-free polymer core solder ball with polymer core inside the solder ball. The polymer core inside the solder ball is able to absorb and relieve stress from the environment stress impact. Figure 1 shows the cross-sectional view of polymer core solder ball with Ni layer [13], [14]. This structure is expected to enhance the ball drop reliability and simultaneously result in improvement to the solder ball joint, compared to the non-coated SAC solder ball.

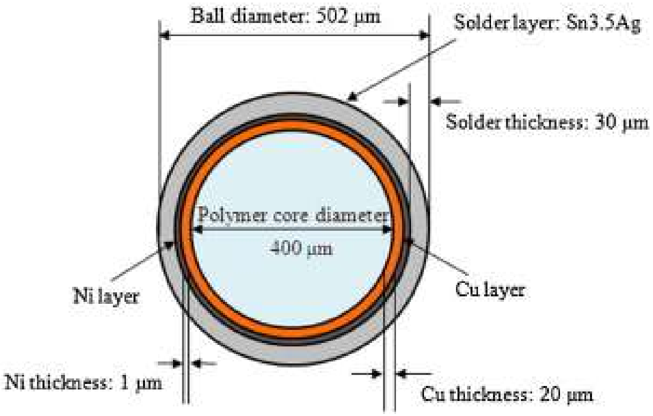

Fig.1. Ni-coated polymer core solder ball [14].

In 2002, Lim and Low introduced the drop test for portable electronic tested at different orientation and height[15]. Tray drop test was carried out to evaluate the solder joint robustness due to handling and impact force [16], [17].

In this paper, Ball Grid Array (BGA) substrate with Ni/Au plating was used. The Ni layer acts as a protection layer on a Cu conductor in electronic devises and circuit fabrications[18], whilst Au is used to shield the Ni- surface finish from oxidation. BGA packages are widely used for many electronic applications, including portable, automotive and telecommunication products. Hence, BGA packages are chosen for this research. Many studies of mechanical solder joint reliability were carried out only in terms of shear strength [19]. Thus, this paper will present the correlation of IMC thickness with the drop performance after subjected to thermal aging.

2. RESULTS AND DISCUSSION

2.1 AC Stress Test

There was no drop ball observed for the tray drop test was completed for stress test points of 24, 48 and 96 hours of AC stress test for both SAC and polymer core solder balls. Dropped ball was observed after AC of 144 hours and 46 th drop for the polymer core solder ball. On the other hand, drop ball was observed after 39 times of dropped for SAC solder ball. Figure 2 shows the IMC thickness chart at each of stress test point from 24 to 144 hours. IMC layer for polymer core solder ball from 24 up to 144 hours is thinner than SAC solder ball from 24 to 144 hours, with an average of 2.5µm thickness.

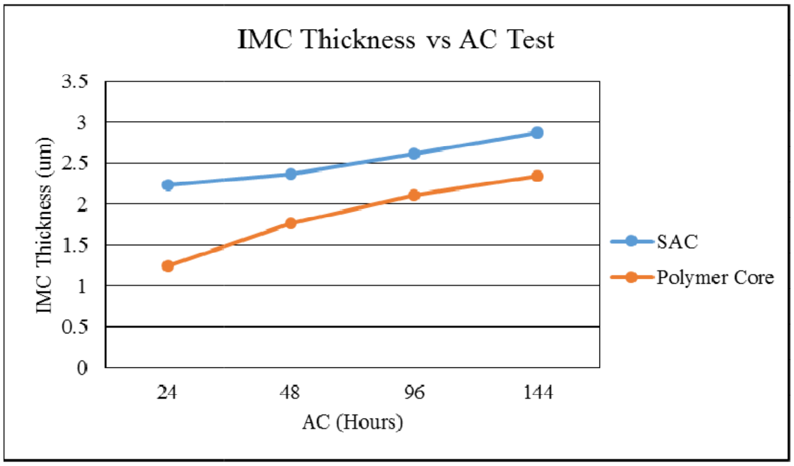

Fig.2. IMC thickness for polymer core solder after subjected to AC stress test.

2.2 TC Stress Test

There was no drop ball observed after the tray drop test for 100, 200 and 500 cycles of TC stress test points for both SAC and polymer core solder balls. However, there was a dropped ball observed after 19 drop-cycles at TC 1000 cycles from the tray drop test for polymer core solder ball. On the other hand, a drop ball was observed after 37 drops for SAC solder balls. Figure 3 shows the IMC thickness of samples at each stress test point after subjected to TC stress test. IMC thickness is thinner in polymer core solder ball from 100 to 500 cycles of TC stress test. The IMC grow rapidly after 1000 of TC cycles for polymer core solder ball as compared to SAC solder ball, which was at an average of 5.04 µm.

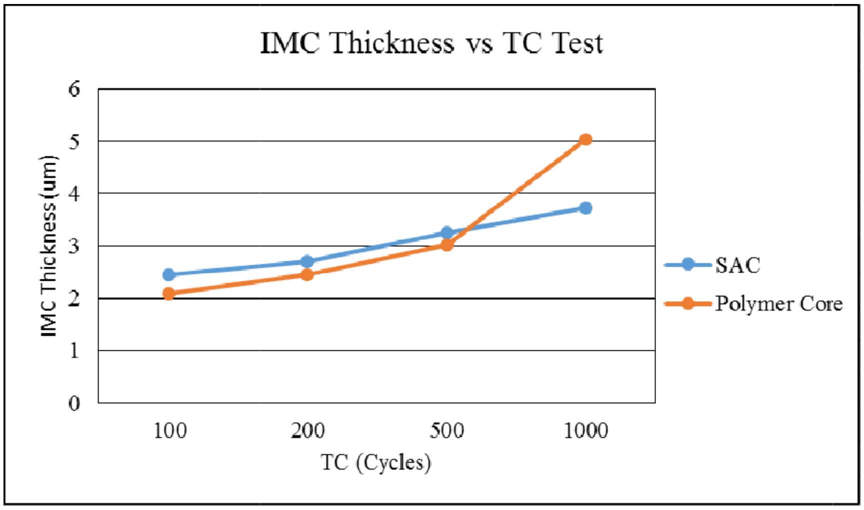

Fig.3. IMC thicknesses for polymer core solder after subjected to TC stress test.

For the drop test result, one of the failed units from TC 1000 cycles was examined and observed under high power of magnification scope after cross-section. It is observed that the crack is induced in the sample TC 1000 cycles for polymer core solder ball. It is observed that the crack was induced in between the Cu and solder layer at the IMC as shown in Figure 4. It is demonstrated before that thermal ageing is among the parameter that was reported to give a big impact to the solder joint reliability[20].

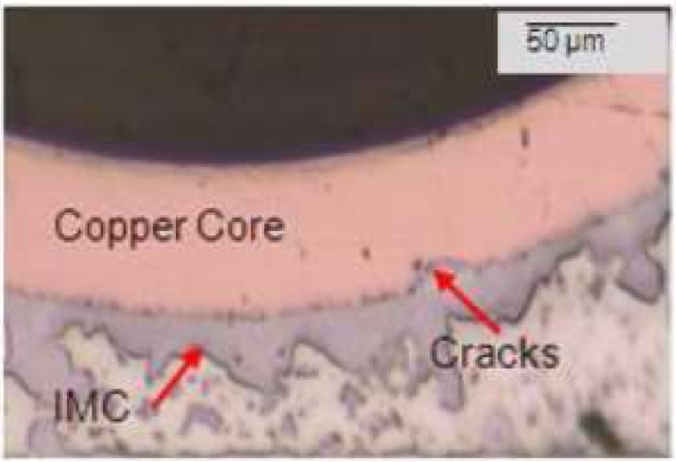

Fig.4. Failed sample of TC 1000 cycles with crack observed.

It is also reported that IMC layer might be the potential site for micro-cracks[21]. The cracks shown in this experiment is probably owing to the sub-micron void formation called "Kirkendall void", thus causing crack, which could affect the joint. The Kirkendall voids inclined to form in between the Cu and Sn when the sample is exposed to high temperature as Cu diffuses much faster into Tin (Sn) than Sn into Cu[22]. Figure 5 illustrates the Kirkendall voids occurring in the microelectronics packaging[23]. On the other hand, no crack was observed for AC stress test for both non-coated and coated polymer core solder ball.

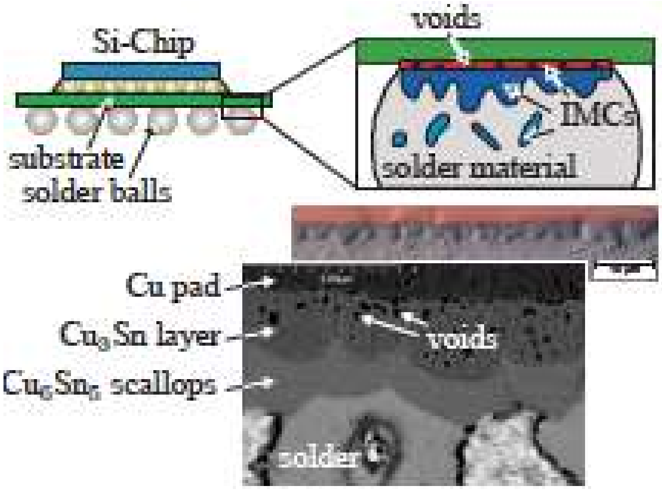

Fig.5. Kirkendall voids in microelectronic packaging. Copied from[23].

The result presented here demonstrates that polymer core solder ball tends to form a thicker IMC due to the diffusion rate of Cu that is faster than that of Sn. The growth rate of the IMC relies on the interfacial kinetics[24]. Nonetheless, thicker IMC may cause brittle failure of solder joints in drop shock by weakening the solder joint strength, and thus affecting the long-term reliability[2], [21], [25]. As a conclusion for this, temperature plays an important factor that affect solder joint strength and not by high humidity.

3. EXPERIMENTAL

Two types of solder balls were used in this work, namely SAC 387 and polymer core solder ball. SAC 387 is a pure metallic solder ball with composition 3.8% Ag, 0.7% Cu and 95.5% Sn. The new technology of the polymer core solder ball consists of three layers with a total diameter of 500 µm as shown in Figure 1. Inner core is 400 µm in diameter and is coated by a Cu layer of 20 µm thickness; while the outermost layer of solder is 30 µm thick. Both types of the solder balls used in this experiment were 500µm.

3.1 Reliability Stress Test

In this research, two stress tests were conducted to test out the solder joint reliability for both SAC and polymer core solder ball, which were Autoclave (AC) and Temperature Cycles (TC) test.AC stress test mainly focuses on the moisture resistance evaluations. Assembled packages were subjected to a condensing with high humid atmosphere under pressure to force the moisture into the package. The temperature was set to 121°C with 100 % humidity and pressure 205 kPa, according to the JEDEC specification, JESD22-A102D [26]. This is to evaluate whether the high moisture will affect the solder joint in the assembled package. There will be four stress points, which are 24, 48, 96 and 144 hours. Samples were taken out at each stress points to access the solder joint effect.

TC stress tests were performed to the study the solder joint effect to the very cold and very hot temperature. There is a total of 11 test conditions based on different industrial need according to the JEDEC standard specification for TC test, JESD22-A104D [27]. Condition C was used in this experiment with temperature -65 and 150°C. Same as in AC test, there will be four stress test points, which are 100, 200, 500 and 100 cycles. Samples were taken out at each stress point to access the solder joint effect.

3.2 Drop Test

Tray drop tests were conducted to assess the solder joints robustness against the vibration and impact shock [28]. For this study, the maximum cycles of drop were fixed at 50 cycles. For each tray drop test, 6 test unit samples were laid on the bottom tray, and the dummy samples were placed on the other top trays for weight balancing. All 10 trays were then fixed with a thermal strap at the end. The tray was then deliberately dropped onto a hard surface at five different angles. The samples were inspected at every cycle for dropped balls. The passing criterion is that drop ball does not occur in all the six test samples. Figure 6 shows the angle direction of drop.

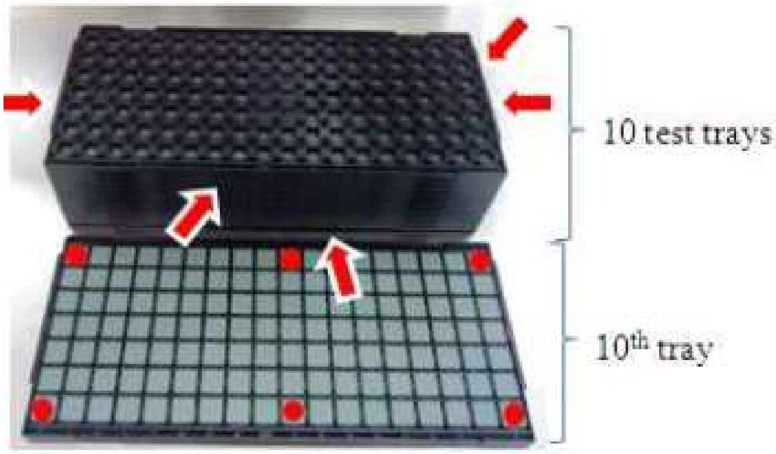

Fig.6. Angle direction of tray drop test.

3.3. IMC Measurement

For cross-section, all samples were cold mounted using the mixture of epoxy resin and hardener for a minimum of 8 hours. To start on the cold mount cross-section, the sand paper grit size grinding started at 180 grit followed by 400, 600 and finally the 1200 grit. 1200 grit size sand paper was used in the last step for the purpose to remove scratches. Each finer grinding stage removes scratches from the previous sand paper. This can be achieved by orienting the specimen perpendicular to the previous scratches. In between each grade, the specimen was washed with water to prevent any contamination from the previous processing step on the specimen surface. Machine Ecomet 3 was used. The IMC thickness observation and measurements were conducted via high power microscope under magnification of 50X. The unit measured for IMC thickness was in micrometer (µm). The relationship between the IMC thickness, X at aging time, t at a thermal aging temperature is calculated via [29]:

$$X = \mathrm{K}t^{1/2} \tag{1}$$

where K is the reaction rate of the IMC formation.

4. CONCLUSION

As a summary, we can conclude that the high temperature affects the solder joint strength not the humidity. We might also conclude that, voids form easily after subjected to long TC (1000 cycles) stress test. High humidity would not affect the solder joint performance caused by voids formation. Even though the polymer core inside the solder ball function as absorber and to reduce the stress impact. However, the crack still occured due to the voids formation from the rapid diffusion from Cu to the Sn. This would be one of the important areas that researcher could focus for further optimization. This problem could be solved via a coating layer to limit the Cu diffusion.

5. ACKNOWLEDGEMENTS

This research work was partially funded and supported by UMRG research grant RP024B-13AET and BOLD Grant (10289176/B/9/2017/24).

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How to cite this article:
Tan C H, Talik N A, Yap B K, Tan C Y. Correlation study between intermetallic layer and drop test for polymer core lead-free solder ball under reliability test. J. Fundam. Appl. Sci., 2017, *9(7S), 600-611.*