Characterization Study for Polymer Core Solder Balls under AC and TC Reliability Test

Cai Hui Tan1,3, Boon Kar Yap1*, Chou Yong Tan2

1 College of Engineering, University Tenaga Nasional (UNITEN), Selangor, Malaysia.
2 Department of Mechanical Engineering, University Malaya (UM), Kuala Lumpur, Malaysia.

1 E-mail: *kbyap@uniten.edu.my, caihui_tan@yahoo.com
2 Tel: +60389212229, Fax: 0389212116
3 Email: chouyong@um.edu.my

Abstract

Since Restriction of Hazardous Substance (RoHS) Regulation came into effect in year 2006 due to the hazardous effects of lead to human’s health and toxicity for environment, Ball Grid Array (BGA) semiconductor chip are widely used for many electronic applications including portable, automotive and telecommunication products that require stringent thermal and mechanical requirements. However, dropped balls in lead-free BGA products due to poor solder joint strength caused by reliability stress are a major concern in the semiconductor industries. A new technology with polymer core inside the solder ball (polymer core/Cu/Sn) is integrated to improve the solder joint strength. The polymer core inside the solder ball is function to dissipate the stress better as compared to the lead-free solder ball. The diffusion rate of Cu is faster than the diffusion rate of Sn, thus Kirkendall voids are tends to form in between the interface at the Cu and Sn layer, especially after subjected to the high temperature reliability stress. This would affect the solder joint strength and causing drop ball issue. To overcome this, an additional of 1 µm Ni layer is coated on the Cu (polymer core/Cu/Sn/Ni) to reduce the diffusion from Cu to Sn, to avoid Kirkendall voids formation. This research work studies the performance of the solder ball shear strength and IMC thickness of two types of polymer core solder balls applied to BGA device. In this research, polymer core solder balls were went through under AC (Autoclave) and TC (Temperature Cycle) reliability test up to 144 hours and 1000 cycles, respectively. Solder ball shear strength test was conducted via Dage 4000 series bond tester and IMC thickness measurement via cold mount cross-section. From the results of the two types of polymer core solder ball, observed that, the ball shear strength were decreased with increased of aging time, while IMC thicknesses were increased with increase of aging time. This is probably due to the rapid Cu diffusion into the Cu core interface resulting in lower shear strength and thicker IMC. From this research work, it can be concluded that the polymer core solder ball with an additional Ni layer showed better performance than the polymer core solder ball without Ni layer, after subjected to the AC and TC reliability test. This is due to the Ni layer could limit the Cu diffusion into the solder thus resulting in good solder joint strength and drop reliability performance as well as reduced crack issues caused from Kirkendall voids.

Keywords — Polymer Core Solder Ball, Shear Strength, IMC, Reliability Test.

1. Introduction

Ball Grid Array (BGA) semiconductor chip are widely used by customer for many electronic applications including portable, automotive and telecommunication products that require stringent thermal and mechanical requirements. BGA has the advantages of smaller size, thinner weight and higher pin counts. Solder balls in BGA play an important function to provide electrical interconnections between silicon die and substrate. Lead solder alloys are used in BGA device at the early stage. However, on July 1, 2006, the European Union (EU) issued the Restriction of Hazardous Substances (RoHS), which regulatory requirement restricting use of lead in electronic assembly, due to the hazardous effects of lead to human’s health and toxicity for environment [1]. Thus, to support a cleaner environment, many industrial are migrating to lead-free solder balls consisting of tin/silver/copper (SAC) alloy. SAC solder alloy perform similar to eutectic, with adequate thermal fatigue properties, strength, and wettability.

However, many research found that the lead-free solder reliability due to the environment stress is still less perform than lead solder balls in semiconductor chips. Thus, in order to develop and improve on the solder joint reliability for lead-free solder balls in semiconductor devices, a lead-free polymer core solder ball with polymer core inside the solder ball is introduced. The polymer core inside the solder ball is able to absorb and relieve stress from the environment impact [2]. This is the main advantages of the polymer core solder ball. This could improve the ball drop reliability as well, thus result in a significant improvement to the solder ball joint, compared to the purely metallic lead-free solder ball. Therefore, it is important to study and choose the suitable solder balls in BGA devices for manufacturing process in order to solve the solder joint reliability issues.

This research work involves using Nickel-Gold (Ni/Au) plated over the Cu pad substrate. The Ni layer is function as a protective layer on a Cu conductor in electronic devises and circuit fabrications [3]; while Au is to protect the surface finish of Ni from oxidation.

2. Experimental

2.1 Polymer Core Solder Ball Structure

The new technology of the polymer core solder ball consists of three layers with total diameter of 500 µm. Inner core consist of 400 µm diameter and is coated by a Cu layer.
of 20 µm thickness; while the outer most layer of solder consist of 30 µm thickness. The internal structure of the polymer core solder ball with an extra 1 µm thickness of Ni layer added has a total diameter of 502 µm with the same thickness for solder and Cu layer.

Ball Grid Array (BGA) substrate with Ni/Au plating was used in this study for the reliability research.

2.2 Reliability Stress Test – TC

Temperature Cycles (TC) stress tests were performed to study the mechanical properties and internal structure of polymer core solder balls in this experiment for solder joint strength test and Intermetallic (IMC) measurement.

According to the JEDEC standard specification for temperature cycle test, JESD22-A104D, there are total 11 test conditions based on different industrial need [4]. Condition C was used in this experiment with minimum and maximum temperature -65 and 150°C, respectively.

2.3 Reliability Stress Test – AC

Autoclave (AC) reliability test is focused on the moisture resistance evaluations. Samples were subjected to a condensing, highly humid atmosphere under pressure to force moisture into the package. Our research evaluated whether the moisture test affected the solder joint strength and the IMC growth. The temperature was set to 121°C with 100% humidity and pressure 205kPa, according to the JEDEC specification, JESD22-A102D [5].

2.4 Solder Ball Shear Test

solder ball shear test is the process of removing a solder ball from a package at room temperature with a certain force at a constant rate applied at the center of solder ball. Solder ball shear test is the most common test applied in semiconductor industrial to evaluate the solder shear strength. The shear strength is defined by how much force is needed to remove the solder ball from the package during the shear test. Specialized equipment is generally required to perform the solder ball shear test, which normally known as Dage bond tester. In this research, Dage 4000 series bond tester was used to perform solder ball shear test. The shear tool height shall be as close to the substrate as possible without touching the substrate during the shear, according to the Joint Electron Devices Engineering Council (JEDEC) specification, JESD22-B117A [5].

To perform for the ball shear test, same shear speed should be used for all comparative testing, since both shear force and failure modes often show a sensitivity to shear speed. The ball shear method is based on the JEDEC standard specification, JESD22-B117A [5].

Total 10 units BGA samples were conducted for solder ball shear test in this research experiment, after subjected to TC and AC reliability stress test. The ball shear location for each unit was fixed with four outer corners, four inner corners and two in the middle of the device. An average is taken on a total of 100 solder ball shear reading.

2.5 IMC Measurement

All units were needed to be cold mounted by epoxy resin and hardener, then mechanically cross-sectioned after minimum 8 hours of cold molding.

To start on the cold mount cross-section, the sand paper grit size grinding started at 180 grit followed by 400, 600 and finally 1200 grit. 1200 grit size sand paper used in the last step for the purpose to remove the scratches. The unit was then polished on 9 µm and 3 µm polishing wheel, and finally with a soft black polishing cloth, which were impregnated with 0.05 µm colloidal silica chemical during the process to further remove all the scratch lines.

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). Three of the highest IMC points were measured in one solder ball and the final value will be based on the average of these three points.

3.  Results

3.1 Ball Shear Strength – TC

Fig. 1 shows the average of ball shear strength for polymer core solder balls with and without Ni. From the graph trend, shows that the average shear strength of the polymer core solder balls with Ni is higher than polymer core solder ball without Ni, after subjected to TC stress condition from 100 to 1000 cycles. The shear strength for polymer core without Ni is decreasing from average of 1140g to 1060g for 100 and 1000 cycles, respectively. Similar to the polymer core with Ni, the strength decreasing from average 1236g to 1100g for 100 and 1000 cycles, respectively. In general, the shear strength for polymer core solder ball with Ni is higher after subjected to TC reliability stress conditions as compared to the sample of polymer core solder ball without Ni.
3.2 Ball Shear Strength – AC

Fig. 2 shows the average of ball shear strength for polymer core solder balls with and without Ni, after subjected to AC stress test. Generally, the average shear strength of the polymer core solder balls with Ni is higher than polymer core solder ball without Ni, from 24 to 144 hours. The shear strength for polymer core without Ni is decreasing from average of 1218g to 1102g for 24 and 144 hours, respectively. As for the polymer core with Ni, the shear strength decrease from average 1276g to 1202g from AC 24 to 144 hours. In conclusion, the shear strength for polymer core solder ball with Ni is higher than without Ni after subjected to AC reliability stress test.

3.3 IMC Thickness – TC

Fig. 3 below shows the average IMC thickness after subjected to TC stress conditions, from 100 to 1000 cycles. As expected, the IMC layer is the thickest in polymer core solder ball without Ni at 2.45 µm and 3.61 µm for 100 and 1000 cycles, respectively. While for polymer core solder with Ni, the IMC is much thinner at 2.1 µm and 2.89 µm at 100 and 1000 cycles, respectively.

3.4 IMC Thickness – AC

Fig. 4 shows the average of the IMC thickness after subjected to AC stress conditions from 24 to 144 hours. Similar result expected with the TC stress test condition, the IMC layer is thickest in polymer core solder ball without Ni then with Ni layer added. IMC thicknesses for AC stress test in 24, 48, 96 and 144 hours in polymer core without Ni are 2.22, 2.37, 2.62 and 2.81 µm, respectively. While for polymer core solder with Ni, the IMC is much thinner at 1.83 µm and 2.34 µm at 24 and 144 hours, respectively.
4. Discussion

From the result shown above, the ball shear strength for polymer core solder balls with additional Ni layer after being subjected to TC and AC stress test is significantly higher than the polymer core solder ball without additional Ni layer. This is probably due to the rapid Cu diffusion into the Cu core interface resulting in thicker IMC. Thicker IMC layer is one of the factors that can affect the solder joint strength performance [2].

From all the TC and AC samples, observed that, crack is induced in the sample TC 1000 cycles. One of the sample units from TC 1000 cycles for both polymer core solder ball with and without Ni layer were further examined under Scanning Electron Microscope (SEM), as shown if Fig. 5. From the SEM observation, crack is take place in between the Cu and solder layer after TC 1000 cycles test in polymer core solder ball without Ni; no crack is observed for the polymer core solder ball with Ni after TC 1000 cycles stress test. This is probably due to the Kirkendall void formation, thus causing crack which could affect the solder joint strength. The Kirkendall voids tend to form more easily in between the Cu and Sn when subjected to high temperature storage, as Cu diffuses much faster into Sn than Sn into Cu [7-9]. The rapid diffusion from Cu to Sn could cause the Kirkendall voids formation under high temperature over a long aging time. No voids or crack is observed for AC stress test since AC stress test is focus on the affect of humidity to the solder joint strength. As a conclusion, solder strength does not affected by high humidity but the high temperature.

Fig. 5 SEM image for TC 1000 cycles stress test: polymer core solder ball without Ni (left) and with Ni layer (right).

As for the IMC thickness result as shown, it is observed that the sample of polymer core solder ball without Ni have thicker IMC layer than that of polymer core solder ball with Ni in both of TC and AC stress test. This can be explained by the more rapid diffusion from Cu to Sn than Sn to Cu.

Overall performance, it is proven that polymer core solder ball with Ni demonstrate higher joint strength and thinner IMC layer in both TC and AC stress test than polymer core solder ball without Ni.

5. Conclusions

From this experiment, we observed that the ball shear strength for polymer core solder balls with Ni is significantly higher than polymer core without Ni, after being subjected to TC and AC reliability stresses. This is probably due to the rapid diffusion from Cu to the Sn that could induce thicker IMC layer, hence affect the solder joint strength. Since TC stress test condition exposed to the temperature -65°C and 150°C, this could accelerate the diffusion rate from Cu to Sn, hence causing crack. However, for the samples of AC stress test, even through the shear strength is decrease from 24 to 144 hours but there is no crack observed up to 144 hours. This could be explained that, the shear strength reducing is due to the 121°C of the temperature, and 100% humidity would not cause any voids formation.

From this research, we can conclude that the polymer core solder ball with Ni demonstrate superior performance in solder ball shear strength and thinner IMC layer in both of the TC and AC stress tests. With an additional coating of Ni layer, Cu diffusion into the solder could potentially be limited by Ni, thus resulting in better reliability performance such as good solder joint strength and thinner IMC layer. We might also conclude that, voids will form easily when subjected to long TC (1000 cycles) or high temperature with long time aging more than 144 hours. High humidity would not affect the shear strength performance that caused by voids formation.

Acknowledgments

This research work was funded and supported by UMRG research grant: RP024B-13AET. The author would like to also thank Freescale Semiconductor for the technical assistance.

References
