<<< Back | Print

Acoustic Tools and Applications for PCB Inspection

Steven R. Martell, Sonoscan Inc., Elk Grove Village, Ill. -- 11/1/01

EP and P

The manufacturability and long-term reliability of new IC package designs often are related directly to the construction quality of internal features hidden from optical view and difficult to interpret with X-ray. This is particularly true of flip chip packages (and to some extent of chip-scale packages), where interconnects, underfill and other critical features may be inaccessible or overlapped.

Figure 1. The top half is a normal, planar, “down-looking” nondestructive view into a CSP-like IC package. The bottom half is a nondestructive cross-section through a slice defined by the yellow line in the top half.

Highly sensitive to internal material interfaces, particularly to those interfaces involving a gap such as a delamination or a void, acoustic micro imaging is useful in characterizing these packages. Many recent developments in acoustic micro imaging, such as the introduction of application-specific higher-frequency transducers and the move to 3D imaging, are well-known. But much of the advanced performance in current systems is the result of less dramatic and less well-known improvements such as better mechanical scanning methods and signal processing. For example, current resolution has reached the point where the acoustic imaging of the die-to-underfill depth in a flip chip also images the traces on the chip face.

Many system advances have paralleled, or been driven by, packaging engineers' needs. Higher acoustic frequencies, which by themselves generally yield higher spatial resolution, were in part driven by the need of flip chip developers to see details of the bond between the pad on the chip face and the solder bump. The need to characterize peripheral solder bumps at the very edge of the die led to another innovative transducer design that also improved resolution across the entire flip chip package.

Determining the defect's depth

In flip chips, the precise vertical location of an underfill void can be significant in determining the process problem that created the void. Voids can form in numerous ways:

- By the change in flow speed when fluid underfill travels around a solder bump
- By an insufficient amount of underfill material
- By contamination of the surface
- By an abrupt change of elevation when the underfill flows over a substrate feature such as a via or trace

When ultrasound is pulsed into a flip chip or other package by the scanning transducer, it travels downward into the package until it encounters the interface between two dissimilar materials. At this interface, a portion of the ultrasound is reflected back to the transducer as an echo. If the interface is a gap, essentially all of the ultrasound would be reflected. Since ultrasound travels at a specific speed through a specified material, echoes from different depths within a package return to the transducer at slightly different times. Methods for determining a feature's depth (such as a void) are based on these time differences.

One method, useful for determining the depth of voids and other defects, is the acoustic virtual cross-section technique. Starting with a planar acoustic image that shows the X-Y area of a package, usually at a gated depth of interest (Z), the transducer raster-scans the area of the package. To make a virtual cross-sectional image, the transducer scans repeatedly along a single line (X) at incrementally shallower depths (Z). The resulting image (Fig. 1) is analogous to a physical cross section of the package, but is nondestructive. Since the speed of ultrasound through the package material is known, scale markers are automatically placed at either side of the image to give an accurate method for measuring the depth of features seen in the cross-sectional view.

A cross-sectional view

Figure 1 shows the cross-sectional view of a CSP-like package. The top half of the image is the X-Y planar view; the horizontal line across the planar image (arrow) indicates the vertical plane through which the virtual cross-sectional view was made. In both images, the red areas are delamination of the molding compound from the internal polyimide substrate. Note that the line does not cross the die itself.

The bottom half of Fig. 1 shows the cross-sectional acoustic view. The "0" marks the top of the package — that is, the top surface of the molding compound. Below the surface, the cross-sectional view is divided into 10 divisions by the markers at the left and right. The distance between markers is 0.17 mm; from the top surface of the device to marker 10 is a distance (or depth) of 1.7 mm. That portion of the delamination (red) crossed by the line in the planar view at top is seen in cross section approximately at marker 8; that is, the depth of this delamination is about 1.36 mm. But the cross-sectional view shows something else as well: the polyimide substrate is warped. If desired, the extent of warpage displacement could be measured from the cross-sectional image. Sonoscan's application laboratories have found that warpage of the substrate is a fairly frequent anomaly in CSPs and similar packages.

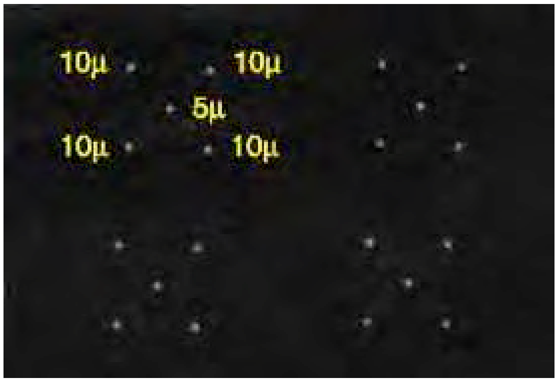

Figure 2. Shown are five-micron (at center of each group) and 10-micron features etched into silicon. An advanced 230 MHz ultrasonic transducer images both features.

Resolution vs. detection

As internal features in flip chips and CSPs become smaller, it becomes more important to be able to image and collect data about finer internal details. The item of interest might be a tiny void adjacent to a solder ball, a crack in a solder ball, or the distribution of filler particles in the cured underfill material.

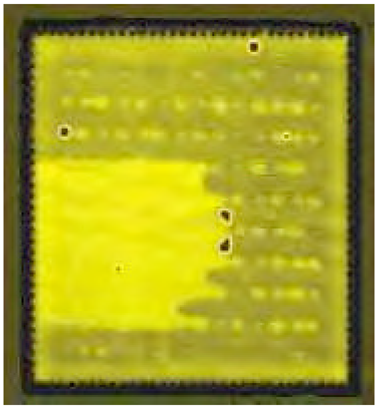

Figure 3. This flip chip was successfully underfilled and reflowed with a few voids (dark red areas), but developed large delaminations (light yellow areas) during humidity exposure.

An ultrasonic transducer of a given frequency has a corresponding "spot size," which can be visualized as the tip of the cone of ultrasound emitted by the transducer. Higher frequencies have smaller spot sizes, which in turn produce higher resolution. As a rule of thumb, the product of the frequency (in MHz) and the spot size (in microns) is approximately 2500 for a typical lens design known as F2. Thus, the relatively low ultrasonic frequency of 10 MHz has a relatively large spot size of 250 microns, while a high frequency such as 230 MHz has a spot size of slightly more than 10 microns.

Resolution is defined as the ability of a system to distinguish the separation between two adjacent features. Thus a 230 MHz transducer would distinguish objects that are separated by 10 microns. But adjacent objects separated by only five microns would be imaged as a single feature.

A transducer can, however, detect features smaller than its resolution limit. This is why a 230 MHz transducer, having a 10-micron spot size, can detect and image a five-micron feature. A five-micron feature, though, will appear the same size as a 10-micron feature. Figure 2 is the 230 MHz acoustic image of the interface between two silicon wafers, onto one of which features of two sizes — five microns and 10 microns — have been etched. Because the resolution of the transducer is being exceeded, features of both sizes appear to have the same diameter.

Looking at no-flow underfill

As the solder joints used in flip chips become smaller, the shrinking height of the offset between the substrate and the chip face makes conventional underfilling more difficult. An additional problem is that topographic irregularities on the substrate become relatively larger as the offset is reduced. These factors make the use of no-flow underfill attractive.

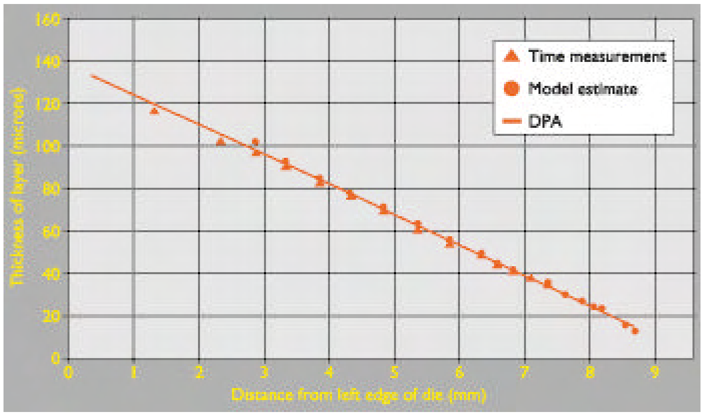

Figure 4. The thickness of an adhesive layer beneath a metal heat sink can be measured by time-domain measurement, an estimate based on the acoustic model. Close agreement shows that the thickness of buried layers can be measured accurately by an acoustic micro imaging system.

No-flow underfill material can be applied to the substrate by dispensing, stencil printing or by dipping. After the chip is put in place, soldering can be accomplished either by conventional reflow or thermode bonding. Since the solder bumps on the chip must push through the uncured underfill to make electrical contact, the chip must be held in place until the underfill has relaxed if conventional reflow is used. If this precaution is not taken, the chip may float during reflow. Thermode bonding accomplishes placement and soldering in one operation lasting a few seconds. In both operations, precise measurement of underfill quantity is critical.

A number of conditions can result in voids and delaminations in the cured no-flow underfill. Topographic features, such as vias in the substrate, can cause voids. So can various forms of surface contamination. Acoustic micro imaging is useful during the development of no-flow underfill processes to image and analyze these defects. If voids are present, the use of acoustic micro imaging to determine whether the void is at the substrate or at the chip face is useful in determining their cause. It is also useful in imaging the diminished or absent bond to the substrate in cases where the die has floated during reflow. Figure 3 is the acoustic image of a flip chip die that was successfully mounted using no-flow underfill having voids (dark red areas), but which subsequently developed large delaminations (light yellow areas) during humidity testing.

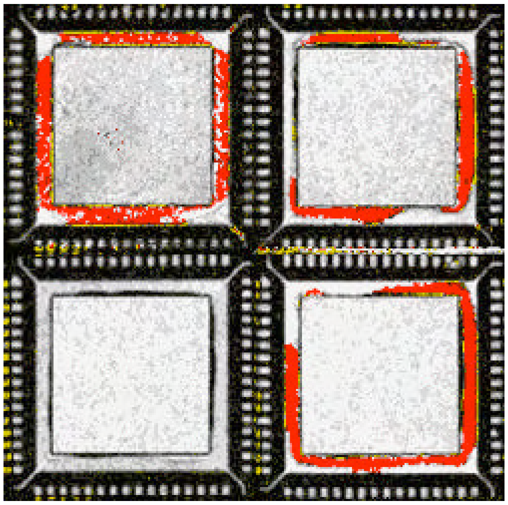

Figure 5. This acoustic image shows that the overmolding is delaminated (red) from the heat sink, which is slightly larger than the die.

Adhesive measurements for heat sinks

Metal heat sinks bonded to flip chip surfaces are a simple and effective way to achieve thermal control. The adhesive bonding the heat sink to the silicon is a relatively poor thermal conductor. If the adhesive is too thick, it would act as a thermal insulator and defeat the purpose of the heat sink. Knowing and controlling the thickness of the adhesive is critical.

Since the adhesive has two interfaces, with the heat sink above and the silicon below, thickness could in theory be measured simply by gauging the time difference between echoes from these interfaces. In practice, this straightforward method will not work because the adhesive layer is typically so thin (about 10 microns) that it is less than one wavelength of ultrasound at the frequencies used to penetrate the heat sink. A 50 MHz transducer, for example, has a wavelength of 60 microns in the adhesive.

Figure 6. An Asymtek customer support engineer checks the quality of the underfill process with AMI to confirm the best equipment operating parameters for the underfill material and flip chip design.

Was there a way to measure the thickness of a buried layer when the thickness is less than one wavelength of the ultrasound being used? In examining samples of flip chips with heat sinks, Sonoscan researchers made two observations. First, the heat sink is usually somewhat larger in area than the chip itself. This enabled researchers to obtain a reference signal from the outer portions of the heat sink. Second, some of the heat sinks under investigation were actually tilted because the adhesive was un distributed evenly. The tilted heat sinks gave a spectrum of thicknesses, some of which were greater than the wavelength of ultrasound. In these thick regions, echoes could be separated by time domain to yield a thickness measurement that could be used to verify measurement methods being developed.

Using the reference signal as a starting point, it was found that thickness could be measured by using the changes in frequency spectrum in the reflected ultrasound. A model using FFTs and other input was created to measure thickness using a reference signal from the heat sink overhang and frequency-domain data from the adhesive layer. To calculate the accuracy of the new method, the flip chip packages were physically sectioned and the adhesive layer thickness measured optically. Accuracy of the acoustic microprobe (as the technique is now called) was found to be ±0.5 micron.

Molding compound

In CSPs, the encapsulant's integrity has considerable impact on long-term device reliability. These packages often involve innovative designs whose manufacturability is not well-known. Acoustic micro imaging is helpful in finding not only delaminations (probably the most common defect) but also voids, cracks and other anomalies.

Figure 5 is the planar acoustic image of a group of overmolded CSPs. In this design, the die rests on a metal heat sink slightly larger than the die. Molding compound covers the top surface of the die and extends down the sides to the heat sink. The image was gated at the depth of the bond of the molding compound to the heat sink, which is the same depth as the die-attach level.

In three of the four CSPs, the bonding of the molding compound to the heat sink has essentially failed; the red areas are delaminations. The attach of the die to the heat sink, however, has no significant defects.

Author Information

To comment on this article, contact Steven R. Martell, manager of technical marketing and communications for Sonoscan in Elk Grove Village, Ill. at smartell@sonoscan.com.

<<< Back | Print