Endoscopic Inspection of Solder Joint Integrity in Chip Scale Packages

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ABSTRACT

This paper reports, for the first time, the use of endoscopy for the nondestructive examination of solder joint integrity in chip scale packages (CSP) such as flip chip on flex (FCF). Borrowed from the medical instrument technology, the endoscope is used to examine visually the inside of an organ. This concept has now been developed and refined by ERSA and KURTZ, and led to an ERSASCOPE inspection system coupled with sophisticated but user-friendly software for data and image analysis. We have successfully used this endoscopic method to evaluate the solder joint integrity in CSP such as cold joints, standoff height measurements, and probing of inner rows of ball joint integrity.

Since this new instrument has only been introduced very recently, we will also report the latest results for obtaining the optimal examination of solder joint integrity achievable in conjunction with ERSA and KURTZ. By analyzing the many varieties of CSP samples from our EPA Center’s clients, we have witnessed the tremendous power of endoscopy when applied to the nondestructive examination of CSP’s solder joints, and found this method of immense use to the quality assessment of miniaturized electronic packages. We will also give a critical review of this inspection method when applied to CSP.

INTRODUCTION

Trends in portable electronics industry are as thin, small and lightweight as possible [1]. The flip chip and chip scale package (CSP) such as μBGA are the most advanced technologies that have gained popularity in a wide variety of the portable electronics applications. Since the size and the pitch of the solder bumps in those advanced packages are very small, any assembly defects such as poor solder joints will result in considerable reliability issues, where the failure of one joint can ruin the entire product.

Nowadays, in order to determine the integrity of the solder joint, X-ray laminography is one of the commonly used inspection method. X-ray inspection has established itself as the state-of-the-art for nondestructive both in-line and off-line, inspection of hidden solder joints, particularly those of BGA, CSP and flip chip components [2-3]. While revealing many
of the possible defects, e.g. bridges, mis-alignment and voids, other critical defects are more difficult to detect, e.g. excess flux residue, surface structure, and micro cracking. The enormous investment associated with top-quality X-ray equipment is too often a deferring factor for many smaller companies to integrate this valid inspection method into their quality control process.

Visual inspection of a solder joint is a critical and necessary step in evaluating process control. Borrowed from the medical instrument technology, the endoscope is used to examine visually the inside of an organ. Endoscopy has been established as a technique for visual inspection in difficult to access environment [4-6]. This concept has now been developed and refined by ERSA and KURTZ, and led to an ERSASCOPE inspection system coupled with sophisticated but user-friendly software for data and image analysis. This endoscopic method has been used to evaluate the solder joint integrity in CSP such as cold joints, standoff height measurements, and probing of inner rows of ball joint integrity. Moreover, we have successfully used this endoscopic method to evaluate the solder joint integrity in CSP such as cold joints, standoff height measurements, and probing of inner rows of ball joint integrity.

EXPERIMENTATION AND RESULTS

A. Sample Preparation

The µBGA CSP46T.75, with Sn/Pb-eutectic solder ball and Dia. = 0.33mm, was placed and soldered on FR-4 printed circuit boards (PCB) using the CASIO YCM-5500V and BTU VIP-70N oven in N2. The assemblies were reflowed with six temperature profiles. The time-resolved temperature between the component and the PCB was measured using a wireless profiler (Super M.O.L.E, E31-900-45/10). The integral of the measured temperature T(t) °C in the liquidus temperature, with respect to time is used to approximate the term t × ΔT. This integral is given the name “heating factor” Qη, and is considered to be a characteristic of the reflow profile [7]. The heating factor, peak temperature, and time above liquidus corresponding to reflowing profiles are summarized in Table 1. The samples were subject to vibration fatigue test. A steel vibration stud of 56g weight was bonded to the top of every µBGA package. The shaker was performed with a sinusoidal excitation with an acceleration of RMS (root-mean-square) 9.1g, and a frequency 30 Hz. The vibration cycling continues until failure occurs. The vibrating lifetime (N50%) vs Qη is listed in Table 1.

B. Standoff Height Measurement

The fatigue lifetime of solder joint will be varied with the heating factor Qη. The lifetime variation can be attributed to the grain coarsening in the solder joint and intermetallic compounds (IMCs) growth [7-8]. It is known that there exists a certain relationship between the standoff height and heating factor Qη. Therefore, the solder height is an important parameter to estimate the soldering quality. The endoscope can measure the standoff height with the ImageDoc image processing and measurement software. With the system optically calibrated, height, width, radius, and angle measurements can be obtained easily, with an accuracy of ±0.01mm. The solder height of the CSP reflowed with different heating factor were inspected and measured, as shown in figure 2. The measured standoff heights are listed in Table 1. The plot of standoff height vs heating factor Qη is shown in figure 3. As shown, the standoff height decreases linearly with the increasing heating factor Qη. Moreover, according to the results of the vibration test, the optimal standoff height is ranging from 0.14 to 0.15mm.

In order to validate the standoff height measurement results, we have further performed our measurement on some flip chip on flex assemblies with the standoff height having a range of ~0.035-0.045mm. First, we have performed our measurement by using the

<table>
<thead>
<tr>
<th>Profiles No.</th>
<th>peak temperature (°C)</th>
<th>Time above liquidus (Sec.)</th>
<th>Heating factor Qη (°C)</th>
<th>Vibrating lifetime N50% (hours)</th>
<th>Solder height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tupl-1</td>
<td>186</td>
<td>17</td>
<td>33</td>
<td>23.2</td>
<td>0.156</td>
</tr>
<tr>
<td>Tupl-2</td>
<td>191</td>
<td>36</td>
<td>205</td>
<td>100.5</td>
<td>0.151</td>
</tr>
<tr>
<td>Tupl-3</td>
<td>197</td>
<td>31</td>
<td>307</td>
<td>146.5</td>
<td>0.146</td>
</tr>
<tr>
<td>Tupl-4</td>
<td>203</td>
<td>49</td>
<td>682</td>
<td>180.8</td>
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<tr>
<td>Tupl-5</td>
<td>207</td>
<td>51</td>
<td>864</td>
<td>45.2</td>
<td>0.132</td>
</tr>
<tr>
<td>Tupl-6</td>
<td>212</td>
<td>100</td>
<td>2004</td>
<td>30.2</td>
<td>0.104</td>
</tr>
</tbody>
</table>

Table 1. Parameters of reflowed profiles.
Figure 2. CSP solder joints reflowed with different profiles

(a) $Q_\eta = 33 \, \text{s}^\circ \text{C}$
(b) $Q_\eta = 205 \, \text{s}^\circ \text{C}$
(c) $Q_\eta = 307 \, \text{s}^\circ \text{C}$
(d) $Q_\eta = 682 \, \text{s}^\circ \text{C}$
(e) $Q_\eta = 864 \, \text{s}^\circ \text{C}$
(f) $Q_\eta = 2004 \, \text{s}^\circ \text{C}$

Figure 3. Relationship between standoff height and heating factor

![Graph showing the relationship between standoff height (mm) and heating factor (Sec. Degree C).](image)

Figure 3. Relationship between standoff height and heating factor
Figure 4. Standoff height measurement of flip chip assembly by endoscope

Figure 5. Standoff height measurement of flip chip assembly by SEM on magnified image

Figure 6. Faulty Solder Joints

Figure 7. Misalignment of CSP solder joints
Fig. 8 Slag spot between solder ball and pad

Fig. 9 Failure cracks of solder joints

Fig. 10 Cross section of failure solder joint
endoscope, then the samples were sectioned. By using the Philips XL40 Scanning Electron Microscope (SEM), standoff height was measured directly from the magnified images (320X). The result of the SEM measurement is 0.0365mm (average of five points measurement). From the endoscope, the standoff height was measured to be 0.037mm. So the results compromise with each other.

C. Integrity of solder joints

The mounting quality of the early failed joint was examined by the endoscope. As shown in figure 6, when the heating factor $Q_h$ is too small, i.e. temperature profile : tupl-1, the soldering is not good, i.e. wetting is not enough. Moreover, for the early failed samples under the vibration test, there are many mounting defects and misalignment in the assemblies, as shown in figure 7. Furthermore, as shown in figure 8, slag spot exists between the solder ball and pad because of its oxidizing surface or flux lacking.

D. Examination of fatigue failure solder joints

For CSP solder joints failed during the vibration cycling test, the failure mechanism can be investigated by observing the surface of the failure solder joint with the aid of the endoscope. Figure 9 show a series of cracks resulted from solder joint fracture. Such investigations can also be obtained by using the Scanning Electron Microscope (SEM) on the sectioned sample, as shown in figure 10, however it’s more time consuming. The results of the endoscope inspection reveal that the fatigue fractures occur inside the solder, with the propagation of the crack approximately parallel to the PCB pad. The crack initiates at the point of the acute angle where the solder joins the PCB pad. Then the crack propagates along the intermetallic layer (IMC)/bulk solder interface. This phenomenon is due to the concentration of stress at this point. It can be seen that the geometry of the joint is due to the width of the solder-mask opening being less than that of the PCB. In the fracture site, internal strain, intercrystalline defects and structural heterogeneity are created and increased gradually with the increasing growth of the intermetallic compounds. Moreover, the structural strength is weakened due to the deviation of element concentration from eutectic.

E. Probing of inner rows of ball joint integrity

The inspection of the interior balls will reveal if either the PCB or component is warped. With the aid of the endoscope, we can visually and expediently examine the surface appearance (i.e. texture, uniformity, smoothness, color and brightness) and surface anomalies (i.e. flux residue – figure 11) of perimeter balls of the package. Similarly, we can probe the interior balls with the zoom and focus-through capabilities of the endoscope, as shown in figure 12.
CONCLUSION

The endoscope system is a bench-to, user-friendly, safe, and cost effective method for quickly inspecting all types of BGA, MicroBGA, and Flip Chip components.

The endoscope system can measure the standoff height of CSP and Flip Chip packages with an accuracy of ±0.01mm. The standoff height is an important parameter to estimate the soldering quality. Our results reveal that the optimal standoff height of the CSP assembly is ranged from 0.14 to 0.15mm, which can be controlled by the reflow heating factor $Q_n$. Moreover, when comparing the standoff height of the flip chip assembly measured by endoscope with the traditional SEM measurement on sectioned sample, the result compromise with each other.

Moreover, the endoscope system can provide a visual and expedient inspection method for solder joint integrity, such as solder volume, shape of solder fillet and alignment, surface appearance, surface anomalies, solder thickness, solder bridge, micro-cracking and excess flux residue.

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