Bias-HAST on tape ball grid array (TBGA) test pattern

N.H. Yeung a, Victor Lau b, Y.C. Chan a,*

a Department of Electronic Engineering, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kong
b Compass Technology Company Limited, Suite 10, 5th Floor, Chiaphua Centre, New Territories, Hong Kong

Received 14 April 2003; received in revised form 27 August 2003

Abstract

Tape ball grid array (TBGA) rather than the traditional BGA, can provide a more flexible, light weight and fine pitch interconnection method to the electronic industry. In this study, two different designs of TBGA, buss-out and buss-in, were used throughout this investigation. Moreover, for those samples were then further sub-divided, one with hot deionized (DI) rinsing after solder resist development and gold plating; while the other matrix samples, no hot DI rinsing were applied. It was found that metallic elements were found after 168 h of Highly Accelerated Stress Testing (HAST). Moreover, result from the cross-section indicated that crack was found in the solder resist and both white and bronze powdery were found. With further elementary analysis of those different colors of powdery, tin and lead in white powdery were found, while tin, lead and copper were found in the bronze powdery. The tin, lead and copper dendrite then will cause short circuit of the package.

2003 Elsevier Ltd. All rights reserved.

1. Introduction

Ball grid array (BGA) is being the most frequently accepted and used package for the advanced micro-electronic interconnection technology. BGA is an area interconnection method in which large complexity and number I/O terminals can exist in one package because the solder bumps are configured at the bottom instead of around the perimeter [1,2]. Tape ball grid array (TBGA) can provide very thin packaging and also it can improve package thermal performance since the chip is attached at the back of the heatsink.

For the TBGA test pattern, two different test patterns were designed; (i) buss-out design (Fig. 1); and (ii) buss-in design (Fig. 2). Those bussing line is for nickel/gold plating purpose and will then be cut off leaving the circuitry open. For these two different designs, they were further divided into two different process conditions, one with hot deionized (DI) rinsing after solder resist development and gold plating; while the other matrix samples, no hot DI rinsing were applied. The temperature and the rinsing time for the hot DI were controlled by 50–60 °C and around 2 min respectively. Moreover, the resistivity of this hot DI is 13 mΩ only. In this study, HAST is used as an accelerated life test (ALT) in which typically consists of elevated temperature, pressure and humidity (121 °C, 2 atm, 85% RH) and a bias voltage.

It is believed that bias, operating time and polar liquid such as water to form an electrolyte are the basic conditions for the electrochemical migration (EMC) [3]. There are numerous reports that have been published dendrite growth and its failure mechanism in different electronic devices and packages [4–8]. Similar to those electronic packages, TBGA is no exception on this issue and it is the main scope of this study.

2. Test matrix

As mentioned, there are totally two different kinds of design, buss-out and buss-in. Table 1 shows the materials and their thicknesses while Fig. 3 indicates
schematic diagram of the TBGA test pattern. Table 2 indicates the details of the test sample used in this investigation. For samples no. A and B, they were carried out normal process, while for the samples no. C and D, they were carried out additional hot DI rinsing after solder resist development. Table 3 reveals the further sub-divided samples for the bias-HAST test pattern. The suffix 1 and 2 imply the TBGA with and without solder ball attached respectively. It should be mentioned that all the test samples were carried out one time of reflow process at peak temperature, 230 °C no matter with or without solder ball attached.

Table 1

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyimide</td>
<td>75</td>
</tr>
<tr>
<td>Adhesive</td>
<td>15</td>
</tr>
<tr>
<td>Copper trace</td>
<td>35</td>
</tr>
<tr>
<td>Nickel</td>
<td>5</td>
</tr>
<tr>
<td>Gold</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig. 1. Buss-out design of TBGA.

Fig. 2. Buss-in design of TBGA.
3. Experimental setup

One of the aims in the design of testing TBGA in this study is to evaluate the effect of the dendrite growth. Fig. 4 shows the schematic diagram of the experimental setup. In this setup, a constant 5 V DC (DC Power Supply: Tektronix PS280, Laboratory DC Power Supply) was applied to provide the electric field to the testing samples. In order to protect the circuit from burning, an external resistor (250 kΩ) was connected (in series to the whole test units) so as to maintain the very low current (down to mA) passed to the test coupon. For each test lot, 5 units were used and connected in parallel. Before putting the samples into the chamber (ENVIRON environmental tester, PTH-401-R) all of the test coupon were tested and should be opened (i.e. resistance is infinite) before the bias-HAST test. After that, they were connected to the data logger so that the change of resistance could be monitored of each set individually. The test condition was 121°C; 85% RH for 168 h (pick out the sample at time = 0, 50, 100 and 168 h for inspection).

4. Results and discussion

The primary objective of this project was to study dendrite growth with effect of accelerated life test (ALT) in the TBGA with solder balls. It was imperative that the proper resistance could be ascertained. The resistance measurement result of the test units is shown in Table 4. Initially, the multi-meter showed OL (Over-Load) for all test units, which implied that, no short circuit or no connection among the pads or traces in the TBGA. After 100 h of HAST, resistance of samples (normal process of buss-in and buss-out design) A-1 and B-1 dropped to around 10⁻⁷ Ω. The resistance of A-1, B-1, C-1 and D-1 decreased more when the time of the HAST further increased (168 h). It should be noted that decreasing of resistance occurred in the TBGA with solder ball attached only. Solder ball is believed to be the source of dendrite and cause the short circuit.

5. Visual inspection

Table 4 shows the visual inspection of all test units. No ion migration was found for all the test units of no
solder ball attached at \( T = 0, 50, 100 \) and 168 h as shown in Table 5. However, white powdery substance was observed for the test units with solder ball attached, samples A-1 and B-1 100 h of test. For those test samples, the white powdery substance was found around the solder ball pad of the cathode (the \( -ve \) pole) and the coverage on overall active area was small around 2–3%. After 168 h bias-HAST conditioning, all the four test lots with solder ball attached were found to have the “white” powder on the test coupon; while lot A-1; B-1 of additional “bronze” powder on the test coupon. For lot A-1 and B-1, solder mask cracked and exposed the underneath of copper. It was suspected this might be the source of tin and lead ion migration for the white powder while tin, lead and copper ion migration for the bronze powder.

### 6. SEM/EDX analysis

The “powder” was analyzed by EDX method (Philips FEI XL-40). Fig. 9 indicates that the EDX result on the solder mask and this sample was only passed through the reflow oven at peak temperature 230 °C. No organic compound was observed before the bias-HAST test. It was found that the “bronze” powder (found on the lot A-1 and B-1) included lead, tin and copper in

<table>
<thead>
<tr>
<th>Table 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>A-1</td>
</tr>
<tr>
<td>A-2</td>
</tr>
<tr>
<td>B-1</td>
</tr>
<tr>
<td>B-2</td>
</tr>
<tr>
<td>C-1</td>
</tr>
<tr>
<td>C-2</td>
</tr>
<tr>
<td>D-1</td>
</tr>
<tr>
<td>D-2</td>
</tr>
</tbody>
</table>

OL stands for the multi-meter was overload, the max measurable resistance reading is \( 10^8 \) Ω.

<table>
<thead>
<tr>
<th>Table 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>A-1</td>
</tr>
<tr>
<td>A-2</td>
</tr>
<tr>
<td>B-1</td>
</tr>
<tr>
<td>B-2</td>
</tr>
<tr>
<td>C-1</td>
</tr>
<tr>
<td>C-2</td>
</tr>
<tr>
<td>D-1</td>
</tr>
<tr>
<td>D-2</td>
</tr>
</tbody>
</table>

Nil means that no white or bronze powder observed.

Fig. 5. Photo on the non-solder ball attached tape substrate. The unit was going through proper reflow process (peak temperature = 230 °C).
Fig. 6. Lot A-1 after 100 h of bias-HAST test. White powder observed around the “cathodic” ball pad. EDX analysis on the white powder, peak of tin and lead were found. Similar observation was found on lot B-1.

Fig. 7. Lot A-1 after 168 h of bias-HAST. SM crack along the ball pad opening can be seen.

Fig. 8. Lot D-1 after 168 h of bias-HAST. White powdery substance found around the “cathodic” ball pad.

Fig. 9. EDX analysis on the solder mask of the sample after passed through the reflow oven.
nature; while the “white” powder (on all test lots) included lead and tin in nature. From the SEM/EDX analysis on test sample A-1 (after 168 h), peak of Sn (major), lead (minor) and copper (minor) were found around the cathodic ball pad (−ve) that is shown in Fig. 10. Besides, in Fig. 11, solder mask crack along the anode ball pad (+ve) might cause the exposure of the underneath of copper, and it was suspected to be the source of the copper for this case. However, for lot C-1 and D-1, no copper was found under EDX analysis, only tin and lead were found. Based on the observation of all the test units, tin and lead migration seems to be a common observation on bias-HAST conditioning after solder balls attached.

7. Electrochemical migration

It is believed that electrochemical migration may be induced under bias voltage condition and can provide the high current density to the metallic conductors; also, high temperature can promote this process [9]. Moreover, surface moisture is another crucible requirement for the electrochemical migration, in which provide the pathway for ions to move from the anode to the cathode. The consequence of the electrochemical migration can generate metallic dendrites and lead to the short circuit and disaster of the assembly. As there was no crack on the solder mask, only tin was found. However, as stated in earlier observation, solder mask crack as

Fig. 10. SM crack along the “anodic” metallization line can be seen. EDX analysis on the powder was inserted on the right, peak of tin lead and copper can be found on lot A-1. Similar observation was found in test sample B-1.

Fig. 11. SEM and EDX analysis on the white powder found in lot D-1. Peak of tin and lead can be located (signal of Ba, Si, S is originated from the solder resist material). Similar observation was found in lot C-1.
shown in Fig. 12, along the “anodic” metallization ball pad/trace was found. It was demonstrated [10] that high stress levels exist in the solder resist at the tri-material point. When the stress is high enough, this crack can propagate into the underlying copper. It is suspected that this crack provides a continuous water channel for the copper to contact with the outside moisture (at the chamber), and starts to oxidize and dissolve (due to the potential applied). Then the mobile copper cation migrates from the anode towards the cathode and then reduce. The following electrochemical reactions can occur at the anode:

\[
\begin{align*}
\text{H}_2\text{O} & \rightarrow \frac{1}{2} \text{O}_2 + 2\text{H}^+ + 2e^- \\
\text{Cu} & \rightarrow \text{Cu}^{+1} + e^- \\
\text{Sn} & \rightarrow \text{Sn}^{+2} + 2e^- \\
\text{Sn} & \rightarrow \text{Sn}^{+4} + 4e^- \\
\text{Pb} & \rightarrow \text{Pb}^{2+} + 2e^- 
\end{align*}
\]

At the cathode, the following reactions are possible:

\[
\begin{align*}
\text{O}_2 + 2\text{H}_2\text{O} + 4e^- & \rightarrow 4\text{OH}^- \\
2\text{H}_2\text{O} + 2e^- & \rightarrow 2\text{OH}^- + \text{H}_2 \\
\text{Cu}^{+1} + e^- & \rightarrow \text{Cu} \\
\text{Cu}^{+2} + 2e^- & \rightarrow \text{Cu} \\
\text{Sn}^{+2} + 2e^- & \rightarrow \text{Sn}
\end{align*}
\]

8. Conclusion

Based on the test result, no metallic materials was found on the samples with no solder ball attachment even though solder balls is believed to be the source of the white powder observed after bias-HAST test. Solder mask cracks were found after 168 h bias-HAST test. EDX analysis showed presence of not only the tin and lead, but also the copper which came from the underneath of mask layer. Finite element analysis [10] indicates that the tri-material point, especially for the sharp corner point (stress singularity), is the most favorable point for crack initiation and propagation. It is recommended to increase the adhesive strength of solder mask, in order to help to increase its resistance to cracking and therefore the dendrite growth over the trace line. Moreover, from the experimental result there was no significant difference between the buss-out and buss-in design in copper or tin migration issue. Finally, the test had been performed for couple of years ago, and due to technology advancement, and material set optimization, the problem had been solved for a long time.

Acknowledgements

The authors would like to acknowledge the financial support provided by the Hong Kong Research Grant Council fund for Cooperative Research Center on Conductive Adhesive Technology for High Density Electronic Packaging (Project No: 8720003) and by the Hong Kong Innovation and Technology Commission for Conductive Adhesive Technology Programme for Fine Pitch Electronic Interconnect (Project No: ITS/182/00). They also wish to thank Compass Technology Company Limited providing special design of tape ball grid array.

References


