Advanced Packaging

Flip chip defect detection

ACOUSTIC MICRO IMAGING AND DESTRUCTIVE CORRELATION

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Acoustic micro imaging (AMI) has been demonstrated as an effective tool for evaluating defects in the underfill and bump attachment of flip chip assemblies. This article discusses two flip chip assemblies that were inspected and found to have defects using AMI. Destructive work was performed to gather more detailed information about the nature of these defects. In these case studies, the defects detected by AMI are unusual and were not detected by other testing techniques. The precision of the AMI technique is demonstrated by the destructive work, and the potential pitfalls of the AMI technique are also illustrated.

Acoustic Micro Imaging Technique

AMI, which is commonly known as C-SAM (C-mode scanning acoustic microscopy), works by alternately producing and receiving pulses of ultrasonic energy, typically from 10 to 300 MHz.[1] Ultrasound will not transmit through air, so the energy is carried to the sample by a coupling medium, typically deionized water. A focused spot of ultrasound is generated by an acoustic lens, and it can be focused at sub-surface levels within the sample.

Ultrasound waves interact within the solid sample, and the echoes reflected can be analyzed for information about the sample; each interface within the sample usually transmits some acoustic energy and reflects some acoustic energy. By studying these echoes produced as the transducer is scanned over the sample, an image can be produced.

The construction of flip chip devices makes them an excellent application for acoustic micro imaging.[2] By focusing the ultrasound through the chip, the chip/underfill interface and the underfill/substrate interface can be examined separately. Evaluating these interfaces offers a wealth of information about defects and potential reliability issues with the part. For example, delamination of the underfill at either interface will be readily apparent to the acoustic microscope. Other underfill defects, such as filler particle segregation or voids within the underfill, can also be detected.

Because the solder bump attachments are in the same plane as the chip/underfill and underfill/substrate interfaces, bump attach quality can also be evaluated. Bulk solder defects, such as a cracked bump, can also be identified.

Material Property Effects

AMI is possible because of the properties of the materials under study. For example, silicon has an acoustic impedance (the product of its mass density and elastic modulus) of about seven times that of a typical epoxy resin.[3] This difference in acoustic impedance defines the reflected echo from this interface, and this is the echo that is studied to understand the condition of the interface.

Because AMI is a pulse-echo technique, what is of interest is the amplitude of an echo relative to the incident acoustic pulse. If this amplitude is called R, it can be determined by:

$$R = (Z_2 - Z_1) / (Z_2 + Z_1)$$

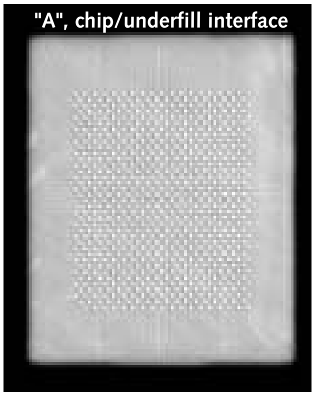

Figure 1. Acoustic micro image of a chip/underfill interface.

Illustration by Gregor Bernard

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where Z_1 is the acoustic impedance of the first material traversed by the ultrasound, and Z_2 is the acoustic impedance of the material on the other side of the interface formed by the two materials.[4]

By using the impedance values for silicon and epoxy, a value of R for the silicon/epoxy interface is calculated to be –0.74, where the sign indicates a negative-going echo. Because air has an acoustic impedance of zero, R at a delamination or epoxy void, meaning a silicon/air interface, is calculated at –1.0. In other words, over a delamination or void, the echo does not change polarity, but it does increase in amplitude by roughly 33 percent. This would be the indication that a defective area has been detected.

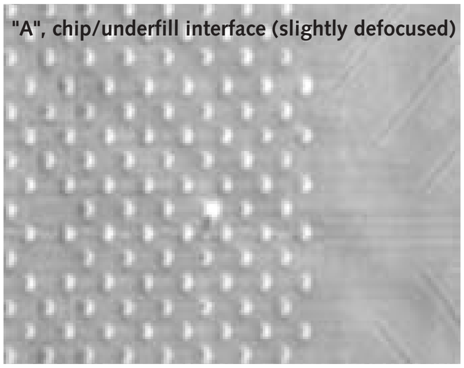

Figure 2. A slightly defocused acoustic micro image of the chip/underfill interface reveals a defect.

Furthermore, the material properties of silicon, along with the fact that it is normally quite thin in flip chip applications, means that high frequencies of ultrasound can be used. High frequencies, generally 180 MHz and higher, are required to achieve the resolution necessary to evaluate the solder bumps. In addition, higher frequencies reduce the "edge effect" — a degradation in the image near the edge — seen in AMI. All of these factors mean that good results can be obtained with AMI in flip chip applications.

Case Study #1

In the first case study, a flip chip assembly was evaluated first by focusing through the chip to the chip/underfill interface (Figure 1). Initially, no defects are apparent. However, some defects close to or at the chip surface do not appear prominently when focused on this interface. Therefore, a second scan was executed with a slightly higher focus (Figure 2). Note that the chip surface circuitry and the bumps are less well defined. However, one of the bumps now appears to be very bright, and a small structure is projecting from this bright area.

This illustrates the sensitivity of the technique to focus, as very slight changes can expose defects that might otherwise remain hidden. The position of the focus, combined with an analysis of the echo placement from the anomalous area, shows that this defect was very close to the chip surface, and was probably a silicon defect at the surface.

We also considered whether voids in the solder bumps could be detected during this inspection. In particular, a solder bump void was detected with a real-time radiography instrument. One might expect this to be seen in the underfill/substrate scan, but it was not. The reason for this is illustrated in Figure 3. The radiography indicated that the void was roughly located where the "white" void is in the center bump. While the "black" voids should be readily detectable, because they are easily within the path of the acoustic energy, the "white" void is out in the curvature of the bump and is not likely to be detected. Of course, bump defects as illustrated in the other two bumps would always be detected.

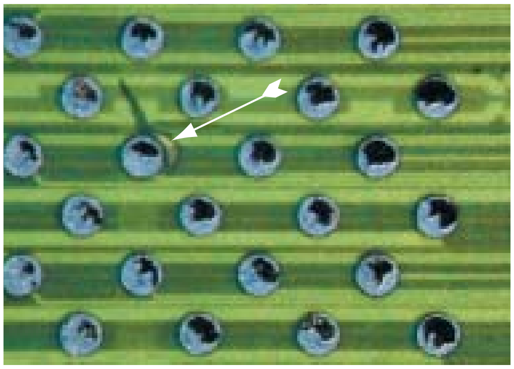

Figure 4. Planar cross-section showing a defect in the chip surface.

To determine the nature of the anomaly found, destructive analysis was performed. The approach was to perform a planar section by grinding away the substrate and then polishing intermediate layers until the defect was located.

Figure 4 shows the defect at one of the intermediate steps. The defect was found to be in the polyimide on the die surface, and it extended well into the bump region. Note that the structure exactly matches the acoustic images. Figure 4 appears to be a mirror reflection of the acoustic images because it is viewed from the bottom (substrate) side, while the acoustic images are from the top (chip) side.

The bright white area in the acoustic images is believed to be because of variations in underfill flow and adhesion in this area. The dark projection is an area where the polyimide defect was so small that there was no underfill flow into it, so it shadows the ultrasound.

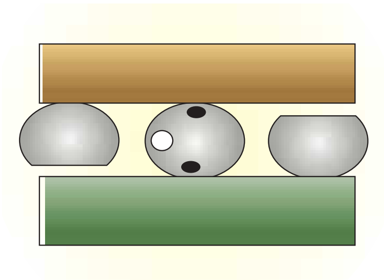

Figure 3. A defect located in the white circle of the middle bump would not be detected by AMI because it is not near an interface, but voids near the black ovals or at the interfaces in the other bumps would be detected.

Case Study #2

The same approach was used in analyzing this flip chip assembly. The initial scan of the chip/underfill interface did not show any defects. After raising the focus slightly, one of the solder bumps appears bright white and lacks the "structure" seen in the other bumps (Figure 5).

This was considered to be most likely a defective bump attachment to the chip. It was initially proposed that some contact may be present, but for some reason the bump was not well-bonded to the chip. This information was again based on the focus change effect, and on the positions of the echoes from this defective area.

The scan of the next interface, the underfill/substrate interface, found no defects, and no indication of the known defective bump. This was as expected

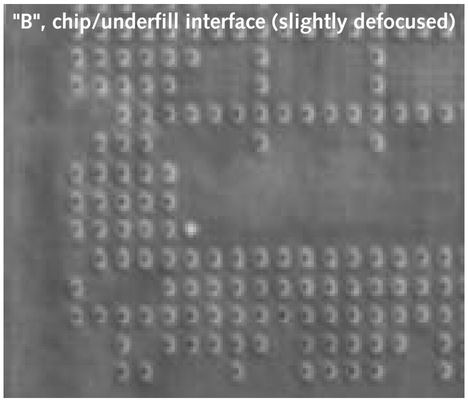

Figure 5. A slightly defocused acoustic micro image of a chip/underfill interface.

because the defect is exactly co-located with the bump, and therefore offers no area to “shadow” and make the bump appear larger in this scan.

This flip chip was also destructively analyzed, and again a planar cross-sectioning technique was used. The suspect bump’s appearance was monitored as the surface of the chip was approached in the polishing process. Figure 6 shows the plane at the chip’s surface; the solder bump is now no longer visible, and no pad exists.

It was subsequently learned that the flip chip manufacturer had used a standard solder bump pattern, and that by design no pad existed here. The bump, however, was in mechanical contact with the polyimide chip surface. The AMI technique was able to distinguish between the metallurgical bond between the functioning solder bumps and the chip, and the mechanical contact of the unused bump and the chip surface. Real-time radiography did not detect this as a “problem” bump.

Conclusion

The AMI technique has been shown to have sensitivity and precision in the analysis of flip chip devices. Due to limitations of the acoustic microscope when near an edge or a curved surface, some solder bump voids may only be detectable by radiography. However, radiography — even high resolution real-time radiography — cannot give the interface information that is obtainable by AMI. **AP**

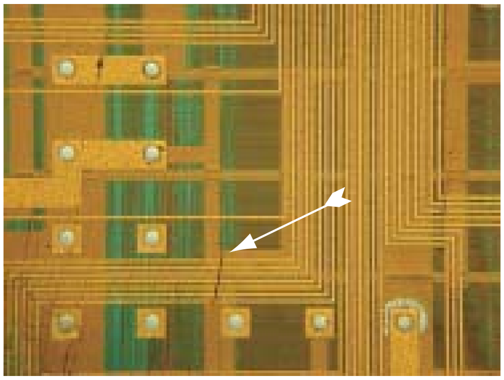

Figure 6. At a chip surface, no pad is present and the bump has not made a metallurgical contact.

Acknowledgments

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References

1. Kerry Oren, "Acoustic Microimaging in Microelectronics," Future Circuits International, March 1999, p. 242.
2. Janet E. Semmens, Lawrence W. Kessler, "Analysis of Flip Chip Devices Using Acoustic Micro Imaging with Correlative Examples," International Acoustic Micro Imaging Symposium, 1997.
3. Alan R. Selfridge, "Approximate Material Properties in Isotropic Materials," IEEE Transactions on Sonics and Ultrasonics, Vol. SU-32, No. 3, May 1985.
4. L.W. Kessler, J.E. Semmens, "Acoustic Micro Imaging Failure Analysis of Electronic Devices," Electronic Failure Analysis Handbook, ed. Perry L. Martin, McGraw-Hill, 1999, p7.4.

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