EFFECTIVE APPROACH TO ENHANCE THE SHOCK PERFORMANCE OF ULTRA-LARGE BGA COMPONENTS

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ABSTRACT

Ultra-large Ball Grid Array (BGA) components with a package size that is equal or greater than 70mm have been adopted in today's high-end network products driven by the explosive demands for faster speed and higher bandwidth. At the same time, larger and/or heavier heat sinks (HS) are required to achieve better thermal management. It becomes more challenging than ever to maintain interconnect integrity under mechanical shock environment.

Metal standoffs are typically used as the supports of Print Circuit Board Assembly (PCBA) to the sheet metal chassis. The metal standoffs provide the necessary mechanical support, special clearance, and ground connection for the PCBA. Due to the increasing BGA body size and HS weight, it is necessary to explore means to control the strain level on BGA corners to lower the risk of interconnect failures in manufacturing, shipping, and field. This study investigates the potential for using rubber anti-vibration standoffs to replace metal standoffs as an effective mitigation for enhancing the shock performance of ultra-large BGA components. The rubber materials are well-known for their excellent shock absorption characteristics. The rubber standoffs is sandwiched two metal pieces (female and male end). The two metal ends serve the same functions as regular the metal standoffs to bolt PCBAs onto sheet metal chassis but the rubber portion effectively decouple the two metal ends and dampen the shock wave passing through it therefore significantly reducing the strain level on the PCBA.

To vet the effectiveness of the approach, shock testing has been performed both at a component and product level. The test results showed 2x improvement in terms of the failure strain for a 75mm BGA mounted on a JEDEC standard test board to allow in-situ continuity monitoring during shock testing. There was an 8% to 42% improvement in terms of BGA corner strains in system level shock with a product that has multiple large BGA components.

Finite Element Analysis (FEA) modeling has been developed that captures well the effect of rubber standoffs. The validated modeling can be helpful to guide the design parameters and optimization of the rubber standoffs based on the specific system architecture such as the component location, HS attachment, and the corresponding product end-use conditions.

Key word: shock mitigation, shock testing, solder joint reliability, mechanical reliability, product level shock

INTRODUCTION

Due to the demand for higher speed and wider bandwidth, the network ASICs BGA components have been growing both in terms of package body size and power consumption on chip, which, combined with the need for new thermal management approaches, makes BGA interconnects more susceptible to failure due to shock and/or vibrational environment. Heat Sink (HS) attachment has a significant impact on the strain levels near BGA components [1]. It is important to consider interconnect mechanical reliability during product design phase, but mitigations may still be required as some interactions of subsystems may not possibly be captured in the design phase due to the complexity of network equipment.

There are effective mitigations such as edge bonding technology that have been developed and demonstrated [2]. The tradeoffs of those solutions could be the increase of production cost, more complex processibility, and the potential impact of long-term reliability concerns. In some occasions, drop-in mitigations without design modification and/or process deviation are preferred especially when the products are marginally passing the qualification, but there is a need to improve the reliability margin to prevent potential issues induced during shipping and/or installation.
Metal standoffs are typically used as the supports of Print Circuit Board Assembly (PCBA) to the sheet metal chassis (Figure 1). The metal standoffs provide the necessary mechanical support, spatial clearance, and ground connection for the PCBA. The lack of damping of metals make them poor shock isolation materials. On the other hand, rubber materials are well-known for their excellent shock absorption characteristics. Rubber materials have widely been used in industry as excellent shock and vibration isolation materials. Recently the rubber standoffs have been gaining their popularity as a way to isolate the controller PCB on drones from the vibration source. The typical anti-vibration rubber standoffs (Figure 2) use rubber material to hold together two-separated metal pieces (female and male end). The two metal ends serve the same function as regular metal standoffs to bolt PCBAs onto sheet metal chassis, but the rubber portion effectively decouples the two metal ends and dampen the shock wave passing through it which could significantly reduce the strain level on the PCBA.

Figure 1. Typical metal standoffs used for PCBA assemblies

Figure 2. Rubber standoffs with excellent flexibility

In this paper, a systematic study on the rubber standoffs and gaskets have been performed. The effectiveness of rubber standoffs and rubber gaskets as shock/vibration mitigation have been evaluated with both component TVs and a real product. The transmissibility of TVs under different mounting conditions serve as a good indicator for material selection. On component TV, the rubber standoffs can significantly reduce the strain level at BGA corners by up to 50%. While on product level, the percentage of strain reduction varies from 8% to 42% due to the complexity of the system tested. While the results of this paper are useful in development of guidelines for enhancing product shock/vibration performance, further study would be needed to develop the optimized solutions.

Test vehicle and testing setup

The test vehicle (TV) uses a 75mm daisy-chained FCBGA mounted onto a 125mil thick PCB. The PCB design follows JEDEC standard. The assembled TVs were mounted to a half-inch thick aluminum plate through four standoffs. The typical test setup is shown in Figure 3.

Four strain gauges are attached 5mm away from the corners of BGA component to allow in situ monitoring of the strain level during shock testing (Figure 4). The TV with different supporting conditions were then subjected to 100G shock (2ms half sine wave).

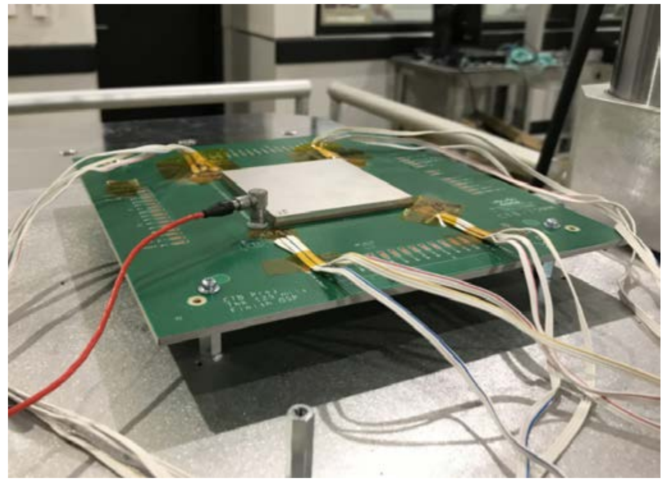


Figure 3. TV test setup

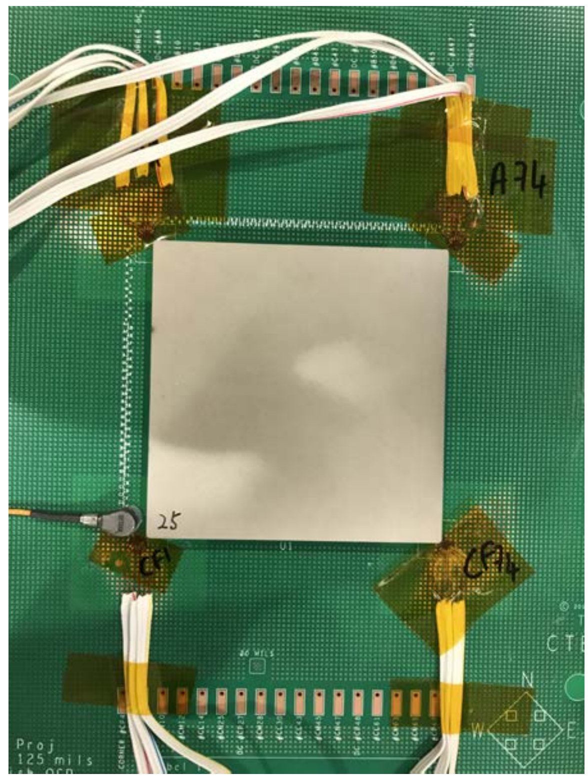


Figure 4. Strain gauge and accelerometer location placement

BOARD MOUNTING CONDITIONS

Rubber standoffs or rubber gaskets have been used in order to tune the TV mounting conditions as shown in Figure 5. To vet the effectiveness of the solution, three types of rubber gaskets were chosen based on their hardness (in Shore A scale). Two kinds of off-the-shelf rubber standoffs, made with different hardness rubber, have been selected based on the compatibility of screw thread and size. Table 1 shows the properties of rubber gaskets and standoffs.

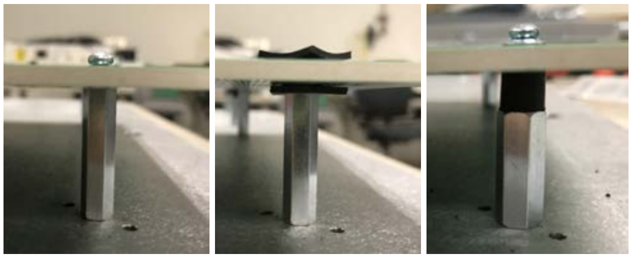


Figure 5. Various mounting conditions (left to right): metal standoff, gasket, and rubber standoff

TRANSMISSIBILITY CHARACTERIZATION

One of the key parameters to characterize the shock isolation properties is the transmissibility, which is defined as the ratio of output to input.

Typically the transmissibility is expressed in the frequency domain as:

$$T(\omega) = \frac{\ddot{x}_o(\omega)}{\ddot{x}_i(\omega)}$$

For our purpose, the transmissibility could be simply considered as the ratio of response acceleration to the input acceleration:

$$\mathrm{T(t)} = \frac{\mathrm{G_{response}}}{\mathrm{G_{input}}}$$

Where Ginput is input acceleration of the shock table; and Gresponse is the acceleration measured on the TV at the location of interest.

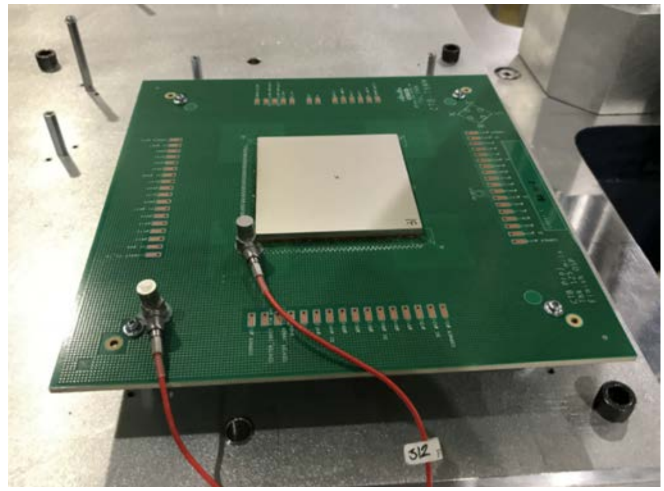
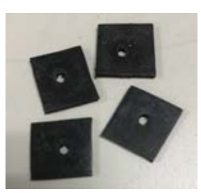


Figure 6. Transmissibility characterization setup

Table 1. Properties of rubber gaskets and standoff

Supporting condition	Material		Description	Rubber thickness, mm	Hardness
standoff	metal		regular hex aluminum standoff	n/a	n/a
	rubber		Type A 5.8mm diameter 7mm height	7 (nominal)	A50
			Type B 8mm diameter, 8mm height	8 (nominal)	A70
gasket	rubber		hard	1.5	A30
				3	
			medium	1.5	A50
				3	
			soft	1.5	A70
				3	

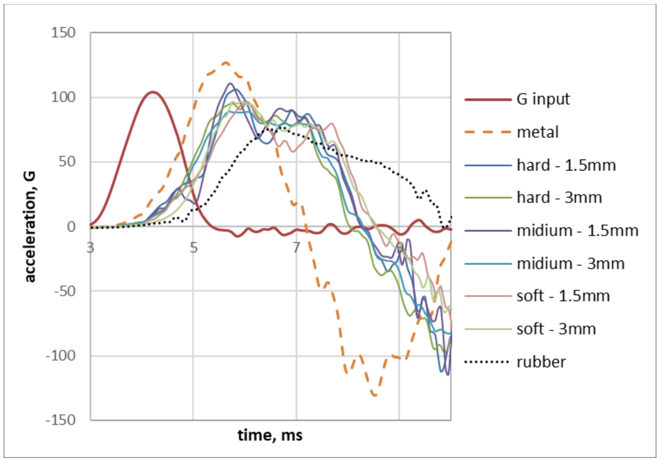


Figure 7. Input and response accelerations

As shown in Figure 6, two accelerometers have been mounted on the TV: one was placed near a corner of BGA component to measure the response acceleration level the critical joints experience during shock testing; the other was placed near a screw that fastened the standoff to the board to capture the dampening contribution from different supporting conditions.

Figure 7 shows the typical input vs response near BGA corner over time under different supporting conditions, which clearly shows metal and rubber standoffs representing the upper and lower bounds of the magnitude for acceleration responses.

The G ratios near the fixture screw, as seen in Figure 8, showed that rubber standoffs, not the gaskets, are much more effective in decoupling the TV from the shock sources. One of the reasons was that it was difficult to control the tightness of the screws when using rubber gaskets. Due to a difference in hardness of gaskets, it is difficult to tighten screws with a pre-set torque. In an effort to achieve consistent results, the screw tightness was controlled by a combination of the depth of screw hole of standoffs and the length of screws—metal standoffs with 11mm screw depth and different length screws (M3x16mm for 1.5mm thick gaskets and M3x18mm for 3mm thick gaskets).

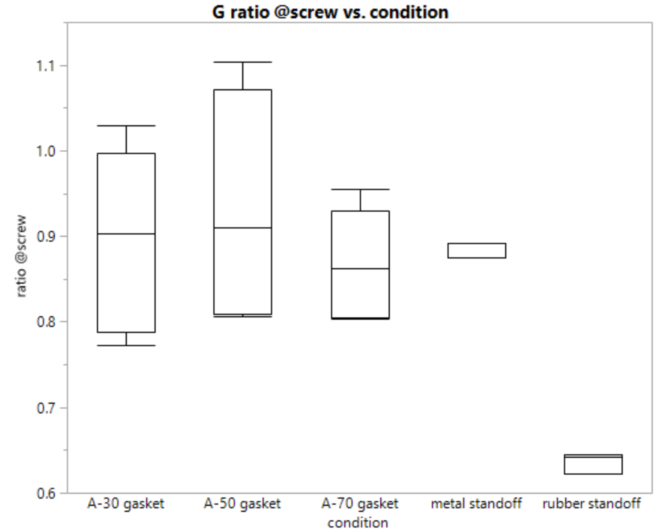


Figure 8. G ratios near fixture screw at PCB corners

The transmissibility T(t) was estimated using the ratio between the response acceleration near BGA and input G, which can be considered as the correlation of the G level at the critical solder joints to the input G. Table 2 shows the transmissibility based on the ratio of response and input G for different fixture conditions. The transmissibility is useful for material down selection and determining the proper damping factors to use in shock modeling.

Table 2. Transmissibility of different board mounting conditions

Conditions	Rubber thickness, mm	Transmissibility	
		Mean	Standard deviation
metal standoff	n/a	1.306	0.074
gasket (hard - A70)	1.5	1.034	0.127
	3	0.971	0.028
gasket (medium - A50)	1.5	0.972	0.052
	3	0.963	0.030
gasket (soft - A30)	1.5	0.956	0.004
	3	0.899	0.017
Type A rubber standoff	7 (nominal)	0.614	0.016
Type B rubber standoff	8 (nominal)	0.718	0.017

STRAIN RESULTS OF TV SHOCK TESTING

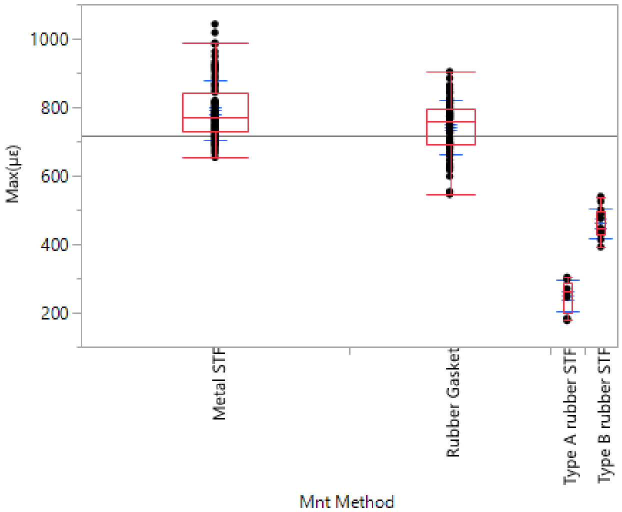


Figure 9. Maximum principal strain at BGA corner under different mounting method

Figure 9 shows the maximum principal strains at BGA corner under different mounting conditions. There are several findings based on the results:

1. Rubber gaskets in general are not effective in terms of shock mitigation. In general, soft rubber materials provide better dampening or isolation in terms of transmissibility, but it does not seem to scale with regards to the reduction of BGA corner strain levels;
2. Rubber gaskets may still be viable and useful mitigations especially in cases where there is not enough clearance between PCBA and chassis to implement rubber standoffs, but further study would be required as the effectiveness of this approach is sensitive to how the gaskets are being installed;
3. Rubber standoffs are effective as they decouple the PCB from the shock source. The softer the rubber, the more effective the mitigation. The drawback of soft rubber standoffs is that they might not be mechanically sturdy enough to support large and heavy PCBAs;
4. The strain level reduction is critical to improve the mechanical reliability safety margin. In our study, the critical joint of a 75mm FCBGA typically failed at 100G shock level. With type A rubber standoffs, the same joint failed at 199G shock level.

PRODUCT LEVEL SHOCK TESTING

To further investigate the effectiveness of rubber standoffs as shock mitigation on an actual product, a system-level drop test was performed. The system was chosen because it utilized standoffs fastened to the chassis from under the PCBA without connection to the front panel as most other system do. The system was mounted, as shown in Figure 10 and Figure 11, on a shock table, and shocked with the same 100G condition that was applied to component TVs. Type A rubber standoffs (Figure 12) were used in the testing due to their compatibility to the existing standoffs of the system and better transmissibility.

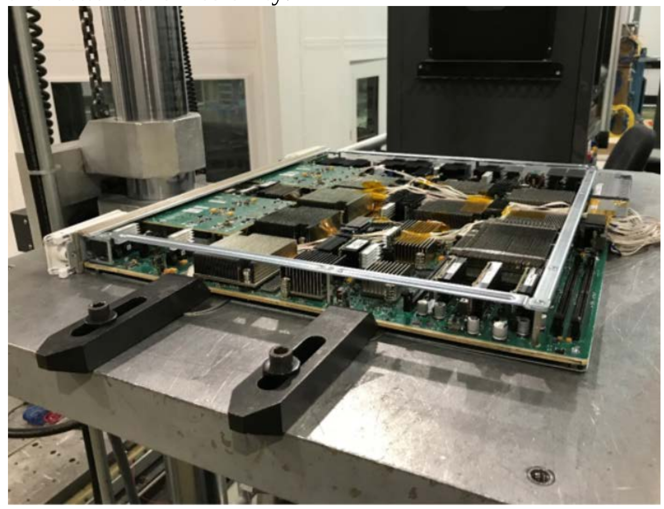


Figure 10. Product-level shock test setup

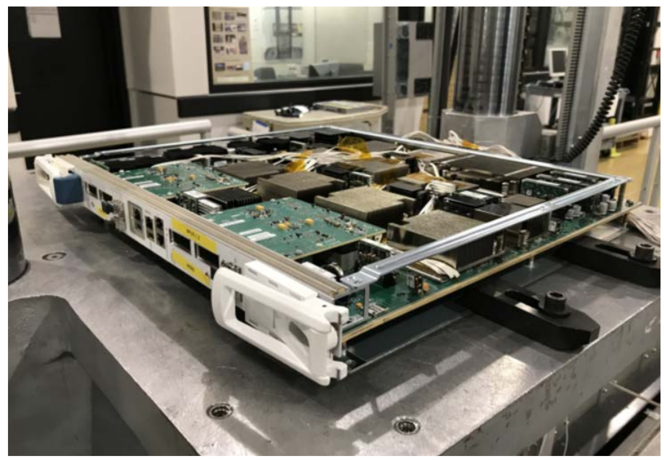


Figure 11. System tested with rubber standoffs

Figure 12. Metal vs rubber standoff

There are multiple ASIC BGA components in the system with different HS designs and attachment methodologies. Strain gauges have been placed at some corners of three components to monitor the strain levels during testing (shown in Figure 13). Figure 14 shows the maximum strains at BGA component corners under shock. With type A rubber standoffs, there were 8% to 42% reduction in terms of strain level observed. The vast variation of strain reduction may be due to many factors such as the HS size and attachment (as shown in Figure 16 and Figure 16), the distance to the standoffs on which the shock wave transferred from the shock table to the PCBA, and even the location of BGAs, etc.

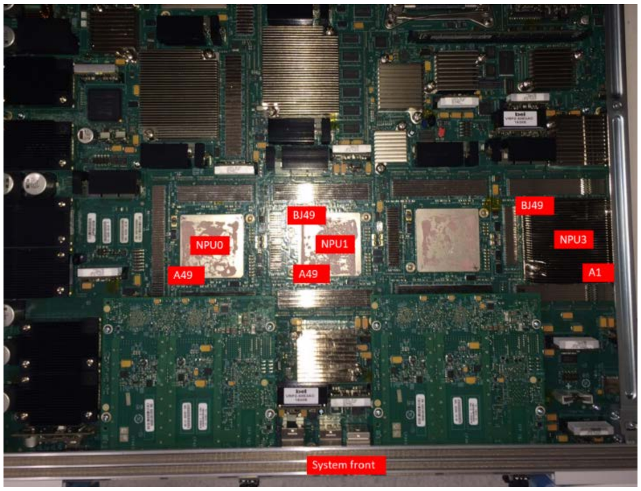


Figure 13. Strain gauge locations

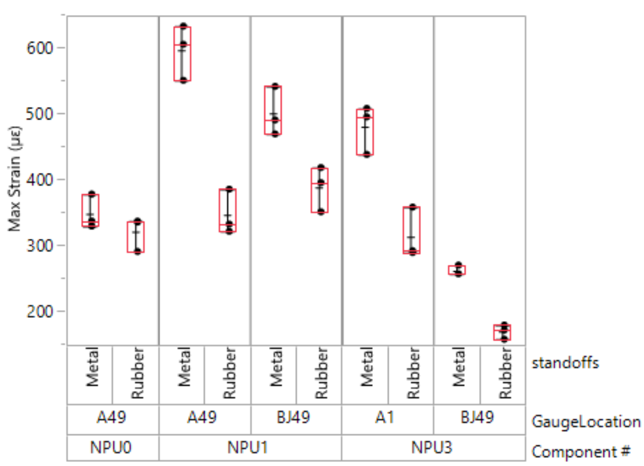


Figure 14. Max principal strains at BGA corners with and without rubber standoffs

Figure 15. Heat sinks mounted on BAG components

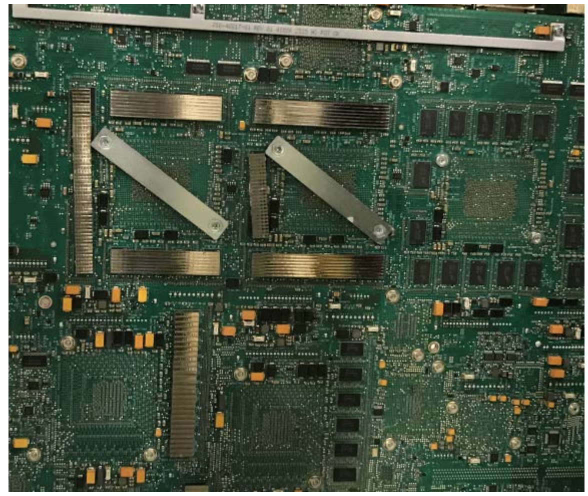


Figure 16. Heat sink attaching methods

CONCLUSIONS

A systematic study of the effectiveness of rubber gasket and rubber standoff as a shock mitigation to ultra-large network BGA components has been performed. The results showed variant percentage of improvement in terms of BGA corner strain level at product level testing. Combined with a proper choice of heat sink attachment, rubber standoffs and/or rubber gaskets could potentially reduce the strain level and improve mechanical reliability to meet the requirements in end-use environment.

Even the component-only TV demonstrated a significant reduction, up to 50%, of strain level at BGA corner joints. Rubber standoffs can be an effective solution for shock mitigation, but there are other operations challenges to be considered.

REFERENCES

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[2] S. Perng, etc, “Enhancing mechanical shock performance using edgebond technology,” SMTAi 2013.