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Measuring Surface Flatness with Acoustic Micro Imaging Tools

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Acoustic micro imaging tools, or acoustic microscopes, are well-known for their ability to pulse ultrasound into a sample, collect the echoes and create acoustic images. These images show the desired depth without harming the sample. These tools can even create nondestructive cross-sections.

Acoustic micro imaging can also be used to inspect the surface of a sample, rather than its interior. The purpose may be simply to ascertain that a batch of newly-packaged devices have a surface that meets the manufacturer's specifications. There may be surface features, such as mold marks, but the rest of the surface should meet flatness standards.

Imaging the surface can also be useful as an early indicator of internal defects. An internal void, for example, may cause local elevation of the surface. Internal material stresses, even in the absence of a void or other gap, can also cause surface disturbances. Such stresses are especially significant, since they are likely to turn into field failures.

Basic Acoustic Imaging

At a basic level, the laterally-scanning transducer of the acoustic microscope may cover 3.3 ft/s (1m/s) when scanning a tray of parts. In that second, it will perform several thousand pulse-echo functions at each of several thousand x/y locations on the sample's surface. Each pulse travels from the transducer through water at about 4,900 ft/s (1,500 m/s) to the sample. The transducer is typically a few millimeters above the sample's surface.

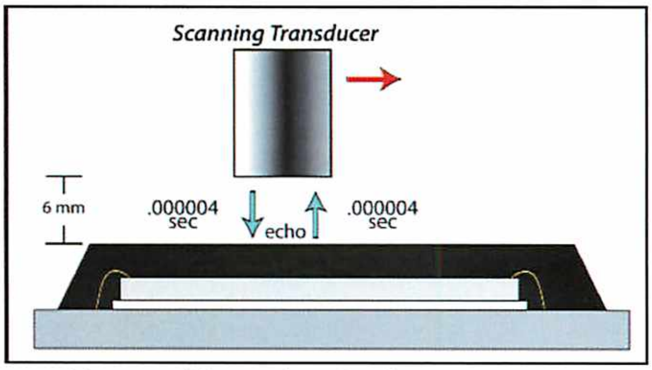

Figure 1: Measuring the distance from the transducer to a single x/y position on a surface.

If, for example, the transducer is 0.25 in. (6 mm) above the surface, ultrasound will reach the sample surface in 4.044 µs and return at the same rate. The time is so brief that each pulse-echo sequence is discrete.

When imaging the surface, the echoes are said to be gated on the surface — meaning that echoes from other depths may arrive at the transducer later, but are ignored. Ultrasound pulsed into the sample travels through the sample until enough of the pulse has been absorbed that no readable echo is possible, or until the pulse exits the backside of the sample. In Sonoscan's C-SAM® tools, one of the many imaging modes scans the backside of samples to detect those regions where no ultrasound exits. These acoustic shadows are caused by gap-type defects higher in the sample.

Measuring Surface Flatness

When mapping the flatness of a sample, what matters is the elevation of each of the thousands, or millions, of x/y locations that will contribute pixels to the acoustic image. When an ultrasonic pulse strikes a material interface, part of the ultrasound is typically reflected as a collection of echoes, while the rest is transmitted across the interface.

The percent of ultrasound reflected or transmitted depends on the physical properties of the two materials at the interface. The interface between water and an ordinary mold compound used in a plastic-encapsulated IC reflects about

35 to 40 percent of the ultrasound and transmits the rest.

The degree of reflection gives the echo its amplitude, or signal strength. The echo also has polarity — positive if the interface was from a material of lower acoustic velocity to a material of higher acoustic velocity, and negative if the reverse. The arrival time tells the distance of each x/y coordinate from the transducer, and thus its altitude on the sample. Sonoscan calls this method Acoustic Surface Flatness™ (ASF).

Figure 2 is the ASF image of an unpopulated FR-4 PCB measuring 7.5 x 3.5 in.(19 x 8.8 cm). It was imaged by a C-SAM system using a 100 MHz transducer and a focal length of 0.5 in. (1.3 cm) The color map at the left border shows the range of elevations. If the board were perfectly flat, or even acceptably flat, the entire board might display only a single color. But that is not the case here. The lowest surface regions are dark red, along the upper left edge.

The most elevated surface regions are near the bottom-center and are pink. The maximum difference in elevation between two surface points in these regions is 0.06 in. (1.5 mm). Holes where the surface is absent are black. The white rectangular feature at the lower left of the image is a hole in the board. It is white because it is so far from the other values on the color map.

Each ultrasonic pulse struck a single x/y coordinate and reported the distance to the coordinate. This distance was converted into color. But the echo also reported the amplitude of each signal. Surface features large and small differ slightly in distance and/or amplitude from the surrounding area. These small differences make many surface features visible. In some regions, however, the resulting contrast is very slight and few details are visible. There are few details in the green region, for example.

Causes of Warpage

Warped PCBs fall into two categories. Many are warped over their entire surfaces. Some, however, have strictly local warpage, typically caused by a defect within the body of the board, such as a bubble between layers.

Figure 2: Acoustic map showing elevation difference on a PCB.

Surface flatness is also measured in many plastic-packaged components. Although any component package can be warped, warping is especially critical in thin, large-area components, such as BGAs. Warpage may simply be the result of forces encountered during production of the component, creating packages that are dished (the edges are the highest points) or domed (the center is the highest point). Warpage will likely be more complex and less symmetrical if an internal gap, such as a void, is present.

Package-on-package (PoP) assemblies can also display surface distortions caused by warpage. Deviations from flatness are often seen in packages where a memory chip rests on top of a processing chip.

Like individual components, wafers also have flatness issues, but the nature of the risk is not the same. A significantly non-flat component is unlikely to be used in populating a board, but a significantly warped wafer may contain nothing but flawless components.

But, the wafer still needs to be scanned acoustically to image and evaluate the features within each device. The acoustic micro imaging tool's transducer expects a wafer to be flat. If it is not, regions above and below the expected focal plane will not be imaged.

Sonoscan solved this problem by incorporating distance-measuring technology to automatically adjust the transducer during the scanning of wafer.

The resulting image of a warped wafer will show, acoustically, a flat wafer, but all anomalies will have been found.

The tool can even take the technology one step farther: if the devices in the wafer are destined to be used in a stack, it can measure the warpage of individual devices to determine their fitness for stacking.

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