Imaging tomorrow’s components, acoustically

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Packages are changing. Acoustic methods provide a way to image and analyze them.

By the year 2020, the design, dimensions and materials of various electronic component packages will have changed in varying degrees from their current forms. PEMs (plastic-encapsulated microcircuits) will still be in production, but likely with shrinking sizes and better (or less expensive) encapsulants. Stacking of die connected by non-wire methods such as through-silicon vias (TSVs) will be in production. These and other package types, along with components such as ceramic chip capacitors, will need to be inspected for internal anomalies, typically by non-destructive acoustic micro imaging. This article takes a forward look at some of the challenges and changes that may take place in various packages and the possible advances in acoustic methods for imaging and analyzing them.

In electronic components, the business of acoustic micro imaging is to make visible and analyze internal structural features. Acoustic micro imaging tools such as Sonoscan’s C-SAM® series are used to image anomalies and defects, or to verify their absence. The defects are typically gaps - delaminations, voids, cracks, non-bonds and the like - but an acoustic micro imaging tool will also reveal surprises such as the out-of-place or missing die sometimes noted in counterfeit components.

New acoustic imaging methods

Today, the prevalent imaging mode for acoustic micro imaging tools is what is commonly called the Time

![Figure 1. Thru-Scan image shows acoustic shadows of anomalies in a BGA package, but gives no depth information.](image)

Domain Amplitude Mode. The scanning transducer sends a pulse of VHF (5 to 100 MHz) or UHF (above 100 MHz) ultrasound into an x-y location. A few microseconds later, the transducer receives a number of echoes from the depth of interest. The amplitude of the highest-amplitude echo within a gate (time window) is used to assign a pixel value to that x-y location. The other echoes are ignored.

At the moment, there are about a dozen other imaging modes which collect data in different ways and which yield different information and images about a sample.

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One example: it is important in imaging IGBT modules to measure and map the thickness of the solder bonding the heat sink to the ceramic raft above. Irregular solder thickness often means that the raft is tilted or warped (and thus may restrict heat dissipation). The Time Difference™ mode will map the interface. This mode ignores echo amplitude altogether and uses the arrival time of the echoes to measure and map the thickness of the solder. Irregular solder thickness means that the raft is tilted or warped (and thus may restrict heat dissipation). Other acoustic imaging modes use other techniques to detect thickness variations.

The Frequency Domain mode produces multiple images of the target depth in a sample. Each image is made using echoes within a very narrow frequency range (e.g., 102.0-103.5 MHz). This mode is useful in samples having subtle anomalies or defects that may be hard to discern with, say, Amplitude Mode.

A new mode is typically developed when the user of an acoustic micro imaging tool expresses the need to push acoustic imaging beyond its current capabilities in order to solve a specific inspection problem. In some instances an existing mode that was previously developed for research purposes is found to be useful for emerging sample types. It is very likely that new acoustic imaging modes will developed as electronic components and assemblies continue to evolve.

A recently developed mode is the Echo Integral Mode. It gives a view similar to, but more informative than, the Amplitude Mode. While Amplitude Mode picks the highest single amplitude to assign a pixel value, The Echo Integral Mode uses the sum of the amplitude of all the echoes at a given x-y coordinate to determine the pixel color for that coordinate. This approach makes it easier to see subtle local differences in, say, the quality of a bond between two materials. FIGURE 1 is the Thru-Scan mode image of a plastic BGA package. Thru-Scan pulses ultrasound into the top of the package and uses a sensor beneath the package to read the amplitude of the arriving ultrasound at each x-y location. Gap-type defects block ultrasound and thus appear in a Thru-Scan image as black acoustic shadows.

In Figure 1, the black features within the die at center are surely significant anomalies, but an engineer cannot tell from this Thru-Scan image what depth they lie at: are they in the die attach material or in the substrate below?

At left in FIGURE 2 is the Amplitude Mode image of the die area. This image is gated on (reads echoes only from) the die attach depth, and ignores echoes from other depths. The black dots are not features in the gated depth, but are the acoustic shadows of voids in the mold compound above the die. The die area itself is rather uniformly pale gray, with no features of note.

The image at right used the Echo Integral Mode, also gated on the die attach material. Using the average amplitude of all the echoes at of millions of x-y coordinates gave a different result: there are significant differences in brightness. The large bright area marked by arrows is a gap-type defect in the die attach, and there are other, smaller defects of the same type. The defects imaged as black shadows by Thru-Scan are imaged here as near-white defects by the Echo Integral Mode. They are clearly in the die attach, and not in the substrate. The roughly spherical feature in the upper right of the Thru-Scan image, however, is the shadow of the void in the mold compound above the die.

Components will continue to shrink
Sonoscan’s laboratories have for some time been imaging PEMs that are only 200 microns thick and 3mm x 3mm in area. The die is typically less than 100 microns thick. In some ways, the small dimensions are an advantage in acoustic imaging: the plastic encapsulant scatters and absorbs ultrasound, so the less encapsulant the pulse and the resulting echo need to
travel through, the better the resolution in the acoustic image. Such a component may be imaged with the very high frequency of 230 MHz, rather than the 15 MHz to 100 MHz of larger plastic packages. Higher frequency means better spatial resolution in the acoustic image.

One of the most commonly imaged non-PEM components is the ceramic chip capacitor, where the goal is to image delaminations and cracks that can lead to leakage between electrode layers. The very smallest ceramic chip capacitors currently being manufactured measure 0.010 inch by 0.005 inch. They can be imaged acoustically, but extremely small dimensions make imaging time-consuming.

**Mid-end components**

So named because they involve both front-end and back-end processes, mid-end components are typically assembled by mounting flip chips onto a wafer and then encapsulating the flip chips with plastic before dicing the wafer. They have been described as non-wired QFNs.

What has evolved is that some mid-end components can be imaged well enough to see details of the solder bump bonds, while others cannot. Sonoscan has developed transducers having an acoustic frequency that is low enough to get through the plastic encapsulant, and high enough to give good details about the bump bonds.

But many mid-end components have an encapsulant that is only partly transparent to ultrasound. Gross features and defects will be visible, but not the details of the bump bonds, which will probably become even smaller in the future. The alternative is to use the Thru-Scan™ imaging mode. Any gap in between, such as a break in a solder bump, will block the arriving ultrasound and be visible as a black feature. These acoustic shadows contain no information about the depth of a feature, but the relatively simple design along with experience with a given mid-end component are helpful.

The evolution of package design may in time alleviate the encapsulant problem. The trend is toward more chip-on-wafer type designs, and toward ever-smaller dimensions. The encapsulants may perhaps become unnecessary; their departure would enhance acoustic inspection.

**Stacked die**

Individual components typically have industry standards that can be used to judge the risk posed by a void in the die attach material or a delamination along a lead finger. Stacked die have no industry standards; presumably each maker of stacked die uses their own guidelines to reduce field failures.

Die stacks can be imaged acoustically before encapsulation, and in the future some may be imaged after encapsulation, particularly if ultrasound-friendly encapsulants are used. In both situations, the same problem occurs: each pulse encountering a material interface is partly reflected and partly transmitted across the interface. Unencapsulated stacks are typically imaged during development in order to refine assembly processes. Even a four-die stack (that has at least eight interfaces) can generate so many echoes that it becomes very difficult to identify the echo being sent by the delamination of the adhesive on the top of die #3.

For unencapsulated stacks, this problem has largely been solved by software developed jointly by Sonoscan and the Technical University of Dresden. The software uses material properties and dimensions to create a virtual stack as much like the physical stack as possible, and works out the imaging techniques, which are then further refined on the physical stack. The goal is to identify the echoes that were returned from specific depths of interest - e.g., the interface between the bottom surface of die #6 and the adhesive beneath it. By repeatedly moving between the virtual sample and the physical sample, the imaging parameters are defined that will show the echoes at this depth.

Nearly all memory devices are stacked, and the die are wire-bonded to each other. But there are stacks have many different configurations; one common configuration puts a small memory chip on top of a larger processing chip.

It’s hard to tell where the architecture of die stacks may go from here. In some stacks, through-silicon vias (TSVs) will replace wires. Defects such as delaminations will be visible acoustically, but whether the TSVs will be visible acoustically is difficult to judge at this point. What manufacturers want to see is that each TSV is filled. Their diameters are already extremely
small. Whether acoustic methods will be devised to make them nondestructively visible is not known yet.

A long-standing problem in imaging typical PEMs is that a delamination on the back side of the die paddle cannot be imaged when scanning the top side of the PEM. Before the PEM is surface-mounted, it can simply be flipped over and imaged from the back side. After mounting, only the top surface is available for scanning. The problem is that there are too many surfaces: the pulsed ultrasound must cross the top surface of the plastic, the plastic-to-die interface, the die-to-die attach interface, and the die attach-to-die paddle interface. This is essentially the same problem encountered in the imaging of stacked die. In theory, a delamination between the die paddle and the plastic below it can be located and imaged by the software developed for die stacks.

**Package-on-package**

Package-on-package assemblies, such as a package containing one or more memory die on top of a package containing one or more logic die, are beginning to appear in Sonoscan's testing laboratories. These package designs have some advantages over the stacking of die; for example, if one of the two packages is found to be defective before assembly, it can be replaced, while the logic package is retained. It seems likely that the popularity of these assemblies will increase in the next few years.

After the two packages are bonded together, the chief structural reliability concern is the adhesive between the two packages. This is where gap-type defects, primarily voids, may be found. If present, voids put stress on the solder joints for the BGA balls.

How acoustic imaging is performed depends on the structure of the assembly. Normal reflection-mode pulse-echo imaging can sometimes be used, but the assembly is likely to have numerous material interfaces that could limit the effectiveness of this method. Because internal structural defects in this assembly are largely limited to voids at a specific known depth, it often makes more sense to use the Thru-Scan mode to reveal the voids.

**Interposers**

The term “interposer” is used rather loosely to describe a redistribution layer between a top die and a lower die or printed circuit board, chip and the solder balls that make connection with a substrate. In terms of acoustic imaging, interposers behave much like flip chips, in that the depth of interest is between two structures.

The common defects are delaminations, significant because they are capable of attracting contaminants (and thus causing corrosion) and of expanding through thermal cycling. The growth of chips having advanced processing capabilities will likely make the acoustic imaging of interposers more frequent.

**Summary**

The advantage of acoustic micro-imaging tools is their ability to image nondestructively gap-type anomalies and certain other anomalies (tilting, warping) in electronic materials. In recent years, the original Amplitude Mode has been joined by roughly a dozen other modes that push imaging capabilities into new areas.

It can be expected that electronic components will continue to add their own capabilities and to reduce their physical dimensions. Some components will become more difficult to image; others, particularly those that become thinner or that use acoustically friendly materials, may permit the use of higher frequencies to image smaller features. Since there is no good non-destructive substitute for acoustic modes, engineers who demand reliability may want to apply acoustic micro-imaging to new device configurations and keep track of new acoustic imaging modes.