Environmental Qualification of Dimpled Ball Grid Arrays for Space Flight Applications

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Abstract

As the demand for smaller and smaller Printed Wiring Boards (PWBs) increases, the need for smaller packages with high I/Os is growing significantly. Thus, the use of Ball Grid Array packages has become necessary for space flight applications. Jet Propulsion Laboratory/NASA technology and system development program that supports various spacecraft missions uses a 3U CompactPCI® form factor. The System Input/Output board requires a large amount of I/Os and has limited area, so the conventional packages, such as Quad Flat Packs will not fit. A 472 Dimpled Ball Grid Array (D-BGA) package was chosen for this application. Since this type of package has not been used in past space flight environments, it was necessary to determine the robustness and reliability of the solder joints. The D-BGA's were qualified by developing assembly, inspection and rework techniques as well as conducting environmental tests. The test article was a printed wiring assembly (PWA) consisting of four daisy chained D-BGA packages. Visual inspection of the outer solder joints and real time X-ray were used to verify solder quality prior to testing. The test article was electrically monitored for shorts and opens at or above 1 μs during all environmental tests. Three environmental tests were conducted: a) random vibration, b) pyroshock for 50 ms, and c) thermal cycling for 200 cycles. After testing, Scanning Electron Microscope (SEM) analysis was performed on various D-BGA cross sections to determine the quality of the package-to-board interface for reliability. The 472 D-BGA packages passed the above environmental tests within the specifications and are now qualified for use on space flight electronics.

Test Configuration

The test article (TA) consisted of a two-sided PWB with two to four 472 Dimpled BGA packages. Figure 1 shows the solder joint of a typical D-BGA. The D-BGA packages had Sn60/Pb40 solder balls. The PWB thickness was 0.080" with six layers of simulated ground planes. The test consisted of two different board materials, Polyimide (Polyimide-glass per IPC-4101/40) and Aramid (Aramid epoxy per IPC-4101/53) to see if the difference in board CTEs effected the reliability. The test PWAs were designed such that when the D-BGAs were attached, four daisy chains per package were formed (Figure 2). Dummy parts were placed on the backside of the PWA to simulate a double-sided assembly. A six slot flight-like Aluminum chassis, with a mounted CompactPCI® backplane, was used for the shock and vibration tests. There were five PWAs installed in the chassis, which included two PWAs with D-BGAs.

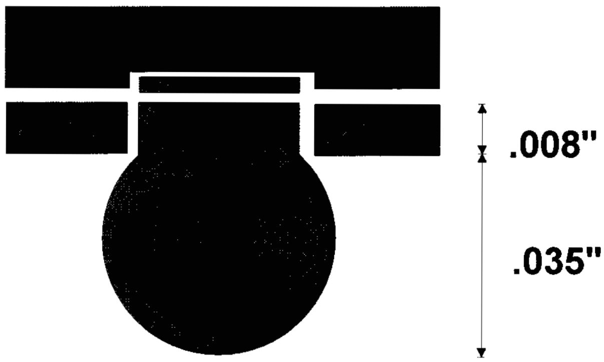

Figure 1. Solder joint on a Dimpled BGA

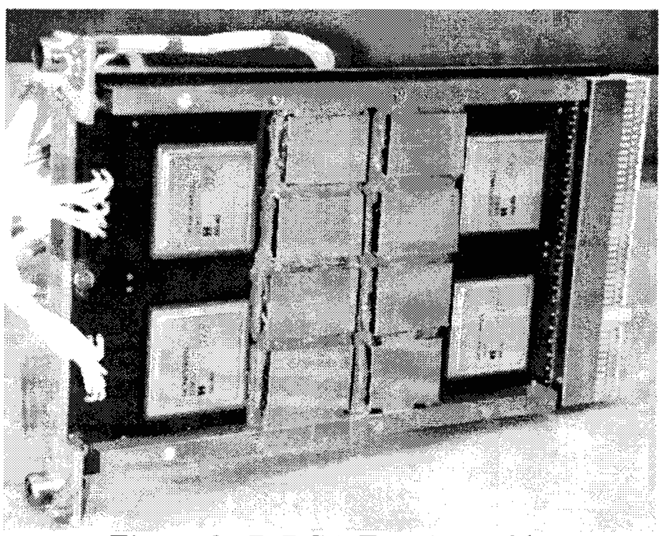

Figure 2. D-BGA Test Assembly

Assembly and Inspection

The D-BGA and PWB were tested for continuity(open and short test) prior to assembly to assure the integrity of the daisy chains. A coplanarity check was performed on the D-BGA parts with a maximum delta in the height of 0.004". The PWB was also tested for solderability. The PWBs were screen printed with Sn63/Pb37 solder paste and the D-BGAs were placed using the Airvac system. The assembled boards were then reflowed through the vapor phase oven. The assemblies were cleaned with semi-aqueous and aqueous chemistry prior to inspection.

The outer solder balls were visually inspected using both a conventional microscope and also an ERSAscope optical inspection system. Real time X-ray was also used to check for missing solder balls, shorts, voids, pad to ball alignment and reflow problems. A thermal profile was generated for a D-BGA removal operation using the Airvac system.

Environmental Tests

Electrical continuity tests were performed with a Fluke meter to assure integrity of all soldered connections before and after each test. All environmental tests were continuously monitored electrically for shorts and opens at or above 1 μs during testing.

The following profile was used for thermal cycling:

- Temperature High End: 100°C $\pm$ 2°C
- Temperature Low End: -55°C $\pm$ 2°C
- Dwell at maximum temperature: 1/2 hour minimum
- Dwell at minimum temperature: 1/2 hour minimum
- Transition rate (high-to-low and low-to-high): $\leq$ 5°C/minute

The PWAs for vibration and shock tests were subjected to three pyroshock pulses in each axis, to simulate launch conditions.

The development level random vibration test spectrum at 0.2 g^2/Hz was conducted first. The higher-level (severe) random vibration test spectrum at 0.4 g^2/Hz was conducted next. Low level sinusoidal survey tests were performed to assess the structural integrity of the PWA and to gain insight into the modal characteristics of the assembly. To minimize overtesting of the assembly, manual notching was imposed on the system at the natural resonance of the chassis during the Y-axis and Z-axis vibration test.

Test Results

- A PWA that was not exposed to any environmental tests was used as a control sample for cross sections. These cross sections showed minimal amounts of separation between the dimple and the package.

- After 150 thermal cycles, one of the two PWAs was cross-sectioned which revealed some signs of cracking or separation at the point where the solder ball and the solder mask meet at the PWB.

- The two thermal cycle PWAs were exposed to an additional 50 cycles, for a total of 200, with no intermittents. These cross-sections demonstrated the same condition as above with further propagation of the cracks. This phenomenon seems to be occurring at the solder ball and solder mask interface only. Further cross sections at the center of the ball did not show this condition.

- The board used for shock and vibration testing was also cross sectioned. The cross sections were conducted on three of the D-BGAs. The cross sections showed minor voiding at 500X that were likely caused by oxidation on the PWB pads during the fabrication process and slight cracks at the ball to pad interface due to the solder mask interference. There were no other anomalies noted.

Conclusions

A standard D-BGA part with Sn63/Pb37 solder, using JPL's SMT assembly process, survived the thermal and mechanical environmental requirements. The cross section data showed no signs of solder joint fatigue. The 472 Dimpled Ball Grid Array (D-BGA) package is now qualified for space flight use.

Acknowledgments

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