Nondestructive Methodology for Standoff Height Measurement of Flip Chip on Flex (FCOF) by SAM

C. W. Tang, Y. C. Chan, K. C. Hung, and D. P. Webb

Abstract—Flip chip technology is the emerging interconnect technology for the next generation of high performance electronics. One of the important criteria for reliability is the width of the gap between the die and the substrate, i.e., the standoff height. A nondestructive technique using scanning acoustic microscopy (SAM) for the standoff height measurement of flip chip assemblies is demonstrated. The method, by means of the implementation of a pulse separation technique, time difference of the representative signals of the die bottom and water interface and water and substrate surface interface from the A-scan image can be found. Then, the corresponding standoff height can be calculated. When compared to the traditional destructive measurement method (SEM analysis on sectioned sample), this nondestructive technique yields reliable results.

Index Terms—Filler particles, flip chip, nondestructive, scanning acoustic microscope, standoff height, underfill.

I. INTRODUCTION

To meet the demands of higher density, greater performance, and lighter weight in the electronics industry, flip chip technology is the emerging interconnect technology for the next generation of high performance electronics [1], [2]. The most important advance in improving the flip chip reliability has been by filling the gap between chip and substrate with an appropriate underfill encapsulant. The underfill provides dramatic fatigue life enhancement by dissipating thermally induced stress between the die and the substrate. However, one of the important criteria for the reliability issue is the size of the gap between the die and the substrate, i.e., standoff height. Control of the standoff height is necessary for formation of well shaped solder joint and of a constant fillet shape for a fixed volume of underfill. Additionally, if the standoff height is too small, the filler particles in the underfill may become trapped and the not be evenly distributed, affecting the thermal performance. Moreover, if the gap is too small, some of the flux residue may remain even after cleaning, potentially causing underfill delamination. Any defects such as void or delamination in the underfill layer may result in solder fatigue failure and ruin the whole flip chip package.

Traditionally, the standoff height was measured by the method of contact measurement or SEM measurement of sectioned samples. However, these methods have the respective disadvantages of lack of accuracy and being more time consuming.

Ultrasonic techniques [3] have been used successfully for thickness measurement and material characterization in several applications primarily because they are nondestructive in nature and can yield reliable results for simple geometries. Acoustic microscopy techniques, in particular, are attractive for IC packaging applications because they afford the potential to perform these measurements over a small, localized area [4]. Scanning acoustic microscope (SAM) is used extensively throughout the microelectronics industry to inspect flip chip packages for delamination or cracking [5]. In this paper, we will discuss how to use this technology to measure the standoff height of a flip chip assembly. Moreover, we verify the results by the SEM measurement of the sectioned and polished samples. Our research results propose a more efficient method of nondestructive standoff height measurement.

II. EXPERIMENT

Flip chip on flex assemblies, as shown in Fig. 1, were used. Three types of samples were studied: assemblies with underfill (filler particles inside) after the curing process, assemblies without underfill and assemblies with underfill (without filler particles) after the curing process. The schematic of the flip chip packages investigated in this study are shown in Figs. 2 and 3.

Scanning acoustic microscope (SAM) was used for data acquisition with a transducer of 230 MHz. Five positions of each
sample were scanned, as shown in Fig. 4. The sample under study was placed in the water tank of the SAM. The transducer is focused at the die bottom and water (or underfill interface). The transducer was moved to a location where the thickness of the standoff height is to be determined. Moving the transducer over any particular location (position 1 to position 5) and repeating the data acquisition can collect data from multiple locations of interest. Ultrasonic thickness is made possible by the reflection of ultrasound at interfaces between dissimilar materials. When ultrasound waves propagating in a material encounter an interface with a dissimilar material (with a different acoustic impedance), a portion of the ultrasonic energy is reflected back. Thus, when ultrasound in the acoustic microscope impinges on an assembly shown in Fig. 5(a), a “typical signal” appears on the oscilloscope. The pulse separation technique described above is relatively straightforward [6]. This is because the reflections from each interface can be clearly separated in the time domain (A-Scan). The reflective inspection mode is time based. A reflection from the top of the package returns earlier than a reflection from a layer within the package. The time base is used to separate layers from the package. For example, as shown in Fig. 5(b), the reflection at the water and package interface is followed by the package and die surface interface, and then by the die and die bottom interface. The thickness of either layer can be determined by measuring the time lag between the two reflections if the velocity of the ultrasound wave in either region is known.

After the standoff height measurement and data acquisition using the SAM, samples were sectioned and polished. In order to validate the results obtained by the acoustic microscopy, Scanning Electron Microscope (SEM) was employed to obtain correlated destructive data. The standoff height of the flip chip assemblies was measured directly from the magnified images (320×) of the sectioned samples.

III. RESULTS

Flip chip on flex assemblies samples had three interfaces in this study. For samples with underfill (either with or without filler particles)/without underfill, the following interfaces are present:

1) water and die surface interface;
2) die bottom and underfill interface (for samples with underfill) or die bottom and water interface (for samples without underfill);
3) underfill and flex substrate interface.

The representative A-scan signals of these interface and the corresponding C-scan images are shown in Figs. 6 and 7 respectively.

Measurements on the samples (6 nos.) without underfill on the five positions of each chip were performed. By means of the measurement of the time lag between the representative signals, the time for the ultrasonic wave to travel to-and-from the chip thickness and standoff height can be determined (Fig. 8). The standoff height can be calculated by

\[ \text{SOH} = V \left( \frac{\Delta T}{2} \right) \]
where

- \( \text{SOH} \) standoff height;
- \( V \) speed of ultrasonic wave in water (samples without underfill) or underfill (samples with underfill); 1370 m/s (for water);
- \( \Delta t \) time lag between two interfaces in an A-scan image.

Table 1

<table>
<thead>
<tr>
<th>Location</th>
<th>Traveling Time (s)</th>
<th>Speed of Ultrasonic wave (m/s)</th>
<th>Standoff Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.61E-08</td>
<td>1370</td>
<td>38.4µ</td>
</tr>
<tr>
<td>2</td>
<td>5.50E-08</td>
<td>1370</td>
<td>37.7µ</td>
</tr>
<tr>
<td>3</td>
<td>5.39E-08</td>
<td>1370</td>
<td>36.9µ</td>
</tr>
<tr>
<td>4</td>
<td>5.39E-08</td>
<td>1370</td>
<td>36.9µ</td>
</tr>
<tr>
<td>5</td>
<td>5.19E-08</td>
<td>1370</td>
<td>35.5µ</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>37.1µ</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td></td>
<td></td>
<td>0.11µ</td>
</tr>
</tbody>
</table>

The chip thickness of the samples is also calculated for the sake of comparison. The calculated standoff height of the samples without underfill was shown in Table I and Fig. 9.

As shown in Fig. 9, we see that the height at the five positions of the sample is not the same, suggesting that there is an intrinsic error (measurement error) or that the bottom of the chip is not perfectly planar. Whether the variation is due to an intrinsic error or imperfect plane, another experiment, the scanning electron microscopy (SEM), was performed to verify the cause of this difference.

After the completion of the acoustic microscopy, two samples were sectioned and polished. Direct standoff height measurement was performed using the SEM on the magnified images, as shown in Figs. 10 and 11. The results of standoff height measurement by scanning acoustic microscope (SAM) and scanning electron microscope (SEM) are compared in order to check the validity of the data obtained by SAM (A-scan). The comparison of standoff height measurement is shown in Table II and plotted in Fig. 12.

As shown in Table II, we find that the maximum deviation between standoff height measured by SAM and SEM for sample 1 is only 0.5 µm, which is only a 1.36% deviation.

Moreover, from Fig. 10, we see that the trend of the standoff heights of each sample measured by SEM is same as the trend by
SAM. Since the data and trend of the two experiments are comparable, it suggests that the deviation of standoff height within each sample is due to the imperfect plane of the sample, and the intrinsic error is very small.

After our investigation on samples without underfill, we have performed the same measurement on the samples with underfill (with and without filler particles). We find that three issues arise during data acquisition by the scanning acoustic microscopy when samples with underfill were scanned. First, due to the presence of underfill, it is difficult to identify the representative signal of the substrate for standoff height calculation. Second, a reference speed of ultrasonic wave travelling in the underfill material must be known before standoff height measurement. Third, due to the irregular density of the filler particles and the density of the underfill material, and hence the speed of the ultrasonic wave varies in different locations, i.e., the reference speed of the ultrasonic wave also varies, so calculated standoff height also varies. Therefore, if samples with underfill (without filler particles) are under investigation, a control experiment must be run to determine the reference speed of the underfill. [Applying underfill to flip chip assembly with known standoff height, then by using the method described (Standoff height measurement by SAM), reference speed of the underfill can be calculated.] However, for underfill with filler particles, due to the irregular density of the filler particles, it is quite difficult to determine an accurate speed for standoff height calculation.

IV. CONCLUSION

A nondestructive technique using the SAM is demonstrated. The method, by means of the implementation of the pulse separation technique, time difference of the representative signals
of the die bottom and water interface and water and substrate surface interface from the A-scan image can be found. Then, the corresponding standoff height can be calculated. When comparing the results obtained by SAM with the traditional destructive measurement method, for an average standoff height of 37.1 μm, the maximum deviation between the two methods is only 0.5 μm, which is a 1.36% deviation. Moreover, the trends of standoff height of each sample measured by SAM and SEM compromise with each other, which suggests that the method under our study yields reliable results. Our research results may contribute to the industry a more efficient method of nondestructive standoff height measurement.

### ACKNOWLEDGMENT

The authors would like to thank Dr. H. Wang and H. Leung, SAE Magnetics (H. K.), Ltd., for providing the samples and their valuable discussion.

### REFERENCES


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