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Reliability Study for Polymer Core Solder Balls with and without Additional Nickel

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ABSTRACT

Drop ball reliability due to poor solder joint strength for BGA packages on lead-free product is a reliability concern when subjected to environmental stress conditions. Integrating a polymer core in the solder ball may be a good strategy to dissipate stress better compared to the metallic solder ball. However, for this polymer core solder ball, the diffusion rate of the Cu is faster than the diffusion rate of Sn. Hence, Kirkendall voids tend to form causing cracks in between the interface at the Cu and solder layer. This could easily affect the solder joint strength, especially when subjected to high temperature stress. The new polymer core solder ball with 1 µm thickness of Ni coated on the Cu could offer better solder ball joint, to prevent Kirkendall voids and to reduce IMC layer thickness. This research work studies the solder ball shear strength and IMC layer thickness for these two types of polymer core solder balls. From this study, we could conclude that the polymer core solder ball with an additional Ni layer coating demonstrates higher joint strength and thinner IMC layer than the polymer core solder ball without Ni layer, after subjected to reliability stress tests.

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INTRODUCTION

Due to the inherent toxicity of lead that is hazardous to human and the environment, lead-free solder balls were recommended to replace the leaded solder balls by the National Center for the Manufacturing Sciences (NCMS) and the National Electronic Manufacturing Initiative (NEMI) (Zheng, 2009). However, solder joint quality problems and drop reliability issues when subjected to environmental stresses are major concerns for most of the electronic packages that incorporate lead-free solder balls. Thus, the polymer core solder ball is introduced. The main advantage of polymer core solder ball is that the polymer core is able to absorb and relieve stress (Kian.P,2010), which improves the solder ball drop reliability when subjected to environmental stresses.

Thus far, most of the research works on the polymer core solder ball focus on the reliability improvement on Wafer Level Chip Scale Package (WLCSP), Chip Scale Package (CSP) and Wafer Level Package (WLP) (Kian.P,2010; Wang, Y.P,2008;Ronak, V., 2011). However, this paper presents on the reliability study between the two different types of polymer core solder balls, namely the polymer core solder ball with and without an additional Ni layer, under multiple reflow and HTS stress tests, focusing on the joint strength and drop reliability for BGA package.

This work involves using the most common surface finish on BGA pads of which Nickel-Gold (Ni/Au) is plated over the Cu pad. The Ni layer is commonly used as a protective layer on a Cu conductor in electronic devises and circuit fabrications (Masazumi, A., 2002). Au is to protect the surface finish of Ni 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. BGA is now extensively integrated in high reliability applications with higher thermal and mechanical cycling requirements (Reza, G., 2012).

MATERIALS AND METHODS

1. Polymer Core Structure:

The polymer core solder ball consists of three layers with a total diameter of 500 µm. The inner core is 400 µm in diameter and is coated by a Cu layer of 20 µm thickness while the outer most layer of solder with 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.

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2. Reliability Tests:

Molded Array Process Ball Grid Array (MAPBGA) substrate with Ni/Au plating was used in this study for both types of polymer core solder balls. The solder ball diameter selected is 500 and 502 µm with solder ball pad 0.5 mm for both types of solder balls.

In this experiment, the polymer core solder balls were investigated via shear tests and mechanical cross-section observation. Different environment stress tests were performed to study the mechanical properties and internal structure of polymer core solder balls. Multiple reflow (1X, 3X and 5X) and HTS stress tests were conducted for both types of solder balls. For HTS stress test, the units were baked at 150 °C to study the IMC growth when subjected to high temperature storage up to 504 hours.

Both the polymer core solder balls underwent reflow at peak temperature of 235°C to 245°C in the seven-zone reflow furnace. The solder ball shear strength test was conducted via the Dage 4000 series bond tester and is recorded in gram (g). Ball shear strength was conducted on 10 units of MAPBGA for both types of the polymer core solder balls under multiple reflow and HTS stress condition.

3. IMC Measurement:

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

The sand paper grit size for the cross-section grinding started at 180 grit followed by 400, 600 and finally 1200 grit. The unit was then polished on the 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 remove all the scratch lines.

The IMC thickness and internal structure observation were conducted under high power microscope of magnitude 50X. The IMC thickness measurement is via the analytical software, which as linked with the high power microscope.

Results:

Multiple Reflow:

1. Ball Shear Strength and IMC Thickness:

Figure 1 (a) shows the average ball shear strengths for both the polymer core solder balls where the shear strength decreases with increasing reflow time. It is shown that the strength for polymer core solder ball with Ni is higher than the polymer core solder ball without Ni, after subjected to multiple reflow (1X, 3X, 5X) stress conditions.

Figure 1 (b) shows the average IMC thickness in multiple reflow stress test for both types of polymer core solder balls with and without Ni. It is observed that the IMC thickness increases with increasing reflow time. However, the IMC is much thicker in polymer core solder ball without Ni than polymer core solder ball with Ni.

High Temperature Storage Stress Test:

Ball Shear Strength and IMC Thickness:

The average ball shear strength for HTS stress test in Fig: 2 (a) shows that, the polymer core solder ball with Ni layer demonstrates higher shear strength than the polymer core without Ni in HTS stress test for all the stress point from 24 to 504 hours.

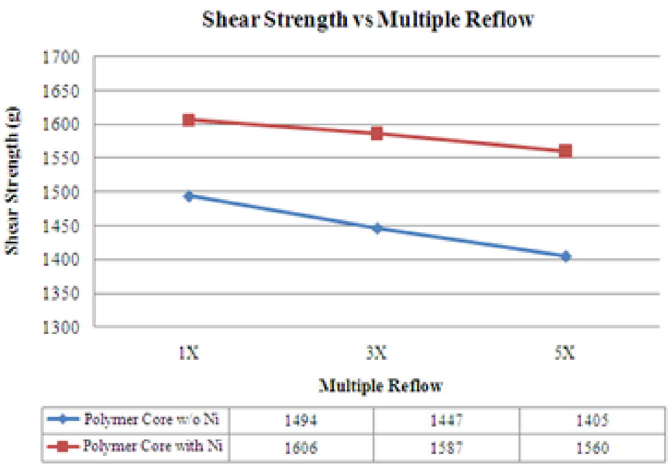

Fig. 1: (a) Average ball shear strength after subjected to multiple reflow stress conditions.

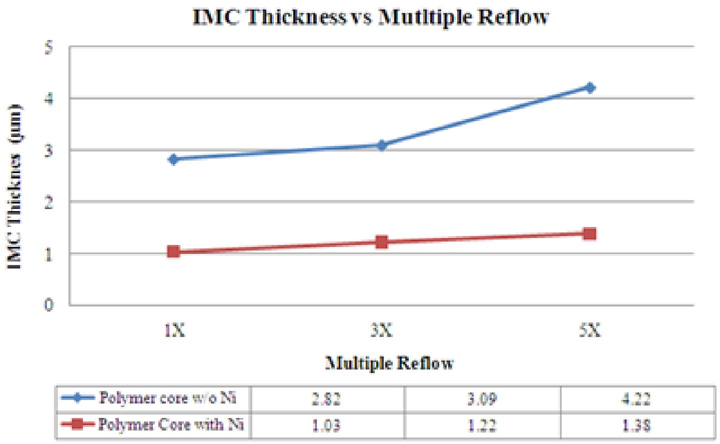

Fig. 1: (b) Average IMC thickness after subjected to multiple reflow stress conditions.

The results of IMC thickness showed in Fig: 2 (b) shows that the IMC increases with increasing HTS aging time from stress point 24 to 504 hours for both the polymer core solder balls with and without Ni. It is observed that the IMC is much thicker in polymer core solder ball without Ni than the polymer core solder ball with Ni, especially at stress point of 504 hours.

Unit after long aging time of 504 hours under high temperature were cross-sectioned to observe the IMC layer. Fig. 3 shows the mechanical cross-sectioned image after HTS 504 hours for polymer core solder balls with and without Ni. The crack in between the Cu and solder layer is observed in the sample of polymer core solder ball without Ni. However, there is no crack observed for polymer core solder ball with Ni.

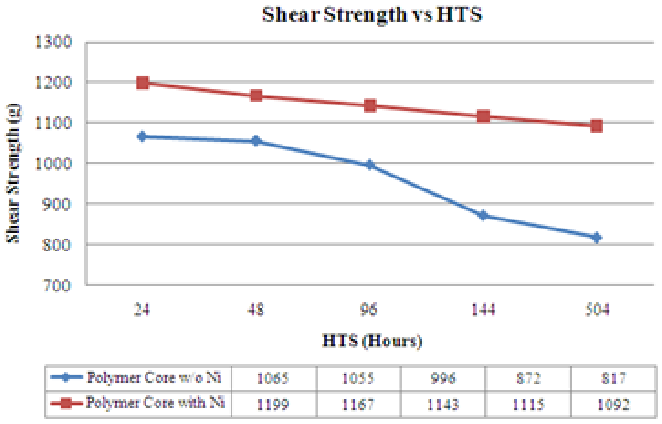

Fig. 2: (a). Average ball shear strength after subjected to HTS stress condition.

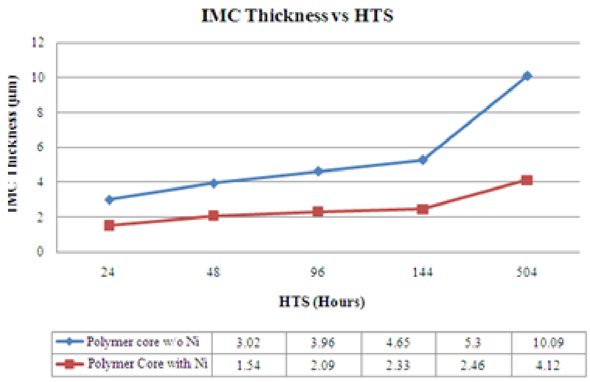

Fig. 2: (b) Average IMC thickness after subjected to HTS stress condition.

Unit after long aging time of 504 hours under high temperature were cross-sectioned to observe the IMC layer. Fig. 3 shows the mechanical cross-sectioned image after HTS 504 hours for polymer core solder balls with and without Ni. The crack in between the Cu and solder layer is observed in the sample of polymer core solder ball without Ni. However, there is no crack observed for polymer core solder ball with Ni.

RESULT AND DISCUSSION

From the results shown, the shear strength is low and the IMC is thicker for the polymer core solder ball without Ni at multiple reflow and HTS stress test. The shear strength is much lower and the IMC thickness is much thicker under high temperature with long time aging especially after HTS 504 hours. In addition, the crack is observed in between the Cu and solder layer for polymer core solder ball without Ni. The cracks form in between the Cu and solder layer, was due to the excessive Kirkendall voids formation. Figure 4 shows the scanning electron microscopy (SEM) image on the structure of polymer core solder balls. Voids form in between the IMC Cu_3Sn and Cu_6Sn_5 layers for the sample of polymer core solder ball without nickel. The Kirkendall void tends to form easily in between the Cu and solder layer when subjected to long term storage stress, as Cu diffuses much faster into Tin (Sn) than Sn into Cu (Yap, B.K, 2012). However, there are no voids or crack observed for the sample of polymer core solder ball with an additional of 1 µm thickness of Ni coated on the Cu. This is because Ni functions as a diffusion barrier and was able to limit the Cu diffusion into the solder (Kar, Y.B, 2012).

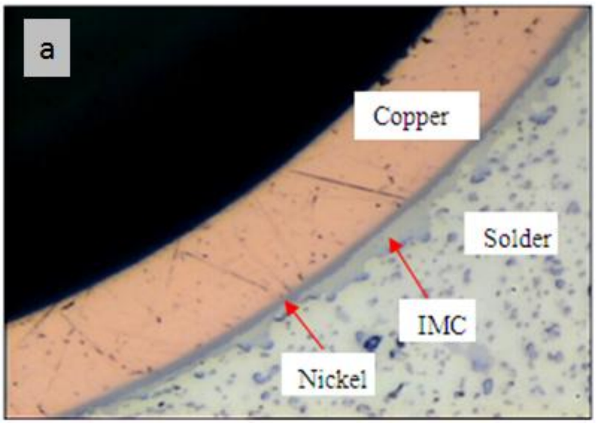

Fig. 3: (a) Mechanical cross-section image for polymer core solder ball with Ni at 504 hours of aging time.

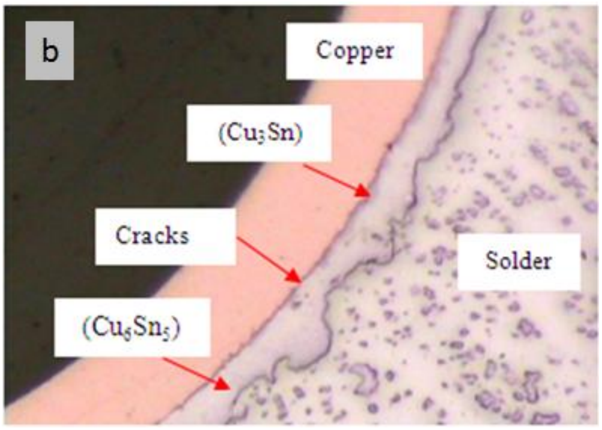

Fig. 3: (b) Mechanical cross-section image for polymer core solder ball without Ni at 504 hours of aging time.

Overall, it is proven that polymer core solder ball with Ni demonstrate higher joint strength and thinner IMC layer in multiple reflow and HTS stress tests than polymer core solder ball without Ni. The shear strength is much lower and IMC is much thicker when subjected to HTS stress conditions at 504 hours storage for the polymer core solder ball without Ni. This is most due to the crack formed in between the solder and Cu resulting from excessive Kirkendall voids formation, thus giving poor reliability performance.

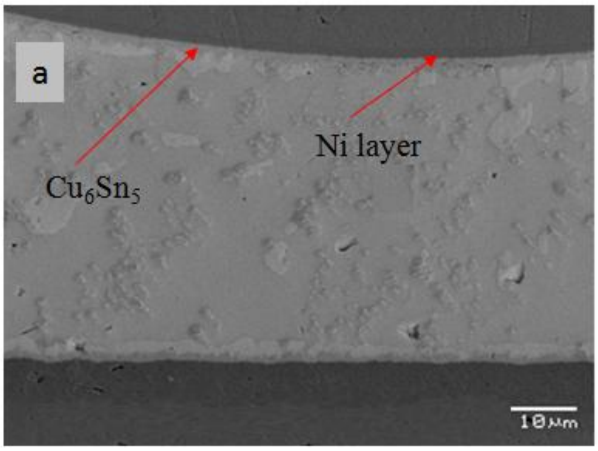

Fig. 4: (a) SEM image of polymer core solder ball with Ni at 504 hours of aging time.

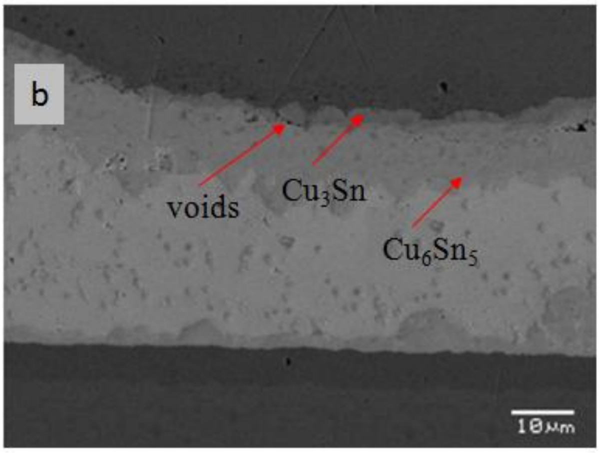

Fig. 4: (b) SEM image of polymer core solder ball without Ni (b) at 504 hours of aging time.

Conclusion:

From this research study, we can conclude that the polymer core solder ball with Ni demonstrate more superior performance in solder ball shear strength and thinner IMC layer in both the multiple reflow and HTS stress tests. It is observed that cracks formed at the sample of polymer core solder ball without Ni after 504 hours of aging at 150 °C was due to the excessive Kirkendall voids. This is due to the more rapid diffusion from Cu into Sn than Sn into Cu. 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.

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