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PBGA packaging reliability assessments under random vibrations for space applications

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ABSTRACT

In this study, experimental and numerical analyses on the solder joint reliability of plastic ball grid array under harsh random vibration and thermal loadings were presented. The chips were assembled on the daisy chained circuit boards for the test samples preparation, and a half of the samples were processed for underfill to investigate the underfill effects on the solder failures. Two consequential steps of the random vibrations, named as acceptance level and qualification level, were applied. Overall required root mean square (rms) of the power spectrum densities of the steps were 22.48 grms for one minutes and 31.78 grms for two minutes, respectively. A thermal shock test was then performed after the vibration tests. It was found that the samples did not show any solder failure under the test requirements, demonstrating the robustness of the packaging structure for potential space applications. The samples were further tested to induce the failures, and finite element analyses were performed to analyze the sample vibration behaviors and the solder stresses to compare the results with the test data. Finally, a simple analytical calculation for the natural frequency estimations was introduced to overcome the complex finite element modeling efforts.

1. Introduction

The applications of Commercially-Off-The-Shelves (COTS) array packaging to harsh environmental conditions such as mobiles, automobiles, avionics and space microelectronics systems for cost effectiveness appear as new challenges to microelectronics reliability analyses [1–4]. Such applications particularly experience strong mechanical loadings such as vibrations and impacts, and the problems exhibit high complexity due to multiple involvements of mechanics and physics phenomena [5,6].

The electronics devices in the space applications on satellites are exposed to unique environmental conditions of vibrations during takeoff to target orbit, and sequentially thermal loadings during operations rotating around the earth. The extremely harsh random vibrations occur during the multiple stage operations of rocket right after the ignition for takeoff, typically three to five minutes of the powerful thrust to escape the earth gravity [7]. After the satellite arrives at the target orbit, the system is then exposed to thermal cycles while rotating around the earth. Apparently, the mechanical reliability of the satellite electronics is critical, as any failure of the device results in the total waste of the entire launching cost. Therefore, the packaging design in this area is very conservative and heavily dependent on old-fashioned heritage, and the structures are quite bulky and over-sized due to high safety factor.

The importance of the modern packaging technology applications to the space electronics exists on the fact that they can lead to the compactness of the devices which directly results in the weight reductions, therefore significant save of the launching cost by decreasing the payload. In the actual applications, due to peculiar environments of the space, there are many technical verification processes for the functional safety. Among them, we considered the mechanical reliability assessments as an important engineering issue, and those are the main goals of this study.

Obviously, the reliability researches on the satellite electronics under vibrations have been performed for decades. However, the results were rarely reported in public and remained as proprietary by the satellite manufacturers until open sources were found to be relatively recent literature forms. Up to date, without particular referring to the space application, the literatures represented the mechanical reliability under the vibrations of either sinusoidal or random types. For example, Che and Pang [8] conducted the constant G-level and varying G-level sinusoidal vibration tests for FCOB assembly, and the maximum G level was 10. Dasgupta

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et al. [9] used a sinusoidal vibrations increasing from 0.1 g^2/Hz to 0.4 g^2/Hz for the durability tests. Yang et al. [10] also employed a sinusoidal vibration excitement to find the first failure of the PBGA assemblies experimentally. On the other hand, Yu et al. [11] considered random vibration loading of PSD with 0.15 g^2/Hz and 0.25 g^2/Hz over a frequency range of 40 and 1000 Hz. Wu [12] and Li [13] presented the finite element modeling for the solder fatigue prediction under the random vibration of 0.55 g^2/Hz, and the frequency range of 50–2000 Hz with 12 root mean square acceleration (grms), respectively. Some studies combined the sinusoidal and random vibration [14], or additionally combined the thermal loadings [15,16]. The packaging structure adopted for the tests in the previous literatures were mostly plastic ball grid array (PBGA), presumably due to the fact that the package is one of the most common types in the commercial market. However, all the strength level of the vibrations in the previous works were not strong enough to simulate the actual random vibration occurred during the rocket launching.

The purpose of this study is to assess the feasibility of the PBGA packaging in much higher level of the random vibration than the previously reported ones for the satellite electronics devices applications. Test specimens were fabricated with PBGA chips to prepare the second level package samples. A half of the PBGA chips were processed for the underfill application to investigate its effects. Then, the specimens were undergone severe random vibrations with two different levels of 22.48 grms for one minute, and 31.78 grms for two minutes. Then, the samples were tested in the thermal shocks to simulate the thermal loads. The test requirements are generally accepted to access the electronics device reliability for about 1000 kg weight of low orbit observation satellite. During the entire tests, in-situ monitoring of the solder connectivity was carried out to detect the failures. To study the mechanism of the stress developments, finite element methods were used to simulate the stresses and strains. The results were compared with the experimental data to define the failure mechanism. The most influential mode under the vibration to the solder failure was at the first natural frequency. An analytical model using a rule of mixture was also introduced for simple calculations of the natural frequencies to avoid the complex numerical modeling process.

2. Sample preparations

Fig. 1 shows the PBGA chips mounted on the printed circuit board. The PBGA size was 8 mm by 8 mm, and the number of the solders was 64, the pitch size of which was 810 μm. The diameter of the Sn/Pb (63/37) eutectic solder was 450 μm. A dummy silicon chip was embedded in the molding compound, and daisy chained BT substrate was attached under the chip. The PBGA chips were attached by a reflow process on the PCB board surface. The final dimensions of the specimen are also included in Fig. 1. The pad surfaces of the PBGA and the PCB were treated by ENIG (Electroless Nickel Immersion Gold) and OSP (Organic Solderability Preservative) processes, respectively. Eight specimens with five PBGA's were prepared, and the half of them was processed for the underfill applications. Same numbers were also prepared for the samples with three PBGA's. Finally, the structural integrities were verified by X-ray inspections and the resistance measurements.

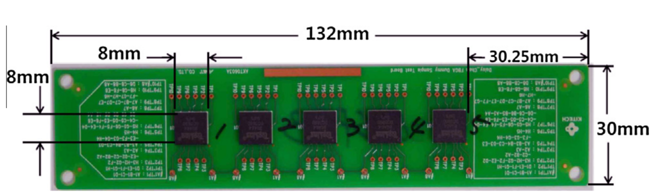

Fig. 1. The configuration of the test coupon, its dimensions and chip numbers.

3. Random vibration tests

3.1. Test conditions

The test conditions employed in this study was composed of two steps of acceptance level and qualification level. Fig. 2 illustrates the power spectrum densities (PSD) of the vibration levels based on the data in Table 1. Basically, the acceptance level was for the inspection of any defaults of the jig and the specimens prior to the qualification level. The qualification level was designed to increase by adding 3 dB to the acceptance level. In this study, 0.35 g^2/Hz and 0.7 g^2/Hz as the acceleration levels, and the overall PSD of 22.48 grms and 31.78 grms were employed, respectively. Comparing with the previous works of 12 grms [12] or 0.4 g^2/Hz [9,12], the test conditions in this study were unprecedentedly harsh. The time consumed for each level was 1 min and 2 min, respectively.

3.2. Boundary conditions

The specimens were fixed using two boundary conditions. The first condition implied the specimens were clamped at the ends. The location of the edge clamp was extended by 8 mm from the edges of the specimen. For the second condition, using the holes at the corners as seen in Fig. 1, the specimens were fixed tightly by screws through the holes in the PCB. Both boundary conditions are demonstrated in Fig. 3. To apply the conditions, a special jig was manufactured, which is also shown in Fig. 3.

3.3. Specimen installation

For in-situ monitoring of the resistance variations during the tests, wires were connected to the daisy chains of the samples. Total 16 PBGA were chosen for the various case measurements of the chip locations, the underfill applications and the boundary conditions. Table 2 summarizes the sample status, explaining the meanings of the numbers in it. Fig. 4 shows the entire test configuration of the aluminum block on top of the shaker, where the specimen fixture jig and the data acquisition lines for the daisy chain resistance measurements were installed. The tests were started first in the x direction, followed by the y and z directions (see Fig. 3) at each level for each boundary condition by attaching the jig at the side surfaces (x and y directions), and the top (z direction) of the aluminum block. To monitor the vibration behaviors, two accelerometers were attached as shown in Fig. 4(b) on the center chip surface (location 3 in Fig. 1) of the specimen fixed by the holes, and the surface of the aluminum block.

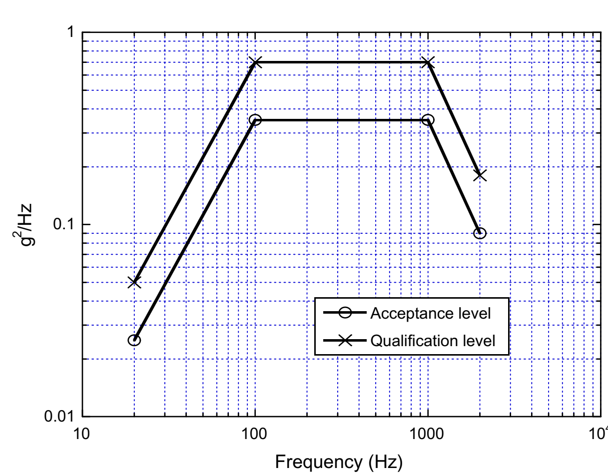

Fig. 2. Power density spectrums of the random vibrations.

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