Simulation and Experimental Study on Edge Bonding Shape for Reliable BGA Packages


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Abstract

In order to ensure thermal reliability including temperature cycling, semiconductor chips and packages mounted on a BGA substrate need a reinforced structure with adhesive resin. In this study, the relationship between reliability and the applied shape of the edge bond (EB) material was verified based on thermal stress simulation and actual experimental results. In consequence, the test vehicle with the cross-sectional area of 0.62 mm² showed higher reliability than the one of 1.04 mm², and maintained the electrical continuity over 3100 cycles. This result showed that there was an optimal cross-sectional area of EB material to obtain high reliability.

Key words

Edge bond material, Thermal stress simulation, Reliable, BGA Packages

I. Introduction

In the packaging of electronic components, the reliability of solder joints is one of the most critical concerns. As the electronic devices become smaller, thinner and more sophisticated, the electronic packages are also required to be smaller and more integrated, and the demand for fine pitch BGAs is inevitably increasing. In fine pitch BGAs, the solder bumps are becoming smaller and smaller, and there are concerns about the reliability of joints of the miniaturized solder bumps under mechanical and thermal loads [1], [2].

In order to ensure thermal reliability including temperature cycling, semiconductor chips and packages mounted on a BGA substrate need a reinforced structure with adhesive resin. Two ways of the reinforcement methods are well known, one is underfill (UF) and the other is edge bond (EB), also called side fill or corner bond.

UF method is widely used to fill the space around solder bumps and the gap between bottom of chips and substrate. Although UF secures high reliability of solder joint fatigue life, it requires somehow complicated penetrating process. In addition, it is generally difficult to accommodate easy rework process after filling.

On the other hand, EB is an attractive method in terms of mass production because it can reduce dispensing time about one tenth compared to UF method as well as the amount of material [3]. Furthermore, EB has an advantage for the application in RF modules because there is no material under the chip, thus no concern is needed about the effect on transmission loss [4], [5].

In this study, highly reliable EB shape, i.e., the effectual cross-sectional area was investigated by conducting thermal stress simulation and experimental evaluation.

II. EXPERIMENTAL METHOD

Simulation Method

Strain around the solder joint was calculated by FEM program MARC2021 provided by MSC Software. It was inefficient to calculate the whole package with the small size mesh, a zooming method was applied to reduce the total calculation load by preparing respective models of a global package and a local solder connected area as shown in Figure 1. The simulation steps were as follows. Firstly, the roughly meshed global model was established and calculated. From the calculation results of the global model, it was found that the maximum strain was applied around the chip corner, and the local model of solder-connected area was established with fine mesh. Then, the displacements obtained from the global model were input to the local model, and finally, the maximum amount of the strain around the solder bumps was calculated.

In the simulation, the silicon and copper were regarded as elasticity materials, and solder were deemed as an elastic-
plasticity material. Other materials were modeled as viscoelasticity solids.

Global model

Die size 6 mm x 6 mm
Die thick. 743 μm

PCB size 30 mm x 30 mm
PCB thick. 975 μm
Core thick. 800 μm

Local model

Si 725 μm

Solder pitch 400 μm
/ height 184 μm
/ Max 270 μm

SR on Cu 18 μm
Cu 15 μm
Buildup layer on Cu 33 μm
Cu 20 μm

The temperature condition for the simulation was set as shown in Figure 2. The stress-free temperature was set at 220°C, where the solder melts. The bottom and top temperatures of the thermal cycle were set at -55 and 125°C, respectively. The time of temperature rise and fall was 2 min and the holding time at each temperature was 13 min. Total equivalent plastic strain, which was a key factor to predict a life of solder joint, was calculated by repeating and accumulating 11 cycles simulation.

A. Material properties

Table 1 shows material properties used in the simulation. Elastic modulus was evaluated with dynamic mechanical analysis (DMA). Glass transition temperature (Tg) and coefficient of thermal expansion (CTE) are measured by thermo-mechanical analysis (TMA).

<table>
<thead>
<tr>
<th>Material</th>
<th>DMA</th>
<th>TMA</th>
<th>Poisson's ratio (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elastic modulus</td>
<td>CTE T&lt;sub&gt;g&lt;/sub&gt;</td>
<td>CTE T&gt;g</td>
</tr>
<tr>
<td></td>
<td>at R.T.(GPa)</td>
<td>(&lt;10&lt;sup&gt;6&lt;/sup&gt;/°C)</td>
<td>(&lt;10&lt;sup&gt;6&lt;/sup&gt;/°C)</td>
</tr>
<tr>
<td>Si</td>
<td>167</td>
<td>3.20</td>
<td>-</td>
</tr>
<tr>
<td>PBO</td>
<td>2.55</td>
<td>64.8</td>
<td>-</td>
</tr>
<tr>
<td>Cu</td>
<td>100</td>
<td>17.0</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>4.15</td>
<td>65.9</td>
<td>178</td>
</tr>
<tr>
<td>SAC&lt;sup&gt;1&lt;/sup&gt;</td>
<td>37.4</td>
<td>21.7</td>
<td>-</td>
</tr>
<tr>
<td>(Solder)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core</td>
<td>29.0</td>
<td>14.5</td>
<td>12.8</td>
</tr>
<tr>
<td>SR</td>
<td>3.90</td>
<td>30.0</td>
<td>95.0</td>
</tr>
<tr>
<td>Buildup</td>
<td>8.13</td>
<td>46.0</td>
<td>120</td>
</tr>
<tr>
<td>EB</td>
<td>10.9</td>
<td>19.0</td>
<td>71.0</td>
</tr>
</tbody>
</table>

1) Yield stress was 29.0 MPa at -40°C and 12.6 MPa at 130°C
B. Assembly process of Test Vehicle

The Specification of the test vehicle (TV) is shown in Figure 3. The TV had a daisy-chain between the die and PCB to check the electric continuity, and assembled by the following process.

(a) Temporary Bonding of the silicon die

The silicon die with solder bumps was placed on the PCB using a flip chip bonder. At that time, a fluxing agent was applied to the solder bumps to obtain assured connectivity in the reflow process mentioned later.

(b) Solder joint

The reflow equipment was used to melt the solder and joint the die to the PCB permanently. The reflow profile is shown in Figure 4.

(c) Flux agent cleaning

To remove the remaining flux agent, the TV was cleaned with an aqueous flux cleaner.

(d) Dispense of EB material

EB material was dispensed along the all-around peripheral edge of the die using an air-pulse type dispenser.

(e) Curing of EB material

The TV was heated on a hot plate at 120°C for 15 min. Note that the TV without EB was prepared with the steps from (a) to (c).

Figure 5 shows the EB shape around the die, and Figure 6 displays the cross-sectional images of the EB portion. The cross-sectional area was controlled by dispensing condition.

C. Test Vehicle for reliability evaluation

The change in the electrical resistance of the daisy chain during the temperature cycle test (-55°C to 125°C, held for 15 min at each temperature) was monitored at every 100 cycles. In this work, the TV that exceeded 20% of the initial resistance was counted as a failure piece.

III. Results and Discussion

Generally, the size mismatch and different physical properties between the die and PCB cause shear strain in the solder bumps. In the case of our simulation model without EB, the largest cumulative solder strain was generated at the corner of the die as shown in Figure 7. Figure 8 shows the cross-sectional pictures of actual solder bump after 700 cycles TCT. In Figure 8, (A), (B) and (C) represent location of the solder bump in Figure 7. As we can see, the large crack was observed in the solder bump at the corner (Figure 8 (A)), and this caused disconnection. On the other hand, no crack was observed in the solder bump in the middle area (Figure 8 (C)). The solder bump on the outer edge (Figure 8 (B)) maintained connectivity, but a small crack was found. From these results, we confirmed that the simulation was well accorded with the actual experiment, and proceeded to the next step, investigating relationship between EB shape and its effect on the reliability.

Figure 9 shows the simulation result of the relationship between cross-sectional area of the EB and total equivalent plastic strain of solder bump. The result revealed that there was an optimum area of EB that can reduce the strain, and this consideration would lead to the high reliability.

To verify the above consideration with actual measurements, the TVs that have different cross-sectional area (including without EB) were put into the TCT. The

Figure 4. Reflow condition.
result was shown in Figure 10. The TVs with EB showed higher reliability while all the three coupons without EB failed in less than 700 cycles. Especially, TV with EB area of 0.62 mm² showed prominent result over 3100 cycles, and this result was better than EB area of 1.04 mm² as we expected.

![Figure 7. Simulation result of solder bumps strain.](image)

Figure 7. Simulation result of solder bumps strain.

![Figure 8. Cross-section of solder bumps and the results of continuity test after TCT. (A), (B) and (C) mean the position of the solder bump in Figure 7.](image)

Figure 8. Cross-section of solder bumps and the results of continuity test after TCT. (A), (B) and (C) mean the position of the solder bump in Figure 7.

![Figure 9. Simulation result of the relationship between the cross-sectional area of EB and the amount of strain of the solder at the die corner.](image)

Figure 9. Simulation result of the relationship between the cross-sectional area of EB and the amount of strain of the solder at the die corner.

![Figure 10. Relationship between the cross-sectional area of EB and result of TCT. Each of the three coupons with different cross-sectional areas was put into the TCT.](image)

Figure 10. Relationship between the cross-sectional area of EB and result of TCT. Each of the three coupons with different cross-sectional areas was put into the TCT.

IV. Conclusion

In this study, we presented the relationship between the cross-sectional area of EB and thermal cycle reliability, and showed that there was an optimum value of cross-sectional area. The TV with the EB area of 0.62 mm² showed excellent reliability over 3100 cycles.

References


